Attachment 1 to Item 10.3.2.

Draft Redbank Creek Flood Study

Date of meeting: 12 November 2024
Location: Council Chambers
Time: 6:30pm

Draft Redbank Creek Flood Study

WORKING DRAFT

Hawkesbury City Council

NSW GOVERNMENT

Redbank Creek Flood Study

Stage 2 Report

Report MHL3008

9 October 2024

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Foreword

NSW government's professional specialist advisor, Manly Hydraulics Laboratory (MHL) were commissioned by Hawkesbury City Council to undertake Redbank Creek Flood Study.

The report was prepared by Armaghan Severi, Maryam Farzadkhoo and Matthieu Glatz.

Executive Summary

This flood study provides a comprehensive assessment of flooding in North Richmond and the surrounding local catchment, with a particular focus on the Redbank Creek catchment and its local overland flooding mechanisms. A thorough literature review of previous flood studies identified a gap in understanding local flooding dynamics, prompting this investigation aimed at enhancing flood risk management in the area.

The study's scope does not encompass direct flooding from the Hawkesbury River, as this has been extensively addressed in the Hawkesbury-Nepean Valley Regional Flood Study; however, backwater effects from the river are considered. It is essential to recognise that areas affected by riverine flooding must be evaluated accordingly. The key components of the flooding assessment included:

- A review of existing studies and data
- Community consultation
- Hydrological and hydraulic analysis and modelling
- Sensitivity analysis
- Flood mapping
- Assessment of flooding consequences on the community
- Evaluation of climate change impacts on local flooding
- Development of a draft and final flood study report

The flood mapping included a comprehensive range of events, from the 20% to the 1 in 5000 Annual Exceedance Probability (AEP) events and the Probable Maximum Flood (PMF) scenarios, representing the critical durations and patterns for the Redbank Creek catchment.

This report acknowledges that the lack of gauging stations in the study area limits data availability for calibration, impacting model validation and introducing uncertainties. To enhance the reliability of findings, future research should consider establishing gauging stations or utilizing alternative data sources. Sensitivity analyses yielded important insights:

- Tailwater Level Impact: While tailwater levels in the Hawkesbury River have minimal effect on upstream flood levels, they substantially impact the extent of flooding and water level along the low-lying areas at the downstream end of Redbank Creek.
- Losses Sensitivity: The removal of all losses could increase flood levels by up to 0.8 m along the creek and 0.2 m in the township. Conversely, ARR 2019 loss estimates may reduce flood levels upstream by 0.2 m while increasing them downstream by 0.1 m.
- Roughness Sensitivity: Increasing hydraulic roughness by 20% can lower water levels by up to 0.25 m along watercourses, while decreasing roughness produces the opposite effect.
- Blockage Sensitivity: A double blockage scenario could raise flood levels by 0.2 m in the township, while a no blockage scenario would result in localised changes of up to 0.1 m.

It was observed that flow within the North Richmond township primarily follows Redbank Creek and the main drainage channel through the township the during majority of events up to including 1 in 2000 AEP. Key flood-prone areas are highlighted below, noting that the described impacts are based on flooding that affects the floor level of buildings on properties:

- Properties located at the northern end of William Street, Elizabeth Street, Susella Crescent, Merrick Place and O'Dea Place are impacted from 1 in 500 AEP event; however, road access may be affected by events as frequent as 20% AEP;
- A few Properties along the northern side of Flannery Avenue are impacted from 1 in 200 AEP event; however, their access may be affected by event as frequent as a 5 AEP;
- A few properties at the north-west corner of Pansy Crescent are impacted by events as frequent as 10% AEP;
- Properties located along the main drainage channel between Pecks and Elizabeth Streets are affected due to 1 in 5000 AEP and PMF events.
- A few properties located between Stephen and Pecks Streets are impacted by events as frequent as 10% AEP.
- Properties situated between Tyne Crescent, Stephen Street and north end of Yvonne Place are impacted by events as frequent as 5% AEP.
- A secondary overland flow path was observed through the North Richmond township, from the sag point along Enfield Avenue through a few properties towards the south end of Monti Place, continuing towards the intersection of Charles and Elizabeth Streets. These areas are impacted by events as frequent as 10% AEP;
- Properties located at the southernmost corner of Tyne Crescent;
- A few properties located at the north-east corner of the intersection of Charles and William Streets are impacted by events as frequent as 5% AEP;
- Properties near the intersection of Charles and Elizabeth Streets are impacted by floods as frequent as 5% AEP event such as North Richmond Community Centre.

It was observed that the North Richmond Community Centre, while used as an evacuation centre for the township of North Richmond, is impacted by an overland flow as frequent as a 5% AEP. Moreover, access to this venue by residents of various parts of the township may be restricted. It is therefore recommended the careful consideration be given to the design and management of the evacuation centre. Moreover, Turnbull Oval is also used as an evacuation centre for the township of North Richmond and, while it is outside of the extent of a PMF event, access to the oval by residents of northern parts of the township may be restricted from a 1 in 200 AEP event and from a 1 in 5000 AEP event, Terrace Road access will become limited for the majority of residents.

An economic impact assessment of flooding was undertaken by estimating the flood damages in the catchment. The preliminary flood damage assessment involved analysing 5,250 buildings within the study area. A total Annual Average Damage of approximate $1.5 million for residential properties and $373,510 for non-residential properties was estimated in the Redbank Creek catchment. To improve accuracy, a comprehensive floor level survey is recommended for future Floodplain Risk Management Studies to enhance damage assessments.

Moreover, climate change scenarios projected for 2040, 2090, and 2100 indicate substantial increases in rainfall intensity, which could exacerbate flood conditions. Specifically:

- 2040 Conditions: A 9.5% increase in rainfall intensity may lead to a 0.40 m rise in riverine flooding and a 0.20 m increase in localised overland flooding.
- 2090 Conditions: A 19.7% increase in rainfall intensity could result in a 0.90 m rise in riverine flooding and a 0.30 m increase in localised overland flooding.
- 2100 Conditions: A 30% increase in rainfall intensity might cause a 1.30 m rise in riverine flooding and a 0.50 m increase in localised flooding levels.

This study lays a robust technical foundation for ongoing flood risk management and further investigations in the Redbank Creek Catchment, contributing to enhanced resilience against future flooding events.

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1 Introduction

NSW Government's Manly Hydraulics Laboratory (MHL) was engaged by Hawkesbury City Council (Council) to undertake a flood study of Redbank Creek with financial support from the NSW State Government Floodplain Management Program, managed by the Department of Climate Change, Energy, the Environment and Water.

It is understood that the Hawkesbury-Nepean River Flood Study (Rhelm and Catchment Simulation Solutions, 2024) was completed in 2024, covering a large geographic area and focusing on mainstream regional scale flooding. However, this study did not include shorter-duration local catchment flooding or overland flow inundation, and a finer resolution flood study is required to delineate flood behaviour and risk in the Redbank Creek catchment.

The key factor of the Redbank Creek Flood Study is the requirement for high quality design flood data, which will be used as an effective planning and advice tool for the community, Hawkesbury City Council and emergency response agencies. This flood study is of vital importance to the understanding of flood behaviour, flood risk and the development of future potential mitigation options for the North Richmond community.

2 Background

2.1 Study area

The focus of the present investigation is the Redbank Creek catchment and the township of North Richmond in the Hawkesbury Local Government Area (LGA), located approximately 55 km northwest of Sydney. Redbank Creek flows east for approximately 12 km from about 450 m southeast of the Patterson Lane and Grose Vale Road roundabout to the Hawkesbury River (1.5 km downstream of the current North Richmond Bridge).

The upstream section of Redbank Creek flows through rural zoned land that is used for residential purposes. The middle portion of Redbank Creek flows through a combination of existing residential development and a greenfield development site named Redbank. The downstream section of the creek flows through rural zoned properties.

The Redbank Creek catchment is characterised by a large number of minor waterbodies, tributaries and drainage lines flowing in a north-south direction into Redbank Creek. The large number of surface water features within the study area are likely attributed to the historical land use of a Keyline dam system developed as part of an experimental farm. This type of farming primarily aims to conserve as much rainfall as possible, reduce evaporation rates, and use the conserved moisture for the improvement of soil fertility.

The study area is bounded by Grose Vale Road in the south and west, Bells Line of Road and Kurmond Road in the north, the Hawkesbury River in the southeast and some natural high ground between Kurmond Road and the Hawkesbury River in the east. The catchment size is estimated to be approximately 27 km^2.

The study area is presented in **Figure 2.1**.

2.2 History of flooding and rainfall

The Redbank Creek catchment can be impacted by two types of flooding mechanisms including:

- Local overland flooding; and
- Mainstream flooding due to:
  - Flooding from Redbank Creek; and
  - Flooding and backwater effects from the Hawkesbury River propagating into the Redbank Creek catchment.

The focus of the present study is to improve understanding of the flood behaviour within Redbank Creek catchment and the local overland flooding mechanisms. Direct flooding from the Hawkesbury River is not part of the scope of the current study as it is extensively covered by the Hawkesbury-Nepean River Flood Study (Rhelm and Catchment Simulation Solutions, 2024). However, backwater effects will be considered.

Recent occurrences of flooding of North Richmond include:

- The July 2022 flood event which is the most recent major flood event. The July 2022 flood was a typical single-peaked event. Peak flood level of 14.85 m AHD were recorded at North Richmond gauge (212200) at 3:00 am on Monday 4th of July 2022 and classified as a 10% Annual Exceedance Probability (AEP) event. North Richmond Bridge was flooded to a depth of about 15.3 m AHD (Infrustructure NSW, 2023);

- The March 2022 flood event was a high-volume flood with two distinct peaks about 5 days apart. Peak flood level of 14.66 m AHD were recorded at North Richmond gauge (212200) at 12:15 am on Wednesday 9th of March 2022 and classified as a 20% to 10% AEP event. North Richmond Bridge was flooded to a depth of about 14.8 m AHD. The March 2022 event led to significant evacuations in North Richmond associated with fear of dam failure occurring at Redbank Dams 13 and 14 (Infrustructure NSW, 2023);
- The March 2021 flood event has been a major flood event in the historical record since 1990 (SES 2022). This flood led to evacuation in North Richmond. A distinctive characteristic was its double peak in upstream areas. It resulted in a large volume of inflows to Warragamba Dam. At North Richmond, the arrival of the floodwaters from Warragamba, plus inflows from the Grose River, saw the Hawkesbury River rise steeply on Saturday 20 and Sunday 21 March, peaking with major flooding at 14.38 m AHD. While a lower, second peak was observed on Wednesday 24 March (13.41 m AHD), it was less pronounced compared to sites upstream (Infrastructure NSW, 2021). North Richmond and Windsor experienced flooding with an estimated magnitude of 5% to 10% AEP. During moderate floods, the Yarramundi, Windsor and North Richmond bridges are all likely to be closed (Infrastructure NSW, 2021).
- The February 2020 flood event was the first moderate flood since the 1990 flood and flooded the North Richmond bridge.

The largest flood on record in the Richmond/Windsor floodplain occurred in June 1867 with a level of 20.14 m AHD at North Richmond Bridge (recorded by SES as the record flood at this location). Other large floods occurred in 1961, 1986, 1988 and 1990 (SES, 2022).

Some photographs of past events are provided in **Figure 2.2** to **Figure 2.4**.

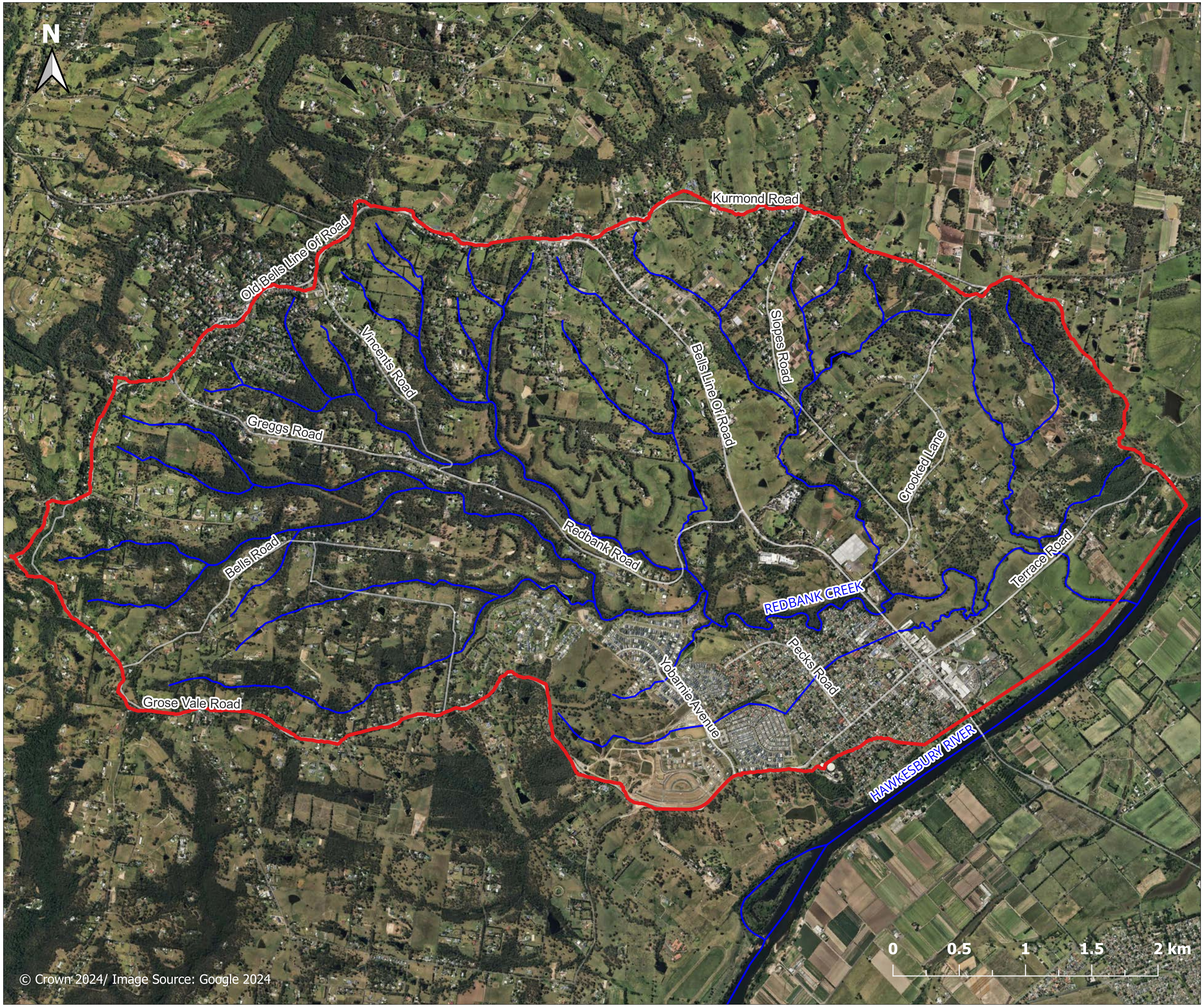

Figure 2.1

Locality map

Legend

- Study area
- Watercourses

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Figure 2.2 North Richmond Bridge, 23 March 2021 (after peak). View is from south (Source: Hawkesbury Flood Stations 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%)

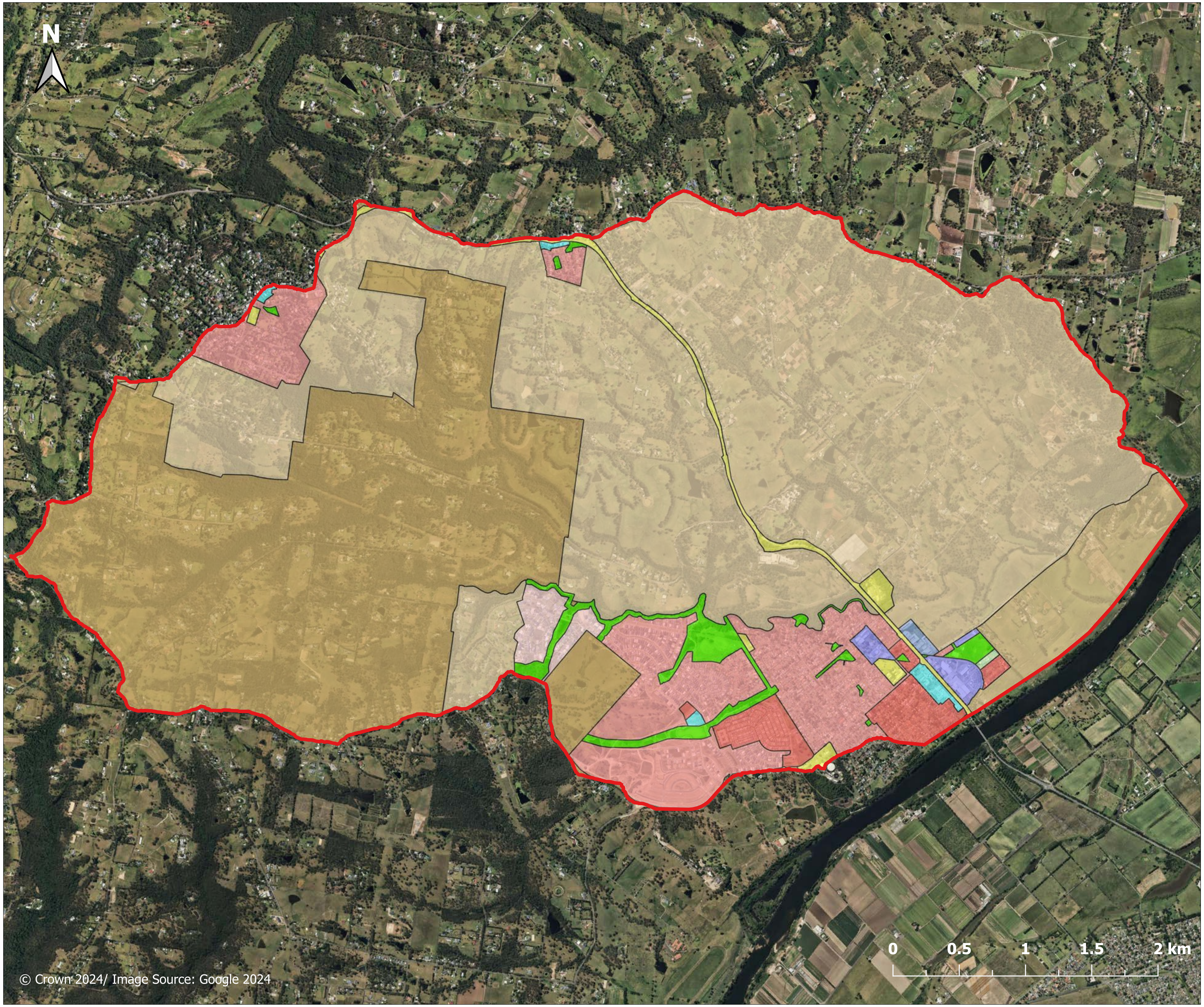

Figure 2.5

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).

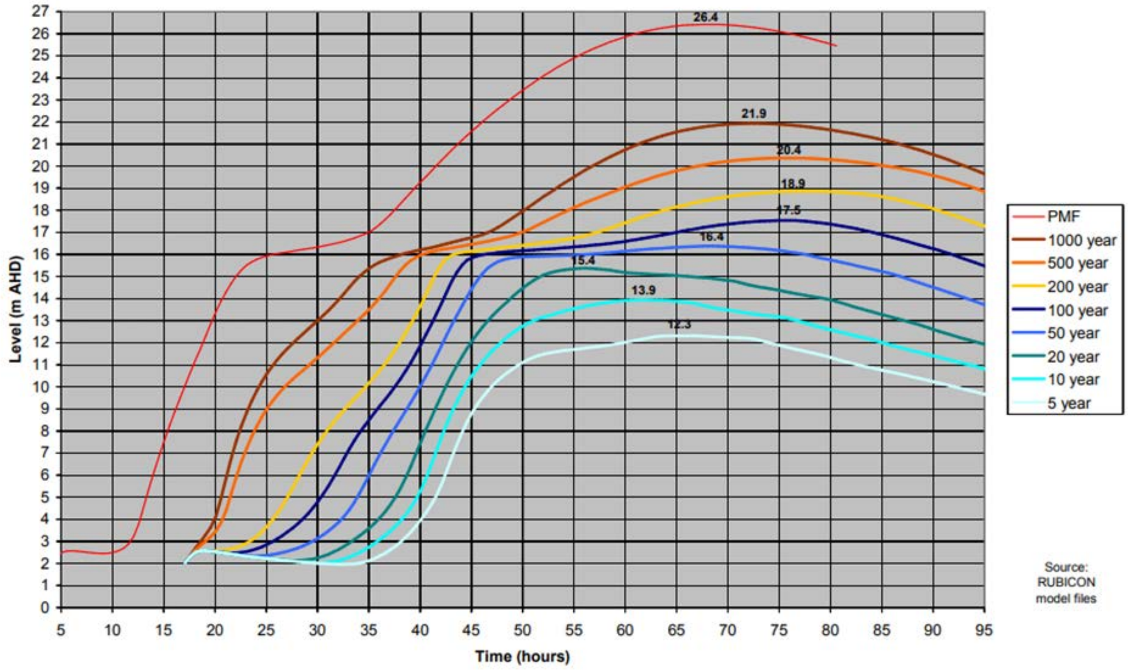

Figure 3.1 Design flood hydrographs for the Hawkesbury River at North Richmond Bridge (Source: WMA Water (1999) Rubicon model files; Retrieved from (Bewsher Consulting Pty Ltd , 2012)

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 Hawkesbury City Council 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 1000, 1 in 2000, 1 in 5000 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.

In the present study, the tailwater level in the Hawkesbury River for design events have been derived from the simulated water level at the North Richmond Bridge reported in the Hawkesbury - Nepean Valley Regional Flood Study (WMA Water, 2019). The downstream reaches of the Redbank Creek catchment have been assessed to understand areas where Redbank Creek flooding predominates and where the Hawkesbury River flooding predominates to determine the most appropriate study to adopt for flood planning level definition.

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 1000 AEP	20.7
1 in 2000 AEP	21.9
1 in 5000 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 for the NSW Government 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 14.38 m AHD at 4:30 pm on 21 March. While a lower, second peak was observed on Wednesday 24 March (13.41 m AHD), it was less pronounced compared to sites upstream. Information on flood behaviour at the North Richmond is shown in **Figure 3.2**.

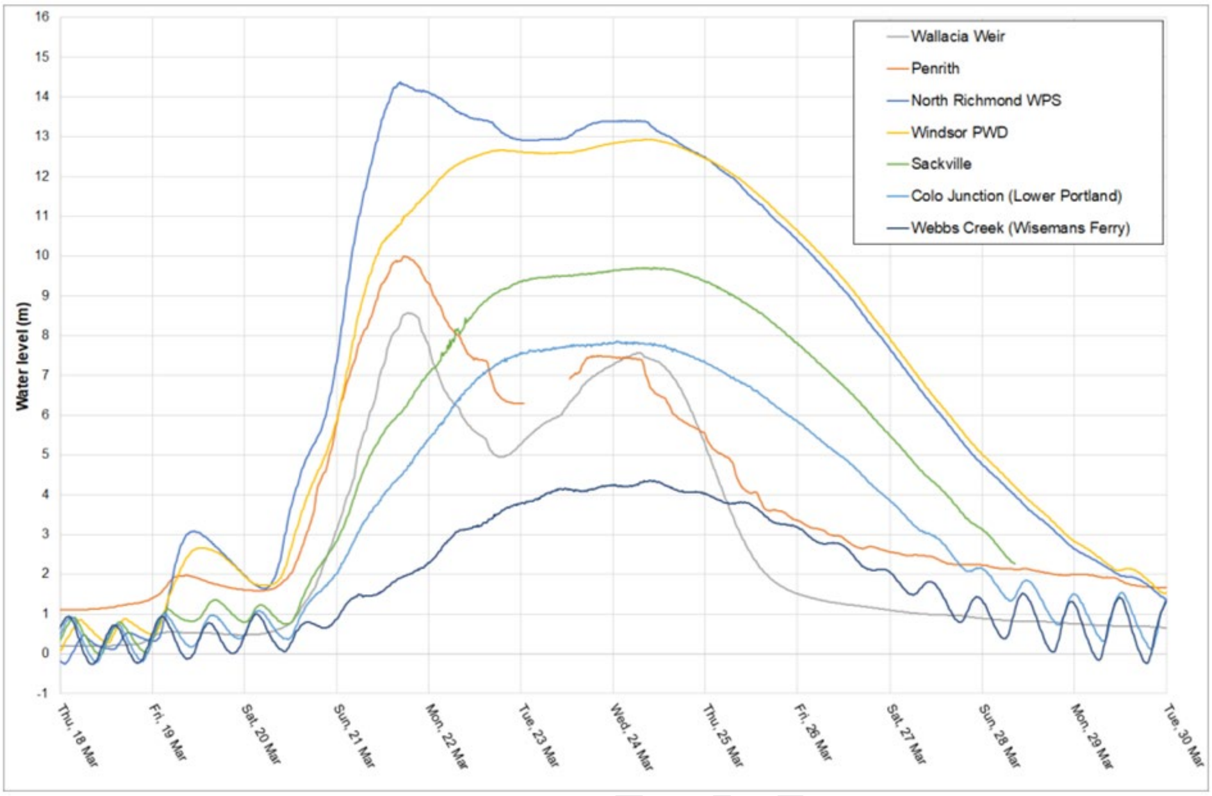

Figure 3.2 Flood hydrographs for selected Hawkesbury-Nepean flood warning gauges, 18 to 29 March 2021 (Retrieved from (Infrastructure NSW, 2021))

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 for the NSW Government 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 reached 14.66 m AHD at 12:15 am 9 March with an approximate likelihood of 1 in 5 to 10 chance per year. North Richmond Bridge was flooded to a depth approaching 14.54 m AHD at the bridge, which is located downstream of North Richmond WPS gauge.

The July 2022 flood event was a more typical single peak event. The Hawkesbury-Nepean River water level reached a peak of 14.85 m AHD at 3:00 am on 4th of July with an approximate likelihood of 1 in 10 chance per year at North Richmond WPS (212200) gauge.

3.7 NSW Coast Flood Summary February / March 2022 (Manly Hydraulics Laboratory, 2023)

The NSW Coast Flood Summary February / March 2022 (MHL2936) was prepared for the former NSW Department of Planning and Environment – Environment and Heritage Group by Manly Hydraulics Laboratory (MHL2936) in August 2023 to summarise the February/March 2022 flood event on the NSW coast (Manly Hydraulics Laboratory, 2023). This flood report (MHL2936) was conducted to provide a snapshot of the intensity of flooding experienced across the coast of NSW based on the river and rainfall data collected within 61 disaster-declared LGAs. This report presents a selected group of water level and rainfall hydrometric data collected between 15 February and 11 March 2022 along the coast of NSW. The peak observed water levels for the North Richmond were reported as 14.66 m AHD at 11:15 pm on 8th of March while the SES flood classification for North Richmond station was 4.3 m AHD, 8.4 m AHD, and 11 m AHD for minor, moderate, and major, respectively. The observed peak water levels for the Hawkesbury River and South Creek region between the period of 15 February to 11 March 2022 are listed in **Table 3.3**.

Table 3.3 Observed peak water level in the Hawkesbury River and South Creek region from 15 February to 11 March 2022

Station name	Station number	Owner	Peak level (m AHD)
Webbs Creek	212408	DPE BCD	5.18
Colo Junction	212407	DPE BCD	8.67
Sackville	212406	DPE BCD	10.68
North Richmond	212200	WaterNSW	14.66
Windsor	212426	DPE BCD	13.80
Penrith	212201	WaterNSW	22.46
Wallacia Weir	212202	WaterNSW	37.96

3.8 Hawkesbury-Nepean River Flood Study (Rhelm and Catchment Simulation Solutions, 2024)

The Hawkesbury-Nepean River Flood Study was prepared for the NSW Reconstruction Authority by Rhelm and Catchment Simulation Solutions in May 2024 to identify areas in the valley affected by flooding from the Hawkesbury-Nepean River (including backwater flooding up tributaries such as Redbank Creek) and assess the potential impacts of climate change on flooding (Rhelm and Catchment Simulation Solutions, 2024). An investigation of flood behaviour for the Hawkesbury-Nepean River between Bents Basin and Brooklyn, was undertaken and included WBNM hydrologic modelling, TUFLOW hydraulic modelling, Monte Carlo framework assessment, flood frequency analysis and Colo / Hawkesbury joint probability analysis.

The study accounted 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 LGAs. Other LGAs in this floodplain include Wollondilly, Liverpool, Hornsby and Central Coast.

A WBNM hydrologic model of the Hawkesbury-Nepean catchment was developed for WaterNSW, as described in (WMA Water, 2018). This model was calibrated to five streamflow gauges within the Warragamba Dam catchment, the Nepean River catchment and the Colo River catchment. The model was calibrated to eight separate historical flood events including, June 1964, June 1975, March 1978, August 1986, May 1988, August 1990, August 1998, and February 2020. An iterative approach in the hydrologic model calibration process was adopted to modify the model parameters including the initial and continuing losses for each storm event to best fit the overall flow gauge data. A summary of the median loss values for the calibrated catchments is provided in **Table 3.4**.

Table 3.4 Calibration Lag and Median Loss Values

Catchment	C	Initial Loss (mm)	Continuing Loss (mm/hr)
Nepean River – Upper catchment	1.00	70.0	2.0
Nepean River – Maldon to Camden	1.90	70.0	1.9
Nepean River – Camden to Wallacia	1.90	80.0	2.0
Grose River	1.36	50.0	0.9
South Creek	1.90	50.0	1.0
Colo River - Upper Colo	1.50	102.5	2.2
Macdonald River - Howes Valley	1.90	87.5	3.4
Macdonald River - St Albans	1.90	110.0	1.0

The TUFLOW Highly Parallelised Computer (HPC) software was used to develop the new hydraulic modelling within the study area. The TUFLOW model extends along the Nepean and Hawkesbury rivers from Cowpasture Bridge, Camden to West Head. A 15 m grid size was used with 5 m sub-grid sampling (SGS) across the full model domain, with 2-metre SGS across critical areas, to ensure a detailed representation of flood conveyance and storage across the full model area. The 2019 LiDAR did not cover the full hydraulic model area, so the 2017 and 2011 LiDAR data were added to ensure complete topographic coverage. Both 2011 and 2017 LiDAR datasets had comparable accuracy, but the 2017 data was prioritised for its more recent description of ground elevations. The roughness values were initially selected in the model based on values obtained in literature (e.g., Chow, 1959), but the values were refined during the model calibration process.

The simulated flows from the calibrated hydrologic model were routed through the hydraulic model to compare surveyed flood levels and/or water levels at stream gauge locations from each historical flood events including, November 1961, June 1964, June 1975, March 1978, August 1986, April / May 1988, August 1990, February 2020, March 2021, March 2022 and July 2022. The March 2021 flood was the highest flood at Penrith since 1925 at 24.1 m AHD and the highest at Windsor since 1990 at 12.9 m AHD and several metres higher than the February 2020 calibration event.

Design flood modelling was undertaken from frequent to extreme including, 20%, 10%, 5%, 2%, 1%, 1 in 200, 1 in 500, 1 in 1000, 1 in 2000, 1 in 5000 AEPs, and PMF event and the results of simulated peak flood levels at several locations were documented in **Table 3.5**. The outputs from each of the design flood simulations were processed and the output types included peak flood levels, depths and velocities, flood extents, flood hazard categories, flood function categories, and information to support emergency services and evacuation.

Table 3.5 Peak Flood Levels at Key Reporting Locations (m AHD)

Design event	North Richmond Bridge (gauge) (m AHD)	Windsor Bridge (gauge) (m AHD)
50% AEP	6.7	5.5
20% AEP	12.3	9.7
10% AEP	14.5	11.7
5% AEP	15.6	13.8
2% AEP	16.3	15.9
1% AEP	17.5	17.3
1 in 200 AEP	18.6	18.5
1 in 500 AEP	20.2	20.2
1 in 1000 AEP	21.4	21.3
1 in 2000 AEP	22.8	22.8
1 in 5000 AEP	24.4	24.4
PMF	30.6	30.6

Building on the comprehensive Monte Carlo assessment conducted in the ungauged catchments of the Hawkesbury River as part of Hawkesbury-Nepean River Flood Study (Rhelm and Catchment Simulation Solutions, 2024), and following the hierarchical method outlined in the Floodplain Risk Management Guide Incorporating 2016 Australian Rainfall and Runoff in studies (OEH, 2019), the present study adopted the initial and continuing losses as specified in **Section 7.2.2.2**. The modelled water levels at the Hawkesbury River at North Richmond bridge were also obtained from this study reflecting the tailwater conditions downstream of Redbank Creek, as noted in **Section 8.2.4.2**. Additionally, flood maps derived from this study provide extensive coverage of direct flooding from the Hawkesbury River, highlighting areas impacted by riverine flooding in the present report, refer to **Section 10.2.2**.

4 Data collection and review

4.1 Water level and rainfall data

MHL manages two water level gauges and one rainfall station in the vicinity of the study area (Castlereagh 212404, Freemans Reach 212410 and Sackville Downstream 212438). Additionally, WaterNSW manages a water level gauge at North Richmond on the Hawkesbury River. However, it is noted that none of the above-mentioned gauges fall within the boundaries of the present study area.

The only gauge within the study area (North Richmond STP 563069) is a near-real-time rainfall monitoring station owned by Sydney Water and maintained by the Bureau of Meteorology (BoM). An overview of the monitoring gauges is provided in **Table 4.1** while their respective locations are depicted in **Figure 4.1**. **Figure 4.2** presents daily rainfall data recorded at North Richmond Station (563069). This station is the only rainfall station located within Redbank Creek study area; therefore, it is the most representative rainfall station to replicate the rainfall events.

Table 4.1 Water level and rainfall stations in vicinity of the study area

Station Name	Station Number	Owner	Latitude	Longitude	Start Date	End Date
Water level						
Hawkesbury River North Richmond	212200	WaterNSW	-33.589	150.714	30/04/1988	Ongoing
Freemans Reach	212410	DCCEEW	-33.570	150.781	03/04/1980	Ongoing
Castlereagh	212404	DCCEEW	-33.634	150.677	11/11/1981	Ongoing
Daily rainfall						
North Richmond STP	563069	Sydney Water	-33.570	150.720	28/06/1997	Ongoing
Richmond - UWS Hawkesbury	67021	BoM	-33.616	150.747	01/01/1881	Ongoing
Richmond RAAF	67105	BoM	-33.600	150.776	01/09/1993	Ongoing
Sackville Downstream	212438	DCCEEW	-33.497	150.877	06/01/1999	Ongoing
Kurrajong Height	063043	BoM	-33.535	150.634	01/01/1866	Ongoing

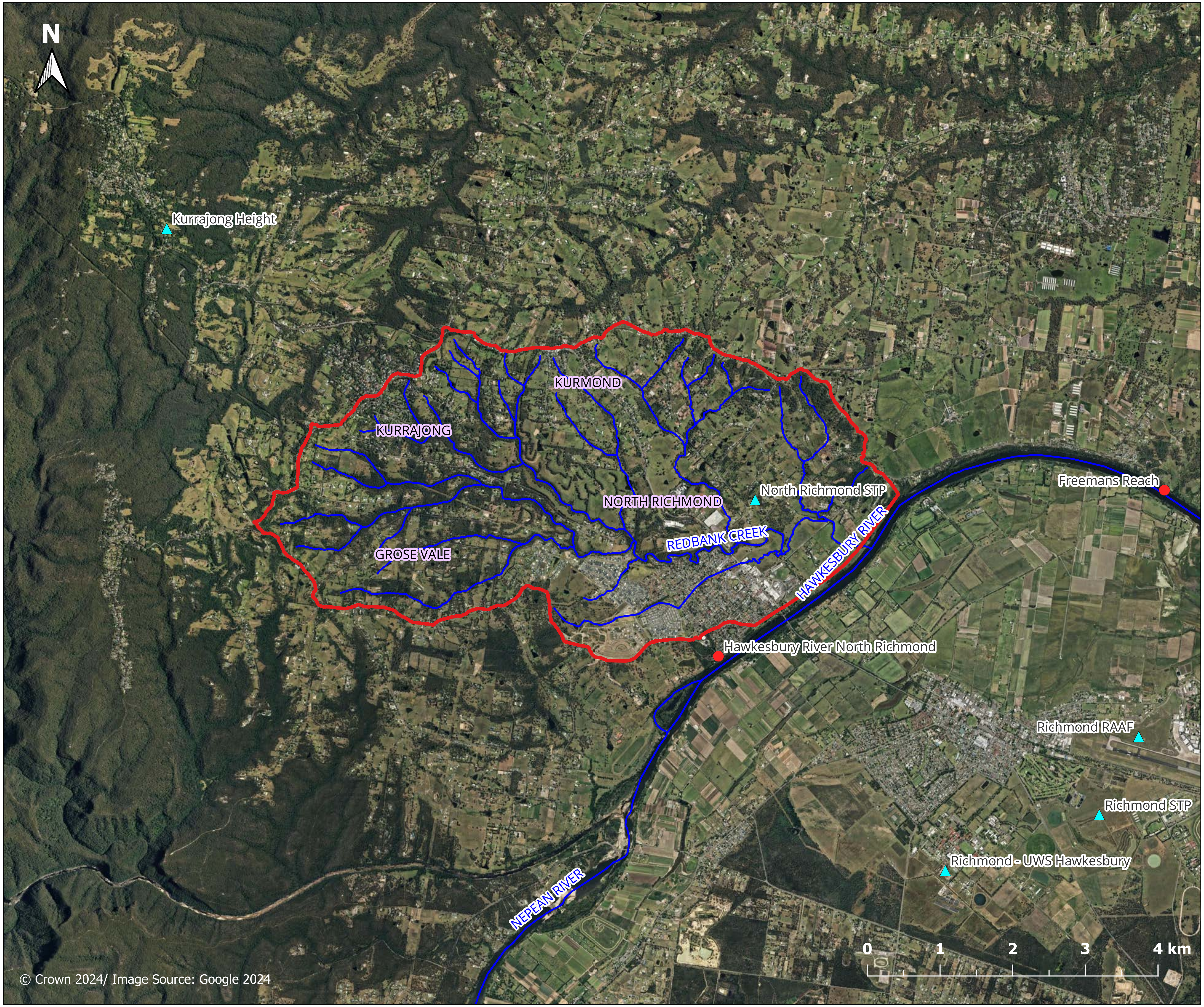

Figure 4.1

Water level and rainfall stations

Legend

Study area

Watercourses

Monitoring stations

Rainfall

Water level

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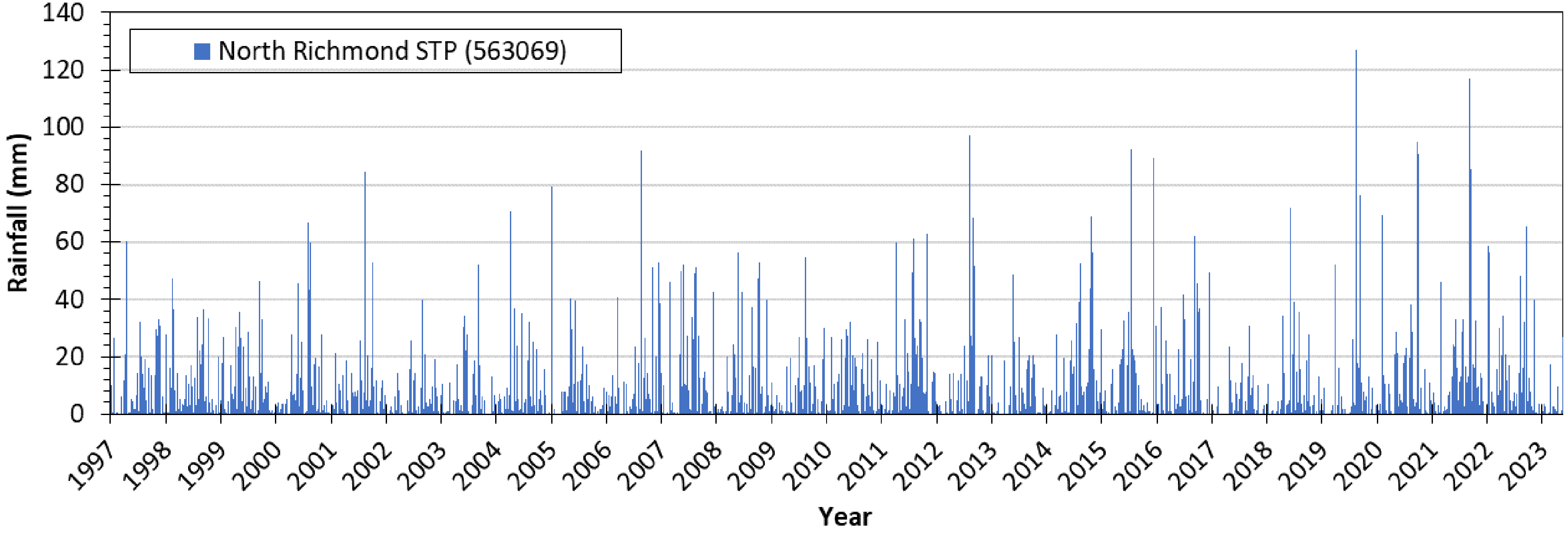

Figure 4.2 Daily rainfall data recorded at North Richmond STP 563069

4.2 Topographic data

Light Detection and Ranging (LiDAR) is an advanced aerial surveying technique that provides a comprehensive topographic representation of the Earth's surface. For this study, LiDAR survey data covering the study area and its immediate surroundings was sourced from the Elevation Information System (ELVIS) (https://elevation.fsdf.org.au/). One-metre resolution LiDAR data from the 'Penrith' datasets (NSW Spatial Services 2011, 2017 and 2019) were available for the Redbank Creek catchment. The horizontal accuracy of these datasets is 0.8 m at 95% confidence interval, while the vertical accuracy is 0.3 m at 95% confidence interval.

A comparative assessment of LiDAR datasets from February 2011, February 2017, and April 2019 were undertaken and presented in **Figure 4.3** and **Figure 4.4.** It is noted that the 1 m resolution 2017 LiDAR dataset only covers the lower half of the study area. While the difference between the various datasets appears significant in a number of locations, this is primarily due to slight horizontal shifts leading to major vertical differences along steep slopes and it can be noted that the various datasets are more consistent in flat areas (e.g., in North Richmond township). Such horizontal shift would have negligible impact on the flood behaviour in the hydraulic model. It is also important to note that the accuracy of the ground information obtained from LiDAR survey can be adversely affected by the nature and density of vegetation, the presence of varying terrain, the vicinity of buildings and / or the presence of water. Considering the recent developments and changes in the area's topography, the most current dataset from 2019 was selected for this study. The terrain topography is illustrated in **Figure 4.5**.

As part of the data review, a comparison of 2019 LiDAR and survey marks was undertaken to check the accuracy of the LiDAR data. These survey marks were obtained from Sixmaps – the Survey Control Information Management System (SCIMS) database developed by the NSW Government's Spatial Services. Under the S&SI Reg 2017, only marks that have a vertical class of L2A, LA, LB, LC, LD, 2A, A or B should be used for the adoption of AHD. Therefore, survey marks were filtered to exclude the following:

- Survey marks that were either damaged or not found; and
- Survey marks that had class of "U" defined as Unknown or unreliable surveys.

Details of the survey marks including name, coordinates, elevation from SCIMS database, corresponding elevation extracted from 2019 LiDAR data and difference in levels are presented in **Appendix A** . The difference between the 2019 LiDAR dataset and the elevation of the survey marks were calculated and are presented in **Figure 4.5**. It was observed that this difference ranges from -0.5 to 0.5 m with the majority of elevation differences falling between -0.2 to 0.2 m which is consistent with the vertical accuracy of the dataset. Marks with differences exceeding ± 0.3 m were inspected; many were near vegetation, fences, road signs, or resurfaced areas, contributing to observed discrepancies.

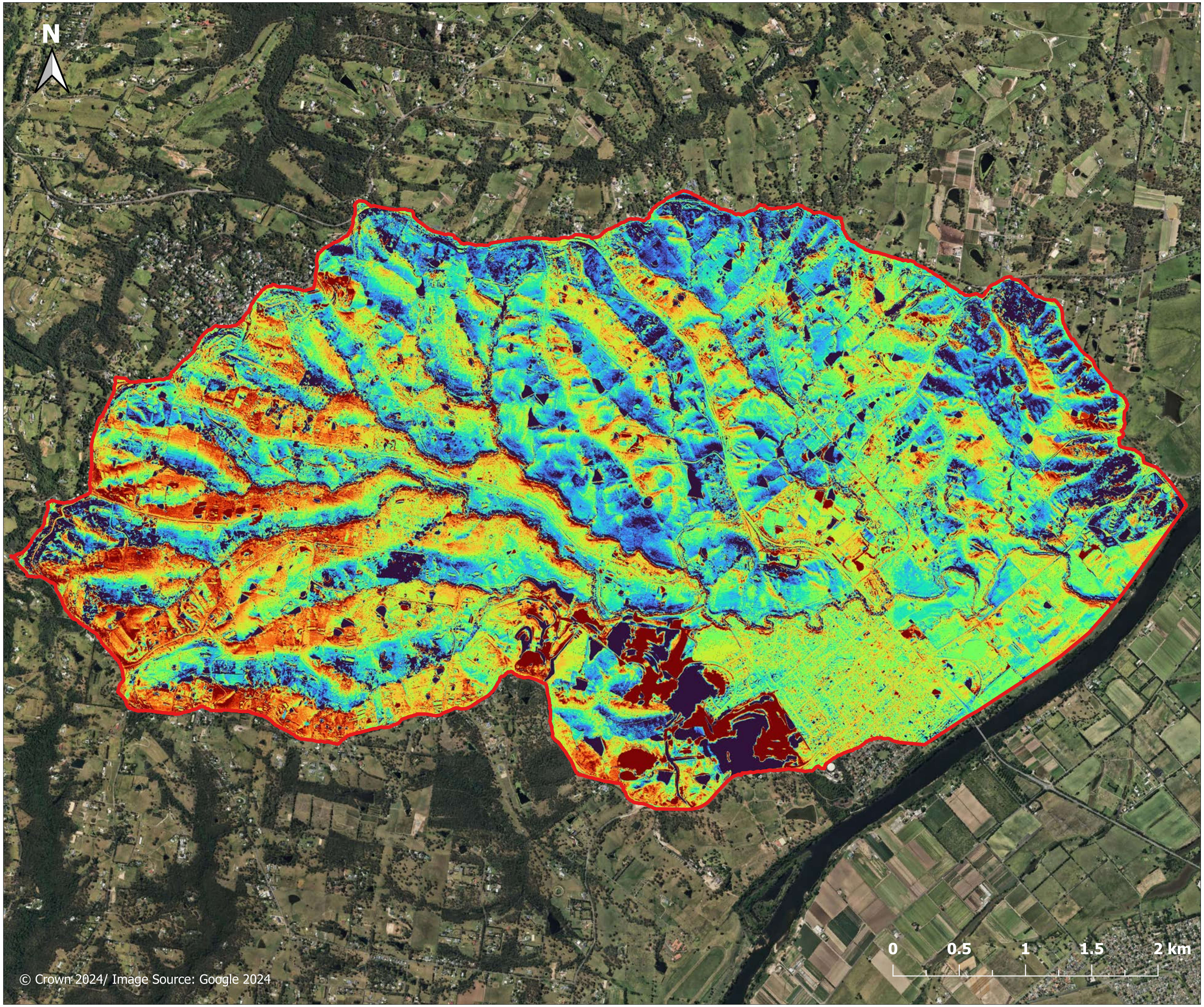

Figure 4.3

Comparison of 1 m resolution LiDAR datasets (2019 LiDAR minus 2011 LiDAR)

Legend

Study area

2019 LiDAR minus 2011 LiDAR

- <= -0.40
- -0.40 - -0.30
- -0.30 - -0.20
- -0.20 - -0.10
- -0.10 - 0.00
- 0.00 - 0.10
- 0.10 - 0.20
- 0.20 - 0.30
- 0.30 - 0.40
- > 0.40

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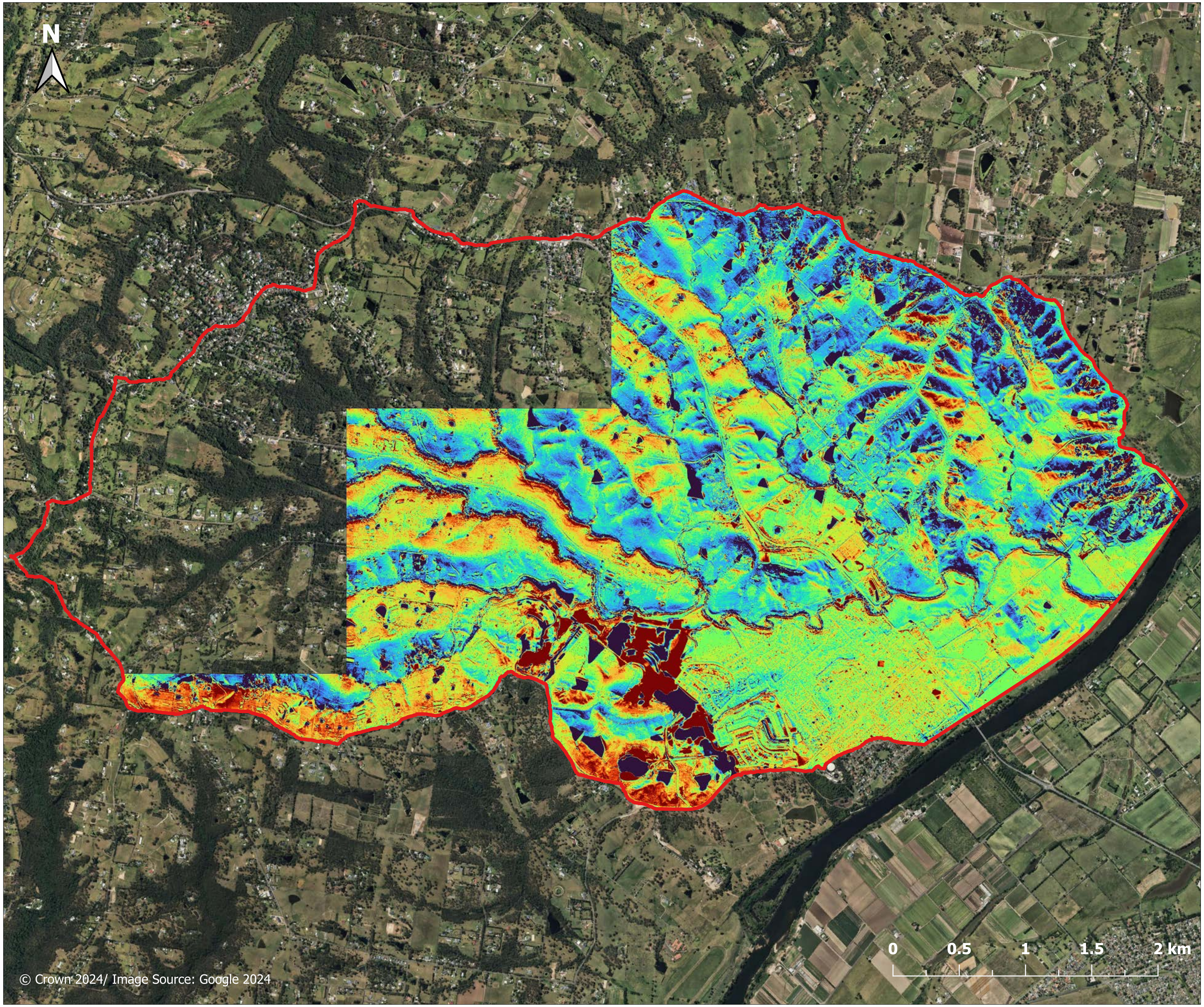

Figure 4.4

Comparison of 1 m resolution LiDAR datasets (2019 LiDAR minus 2017 LiDAR)

Legend

Study area

2019 LiDAR minus 2017 LiDAR

- <= -0.40
- -0.40 - -0.30
- -0.30 - -0.20
- -0.20 - -0.10
- -0.10 - 0.00
- 0.00 - 0.10
- 0.10 - 0.20
- 0.20 - 0.30
- 0.30 - 0.40
- > 0.40

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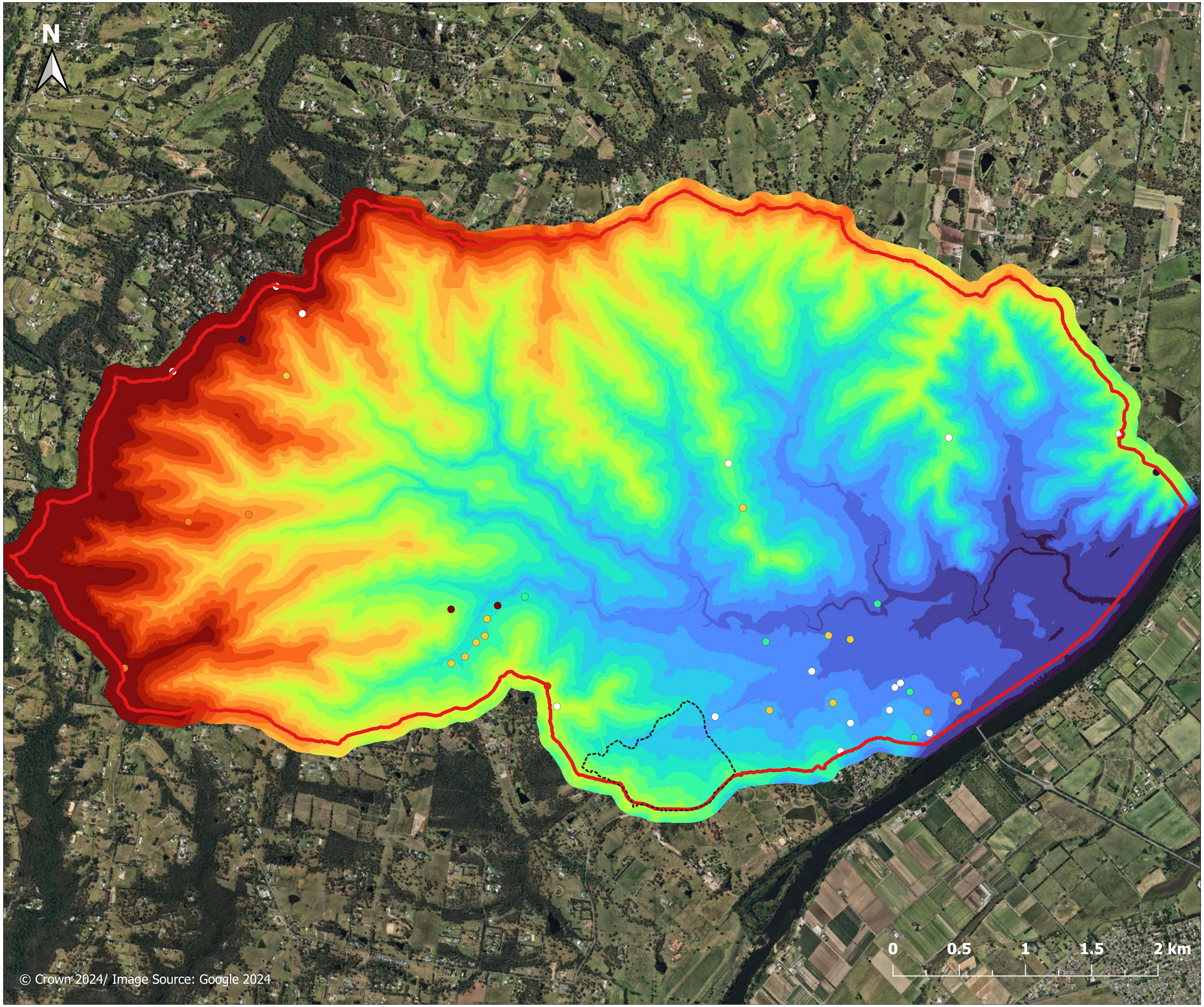
Figure 4.5

Topographic data



Legend

Study area

New development extent

2019 LiDAR minus survey mark elevation (m)

-0.5 - -0.4
-0.4 - -0.3
-0.3 - -0.2
-0.2 - -0.1
-0.1 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5

Elevation (m AHD) 2019 Penrith LiDAR

<= 8
8 - 16
16 - 24
24 - 32
32 - 40
40 - 48
48 - 56
56 - 64
64 - 72
72 - 80
80 - 88
88 - 96
96 - 104
104 - 112
112 - 120
120 - 128
128 - 136
136 - 144
144 - 152
> 152

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4.3 Aerial photography

The most recent available aerial imagery was obtained from Google Earth (www.googleearth.com), captured in 2023 to observe current features within the study area. Some high-resolution (0.075 m resolution) aerial imagery from 2 November 2023 was also available from Nearmap for the township of North Richmond.

4.4 Council's drainage network

Council's drainage network GIS layers were reviewed to determine the adequacy of the data for flood modelling purposes. A map of the drainage network within the study area is shown in **Figure 4.6**.The review identified some missing data required for modelling the stormwater network and the main observations are summarised as follows:

- Pipe / culvert data including approximate locations and sizing were available for the majority of the catchment, but no invert level was provided.
- Information for several pipes was unknown along Shortland Close, Bells Line of Road, Yobarnie Avenue and between Elizabeth Street and Pecks Road. Most of the missing pipes with unknown diameter were inspected to obtain basic dimensions during the site visit (except for the area nearest to the Hawkesbury River where no flooding was observed in our preliminary model).
- Drainage network in the senior housing development located directly east of Yobarnie Ave was not included in Council's drainage network data; however, PDFs of the Work as Executed have been provided for this location to facilitate the estimation of the pits and pipes.
- Locations of pits were mostly available; however, the provided data did not include invert levels or pit sizes. The inlets and outlets of the drainage system were checked to ensure alignment with the available elevation data and aerial imagery (e.g., confirming that headwalls are not positioned just outside of a dish drain). Consequently, the positions of several pits were adjusted to properly align with the stormwater lines.

It is noted that for the purpose of flood modelling, a minimum pipe diameter of 0.3 m was included in the hydraulic model. A minimum cover depth of 300 mm was assumed for all provided pits using standard pipe grading as a guide to ensure hydraulic continuity. The inlets and outlets of the drainage system were checked to ensure alignment with the available elevation data and aerial imagery (e.g., confirming that headwalls are not located just outside of a dish drain). All kerb-type pits were assumed to be 1800 mm wide and 100 mm high.

Figure 4.6

Drainage network

Legend

Study area

Pipe diameter (mm) from Council's stormwater drainage network dataset

- 300
- 375
- 400
- 450
- 525
- 600
- 675
- 750
- 825
- 900
- 1050
- 1200
- 1350
- 1500
- 1800
- 3000
- Unknown Dimension

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5 Site inspection

A site inspection was carried out by the MHL project team on Thursday 2nd of November 2023. The purpose of this inspection was to gain an overall appreciation of the relevant characteristics of the area and to identify areas that either contributed to flood risk or that were subject to the greatest flood risk. A preliminary 1% AEP flood event was run prior to the site inspection to understand the main flow paths within the study area. A number of hydraulic structures including bridges, culverts, and pipes were then inspected within the study area. The goal was to assess the dimensions of these structures and gather information to fill any gaps in the data provided by the Council. During this inspection, the dimensions of key pipes / culverts along main flow paths were verified to confirm the accuracy of the barrel / pipe sizes as indicated in the Council's data. **Figure 5.1** and **Figure 5.2** present the various hydraulic structures that have been inspected during the site inspection. The following key observations were made:

- In the western part of North Richmond, new developments including residential constructions, have been initiated and are still in progress.
- The dimension of the majority of pipes appeared to be correctly recorded in Council's database.
- Some structures not included in Council's dataset were inspected during the site visit including:
    - Two pits and associated 375 mm diameter pipes at the intersection of Terrace Road and Bells Line of Road (items 24 and 25).
    - A large 900 mm pipe led to 2 × 750 mm diameter pipes within a sag pit in an open area between Williams Street and Bells Line of Road (item 30). It was noted that access to measure exact size was restricted and only the outer part of the pipes was measured and are therefore indicative.
    - A small 1.2 m tall weir was observed underneath a wooden bridge near Kuyper Christian School (item 41).
- It was also noted that the upstream catchment is subject to significant developments known as the Redbank development and therefore, the 2019 LiDAR data is not always representative of the current upper catchment conditions. Hence, further information was provided by the Council.
- Seven bridges were inspected including two along Terrace Road (items 1 and 2), one along Crooked Lane (item 3), a footbridge in the open area at the back of Monti Place (item 33), a footbridge in the open area near Tyne Crescent (item 37), a small timber bridge along a bush track near Redbank Road (item 41), and a large bridge along Bells Line of Road (item 39). The data collected during the inspection for bridges was length, width, railing height, and location and informed the flood modelling. Example of bridges photographs are shown in **Figure 5.3.**

- Seventeen culverts were inspected within the study area. The data collected during the inspection included the number of barrels, diameter or width / height, and location of each culvert. One of the culverts was found heavily blocked between Pecks Road and Elizabeth Street, as shown in **Figure 5.4**.

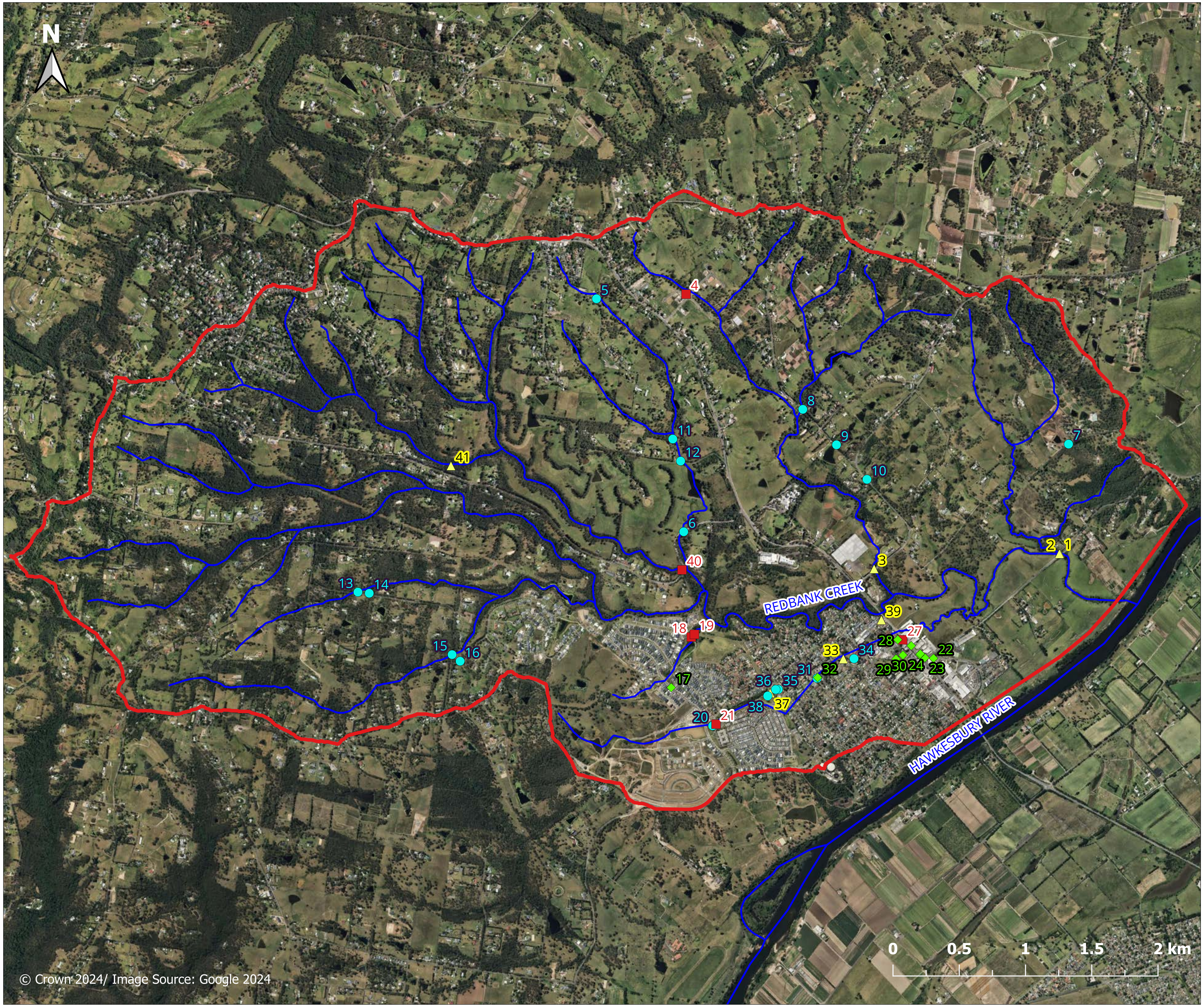

Figure 5.1

Inspected hydraulic structures within the study area

Legend

- Study area
- Watercourses

Inspected hydraulic structures

- Bridge
- Box culvert
- Circular culvert
- Pits and pipes

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Figure 5.2

Inspected hydraulic structures at North Richmond

Legend

- Study area
- Watercourses

Inspected hydraulic structures

- Bridge
- Box culvert
- Circular culvert
- Pits and pipes

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Figure 5.3 Example of photographs of inspected bridges within the study area

Figure 5.4 Photograph of inspected blocked culvert in the urbanised area (North Richmond)

6 Community consultation

6.1 Community questionnaire process

Consultation provides an opportunity for various stakeholders, including the community, to collaborate in providing information for Redbank Creek Flood Study. Engaging with the community throughout the process provides opportunities to both garner useful feedback on key areas of concern and ideas regarding future potential flood management measures and increase community acceptance of the flood study.

A project website was developed to provide information about the study, general flooding information, and a link to an online community questionnaire. A snapshot of the project website and a copy of the community questionnaire are presented in **Appendix B**.

6.2 Community questionnaire results

A total of seven responses were received from the online questionnaire. The approximate location of properties that participated in the questionnaire is also shown in **Appendix B.**

The following key observations were made based on the community questionnaire responses:

- All the seven responses indicated that the property is owner-occupied.
- Six responses specified the property type as residential, while one response indicated as other.
- Five residents have lived in the catchment for more than 20 years, one resident has lived there between 10 and 20 years, and one for less than five years.
- All of the respondents mentioned that only their property yards were affected by flooding.
- One of the respondents provided examples of flood events. The most commonly impacted part of the property included damage to trees and a wall in the yard.
- Observed flood depths were typically described as being over 3 m rise in the creek (three respondents).
- Flooding durations range between one day and 10 days (two respondents describing flooding as lasting for one day while one describes flooding as lasting for 10 days).
- The flood water was described as having a running pace by three respondents and as having a walking pace by three respondents.
- The main sources of flooding (six respondents) were described as the water flowing from Redbank Creek with floodwater rising in the Creek, Hawkesbury River inundation (one respondent), and overflow from neighbouring properties, followed by ponding of water within property.
- Two of the respondents reported that there are flood marks near the property.
- One of the respondents provided photographs as well as videos. Example of photographs are provided in **Figure 6.1** and **Figure 6.2**.

- The main concerns and suggestions from the respondents regarding flooding was the new development in the Redbank Creek catchment and the potential this development may have on increasing flooding. Respondents ask council to conduct studies to understand downstream impacts of these developments.

Figure 6.1 Flooding at the back of Susella Crescent on March 2022 (Courtesy of a community member)

Figure 6.2 Flooding in 2020 (location is unknown) (Courtesy of a community member)

7 Hydrologic analysis

Hydrologic modelling consists of determining the volume of water and the flows generated in a catchment based on various parameters including rainfall, catchment area, percentage of the ground that is pervious (such as grass or bare earth for example) or impervious (such as concrete or roads) and typical lag coefficient (which defines the time the flood water takes to travel through the catchment).

7.1 Model selection

The hydrological model selected for this study is WBNM (version 2017). This version of the model has been developed to include the 2016 Intensity-Frequency-Duration (IFD) diagrams that are at the basis of the ARR 2019 guideline requirements.

7.2 Model setup

7.2.1 Catchment delineation

Redbank Creek catchment extends from Grose Vale Road in the south and west, Bells Line of Road and the western extent of Kurmond Road in the north, down to the Hawkesbury River in the southeast and some natural high ground between Kurmond Road and the Hawkesbury River in the east. The sub-catchments were delineated using CatchmentSIM version 3.6 covering the area of approximately 27 km^2. This software was specifically developed to identify how sub-catchments are connected and determine the surface characteristics of each sub-catchment such as area and percentage impervious. The catchment was divided into 170 sub-catchments, delineated based on a 5 m DEM developed from the available 2019 LiDAR dataset shown on **Figure 7.1.**

7.2.2 Model parameters

Parameters required by the WBNM model include sub-catchment area and linkage, pervious and impervious percentage, runoff lag factor, stream routing lag factor, rainfall input, initial losses and continuing losses. Key parameters are described in the following sections.

7.2.2.1 Impervious areas

Impervious areas were derived by adopting impervious percentages for various land cover developed by Geoscape Australia in December 2022 obtained from the Department of Climate Change, Energy, the Environment and Water (DCCEEW). The land cover map with resolution of 2 m were utilised in the present study. Based on land cover areas, a weighted average was calculated for each sub-catchment. The building footprints, roadway corridors and water bodies / basins were assumed to be 100% impervious while the rest was assumed as pervious surface. **Table 7.1** summarises the percentage imperviousness used for each sub-catchment.

Table 7.1 Adopted percentage impervious for each sub-catchment

Sub-catchment	Area (ha)	% Impervious	Sub-catchment	Area (ha)	% Impervious	Sub-catchment	Area (ha)	% Impervious
1	11.0	2.5	58	15.1	4.2	115	21.5	5.0
2	21.2	5.9	59	16.1	5.4	116	19.7	51.8
3	15.2	9.6	60	27.8	17.0	117	15.0	9.8
4	18.2	0.8	61	15.2	11.7	118	22.5	55.7
5	15.8	22.3	62	15.4	1.0	119	15.1	8.1
6	15.1	8.1	63	16.8	8.4	120	16.0	48.7
7	15.1	3.1	64	15.1	6.7	121	18.3	22.0
8	15.1	5.0	65	15.2	7.8	122	15.3	41.9
9	15.3	4.5	66	16.0	7.8	123	15.0	54.5
10	20.0	2.0	67	14.9	7.8	124	15.1	13.1
11	17.5	10.9	68	15.6	6.8	125	2.9	7.5
12	17.3	4.5	69	16.1	4.7	126	8.3	4.5
13	15.6	5.8	70	16.9	13.9	127	16.9	21.2
14	15.0	2.7	71	17.5	4.7	128	15.2	4.7
15	15.1	0.0	72	19.3	4.3	129	16.1	14.9
16	15.4	1.8	73	15.6	3.6	130	15.3	9.9
17	15.8	4.1	74	17.9	7.4	131	15.0	5.5
18	15.4	4.4	75	17.9	26.7	132	21.2	6.5
19	15.1	5.7	76	15.9	8.4	133	15.0	28.9
20	20.0	8.9	77	15.2	5.8	134	17.4	5.9
21	17.8	10.3	78	14.9	12.2	135	15.4	6.8
22	25.5	6.0	79	15.1	6.2	136	16.1	18.0
23	14.9	5.6	80	23.5	7.5	137	8.7	5.2
24	17.9	12.6	81	15.3	31.2	138	15.2	5.1
25	12.1	13.5	82	15.5	5.4	139	15.0	11.5
26	14.9	10.2	83	16.1	3.5	140	15.1	8.9
27	15.4	1.0	84	19.3	7.6	141	24.7	5.1
28	15.5	10.7	85	15.0	2.3	142	25.9	7.3
29	17.3	3.5	86	15.0	14.1	143	15.2	8.3
30	15.3	2.8	87	17.6	10.4	144	16.5	5.1
31	15.1	6.4	88	22.6	24.1	145	14.9	23.6

Sub-catchment	Area (ha)	% Impervious	Sub-catchment	Area (ha)	% Impervious	Sub-catchment	Area (ha)	% Impervious
32	15.1	9.1	89	15.1	8.8	146	16.4	7.5
33	15.3	5.2	90	15.0	21.1	147	15.1	2.7
34	15.1	3.8	91	14.9	4.1	148	15.2	3.8
35	21.4	5.9	92	15.5	17.7	149	5.2	0.5
36	24.3	5.6	93	15.2	10.3	150	19.3	8.0
37	20.8	1.9	94	15.1	6.4	151	15.0	7.5
38	7.9	8.3	95	15.3	6.3	152	15.0	7.5
39	20.5	6.1	96	17.8	8.5	153	19.9	3.8
40	15.2	4.9	97	15.9	0.5	154	16.0	1.3
41	15.1	8.1	98	17.0	7.8	155	16.1	8.6
42	15.0	6.0	99	21.8	11.9	156	15.7	2.9
43	19.4	6.5	100	15.5	8.7	157	20.6	5.0
44	19.5	5.5	101	16.6	51.3	158	15.3	2.6
45	15.2	2.4	102	15.2	48.8	159	6.0	16.6
46	15.3	1.7	103	17.7	5.2	160	4.8	2.5
47	15.6	6.6	104	17.9	63.9	161	2.9	7.0
48	6.7	2.3	105	15.9	49.0	162	3.2	10.7
49	15.2	3.4	106	23.4	5.9	163	11.5	7.9
50	24.9	2.4	107	17.9	49.3	164	9.9	13.2
51	15.1	2.3	108	15.0	5.6	165	7.6	7.4
52	15.7	8.9	109	15.7	4.5	166	6.4	44.3
53	16.3	7.5	110	15.1	9.1	167	4.2	24.5
54	24.3	5.3	111	15.1	9.5	168	9.9	11.1
55	16.1	5.6	112	15.2	3.2	169	6.3	5.1
56	15.1	3.1	113	15.7	60.8	170	8.5	11.2
57	17.4	9.2	114	19.4	5.8	-	-	-

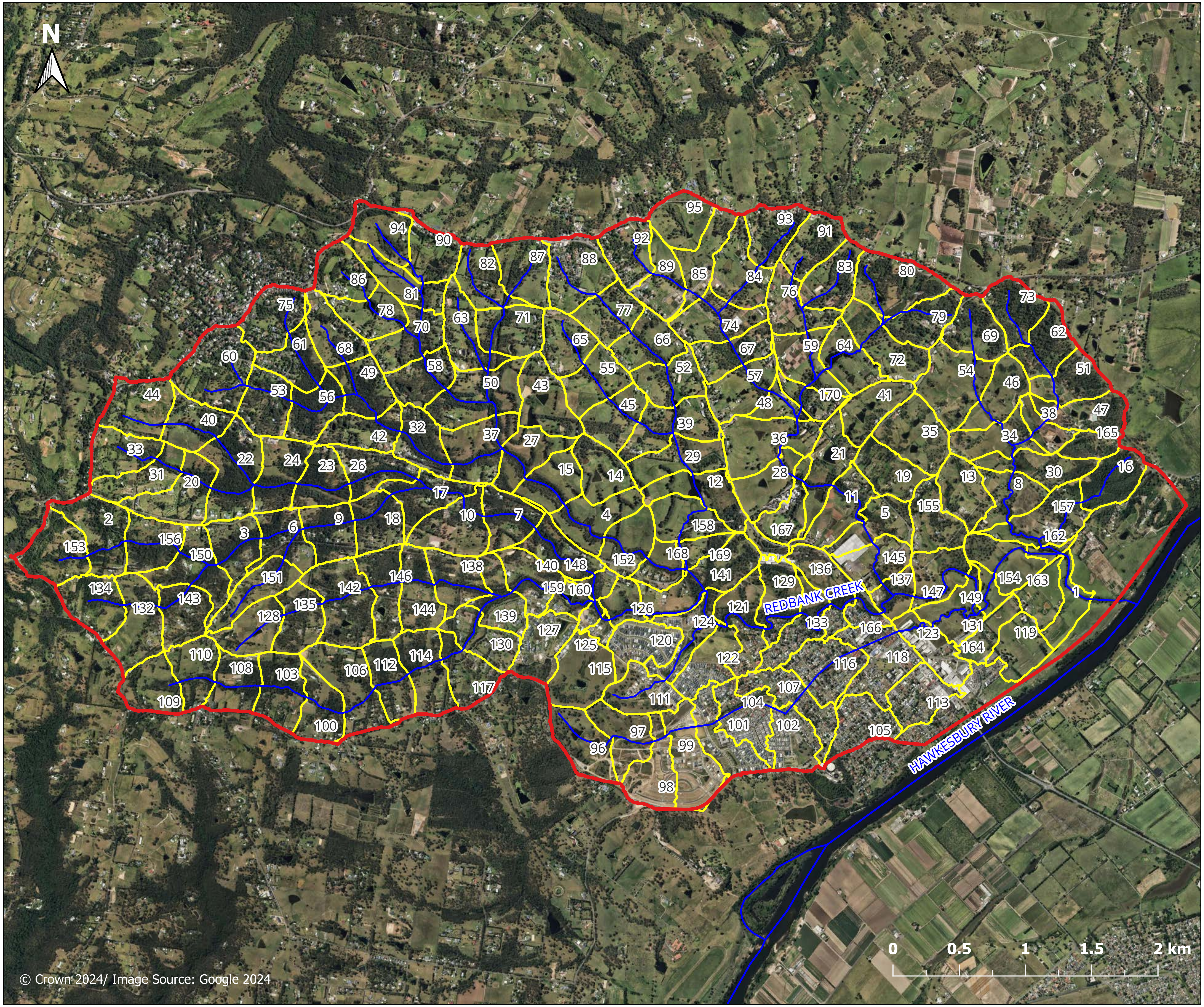

Figure 7.1

Hydrologic model catchment delineation

Legend

- Study area
- Subcatchment boundary
- Watercourses

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7.2.2.2 Rainfall losses

In compliance with the Floodplain Risk Management Guide Incorporating 2016 Australian Rainfall and Runoff in studies (OEH, 2019), a hierarchical method was implemented to ascertain rainfall losses and pre-burst estimation. This approach prioritises utilising the average calibration losses from the specific catchment if available, yet due to the absence of gauges within the current study area, this option was not feasible. Consequently, following the hierarchical method, the second preferred approach involved employing the average calibration losses from other studies in the catchment, if available and appropriate for the study. As a result, rainfall losses were sourced from the Hawkesbury-Nepean River Flood Study Technical Volume 7 (Rhelm and Catchment Simulation Solutions, 2024).

As part of the Hawkesbury-Nepean River Flood Study Technical Volume 7 (Rhelm and Catchment Simulation Solutions, 2024), WMA water was commissioned to carry out a Monte Carlo assessment within the ungauged catchments of the Hawkesbury River. **Table 7.2** summarises the initial and continuing loss values applied in the study. According to the Floodplain Risk Management Guide Incorporating 2016 Australian Rainfall and Runoff in studies (OEH, 2019), it is recommended to utilise the probability neutral burst initial loss values from the ARR data Hub for catchments in NSW unless a detailed Monte Carlo assessment of pre-burst and losses has been conducted. A summary of the adopted rainfall losses on pervious surfaces is provided in **Table 7.2**. Additionally, initial and continuing losses of 1.0 mm and 0.0 mm/hr, respectively, were adopted on impervious surfaces for all events excluding the PMF event. No losses were attributed to impervious or permanently wet areas for the PMF.

Table 7.2 Adopted rainfall losses on pervious surfaces obtained from Hawkesbury-Nepean River Flood Study Technical Volume 7 (Rhelm and Catchment Simulation Solutions, 2024)

Event	Pervious surfaces	
	Initial loss (mm)	Continuing loss (mm/hr)
20% AEP	30	1.2
10% AEP		1.5
5% AEP		2.4
2% AEP		2.7
1% AEP		2.7
1 in 200 AEP		2.2
1 in 500 AEP		2.2
1 in 1000 AEP		2.2
1 in 2000 AEP		2.2
1 in 5000 AEP		2.2
PMF	0	0.1

7.2.2.3 Lag and routing

A lag parameter (C) of 1.6 was adopted for the WBNM model. WBNM recommends lag parameter values ranging between 1.3 and 1.8 with an average value of 1.6. It is also, the recommended value for use on ungauged catchments for NSW (Boyd and Bodhinayake 2006). A stream lag routing Type R with a value of 1 was adopted. This is the recommended natural channel routing value.

7.3 Design events

The design events modelled in this study include:

- Frequent events: 20% and 10% AEPs;
- Rare events: 5%, 2% and 1% AEPs;
- Very rare events: 1 in 200, 1 in 500, 1 in 1000 and 1 in 2000 AEPs; and
- Extreme events: 1 in 5000 AEP and Probable Maximum Flood (PMF).

The terminology of these events is defined as per the ARR 2019 guidelines presented in **Table 7.3.** All events (except the 1 in 5000 AEP and PMF) use spatial and temporal patterns provided by the ARR 2019 Data Hub. The 1 in 5000 AEP and PMF use a combination of other temporal and areal patterns as described in the following **Section 7.4**.

7.4 Probable Maximum Flood event

The Probable Maximum Flood (PMF) is the largest flood event resulting from the Probable Maximum Precipitation (PMP). The PMP rainfall depth has been estimated using the ARR 2019 guidelines. According to the PMP method zones diagram (Bureau of Meteorology, 2003), Redbank Creek catchment falls within the GSAM Coastal Zone. Therefore, durations of up to 6-hours have been considered for the PMP in accordance with the Generalised Short Duration Method (GSDM) derived by the Bureau of Meteorology (BoM) (Bureau of Meteorology, 2003) and durations of 24 hours or longer have been estimated using the Generalised Southeast Australia Method (GSAM) (Bureau of Meteorology., 2006). Intermediary durations (i.e., 9 hr, 12 hr and 18 hr) have been estimated using the best fit of PMP values of both methods. A summary of the GSDM and GSAM results was provided in **Table 7.4** and **Table 7.5**, respectively.

Table 7.3 Design Event Terminology as per ARR 2019

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
Very Frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
Frequent	0.69	50	2	1.44
	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	19.5
	0.02	2	50	49.5
	0.01	1	100	99.5
Very Rare	0.005	0.5	200	199.5
	0.002	0.2	500	499.5
	0.001	0.1	1000	999.5
	0.0005	0.05	2000	1999.5
Extreme	0.0002	0.02	5000	4999.5
			↓	
			PMP/ PMP Flood	

Table 7.4 GSDM summary for Redbank Creek catchment

LOCATION INFORMATION					
Catchment Name:	Redbank Creek Catchment		State:	NSW	
Duration Limit:	6 hours	(3 - 6) hours	Area:	27	km^2
Approx. Centroid		Latitude	Longitude		
	Easting	285917.4672	Northing	6283354.258	
Portion of Area Considered:					
Smooth, **S** =	0.00	(0.0 - 1.0)	Rough, **R** =	1.00	(0.0 - 1.0)

ELEVATION ADJUSTMENT FACTOR (EAF)		
Mean Elevation:	74.95	m required if greater than 1500 m
Adjustment for Elevat	0.00	- 0.05 per 300 m above 1500 m
EAF =	1.00	(0.85 - 1.00)

GSDM MOISTURE ADJUSTMENT FACTOR (MAF)			
$EPW_{chatchment}$ =	72.92	**GSDM MAF = $EPW_{catchment}$ / 104.5**	0.70
	OR		
Read directly off GSDM Moisture Adjustment Factor chart at centroid			
GSDM MAF =	0.70	(0.46 - 1.19)	

Summer PMP values (mm)			Autumn PMP values (mm)		
Duration (hours)	**Initial Depth (D_{summer})**	**PMP Estimate (D_s×TAF×MAF_s)**	**Duration (hours)**	**Initial Depth (D_{autumn})**	**PMP Estimate (D_a×TAF×MAF_a)**
24		0.00	**24**		0.00
36		0.00	**36**		0.00
48		0.00	**48**		0.00
72		0.00	**72**		0.00
96		0.00	**96**		0.00

PMP Values (mm)				
Duration (hours)	**Initial Depth - Smooth (D_s)**	**Initial Depth - Rough (D_R)**	**PMP Estimate = (D_s×S+D_R×R)×MAF×EAF**	**Final PMP Estimate (from envelope)**
0.25	195	195	137	140
0.5	287	287	201	200
0.75	366	366	256	260
1	432	432	302	300
1.5	494	554	388	390
2	554	645	452	450
2.5	590	716	501	500
3	619	778	545	550
4	689	887	621	620
5	432	975	683	680
6	554	1040	728	730

Table 7.5 GSAM summary for Redbank Creek catchment

LOCATION INFORMATION			
Catchment Name:	Redbank Creek Catchment	State:	NSW
GSAM Zone:	Coastal	Area:	27 km^2

CATCHMENT FACTORS				
Topographical Adjustment Factor		**TAF =**	1.67	(1.0 - 2.0)
Annual Moisture Adjustment Factor		**MAF = EPW $_{seasonal\ catchment\ average}$ / EPW $_{seasonal\ standard}$**		
Season	**EPW $_{seasonal\ catchment\ average}$**	**EPW $_{seasonal\ standard}$**	**MAF**	
Summer (Annual)	72.92	80.8	0.90	(0.60 - 1.05)
Autumn	59.59	71	0.84	(0.56 - 0.91)

Summer PMP values (mm)			Autumn PMP values (mm)		
Duration (hours)	**Initial Depth (D_{summer})**	**PMP Estimate (D_s×TAF×MAF_s)**	**Duration (hours)**	**Initial Depth (D_{autumn})**	**PMP Estimate (D_a×TAF×MAF_a)**
24	848	1274.55	**24**	564	788.24
36	948	1425.50	**36**	695	971.00
48	1000	1503.57	**48**	816	1141.32
72	1046	1572.32	**72**	1032	1443.18
96	1082	1625.72	**96**	1105	1545.29

Final GSAM PMP Estimates			
Duration (hours)	**Maximum of the Seasonal Depths**	**Preliminary PMP Estimate (nearest 10 mm)**	**Final PMP Estimate (from envelope)**
1		300	300
2	Where applicable,	450	450
3	calculate GSDM depths	550	550
4	(Bureau of Meteorology,	620	620
5	2003)	680	680
6		730	730
9	(no preliminary estimates available)		880
12	(no preliminary estimates available)		100
18	(no preliminary estimates available)		1160
24	1275	1280	1280
36	1425	1430	1430
48	1504	1500	1500
72	1572	1570	1570
96	1626	1630	1630

The temporal patterns used to derive the PMF should be selected from an ensemble of patterns appropriate for use with the Generalised PMP.

At present, the best source of ensemble temporal patterns for use with short duration PMF events are those derived by (Jordan, Nathan, & Mittiga, 2005) for durations up to 6 hours. The procedure suggested to derive the design temporal distribution of GSAM patterns for duration of 24 hours or longer were described in the revised edition of Australian Rainfall and Runoff, Book IV, ARR (Nathan and Weinmann, 1999) using the Average Variability Method (AVM) of

Pilgrim et al., (1969) (Bureau of Meteorology., 2006) and (Bureau of Meteorology, 2005). The GSDM and GSAM patterns were used for intermediary durations (i.e., 9 hr, 12 hr and 18 hr). The (Jordan, Nathan, & Mittiga, 2005) patterns were derived specifically from storms associated with thunderstorm or deeply convective events while the GSDM and GSAM patterns are defined in the associated guidelines. The ellipse approach from the GSDM was applied to define the areal pattern for the shorter duration events.

These patterns were therefore adopted in this study and applied to the calculated PMP rainfall depth. The critical pattern determined as per the typical ARR 2019 guidelines was applied to all other design events.

7.5 Model results and critical duration

For each design event, 23 different durations were modelled ranging from 10 minutes to 168 hours, except for the PMF which had twenty durations ranging from 15 minutes to 120 hours. Within each duration, 10 specific rainfall events were modelled (as recommended in ARR 2019) which varied the rainfall temporal pattern, though not the magnitude, over that period. This led to 230 individually modelled rainfall events per design event which were then analysed to pick the most appropriate events to use as design rainfall.

Critical durations were selected based on the methodology described in ARR 2019. This methodology consists of selecting, for each duration, the rainfall temporal pattern that is the closest to the average flow obtained from the 10 specific patterns provided in the ARR 2019 database. This provides an automated approach that can then be adjusted for consistency in durations between the various events.

Figure 7.2 presents the critical durations with the associated temporal pattern (TP) of each sub-catchment across the study area for the 1% AEP event. It is evident that in most sub-catchments, durations of 120 and 720 minutes corresponded to the highest peak flows, while a few sub-catchments exhibited critical durations of 20 and 45 minutes. As a result, these four durations were adopted as critical durations.

For the 20 and 45 minute events, temporal patterns 4404 and 4531 resulted in peak flows. However, the 120 and 720 minute events yielded multiple temporal patterns contributing to peak flows. A comparative analysis of these temporal patterns was conducted to identify the most representative temporal pattern. Notably, in the majority of sub-catchments with a critical duration of 120 minutes, temporal patterns 4611, 4614, 4615 and 4618 generated closely aligned peak flows. **Figure 7.3** demonstrates that these temporal patterns exhibit similar peak flow characteristics; therefore, given that temporal pattern 4614 was the most frequently occurring, it was selected as the critical duration / temporal pattern. A similar approach was employed for 720 minutes event, resulting in the selection of temporal pattern 4443.

A summary of the selected critical durations / temporal patterns for each design event was tabulated in **Table 7.6**.

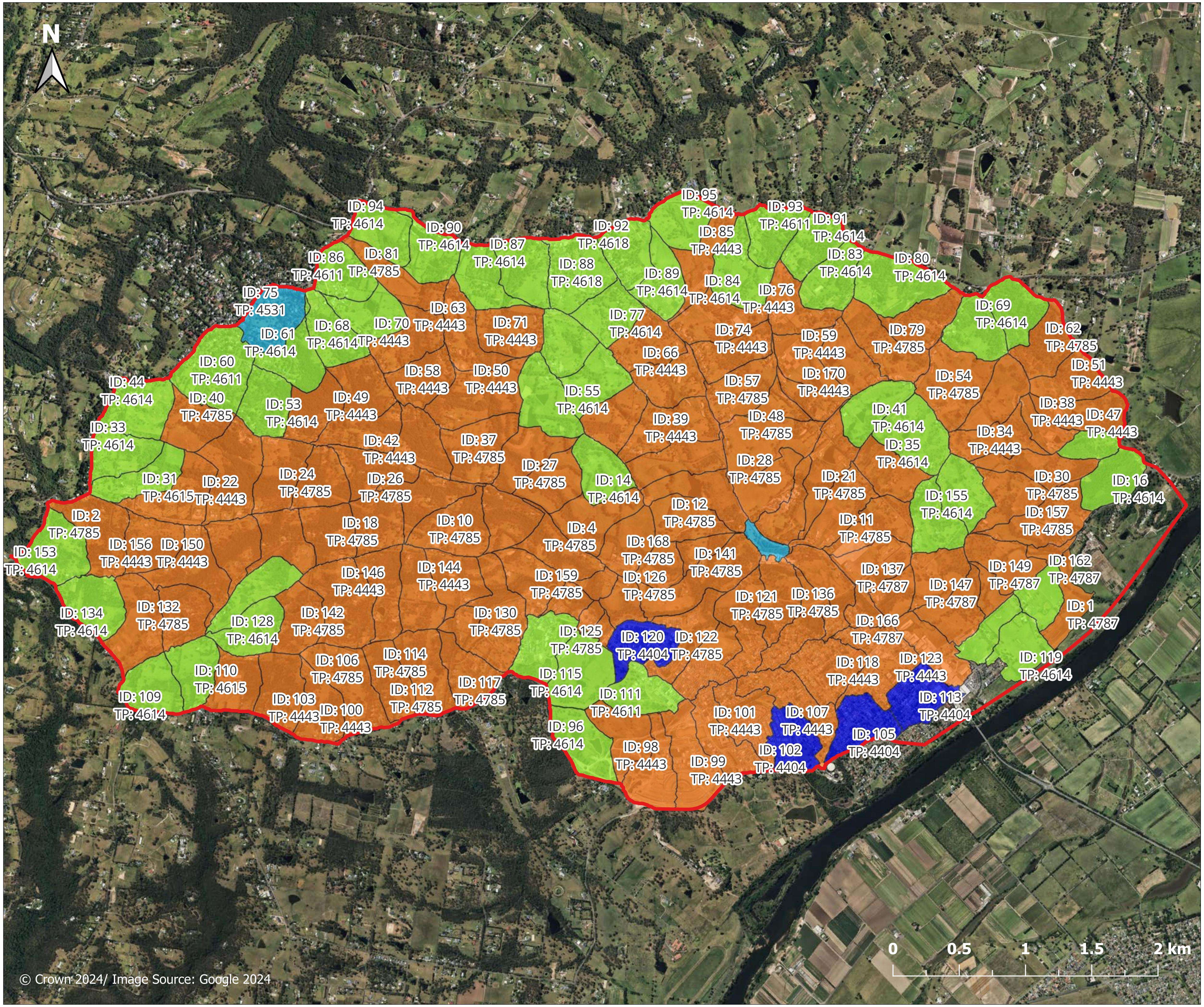

Figure 7.2

Critical duration 1% AEP event

Legend

Study area

Critical duration (min)

- 20
- 45
- 120
- 720

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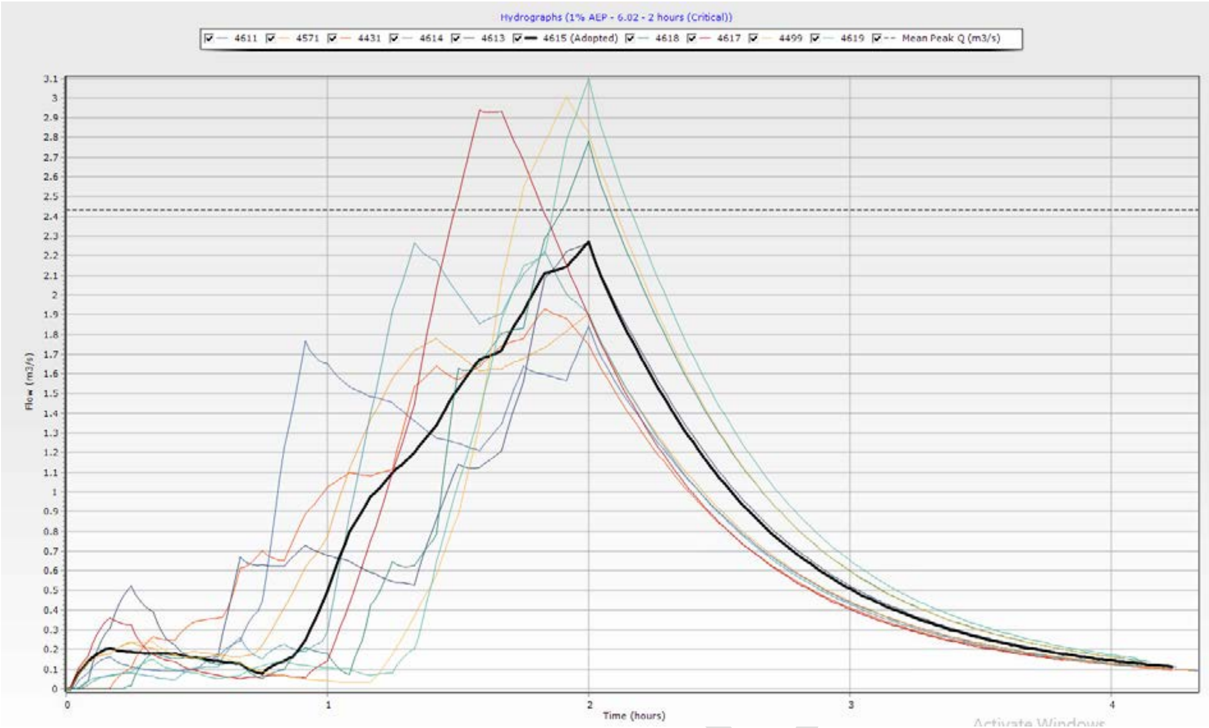

Figure 7.3 TPs distribution for all durations for the 1% AEP event (sub-catchment 110)

Table 7.6 Adopted critical duration and temporal pattern for each design event

Event	Adopted critical duration (min)	Adopted temporal pattern from ARR 2019 Data Hub
20% AEP	20 45 60 120 540 720	4440 4540 4569 4630 4764 4793
10% AEP	20 45 60 120 540 720	4440 4540 4569 4630 4764 4793
5% AEP	20 45 60 120 540 720	4440 4540 4569 4630 4764 4793
2% AEP	20 45 120 720	4404 4531 4614 4443

Event	Adopted critical duration (min)	Adopted temporal pattern from ARR 2019 Data Hub
1% AEP	20 45 120 720	4404 4531 4614 4443
1 in 200 AEP	20 45 120 720	4404 4531 4614 4443
1 in 500 AEP	20 45 120 720	4404 4531 4614 4443
1 in 1000 AEP	20 45 120 720	4404 4531 4614 4443
1 in 2000 AEP	20 45 120 720	4404 4531 4614 4443
1 in 5000 AEP	30 45 120 720	4 1 4 1
PMF	30 45 120 720	4 1 4 1

8 Hydraulic modelling

Hydraulic modelling consists of understanding the physical properties of the flood water such as depth and velocity. This can be completed in various ways including:

- One-dimensional (1D) modelling, which consists of representing a creek or river with flood information provided at regular interval cross-sections along a stream as well as pipe systems and drainage networks;
- Two-dimensional (2D) modelling, which consists of representing a floodplain as a grid with flood information provided at each cell of the grid allowing the model to define flowpaths; and
- 1D/2D modelling, which can be completed as a combination of the above.

8.1 Model selection

A 1D / 2D TUFLOW Heavily Parallelised Compute (HPC) hydraulic model was developed to simulate flood behaviour across the study area. The use of a TUFLOW model allows integrated investigation of local overland flooding, mainstream creek flooding, foreshore flooding and tidal influences, and the inclusion of stormwater drainage infrastructure.

The GIS data layers, and control files used to drive the model can be easily modified for use in any future options assessment, including modelling the impact of mitigation measures, or assessment of development applications. MHL flood modelling processes follow guidance provided in ARR 2019.

The dynamically linked 1D/2D model requires a number of GIS data layers to represent the study area. These include:

- 1D Domain
    - Pits and headwalls GIS layer;
    - Pipe network GIS layer;
    - Culverts GIS layer;
- 2D Domain
    - 2D grid / digital elevation model (DEM);
    - Topographic modifications and break lines (e.g., to incorporate embankments);
    - Materials layer (specifies surface roughness and infiltration);
    - Rainfall on the grid;
    - Layered flow constrictions layer for 2D bridges; and
    - Initial water level polygons.

The latest version of TUFLOW at the time of the model construction has been used for modelling (2023-03-AC).

8.2 Model setup

The following considerations were required to set up the TUFLOW model.

8.2.1 Model extent and grid size

A grid cell size of 2 m by 2 m was found to be suitable to represent flooding within the township and was also applied to represent embankment structures such as elevated roads (blue extent in **Figure 8.1**). The Quadtree capability was then used to transition to a 4 m cell size in the floodplain where rural properties are located and outside of the PMF extent.

The sub-grid sampling (SGS) capability of the TUFLOW model was also set to 1 m (i.e., the resolution of the available DEM). The SGS capability allows the use of sub-grid scale elevation data to enhance the hydraulic accuracy of the model (by providing an improved representation of flows in and out of each cell and the definition of the volume within each cell) while keeping reasonable run times.

This variable size grid complemented by the activation of the SGS allows an appropriate representation of the features of the local urban catchment while keeping the run time reasonable. Initial timesteps of 1.0 second for the 2D model and 0.5 second for the 1D model have been adopted as these are the recommended values for a 2 m cell size (being the smallest cell size in the model). TUFLOW HPC uses an adaptive timestep approach to maintain stability and varies this original value as required.

8.2.2 Modelling approach

MHL applied the following modelling approach to the development of a detailed and reliable 1D / 2D TUFLOW hydraulic model for the study area:

- Extent of the study area and 2D hydraulic model was determined based on the available elevation data;
- Direct rainfall method was adopted over the 2D model extent;
- Tailwater level was estimated at the downstream boundary condition located along Hawkesbury River based on the representative event water level in the Hawkesbury River modelled in the Hawkesbury-Nepean River Flood Study (Rhelm and Catchment Simulation Solutions, 2024) as reported in **Section 8.2.4;**
- Stormwater infrastructure: all pits, pipes, culverts and bridges were modelled as described in **Section 8.2.5**;
- Blockage: the blockage applied to the pits and pipes system has been established by following the method described in the blockage assessment form provided in ARR 2019 and ARR Project 11: Blockage of Hydraulic Structures; and
- Hydraulic roughness: a materials layer was delineated based on Council LEP zoning, NSW Surface cover, cadastral data and aerial photography along with site observations. Initial material categories and associated depth-varying Manning's roughness coefficients were established for the present study (refer to **Section 8.2.3**).

8.2.3 Hydraulic roughness

Hydraulic roughness coefficients (Manning's n) are used to represent the resistance to flow of different surface materials. Hydraulic roughness has a major influence on flow behaviour and is one of the primary parameters in hydraulic model calibration.

Spatial variation in hydraulic roughness is represented in TUFLOW by delineating the catchment into zones of similar hydraulic properties. The hydraulic roughness zones adopted in this study have been delineated based on consideration of Council LEP zoning, NSW Surface cover, cadastral data and aerial photography. Factors affecting resistance to flow were of primary importance including surface material, vegetation type and density, and the presence and density of flow obstructions such as buildings and gross pollutant traps (GPTs). Manning's n values assigned to each zone were determined based on aerial imagery, with reference to standard values recommended by (Te Chow, 1959). As resistance to flow due to surface and form roughness varies with depth (e.g., Chow 1959, Institution of Engineers Australia 1987), variable depth-dependent hydraulic roughness values have been adopted for this study to consider the typical sizes of vegetation/obstruction (i.e., typical grass or brush height). Once obstruction is underwater, roughness reduces. **Figure 8.2** and **Table 8.1** summarise the Manning's n values used in the hydraulic model.

Table 8.1 Adopted Manning's n Hydraulic Roughness Coefficients

Material	Manning's n below each threshold	Threshold of depth variable roughness (m)
Waterbodies	0.03 / 0.013	0.1 / 0.5
Residential – Medium density	0.03 / 0.02	0.04 / 0.10
Open Space / Light vegetation	0.05 / 0.035	0.10 / 0.50
Vegetation – Medium density	0.075 / 0.40	0.10 / 0.50
Vegetation – high density	0.10 / 0.08	0.40 / 2.0
Roadways	0.03 / 0.02	0.04 / 0.10
Dry water courses / Vegetated channel	0.04 / 0.06	0.10 / 0.50
Building footprint	0.10 / 1.0	0.03 / 0.10

N.B.: The Manning's n value is changing with depth and for example, for Open Space, the Manning's n value is 0.05 up to a depth of 0.1 m and then transition to a smaller Manning's n of 0.035 at a depth of 0.5 m or more.

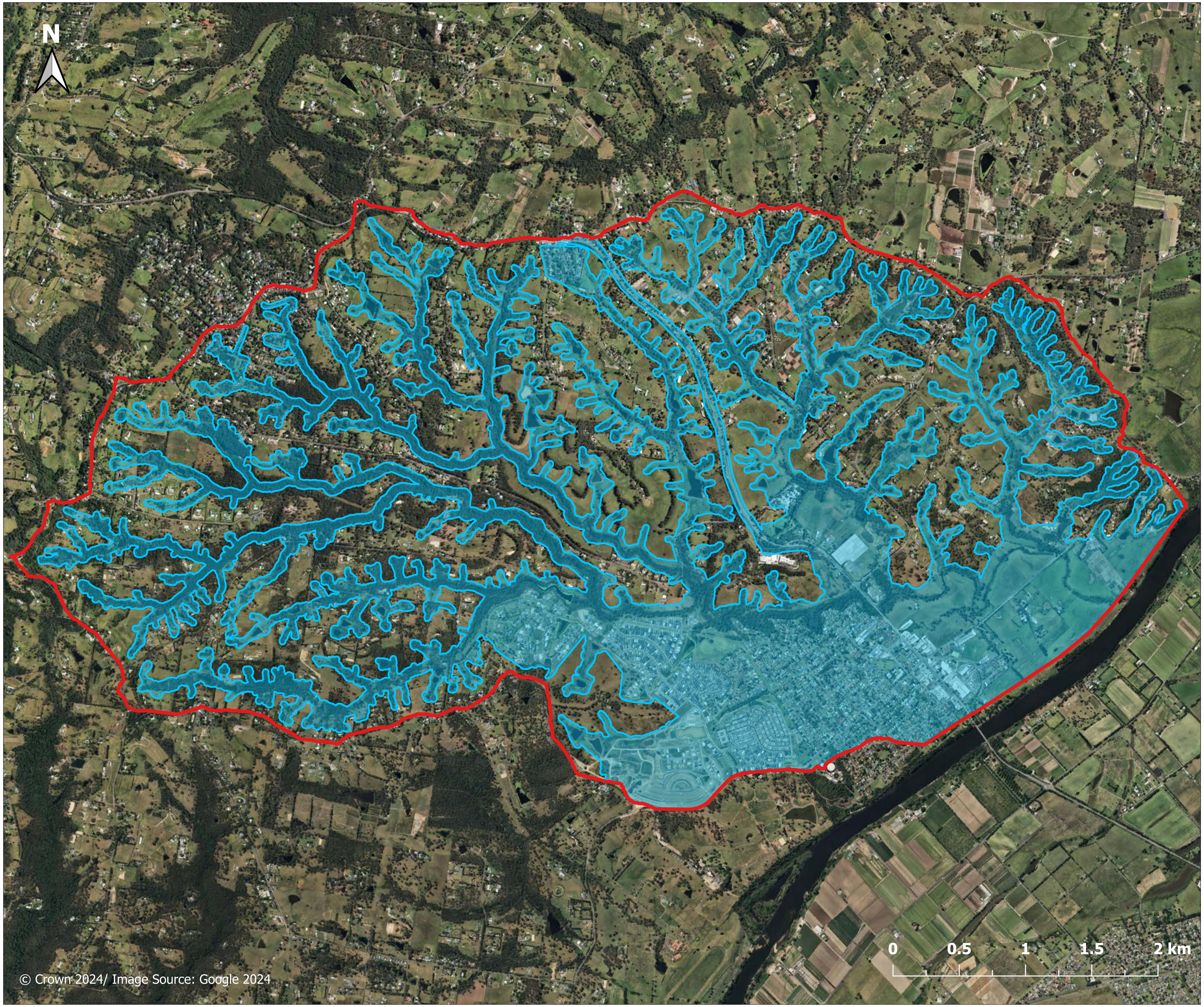

Figure 8.1

TUFLOW model grid definition

Legend

Grid resolution

- 4 m
- 2 m

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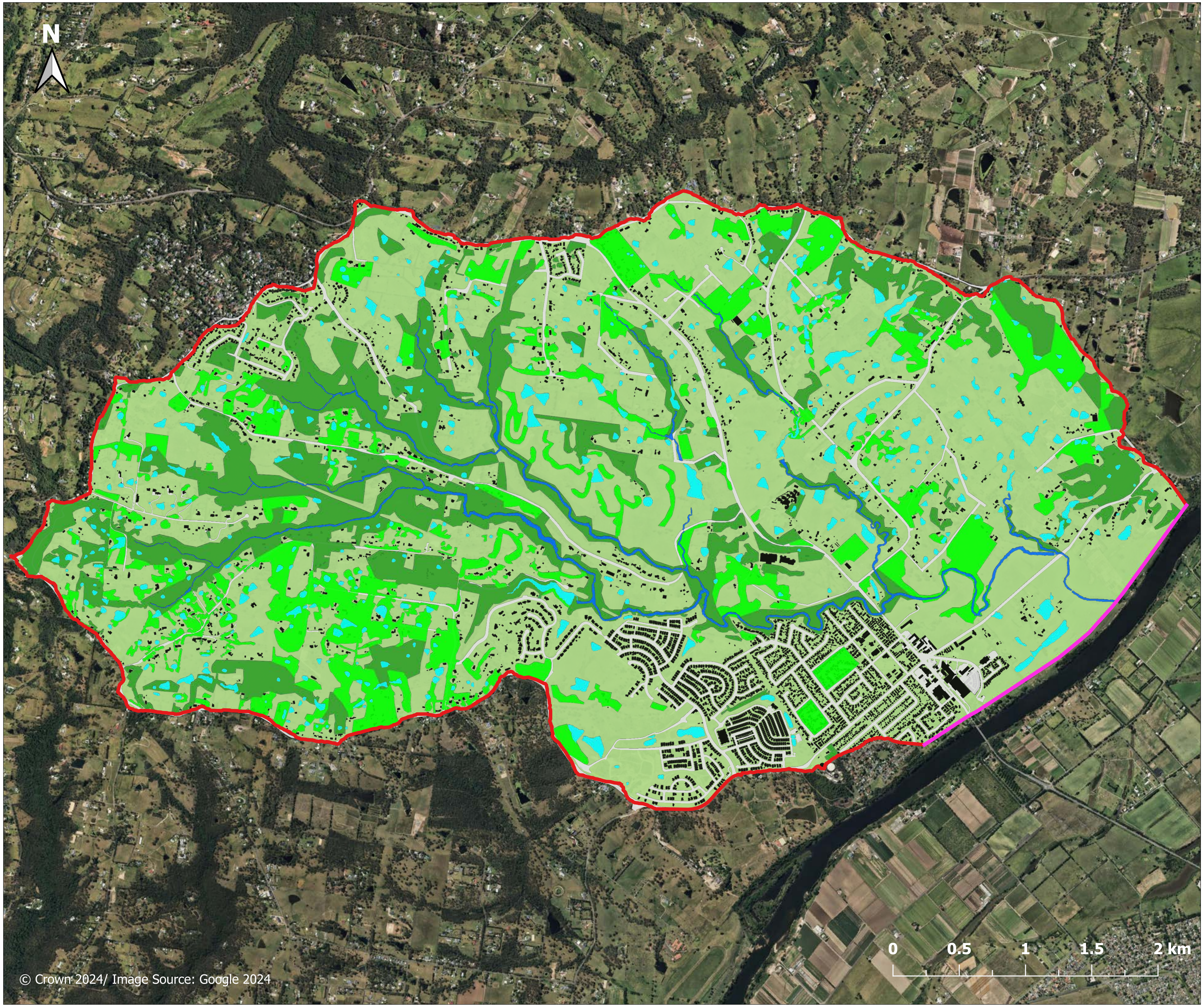

Figure 8.2

TUFLOW model Manning's n and boundary conditions

Legend

- Study area
- Building footprint
- Road corridor
- Thick vegetation
- Medium vegetation
- Light vegetation
- Dry watercourse
- Water body/Reservoir/ Lagoon

Boundary conditions

- Downstream tailwater

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8.2.4 Boundary conditions

Key boundary conditions are illustrated in **Figure 8.2**, providing a detailed overview of critical parameters.

8.2.4.1 Rainfall

The direct rainfall approach was applied to the model using the design events identified and defined in the hydrological analysis (**Section 7.5**).

8.2.4.2 Downstream boundary condition

Downstream water levels were determined following an approach consistent with the Floodplain Risk Management Guide: Modelling the interaction of catchment flooding and oceanic inundation in coastal waterways (OEH, 2015) and in conjunction with the reported water levels in the Hawkesbury River for representative design events (Rhelm and Catchment Simulation Solutions, 2024).

Table 8.2 summarises the recommended combinations of catchment flooding and downstream water levels scenarios following an approach consistent with (OEH, 2015) as well as adopted downstream water levels and their sources. For events more frequent than and including 5% AEP, a level-flow (HQ) boundary condition was adopted representing the outflows from the model area to the Hawkesbury River. For events rarer than and including 2% AEP, modelled water levels at the Hawkesbury River at North Richmond bridge were obtained from the Hawkesbury-Nepean River Flood Study, Technical Volume 11: Design Flood Modelling (Rhelm and Catchment Simulation Solutions, 2024).

Table 8.2 Downstream water level conditions

Catchment flood scenario	Boundary type	Water level boundary scenario	Adopted downstream water levels (m AHD)	Source
20% AEP	HQ	-	-	-
10% AEP	HQ	-	-	-
5% AEP	HQ	-	-	-
2% AEP	HT	10% AEP	14.5	(Rhelm and Catchment Simulation Solutions, 2024)
1% AEP	Envelope of HT and HQ	10% AEP	14.5	(Rhelm and Catchment Simulation Solutions, 2024)
1 in 200 AEP	HT	10% AEP	14.5	(Rhelm and Catchment Simulation Solutions, 2024)

Catchment flood scenario	Boundary type	Water level boundary scenario	Adopted downstream water levels (m AHD)	Source
1 in 500 AEP	HT	10% AEP	14.5	(Rhelm and Catchment Simulation Solutions, 2024)
1 in 1000 AEP	HT	5% AEP	15.6	(Rhelm and Catchment Simulation Solutions, 2024)
1 in 2000 AEP	HT	5% AEP	15.6	(Rhelm and Catchment Simulation Solutions, 2024)
1 in 5000 AEP	HT	5% AEP	15.6	(Rhelm and Catchment Simulation Solutions, 2024)
PMF	HT	1% AEP	17.5	(Rhelm and Catchment Simulation Solutions, 2024)

8.2.5 Building

Visual inspection of the available LiDAR data at the location of building footprints revealed that the building footprints were removed as part of the post-processing approach from the LiDAR dataset and in majority of the locations it resulted in misrepresentation of the ground level at the building footprints. Therefore, the majority of the building footprints were adjusted using the 85 percentiles of the topography level within the building footprint excluding big commercial / industrial buildings that were built in various levels. Also, high hydraulic roughness coefficient was applied to building footprints, refer to **Section 8.2.3**. This approach allow flow to enter buildings which is a more realistic representation of the flooding behaviour for buildings. The buildings GIS layer was reviewed using aerial imagery from 2024 (Google Earth) to confirm no significant changes had occurred. Moreover, commercial / industrial building walls were represented as a fence with 90% blockage giving the possibility of flow entering the building through doors / windows.

8.2.6 Blockage

Bridges and culverts are structures that allow water to flow under roads, railways or other obstruction from one side to the other. These structures can be affected by various blockage mechanisms, resulting in increased flood levels, changes to stream flow patterns, changes to erosion and deposition patterns in channels, and physical damage to the structures. Blockage of these structures is discussed in ARR 2019.

ARR 2019 blockage procedure presented in the Blockage Assessment Form was followed. Cross-drainage structures were identified from Council GIS.

Each cross-drainage was assigned a “High”, “Medium” or “Low” rating for the following ARR 2019 attributes:

- Debris availability – this rating was based on aerial imagery to assess the upstream catchment and the availability of debris;
- Debris mobility – this rating was defined using contours based on steepness of the

source area and proximity of source area to streams;

- Debris transportability – based on stream dimension in comparison to potential debris as well as stream shape;
- Debris length L_{10} : ARR 2019 defines this value as:
  - The average length of the longest 10% of the debris reaching the site and should preferably be estimated from sampling of typical debris loads. However, if such data is not available, it should be determined from an inspection of debris on the floor of the source area, with due allowance for snagging and reduction in size during transportation to the structure.
  - In an urban area the variety of available debris can be considerable with an equal variability in L_{10}. In the absence of a record of past debris accumulated at the structure, an L_{10} of at least 1.5 m should be considered as many urban debris sources produce material of at least this length such as palings, stored timber, sulo bins and shopping trolleys.
  - A value of 1.5 m has been adopted for L_{10} for all blockage structures in the model.

Based on the above approach, the majority of cross-drainages have opening lower than the selected L_{10} and have a design blockage varying between 25% and 100% depending on the AEP of the event. The culvert on Redbank Creek near Terrace Road has a larger opening and the blockage would vary between 10% and 20% depending on the AEP of the event.

Following the Western Sydney Engineering Design Manual (Western Sydney Planning Partnership, 2021), a 20% design blockage was adopted for on-grade and letterbox pits and 50% design blockage was adopted for all other pits and headwalls.

8.2.7 Structures

In accordance with the available structures data and topographic data the following structures were included in the hydraulic model:

- All pipes and culverts within the study area were modelled as 1D elements. Pits and pipes' location data provided by Council was incorporated in the modelling.
- The following bridges were modelled as 2D elements:
  - Crooked Lane Bridge (item 3) in **Figure 5.3**
  - Bells Line of Road Bridge over Redbank Creek (item 39) in **Figure 5.3**
  - Bells Line of Road Suspension footbridge over Redbank Creek (item 39) in **Figure 5.3**
  - Terrace Road Bridge over Redbank Creek (item 1) in **Figure 5.3**
  - Unnamed footbridge situated in the open area at the back of Monti Place (item 33) **Figure 5.3.**

8.2.8 Initial water level

The initial water levels in the farm dams, reservoirs, and ponds were assumed to be at full capacity at the start of the modelled events, thereby minimising the storage capabilities in the model. Also, at the downstream end of Redbank Creek, initial water level polygons were utilised to represent the area of inundation caused by corresponding water level conditions in the Hawkesbury River, as tabulated in **Table 8.3**.

For events more frequent than and including 5% AEP, the annual average of High High Water Solstices Springs (HHWS) at the Hawkesbury River at Windsor gauge was obtained from MHL2786 report on NSW Tidal Planes Analysis (MHL, 2023) to represent the initial water level at the confluence of Redbank Creek and Hawkesbury River. For events rarer than and including 2% AEP, modelled water levels at Hawkesbury River at North Richmond bridge were obtained from the Hawkesbury-Nepean River Flood Study, Technical Volume 11: Design Flood Modelling (Rhelm and Catchment Simulation Solutions, 2024) representing initial water level conditions within the study area.

Table 8.3 Initial water levels downstream of Redbank Creek

Catchment flood scenario	Hawkesbury River flood scenario	Adopted initial water levels at downstream boundary (m AHD)	Source
20% AEP	HHWS(SS)[1]	0.94	MHL2786 (MHL, 2023)
10% AEP	HHWS(SS)	0.94	MHL2786 (MHL, 2023)
5% AEP	HHWS(SS)	0.94	MHL2786 (MHL, 2023)
2% AEP	10% AEP	14.5	(Rhelm and Catchment Simulation Solutions, 2024).
1% AEP	10% AEP	14.5	(Rhelm and Catchment Simulation Solutions, 2024).
1 in 200 AEP	10% AEP	14.5	(Rhelm and Catchment Simulation Solutions, 2024).
1 in 500 AEP	10% AEP	14.5	(Rhelm and Catchment Simulation Solutions, 2024).
1 in 1000 AEP	5% AEP	15.6	(Rhelm and Catchment Simulation Solutions, 2024).
1 in 2000 AEP	5% AEP	15.6	(Rhelm and Catchment Simulation Solutions, 2024).

[1] HHWS(SS): The annual average of High High Water Solstices Springs at Hawkesbury River at Windsor was obtained from MHL2786 report on NSW Tidal Planes Analysis (MHL 2023).

Catchment flood scenario	Hawkesbury River flood scenario	Adopted initial water levels at downstream boundary (m AHD)	Source
1 in 5000 AEP	5% AEP	15.6	(Rhelm and Catchment Simulation Solutions, 2024).
PMF	1% AEP	17.5	(Rhelm and Catchment Simulation Solutions, 2024).

9 Model sensitivity

9.1 Preamble

This report recognises the limitations in data availability for proper calibration due to the absence of gauging stations within the study area. The lack of such critical hydrological data hampers the ability to calibrate models accurately, which in turn introduces uncertainties that may affect the reliability of the findings. It is essential to acknowledge these limitations when interpreting the results, and future research should consider the establishment of gauging stations or explore alternative data sources to enhance model calibration and validation efforts.

A number of factors required some sensitivity analysis prior to completing the design runs. These factors include:

- Tailwater level: impact of various water levels in the Hawkesbury River was investigated.
- Losses: impact of no loss and ARR 2019 losses were investigated.
- Roughness: impact of reduced and increased roughness coefficient was investigated.
- Blockage: ARR 2019 recommends running two blockage sensitivity scenarios including double design blockage and no blockage.

Sensitivity results are provided in **Appendix D** .

9.2 Tailwater level sensitivity analysis

In order to analyse the influence of the tailwater level on the flood behaviour, the following scenarios were modelled:

- HHWS(SS) in Hawkesbury River (0.94 m AHD);
- 50% AEP water level in Hawkesbury River (6.7 m AHD);
- 20% AEP water level in Hawkesbury River (12.3 m AHD);
- 10% AEP water level in Hawkesbury River (14.5 m AHD); and
- 5% AEP water level in Hawkesbury River (15.6 m AHD).

Each of these scenarios were modelled for 120-minute critical durations with design blockage condition for the 1% AEP flood event. The following observations were made:

- **Appendix D (Figure D.1)** illustrates the extent of flooding for various scenarios revealing that the tailwater level condition in the Hawkesbury River resulted in increase in flood level and expansion of the flood extent along the lower reaches of Redbank Creek. However, tailwater levels have negligible impact on the flood extent and water level in areas upstream of Douglas Street, Crooked Lane and Bells Line of Road.
- **Figure 9.1** illustrates the peak water levels for 1% AEP flood event with various tailwater conditions along Redbank Creek. It was observed that the corresponding 5%, 10%, 20% and 50% AEPs tailwater levels would extend the backwater up to approximately 3.2, 3.0, 2.3 and 0.6 km along Redbank Creek from the Hawkesbury River.

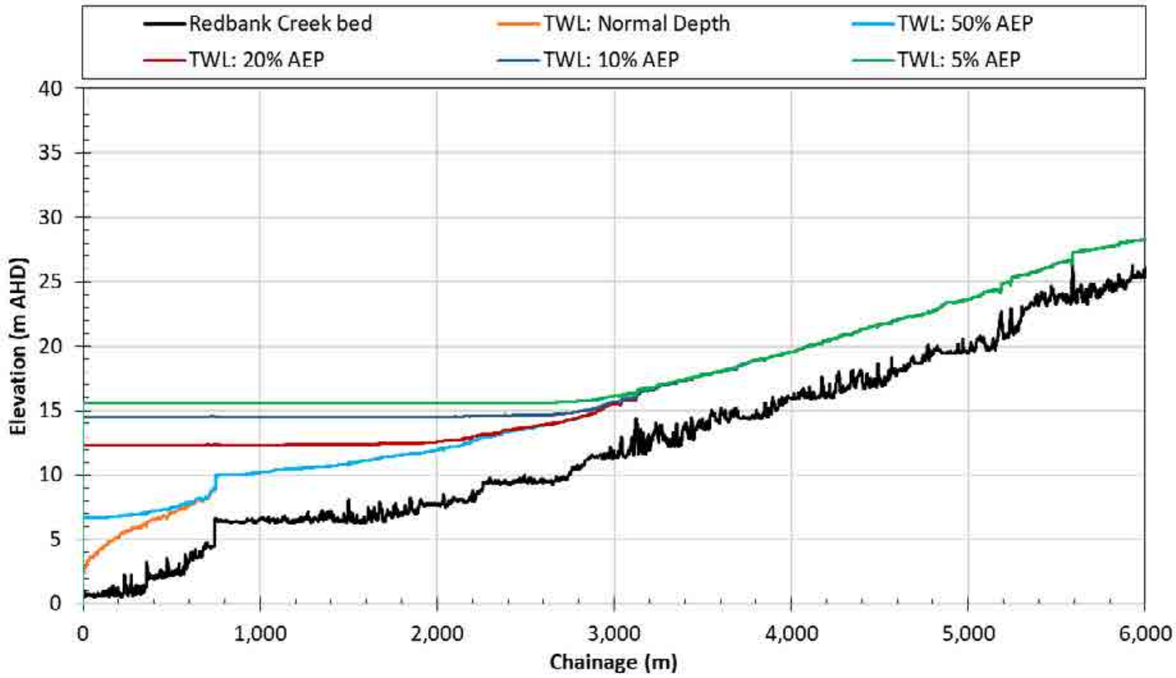


Figure 9.1 Peak water level for 1% AEP flood event with various tailwater levels along Redbank Creek

9.3 Losses sensitivity analysis

In order to analyse the influence of losses on the flood behaviour, the following scenarios were modelled:

- No loss scenario with neither continuing losses nor initial losses in the pervious areas for the 1% AEP flood event.
- ARR 2019 losses with 1.52 mm/hr (3.8 x 0.4 = 1.52 mm/hr) continuing losses and 50 mm initial losses in the pervious areas for the 1% AEP flood event. It is important to note that the initial loss of 30 mm and continuing loss of 2.7 mm/hr were adopted for 1% AEP event.

Each of these scenarios was modelled for all the adopted critical durations under design blockage condition and the resulting envelope of these critical durations were utilised in the assessment. The following observations can be made:

- The removal of all losses would generate increases in water levels in the order of up to 0.05 to 0.2 m around the township and up to 0.8 m along the creek.
- ARR 2019 losses would result in decrease in flood level by up to 0.05 to 0.10 m within the township, and by up to 0.2 m along the upstream reaches of the watercourses while water level increases by 0.1 m along the downstream reaches of the creek.

9.4 Roughness sensitivity analysis

In order to analyse the influence of hydraulic roughness on the flood behaviour, the following scenarios were modelled:

- Low roughness scenario with roughness reduced by 20% for the 1% AEP flood events.
- High roughness scenario with roughness increased by 20% for the 1% AEP flood events.

Each of these scenarios was modelled for all adopted critical durations with design blockage condition and the resulting envelope of these critical durations were utilised in the assessment. The following observations can be made:

- Increase in material roughness by 20% may increase water levels by up to 0.25 m along the watercourses but has a lesser impact on the flood levels within the North Richmond township with increases of up to 0.07 m. It is noted that some areas are subject to decreases in flood level by up to 0.05 m. These areas are typically located in basins and other storage areas due to upstream flows taking longer to reach the storage area and giving it more time to drain.
- Similarly, decrease in material roughness by 20% may decrease water levels by up to 0.25 m along the watercourses but has a lesser impact on the flood levels within the North Richmond township with decreases of up to 0.07 m. It is noted that some areas are subject to increases in flood level by up to 0.05 m. These areas are typically located in basins and other storage areas due to upstream flows reaching the storage area faster and giving it less time to drain.

9.5 Blockage sensitivity analysis

In order to analyse the influence of blockage on the flood behaviour, the following scenarios were modelled:

- No blockage scenario for the 1% AEP event. These scenarios assumed that all the pits and pipes were free of blockages.
- Double design blockage scenario for the 1% AEP flood event. These scenarios consider the double of the design blockage assigned to cross-drainage structures, pits and pipes.

Based on the results of this analysis, the following observations can be made:

- The double blockage scenario can lead to water level increases of up to 0.2 m within the North Richmond township, with some localised areas experiencing even higher water levels. These local increases are typically located along main drainage channels and upstream of major culverts, where the reduced capacity for drainage leads to an accumulation of water. Conversely, this scenario may cause decreases of up to 0.02 m in water levels along Redbank Creek, especially north of Pansy Crescent. This reduction is attributed to a greater volume of water that remains undrained in the system.

The no blockage scenario may result in localised variations in water levels of up to 0.10 m. Certain areas, particularly upstream of major culverts / pipes may experience reduced water levels, while downstream of major structures - especially along Redbank Creek north of Pansy Crescent - could experience increases in water levels. These changes are attributed to the enhanced drainage capacity, allowing a greater volume of water to flow through the system.

10 Flood modelling results

10.1 Flood modelling description

The 1D / 2D TUFLOW hydraulic model was run for events including the 20%, 10%, 5%, 2%, 1%, 1 in 200, 1 in 500, 1 in 1000, 1 in 2000 and 1 in 5000 AEPs and PMF events. Multiple durations and temporal patterns were modelled for all the events, refer to **Table 7.6**, to provide representative critical duration for the majority of the catchment and also consider area acting as detention basin (and hence with longer critical duration). An envelope of these durations was produced to represent the flooding for each event.

10.2 Flood mapping

10.2.1 Mapping filtering

The flood extents were filtered to remove shallow depths areas generated by the direct rainfall methodology. The filtering criteria used to retain relevant areas including the following conditions:

- Depth > 0.10 m; OR
- Depth > 0.05 m AND Velocity × Depth > 0.025 m^2/s; OR
- Velocity > 2 m/s.

Further to these criteria, “puddles” smaller than 100 m^2 were also excluded from the flood extent. These filtering criteria are informed by recent studies completed along the NSW coastline such as the Coastal Lagoons Catchments Overland Flood Study for Central Coast Council and the Racecourse Creek Flood Study and Option Assessment for MidCoast Council.

As part of the present study, a sensitivity analysis was undertaken to assess the impact of removing various puddle sizes from the flood maps. During this process, the aforementioned filtering criteria were applied, and puddles of different sizes were systematically excluded.

The analysis estimated the volume of the water within the study area, as summarised in **Table 10.1.**

Table 10.1 Summary of estimated volume of water and impact of puddle removal

Puddle sizes were removed	Flood / Water Volume (m^3)	% Removed
0	1,236,053	-
< 50 m^2	1,232,997	-0.25%
< 100 m^2	1,230,567	-0.44%
< 250 m^2	1,225,312	-0.87%

Table above reveals that the removal of puddles with areas less than 50, 100 and 250 m^2 resulted in reductions in volume of water of 0.25%, 0.44% and 0.87%, respectively. Given the minimal impact on the overall water volume within the study area, excluding puddles smaller than 100 m² was confirmed as a reasonable approach by the Council and DCCEEW.

10.2.2 Flood maps

Flood mapping presenting the peak flood level, peak flood depth and peak flood velocity envelops of each event is provided in **Appendix E** . These results are further discussed in the following section.

The flood extents due to a range of riverine flooding mechanism were derived from the Hawkesbury-Nepean River Flood Study (Rhelm and Catchment Simulation Solutions, 2024) and were added to the peak flood depth maps. This integration allows for a comparison between overland flooding extent and riverine flooding. It is essential to recognise that areas affected by riverine flooding must be evaluated accordingly.

11 Consequences of flooding on the community

This section outlines the effects of flooding on the community. To grasp the impact of flooding, it is essential to analyse the flood behaviour within the catchment and identify key problem areas. Following this, the consequences of flooding, including road closures and damage can be evaluated and more details are provided in this section.

11.1 Flood behaviour

Flow within the study area is mostly maintained within Redbank Creek and the main drainage channel through the township. Key flood-prone areas are highlighted below, noting that the described impacts are based on flooding that affects the floor level of buildings on properties:

- Properties located at the northern end of William Street, Elizabeth Street, Susella Crescent, Merrick Place and O'Dea Place are impacted from 1 in 500 AEP event; however, road access may be affected by events as frequent as 20% AEP;
- A few Properties along the northern side of Flannery Avenue are impacted from 1 in 200 AEP event; however, their access may be affected by event as frequent as a 5 AEP;
- A few properties at the north-west corner of Pansy Crescent are impacted by events as frequent as 10% AEP;
- Properties located along the main drainage channel between Pecks and Elizabeth Streets are affected due to 1 in 5000 AEP and PMF events. Up to including 1 in 2000 AEP event, flow is mostly contained within the main drainage channel.
- A few properties located between Stephen and Pecks Streets are impacted by events as frequent as 10% AEP.
- Properties situated between Tyne Crescent, Stephen Street and north end of Yvonne Place are impacted by events as frequent as 5% AEP.
- A secondary overland flow path was observed through the North Richmond township, from the sag point along Enfield Avenue through a few properties towards the south end of Monti Place, continuing towards the intersection of Charles and Elizabeth Streets. These areas are impacted by events as frequent as 10% AEP;
- Properties located at the southernmost corner of Tyne Crescent;
- A few properties located at the north-east corner of the intersection of Charles and William Streets are impacted by events as frequent as 5% AEP;
- Properties near the intersection of Charles and Elizabeth Streets are impacted by floods as frequent as 5% AEP event such as North Richmond Community Centre.

11.2 Flood damage assessment

11.2.1 Flood damage categories

A preliminary flood damage assessment has been conducted to evaluate the economic impacts of flooding. Economic impacts can be categorised as tangible or intangible. According to the Flood Risk Management Manual (DPE - EHG, 2023), flood damages are categorised as follows:

- Tangible Damages: Those that can be readily assigned a monetary value and measured
  - Direct Damages: Losses incurred from floodwaters wetting goods and possessions.
  - Indirect Damages: Financial losses related to the flood, including lost wages and increased expenses for cleanup and recovery efforts.
- Intangible Damages: Involve effects that are challenging to quantify financially, these may include:
  - Increased emotional stress and mental health issues resulting from the flooding.
  - Loss of personal items such as photographs and documents, contributing to feelings of grief.
  - Financial strain from replacing damaged possessions.
  - Disruption to family life due to temporary relocation, school changes, and increased commuting times.

This assessment primarily focuses on direct tangible damages to properties, including residential, commercial, industrial, and public buildings. Other potential damages, such as those to infrastructure (e.g., roads and bridges), are not included due to the absence of a clear methodology for quantification.

While the damage assessment provides insight into the magnitude of flooding issues, its utility for absolute economic evaluation is limited. Nonetheless, it serves as a valuable foundation for quantifying the benefits of mitigation strategies, allowing for a comparison of the reduction in tangible property damages against implementation costs. Additional assessments of tangible infrastructure damages and intangible impacts are incorporated into the multi-criteria matrix assessment during the option investigation process. The methodology for this damage assessment adheres to the latest guidelines and is summarised below.

11.2.2 Assessment methodology

The flood damages assessment methodology is presented below:

- **Establish design flood modelling results** for the 20%, 10%, 5%, 1%, 1 in 200, 1 in 500, 1 in 1000, 1 in 2000, 1 in 5000 AEPs and the PMF events. Flood modelling results are derived from the models established in Redbank Creek catchment area, and are based on an envelope of overland flooding for various critical durations / temporal patterns;
- **Obtain floor level data** (refer to **Section 11.2.3**);
- **Determine the peak flood depth** that would occur at each property during each design flood event;

- **Apply damage curves** derived from Excel template version DT01-v1.02 developed as part of Flood risk management manual: the management of flood liable land (the manual) and its supporting toolkit (NSW DPE, 2023) to relate the depth of flooding to a monetary cost in each design flood event;
- **Calculate the Average Annual Damage (AAD):** The AAD represents the estimated tangible damages sustained every year (on average), over a long period of time.

Note that the results are not an indicator of individual flood risk exposure, but part of a regional assessment of flood risk. Furthermore, the purpose of the damages assessment is not to calculate the actual damage that would be incurred in a flood, but to form a basis of comparison with other flood prone communities throughout NSW, and a baseline against which future mitigation options can be assessed.

Considering that the Excel template version DT01-v1.02 is constrained by up to 10 events; preliminary damage assessment was undertaken revealing a linear trend among 1 in 500, 1 in 1000 and 1 in 2000 AEP events. It appeared that discarding the 1 in 1000 AEP event may not cause a significant change in the trend; therefore, 1 in 1000 AEP was excluded from the process of damage assessment.

11.2.3 Floor level database

The preliminary flood damages assessment is based on the depth of flooding that occurs above and below the floor level of each property in the PMF extent. A desktop study was undertaken determining a total of 5250 buildings located within the present study area including 5093 residential and 157 non-residential building. For non-residential buildings, aerial photographs, available DEM data and Google Street View were used to identify the number of steps to the entrance; however, in case of invisibility of the entrance zero steps were assumed. Given the absence of detailed floor level survey dataset, a blanket approach of assuming two steps (2 * 0.15 m = 0.30 m) was adopted to represent the floor level of residential properties excluding the residential properties within the senior housing area. Google Street view revealed that, the assumption of zero steps was reasonable to represent the floor level of the majority of the residential buildings within the senior housing area. Also, a blanket approach of assuming one step was employed to represent the floor level of school buildings. It is noted that each building was analysed separately and some properties such as schools may include multiple buildings. Outlines of the building were estimated from the available aerial imagery. It is also noted that some buildings are spreading over multiple lots and some lots include multiple buildings. The maximum water level encroaching the building outline was adopted as the building flood level to be used in the damage calculation for each event. It is recommended to undertake a thorough site inspection as part of a future Floodplain Risk Management Study and Plan (FRMS&P) for a detailed damage assessment.

11.2.4 Flood damage assessment results

Table 11.1 and **Table 11.2** are presenting the flood damages results for Redbank Creek catchment area and are divided into residential damages, commercial damages and the total combined damages. The spread of the AAD across the Redbank Creek catchment is illustrated in **Appendix F** .

In addition, a sensitivity analysis was carried out demonstrating the crucial role of the number of steps on estimating the AAD, tabulated in **Table 11.3**. It was observed that increasing one step resulted in decrease of AAD up to 62% while decreasing the number of steps by one resulted in increase of AAD up to 96%.

Table 11.1 Redbank Creek catchment residential damage disbenefits and costs summary for base case

Summary of residential damage												
Event	No. of properties flooded above ground	No. of properties flooded above floor	Total damage	Contribution to AAD Total	Damage / Cost components (Contribution to AAD)							
					Structural	Contents	External	Intangibles	Infrastructure uplift	Mental health	Clean-up	Social and wellbeing
PMF	2,145	1,310	$303,922,373	$55,018	$28,280	$14,308	$4,363	$8,068	$5,502	$1,443	$1,155	$0
1 in 5000 AEP	2,069	1,232	$275,217,753	$47,719	$25,263	$12,331	$3,989	$6,136	$4,772	$1,225	$1,056	$0
1 in 2000 AEP	515	240	$42,909,347	$54,209	$33,109	$13,205	$5,718	$2,178	$5,421	$1,190	$1,513	$0
1 in 500 AEP	397	182	$29,369,552	$70,623	$44,229	$16,135	$8,102	$2,158	$7,062	$1,414	$2,145	$0
1 in 200 AEP	283	117	$17,712,283	$79,187	$49,566	$17,649	$9,484	$2,487	$7,919	$1,547	$2,510	$0
1% AEP	242	93	$13,962,329	$123,076	$77,074	$27,467	$14,904	$3,631	$12,308	$2,414	$3,945	$1,227
2% AEP	202	72	$10,652,895	$267,261	$171,076	$57,045	$33,059	$6,082	$26,726	$4,843	$8,751	$10,403
5% AEP	164	50	$7,164,512	$276,311	$181,531	$52,768	$37,485	$4,526	$27,631	$4,154	$9,922	$11,417
10% AEP	116	33	$3,887,913	$286,330	$188,647	$53,691	$39,743	$4,249	$28,633	$4,249	$10,520	$15,289
20% AEP	54	11	$1,838,679	$275,802	$188,915	$52,831	$29,807	$4,249	$27,580	$4,249	$7,890	$7,668
Total AAD				**$1,535,535**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Table 11.2 Redbank Creek catchment commercial / industrial and public buildings damage disbenefits and costs summary for base case

Summary of commercial / industrial and public buildings damage						
Event	No. of properties flooded above ground	No. of properties flooded above floor	Total damage	Contribution to AAD Total	Damage / Cost components (Contribution to AAD)	
					Structural and Internal	Loss of trading + Clean-up
PMF	70	0	$22,842,042	$4,106	$4,106	$1,232
1 in 5000 AEP	70	0	$20,381,547	$3,876	$3,876	$1,163
1 in 2000 AEP	31	0	$5,458,890	$7,535	$7,535	$2,261
1 in 500 AEP	26	0	$4,588,130	$10,919	$10,919	$3,276
1 in 200 AEP	15	0	$2,690,878	$12,381	$12,381	$3,714
1% AEP	10	0	$2,261,542	$19,050	$19,050	$5,715
2% AEP	6	0	$1,548,549	$44,863	$44,863	$13,459
5% AEP	5	0	$1,442,322	$62,720	$62,720	$18,816
10% AEP	3	0	$1,066,459	$92,007	$92,007	$27,602
20% AEP	2	0	$773,686	$116,053	$116,053	$34,816
Total AAD				**$373,510**	**-**	**-**

Table 11.3 Summary of sensitivity analysis of number of step on AAD

Event	Plus One Step				Minus One Step			
	Residential		Commercial / Industrial		Residential		Commercial / Industrial	
	Total damage	Contribution to AAD Total	Total damage	Contribution to AAD Total	Total damage	Contribution to AAD Total	Total damage	Contribution to AAD Total
PMF	$240,614,381	$42,996	$17,698,440	$3,091	$416,578,365	$76,331	$24,771,325	$4,479
1 in 5000	$211,977,528	$35,724	$14,837,328	$2,590	$386,906,827	$67,951	$22,375,420	$4,203
1 in 2000	$26,183,826	$29,980	$2,428,486	$3,197	$66,101,327	$85,594	$5,647,881	$7,847
1 in 500	$13,789,419	$33,283	$1,833,939	$4,818	$48,023,524	$118,503	$4,815,316	$11,604
1 in 200	$8,398,958	$37,126	$1,377,849	$6,703	$30,978,326	$140,914	$2,920,557	$13,270
1% AEP	$6,451,423	$57,216	$1,303,535	$11,580	$25,387,177	$225,171	$2,387,484	$19,962
2% AEP	$4,991,757	$110,422	$1,012,368	$27,237	$19,647,071	$513,791	$1,604,825	$46,066
5% AEP	$2,369,678	$91,085	$803,413	$29,047	$14,605,630	$566,460	$1,466,256	$63,318
10% AEP	$1,273,732	$91,902	$358,456	$26,884	$8,052,758	$607,252	$1,066,459	$92,007
20% AEP	$564,307	$84,646	$179,228	$26,884	$4,092,280	$613,842	$773,686	$116,053
Total AAD	**-**	**$614,380**	**-**	**$142,030**	**-**	**$3,015,808**	**-**	**$378,809**
% Difference	**-**	**-60%**	**-**	**-62%**	**-**	**96%**	**-**	**1%**

11.3 Key infrastructure assets

There are two main types of key infrastructure assets as presented below:

- The first type includes facilities that are occupied by emergency responders such as police stations, fire stations or SES Centres.
- The second type includes facilities with particularly vulnerable residents such as schools, childcare centres, aged care facilities and hospitals.

The locations of these key assets have been sourced from publicly available information (e.g. Google Map). A list of these facilities is provided in **Table 11.4** along with a brief description of the flood affectation of each asset. A map showing the location of the main infrastructure assets is presented in **Figure 11.1**.

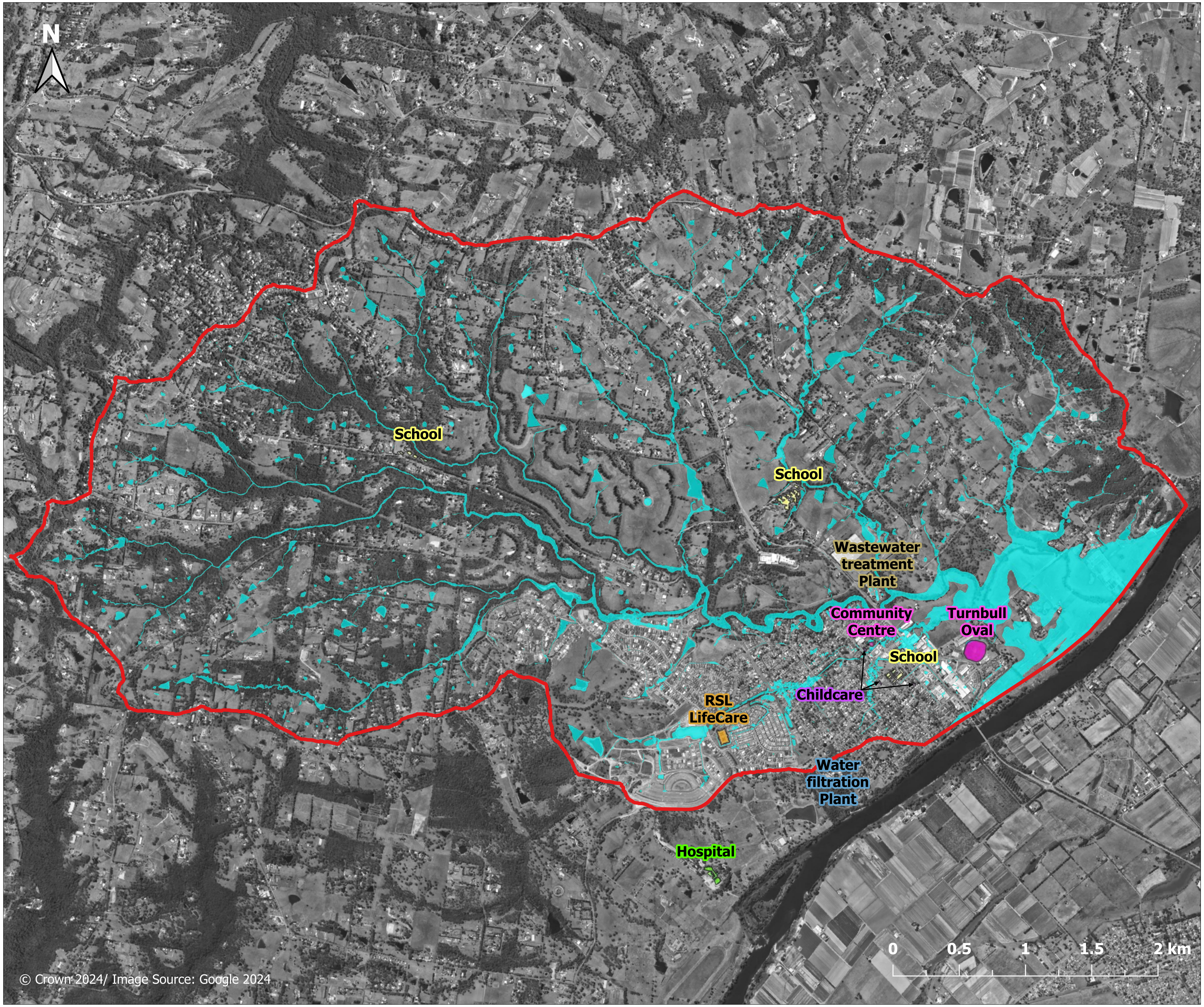
Table 11.4 List of Key Infrastructure assets

Location	Comments on Flood Risk
Police and Fire Stations	
Police Station	There are no Police Stations located within the study area. The nearest Police Station is Windsor Police Station located at Mileham St, Windsor.
SES Centres	
SES	There are no SES facilities located within the study area.
Hospital and Ambulance Stations	
St John of God Richmond Hospital	St John of God Richmond Hospital is outside the PMF extent and access to the hospital may become limited during a PMF event.
Schools	
Kuyper Christian School	A few buildings of the school are impacted by local overland flooding from 1 in 5000 AEP event. However, Redbank Road access approximately 2 km south of the school may get impacted from 1% AEP.
Richmond North Public School – Elementary School	The school is within the extent of the 1 in 5000 AEP flood event and the access roads may be impacted from 1 in 5000 AEP event.
Colo High School	A few buildings of the school are impacted by local overland flooding from 1 in 5000 AEP event. However, Bell Lines of Road bridge (road bridge) may be impacted from 1 in 5000 AEP event.
Childcare Facilities and Preschools	
Elizabeth Street Extended Hours Pre-School	The pre-school building is impacted by a 1 in 500 AEP flood event. Elizabeth Street access may become limited from 1 in 500 AEP event.
Caring 4 Kids	The childcare is affected by 1 in 5000 AEP flood event and the access roads may be impacted from 1 in 5000 AEP event.

Location	Comments on Flood Risk
Aged Care Facilities and Retirement Villages	
RSL LifeCare	The RSL Lifecare building is outside of the extent of the PMF event; however, the access to the building may become limited during a 1 in 5000 AEP flood event.
Designated Evacuation Centres	
North Richmond Community Centre	The North Richmond Community Centre is used as an evacuation centre for the township of North Richmond. This venue is impacted by an overland flow as frequent as a 5% AEP. Moreover, access to this venue by residents of various parts of the township may be restricted. It is therefore recommended that careful consideration be given to the design and management of the evacuation centre.
Turnbull Oval	The Turnbull Oval is used as an evacuation centre for the township of North Richmond. Majority of this oval is outside of the extent of a PMF event. However, access to the oval by residents of northern parts of the township may be restricted from 1 in 200 AEP event and from 1 in 5000 AEP event Terrace Road access will become limited for the majority of residents.
Key plants	
North Richmond water filtration plant	The water filtration plant is outside of the extent of the PMF event; however, the Grose Vale Road access may get impacted from 1 in 5000 AEP event.
North Richmond wastewater treatment plant	The wastewater treatment plant is affected from 1 in 5000 AEP event; while Bell Lines of Road bridge (road bridge) access may become limited from 1 in 5000 AEP event.

Figure 11.1

Key infrastructure locations



Report MHL3008

Redbank Creek Flood Study

NSW GOVERNMENT

Manly Hydraulics Laboratory

11.4 Road closure

An assessment of the frequency and hazard of road inundation is important to understand the risk of vehicles becoming unstable, posing a risk to life for their drivers and passengers. It is also important in order to understand evacuation risks and informing the classification of communities according to flood emergency response planning considerations. Measures to increase the flood immunity of critical roads could be considered as a result of this assessment. **Appendix G** depicts the flood events which result in road closures within the North Richmond township. Road closure was assumed as occurring when the depth of water over road reaches over 0.15 m, which is the depth that can start mobilising cars and the depth that has been recommended by the NSW SES to be considered as unsafe to drive through. **Table 11.5** summarises the peak depth, duration of flooding over 0.15 m and time to depth above 0.15 m for each location presented in **Appendix G** .

Table 11.5 Peak depth, duration of flooding over 0.15 m and time to depth above 0.15 m at road closure locations

Road ID-	First AEP to flood-	Peak depth (m)										
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	1 in 500 AEP	1 in 1000 AEP	1 in 2000 AEP	1 in 5000 AEP	PMF
1	20%	0.27	0.30	0.31	0.33	0.34	0.34	0.36	0.36	0.37	0.50	0.50
2	20%	0.19	0.21	0.22	0.24	0.25	0.26	0.31	0.32	0.33	0.50	0.50
3	20%	0.18	0.21	0.23	0.24	0.25	0.26	0.29	0.30	0.31	0.39	0.40
4	20%	0.15	0.18	0.21	0.22	0.23	0.23	0.24	0.24	0.25	0.47	0.47
5	1%	-	0.10	0.14	0.15	0.15	0.16	0.17	0.17	0.18	0.38	0.38
6	20%	0.50	0.57	0.69	0.73	0.77	0.80	0.96	1.00	1.03	2.24	2.45
7	5%	0.11	0.15	0.17	0.18	0.21	0.23	0.30	0.31	0.33	1.37	1.72
8	1 in 5000	-	-	-	-	-	0.05	0.08	0.08	0.09	0.40	0.57
9	20%	0.31	0.37	0.42	0.45	0.48	0.49	0.55	0.57	0.58	1.01	1.02
10	20%	0.19	0.25	0.29	0.30	0.32	0.33	0.37	0.39	0.41	0.66	0.66
11	20%	0.33	0.36	0.40	0.40	0.41	0.42	0.47	0.49	0.51	0.72	0.72
12	20%	0.25	0.26	0.27	0.27	0.27	0.28	0.30	0.30	0.31	0.38	0.38
13	5%	0.07	0.12	0.24	0.26	0.30	0.35	0.41	0.44	0.46	1.06	1.11
14	20%	0.19	0.24	0.38	0.41	0.50	0.62	0.76	0.81	0.85	2.10	2.19
15	20%	0.45	0.59	0.71	0.74	0.78	0.81	0.88	0.90	0.92	1.50	1.58
16	20%	0.20	0.34	0.45	0.49	0.66	0.79	0.91	0.94	0.96	1.74	1.80
17	1 in 5000	-	-	-	-	-	-	-	-	-	0.30	0.31
18	5%	-	0.13	0.17	0.20	0.22	0.23	0.28	0.29	0.30	0.54	0.62
19	1 in 5000	-	-	-	-	-	-	-	-	-	0.54	0.73
20	20%	0.21	0.27	0.58	0.61	0.63	0.64	0.91	1.16	1.32	5.96	6.24
21	20%	0.27	0.28	0.30	0.30	0.31	0.31	0.53	0.77	0.95	5.71	5.97
22	20%	0.53	0.55	0.57	0.59	0.60	0.61	0.64	0.65	0.65	2.95	3.30
23	10%	0.13	0.30	0.38	0.40	0.41	0.42	0.43	0.44	0.45	4.95	5.28
24	5%	-	-	0.74	0.77	0.78	0.79	0.79	0.80	0.81	4.77	5.08
25	1 in 200	-	0.10	0.12	0.13	0.15	0.16	0.20	0.21	0.22	0.88	1.14
26	20%	0.32	0.33	0.33	0.34	0.35	0.35	0.36	0.37	0.37	0.43	0.43
27	20%	0.59	0.62	0.65	0.66	0.66	0.67	0.70	0.70	0.71	0.82	0.83
28	20%	0.51	0.58	0.62	0.74	0.78	0.82	0.86	0.89	0.92	2.58	2.82
29	20%	0.35	0.45	0.53	0.65	0.69	0.72	0.77	0.79	0.82	3.74	4.02
30	20%	0.44	0.52	0.59	0.68	0.72	0.74	0.76	0.78	0.80	3.58	3.86
31	20%	0.31	0.33	0.34	0.35	0.36	0.37	0.39	0.40	0.41	0.56	0.56

Road ID-	Duration of depth above 0.15 m (hr)										
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	1 in 500 AEP	1 in 1000 AEP	1 in 2000 AEP	1 in 5000 AEP	PMF
1	3.12	5.08	6.21	6.89	8.00	8.72	18.59	18.60	18.69	19.65	19.87
2	-	0.04	0.24	0.37	0.47	0.56	1.51	1.73	2.08	11.22	11.35
3	0.25	0.51	0.59	1.18	1.54	1.73	7.62	8.60	9.10	12.05	12.14
4	-	0.02	0.44	0.69	1.03	1.22	1.45	1.86	2.21	10.26	10.42
5	-	-	-	-	-	-	0.31	0.45	0.51	8.92	9.04
6	18.58	18.76	19.05	18.73	18.86	18.91	19.11	19.07	19.12	19.73	20.08
7	-	-	0.15	0.31	0.48	0.58	1.91	2.25	2.58	11.20	11.48
8	-	-	-	-	-	-	-	-	-	1.42	1.56
9	1.43	2.40	5.85	6.03	7.21	8.60	12.13	12.18	12.25	13.06	13.20
10	0.05	0.20	0.36	0.63	0.88	1.01	1.88	2.10	2.31	10.46	10.76
11	3.57	5.26	17.75	17.65	17.77	17.78	17.83	17.81	17.86	18.38	18.58
12	17.68	17.92	18.08	18.07	18.18	18.23	18.30	18.27	18.32	18.95	19.12
13	-	-	4.04	6.49	7.36	7.77	8.61	9.30	9.91	12.70	13.03
14	1.31	3.35	8.97	10.86	11.22	11.43	19.03	19.04	19.10	19.75	19.90
15	3.46	5.75	7.76	9.42	10.09	10.62	19.00	18.98	19.03	19.73	19.90
16	-	1.81	3.15	6.63	7.19	7.48	18.49	18.48	18.54	19.29	19.46
17	-	-	-	-	-	-	-	-	-	0.79	0.89
18	-	0.17	2.36	1.68	3.78	5.15	13.25	13.40	13.55	15.46	15.72
19	-	-	-	-	-	-	-	-	-	0.55	0.57
20	3.78	5.01	18.76	18.33	18.52	18.62	18.77	18.78	18.86	19.70	19.90
21	18.70	18.89	19.04	18.75	18.87	18.93	19.01	18.98	19.03	19.71	19.90
22	19.00	19.15	19.32	19.05	19.12	19.15	19.22	19.17	19.21	19.78	19.94
23	-	0.73	18.88	18.55	18.69	18.75	18.87	18.85	18.91	19.66	19.87
24	-	-	18.62	18.10	18.32	18.43	18.62	18.64	18.74	19.68	19.88
25	-	-	-	-	-	0.10	0.69	0.78	0.93	9.50	9.79
26	16.37	16.66	16.96	17.02	17.11	17.15	19.17	19.12	19.16	19.68	19.83
27	19.44	19.51	19.57	19.33	19.38	19.40	19.44	19.38	19.41	19.82	19.97
28	4.04	5.34	8.91	11.14	11.39	11.52	18.25	18.23	18.28	18.99	19.16
29	2.11	3.81	6.48	8.93	9.66	9.86	12.47	12.58	12.70	13.86	14.04
30	19.03	19.18	19.29	19.03	19.10	19.13	19.19	19.14	19.18	19.76	19.94
31	11.99	12.20	12.32	12.35	12.45	12.51	19.26	19.21	19.24	19.78	19.93

Road ID-	Time to depth above 0.15 m										
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	1 in 500 AEP	1 in 1000 AEP	1 in 2000 AEP	1 in 5000 AEP	PMF
1	7.30	7.31	6.70	4.42	4.27	4.00	3.84	3.72	3.58	0.40	0.24
2	-	1.58	1.59	7.27	7.33	7.33	7.16	7.12	7.07	0.49	0.31
3	1.64	1.58	7.25	7.09	6.06	4.40	4.26	4.20	4.06	0.34	0.21
4	-	1.66	7.36	4.98	4.77	7.41	4.13	7.38	7.23	0.84	0.74
5	-	-	-	-	-	-	1.16	1.08	1.09	1.14	1.12
6	2.14	1.80	1.51	1.52	1.41	1.35	1.23	1.16	1.10	0.27	0.00
7	-	-	1.86	7.41	7.46	7.40	7.43	7.34	7.31	0.82	0.58
8	-	-	-	-	-	-	-	-	-	0.79	0.79
9	7.42	7.37	6.89	4.24	4.09	3.99	3.85	3.78	3.73	0.47	0.27
10	1.70	1.62	7.29	7.11	7.03	6.21	4.75	4.89	4.84	0.58	0.35
11	6.72	5.31	4.91	3.72	3.58	3.37	2.84	2.53	2.37	0.23	0.14
12	1.49	1.25	1.09	1.15	1.04	1.00	0.92	0.87	0.83	0.20	0.13
13	-	-	7.24	7.38	7.46	7.41	7.25	6.78	5.01	0.79	0.60
14	7.46	7.51	7.52	7.14	6.53	4.39	4.21	4.11	3.98	0.59	0.26
15	7.16	6.89	5.39	4.05	3.85	3.74	3.52	3.01	2.69	0.50	0.25
16	-	7.59	7.13	6.50	6.38	4.51	4.15	4.04	3.86	0.61	0.33
17	-	-	-	-	-	-	-	-	-	1.42	0.93
18	-	2.02	7.81	7.41	7.40	7.33	7.19	6.93	4.54	0.66	0.43
19	-	-	-	-	-	-	-	-	-	1.74	1.73
20	5.82	5.12	4.41	3.33	2.91	2.79	2.49	2.31	1.97	0.30	0.17
21	1.68	1.39	1.22	1.29	1.17	1.11	1.02	0.96	0.92	0.24	0.16
22	1.39	1.20	1.07	1.12	1.03	0.99	0.91	0.87	0.83	0.21	0.15
23	-	7.60	7.42	7.41	7.26	7.21	7.13	7.07	4.43	0.63	0.29
24	-	-	2.11	1.96	1.73	1.61	7.78	7.67	7.58	1.24	1.00
25	-	-	-	-	-	1.18	6.22	6.17	6.68	0.98	0.93
26	1.54	1.38	0.97	1.01	0.90	0.86	0.79	0.75	0.72	0.17	0.13
27	0.85	0.76	0.69	0.73	0.68	0.66	0.62	0.59	0.56	0.14	0.11
28	8.67	7.76	7.25	5.77	5.10	4.85	3.92	3.86	3.79	0.32	0.22
29	9.15	8.20	7.65	7.25	5.72	5.14	4.80	4.60	4.44	0.71	0.48
30	1.26	1.10	0.99	1.04	0.96	0.92	0.86	0.82	0.79	0.20	0.14
31	1.47	1.26	1.12	1.18	1.08	1.03	0.96	0.92	0.88	0.24	0.18

Road ID-	First AEP to flood-	Peak depth (m)											Duration of depth above 0.15 m (hr)											Time to depth above 0.15 m										
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	1 in 500 AEP	1 in 1000 AEP	1 in 2000 AEP	1 in 5000 AEP	PMF	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	1 in 500 AEP	1 in 1000 AEP	1 in 2000 AEP	1 in 5000 AEP	PMF	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	1 in 500 AEP	1 in 1000 AEP	1 in 2000 AEP	1 in 5000 AEP	PMF
32	10%	0.15	0.17	0.19	0.20	0.21	0.22	0.23	0.25	0.26	0.41	0.42	-	0.33	0.44	0.77	0.97	1.10	2.10	2.38	2.58	11.23	11.42	-	1.61	1.56	7.00	6.91	6.20	5.96	4.51	4.14	0.44	0.26
33	1 in 5000	-	-	-	-	0.05	0.06	0.07	0.07	0.07	0.33	0.34	-	-	-	-	-	0.04	0.10	0.11	0.13	2.74	2.82	-	-	-	-	-	1.26	1.14	1.10	7.39	1.27	1.26
34	1%	0.09	0.11	0.13	0.15	0.16	0.17	0.18	0.19	0.20	0.54	0.54	-	-	-	-	0.10	0.14	0.23	0.28	0.32	7.84	8.02	-	-	-	-	1.20	1.16	7.35	7.25	7.18	1.36	1.35
35	10%	0.14	0.16	0.18	0.18	0.19	0.19	0.20	0.20	0.21	0.33	0.33	-	0.20	0.32	0.52	0.64	0.75	1.26	1.46	1.62	10.97	11.30	-	1.65	1.58	7.05	6.95	6.89	4.52	4.31	4.13	0.53	0.26
36	10%	0.14	0.16	0.21	0.22	0.23	0.23	0.24	0.24	0.25	0.32	0.32	-	0.39	4.06	4.68	5.26	5.61	6.17	7.14	7.61	11.98	12.13	-	1.50	4.71	3.44	3.27	3.20	3.09	2.56	2.28	1.26	1.24
37	10%	-	0.15	0.19	0.20	0.21	0.22	0.29	0.30	0.31	0.39	0.39	-	-	0.12	0.21	0.27	0.34	5.12	5.66	6.26	11.60	11.86	-	-	1.61	1.16	1.18	1.14	7.16	7.09	6.38	0.83	0.78
38	1 in 5000	-	-	-	-	-	-	0.11	0.12	0.13	0.25	0.26	-	-	-	-	-	-	-	-	-	1.29	1.32	-	-	-	-	-	-	-	-	-	1.01	1.00
39	1 in 500	-	0.11	0.13	0.14	0.14	0.15	0.16	0.17	0.18	0.37	0.37	-	-	-	-	-	-	-	-	0.07	4.84	4.96	-	-	-	-	-	-	-	-	0.31	1.34	1.29
40	10%	-	0.16	0.19	0.20	0.22	0.23	0.26	0.27	0.28	0.39	0.39	-	0.14	0.31	0.39	0.50	0.56	11.17	11.25	11.37	12.77	12.88	-	1.63	1.61	7.28	7.33	7.41	7.27	7.18	7.13	0.55	0.32
41	1 in 5000	-	-	-	-	-	-	-	0.07	0.08	0.19	0.19	-	-	-	-	-	-	-	-	-	0.31	0.33	-	-	-	-	-	-	-	-	-	0.29	0.22
42	1 in 1000	-	-	-	-	0.08	0.10	0.15	0.16	0.16	0.27	0.27	-	-	-	-	-	-	0.04	0.06	0.08	2.89	2.93	-	-	-	-	-	-	0.31	0.30	0.29	1.08	1.06
43	20%	0.17	0.21	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.59	0.60	0.52	1.18	5.29	6.22	6.90	7.42	8.26	8.87	9.29	11.98	12.24	7.18	6.78	4.92	7.06	7.25	7.23	7.16	7.11	7.02	0.63	0.28
44	5%	-	-	0.15	0.15	0.16	0.18	0.20	0.21	0.22	0.39	0.40	-	-	0.05	0.10	0.25	0.30	0.36	0.40	0.44	8.61	8.98	-	-	1.60	1.20	1.10	1.17	1.04	1.15	6.99	0.80	0.76
45	5%	-	0.09	0.16	0.17	0.19	0.19	0.21	0.22	0.23	0.57	0.60	-	-	0.09	0.18	0.28	0.32	0.43	0.48	0.57	9.45	9.96	-	-	1.61	1.20	1.13	1.10	7.19	7.20	7.11	0.91	0.90
46	5%	-	-	0.15	0.18	0.20	0.21	0.22	0.23	0.24	0.52	0.52	-	-	-	0.76	0.98	1.15	1.54	1.93	2.13	10.90	11.30	-	-	-	6.29	6.19	5.96	5.72	4.10	4.02	0.69	0.34
47	2%	-	-	0.15	0.17	0.21	0.22	0.25	0.26	0.27	0.56	0.57	-	-	-	-	0.92	1.15	1.36	1.52	1.66	10.03	10.39	-	-	-	-	6.68	6.60	6.12	6.10	6.02	0.87	0.76
48	5%	0.14	0.15	0.17	0.18	0.20	0.21	0.29	0.31	0.32	0.49	0.49	0.33	0.48	0.56	1.14	1.35	1.63	10.65	10.75	10.88	12.37	12.44	1.52	7.29	7.02	4.45	7.15	7.10	7.15	7.09	7.06	0.58	0.30
49	1 in 5000	-	-	-	-	-	0.07	0.11	0.11	0.12	0.26	0.26	-	-	-	-	-	-	-	-	-	1.35	1.42	-	-	-	-	-	-	-	-	-	0.58	0.50
50	1 in 5000	-	-	-	-	-	-	-	-	-	0.24	0.25	-	-	-	-	-	-	-	-	-	1.55	1.69	-	-	-	-	-	-	-	-	-	0.47	0.32
51	1 in 200	-	-	-	-	-	0.19	0.19	0.20	0.21	0.35	0.35	-	-	-	-	-	-	-	-	-	1.61	1.70	-	-	-	-	-	-	-	-	-	0.43	0.33
52	20%	0.99	1.14	1.21	1.51	1.64	1.73	1.88	1.99	2.20	7.18	7.37	11.42	11.97	12.39	14.73	14.94	15.04	15.16	15.15	15.34	18.23	18.72	7.11	6.80	6.60	4.15	3.95	3.85	3.75	3.69	2.86	0.64	0.25
53	5%	-	0.07	0.18	0.20	0.24	0.27	0.31	0.33	0.35	1.14	1.17	-	-	0.19	0.40	0.60	0.72	1.00	1.26	1.52	10.55	11.00	-	-	1.79	7.25	6.34	7.31	5.82	7.33	7.25	0.81	0.51
54	1 in 5000	-	-	0.06	0.06	0.08	0.08	0.10	0.12	0.14	0.49	0.49	-	-	-	-	-	-	-	-	-	1.10	1.17	-	-	-	-	-	-	-	-	-	0.49	0.44
55	1 in 500	-	0.08	0.10	0.10	0.11	0.13	0.15	0.17	0.18	0.35	0.35	-	-	-	-	-	-	0.04	0.07	0.10	3.96	4.05	-	-	-	-	-	-	0.32	0.31	0.29	1.18	1.15
56	10%	0.12	0.19	0.24	0.24	0.25	0.26	0.28	0.30	0.31	0.44	0.44	0.20	0.38	8.10	8.22	8.80	9.32	9.63	9.81	10.00	12.97	13.18	1.73	7.30	6.85	7.21	7.17	7.13	6.53	5.73	5.65	0.59	0.22
57	1%	-	-	0.09	0.14	0.20	0.23	0.27	0.30	0.33	0.96	0.98	-	-	0.13	0.25	0.37	0.45	0.57	0.82	1.02	10.16	10.60	-	-	1.69	7.25	7.21	7.15	5.75	5.25	5.28	0.71	0.33
58	1%	-	-	0.09	0.12	0.16	0.19	0.22	0.24	0.26	0.66	0.66	1.45	2.04	2.78	2.72	3.35	3.84	4.48	5.13	6.53	11.34	11.79	6.95	6.84	5.45	4.62	4.46	4.33	4.14	3.84	3.34	0.68	0.30
59	2%	-	-	-	2.79	2.80	2.82	2.83	3.90	3.90	4.79	5.95	-	-	-	*20.07*	*20.06*	*20.06*	*20.05*	19.97	19.97	19.96	*20.08*	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	2%	-	-	-	3.65	3.65	3.65	3.65	4.68	4.68	4.74	6.62	-	-	-	*20.07*	*20.06*	*20.06*	*20.05*	19.97	19.97	19.96	*20.08*	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61	1 in 5000	-	0.05	0.06	0.07	0.09	0.09	0.10	0.11	0.11	0.29	0.29	-	-	-	-	-	-	-	-	-	1.51	1.64	-	-	-	-	-	-	-	-	-	0.38	0.26
62	1 in 5000	-	-	-	-	-	-	-	-	0.09	3.06	3.27	-	-	-	-	-	-	-	-	-	9.04	10.90	-	-	-	-	-	-	-	-	-	1.53	1.11

Road ID-	First AEP to flood-	Peak depth (m)											Duration of depth above 0.15 m (hr)											Time to depth above 0.15 m										
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	1 in 500 AEP	1 in 1000 AEP	1 in 2000 AEP	1 in 5000 AEP	PMF	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	1 in 500 AEP	1 in 1000 AEP	1 in 2000 AEP	1 in 5000 AEP	PMF	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	1 in 200 AEP	1 in 500 AEP	1 in 1000 AEP	1 in 2000 AEP	1 in 5000 AEP	PMF
63	1 in 500	0.07	0.11	0.13	0.13	0.14	0.14	0.16	0.17	0.18	0.25	0.25	-	-	-	-	0.12	0.15	0.20	0.22	0.25	4.80	5.01	-	-	-	-	1.14	1.10	1.06	1.03	7.14	0.63	0.45
64	1 in 5000	-	-	-	-	-	0.06	0.09	0.11	0.12	0.31	0.31	-	-	-	-	-	-	-	-	-	1.04	1.12	-	-	-	-	-	-	-	-	-	0.61	0.60
65	1 in 1000	-	0.07	0.09	0.09	0.10	0.11	0.15	0.17	0.18	0.35	0.35	-	-	-	-	-	-	-	-	-	1.44	1.55	-	-	-	-	-	-	-	-	-	0.45	0.24
66	20%	0.17	0.22	0.24	0.27	0.31	0.37	0.55	0.60	0.64	1.78	2.05	0.80	1.65	2.36	2.97	4.11	4.75	11.93	12.04	12.16	13.53	13.74	7.53	7.57	7.50	7.15	4.42	4.31	4.17	4.06	3.95	0.66	0.42
67	20%	0.25	0.26	0.30	0.34	0.37	0.40	0.58	0.63	0.66	1.88	2.09	18.16	18.37	18.53	18.19	18.34	18.40	18.50	18.49	18.55	19.43	*20.08*	2.47	2.11	1.96	2.03	1.87	1.79	1.64	1.56	1.49	0.54	0.00

N.B.: Durations in italic are likely to be exceeded as the depth in the model was still higher than 0.15 m at the end of the simulation.

12 Post-processing of results

12.1 Preamble

Upon completion of the flood mapping for main parameters (water level, depth, and velocity), it became possible to determine the flood function, flood hazard and flood emergency response classification resulting from these data. Development of such categorisations is described in this section.

12.2 Flood hazard

A starting point for the assessment of Flood Life Hazard categories is to better understand the flood hazard. Flood risk management guideline (FB03) (DPE, 2023) present a set of hazard vulnerability curves shown in **Figure 12.1**. This shows how flood depths, velocities and depth-velocity product affect the stability of vehicles, pedestrians and buildings.

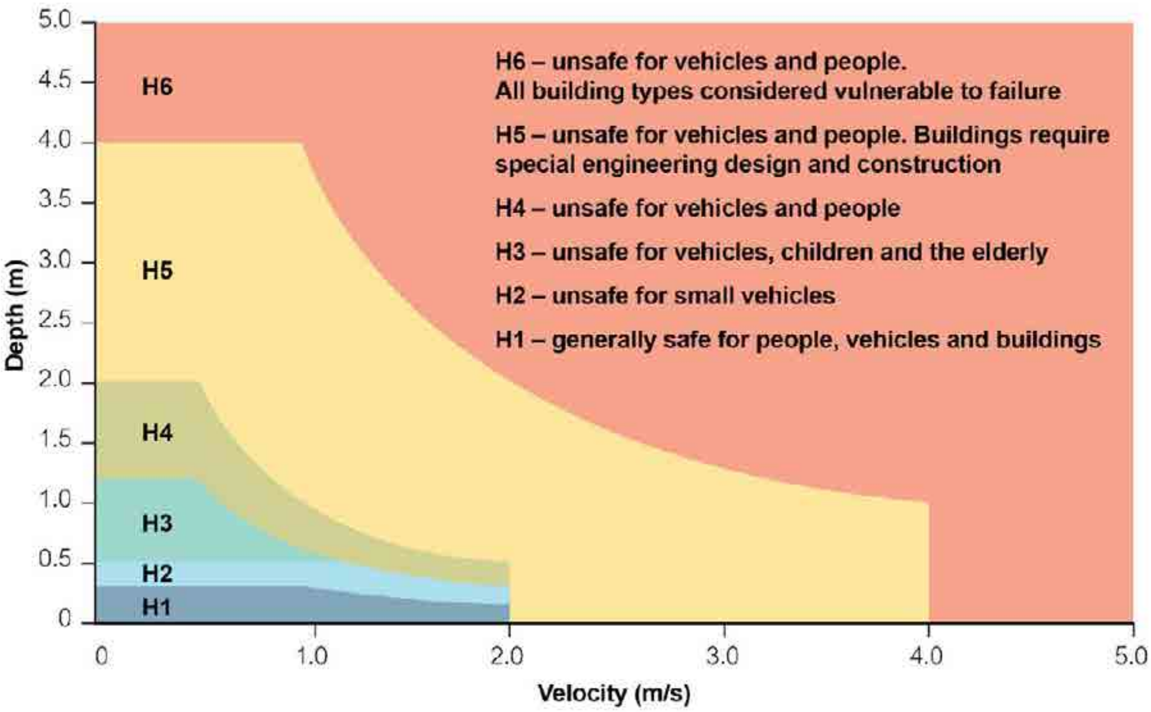


Figure 12.1 General flood hazard vulnerability curves; Source: (DPE, 2023)

Appendix H Appendix F presents the hazard vulnerability categories based on the H1 to H6 delineations for the 5%, 1%, 1 in 200, 1 in 500 AEPs and the PMF events.

During the 5%, 1%, 1 in 200 and 1 in 500 AEP flood events, the extent of hazard conditions between H3 and H6 remain typically concentrated along Redbank Creek and drainage channels, while the majority of the township flooding is classified as H1 or H2 hazard category. However, some larger hazard of H3 classification can be observed at the northern end of Elizabeth Street, the northern end of Micheal Street north-west of Gregory Street, Tyne

Crescent north-west of Stephen Street, Susella crescent, areas between Stephen Street and Pecks Road north of Arnorld Street, a lot between William Street and Bells Line of Road as well as Bells Line of Road between Grose Vale Road and Cherles Street. Northern end of Willian Street would be subject to hazard of H3 category during 1 in 500 AEP event.

During a PMF flood event, the majority of the township is either not impacted or subject to lower flooding categories (H1 and H2). However, most properties located along both sides of Bells Line of Road, William Street, Elizabeth Street between Redbank Creek and Grose Vale Road would be subject to H3 or above hazard categories. Most properties located along Pecks Road, Stephen Street and Michael Street between Gregory Street and Tyne Crescent would also be subject to H3 to H5 Hazard.

12.3 Flood function (Hydraulic categorisation)

Hydraulic categorisation is a useful tool in assessing the suitability of land use and development in flood-prone areas. Flood function - Flood risk management guideline FB02 (DPE, 2023) describes the following three hydraulic categories of flood-prone land:

- **Floodway / Flow Conveyance:** Flow conveyance areas are defined as those areas where a significant flow of water occurs. They typically flow continuously from the upper reaches of waterways and flow paths within the catchment to the outlet during a flood. These flows often align with naturally defined channels. They are areas that, even if only partially blocked by changes in topography or development, cause a significant redistribution of flood flow or a significant increase in flood levels. They are often, but not necessarily, areas of deeper flow or areas where higher velocities occur. In the DFE, they generally extend beyond the waterway banks.
- **Flood Storage:** During a flood event, significant amounts of floodwater can also extend into, and be temporarily stored in, areas of the floodplain. This water flows downstream as the flood recedes. Where storage is important in attenuating downstream flood flows and levels, areas storing this water are classified as flood storage areas. Filling of flood storage areas reduces their ability to attenuate downstream flood flows and, as a result, flood flows and flood levels may increase.
- **Flood Fringe:** Flood-fringe areas make up the remainder of the flood extent for the particular event. It is the area where the effects on flood function are not a constraint. Developing in flood-fringe areas is unlikely to significantly alter flood behaviour, beyond the broader impact of changes to run-off because of urbanisation within the catchment. However, other flood-related constraints may exist in flood-fringe areas.

These qualitative descriptions do not prescribe specific thresholds for determining the hydraulic categories in terms of model outputs, and such definitions may vary between floodplains depending on flood behaviour and associated impacts. For the purposes of the Redbank Creek Flood Study, hydraulic categories have been defined as per the criteria in **Table 12.1**. The floodway criterion has been selected as it provides improved continuity of flow along the various flow paths and considers areas of deeper flows. The flood storage criteria were selected as they have been commonly applied on various recent overland studies around NSW and consider areas with deep flood depth allowing storage of flood water.

Hydraulic category mapping for the 5%, 1%, 1 in 200, 1 in 500 AEPs and the PMF events are presented in **Appendix H**

Table 12.1 Hydraulic category criteria

Hydraulic Category	Criteria	Description
Floodway	Velocity x Depth > 0.25 m^2/s	Flow paths and channels where a significant proportion of flood flows are conveyed
Flood Storage	Depth ≥ 0.3 m, Not Floodway	Areas that temporarily store floodwaters and attenuate flood flows
Flood Fringe	Depth < 0.3 m, Not Floodway or Flood Storage	Generally shallow, low velocity areas within the floodplain that have little influence on flood behaviour

During a 5% AEP flood event, the floodways typically remain within the main watercourses and drainage channels. A large anabranch off Redbank Creek cuts through the northern end of Flannery Avenue and Pansy Crescent. A few properties located between Stephen Street and Pecks Road north of Arnold Street are located within a flood storage area. It was observed that a piece of land located on William Street as well as a commercial building on Bells Line of Road between Charles Street and Grose Vale Road are located within the flood storage area. It was observed that the northern end of William Street, Elizabeth Street, Susella Crescent, Merrick Place, O'Dea Place, the corner of Bradley Road and Morton Street, the corner of Tyne Crescent as well as a section of Arthur Phillip Drive south of Peel Park were located within flood storage areas.

During a 1%, 1 in 200 and 1 in 500 AEP flood event, the floodways generally remain confined to the main watercourses and drainage channels, similar to the 5% AEP event. A significant anabranch off Redbank Creek continues to traverse the northern end of Flannery Avenue and Pansy Crescent, and a small anabranch shortcut the bend of Redbank Creek near the northern end of Elizabeth Street. While during 1%AEP event a few properties remain within the flood storage area between Stephen Street and Pecks Road north of Arnold Street, additional areas have been identified. Specifically, the flood storage areas are slightly larger, encompassing the same properties on William Street and Bells Line of Road, as well as extending to include the corner of Tyne Crescent. The northern ends of William Street, Elizabeth Street, Susella Crescent, Merrick Place, O'Dea Place, the corner of Bradley Road and Morton Street, and a section of Arthur Phillip Drive south of Peel Park are also located within these expanded flood storage areas.

During 1 in 200 and 1 in 500 AEP events, a few properties located between Michael Street and Pecks Road south of Tyne Crescent and at the corner of Tyne Crescent are located within a flood storage area. It was observed that a piece of land located on William Street as well as a commercial building on Bells Line of Road between Charles Street and Grose Vale Road are located within the flood storage area. It was observed that the northern end of William Street, Elizabeth Street, Susella Crescent, Merrick Place, O'Dea Place, the corner of Bradley Road and Morton Street as well as a section of the Arthur Phillip Drive south of Peel Park were located within flood storage areas. Properties either side of Elizabeth Street and Bell Line of Road between Campbell Street and Grose Vale Road were located within flood storage area.

During a PMF flood event, the northwestern half of the township would be located within the floodway of Redbank Creek. Properties located along drainage channels flowing through the township would also be within the floodway. A few more properties around the township would be located within the flood storage area. During a PMF flood event, the larger part of the floodplain and a section of Crooked Lane between Bells Line of Road and Douglas Street would be classified as floodway.

12.4 Flood emergency response classification of communities

In order to assist in the planning and implementation of response strategies, DCCEEW developed support for emergency management planning guideline (EM01) to classify communities according to the ease of evacuation (DPE, 2023). The guidelines classify communities as presented in **Figure 12.2**.

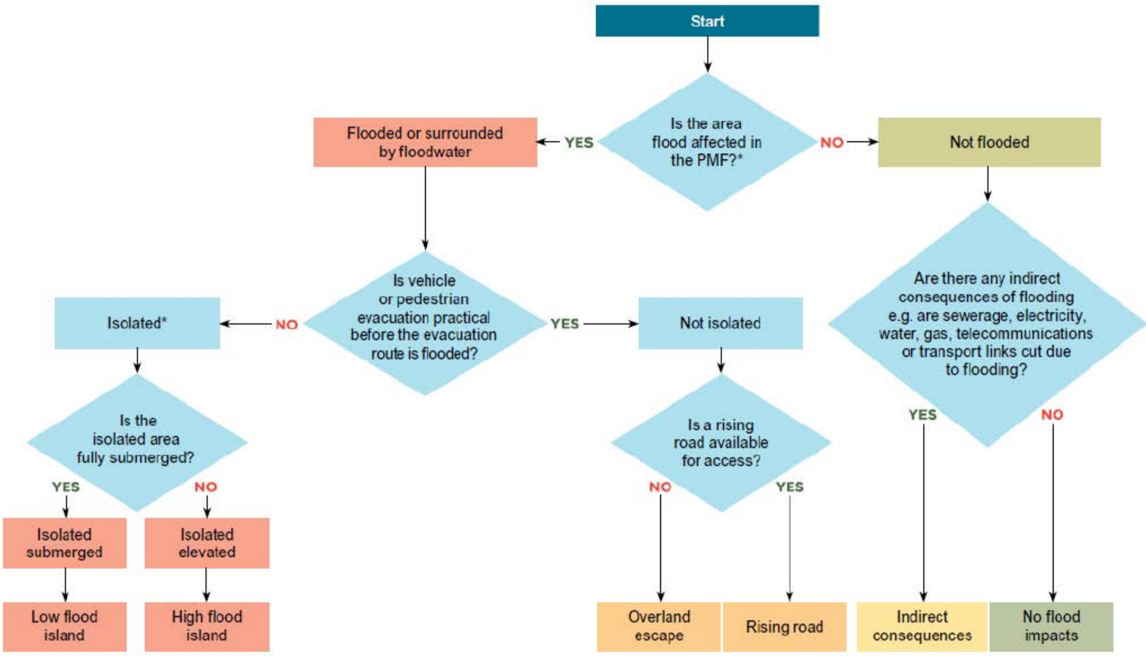


Figure 12.2 Flow chart for determining flood emergency response classifications (DPE, 2023)

Flood Emergency Response Classifications (ERC) are based upon the probable maximum flood (PMF) or a similar extreme flood, if the PMF is not available. Where classifications are being retrofitted to areas covered by existing studies and the PMF or a similar extreme flood is not available, and a decision is made to not estimate or approximate an extreme event, classifications should be clearly indicated as 'Preliminary based upon the largest flood available'. Some consideration has been given to building locations on a block affected by flooding, but no consideration has been given to building styles.

Isolated areas may also be known as flood islands, where areas are isolated solely by flood waters. Where flood islands are completely submerged in the PMF, these may be called low-flood islands. Where flood islands have elevated areas above the PMF, they may be called high-flood islands.

Trapped perimeter areas are areas isolated by a combination of floodwaters and impassable terrain. Where trapped perimeter areas are completely submerged in the PMF, these may be called low-trapped perimeter areas. Where trapped perimeter areas have elevated areas above the PMF, they may be called high-trapped perimeter areas.

Mapping Flood Emergency Response Planning classifications is to a degree a subjective exercise. Nevertheless, it serves to highlight areas most at risk in the event of severe flooding where people fail to evacuate early or shelter in houses is unsuitable for that purpose.

This exercise was completed for the 5%, 1%, 1 in 200, 1 in 500 AEPs and the PMF. The summary of the flood Emergency Response Classification is presented in **Appendix I** .

During a 5%, 1%, 1 in 200 and 1 in 500 AEP flood events, the majority of the flood affected properties located at the north end of William Street, Elizabeth Street, Susella Crescent, Merrick Place, O'Dea Place of Jackson Street and north of Flannery Avenue are classified as isolated elevated and properties along the drainage channel through the township classified as flooded with overland escape or rising road route classification. It was observed that two properties at the corner of the Pansy Crescent are classified as flooded, isolated and submerged classification.

During PMF event, the majority of properties were classified as either flooded, isolated and submerged along Redbank Creek and main drainage channel through the township as well as flood-affected, isolated and elevated within the township as the PMF would cut access on the main roads. It is however noted that this road closure on the main roads will be over a relatively long period of time, refer to **Table 11.5**.

13 Implication of Climate Change

13.1 Climate change impacts on flood risk management

The Sixth Synthesis Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC, 2023) underscores the clear and growing influence of human activities on the climate system, with observable impacts across all continents and oceans. Notably, projected changes in climate are anticipated to significantly affect flood risk, primarily through sea level rise and alterations in the hydrologic cycle, particularly the increase in frequency and intensity of heavy rainfall events.

13.1.1 Sea level rise

According to (DPE - EHG, 2023) flood risk management should examine the likelihood and consequences of sea level rise based on the latest locally relevant and broadly recognised projection. (DPE - EHG, 2023) provided advice on projected changes to New South Wales mean sea level (MSL) from the International Panel on Climate Change's (IPCC) Sixth assessment report (AR6) (Garner et al. 2021) for medium confidence modelling. The medium confidence modelling includes ocean / atmosphere interaction but excludes ice sheet processes. This estimates that the very likely range of the highest projection (SSP5–8.5 or RCP8.5) is from 0.5 to 1.3 m by 2100 for the 95% confidence interval.

However, recent IPCC publication in 2023 indicate significant projections, with a likely global mean sea level rise of 0.20 - 0.29 m by 2050, 0.63 - 1.01 m by 2100 and 0.98 – 1.88 m under 2150 under the SSP-8.5 GHG emission scenario (medium confidence). Furthermore, global mean sea level is forecasted to rise by 2-3 m with a 1.5°C warming limit and 2 - 6 m with a 2°C limit over the next 2000 years (low confidence) (IPCC, 2023). These projections underscore the urgency of addressing rising sea levels to mitigate flood risks.

The NASA satellite measurements since January 1993 indicate a steady rise in mean sea level, with the latest observation from March 2024 showing a level 103.8 mm above the January 1993 benchmark. Regional variations in sea level rise, such as those observed in the Western Pacific, can be notably larger or smaller than the global mean, underscoring the need for localised assessments (IPCC, 2014).

NASA has recently developed Sea Level Rise projections associated with climate change for Fort Denison available at https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool and documented in **Table 13.1**. Noting this assessment adopted the latest nomenclature of Shared Socioeconomic Pathways (SSP) as opposed to RCP. These projections extend to the year 2150.

Table 13.1 NASA Sea Level Rise projections for Fort Denison

Year	Percentile	SSP 2-4.5 (m)	SSP 5-8.5 (m)
2040	50th	0.138	0.158
	95th	0.242	0.267
2050	50th	0.197	0.233
	95th	0.377	0.377
2090	50th	0.454	0.646
	95th	0.794	1.072
2100	50th	0.530	0.778
	95th	0.939	1.300
2150	50th	0.891	1.354
	95th	1.640	2.414

13.1.2 Flood-producing rainfall events

Climate change projections also indicate potential shifts in the intensity and volume of flood-producing rainfall events (DPE - EHG, 2023). Research continues into the scale of these impacts, therefore advice on how we consider changes to flood-producing rainfall events will need to be updated over time.

The Australian Rainfall and Runoff (ARR) Data Hub provides valuable interim climate change factors, including temperature increases and percent rainfall increases. Using representative concentration pathway (RCP) or shared socioeconomic pathway (SSP) values, such as 4.5 and 8.5, allows for the estimation of future changes in rainfall intensity. Studies under the Floodplain Management Program consider various flood events, including rare events, to understand their impacts on communities (DPE - EHG, 2023).

According to (DPE - EHG, 2023), the general changes to the intensity and volume of flood-producing rainfall events are based on a 7% change in the intensity and volume for every 1°C change in mean temperature for the recommended scenarios of RCP 4.5 and 8.5 from the CSIRO work. Using this multiplier with temperature changes identified on the ARR Data Hub indicates that by 2090, values nearing 9.5% for RCP 4.5, and 19.7% for RCP 8.5 are expected in Redbank Creek study area. ARR 2019 follows Representation Concentration Pathway (RCP) scenarios up to the year 2090. For the Redbank Creek catchment these factors are tabulated in **Table 13.2**.

Table 13.2 Increase in rainfall intensity associated with climate change temperature increase (ARR 2019 Data Hub)

Year	RCP 4.5	RCP 6.0	RCP 8.5
2030	**0.869 (4.3%)**	0.783 (3.9%)	**0.983 (4.9%)**

Year	RCP 4.5	RCP 6.0	RCP 8.5
2040	**1.057 (5.3%)**	1.014 (5.1%)	**1.349 (6.8%)**
2050	**1.272 (6.4%)**	1.236 (6.2%)	**1.773 (9.0%)**
2060	**1.488 (7.5%)**	1.458 (7.4%)	**2.237 (11.5%)**
2070	**1.676 (8.5%)**	1.691 (8.6%)	**2.722 (14.2%)**
2080	**1.810 (9.2%)**	1.944 (9.9%)	**3.209 (16.9%)**
2090	**1.862 (9.5%)**	2.227 (11.5%)	**3.679 (19.7%)**

Note: Brackets indicate the percentage increase in rainfall intensity.

ARR introduced an updated approach at the time of this report was prepared to implicate climate change including climate change factor for IFD, initial and continuing losses Climate Change Considerations (Book 1: Chapter 6) in ARR (Version 4.2).

The impacts of climate change on flood-producing rainfall events should be analysed both separately and in conjunction with changes to sea level rise, as discussed below (DPE - EHG, 2023).

13.1.3 Hawkesbury City Council approach

Climate change sensitivity analyses undertaken in floodplain risk management studies under the DCCEEW Floodplain Management Program typically adopt sea level rise (SLR) values of between 0.4 m and 0.9 m and increases in rainfall intensity of between 10% and 30% as per the Floodplain Risk Management Guidelines Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments (DECCW 2010) and Practical Consideration of Climate Change (DECC 2007). The ranges of values recommended in these documents were based upon studies from the IPCC and CSIRO for the period to 2100.

In 2012 the NSW Government announced its Stage One Coastal Management Reforms, a result of which is that the NSW Government no longer recommends state-wide sea level rise benchmarks for use by local councils. The NSW Chief Scientist and Engineer's report titled Assessment of the Science behind the NSW Government's Sea Level Rise Planning Benchmarks (2012) however identified that the science behind sea level rise benchmarks from the 2009 NSW Sea Level Rise Policy Statement was adequate.

Following discussion with Hawkesbury City Council, a similar approach as the recent Hawkesbury-Nepean River Flood Study (Rhelm and Catchment Simulation Solutions, 2024) was adopted for the purpose of the sensitivity analysis on Climate Change based on a 2040, 2090 and 2100 scenarios. The 2040 scenario includes a sea level rise of 0.40 m with 9.5% increase in 1% AEP rainfall intensity, the 2090 scenario includes a sea level rise of 0.90 m with 19.7% increase in 1% AEP rainfall intensity, and the 2100 scenario includes a sea level rise of 1.30 m with 30% increase in 1% AEP rainfall intensity.

13.2 Impact of climate change on local flood behaviour

For the purpose of sensitivity analysis for this study, three scenarios have been run to understand the potential impact of climate change in the Redbank Creek catchment study area including:

- **2040 Conditions:** Increase in 1% AEP rainfall intensity by 9.5% and increase in sea level by 0.40 m;
- **2090 Conditions:** Increase in 1% AEP rainfall intensity by 19.7% and increase in sea level by 0.90 m; and
- **2100 Conditions:** Increase in 1% AEP rainfall intensity by 30% and increase in sea level by 1.30 m.

Changes in comparison to the 1% AEP peak flood levels associated with the simulated climate change scenarios for 2040, 2090 and 2100 conditions are presented in **Appendix J** .

In comparison with current design conditions, simulation of the 2040, 2090 and 2100 conditions highlighted the following impacts on 1% AEP design flood conditions:

- **2040 Conditions:**
    - Areas affected by riverine flooding along the Hawkesbury River may increase by 0.40 m.
    - Flood levels on Flannery Avenue and Pansy Crescent may increase by up to 0.05 m.
    - Overland flooding originating from the western side of North Richmond impacting Pecks Road, Stephen Street, Michael Street and Tyne Crescent may increase by up to 0.20 m.
    - Flood levels between Elizabeth Street and Bells Line of Road may increase by up to 0.20 m.
    - Overland flooding between Elizabeth Street and Monti Place may increase by up to 0.05 m.
- **2090 Conditions:**
    - Areas affected by riverine flooding along the Hawkesbury River may increase by 0.90 m.
    - Flood levels on Flannery Avenue and Pansy Crescent may increase by up to 0.05 m.
    - Overland flooding originating from the western side of North Richmond impacting Pecks Road, Stephen Street, Michael Street and Tyne Crescent may increase by up to 0.30 m.
    - Flood levels between Elizabeth Street and Bells Line of Road may increase by up to 0.40 m.
    - Overland flooding between Elizabeth Street and Monti Place may increase by up to 0.10 m.

- Flood levels at the northern end of Elizabeth and William Streets may increase by up to 0.20 m.

- **2100 Conditions:**
    - Areas affected by riverine flooding along the Hawkesbury River may increase by 1.30 m.
    - Flood levels on Flannery Avenue and Pansy Crescent may increase by up to 0.05 m.
    - Overland flooding originating from the western side of North Richmond impacting Pecks Road, Stephen Street, Michael Street and Tyne Crescent may increase by up to 0.20 m.
    - Flood levels between Elizabeth Street and Bells Line of Road may increase by up to 0.50 m.
    - Overland flooding between Elizabeth Street and Monti Place may increase by up to 0.15 m.
    - Flood levels at the northern end of Elizabeth and William Streets may increase by up to 0.50 and 0.45 m, respectively.
    - Flood levels at the Susella Crescent, at the western end of O'Dea Place and the intersection of Bradley Road and Morton Street may increase by up to 0.05 m.

14 Conclusion

The Redbank Creek Flood Study has been completed to provide a detailed flooding assessment of North Richmond and the surrounding local catchment. A thorough literature review of previous Flood Studies was conducted, revealing a gap in flooding in Redbank Creek catchment due to the local overland flooding mechanisms.

The objective of this study is therefore to improve understanding of flood behaviour and impacts, and better inform management of flood risk in the study area due to the local overland flooding mechanisms. Direct flooding from the Hawkesbury River is not part of the scope of the current study as it is extensively covered by the Hawkesbury-Nepean Valley Regional Flood Study. It is essential to recognise that areas affected by riverine flooding must be evaluated accordingly. However, backwater effects were considered. The study also provides a sound technical basis for any further flood risk management investigation in the area.

The key components of the flooding assessment included:

- Review of previous studies and available data
- Community consultation
- Hydrological analysis and modelling
- Hydraulic analysis and modelling
- Sensitivity analysis
- Flood mapping
- Description of consequences of flooding on the community
- Impact of climate change on local flooding
- Development of a draft flood study review report followed by a final report

The flood maps appended to this report are presenting the flood levels, depths and velocities for the critical duration and rainfall pattern of a full set of events including the 20%, 10%, 5%, 2%, 1%, 1 in 200, 1 in 500, 1 in 1000, 1 in 2000, 1 in 5000 AEPs and PMF events and represent an envelope of the adopted critical durations / temporal pattern for the Redbank Creek catchment.

This report acknowledges that the lack of gauging stations in the study area limits data availability for calibration, impacting model validation and introducing uncertainties. To enhance the reliability of findings, future research should consider establishing gauging stations or utilising alternative data sources. Sensitivity analysis highlighted the following points:

- Tailwater level impact: tailwater levels in the Hawkesbury River minimally affect upstream flood levels but have substantial impact on the extend of flooding and water level along the low-lying areas of Redbank Creek.
- Losses sensitivity: removing all losses can raise flood levels by up to 0.8 m along the creek and 0.2 m in the township, while ARR 2019 losses can reduce levels by up to 0.2 m upstream and increase them by 0.1 m in the downstream areas.

- Roughness sensitivity: increasing roughness by 20% reduces water levels by up to 0.25 m along watercourses with minor effects in the township, while decreasing roughness by the same amount has a similar but reversed effect.
- Blockage sensitivity: a double blockage scenario can raise flood levels by up to 0.2 m in the township, while a no blockage scenario causes local changes of up to 0.1 m, affecting areas upstream and downstream of major culverts.

The above results allowed the definition of the flood hazard (i.e., H1 - H6 flood hazard categories), hydraulic categories and emergency response classifications in the Redbank Creek catchment. These have been created and mapped to inform development control planning.

Results of the model allow the identification of main flooding areas, key infrastructure assets impacted by flooding, and road closures around the catchments. Key infrastructure typically may have access issues during severe flood events rather than flooding issues, except during the PMF event.

It was observed that flow within the North Richmond township primarily follows Redbank Creek and the main drainage channel through the township during majority of events up to including 1 in 2000 AEP. Key flood-prone areas are highlighted below, noting that the described impacts are based on flooding that affects the floor level of buildings on properties:

- Properties located at the northern end of William Street, Elizabeth Street, Susella Crescent, Merrick Place and O'Dea Place are impacted from 1 in 500 AEP event; however, road access may be affected by events as frequent as 20% AEP;
- A few Properties along the northern side of Flannery Avenue are impacted from 1 in 200 AEP event; however, their access may be affected by event as frequent as a 5 AEP;
- A few properties at the north-west corner of Pansy Crescent are impacted by events as frequent as 10% AEP;
- Properties located along the main drainage channel between Pecks and Elizabeth Streets are affected due to 1 in 5000 AEP and PMF events.
- A few properties located between Stephen and Pecks Streets are impacted by events as frequent as 10% AEP.
- Properties situated between Tyne Crescent, Stephen Street and north end of Yvonne Place are impacted by events as frequent as 5% AEP.
- A secondary overland flow path was observed through the North Richmond township, from the sag point along Enfield Avenue through a few properties towards the south end of Monti Place, continuing towards the intersection of Charles and Elizabeth Streets. These areas are impacted by events as frequent as 10% AEP;
- Properties located at the southernmost corner of Tyne Crescent;
- A few properties located at the north-east corner of the intersection of Charles and William Streets are impacted by events as frequent as 5% AEP;
- Properties near the intersection of Charles and Elizabeth Streets are impacted by flood as frequent as 5% AEP event such as North Richmond Community Centre.

It was observed that the North Richmond Community Centre, while used as an evacuation centre for the township of North Richmond, is impacted by an overland flow as frequent as a 5% AEP. Moreover, access to this venue by residents of various parts of the township may be restricted. It is therefore recommended that careful consideration be given to the design and management of the evacuation centre. Moreover, Turnbull Oval is also used as an evacuation centre for the township of North Richmond and, while it is outside of the extent of a PMF event, access to the oval by residents of northern parts of the township may be restricted from a 1 in 200 AEP event and from a 1 in 5000 AEP event, Terrace Road access will become limited for the majority of residents.

An economic impact assessment of flooding was undertaken by estimating the flood damages in the catchment. The preliminary flood damage assessment involved analysing 5,250 buildings within the study area. A total Annual Average Damage of approximate $1.5 million for residential properties and $373,510 for non-residential properties was estimated in the Redbank Creek catchment. To improve accuracy, a comprehensive floor level survey is recommended for future Floodplain Risk Management Studies to enhance damage assessments.

At last, a comparison of current design conditions, with the 2040, 2090 and 2100 climate change scenarios highlighted the following impacts on 1% AEP design flood conditions:

- 2040 Conditions: Rainfall intensity is expected to increase by 9.5%, resulting in riverine flooding along the Hawkesbury River rising by 0.40 m and localised overland flooding increasing by up to 0.20 m in North Richmond.
- 2090 Conditions: A 19.7% increase in rainfall intensity may lead to riverine flooding along the Hawkesbury River rising by 0.90 m, with overland flooding in areas like Pecks Road increasing by up to 0.30 m.
- 2100 Conditions: Rainfall intensity could rise by 30%, causing riverine flooding to increase by 1.30 m along the Hawkesbury River, while flood levels in localised areas, such as between Elizabeth Street and Bells Line of Road, may increase by up to 0.50 m.

15 References

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Appendix A Survey marks

Survey Mark	Easting	Northing	SCIMS Elevation (m AHD)	LiDAR 2019 Elevation (m AHD)	Difference (m)
SS 26765	287994.7	6282519	19.995	77.386	-0.44
SS 83983	288009.8	6282523	20.411	75.38	0.08
PM 81570	286993.8	6283248	63.798	48.776	-0.04
SS 12706	288296.2	6284181	86.41	27.33	-0.03
PM 81571	286838.8	6283802	81.274	19.976	-0.02
PM 81572	286613.8	6284429	84.182	20.249	-0.16
TS 1117	281485.2	6282886	247.673	70.495	0.06
SS 61312	282325.6	6282038	171.233	68.597	0.07
PM 81036	282157	6283336	186.915	63.967	0.17
PM 46087	285210.2	6282000	92.17	81.266	-0.01
PM 46088	285518.7	6281902	86.551	86.4	-0.01
PM 46089	285589.7	6281749	85.831	81.266	-0.01
SS 82069	285226.1	6282001	92.318	84.105	-0.08
SS 132542	284895.8	6282123	55.945	171.447	0.21
SS 132543	284980.2	6282232	57.001	187.333	0.42
SS 132545	285061.9	6282410	53.592	157.537	0.57
SS 132546	285142.3	6282510	51.952	138.185	0.32
SS 132547	285348.2	6282577	53.03	135.51	0.25
SS 58886	286858.8	6282057	36.828	136.774	0.58
PM 44005	287513.7	6282014	24.749	119.988	-0.02
PM 44006	287804.7	6282254	21.518	118.675	0.22
SS 81832	288183.5	6281925	24.946	86.87	0.32
SS 58295	288178.9	6282270	17.345	85.845	0.01
SS 89925	287806	6281623	36.427	75.757	0.5
SS 89927	287168.5	6282238	27	57.733	0.16
SS 89928	286820.3	6281708	32.783	56.098	0.15
SS 58890	286784.9	6281672	33.27	57.142	0.14
SS 90769	287724.3	6282054	21.67	55.837	0.14
SS 185090	287195.2	6281719	35.16	53.716	0.12
SS 185081	287360	6281455	37.71	52.364	0.41
SS 185082	287317.5	6281619	32.7	52.875	-0.16
SS 89933	283547.5	6284244	123.385	36.795	-0.03
SS 89934	283214	6284519	158.079	24.836	0.09
PM 45481	283647.2	6284915	164.906	21.683	0.16
PM 45482	283471.7	6284919	165.531	26.943	0.07
PM 45483	283335.9	6284864	162.538	24.999	0.05
PM 45484	283250.6	6284626	166.823	17.263	-0.08
PM 81034	283691.7	6284931	163.943	33.335	-0.01
PM 81035	282690.2	6284277	175.813	36.531	0.1
SS 89930	283304.6	6284805	161.078	35.672	0.15
SS 89932	283667.9	6284713	139.766	26.898	-0.1
SS 89933	283547.5	6284244	123.385	32.771	-0.01
SS 89934	283214	6284519	158.079	33.296	0.03
SS 89932	283667.9	6284713	139.766	21.636	-0.03
SS 49952	288482.8	6281751	26.71	23.749	0.13
PM 46073	287539.3	6281389	56.672	35.321	0.16
SS 52733	288303.9	6281658	35.08	37.649	-0.06
SS 52737	288540.3	6281661	24.266	32.615	-0.09

Survey Mark	Easting	Northing	SCIMS Elevation (m AHD)	LiDAR 2019 Elevation (m AHD)	Difference (m)
SS 52722	288389.6	6281707	29.795	123.495	0.11
SS 52731	288402.6	6281548	30.702	157.676	-0.4
SS 80087	287731.4	6281411	48.466	165.619	0.09
SS 62559	288583.4	6281827	23.688	166.731	-0.09
SS 83982	288681.6	6281681	13.223	140.343	-0.08
PM 44007	288141.4	6281892	26.876	175.853	0.04
PM 45708	288597.6	6281837	23.5	161.043	-0.03
SS 52733	288303.9	6281658	35.08	139.81	0.04
SS 52737	288540.3	6281661	24.266	123.495	0.11
SS 52722	288389.6	6281707	29.795	157.676	-0.4
SS 81832	288183.5	6281925	24.946	139.81	0.04
SS 67451	288621.7	6281786	21.95	26.695	-0.02
SS 62559	288583.4	6281827	23.688	56.631	-0.04
SS 58295	288178.9	6282270	17.345	35.057	-0.02

Appendix B Community consultation

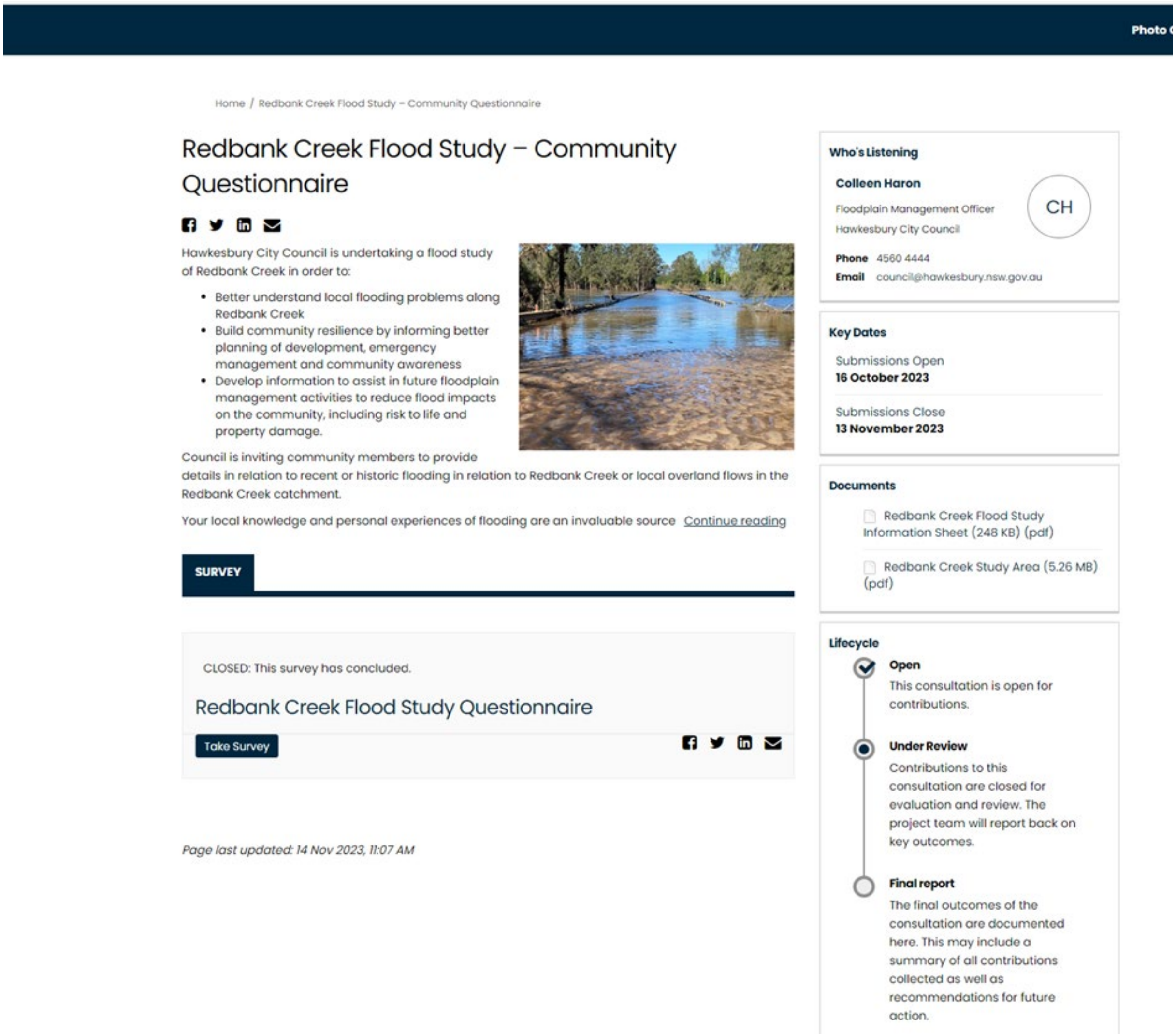


Figure B.1 Snapshot of project website

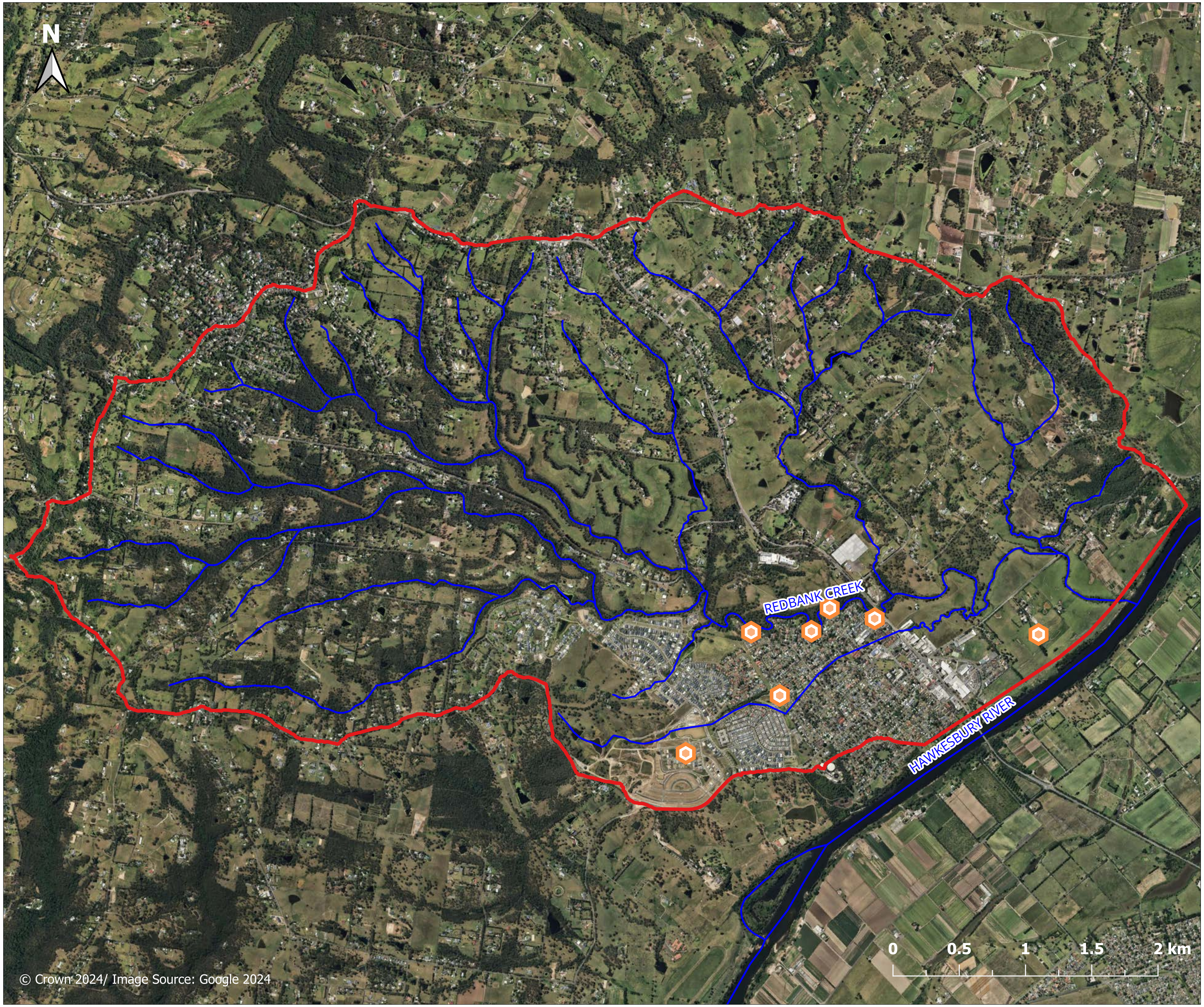


Figure B.2

Approximate location of questionnaire respondents

Legend

- Study area
- Watercourses
- Approximate location of respondents

Report MHL3008

Redbank Creek Flood Study

NSW GOVERNMENT

Manly Hydraulics Laboratory

Redbank Creek Flood Study Questionnaire

Address of property in the study area **(This information will only be used to complete the Flood Study)**

What is the type of property?

☐ Residential
☐ Vacant land
☐ Commercial
☐ Other (please specify)

What is the status of the property?

☐ Owner occupied / Owner operated business
☐ Leased to rental tenants
☐ Other – please specify

How long have you lived or operated a business at this address?

☐ 0-5 years
☐ 6-10 years
☐ 10-20 years
☐ More than 20 years

As far as you are aware, has the property (which includes land, back and front yards, etc) ever been adversely affected by flooding? Flooding impacts could include inundation, restricted access to/from the property, property isolated by floodwaters, risk to personal safety, damage to property, etc?

☐ Yes
☐ No

Please provide dates for up to 4 flood events that have affected the property.

Event 1 ______ Event 3 ______

Event 2 ______ Event 4 ______

What part(s) of the property were affected by flooding? **(select more than one if appropriate)**

	Yard	Garage/Shed	Building
Event 1	☐	☐	☐
Event 2	☐	☐	☐
Event 3	☐	☐	☐
Event 4	☐	☐	☐

Please provide any additional details here.

What was the depth of flooding? **(cm)**

Event 1		Event 3	
Event 2		Event 4	

Please provide any additional details here.

What was the duration of flooding? **(hours/days)**

Event 1		Event 3	
Event 2		Event 4	

Please provide any additional details here.

What was the velocity of the flood waters at the peak/worst?

	Stationary	Walking Pace	Running Pace
Event 1	☐	☐	☐
Event 2	☐	☐	☐
Event 3	☐	☐	☐
Event 4	☐	☐	☐

What was the source of the floodwaters? **(select more than one if appropriate)**

	Redbank Creek (flood waters rising in creeks)	Hawkesbury River inundation	Water flowing down the roads	Ponding of water within property	Ponding of water on roads	Overflow from neighbouring properties	Drainage channel (floodwaters rising in drainage channels)
Event 1	☐	☐	☐	☐	☐	☐	☐
Event 2	☐	☐	☐	☐	☐	☐	☐
Event 3	☐	☐	☐	☐	☐	☐	☐
Event 4	☐	☐	☐	☐	☐	☐	☐

Are there any flood marks on or near your property?

☐ Yes

☐ No

If Yes, do we have your permission for surveyors to access your property? (Please ensure you have completed the contact details at the bottom of this survey so we can contact you)

If you wish to stay informed about this study, please provide your preferred contact method below.

Name	
Address	
Phone	
Email	

Privacy Notice

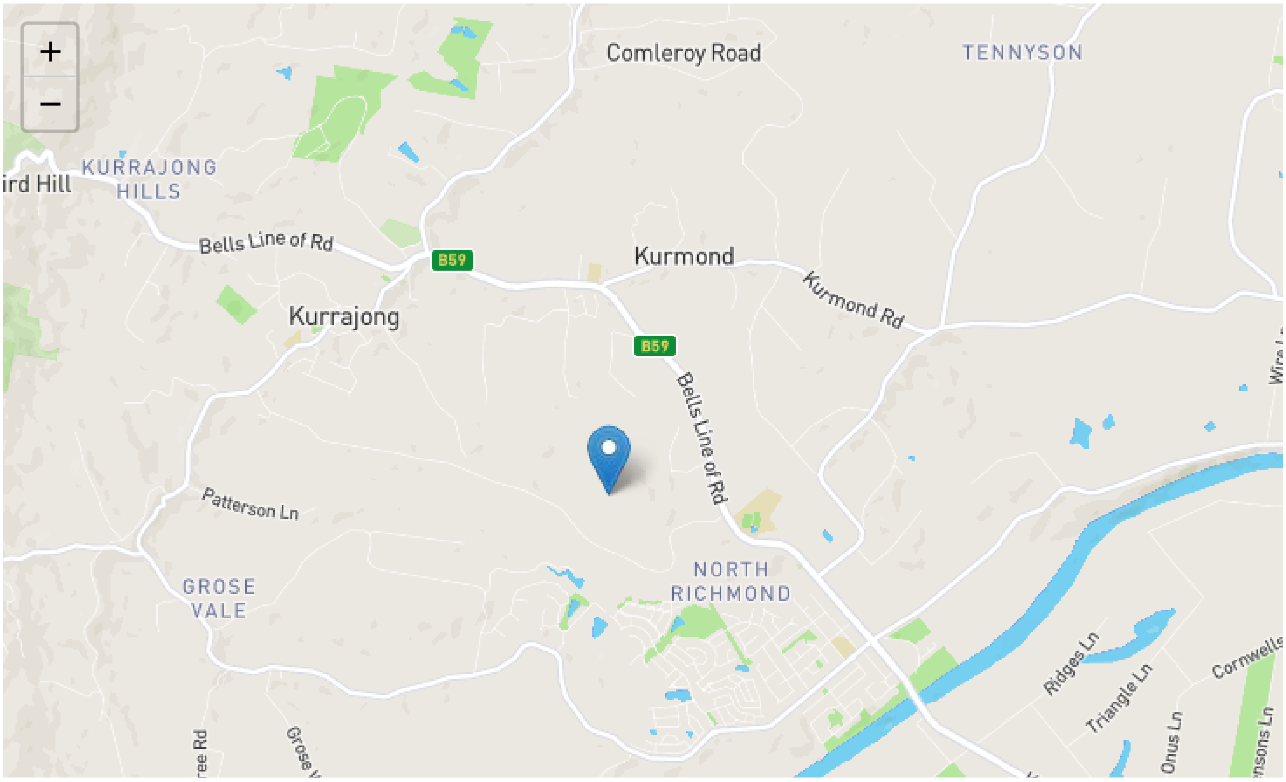
Council is bound by the provisions of the Privacy and Personal Information Protection Act 1998, in the collection, storage and utilisation of personal information provided in this form. Accordingly, the personal information will only be utilised for the purposes for which it has been obtained and may be available for public access and/or disclosure under various NSW Government legislation.

Appendix C ARR 2019 Data Hub

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	150.694
Latitude	-33.568
Selected Regions (clear)	
River Region	show
ARF Parameters	show
Storm Losses	show
Temporal Patterns	show
Areal Temporal Patterns	show
BOM IFDs	show
Median Preburst Depths and Ratios	show
10% Preburst Depths	show
25% Preburst Depths	show
75% Preburst Depths	show
90% Preburst Depths	show
Interim Climate Change Factors	show
Probability Neutral Burst Initial Loss (./nsw_specific)	show
Baseflow Factors	show



Data

River Region

Division	South East Coast (NSW)
River Number	12
River Name	Hawkesbury River

Layer Info

Time Accessed	17 October 2023 01:16PM
Version	2016_v1

ARF Parameters

$$ARF = Min\left\{1, \left[1 - a\left(Area^{b} - c\log_{10}Duration\right)Duration^{-d} + eArea^{f}Duration^{g}\left(0.3 + \log_{10}AEP\right) + h10^{iArea\frac{Duration}{1440}}\left(0.3 + \log_{10}AEP\right)\right]\right\}$$

Zone	a	b	c	d	e	f	g	h	i
SE Coast	0.06	0.361	0.0	0.317	8.11e-05	0.651	0.0	0.0	0.0

Short Duration ARF

$$ARF = Min\left[1, 1 - 0.287\left(Area^{0.265} - 0.439\log_{10}(Duration)\right).Duration^{-0.36} + 2.26 \text{ x } 10^{-3} \text{ x } Area^{0.226}.Duration^{0.125}\left(0.3 + \log_{10}(AEP)\right) + 0.0141 \text{ x } Area^{0.213} \text{ x } 10^{-0.021\frac{(Duration-180)^{2}}{1440}}\left(0.3 + \log_{10}(AEP)\right)\right]$$

Layer Info

Time Accessed	17 October 2023 01:16PM
Version	2016_v1

Storm Losses

Note: Burst Loss = Storm Loss - Preburst

Note: These losses are only for rural use and are **NOT FOR DIRECT USE** in urban areas

Note: As this point is in NSW the advice provided on losses and pre-burst on the NSW Specific Tab of the ARR Data Hub (./nsw_specific) is to be considered. In NSW losses are derived considering a hierarchy of approaches depending on the available loss information. The continuing storm loss information from the ARR Datahub provided below should only be used where relevant under the loss hierarchy (level 5) and where used is to be multiplied by the factor of 0.4.

ID	2044.0
Storm Initial Losses (mm)	50.0
Storm Continuing Losses (mm/h)	3.8

Layer Info

Time Accessed	17 October 2023 01:16PM
Version	2016_v1

Temporal Patterns | Download (.zip) (static/temporal_patterns/TP/ECsouth.zip)

code	ECsouth
Label	East Coast South

Layer Info

Time Accessed	17 October 2023 01:16PM
Version	2016_v2

Areal Temporal Patterns | Download (.zip) (./static/temporal_patterns/Areal/Areal_ECsouth.zip)

code	ECsouth
arealabel	East Coast South

Layer Info

Time Accessed	17 October 2023 01:16PM
Version	2016_v2

BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-33.568037&longitude=150.693634&sdmin=true&sdhr=true&sdday=true&user_label=) to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	17 October 2023 01:16PM

Median Preburst Depths and Ratios

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.5 (0.021)	0.9 (0.026)	1.2 (0.028)	1.4 (0.029)	2.2 (0.038)	2.8 (0.043)
90 (1.5)	3.3 (0.114)	2.6 (0.064)	2.0 (0.043)	1.6 (0.028)	1.2 (0.019)	1.0 (0.014)
120 (2.0)	0.0 (0.000)	0.7 (0.016)	1.1 (0.022)	1.6 (0.027)	1.5 (0.021)	1.4 (0.018)
180 (3.0)	0.9 (0.025)	1.3 (0.026)	1.5 (0.026)	1.8 (0.026)	2.3 (0.028)	2.6 (0.029)
360 (6.0)	2.4 (0.052)	5.4 (0.087)	7.4 (0.099)	9.3 (0.107)	10.2 (0.097)	10.8 (0.090)
720 (12.0)	2.0 (0.032)	6.7 (0.079)	9.8 (0.096)	12.8 (0.106)	14.5 (0.099)	15.7 (0.095)
1080 (18.0)	0.1 (0.002)	4.3 (0.041)	7.0 (0.056)	9.7 (0.065)	13.3 (0.074)	16.1 (0.079)
1440 (24.0)	0.0 (0.000)	3.2 (0.027)	5.2 (0.036)	7.2 (0.042)	9.4 (0.045)	11.0 (0.047)
2160 (36.0)	0.0 (0.000)	2.0 (0.014)	3.4 (0.019)	4.6 (0.022)	5.4 (0.021)	5.9 (0.021)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.7 (0.002)	1.2 (0.004)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	17 October 2023 01:16PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

10% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
90 (1.5)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
120 (2.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
180 (3.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
360 (6.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
720 (12.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1080 (18.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	17 October 2023 01:16PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

25% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
90 (1.5)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
120 (2.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
180 (3.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
360 (6.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
720 (12.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1080 (18.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	17 October 2023 01:16PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

75% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	13.3 (0.517)	14.8 (0.416)	15.8 (0.372)	16.7 (0.339)	26.1 (0.445)	33.2 (0.501)
90 (1.5)	29.6 (1.022)	23.2 (0.585)	18.9 (0.401)	14.9 (0.271)	18.5 (0.283)	21.2 (0.288)
120 (2.0)	10.1 (0.319)	18.0 (0.420)	23.3 (0.456)	28.4 (0.478)	28.3 (0.399)	28.2 (0.352)
180 (3.0)	17.1 (0.477)	31.6 (0.650)	41.2 (0.713)	50.4 (0.750)	43.7 (0.544)	38.6 (0.425)
360 (6.0)	19.5 (0.427)	33.0 (0.529)	42.0 (0.562)	50.5 (0.578)	60.9 (0.580)	68.7 (0.576)
720 (12.0)	21.8 (0.357)	34.9 (0.411)	43.6 (0.425)	51.9 (0.429)	52.1 (0.357)	52.3 (0.315)
1080 (18.0)	17.7 (0.242)	27.7 (0.269)	34.4 (0.274)	40.8 (0.274)	49.7 (0.276)	56.4 (0.276)
1440 (24.0)	5.4 (0.065)	19.8 (0.166)	29.3 (0.202)	38.5 (0.223)	44.4 (0.213)	48.9 (0.206)
2160 (36.0)	6.7 (0.068)	12.8 (0.089)	16.9 (0.096)	20.8 (0.099)	30.9 (0.122)	38.5 (0.134)
2880 (48.0)	1.2 (0.011)	3.2 (0.020)	4.6 (0.023)	5.8 (0.024)	11.1 (0.039)	15.1 (0.047)
4320 (72.0)	0.0 (0.000)	0.2 (0.001)	0.3 (0.002)	0.5 (0.002)	4.7 (0.014)	7.9 (0.021)

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Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

90% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	46.3 (1.799)	57.2 (1.610)	64.4 (1.520)	71.3 (1.448)	76.3 (1.299)	80.0 (1.208)
90 (1.5)	58.2 (2.007)	80.0 (2.017)	94.5 (2.001)	108.3 (1.976)	88.9 (1.360)	74.4 (1.008)
120 (2.0)	38.8 (1.227)	70.0 (1.628)	90.7 (1.776)	110.6 (1.864)	104.4 (1.475)	99.8 (1.247)
180 (3.0)	59.4 (1.658)	68.6 (1.411)	74.7 (1.292)	80.5 (1.198)	104.1 (1.296)	121.8 (1.339)
360 (6.0)	53.6 (1.171)	67.3 (1.077)	76.3 (1.022)	85.0 (0.973)	107.1 (1.021)	123.7 (1.037)
720 (12.0)	55.2 (0.904)	74.3 (0.875)	86.9 (0.848)	99.0 (0.819)	108.8 (0.745)	116.1 (0.698)
1080 (18.0)	37.7 (0.515)	53.0 (0.513)	63.1 (0.502)	72.8 (0.489)	91.4 (0.508)	105.3 (0.514)
1440 (24.0)	30.9 (0.371)	54.2 (0.456)	69.6 (0.479)	84.4 (0.489)	96.3 (0.462)	105.2 (0.444)
2160 (36.0)	32.2 (0.322)	40.4 (0.280)	45.8 (0.259)	51.0 (0.242)	68.3 (0.269)	81.3 (0.283)
2880 (48.0)	9.9 (0.089)	13.5 (0.083)	15.8 (0.079)	18.0 (0.076)	48.8 (0.170)	71.8 (0.222)
4320 (72.0)	15.0 (0.116)	19.5 (0.103)	22.5 (0.097)	25.4 (0.092)	32.8 (0.100)	38.4 (0.104)

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Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

Interim Climate Change Factors

	RCP 4.5	RCP6	**RCP 8.5**
2030	**0.869 (4.3%)**	0.783 (3.9%)	**0.983 (4.9%)**
2040	**1.057 (5.3%)**	1.014 (5.1%)	**1.349 (6.8%)**
2050	**1.272 (6.4%)**	1.236 (6.2%)	**1.773 (9.0%)**
2060	**1.488 (7.5%)**	1.458 (7.4%)	**2.237 (11.5%)**

2070	**1.676 (8.5%)**	1.691 (8.6%)	**2.722 (14.2%)**
2080	**1.810 (9.2%)**	1.944 (9.9%)	**3.209 (16.9%)**
2090	**1.862 (9.5%)**	2.227 (11.5%)	**3.679 (19.7%)**

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Note	ARR recommends the use of RCP4.5 and RCP 8.5 values. These have been updated to the values that can be found on the climate change in Australia website.

Probability Neutral Burst Initial Loss

min (h)\AEP(%)	50.0	20.0	10.0	5.0	2.0	1.0
60 (1.0)	25.6	19.3	16.2	15.6	14.4	11.6
90 (1.5)	28.9	16.4	14.6	15.5	15.1	13.5
120 (2.0)	31.4	21.1	16.8	15.6	13.4	12.3
180 (3.0)	35.5	18.2	15.9	15.2	14.3	11.4
360 (6.0)	35.2	20.7	17.5	16.7	15.2	10.0
720 (12.0)	34.8	22.7	20.9	20.5	18.2	12.2
1080 (18.0)	38.2	28.0	26.6	26.1	23.0	11.4
1440 (24.0)	41.9	32.0	29.7	28.4	26.0	17.4
2160 (36.0)	43.0	35.4	35.1	36.7	31.8	16.8
2880 (48.0)	48.9	43.4	44.6	48.2	37.6	22.0
4320 (72.0)	49.5	43.7	43.4	50.2	42.7	31.2

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Note	As this point is in NSW the advice provided on losses and pre-burst on the NSW Specific Tab of the ARR Data Hub (./nsw_specific) is to be considered. In NSW losses are derived considering a hierarchy of approaches depending on the available loss information. Probability neutral burst initial loss values for NSW are to be used in place of the standard initial loss and pre-burst as per the losses hierarchy.

Baseflow Factors

Downstream	10098
Area (km2)	12001.1858227
Catchment Number	10137
Volume Factor	0.166834
Peak Factor	0.040854

Layer Info

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Appendix D Model sensitivity