CITY OF PARRAMATTA

A'Becketts Creek Flood Study and Floodplain Risk Management Study and Plan

Final Draft Flood Study Report for Community Consultation

April 2025

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A'Becketts Creek Flood Study and Floodplain Risk Management Study and Plan

Flood Study Report

Project: A'Becketts Creek Flood Study and Floodplain Risk Management Study and Plan

Project Number: 210025

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Verified by: Stephen Gray

Date	Version	Description
29-Mar-2023	1	Stage 2 Draft Flood Study Report
25-Jul-2023	2	Final Draft Flood Study Report
30-Sep-2024	3	Draft Flood Study Report for Community Consultation
18-Apr-2025	4	Final Draft Flood Study Report for Community Consultation

Filepath: J:\210025\Admin\Report\AbecketttsFS_FRMS_FloodStudy_v5.docx

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EXECUTIVE SUMMARY

This report presents a draft flood study for the A'Becketts Creek catchment. The study provides design flood behaviour for the catchment. Flooding in the area is caused by A'Becketts Creek, Duck Creek and Duck River flooding, and occasionally Parramatta River flooding or elevated ocean levels.

This flood study has been initiated by the City of Parramata Council to investigate and document the impacts of flooding in the A'Becketts creek catchment and to develop a Floodplain Risk Management Plan (planned to be completed in 2025) in accordance with NSW Government's Flood Prone Land Policy. Both Flood Study and FRMS&P are aimed at meeting the needs of a range of end users including Parramatta City Council, DPE, Sydney Water, the SES and the local community. Detailed information describing flooding is used by Council and others to plan and respond to future flood events, and to ensure that flood risk is reduced over time.

The report presents the previous studies related to flooding in the A'Becketts Creek catchment. There are a large number of previous studies, due to the history of flooding in the area, and because the creek is affected by both Duck Creek and Duck River flooding, which have their own studies. The area is also subject to historical and current development including the M4 Motorway and the Metro West rail line, the latter of which has ongoing flooding investigations. The current report presents the relevant features of previous studies and their spatial location, in summarising their relative importance.

The report also presents the various sources of data utilised by the current study, including those from previous flood investigations. The review of the available data finds that available LiDAR and bathymetry data can be used to describe the large majority of the study area, and that pit and pipe data is also extensive. Data gaps in the various data are not significant enough to require further survey, and interpolation of existing data along with site visit can fill in what gaps do exist. With regards to calibration data, a combination of rainfall and stream gauge data, and photos and flood levels from recent flood events has been used.

A hydrologic model (WBNM) and a hydraulic model (TUFLOW) have been used to define design flood behaviour in the study area, including peak flood depths and levels, extents, velocities and flood hazard. The WBNM model is the Parramatta River catchment model established in 2019, updated slightly to fit the current study. The TUFLOW model has utilised the recent model established for the Metro West project, which itself was based on earlier TUFLOW models of the area. The models were both calibrated to recent flood events including the February 2020, March 2021, February 2022 and July 2022 floods, with the models showing a close fit to observed flooding. The models were then used to simulate the full range of design flood events (20%, 5%, 2%, 1% AEP and PMF) with outputs including flood depths, levels, velocities, flow rates and flood hazard, as well as carrying out sensitivity analysis of the adopted model parameters.

The catchment contains medium and high density urban areas, as well as a number of large bridges and other structures over A'Becketts Creek itself. The study shows that flooding can inundate roads and properties, particularly in the lower catchment, impacting residential properties, commercial areas and infrastructure. Flood levels and velocities in the lower catchment are affected by Duck Creek and Duck River flooding, and to a lesser extent, Parramatta River levels. Areas of overland flow flooding also exist with significant hazard for vehicles and pedestrians. With regards to the range of floods that can occur, the creek experiences significant out of bank flooding in the lower reaches in a 20% AEP event, while larger events greatly exceed the channel capacity, with more extensive flooding in adjacent areas. In extreme flood events there is widespread flooding of residential areas with depths of 1 m and greater.

The study has been carried out in accordance with Australian Rainfall and Runoff 2019 and the NSW Floodplain Risk Management Manual. The next steps are public exhibition of the draft Flood Study and finalisation of the Flood Study. The study will then be followed by a Floodplain Risk Management Study and Plan for the catchment for which there will be a public exhibition period. The draft FRMS&P will be updated based on the feedback received during the public exhibition.

FOREWORD

The New South Wales (NSW) Government's Flood Prone Land Policy aims to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods.

Through the NSW Department of Planning and Environment (DPE) and the NSW State Emergency Service (SES), the NSW Government provides specialist technical assistance to local government on all flooding, flood risk management, flood emergency management and land-use planning matters.

The Floodplain Development Manual (NSW Government 2005) and more recently the Floodplain Risk Management Manual assists councils to meet their obligations through a five-stage process resulting in the preparation and implementation of floodplain risk management plans. Sketch 1 presents the process for plan preparation and implementation, from the 2022 NSW Flood Risk Management Manual.

The current report is for the Flood Study phase and the current project covers all four stages in Sketch 1.

Sketch 1 The floodplain risk management process in New South Wales (FRMM, 2022)

1. INTRODUCTION

1.1 The Floodplain Risk Management Program

Parramatta City Council (Council) in partnership with Sydney Water has received support from the State Floodplain Management program managed by the Department of Planning and Environment (DPE) to prepare a Flood Study and Floodplain Risk Management Study and Plan (FRMS&P) for the A'Becketts Creek catchment in the Parramatta LGA. To meet this objective GRC Hydro Pty Ltd (GRC Hydro) have been engaged by Council.

This study composes stages 1 to 4 of the five-stage process outlined in the NSW Government's Floodplain Development Manual (FDM, 2005). These works include:

- Data Collection
- Flood Study – Defines the nature and extent of the flood problem
- Floodplain Risk Management Study (FRMS) – assess the impacts of floods on the existing and future community and allows the identification of management measures to treat flood risk; and
- Floodplain Risk Management Plan (FRMP) – outlines a range of measures, for future implementation, to manage existing, future and residual flood risk effectively and efficiently.

Following the completion of the FRMP, the final stage of the FDM (2005) floodplain management process will involve implementing the findings of the updated FRMP.

1.2 Objectives

The primary objective of the New South Wales (NSW) Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible review. The project consists of both a Flood Study, which is a technical investigation into how and where flooding occurs, and a FRMS, which more broadly assesses the impacts of flooding and how to manage them. The Study will provide a basis for informing the development of a Plan which will document and convey the decisions on the management of flood risk into the future.

The overall project provides an understanding of, and information on, flood behaviour and associated risk to inform:

- relevant government information systems;
- government and strategic decision makers on flood risk the community;
- flood risk management planning for existing and future development;
- emergency management planning for existing and future development, and strategic and development scale land-use planning to manage growth in flood risk;
- other key stakeholders (including utility providers and the insurance industry) on flood risk;

- providing a better understanding of the:
    - variation in flood behaviour, flood function, flood hazard and flood risk in the study area;
    - impacts and costs for a range of flood events or risks on the existing and future community;
    - impacts of changes in development and climate on flood risk;
    - emergency response situation and limitations;
    - effectiveness of current management measures;
- facilitating information sharing on flood risk across government and with the community.

The study outputs can also inform decision making for investing in the floodplain; managing flood risk through prevention, preparedness, response and recovery activities; pricing insurance, and informing and educating the community on flood risk and response to floods. Each of these areas has different user groups, whose needs vary.

A key objective of this study is to meet the requirements of the identified end user groups (see Section 1.3), which have been tailored to the context of the current study.

The study is overseen by a Floodplain Risk Management Committee managed by Council. The committee is involved in steering and overseeing the current study and is made up of community representatives, elected councillor representatives, Council technical staff, and DPE and SES representatives.

1.3 Project End Users

The study outputs are suitable to inform decision making for investing in the floodplain; managing flood risk through prevention, preparedness, response and recovery activities; pricing insurance, and informing and educating the community on flood risk and response to floods. Each of these areas has different user groups, whose needs vary. The key end-user groups that this study aims to support are identified in Table 1.

Table 1:Project End Users

End user groups
Emergency Services (SES, NSW Police, RFS, NSW Fire and Rescue)
Council for floodplain management and flood forecasting
Consultants and Developers – development compliance
State Government including DPE- Disaster Relief & strategic development
Community - Disaster awareness & preparation
Insurers - provision of insurance against flood damage
Public Utility & Infrastructure - assessing flooding impacts
Insurers and utility providers

2.BACKGROUND

2.1 Study Area

A'Becketts Creek is located in Sydney's western suburbs around 1 km south of the Parramatta CBD. The creek, which generally flows from west to east, has a catchment of approximately 680 hectares, mostly located in Granville but also in parts of Rosehill, Harris Park and Merrylands. The catchment is fully urbanised with mostly residential areas mixed with pockets of commercial and industrial usage as well as urban parks. The creek is comprised of the following sections, beginning from the upstream:

1. Downstream of Neil Street to Holroyd Sportsground – approximately 900 m of natural channel through residential and industrial areas, in Cumberland Council.
2. Holroyd Sportsground to upstream of James Ruse Drive – approximately 2.0 km of concrete channel with large portions directly beneath the elevated M4 motorway, and suburban residential areas north and south of the creek. In this section the LGA boundary to Parramatta Council is crossed. The channel is a Sydney Water asset that is operated and maintained by Sydney Water.
3. A final section between James Ruse Drive and the confluence with Duck Creek that has a natural channel and is approximately 200 m long. From there, the creek discharges to Duck Creek, which itself flows into Duck River before it joins the Parramatta River.

The creek's catchment is located in the Parramatta and Cumberland LGAs, with the majority (~80%) in Cumberland and the lower portion (~20%) in Parramatta. The current study is for the section of A'Becketts Creek in the Parramatta LGA but will include modelling of the entire catchment as well as the creek's interaction with Duck Creek and Duck River/Parramatta River. The relevant catchment areas are A'Becketts Creek (7 km^2), Duck Creek including Little Duck Creek (9 km^2), Duck River including these two tributaries (41 km^2) and Parramatta River (104 km^2 to Marsden Street Weir and 217 km^2 in total).

2.1.1 Physical Characteristics

The study area is located in the Parramatta River catchment and is generally located on the edge of the Parramatta River hydrogeological landscape. Available literature[1] describes this landscape, which extends to A'Becketts Creek and adjacent areas to the south and north of the creek, as characterised by low lying Quaternary and Tertiary Alluvial floodplains. It states there are areas of reclaimed land, and in general, areas which are "commonly waterlogged and contain ponded water and back swamps, and are areas with potential for acid sulfate soils". With regards to types of soil, the literature states the landscape contains "unconsolidated sedimentary fine-grained sands, silts and clays from the Quaternary period. These have been derived from (and overlie) the surrounding Wianamatta Group rocks and Hawkesbury Sandstone". With regards to current

[1] "Parramatta/Georges River Hydrogeological Landscape", NSW DPE, accessed via eSPADE website

day conditions, it is understood from Council that there a series of areas in the vicinity of A'Becketts Creek that are contaminated lands.

The study area's topography consists of a flat area adjacent to the creek channels, surrounded by higher areas with greater slope. The study area is generally comprised of the following topographic features:

- The channels of A'Becketts Creek, Duck Creek and Duck River
- Flat areas adjacent to A'Becketts Creek, typically 200 to 300 m wide, with grade of around 0.2% to 0.7%
- The creek's northern floodplain, towards Harris Park, is narrower (around 100 m) before rising to an east-west ridge that separates A'Becketts Creek from Clay Cliff Creek to the north. The sloped area has grade of around 3-6%, rising to around 21-30 mAHD.
- Sloped areas to the south of the creek, mainly located in the Granville area, have grade of around 3% and rise to 33 mAHD.
- The confluence area, where the two creeks meet Duck River, has large flat areas, generally between 3-5 mAHD while the channels themselves are at sea level.

The area's topography is also shown on the LiDAR (see Figure 3).

2.1.2 Land use

The catchment is fully urbanised with large residential areas mixed with pockets of commercial and industrial usage as well as urban parks. Zoning contains large areas of R2 (residential) particularly away from the creeks, and also business zoning along the railway lines, along Parramatta Road and other main roads. The confluence area at the downstream of A'Becketts Creek has large areas of industrial zoning.

2.1.3 Climate

The study area experiences a humid subtropical climate, common to eastern New South Wales and south-east Queensland. Sydney experiences mild to cool winters and warm to hot summers, with temperatures moderated by the proximity to the ocean. Mean annual rainfall is around 970 mm with rainfall throughout the year but with wetter periods typically in January to June. As with other coastal areas, the area is affected by East Coast Lows which are associated with heavy rainfall lasting a number of days, and are more common in autumn and winter than other times of year.

2.1.4 Flood Mechanisms

The study area experiences mainstream flooding along A'Becketts Creek and overland flooding in the urban areas that drain to the creek. The primary flooding mechanism is heavy rainfall over the A'Becketts Creek catchment leading to flooding of the creek and localised instances of overland flooding. Overland flooding typically occurs when the stormwater network's capacity is exceeded and overland flowpaths form, or runoff accumulates in trapped low points.

In addition, flooding can occur on A'Becketts Creek as a result of backwater from Duck Creek and/or Duck River at the downstream area, and this can also coincide with floodwaters coming down A'Becketts Creek. Lastly, in exceptionally large floods, Parramatta River flooding, either as a result of elevated ocean levels or rainfall-runoff flooding, may affect A'Becketts Creek flooding.

2.1.5 Historical Flooding

A'Becketts Creek has an established history of flooding with various studies of the catchment and neighbouring creeks setting out flood events in the last ~70 years. The A'Becketts Creek Catchment Management Study (Bewsher Consulting, 1990) undertook a review of historical events including a questionnaire to residents and identified the following events:

- April 1956 and March 1967 were recorded as minor flood events in neighbouring catchments and may have also occurred on A'Becketts Creek
- April 1974 saw very significant flooding of Duck Creek which then caused flooding on A'Becketts Creek via a backwater effect.
- August 1986 – significant flooding along A'Becketts Creek with the 1990 study noting there appeared to be a period of less flooding in the ~30 years prior.
- November 1986, April 1988, 3 February 1990, 10 February 1990 were all noted as severe events, though not as large as 1986

The reporting did not include flood levels for A'Becketts Creek for these historical events so their approximate AEP cannot be estimated.

The current study more recently recorded floods in:

- February, March 2020 (February approximately 5% AEP in lower A'Becketts Creek)
- March 2021 (approximately 20% AEP)
- January, February, March, June and July 2022 (February was approximately 20% AEP, July was less than a 20% AEP event)

Based on the current design flood estimates, the approximate AEP for each observed flood level in the lower catchment is provided above.

The current study has sent out a questionnaire and gathered data on the recent flood events. The results of the questionnaire are presented in Section 4.1.

3. DATA COLLECTION AND REVIEW

All data and information relevant to the current study was collected and documented in the project's Information Review report, which is set out in the following section.

3.1 Previous Studies

There have been approximately twelve studies of flooding in the area that either included A'Becketts Creek or the confluence area with Duck Creek and Duck River. As per the NSW Floodplain Management Program, studies are regularly reviewed and updated to reflect catchment changes and advances in hydrologic/hydraulic data and modelling. The previous studies are:

- Covering the majority of A'Becketts Creek:
    - A'Becketts Creek and Duck Creek Flood Study (Sinclair Knight and Partners for the Water Board and the RTA, 1987)
    - A'Becketts Creek SWC No. 46, Catchment Management Study (Bewsher Consulting for the Water Board, 1990)
        - As an update to the 1990 study, a short letter report is on file: A'Becketts Creek, Revision of Flood Levels as a consequence of the Duck Creek Stormwater Channel No. 35 Catchment Management Study (author unknown, 1993)
    - A'Becketts Creek Drainage Master Plan (Jacobs for Parramatta City Council, 2009) <u>Note: the report is in draft.</u>
    - Hydrologic Model Conversion for Parramatta River Catchment (WMAwater for Parramatta City Council, 2019) <u>Note: the report was not focussed on A'Becketts Creek but it is included in the hydrologic model.</u>
- Covering the confluence area:
    - Duck River Flood Study and Duck River Study (two studies by Brian O'Mara and Associates for Parramatta City Council, 1992 and 1994)
    - Duck Creek Sub-Catchment Management Plan (Cardno Willing for Parramatta City Council, 2003)
    - Duck River Flood Study (Cardno Willing for Parramatta City Council, 2005)
    - Lower Parramatta River Floodplain Risk Management Study and Plan (SKM for Parramatta City Council, 2005)
        - As an update to the study, SKM also prepared Lower Parramatta River Floodplain Risk Management Study and Plan -Climate Change Impacts in 2014
    - Duck River Catchment Floodplain Risk Management Study (Molino Stewart for Parramatta, Auburn and Bankstown Councils, 2012)
    - Duck River and Duck Creek Flood Study Review (WMAwater for Parramatta City Council, 2012)
    - Parramatta River Flood Study (Cardno now Stantec currently undertaking for Parramatta City Council)

    - Sydney Metro West, Westmead to The Bays and Sydney CBD, EIS Concept and Stage 1, Technical Paper 1, Hydrology and Flooding (Jacobs for Sydney Metro, 2020)
    - Sydney Metro West, Clyde Maintenance and Stabling Facility – Hydraulic Concept Flood Modelling Report (GRC Hydro for Sydney Metro, 2022)
- Covering adjacent catchments in Parramatta LGA:
    - Clay Cliff Creek Catchment Master Drainage Plan (Cardno Willing for Parramatta City Council, 2007)
    - Flood Control Study for Rosehill/Camellia (SKM for Parramatta City Council, 2013)

Of these studies, some have limited information for use by the current study. The 1987 A'Becketts Creek study is fairly old and has been superseded by the latter two studies, similarly the 1992 and 1994 studies have not been utilised for the same reason. The 2012 Molino Stewart study used flood modelling from the 2012 WMAwater study and so the latter has been utilised for data and modelling. Lastly, the two studies in the adjacent Clay Cliff Creek catchment do not affect A'Becketts Creek flooding and have not been utilised. The following section therefore summarises the scope and relevant data from the following eight studies:

- Covering the majority of A'Becketts Creek:
    - A'Becketts Creek SWC No. 46, Catchment Management Study (Bewsher Consulting for the Water Board, 1990)
        - As an update to the 1990 study, a short letter report is on file: A'Becketts Creek, Revision of Flood Levels as a consequence of the Duck Creek Stormwater Channel No. 35 Catchment Management Study (author unknown, 1993)
    - A'Becketts Creek Drainage Master Plan (Jacobs for Parramatta City Council, 2009) <u>Note: the report is in draft</u>
    - Hydrologic Model Conversion for Parramatta River Catchment (WMAwater for Parramatta City Council, 2019) <u>Note: the report was not focussed on A'Becketts Creek but it is included in the hydrologic model.</u>
- Covering the confluence area:
    - Lower Parramatta River Floodplain Risk Management Study and Plan (SKM for Parramatta City Council, 2005)
        - As an update to the study, SKM also prepared Lower Parramatta River Floodplain Risk Management Study and Plan -Climate Change Impacts in 2014
    - Duck River and Duck Creek Flood Study Review (WMAwater for Parramatta City Council, 2012)
    - Parramatta River Flood Study (Cardno currently undertaking for Parramatta City Council)
    - Sydney Metro West, Westmead to The Bays and Sydney CBD, EIS Concept and Stage 1, Technical Paper 1, Hydrology and Flooding (Jacobs for Sydney Metro, 2020)
    - Sydney Metro West, Clyde Maintenance and Stabling Facility – Hydraulic Concept Flood Modelling Report (GRC Hydro for Sydney Metro, 2022)

3.1.1 A'Becketts Creek SWC No. 46, Catchment Management Study (1990)

The Sydney Water study investigated flood behaviour along A'Becketts Creek. The analysis applied ARR87 temporal patterns and IFD data for the creek's catchment. The hydrologic model was RAFTS and covered the entire A'Becketts Creek catchment. HEC-2 was used for the hydraulic modelling with the model domain covering the main channel from Neil Street down to the confluence with Duck Creek. The hydraulic model extent is shown on Figure 2. Surveyed cross sections taken for the study in 1987 covering the creek, as shown in Figure 4, along with resultant design levels are available from the study. Design events consisted of 5 year ARI, 20 year ARI, 100 year ARI and the PMF. The study also assessed water quality issues and evaluated and recommended measures to reduce flood risk.

3.1.2 A'Becketts Creek Drainage Master Plan (2009)

The study, which appears to have not been finalised, investigated flood behaviour along A'Becketts Creek from the Western Railway line to the confluence with Duck Creek. DRAINS was used to model the stormwater pipe network, which was digitised based on the 1987 asset mapping where data was available and assumed values used otherwise. No invert information was available and a 600 mm cover with minimum gradient of 1% was assumed. RAFTS was used to model the hydrology which was used as the upstream boundary condition in the hydraulic model (MIKE-11) covering the study area. The MIKE-11 cross sections are from the survey in 1987 and the RAFTS model is from 2006. The hydraulic model extent is shown on Figure 2.

3.1.3 Lower Parramatta River Floodplain Risk Management Study and Plan (2005)

The study investigated design flood behaviour and flood risk management measures for the Lower Parramatta River. The study area is from the Charles Street Weir, on the Parramatta River, and includes inflows from the Clay Cliff Creek, Vineyard Creek, Subiaco Creek, Haslams Creek, Powells Creek and Duck River catchments. The Duck River catchment included the confluence of Duck Creek and A'Becketts Creek, with inflows based off a XP-RAFTS hydrology model developed as part of the study. Results from the MIKE-11 model and XP-RAFTS are both available for this study. The hydraulic model extent is shown on Figure 2.

3.1.4 Duck River and Duck Creek Flood Study Review (2012)

The study reviewed and revised previous analysis to provide updated design flood mapping for Duck River and Duck Creek. For A'Becketts Creek the hydrologic XP-RAFTS model from 2006 was adapted for inflows and cross sections from the MIKE-11 model were used. Together these were implemented into one of three TUFLOW models developed in this study. Of interest is the 'Confluence' TUFLOW model which includes the confluence of A'Becketts Creek and Duck Creek, along with the Duck Creek and Duck River confluence. The three hydraulic model extents are shown on Figure 2.

3.1.5 Parramatta River Flood Study (expected 2023)

The ongoing study is updating design flood behaviour for the Parramatta River in the LGA. Preliminary results indicate the hydraulic model extends up Duck Creek to the confluence point with A'Becketts Creek, and up Duck River to the Duck Creek confluence. The study's hydraulic model extent is shown on Figure 2. Once finalised, the study will be used to define Parramatta River design flood levels for the current study, as required.

3.1.6 Sydney Metro West, EIS Concept and Stage 1 (2020)

The full name is "Sydney Metro West, Westmead to The Bays and Sydney CBD, EIS Concept and Stage 1, Technical Paper 1, Hydrology and Flooding". The report was undertaken as part of the technical investigations at the concept stage of the Metro West project, a large infrastructure project involving a new rail line through Sydney's western suburbs. The rail line includes a section connecting Parramatta and Sydney Olympic Park that will pass through or in the vicinity of A'Becketts Creek, and the report describes a new Clyde stabling and maintenance facility (CSMF) to be built at the confluence of Duck Creek and A'Becketts Creek, and just upstream of the Duck River/Duck Creek confluence. The works have the potential to impact flood behaviour, and this is the subject of ongoing assessment by the TfNSW project team.

The project undertook flood modelling for the area by utilising and in some instances combining four previous models: Parramatta Light Rail (Arup 2017), Duck River and Duck Creek Flood Study Review (WMAwater, 2012), A'Becketts Creek Drainage Master Plan (GHD 2009) and Lower Parramatta River Flood Study (SKM 2005). The study's model extends up A'Becketts Creek to Harris Street, which is approximately half of the current study's model area. The study reports "the terrain and hydraulic structures data from each model were extracted to develop the current TUFLOW model for this assessment".

Sydney Metro West was contacted at the outset of the current study requesting use of any available survey data. They have provided survey by RPS Group undertaken in 2021. The survey data consists of:

- Detailed ground and channel survey in the confluence area and along each of the waterways, including A'Becketts Creek, and provided in TIN format.
- Survey of flood level and ground level at around 10 points (date is unknown)
- Structure survey for a series of creek crossings along A'Becketts Creek and in the confluence area
- Stormwater drainage (pit and pipe network) survey including for some areas draining to A'Becketts Creek
- Pit cards for the above survey detailing different pit types.
- Survey of the Duck River gauge

The location and use of the survey data by the current study is described in Section 3.3. Based on discussion with Council, it was agreed that the finalised Metro West design will be included in the current study's model, once both are available, and be considered as part of a 'future development' scenario (as works are still ongoing).

3.1.7 Sydney Metro West - Hydraulic Concept Flood Modelling Report (2022)

The full name is "Sydney Metro West, Clyde Maintenance and Stabling Facility – Hydraulic Concept Flood Modelling Report". The study continues on from the Technical Paper (previous reference) and uses an updated hydrologic and hydraulic model to assess existing and proposed flood behaviour, as part of the assessment of the Clyde Maintenance and Stabling Facility.

The TUFLOW model setup as part of the study is based on the detailed survey undertaken by RPS and described in the previous section. For this reason, the model was requested to be utilised for the current study and Sydney Metro granted this permission, for the existing case model. The TUFLOW model extent covers the majority of the current study's modelling area. Review of the model is presented in Section 3.2.2

3.1.8 Hydrologic Model Conversion for Parramatta River Catchment (2019)

The study converted the existing XP-RAFTS hydrologic model of the Parramatta River catchment used by Council to a WBNM (Watershed Bounded Network Model) model and was carried out by WMAwater on behalf of Parramatta City Council. The study simplified the model as part of the conversion and undertook a number of model fixes and improvements. The WBNM model was then calibrated to the same three historical events as previously used (1988, 2015 and 2016) with the main calibration data being the Marsden Street gauge. It is noted that this gauge is located on the Parramatta River upstream of the Duck River confluence. The calibration was reported to be an improvement in fit and accuracy over the previous XP-RAFTS model. The adopted model schematisation and parameters are shown below.

- Total of 1192 subcatchments
- Lag parameter ('C' value) of 1.29
- 'Basin' features adopted for 61 locations, taken from the XP-RAFTS model and using a stage-storage-discharge relationship in WBNM.
- ARR2019 point temporal patterns adopted for design rainfall events.
- Losses of 30 mm Initial Loss (all AEP) and 3.5 mm/hour (20% AEP), 2.5 mm/hour (10% and 5% AEP) and 0.5 mm/hour (2% and 1% AEP) Continuing Loss.
- 90th percentile pre-burst depths for design events

The model has been adopted for use and updated by the current study, as per the technical brief (see Section 5.2).

3.1.9 Summary of Previous Studies

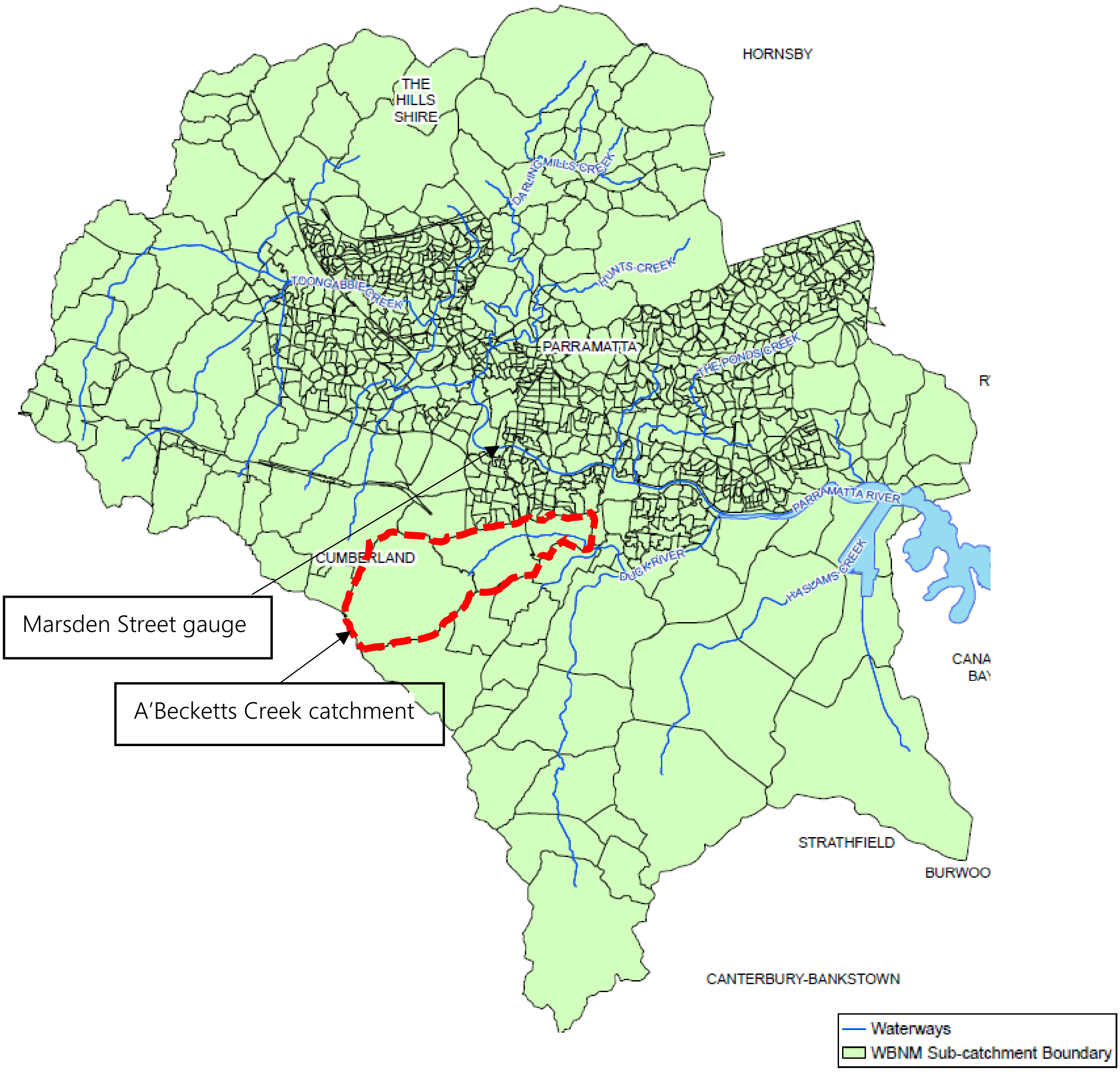
As established, there are numerous studies of flooding in the LGA, all with varying degrees of relevance to the current study. Those that modelled either A'Becketts Creek or the Duck Creek confluence area have been focussed upon. Figure 2 shows the location of all relevant hydraulic models, of which there are eight (not including the Rosehill model). This mapping and review of previous studies then forms the basis of deciding which studies results are most relevant (i.e., should be used for comparison to the current study) and which studies have relevant model data that can be utilised.

3.2 Review of Relevant Models

The current study adapts the Parramatta WBNM model and Metro West TUFLOW model, for the study area. Review of previous models is therefore focussed on the WBNM model (which itself was based on an earlier RAFTS model), the Metro West model, and the other hydraulic models used for comparison purposes.

3.2.1 Parramatta River Catchment WBNM Model

The WBNM model was converted from a previous XP-RAFTS model in 2019 and is recommended by Council for use in the current study. The model covers the entire Parramatta River catchment including the watercourses of interest (A'Becketts Creek, Duck Creek and Duck River). The model was calibrated to three historical events (1988, 2015 and 2016) using available rainfall data and the Marsden Street Weir gauge (gauge number 213004). The location of the gauge, the model extent and A'Becketts Creek are shown in Sketch 2 below, based on an extract from the 2019 report.



Sketch 2 Parramatta River WBNM model showing A'Becketts Creek catchment and Marsden Street gauge.

The calibration process considered four calibration parameters: temporal pattern, initial loss, continuing loss and WBNM lag parameter 'C'. The calibration determined a 'C' of 1.29 and an initial loss varying from 80 mm (2016 event) to 30 mm (2015 and 1988 events). The continuing loss adopted was 1.5 mm/hour for the 1988 event and 2.5 mm/hour for 2015. The report states that an initial loss of 30 mm was selected for all design events, and a continuing loss of 3.5 mm/hour was used for 20% AEP, 2.5 mm/hour for 10%-5% AEP, and 0.5 mm/hour for 2-1% AEP.

The conversion report notes that catchment delineation was not adjusted (apart from where subcatchments were combined) and imperviousness factors were also not changed (although possible discrepancies were recorded).

Review found the WBNM model is suitable for use by the current study. The model updates are described in Section 5.2.

3.2.2 Sydney Metro West Hydraulic Concept TUFLOW Model

The Sydney Metro TUFLOW model represents the most recent and up to date hydraulic model of the A'Becketts Creek catchment. It considers flooding from the potential five sources of flooding in the catchment (Duck/A'Becketts Creek flooding, Duck/Parramatta River flooding, and elevated ocean levels). The model has been reviewed and the approach and parameters are set out below:

- TUFLOW version - 2020-10-AB with Single Precision HPC solver
- Grid cell size: 2 m with Sub-grid Sampling of 0.5 m distance
- 2019 LiDAR ('Sydney201906-LID1-AHD') used for the majority of the model, 2013 LiDAR used for the Parramatta River riparian area.
- Structures, overbank areas and channel bathymetry based on RPS survey, except for Parramatta River bathymetry which used survey from Parramatta Light Rail project.
- Pits and pipes data based on Council GIS data from Parramatta City Council, Cumberland Council and RPS survey.
- Downstream boundary: 1D network with HT boundary, located several kilometres downstream of the 2D model domain, on Parramatta River
- Mannings 'n' values:
  - Road 0.02
  - Rail 0.04
  - Residential 0.05
  - Commercial 0.04
  - Paved areas 0.025
  - Park / grass 0.035
  - Medium density vegetation 0.045
  - High density vegetation 0.09
  - Natural creek channel 0.05
  - Deep water creek channel 0.03
  - Concrete channel 0.025
  - Buildings 3.0
- Bridge and culvert representation: Modelled as 2D elements, with form losses based on Hydraulics of Bridge Waterways (FHWA, 1978) for piers, and WBM BMT's 'TUFLOW Form Loss.xlsx' spreadsheet for bridge deck and railing form losses.

- Structure blockage: Structures (bridges and culverts) along each creek and river were assumed to have no blockage on the basis that blockage would potentially reduce flooding at the area of interest (confluence area)
- Downstream tailwater levels: The coincidence of creek and Duck River flooding with Parramatta River flooding, and elevated ocean levels, was assessed in detail through a Monte Carlo Analysis. The analysis established AEP-neutral tailwater levels to be used along Parramatta River, in order to avoid the tailwater unduly influencing the AEP of the flood level on Duck Creek/Duck River.

The hydrologic and hydraulic models were used to test two historical events, February 2020 and February 2022. Comparison to ten observed flood levels across the two events showed an absolute average difference of 61 mm, which the report compares to the earlier 2012 Duck River and Duck Creek Flood Study Review which achieved a match of around 0.6 m between modelled and observed. The study used Duck River stream gauge data but utilised a HEC-RAS model to establish a stage-discharge relationship at the gauge, of improved accuracy relative to the Sydney Water rating curve. The established rating curve is used by the current study as Sydney Water did not supply a rating curve for the gauge.

The review found the model was detailed and fit-for-purpose and can be described as a best-practice model. The TUFLOW model has therefore been adopted for use in the current study (see Section 5.3). The main differences in the approach used by the current study are:

- Extension of the model to cover the upper portion of the study area.
- Blockage of drainage pits and hydraulic structures along A'Becketts Creek was modelled in one scenario (see Section 6.2)
- Design tailwater levels were based on Council guidance and the Parramatta River Flood Study, not the Monte Carlo Analysis results (see Section 6.2)
- Finer-scale subcatchment representation in the study area, with all model inflows derived from the WBNM model described in the previous section.

3.2.3 Duck River and Duck Creek Models

The XP-RAFTS (hydrologic) and TUFLOW (hydraulic) models used by the 2012 study (Duck River and Duck Creek Flood Study Review) are of interest to the current study as these define current design flood levels in the confluence area that includes A'Becketts Creek and consider coincident flooding of the three catchments. The report does not document the Areal Reduction Factor used but notes the previous study did not apply any reduction. The downstream tailwater at the Parramatta River was modelled as a constant level and was taken from the 2005 Lower Parramatta River Flood Study, which also modelled the lower Duck River catchment. The 20% AEP design event used the 2005 study's 20% AEP level at the Duck River/Parramatta River confluence, the 5% AEP event used the 2005 5% AEP level, and so on. It's also noted the A'Becketts Creek design inflows were taken from the XP-RAFTS model of the A'Becketts Creek Drainage Master Plan (GHD, 2009).

For comparison purposes, the following design flows and levels have been extracted from the 2012 study and are shown in Table 2. The A'Becketts Creek inflows and two flood level locations have also been included, which are used in the 2012 study but were sourced from the 2009 study.

Table 2: Overview of Previous Design Flood Information

Location	20% AEP	5% AEP	2% AEP	1% AEP	PMF
	Peak Flood Levels (mAHD)				
Duck River: Confluence Duck Creek & Duck River	3.2	3.7	4.0	4.2	6.8
Duck River: Confluence with Parramatta River	3.2	3.2	3.2	3.2	5.5
Duck River: Upstream Parramatta Road	3.6	4.2	4.5	4.7	7.4
Duck Creek: Upstream M4	4.1	4.6	4.8	5	7.3
Duck Creek: Upstream Parramatta Road	4.2	4.7	5.1	5.4	7.8
A'Becketts Creek: Arthur Street Bridge	4.80	4.96	*	5.73	*
A'Becketts Creek: Harris Street Footbridge	5.45	5.70	*	6.11	*
	Peak Flows (m3/s)				
Duck River: Upstream Parramatta Road	100	133	159	168	225
Duck Creek: Upstream Parramatta Road	48	62	73	82	203
A'Becketts Creek at Dalley Street	82	98	*	118	*
A'Becketts Creek at Rail Bridge near Duck Creek	86	104	*	127	*

*Flows/levels not presented for these events

These design flood levels and flows are compared to the current study's design flood levels and flows in Section 6.10.

3.3 Model Build Data

The hydrologic and hydraulic models use a series of datasets in establishing the hydrologic and hydraulic models of A'Becketts Creek. Each of these datasets are combined to accurately describe the features of the catchment that govern how and where flooding occurs.

An overview of the datasets used for the hydrologic and hydraulic models is as follows:

- Hydrologic model
    - Elevation data to define subcatchments – LiDAR will be used, see Section 3.3.1
    - Description of the types of land-use and imperviousness – A combination of aerial photos and site visit will be used.
    - Previous studies that model the adjacent catchments' hydrology, see Section 3.1
    - Gauged data of historical rainfall, levels and flows – Fifteen rainfall stations have been used, and stream gauges on Duck River and A'Becketts Creek have been used, see Section 3.3.3
    - Design rainfall data including temporal patterns and rainfall losses – ARR2019 data has been used and accessed via ARR DataHub
- Hydraulic model
    - Elevation data – LiDAR and survey has been used. Survey consists of various sources with the main data being the RPS survey previously described, and also described in the following section.
    - Bathymetry data – Surveyed cross-sections and bathymetry of A'Becketts Creek, Duck Creek and Duck River has been used, see Section 3.3.5

- Pit and pipe data – Data has been provided by Council in GIS format and survey and site visit will be used to supplement gaps in the data, see Section 3.3.7. Pit and pipe data was also available via the Metro West TUFLOW model.
- Building outlines – Aerial photographs and site inspection has been used to digitise building outlines.
- Channel crossings (bridges and culverts) – surveyed cross-sections have been used, see Section 3.3.6
- Design flood behaviour in adjacent catchments that affect A'Becketts Creek – previous studies have been used, see Section 3.1
- Flood marks or similar data describing historical floods – see Section 3.3.4
- Recent developments in the catchment, see Section 3.3.8

The following sections present each of the relevant data sources in detail including their coverage and accuracy.

3.3.1 LiDAR Data

Ground elevation data is one of the primary datasets used in both the hydrologic and hydraulic models. LiDAR (Light Detection and Ranging) data will be used to describe the topography of the catchment and will be supplemented by survey in areas where LiDAR is not accurate.

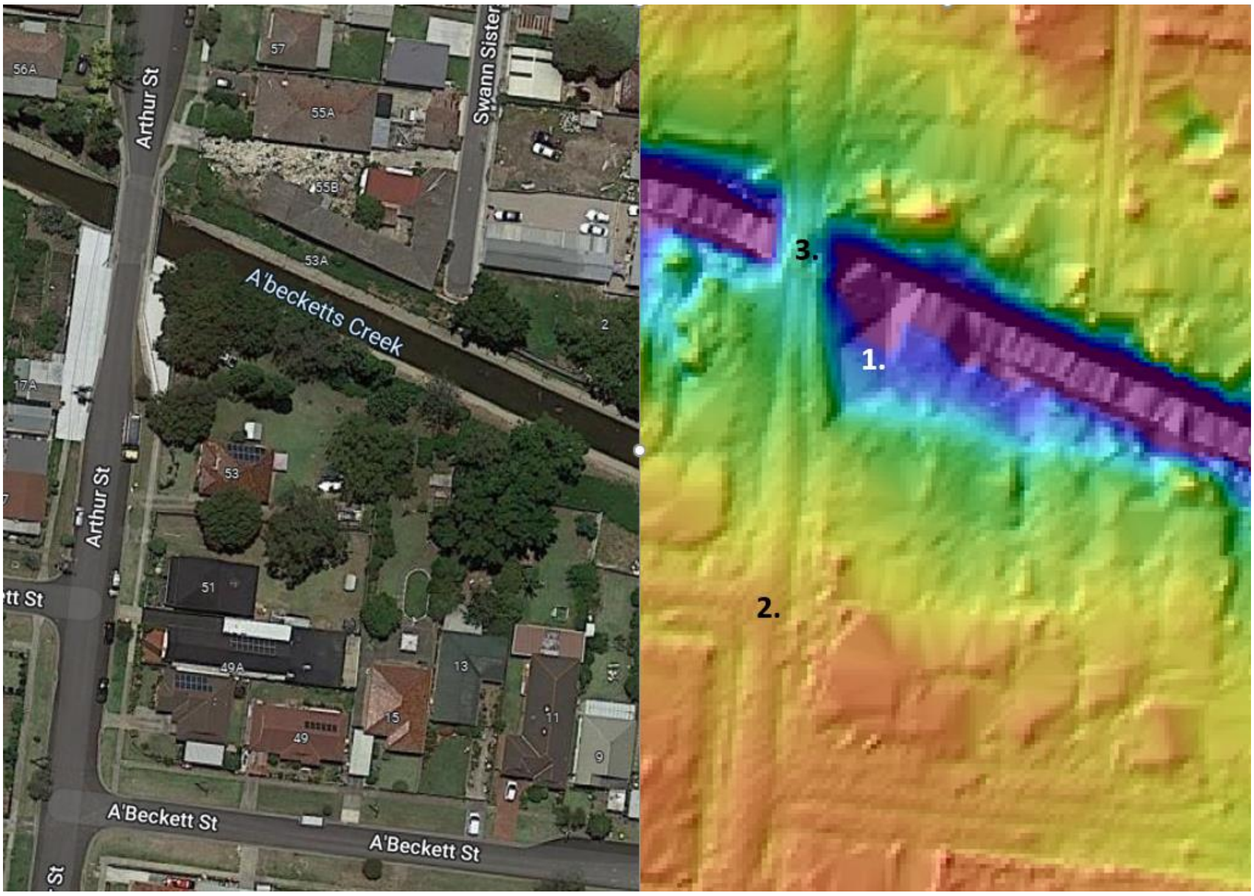
The following LiDAR datasets are available via the ELVIS website (https://elevation.fsdf.org.au/):

- "Sydney" 1 m resolution data, dated 11th -24th April 2013
- "Sydney" 1 m resolution data, 29th June-10th July 2019

Metadata for both datasets report a vertical accuracy of 0.3 m (95% Confidence Interval) and a horizontal accuracy 0.8 m (95% Confidence Interval). After a series of quality checks, the 2019 data has been used as it is more recent data. The LiDAR data is shown on Figure 3. The quality checks indicated:

- Comparison to surveyed levels was taken at twenty points. The average difference between surveyed points and LiDAR was 0.01 m with most points within 0.1 m difference. This indicates the LiDAR is accurate and can be used in comparison with the survey.
- As is typical, the LiDAR does not capture areas obscured by the M4 motorway, and does not capture the channel bathymetry in submerged areas. Examples are provided in Sketch 3 of poor channel bank representation due to high vegetation (point 1), good quality road definition including the road crest and gutters (point 2) and a bridge blocking the model (point 3).

Survey was used to correct the former and latter in areas of poor LiDAR representation. The primary survey used is the previously described RPS survey. The survey defines the majority of the A'Becketts Creek channel in the study area, as well as downstream areas, as well as overbank areas along each watercourse. The survey was used to produce a 3D surface of ground and bathymetry elevations, similar to a LiDAR DEM, which was read directly into the TUFLOW hydraulic model. This ensures accurate representation where trees, bridges, and the M4 significantly obscure the topography, in the LiDAR.



Sketch 3 LiDAR sample area

3.3.2 Site Visit

Site visit was undertaken in June 2022 and December 2022 by the project team. The site visit walked the length of A'Becketts Creek as well as areas with potential overland flowpaths. The purpose of the site visit was to familiarise with the catchment and the range of land-uses, document the state of the creek channel, check visible stormwater drainage and measure invert depths where possible.

Beyond familiarising with the catchment as a whole, the site visit noted (refer to Sketch 4):

- The upper section of A'Becketts Creek, outside the Parramatta LGA, was a shallow creek bed with medium to light vegetation and various debris including litter and other waste (example in photo 1). Around Walpole Street the channel has manmade features before becoming a fully concrete channel adjacent to Holroyd Sportsground (photo 2)
- The concrete channel then continues for the length of the creek, except for potentially the final section near Duck Creek which was not accessed, and some middle sections (it was unclear due to sediment and vegetation). Significant portions have sediment build-up and vegetation (photo 3). Large debris including logs, trolleys and similar sized waste was observed (photo 4). Stormwater pipes servicing the adjacent residential areas are visible where they discharge into the creek channel.
- The large middle section where the creek runs below the M4 had a more incised channel (photo 5). Although large areas were present below the motorway that could convey flow

or act as flood storage (photo 6), there were also low-lying residential areas on either side of the creek.

- Large areas of vacant land were present in the lower section of the creek (photo 7).
- Areas surrounding the creek in the Parramatta LGA were generally flat (photo 8) to moderately sloped, with greater grade sloping away from the creek on the north, Harris Park side.
- Areas adjacent to the creek around Arthur Street, Alfred Street and Good Street show residential properties where the backyard is directly adjacent to the creek and where flooding would occur when channel capacity is exceeded.
- Bridges spanning the creek in the study area were observed that may have a blockage effect due to the bridge deck and/or columns.

Sketch 4 Site Visit Photos

3.3.3 Hydrologic Data

Hydrologic data consists of timeseries data from stream and rainfall gauges, and data describing design rainfall events including Intensity-Frequency-Duration (IFD) data, rainfall losses and temporal patterns.

Stream and rainfall gauge data was requested from Sydney Water, Bureau of Meteorology (BOM) and Council for the catchment and surrounding areas. The location of the gauge data used in the study is shown in Figure 6. A summary of the data is presented in Table 3 and Table 4.

Table 3: Rainfall stations used in the study

Station Number	Station Name	Source	Resolution
066137	Sydney Olympic Park AWS	BOM	1 minute
066212	Bankstown Airport AWS	BOM	1 minute
566059	Auburn (Rosnay Golf Club)	BOM	Point Data
566060	Guildford (Woodville Golf Club)	BOM	Point Data
566036	Potts Hill Reservoir	Syd Water	Point Data
566037	Ryde Pumping Station	Syd Water	Point Data
566049	Liverpool STP	Syd Water	Point Data
566082	Auburn RSL Bowling Club	Syd Water	Point Data
566081	Carling Bowling Club	Syd Water	Point Data
566169	Chester Hill Bowling Club	Syd Water	Point Data
567079	Guildford (Pipehead)	Syd Water	Point Data
567083	Prospect Reservoir	Syd Water	Point Data
10	Valentine Avenue Parramatta	Council	5 minute
30	Redbank Road	Council	5 minute
17	Subiaco Creek	Council	5 minute

Table 4: Stream gauge data used in the study

Station Number	Station Name	Source	Type
213209	Duck River @ Mackay Road	Sydney Water	Water Level
37	A'Becketts Creek*	Council	Water Level

*The gauge location is on the upstream side of Arthur Street Bridge

IFD data for ARR2019 and ARR87 was downloaded from the BOM website. Rainfall losses and temporal patterns were downloaded from the Datahub website.

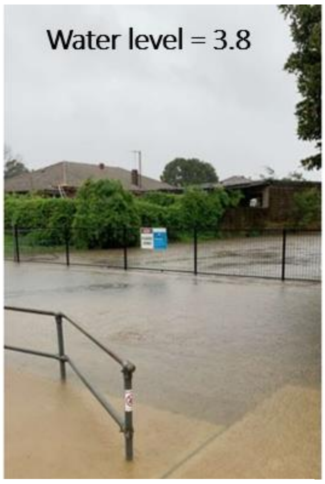
3.3.4 Historic Flood Information and Flood Survey

This data consists of photos, videos, measurements and written descriptions of historical flood events, alongside gauged data (see previous section). Data typically includes photos or videos taken during a flood, surveyed depths or levels at a particular location, or a flood extent map based on observations of the event. Data may also include the rate of rise and duration of flooding. Data for four of the events has been used for model calibration and validation (see Section 5.5).

The following data has been provided by Council:

- Six photos of flooding at or near Louis Street, Granville on Duck Creek around 1.9 km upstream of the A'Becketts Creek confluence. Time and date to be determined.
- Six photos of flooding or flood marks in Rosehill, time, date and exact location to be determined but possibly 6 October 2018 and 28 November 2018.
- Sydney Water spreadsheet recording flood depths and levels at specific addresses, with 122 instances recorded between 1972 and 2016, with 10 separate flood events, and over half (68 out of 122) from 6 August 1986 flood event.
- 13 photos from a flood on 22 February 2022, including flood marks at specific addresses (see Sketch 5 below)
- 89 photos of flooding on 7 March 2022 in the Parramatta LGA, including 61 recorded as being from A'Becketts Creek. A spreadsheet is included which details the location and time of each photo.

Further calibration data was received as part of the community consultation process and consists of photos of flooding in the vicinity of Arthur Street bridge and A'Becketts Street for the February 2020, March 2021 and February 2022 flood events. The photos and flood levels are shown on Sketch 5 below. Each photo shows the estimated flood level, based on comparing on observed flooding to bridge survey and LiDAR levels. In addition, the water level warning gauge installed by Council at the Arthur Street bridge recorded the July 2022 flood event and was used for calibration. This data is presented in Section 5.5.1.4.



Photos taken 9/2/20 at Arthur Street Bridge

Photo taken 20/03/21 at Arthur Street Bridge

Photo taken 22/02/22 near Arthur St Bridge

Photos taken 22/02/22 at A'Beckett Street

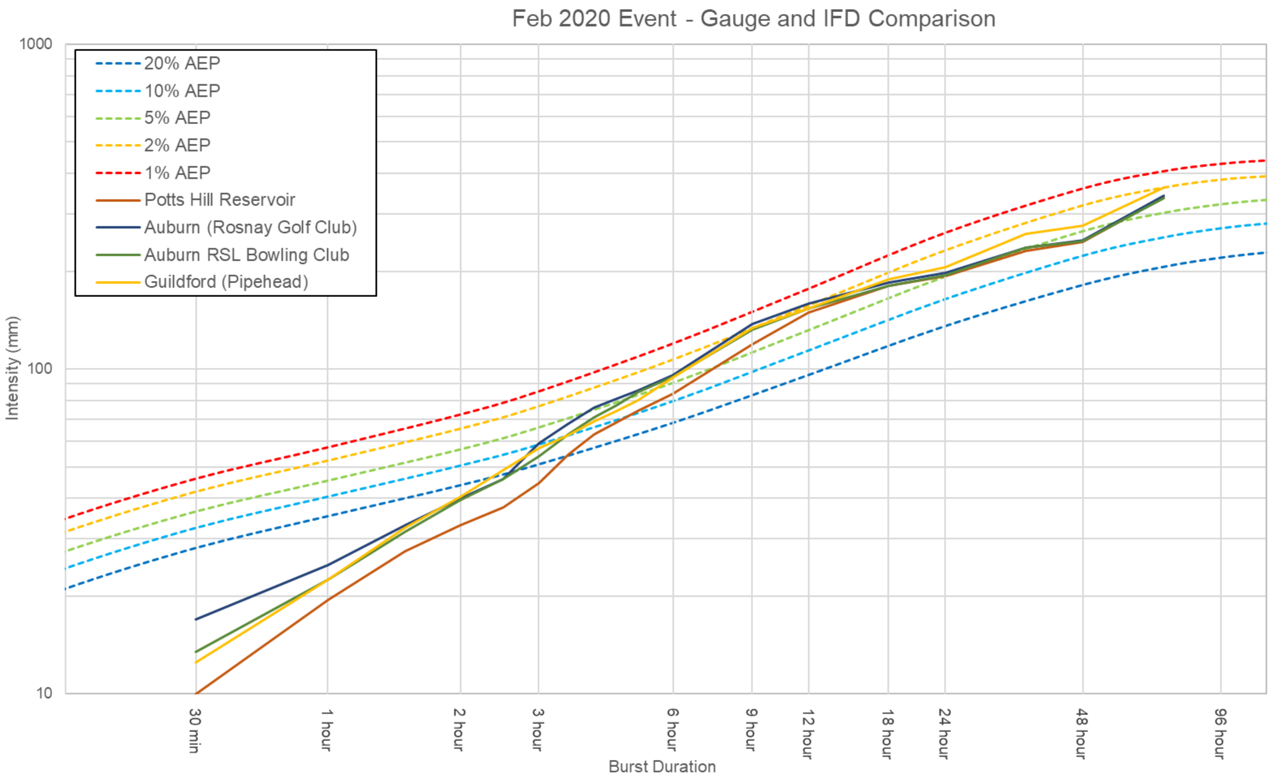
Sketch 5 Overview of flood photos used for calibration, taken by SES and residents

The estimated AEP of each of the three events shown in Sketch 6, as well as for a July 2022 flood event, have been estimated by comparing rainfall gauge data to the IFD data for the Duck River gauge centroid. These four events are used in model calibration. An overview is presented in Table 5 while the IFD comparison is shown in Sketch 6 to Sketch 9.

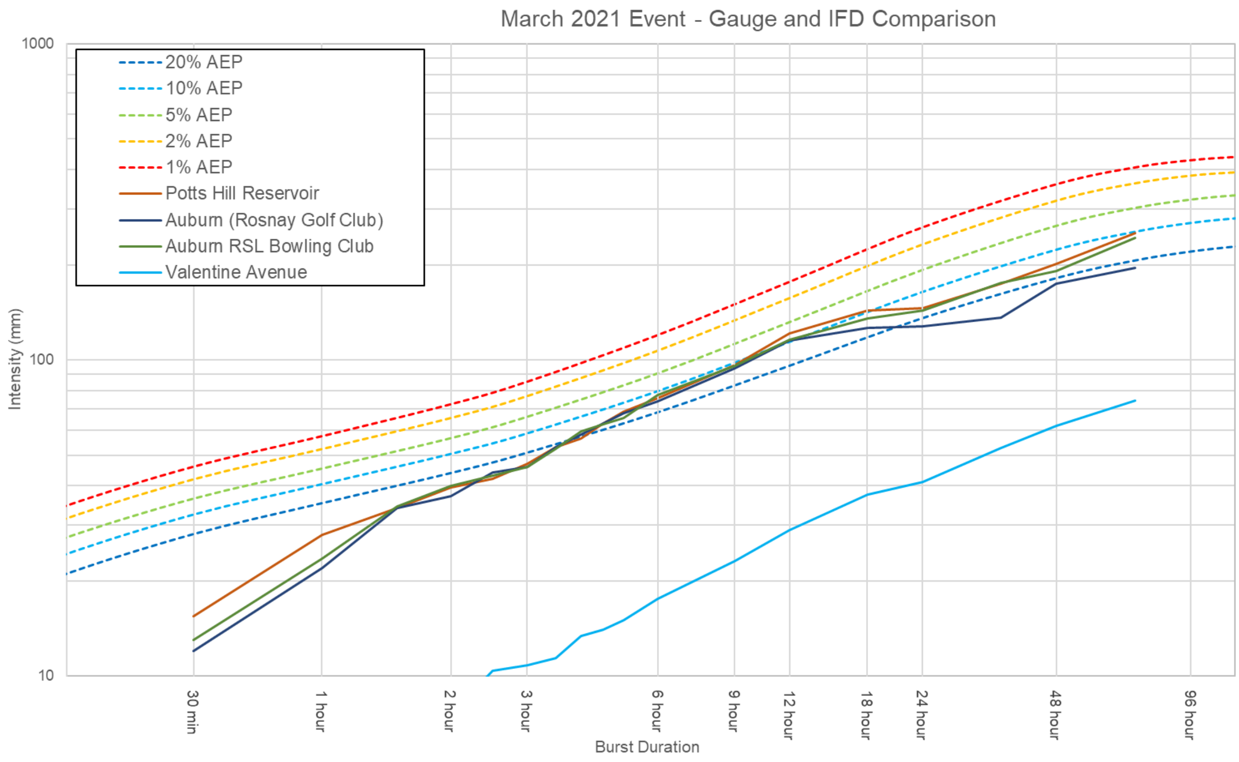
Table 5: Summary of Calibration Event Rainfall AEP

Start Date	Rarest AEP	AEP of 3 hour burst
6 February 2020	2-1% AEP (9 hours)	20-10% AEP
16 March 2021	10-5% AEP (12 hours)	More common than 20% AEP
22 February 2022	10% AEP (4.5-6 hours)	20-10% AEP
1 July 2022	20-10% AEP (72 hours)	More common than 20% AEP

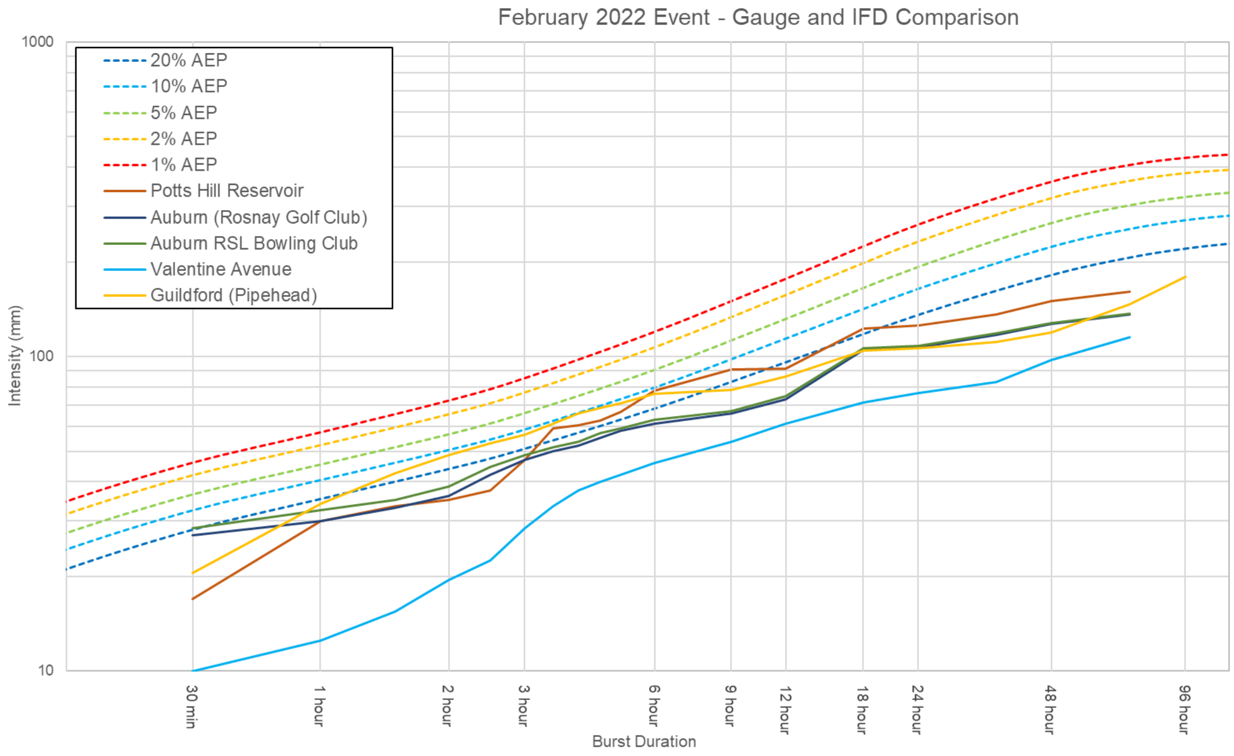
In summary the wet period from 2020-2022 across Sydney and NSW included several significant rainfall events in the catchment, however, in most cases the AEP was rarer for long durations than for shorter durations of around 3-6 hours that would be expected to cause the worst flooding in the study area.



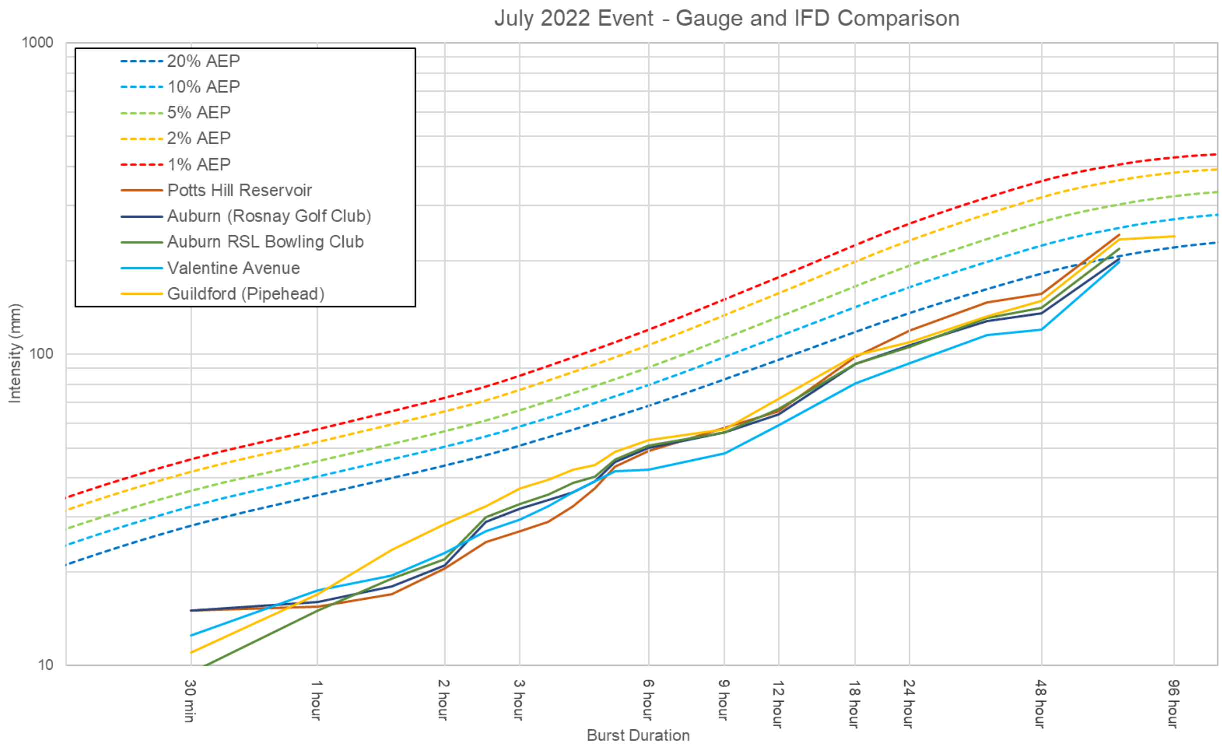
Sketch 6 February 2020 Event - Gauge and IFD Comparison



Sketch 7 March 2021 Event - Gauge and IFD Comparison



Sketch 8 February 2022 Event - Gauge and IFD Comparison



Sketch 9 July 2022 Event - Gauge and IFD Comparison

3.3.5 Bathymetric Data and Cross-sections

Bathymetric data refers to elevation data for submerged areas such as creeks, river and lakes. This data is required to define the dimensions of A'Becketts Creek as well as Duck Creek and Duck River, as it is not well-captured in LiDAR data. As the main conduit for runoff, the dimensions and alignment of the creek channel must be accurately represented in the hydraulic model. For this study, surveyed cross-sections of the creek and river channels have been used to generate a bathymetry grid, which interpolates between cross-sections to define a grid of elevation data, which can also include LiDAR data.

The available sources of bathymetric data are shown on Figure 4. These are:

- Cross-sections taken in 1987 of A'Becketts Creek used by the 1990 and 2009 A'Becketts Creek studies, with the latter extending the cross-sections using LiDAR data. As shown on Figure 4 there are 35 cross-sections, taken from the 2009 study. It's likely further sections were made upstream of this section and used in the 1990 study, but this data is not available.
- Cross-sections of Duck Creek used in the 2012 Duck Creek and Duck River study. As shown on the figure, these extend up to the confluence with A'Becketts Creek.
- Cross-sections of Duck River used in the same 2012 study.
- Cross-sections primarily of Duck River used in the 2009 Lower Parramatta River study.
- Bathymetry data for Duck River and Parramatta River with the file name "LLS Lower Parra Duck Bathy mAHD.dem". Email correspondence forwarded by Council indicates this was generated using Local Land Services depth soundings in 2012 and 2013, from Marsden Street Weir to Ryde Bridge. The data extends up Duck Creek to the confluence with A'Becketts Creek, and around 500 m up Duck River upstream of the confluence with Duck Creek.

- Bathymetry data for the Lower Parramatta River, including Duck River, with the file name "Duck River Camellia_Clip.asc". Email correspondence forward by Council indicates this grid is extracted from the 2012 Duck River Floodplain Risk Management Study, and is noted in the correspondence as being suitable for use but the LLS data is of higher resolution and therefore preferred.
- Sydney Metro West data includes a large detailed survey of the area shown on Figure 4, provided as a TIN of ground elevation points in .dwg format. The TIN has a level of detail along the watercourses including A'Becketts Creek and the confluence area. As shown on the figure, it extends to Church Street/Woodville Road. A combination of LiDAR and site visit measurements has been used to define the channel upstream of this location.

3.3.6 Channel Crossings

Channel crossings are roads and other structures that cross the creeks and rivers that affect flood behaviour. Most crossings consist of a road bridge with culverts beneath the road. The channel crossings in the hydraulic model area are:

- A'Becketts Creek starting from upstream end
    - Pedestrian bridge approximately 80 m west of Parramatta Road/Woodville Road intersection
    - M4 ramp at same location, immediately downstream
    - Church Street bridge
    - Railway crossing near the north end of Duke Street
    - Pedestrian bridge at the same location
    - Pedestrian bridge at Harris Street
    - Good Street bridge
    - Alfred Street bridge
    - Arthur Street bridge
    - Motorway bridge joining M4 and James Ruse Drive, near east end of A'Beckett Street
    - Rail bridge approximately 50 m downstream (old Carlingford line)
    - Fleet Street bridge, immediately downstream of the rail bridge
    - Unwin Street bridge
- Duck Creek starting from upstream end
    - William Street bridge/culverts
    - Memorial Drive bridge
    - Train line immediately downstream of Memorial Drive
    - Bridge at end of East Street
    - Parramatta Road bridge
    - Rail bridge near Arthur Street
    - Driveway bridge near George Street
    - James Ruse Drive bridge
    - M4 (multiple elevated roadways)
    - Kay Street bridge

- Duck River starting from upstream end

- Rail bridge near Clyde Station
    - Unnamed road bridge immediately downstream
    - Parramatta Road bridge
    - Pedestrian bridge just upstream of M4
    - M4

Each of these 28 crossings is represented in the hydraulic model, except for very elevated structures such as parts of the M4 that are well above the PMF flood level. Data describing the crossings is available from a variety of sources:

- The 2009 A'Becketts model data includes assumed soffit and deck levels for 11 crossings in its model area but notes they are not based on survey, but rather the values were taken from the 1987 study and then checked against LiDAR data. It notes the rail bridge near Duke Street, the M4 above A'Becketts Creek and James Ruse Drive are well above the PMF and therefore were not modelled.
- Crossings on Duck Creek and Duck River were modelled in the 2012 Duck River and Duck Creek study, which itself took structure dimensions from the 2003 and 2006 studies as well as site visit.
- Sydney Metro West survey includes the structures within the orange polygon on Figure 4, which covers the confluence area and all but two of the crossings on the section of A'Becketts Creek to be modelled.

3.3.7 Pit and Pipe Data

Stormwater infrastructure in the study area consists of a pit and pipe network that channels runoff from the kerb and gutter system on each road, to the main watercourses. GIS data describing the pit and pipe network has been provided by Parramatta City Council and is shown on Figure 5. The GIS layers have the following attributes:

- Pit type information (kerb, junction, sag) for about half the pits.
- Inlet information (cover, cover size) for about half the pits
- Lintel length and/or grate sizes for a small number of pits
- Pipe widths and heights for most of the pipes
- Pipe material type for most of the pipes
- Invert information is not available for most pits and pipes

To supplement the data gaps in the GIS data, several "drainage sheets" were used. These are scanned maps showing the pit and pipe network with inverts and some information labelled, in some areas. It is noted the maps have a disclaimer that the data should be confirmed by site investigation. Figure 5 shows an estimate of the invert coverage, as a percentage, in a series of sub-areas across the study area. The sub-areas of particular interest are those draining to A'Becketts Creek. Around half of these areas have no invert data, and the other half have around 10-50% coverage. The figure shows the location of pits and pipes surveyed by the Sydney Metro West project, which will supplement gaps in Council's data. The remaining inverts have been estimated using a combination of site visit to measure pit depths, and interpolation between existing data, where suitable. In one location, the Woodville Road rail underpass between Wallace Street and Crescent Street, there is some drainage observed during site visit but no available data across the data sources, but given the drainage would likely have negligible effect on flooding in the sag point, its omission is acceptable.

3.3.8 Development in the Catchment

Recent and ongoing development in the catchment is required to be manually inserted in the hydraulic model where LiDAR and other datasets pre-date the development. The study area is heavily urbanised and is largely unchanged in the last two decades. The following changes were noted in review of aerial photos and site visit, and were specifically included in the model were appropriate:

- New high-rise buildings immediately north of Granville Station. These are in the model domain but are in the Duck Creek catchment.
- Widening of the M4 viaduct above A'Becketts Creek. This was completed around 2017 and the viaduct columns are included in the hydraulic model.
- Removal of the building at 1-3 Onslow Street Granville, close to the Duck Creek channel. This appears to have been done around 2019-2020 and has been included in the hydraulic model.

The Sydney Metro West project is ongoing at the time of writing with concept reporting showing significant works will be carried out in the study area. Plans of the proposed works were requested in April 2022 but were not able to be provided at the time of writing.

3.3.9 Future Recommended Flood Model Improvements

As described in the previous report sections, there is detailed data available for the catchment for use in flood modelling. All major catchment features have been captured in the various datasets. Future modelling of the catchment will therefore be focussed on incorporating the latest available data and filling in various gaps where data has been estimated. Recommended improvements include use of:

- Extended records of hydrologic data for use in model calibration, specifically future flood events on Duck River, Duck Creek and A'Becketts Creek captured at the various stream and rainfall gauges.
- New survey of the creek channel and overbank areas, if significant time has passed and the creek bathymetry has changed relative to survey used in the current study. Similarly, use of future LiDAR for the catchment.
- Survey of pit and pipe network in the A'Becketts Creek catchment for areas where estimates have been used in the current study.

4. COMMUNITY CONSULTATION

4.1 Newsletter and Questionnaire

A newsletter and questionnaire were made available to residents of the catchment in August and September 2022. The purpose of the consultation was to inform residents and businesses of the purpose and function of the study, and to request information on flood events and residents' experiences regarding flooding. The questionnaire questions are shown in Appendix B. Notification was made to residents via a mailout and the questionnaire was set up online by Council. Council has maintained an online portal for survey and for advising residents on the purpose and progress of the study.

A total of 40 responses were received from the questionnaire. 38 responses filled out the online questionnaire and a further two people used the mapping tool, and some responses used both. The responses provided useful information, particularly in regard to previous flooding. A summary of a selection of the responses is shown in Figure 7 while Figure 8 maps the location of the responses. The results of the 38 responses to the questionnaire gave the following:

- 55% have experienced flooding and most (76%) only reported on a single flood event
- Around a quarter of responses have been at the address for three years or less, while around a third have been there more than 10 years
- Residents reported a range of observed flooding depths. A third saw a few centimetres, and 29% saw over 1 m, likely along Duck Creek or A'Becketts Creek.
- Similarly, while many (38%) reported flooding only lasting several hours, around half reported flooding of more than one day. Duration of more than one day is very likely describing the lower area where Duck River flows cause a backwater effect on A'Becketts Creek and flood durations are longer than from just A'Becketts Creek flow, alone.
- 14 responded that A'Becketts Creek was the source of flooding, while 13 noted flow came from either overflowing street drainage or adjacent properties, roads and open areas. This indicates a mix of overland flow and mainstream flooding has been observed.
- A significant number (10) had their home flooded, while other common flooding locations were garages, gardens and roads.

Figure 8 showing the location of responses shows some of the same trends outlined above, including:

- Nearly all responses that identified the source of flooding as A'Becketts Creek were located in the lower catchment where the creek is no longer under the M4 motorway. This indicated the section under the motorway, and upstream of there, may experience less mainstream flooding issues.
- There is a collection of 7 responses in the lower catchment, generally near Arthur Street Bridge and the downstream area, that all reported flooding, with the three of the seven at lower elevations also reporting house flooding. This area is considered a flooding hotspot on this basis and will be assessed in greater detail as part of the Floodplain Risk Management Study.

- Three responses on Virginia Street some 330 m north of the creek identified A'Becketts Creek as the source of house flooding, to a depth of a few centimetres. They may have been referring to having seen creek flooding separate to the house flooding, as no evidence supports the possibility the creek reached Virginia Street.
- All responses that noted road flooding are located in the lower catchment where two relatively low bridge crossings, and some adjacent roads, were shown to be flood-affected in photos sent in.

Residents uploaded a range of photos of flooding as part of the questionnaire. A selection of the photos has been used in model calibration and validation (see the following section). Residents noted the following flood events in their responses:

- 1980s (response states it was during construction of the M4 when there was waste in the channel)
- May 1992
- 2015
- February, March 2020
- March 2021
- January, February, March, June and July 2022
- One resident reported flooding of Arthur Street bridge an estimated 10 times since 1998, another reported six times in 50 years but more frequently in recent times

Overall, the questionnaire provides valuable information on the location, severity and frequency of flooding. Responses indicate there is a significant flooding issue in the catchment, particularly in the lower section of the creek. Reported hazards include significant house and property flooding, and access road flooding.

5. FLOOD MODELLING

5.1 Approach

Flood modelling of the catchment has been carried in accordance with the study's technical brief. The approach has been to use the existing Parramatta River catchment WBNM model (see Section 3.1.8), which includes the catchments of Duck River, Parramatta River, Duck Creek and A'Becketts Creek. The model has been updated slightly to provide greater detail in the area of interest (see following section). The WBNM then provides inflow hydrographs to a TUFLOW hydraulic model, covering the study area. The TUFLOW model area is characterised by a series of large drainage structures along A'Becketts Creek, including bridges, channels and culverts, along with similar structures in the confluence area with Duck Creek and Duck River. These structures were recently surveyed and schematised in the Metro West TUFLOW model (see Section 3.2.2) and so the relevant parts of that model were utilised for the current study's TUFLOW model.

Both the Parramatta River WBNM model and the Metro West TUFLOW have been calibrated to a number of historical flood events and reporting indicates they are robust and well-calibrated models. The current study utilises this good calibration and has run a further four historical events to undertake a joint calibration exercise. Results showed that both models performed well with no adjustment to model parameters or catchment schematisation, and so in effect the four events are considered to be closer to model validation events, where events are run without changing model parameters in order to confirm or validate the model accuracy.

Completely separately to the hydrologic and hydraulic models described above, a TUFLOW rainfall-on-grid (ROG) model was setup. The ROG model covers the Duck River, Duck Creek and A'Becketts Creek catchments and is only used for comparison of flows, and for confirming all overland flowpaths have been captured in the study area. The ROG model is described in Section 5.4.

5.2 Hydrologic Model

WBNM (Watershed Bounded Network Model) is a hydrologic model commonly used in NSW for flood estimation. The model represents the catchment as a series of linked subcatchment areas and replicates the conversion of rainfall to runoff, and runoff flowing to downstream subcatchments. The physical properties of each subcatchment that are represented in the model are the area, the imperviousness and the stream length. Model parameters can then be adjusted to achieve model fit against historical data, including the model lag parameter, the rainfall losses, or the estimation of impervious area.

The recently setup Parramatta River WBNM model (see Section 3.1.8) has been used for the current study and updated in the area of interest. The following updates were made to the model:

- Finer subcatchment resolution in the area of interest. The previous model used a series of large subcatchments for A'Becketts Creek and Duck Creek. The current study has replaced these with smaller subcatchments in order to represent additional inflow locations along the creeks, and also to model overland flow.
- All subcatchments in the Duck River catchment (including Duck Creek and A'Becketts Creek) have updated imperviousness, based on imperviousness values of:
    - Roads: 70% imperviousness
    - Residential: 65%
    - Industrial: 90%
    - Parks and recreation: 0%

  This has generally increased the impervious percentage for each subcatchment from the existing model, which appeared to use a value of around 45% for residential area, and was considered low for residential areas in the catchment.
- The WMAwater conversion report identified subcatchments where the imperviousness in the previous model (RAFTS) appeared either too low or too high. These subcatchments were reviewed and updated where it was agreed the imperviousness should be slightly revised (total of 13 subcatchments adjusted).
- Ten subcatchments' areas were updated as the actual area was different to the modelled area, with more than 10% difference.
- No changes were made to the various basin features in the WBNM model

Overall, the WBNM updates consisted of two significant revisions: the subcatchments' imperviousness and the addition of much smaller subcatchments in the A'Becketts catchment, and then minor adjustments were made to a handful of subcatchment parameters. The updated WBNM model is shown on Figure 9.

5.3 Hydraulic model

Hydraulic models are used to produce flood depths, levels and velocities across the study areas, based on the inflow hydrographs output from the hydrologic models.

A hydraulic model was established for the study area using the TUFLOW software. TUFLOW is a hydrodynamic modelling package that represents the floodplain as a grid of cells and resolves flow behaviour using a finite difference method. The hydraulic models established herein include 1D (one-dimensional) elements such as the pits and pipes network as well as the floodplain and creeks represented in 2D (two-dimensional). Many of the key inputs to the hydraulic model were adopted from the Metro West TUFLOW model as it is based on recent, detailed survey of the area. The model version used is 2020-10-AB-iSP-w64 with HPC solver.

The key inputs to the hydraulic model are:

- Topographic data. Digital elevation model (DEM) in a 2 m x 2 m grid developed using the LiDAR data and RPS survey data (see Section 3.3.1 and 3.3.5) with the latter defining the channel bathymetry. Bathymetry of the Duck Creek channel from the 2012 study (Duck River and Duck Creek Flood Study Review) was also used, and some areas of survey from the Clay Cliff Creek Catchment Master Drainage Plan (2007). Sub-grid Sampling is used to a distance of 0.5 m. Figure 16 shows the model DEM.
- Stormwater drainage. The slope, diameter, roughness and other parameters of subsurface drainage were represented as 1D elements in the hydraulic model. Pit/pipe networks were provided by Council and survey, and estimates were used in some areas of invert levels. Hydraulic roughness of 0.015 was applied to pipes.
- Impermeable obstructions. Buildings and other obstructions have been included in the model to incorporate the hydraulic effects of these structures on flood behaviour. Buildings on Duck River downstream of Duck Creek are represented with high roughness, on the basis the area is a wide, flat floodplain and the majority of buildings will gradually fill with floodwater.
- Bridges. Road, rail or pedestrian crossings of watercourses were explicitly represented in the model build using the TUFLOW layered flow constriction method.
- Hydraulic roughness. The ground type (heavy/light vegetation, concrete, asphalt etc) determines the hydraulic roughness or Mannings 'n' value, which was set for each model grid cell. The brief recommends the use of Parramatta River Flood Study (PRFS) (2023) hydraulic roughness values. The values applied were slightly different on the basis that the PRFS values were applied based on land-use types whereas the Metro West values were based on site visit to each watercourse, and aerial photos, giving slightly greater resolution in how roughness were applied, and because the modelled showed good calibration to these values. Testing of PRFS values, which are lower for creeks and vegetation, produced significantly lower (~0.4 m) lower flood levels in the confluence area, and so were not adopted on this basis. The adopted roughness values are:
  - 0.020 - Roads
  - 0.040 - Railways

  - 0.050 - Residential
  - 0.040 - Commercial
  - 0.025 - Paved areas
  - 0.035 - Park/Grass
  - 0.045 - Medium Density Vegetation
  - 0.090 - Heavy Density Vegetation
  - 0.050 - Creek
  - 0.030 - Unsealed/Unpaved areas
  - 0.05 - Area below the motorway
  - 0.03 - Deep water creeks
  - 0.03 - Fish Passage
  - 0.06 - River Bed Armouring
  - 3.0 - Buildings in lower Duck River area
- Boundary conditions. Model inflows and tailwater conditions were set based on hydrologic model outputs and other available data. The mainstream creek and river inflows were applied as upstream boundary conditions located on each watercourse, near the model boundary and the local inflows were applied to sub-catchment low points. For the 2% AEP and rarer events, the downstream boundary is represented as a water level-time (HT) boundary at the Duck River-Parramatta River confluence. The same boundary location is used with stage-discharge (HQ) relationship for 5% AEP and 20% AEP. The location is shown on Figure 10. The adopted design tailwater levels are based on the Parramatta River Flood Study approach (as recommended by the brief) and are described in Section 6.1. Figure 15 shows the subcatchments and inflow locations.
- Blockage and Areal Reduction Factors were only applied to design events and are set out in Section 6.1. Blockage parameters are also listed in Appendix C.

The hydraulic model layout is shown on Figure 10 and the hydraulic roughness values are shown separately on Figure 11.

5.4 TUFLOW Rainfall on Grid (ROG) Model

A second TUFLOW model was setup using the Rainfall on Grid (ROG) approach. ROG modelling applies rainfall depths directly to each model cell rather than applying inflow hydrographs from WBNM or another hydrologic model. This report uses the following terminology:

- ROG model – TUFLOW model with Rainfall on Grid methodology.
- TUFLOW model –TUFLOW model that applies inflows from WBNM <u>and is used for producing all design flood results presented in this study</u>.

The ROG model is completely separate from the TUFLOW model and generally has a coarser representation of the catchment features. The ROG model is only used for producing flows for comparison to TUFLOW and WBNM, and for confirming the TUFLOW model has captured all overland flowpaths in the study area.

The ROG model was setup using the following schematisation and parameters:

- Cell size: 2 m

- Ground surface: 2019 LiDAR (Penrith201906_1m_combined) combined with the RPS survey of the creek channels and adjacent areas. Z-lines were used to increase the creek and river channel capacity outside the survey area, as LiDAR does not capture the channel bathymetry.
- TUFLOW version 2020-10-AD with single precision and HPC
- Pipe drainage is not included in the model
- Buildings are represented as impermeable obstructions (i.e., coded out of model domain) in the Grid Area boundary, and as high roughness outside the Grid Area
- Bridges and culverts are represented but only along the watercourses in the Grid Area
- Mannings 'n' values of 0.04 across the model domain
- A 50 mm rainfall burst was applied 10 hours before the design storm to fill topographic depressions in the model DEM without affecting peak flow rates. The design rainfall applied is either ARR87 or ARR2019 IFD and temporal pattern, with uniform rainfall applied across the model area based on the average design rainfall applied in WBNM.
- The same design tailwater as the TUFLOW model, which is 1.74 mAHD in the Parramatta River for the 1% AEP event.

The schematisation of the ROG model is shown on Figure 12. The main differences between the schematisation of the ROG model and the TUFLOW model are:

- The TUFLOW model applies an inflow hydrograph at the lowest point in each subcatchment area, whereas the ROG model applies rainfall to every model cell. In some subcatchments this may result in a similar flow hydrograph occurring at the subcatchment outlet, but in areas where buildings obstruct flow, or where there are depressions in the DEM, peak flows will tend to be lower in the ROG model.
- The ROG model does not model the pit and pipe network. In some areas this may result in lower peak flows reaching the watercourses. It will also mean the trapped depressions that have pit and pipe drainage may show greater flood depths.
- WBNM uses a rainfall loss model based on the imperviousness of each subcatchment, whereas TUFLOW does not vary losses depending on the imperviousness.

The results of the ROG model are presented in Section 6.11.

5.5 Model Calibration and Validation

Model calibration and validation has been carried out as part of the study. As described, both the Parramatta River WBNM model and the Metro West TUFLOW have been calibrated to a number of historical flood events and reporting indicates they are robust and well-calibrated models. The current study utilises this good calibration and has run a further four historical events to undertake a joint calibration exercise. The calibration data is presented in Section 3.3.3 and 3.3.4 and, as an overview, consists of:

- Rainfall gauge data to define the rainfall for each event, to be applied to WBNM
- Stream gauge data consisting of water level data for Duck River (three of four events were available) and A'Becketts Creek (one of four events were available). Duck River is converted to flow (see 3.2.2) so it can be compared to the WBNM results (the gauge is located well upstream of the TUFLOW model).

- Flood photos showing flooding and debris marks in A'Becketts Creek catchment, used to compare to TUFLOW results.

5.5.1 Calibration Results

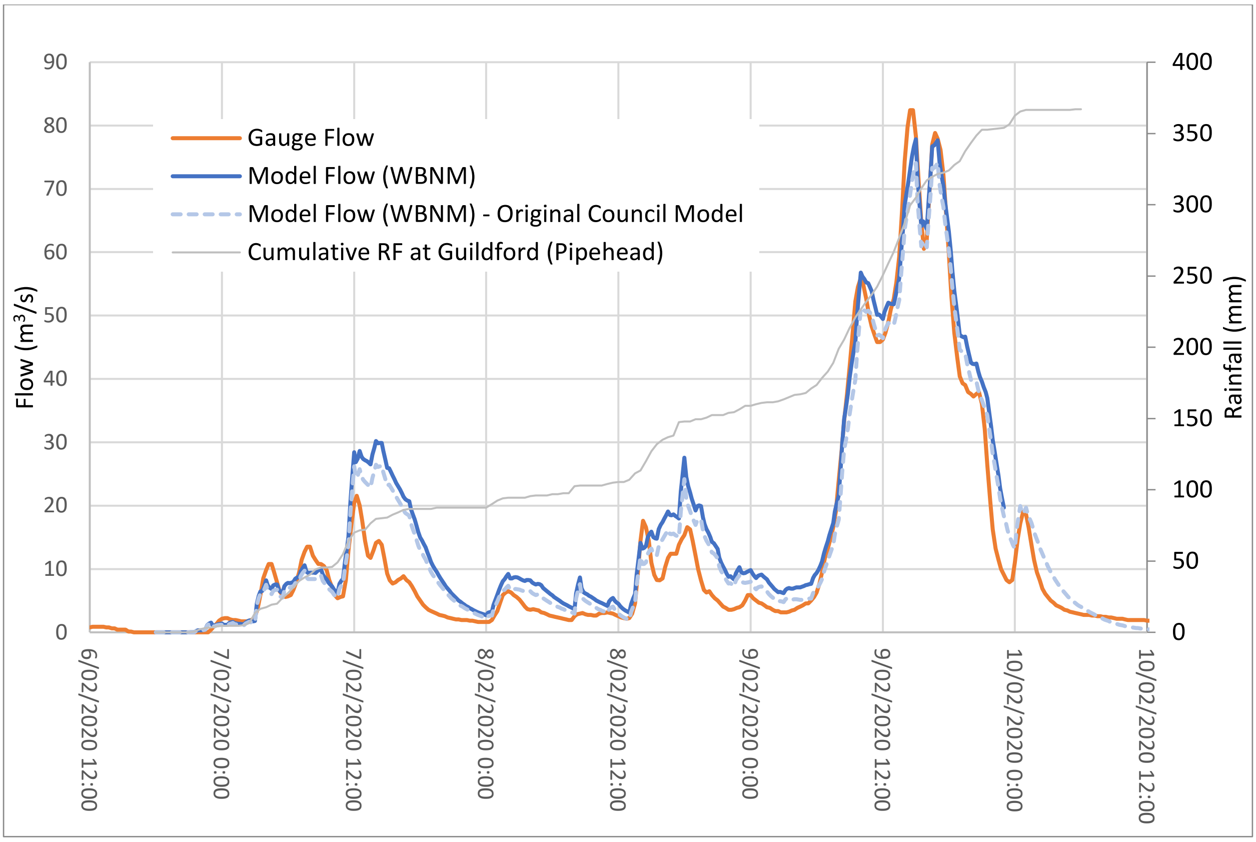
The calibration and validation process produced a very close match between observed and modelled flood levels and flows, allowing the models to be subsequently for design flood event modelling. Little to no adjustment was made to model parameters, indicating the existing WBNM model was already representing catchment behaviour, and that TUFLOW structures were similarly already replicating hydraulic behaviour along each watercourse. For this reason, the process is closer to a validation process, where historical events are used to demonstrate model accuracy, rather than a calibration process, where model parameters are adjusted until accuracy is achieved.

5.5.1.1 February 2020

The event occurred on 9th February 2020 while the modelled period was 6:00pm 6 February to 11:00pm 9 February, as Duck River showed earlier, smaller events on 7th and 8th February. The observed and modelled flow at the Duck River gauge is shown on Sketch 10. A close match was produced by the initial model run that used the assumed rainfall losses and routing parameter. Following Council and peer review, the C parameter in WBNM was kept at 1.29 (a value of 1.16 was trialled but was considered outside the recommended C value range, for marginal improvement in calibration fit) and the continuing loss value was reduced to 0 mm, on the basis that the event (and others) occurring during a wet period (around 400 mm of rainfall fell across in 3-10 February 2020, as shown by the cumulative rainfall total shown below). The Sketch shows the results based on the adjusted model parameters, and shows:

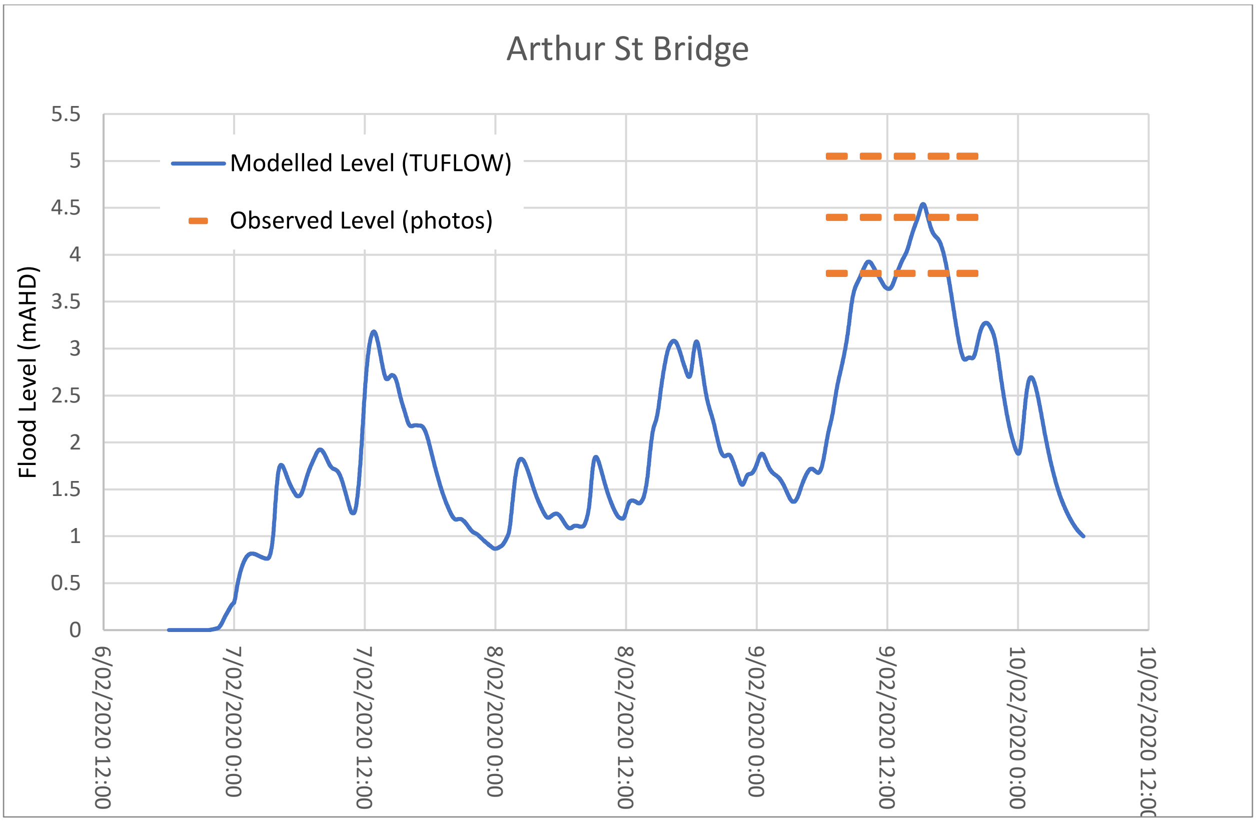
- Very close match in shape of the main flood hydrograph, with regards to rising limb and falling limb and overall volume
- Very close match in peak flows
- Replication of the observed three individual peaks during the event on 9 February.

Overall, the match is very close and indicates the model is accurately converting rainfall to flow. The chart also shows the result from the original model before any parameters were adjusted. As shown, the result is very similar.



Sketch 10 Observed and modelled flow at Duck River stream gauge, Feb-2020 Event

The observed and modelled TUFLOW flood levels on A'Becketts Creek are shown on Sketch 11 Observed and modelled levels at Arthur Street Bridge, Feb-2020 Event. The photos had conflicting timestamps and so each level is represented as a line. The model passes through the first two observed flood levels at the bridge but is 0.4 m lower than the highest observed level. The likely reasons for the higher level not being produced in the model are that the highest rainfall intensities were not captured in the A'Becketts catchment or other gauges, and blockage at the bridge or downstream locations exacerbated flood levels (the calibration runs applied no blockage). Changing the WBNM lag parameter, the catchment imperviousness or the rainfall losses did not significantly change the peak flood level, indicating those model parameters are unlikely to be the source of the discrepancy.



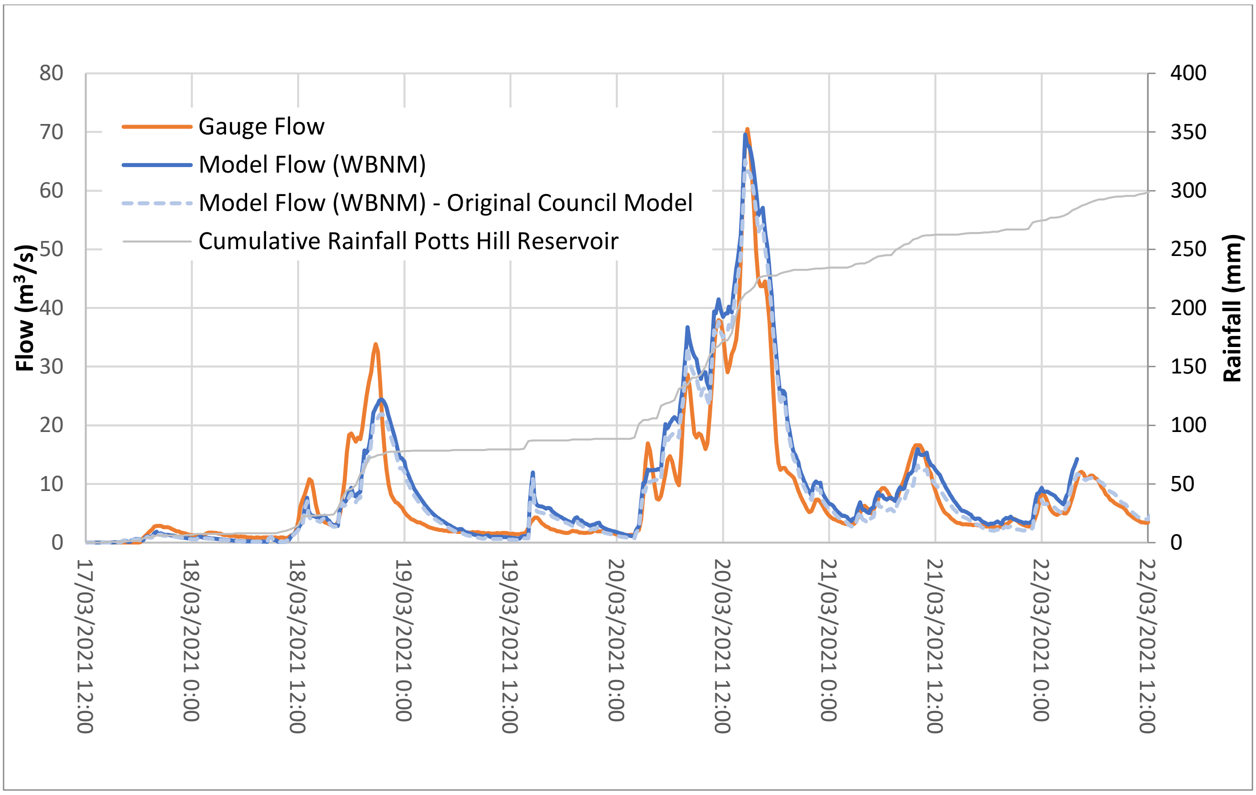
Sketch 11 Observed and modelled levels at Arthur Street Bridge, Feb-2020 Event

5.5.1.2 March 2021

The event occurred on 20th March 2021 while the modelled period was 12:00pm 17th March to 7:30pm 23rd March as Duck River showed earlier and later, smaller events on 18th March and 21st March. The observed and modelled flow at the Duck River gauge is shown on Sketch 12 Observed and modelled flow at Duck River stream gauge, Mar-2021 Event. As with the February 2020 event, the initial model run produced a close fit but was then revised to the lowered C parameter and continuing losses (the 2021 and 2022 events occurred during a wet, La Niña period). The figure shows:

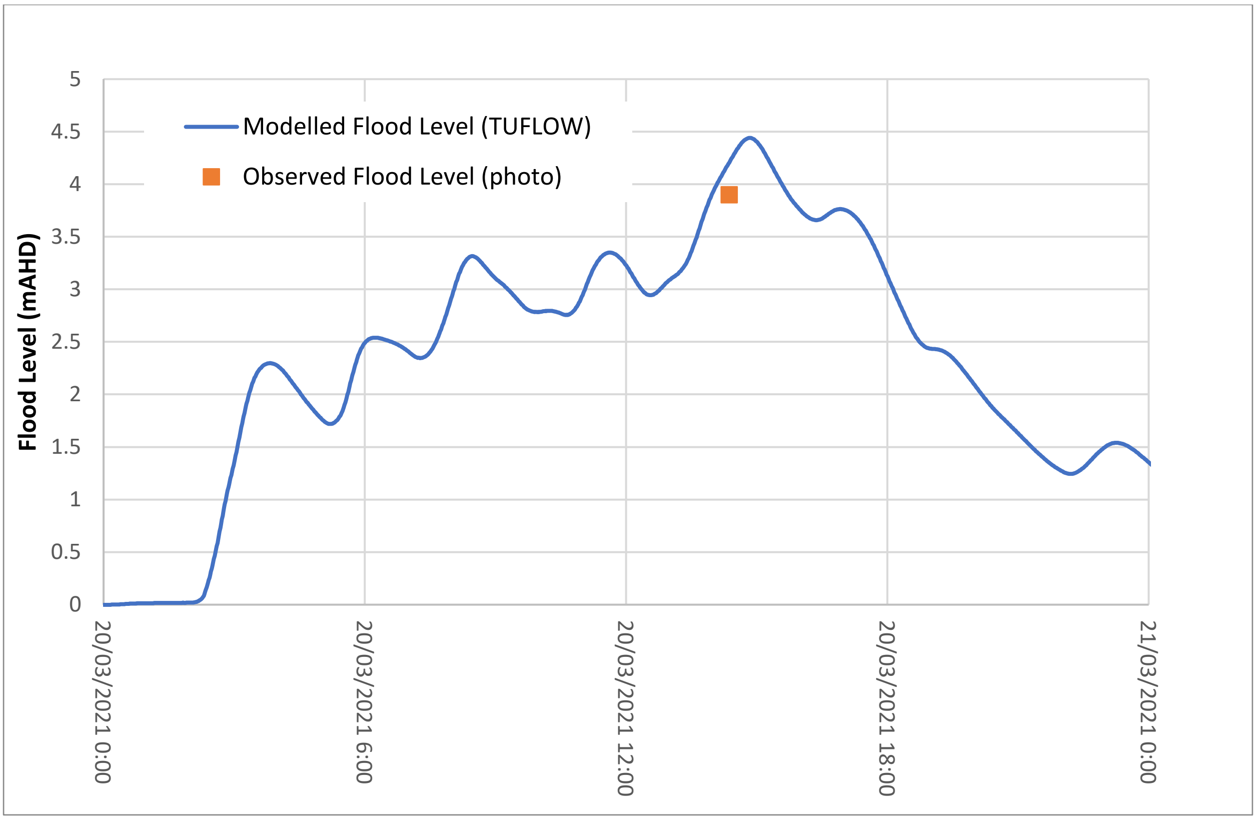
- Very close match in shape of the main flood hydrograph
- Very close match in peak flows
- Replication of relative peaks within the hydrograph

Overall, the match is very close as with the previous event and indicates the model is accurately converting rainfall to flow. As with the 2020 event, the result from the original Council model is also presented and as shown is very close to the adjusted model.



Sketch 12 Observed and modelled flow at Duck River stream gauge, Mar-2021 Event

The observed and modelled flow levels on A'Becketts Creek are shown on Sketch 13 Observed and modelled levels at Arthur Street Bridge, Mar-2021 Event. The photo shows a level of approximately 3.9 mAHD at 2:22pm on 20th March. The figure shows this level is reached approximately 30 minutes earlier in TUFLOW and is therefore considered a generally good fit of the observed behaviour.



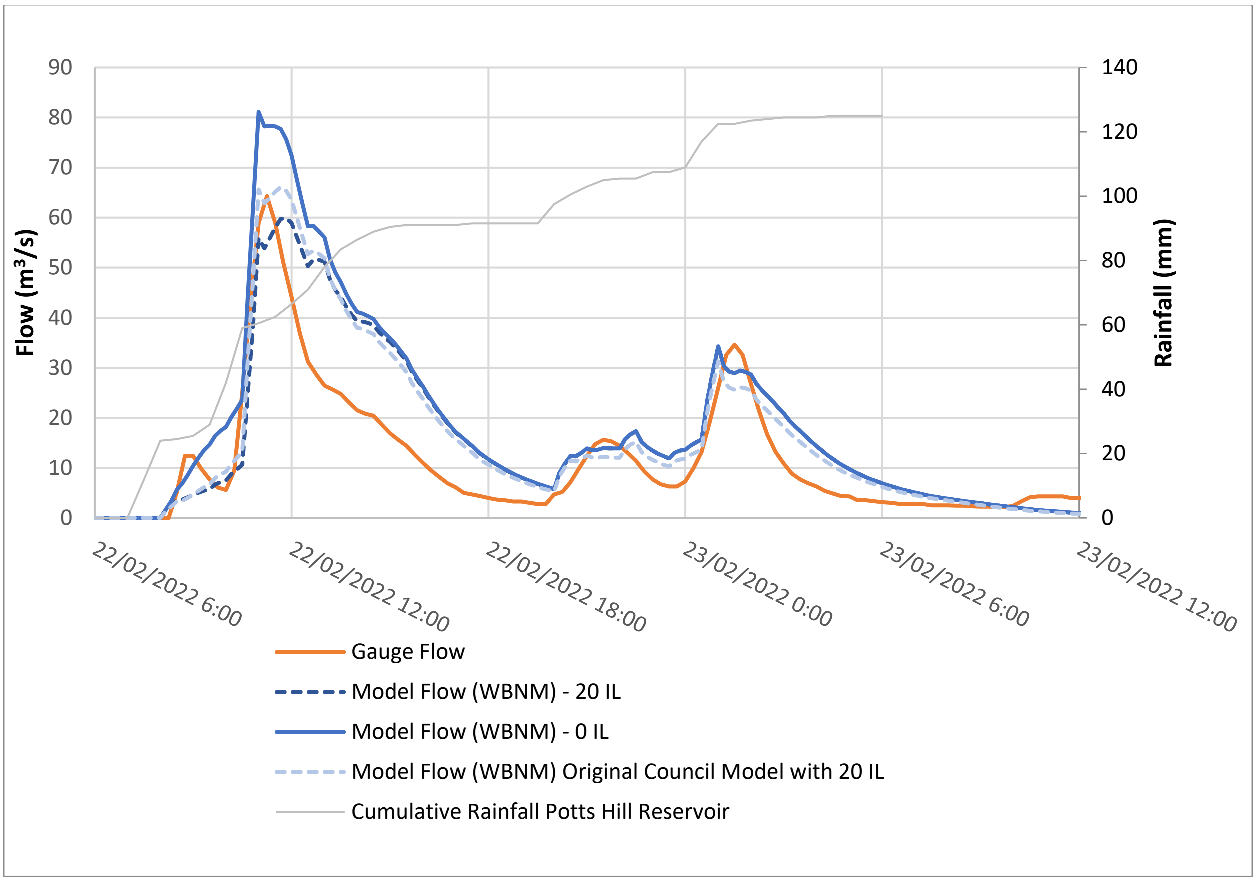
Sketch 13 Observed and modelled levels at Arthur Street Bridge, Mar-2021 Event

5.5.1.3 February 2022

The event occurred on 22nd February 2022 while the modelled period was 6:00am 22nd February to 12:00pm 23rd February as Duck River showed a second, smaller event. The observed and modelled flow at the Duck River gauge is shown on Sketch 14 Observed and modelled flow at Duck River stream gauge, Feb-2022 Event. As with the February 2020 event, the initial model run produced a close fit but was then revised to use lower continuing losses (the 2021 and 2022 events occurred during a wet, La Niña period). Similarly to 2020, a lower C value of 1.16 was trialled but was outside the recommended value range and gave marginal benefit. The event was shown to be quite sensitive to the Initial Loss (IL) value used, with both 0 mm and 20 mm IL shown below. The figure shows:

- For both results, very close match in rising limb of main hydrograph, falling limb shape is matched but volume of flow is significantly greater in WBNM than observed.
- Very close match in peak flow for 20 IL, while 0 IL is around 15 m^3/s higher than observed.
- For both results, very close match in rising limb and peak flow of second event on 23/02, and decent fit of falling limb.

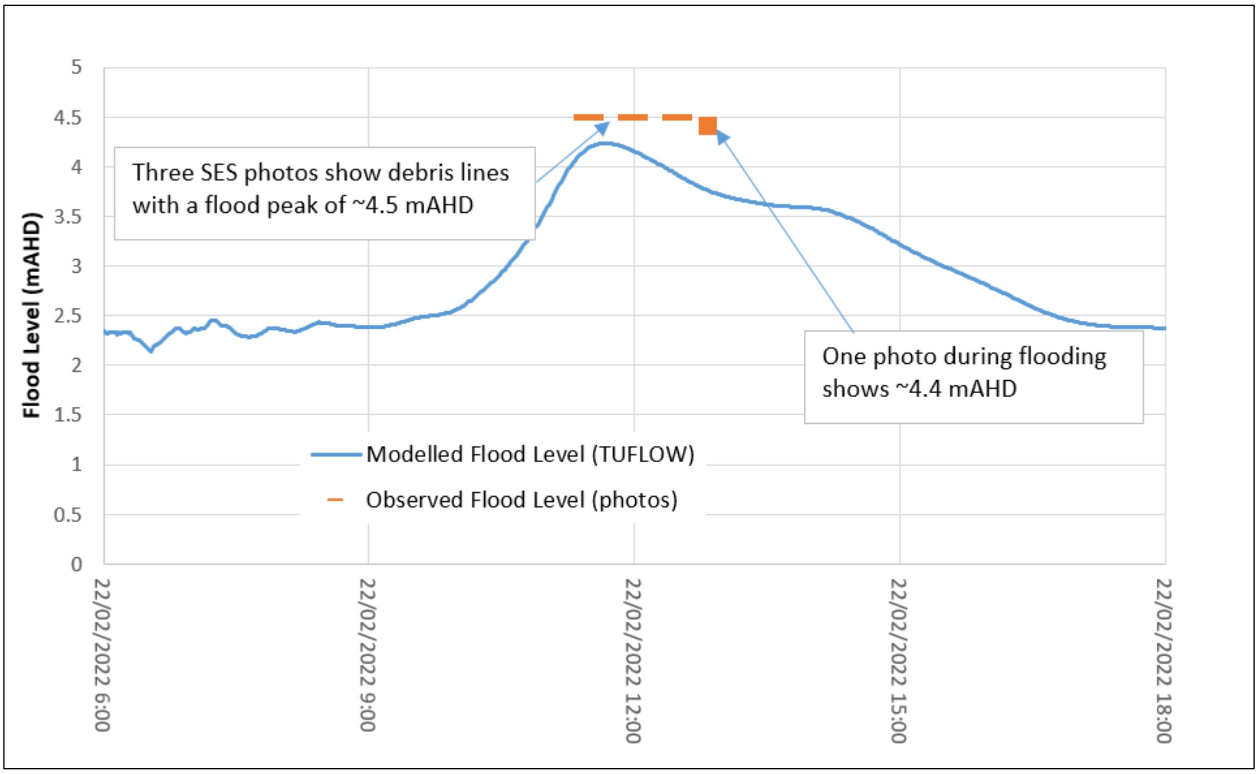
As with the previous two events, the original Council model result is also shown, with an assumed IL of 20 mm.



Sketch 14 Observed and modelled flow at Duck River stream gauge, Feb-2022 Event

The observed and modelled TUFLOW flood levels on A'Becketts Creek are shown on Sketch 15 Observed and modelled levels at Arthur Street and A'Beckett Street, Feb-2022 Event, based on the 0 IL model run. There are four photos: three from after the flood which showed debris lines (i.e., the peak flood level) and one during the flood, and they are taken at Arthur Street and A'Beckett Street, which have minimal difference in flood level so the same TUFLOW level location is used.

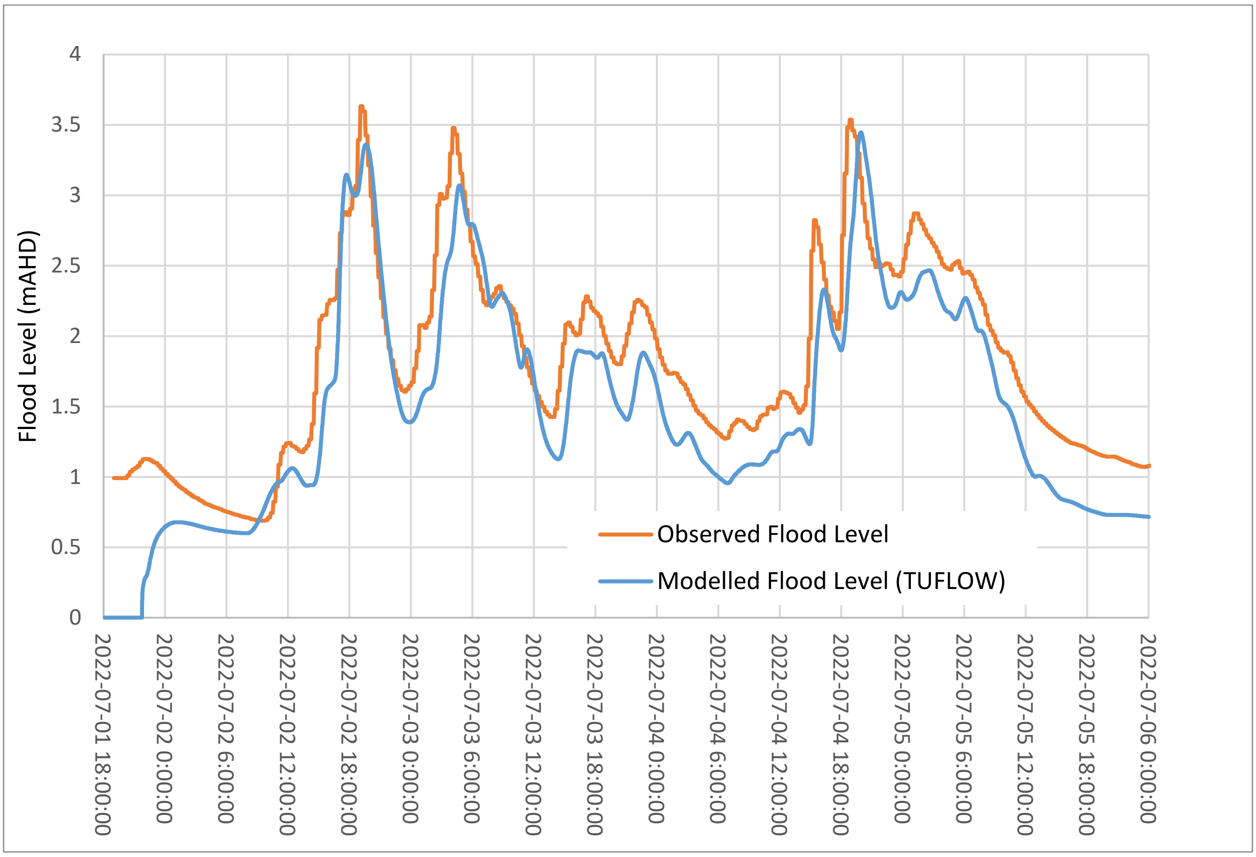
The model reaches 4.24 mAHD while the photos show a peak flood level of approximately 4.5 mAHD, so the model underestimates peak flood levels by around 0.26 m. As with the 2020 event, the likely reasons for the higher level not being produced in the model are that the highest rainfall intensities were not captured in the A'Becketts catchment or other gauges, and blockage at the bridge or downstream locations exacerbated flood levels (the calibration runs applied no blockage). As with that event, altering the catchment impervious and lag parameter did not significantly improve the calibration fit, indicating these parameters are unlikely to be the source of the discrepancy. Adjusting the rainfall initial loss did improve the fit slightly.



Sketch 15 Observed and modelled levels at Arthur Street and A'Beckett Street, Feb-2022 Event

5.5.1.4 July 2022

The event consisted of three distinct flood peaks, around 7pm on 2nd July, then around 4am on 3rd July, and on 7pm on 4th July. The modelled period was 9:00am 1st July to 12:00am 6th July. The Duck River gauge does not contain any data for the length of the flood event. The comparison was therefore only made to TUFLOW results. No photos of the event were supplied, however, Council's water level gauge at Arthur Street Bridge recorded the creek water level for the length of the event. This data is the best opportunity to test the TUFLOW model, as model results can be compared to continuous water level data over a five-day period. This comparison is shown on Sketch 16.



Sketch 16 Observed and modelled levels at Arthur Street Bridge, July-2022 Event

The results show exceptionally close fit between modelled and observed flood levels for what is essentially a validation event, as no model parameters in TUFLOW or WBNM were adjusted as part of this event. The third peak during the event is matched to within 0.1 m by the model while the earlier two high levels are well matched overall with the model slightly underestimating levels. The rising and falling limbs are likewise a close match, for all three peaks. The close match of each of the three main floods within the event shows that TUFLOW is accurately modelling the catchment behaviour during a flood event.

6. DESIGN FLOOD MODELLING

6.1 Overview

The calibrated hydrologic and hydraulic models have been used to define design flood behaviour. Design floods are theoretical events defined by their probability, with relatively common floods such as a 20% AEP event being smaller than rare events such as a 1% AEP event. Design floods are used in the design of new buildings and other development on the floodplain. They also allow modelling of the full range of possible floods, up to the largest possible flood, the Probable Maximum Flood (PMF).

6.2 Design Model Parameters

The hydrologic and hydraulic model setup is described in Section 5.2 and 5.3. Certain parameters were varied for the design flood modelling. These are as follows:

- Rainfall Losses were based on those previously established for the WBNM model, as part of its conversion from RAFTS. The same losses were shown to work during model calibration events. The only change is to adjust slightly the continuing loss for rare events to 0 mm/hour, on the basis that this was shown to improve the model fit for the calibration events, one of which (February 2020) showed particularly high rainfall of up to 2% AEP. The adopted losses are:
    - 20% AEP: 30 mm Initial Loss, 3.5 mm/hour Continuing Loss
    - 10% and 5% AEP: 30 mm and 2.5 mm/hour
    - 2% AEP and rarer: 30 mm and 0 mm/hour (lowered from 0.5 mm/hour in previous study)
- 75th percentile pre-burst rainfall was used from ARR Datahub. Comparison to historical events showed the pre-burst rainfall varied significantly between events. When the rainfall losses exceeded the pre-burst rainfall depth, the remaining loss was taken from the start of the main storm event in WBNM.
- Each design event is set out in a separate .wbn model file, using the recorded storm block section of the file with hyetographs with the percentage of rainfall across the duration of the event. The depth of rainfall applied to each subcatchment is then based on the gauge weighting blocks, to account for the variation in the IFD values.
- The Areal Reduction Factor was based on the catchment sizes of A'Becketts Creek, Duck Creek and Duck River. Design flood events used an ARF of 1.0 for A'Becketts Creek, while the Duck Creek and Duck River were downloaded from ARR Datahub based on a catchment area of 8.0 km^2 and 28.1 km^2, respectively. This is in accordance with the brief and will produce slightly conservative flood levels for the confluence area where peak flood levels are produced by combined flooding on all three catchments and therefore could also consider them as a combined catchment with its own Areal Reduction Factor. In summary:
    - A'Becketts Creek, 7 km^2, 1.0 ARF (no reduction)
    - Duck Creek, 8.0 km^2, example ARF: 0.97 (for 1% AEP, 1 hour event)
    - Duck River, 28.1 km^2, example ARF: 0.95 (for 1% AEP, 1 hour event)
- Structure blockage refers to debris partially or completely blocking culverts and drainage pits, which can cause a localised increase in flood levels, relative to if no blockage occurs. Structure blockage has been applied based on a combination of:
    - the ARR2019 approach (in some regards)
    - the requirements of the project brief, which states that no blockage should be applied to openings of 6.1 m or greater diagonal width.
    - Council instruction to not use debris in the catchment to estimate the L10 parameter but instead to use 1.5 m.
- The only locations along A'Becketts Creek and Duck Creek where a smaller opening is present are:
    - Culvert running parallel to the creek under Church Street bridge pedestrian path (2.5 x 2.5m)

- Under the railway bridge near Duke Street, the openings between the pedestrian bridge under the railway, and the railway bridge pier, and the creek bank. These openings are approximately 3.5 m and 4.5 m diagonal width.
- The William Street culverts on Duck Creek, which are 3.35 m wide
- The train line bridge on Duck Creek just downstream of Church Street, which is arched with width of 5.6 m before the opening is submerged.

The blockage for these structures in each event is presented in Appendix C.

Council also determined design blockage factors for the following locations:

- M4 to Woodville Road Cycle Bridge/Traffic ramp between the piers and embankment, the Church Street Bridge (left bank cell), and M4 to James Ruse exit ramp at Rosehill (left of the pier):
    - 0% blockage for events >5% AEP
    - 10% blockage for events 5% AEP to 0.5% AEP
    - 20% blockage for rarer events

As per the project brief, on-grade drainage pits use 20% blockage and sag pits use 50%.

The design model runs then have a 'blockage' scenario where the above blockage is applied, and a 'no blockage' scenario as well, and the final design result is an envelope of the two. Section 6.12 on model sensitivity analysis includes the results of blockage at individual structures.

- Design tailwater levels were based on the approach used for the Parramatta River Flood Study (PRFS), as recommended by the project brief. The approach assumes flood-producing rainfall in the A'Becketts Creek catchment coincides with some level of Parramatta River flooding, for events of 2% AEP and rarer. The river flood levels were those determined by the PRFS via modelling. The approach is in accordance with the guideline "NSW Floodplain Risk Management Guide- Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways" (NSW DPE, 2015). The adopted tailwater levels are:
    - For 5% AEP and more common events, a normal-depth boundary is used. This is equivalent to no flood occurring on the Parramatta River.
    - For 2% AEP and 1% AEP events, a fixed 5% AEP Parramatta River flood level of 1.75 mAHD was used. This means that relatively large floods are assumed to coincide with a flood also occurring on the river.
    - For rarer events, a fixed 1% AEP Parramatta River flood level of 2.55 mAHD was used. This means that for extreme flood events, it is assumed a large flood is also occurring on the Parramatta River.
- Design rainfall was based on ARR2019 IFD data except for the 1% AEP. The 1% AEP was based on the ARR2019 IFDs increased by 19% for storm durations of 0-6 hours and 9% for 6-12 hour durations. Longer durations were found to be outside the range of critical durations and so factor was applied. The scaling factors were based on analysis carried out as part of the Parramatta River Flood Study and summarised in "PRFS- VARIATION 39 FFA – FFA

MATCHING -SUMMERY" [sic] (Stantec, 2023) and accompanied by Council advice[2] on its application. The upscaling is to account for rainfall estimates underestimating design flows derived from Flood Frequency Analysis. In addition to the upscaling factor, the rainfall was then run for Temporal Pattern 10 (TP10) for 0-6 hour durations and TP3 for >6-12 hour durations. A 1% AEP estimate were also made using the unscaled rainfall, for comparison.

- The PMF uses the Generalised Short Duration Method and uses an ensemble of temporal patterns for each duration, derived in "Growth curves and temporal patterns of short duration design storms for extreme events" (Jordan et al, 2005). It is noted that PMF design flow estimates from the hydrologic model (and therefore design flood depths and levels) are likely to be quite conservative, given that the storage characteristics of the catchment are likely to be under-estimated in WBNM for extreme flood events. Flow comparison between the Duck River outlet in WBNM and TUFLOW showed significant attenuation in the TUFLOW model flow, not present in the WBNM model.
- Design rainfall is applied to the WBNM subcatchments as a time-series of rainfall depths, weighted to the nearest IFD data for each subcatchment location.

6.3 Critical Duration

Critical storm durations were determined for the study area. The critical duration is the rainfall duration that produces the largest flow or highest flood levels for a particular AEP. The critical duration has been determined using the following process:

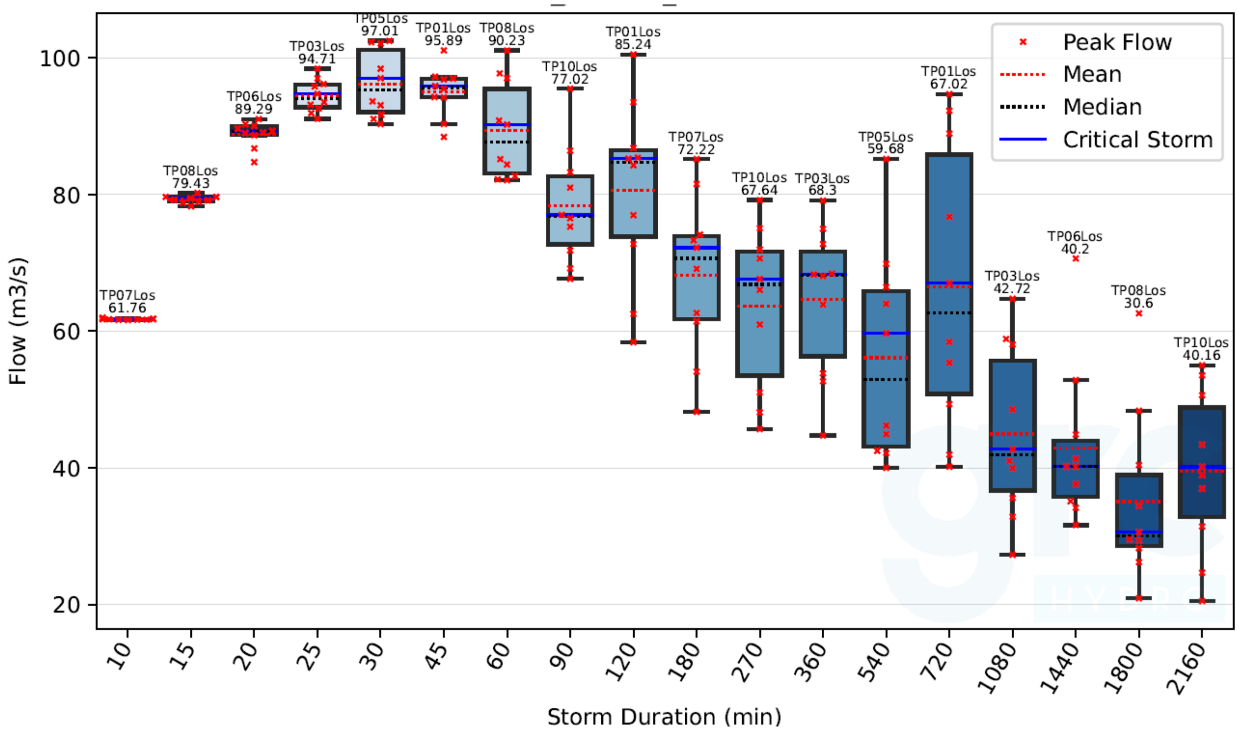
1. For each design event AEP, the full ensemble of temporal patterns was run for each duration, in WBNM. The peak flows are then reviewed for the A'Becketts Creek outlet, A'Becketts Creek at Woodville Road, the Duck Creek outlet, and the Duck River section downstream of the Duck Creek confluence. The largest overland flowpath in A'Becketts Creek was also checked.
2. Based on the WBNM results, a critical duration was selected for the upper A'Becketts Creek, from around Woodville Road to Good Street, and the lower A'Becketts Creek, from around Good Street to the Duck Creek confluence. A short duration of around 30-60 minutes was critical for the upper section, while the lower section has a longer duration of around 3-12 hours due to higher Duck River flows for these durations, which affect the lower A'Becketts Creek area.
3. The critical durations and median temporal patterns from WBNM were then confirmed in TUFLOW by running a range of temporal patterns and durations, and confirming the WBNM critical duration and temporal pattern also produced the same critical duration and temporal pattern in TUFLOW. Only a subset of events were required in TUFLOW as the results showed a strong correlation between peak flow at Woodville Road and the flood level in the upper

[2] Council advice was set out in "Advice 206-FFA Matched 1% AEP Storm.pdf" and advised that for tributary creeks (which includes Duck River, Duck Creek and A'Becketts Creek:
"11. All Tributary Creek Systems utilise a 19% increase in IFD in conjunction with TP 10 (rank not identified) for all durations up to and including 6 hours.
12. All Tributary Creek Systems utilise a 9% increase in IFD in conjunction with TP 3 (rank not identified) for all durations exceeding 6 hours and up to and including 12 hours."

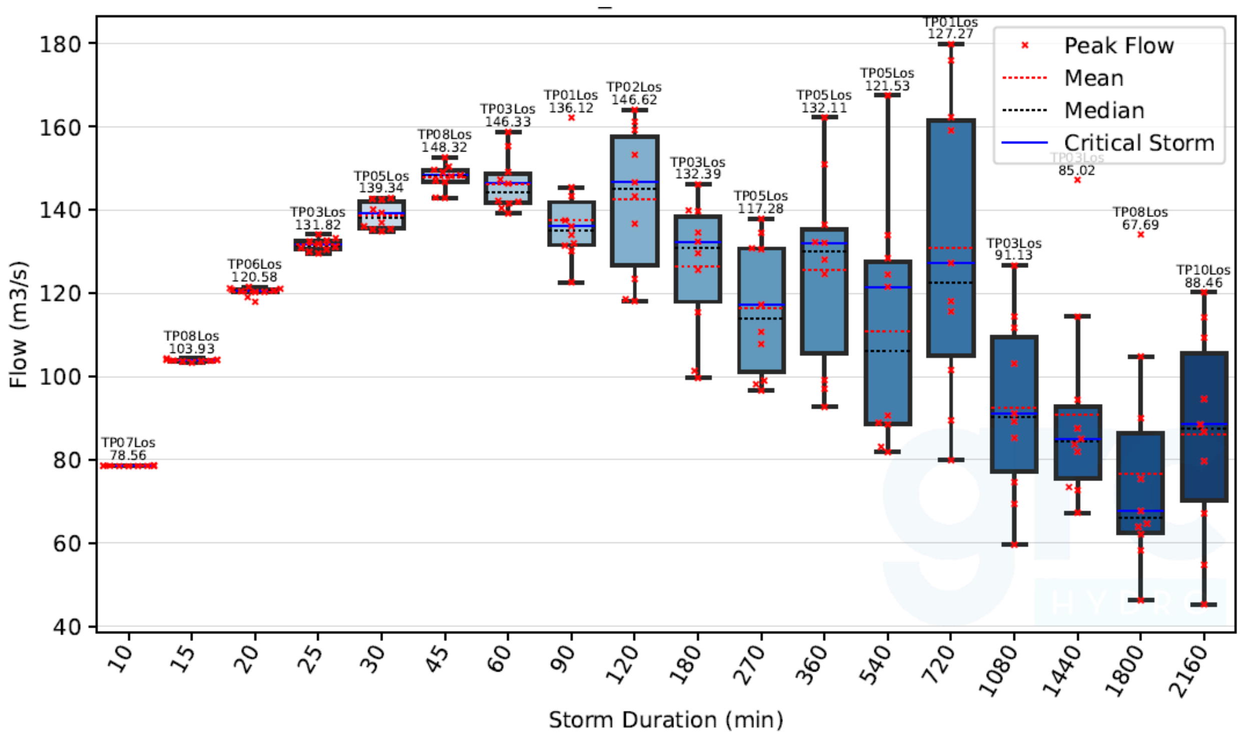
A'Becketts Creek, and peak flow at the Duck River and Duck Creek confluence correlating with the flood level in the lower A'Becketts Creek.

4. For the 1% AEP, which uses the upscaled rainfall, the temporal patterns were TP10 and TP03 (see previous section), not the median TP.
5. The overland flow results were also checked to ensure the upper A'Becketts Creek critical duration also produced the peak level (or close to it) in the overland flow areas.

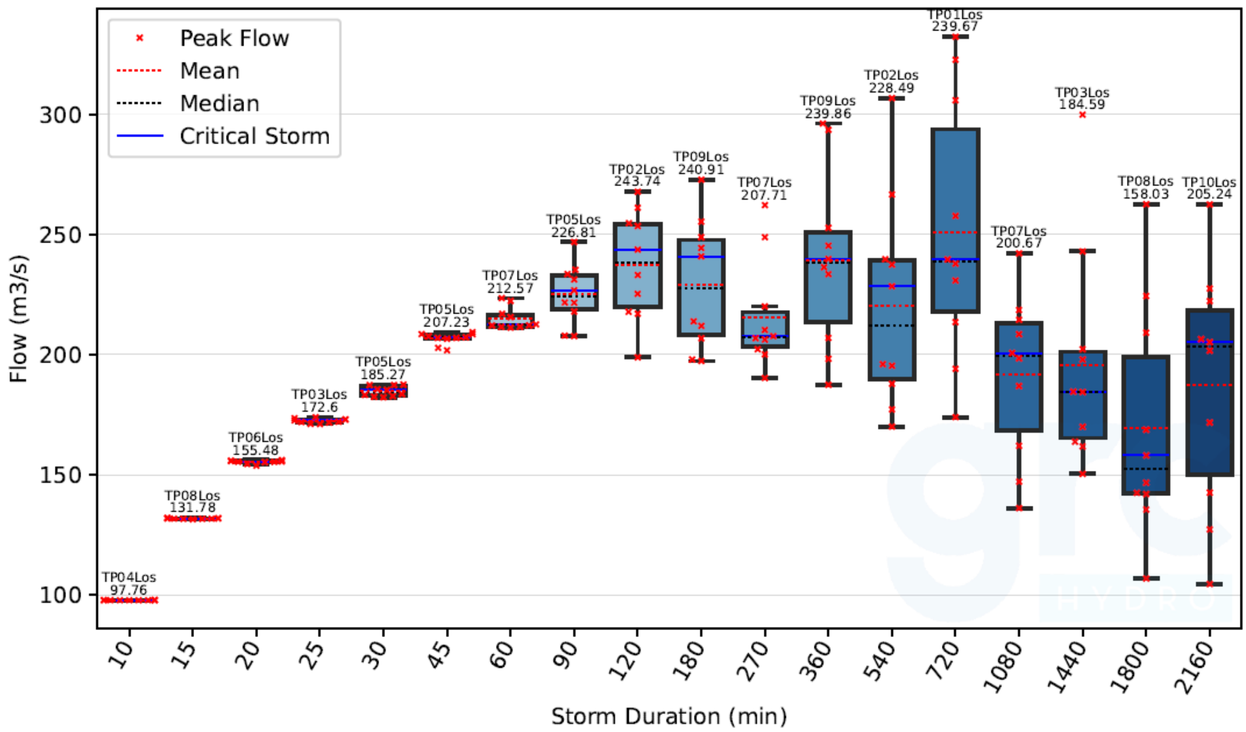
The WBNM results for the 2% AEP are shown in Sketch 17 to Sketch 18, as the 1% AEP use the nominated TP not the median. Sketch 20 shows hydrographs from a range of durations to demonstrate how certain durations produce higher peak flows at a particular location.



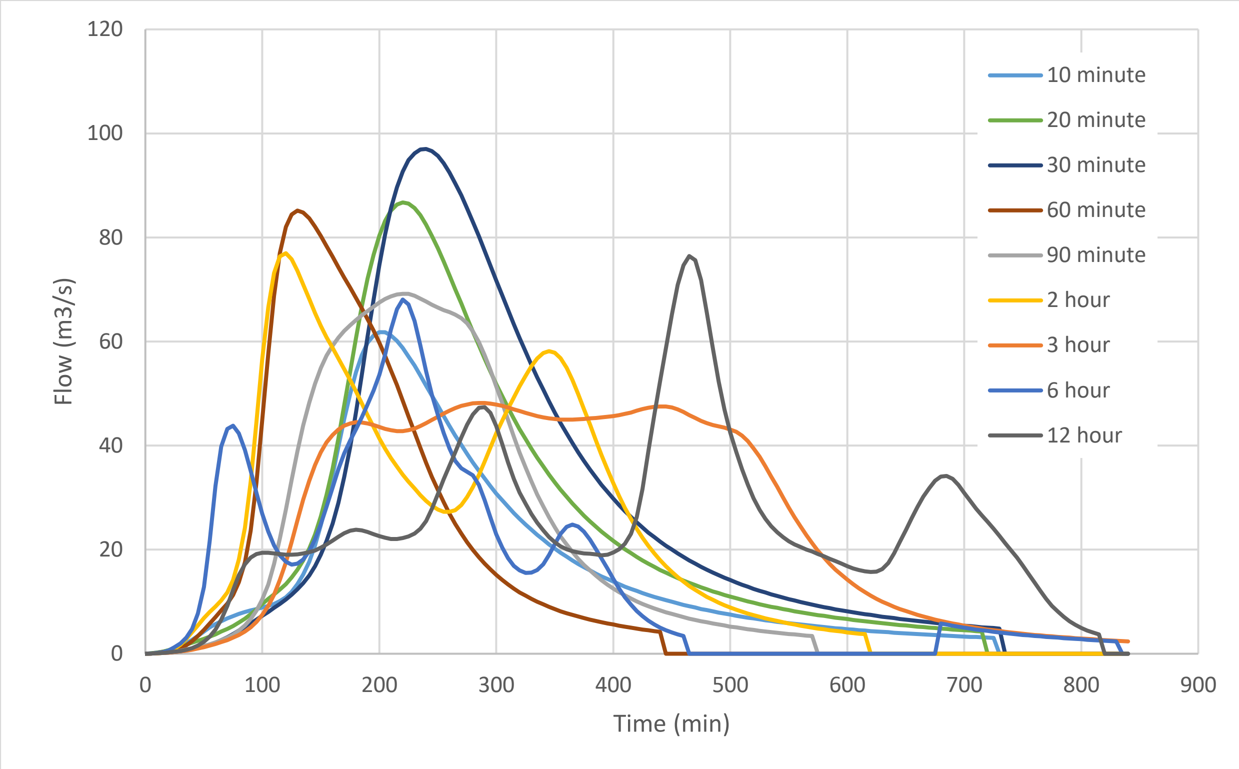
Sketch 17 2% AEP Critical Duration WBNM Results - A'Becketts Creek at James Ruse Drive



Sketch 18 2% AEP Critical Duration WBNM Results - Duck Creek outlet



Sketch 19 2% AEP Critical Duration WBNM Results - Duck River downstream of Duck Creek



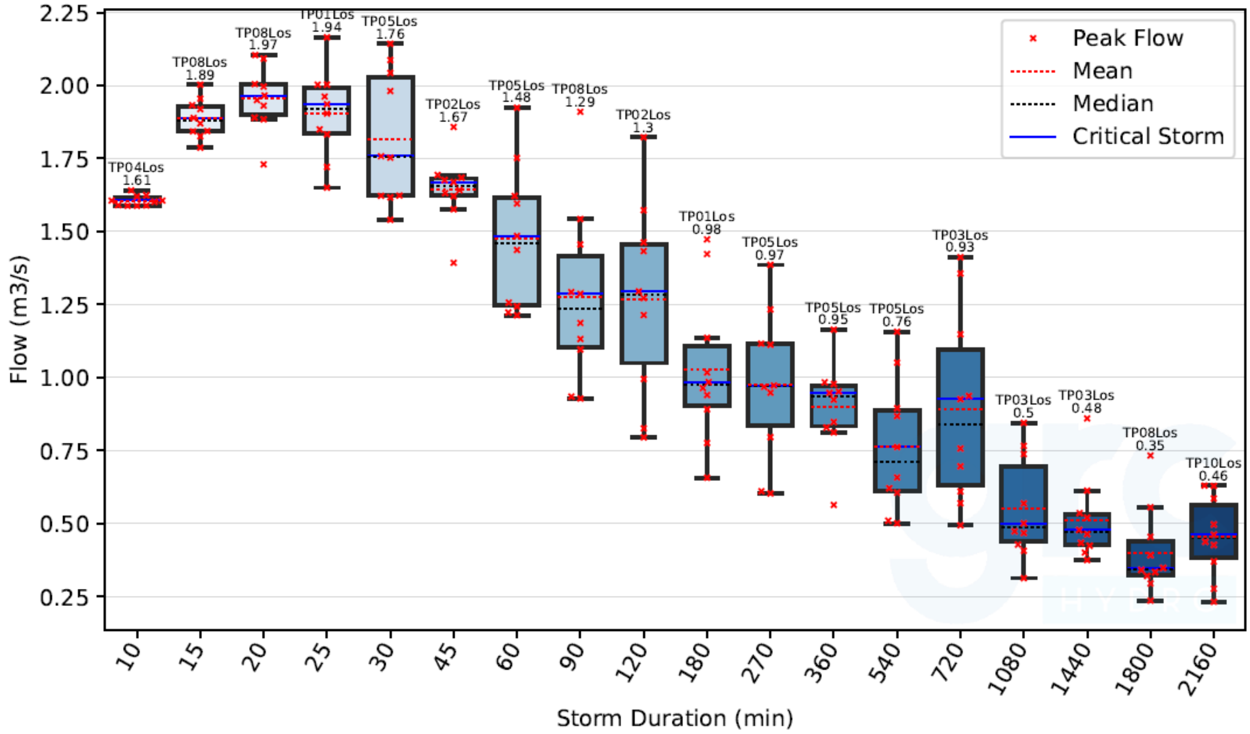
Sketch 20 2% AEP WBNM hydrographs at A'Becketts Creek at James Ruse Drive, for a range of durations

The results of the critical duration assessment are shown in Table 6. As shown, two critical durations were adopted for each AEP. The shorter duration is critical for the upper creek and areas of overland flow, while the longer duration is for the lower creek where Duck Creek and Duck River flows affect the peak flood level. For the 1% AEP, the longer duration sets the peak flood level from the Duck Creek confluence up to the Good Street bridge, i.e. the last 1.1 km of A'Becketts Creek.

Table 6: Critical Duration Results

AEP	Critical Duration 1	Critical Duration 2
20%	45 minute, TP10	2 hour, TP04
5%	30 minute TP04	6 hour TP02
2%	30 minute, TP05	2 hour, TP02
1%	1 hour, TP10	12 hour, TP03
1% (original, unscaled rainfall, for comparison only)	30 minute, TP05	12 hour, TP08
PMF	60 minute TP06	2 hour TP03

For overland flow, WBNM results indicated overland flowpaths in the area have a critical duration of 20-30 minutes. Given the 30 minute duration has only marginally less flow when the 20 minute is critical, and this was the critical duration for the upper creek, the 30 minute duration was adopted. The results along a sample overland flowpath at A'Beckett Street near Kemp Street are shown on Sketch 21.



Sketch 21 2% AEP Critical Duration WBNM Results – Overland flowpath

6.4 Flood Depths and Levels

Peak flood depth maps with levels contours for the design events are shown on Figure A1, Figure A2, Figure A3, Figure A4 and Figure A5 in Appendix A, while Table 7 summarises design flood levels for a number of locations in the study area. The locations of the key locations in the study area are mapped on Figure 1 and also presented below on Sketch 22.

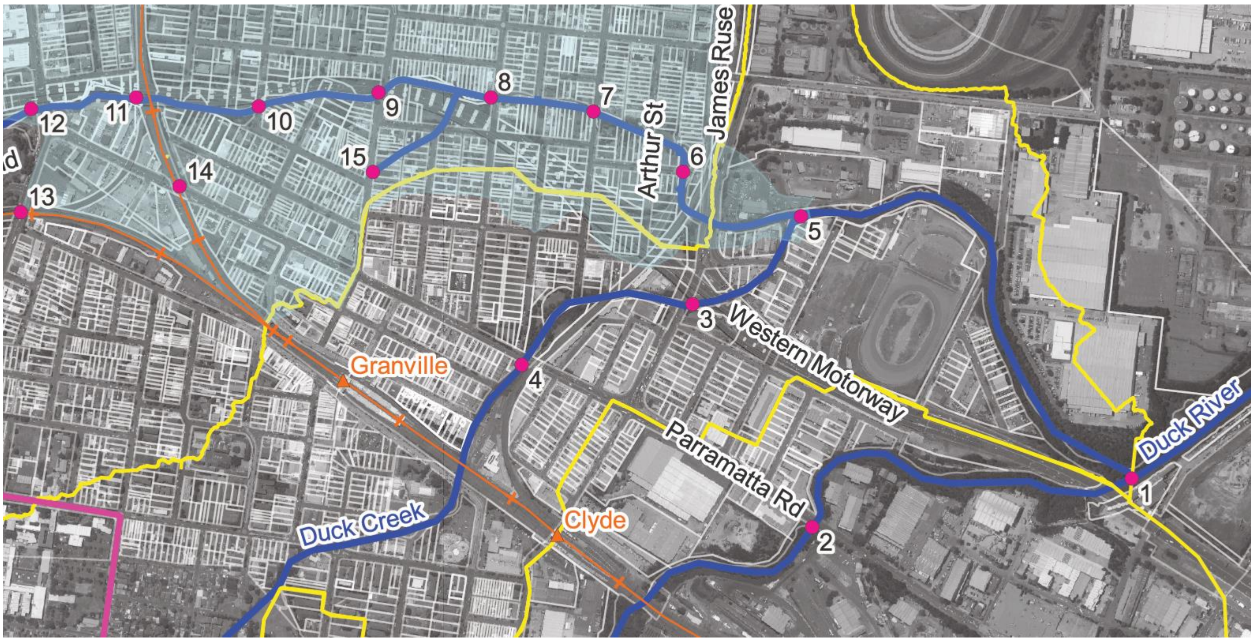
Table 7: Design Water Level for each AEP

ID	Location	Ground Level (mAHD)	Peak Flood Level (mAHD) per design event					
			20% AEP	5% AEP	2% AEP	1% AEP	PMF	1% AEP unscaled†
1*	Duck River: Confluence Duck Creek & Duck River*	-1.85	1.86	2.64	2.96	3.92	6.41	3.38
2*	Duck River: Upstream Parramatta Road*	0.13	2.48	3.46	3.59	4.72	7.07	4.23
3*	Duck Creek: Upstream M4*	0.16	4.35	4.85	5.01	5.58	7.30	5.21
4*	Duck Creek: Upstream Parramatta Road*	-0.04	4.52	5.08	5.25	6.02	7.55	5.55
5	A'Becketts Creek: Confluence with Duck Creek	-0.36	3.99	4.52	4.74	5.41	7.14	4.95
6	ABC: East end of A'Beckett Street	-0.24	4.35	4.87	5.19	5.78	7.38	5.30
7	ABC: Upstream Arthur Street Bridge	0.05	4.43	4.93	5.26	5.85	7.49	5.36
8	ABC: Upstream Alfred Street Bridge	0.29	4.47	4.97	5.31	5.91	7.58	5.39

ID	Location	Ground Level (mAHD)	Peak Flood Level (mAHD) per design event					
			20% AEP	5% AEP	2% AEP	1% AEP	PMF	1% AEP unscaled†
9	ABC: Upstream Good Street Bridge	1.76	4.66	5.11	5.65	6.20	7.83	5.67
10	ABC: Upstream Harris Street footway	1.22	5.13	5.60	6.10	6.78	8.45	6.27
11	ABC: Upstream railway overpass near Duke Street	2.80	6.49	7.16	7.59	8.67	12.71	7.90
12	ABC: Upstream Woodville Road Bridge	5.66	8.99	9.56	9.90	10.63	13.10	10.11
13	Overland Flow: Woodville Road Underpass	7.05	9.47	10.12	10.23	10.56	13.45	10.46
14	Overland Flow: Parramatta Road Underpass east of Mort Street	5.52	6.42	6.75	6.98	8.60	10.15	7.35
15	Overland Flow: Good Street near Prince Street	5.54	5.64	5.65	5.66	5.97	7.82	5.68

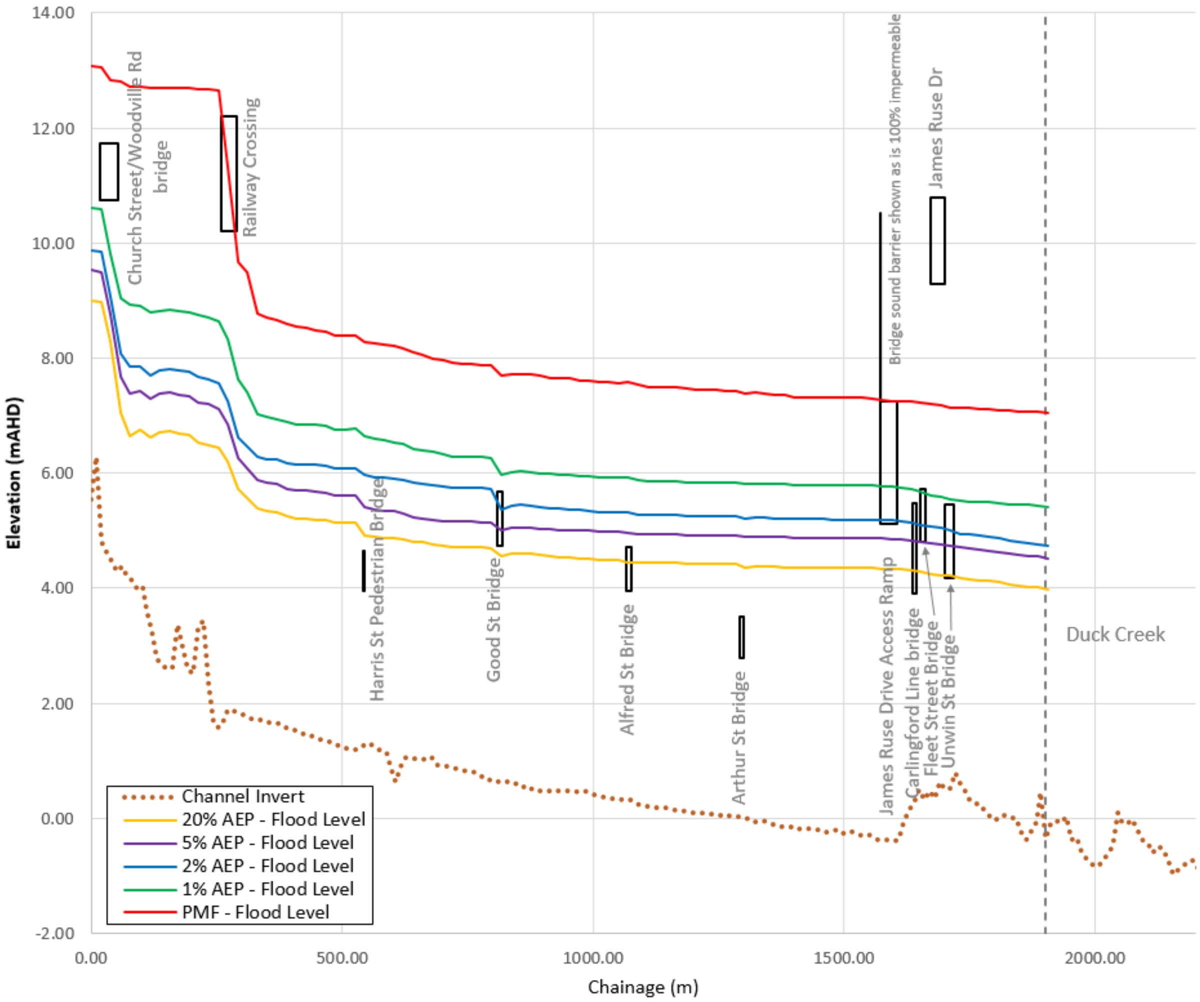
*Note: Locations are for understanding effect of Duck Creek/River on A'Becketts Creek, only. The current study is only producing design flood information for A'Becketts Creek (ID locations 4-15).

†Note: The unscaled 1% AEP results use unadjusted 1% AEP design rainfall and are presented for comparison purposes only.



Sketch 22 Results reporting locations 1-15

Flood level profiles for the design events are shown below in Sketch 23.



Sketch 23 Design Flood Level Profiles

6.5 Velocities

Peak flood velocity maps for the design events are presented in Figure A6, Figure A7, Figure A8, Figure A9 and Figure A10, for the design events, while Table 8 summarises peak velocities at the reporting location points.

Table 8: Design Flood Velocities

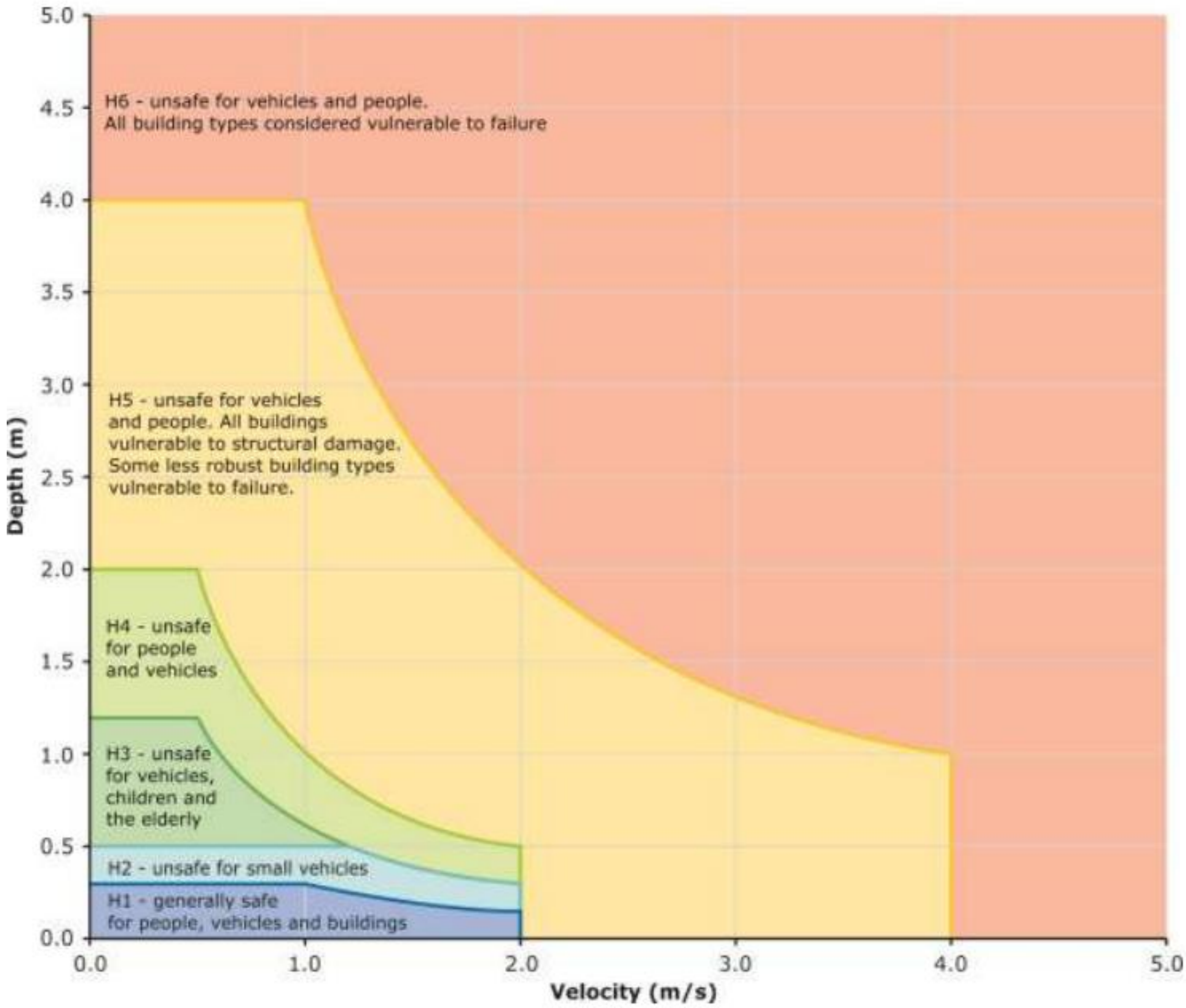
ID	Location	Peak Velocity (m/s) for each design event				
		20% AEP	5% AEP	2% AEP	1% AEP	PMF
1*	Duck River: Confluence Duck Creek & Duck River*	1.2	1.2	1.0	1.3	1.8
2*	Duck River: Upstream Parramatta Road*	1.4	1.4	1.2	1.3	1.6
3*	Duck Creek: Upstream M4*	0.5	0.7	0.5	0.5	0.9
4*	Duck Creek: Upstream Parramatta Road*	0.9	1.3	1.0	1.1	1.3

ID	Location	Peak Velocity (m/s) for each design event				
		20% AEP	5% AEP	2% AEP	1% AEP	PMF
5	A'Becketts Creek: Confluence with Duck Creek	0.9	1.0	1.0	1.0	1.0
6	ABC: East end of A'Beckett Street	0.7	0.7	0.7	0.7	0.9
7	ABC: Upstream Arthur Street Bridge	1.2	1.2	1.2	1.1	1.0
8	ABC: Upstream Alfred Street Bridge	1.3	1.5	1.5	1.4	1.4
9	ABC: Upstream Good Street Bridge	1.5	1.7	1.8	1.8	1.7
10	ABC: Upstream Harris Street footway	2.0	2.3	1.9	1.8	1.6
11	ABC: Upstream railway overpass near Duke Street	0.6	0.7	0.8	0.8	0.9
12	ABC: Upstream Woodville Road Bridge	0.9	1.0	1.1	1.1	2.1
13	Overland Flow: Woodville Road Underpass	0.2	0.3	0.3	0.3	0.7
14	Overland Flow: Parramatta Road Underpass east of Mort Street	0.4	0.4	0.4	0.3	3.8
15	Overland Flow: Good Street near Prince Street	0.1	0.1	0.2	0.5	2.4

*Note: Locations are for understanding effect of Duck Creek/River on A'Becketts Creek, only. The current study is only producing design flood information for A'Becketts Creek (ID locations 4-15).

6.6 Hazard

Flood hazard is defined as the threat that flooding will pose to human activity. The hazard categories utilised for this study are based on the Australian Emergency Management Handbook 7 guideline, which considers the threat to types of people (children, adult) and activity (pedestrian, vehicle and within a building. These flood hazard categories are presented in Sketch 24.



Sketch 24 Australian Emergency Management Hazard Categories

The chart divides a flood event into six categories of hazard, specifically:

- H1 – Generally safe for people, vehicles and buildings (corresponding to very shallow and slow flow);
- H2 – Unsafe for small vehicles
- H3 – Unsafe for vehicles, children and the elderly;
- H4 – Unsafe for people and vehicles;
- H5 – Unsafe for people and vehicles. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure; and
- H6 – Unsafe for people and vehicles. All building types considered vulnerable to failure (corresponding to very deep and fast flow).

Figure A11, Figure A12, Figure A13, Figure A14 and Figure A15 present the flood hazard maps for the 20% AEP, 5% AEP, 2% AEP, 1% AEP and PMF design events. In the 20% AEP, channel flow is largely H5 and H6 while out of bank flooding has areas of H3 and H4, while Parramatta Road has H3 at the rail underpass. In the 1% AEP, there are large areas of H3 and H4 hazard across residential areas in the lower study area, as well as some H5 areas, while the Parramatta Road underpass has H5 hazard.

Further description of hazard including on key roads and flooding hotspots will be included in the Floodplain Risk Management Study and Plan.

6.7 Flood Function

Flood Function (also referred to as 'Hydraulic Categories') refers to the classification of floodwaters into three categories: floodway/flow conveyance, flood storage and flood fringe. These categories help to describe the nature of flooding across the floodplain and aid planning when assessing developable areas. According to the Australian Emergency Management Handbook 7, these three categories can be defined as:

- Floodway – the areas where a significant proportion of the floodwaters flow and typically align with defined channels. If these areas are blocked or developed, there will be significant redistribution of flow and increased flood levels across the floodplain. Generally, floodways have deep and/or fast moving floodwaters.
- Flood storage – areas where, during a flood, a significant proportion of floodwaters extend into, water is stored and then recedes after a flood. Significant filing or development in these areas may increase flood levels nearby; and
- Flood fringe – areas that make up the remainder of the flood extent. Development in these areas are unlikely to alter flood behaviour in the surrounding area.

The prescribed methodology for deriving each category is presented in the recent NSW DPE guideline, "Flood Function, Flood Risk Management Guide FB02". The DPE guideline are largely focussed towards determining flood function for mainstream flooding where a creek, river or other channel exists. The approach for A'Becketts Creek channel is described below. For areas of overland flow, the guideline states:

- Defining flood function is complex
- It is important to define a continuous flowpath or floodway once it has formed
- Conveyance and encroachment techniques are difficult to use, and the indicator technique likely more appropriate (this means using depth and velocity, or similar outputs, to estimate areas of flood function)
- Large flood storage areas are not common and may not be present

The approach used consists of the conveyance technique and the encroachment technique for defining floodway, and then the indicator technique is used to separate flood storage and flood fringe in the remaining areas. More specifically, the following steps were followed:

- Floodway
    - For the 1% AEP, sum the cumulative flow along a series of flow measurement lines (spaced every 0.2 m change in flood level) and estimate the width that captures 80% of the total flow. This is the initial floodway estimate.
    - For significant areas of non-floodway alongside the main channel, apply a high roughness of n = 3.0 in each area to represent blocking non-floodway areas, and test the effect on flood levels in a 1% AEP event.
    - This showed an impact on flood levels of only 0.01 m, indicating the estimate was too wide a flow extent. A revised estimate was made of 70% flow and only taking

areas of velocity * depth greater than or equal to 0.3 m^2/s. The revised estimate showed an impact of up to 0.05 m with 0.02-0.03 m in some sections. Given that a lower threshold would deviate significantly from the guideline starting value of 80%, and the floodway captures the channel and high flow areas on the adjacent banks, the floodway was adopted. It is also noted that relatively low velocities in the lower channel likely mean the flood levels are less sensitive to high roughness areas, compared to a typical creek or river.
    - The same flow percentage criteria of 70% of total flow and v*d of 0.3 m^2/s minimum has then been used for the 20% AEP, 5% AEP, 2% AEP and PMF.
- Flood Storage and Flood Fringe
    - An initial estimate was taken as flood storage being flooded areas where depths exceed 0.5 m, that were not floodway. The 0.5 m threshold has been used in numerous urban studies in the Sydney region.
    - As a sensitivity test, the remaining areas (which would become Flood Fringe) were blocked out in the model, representing a scenario where these areas are filled over time. The effect was small impacts of around 0.01 m. This showed that overall, the flood storage selected is sufficiently large.
    - The same depth cut-off has then been used for the four 20% AEP, 5% AEP, 2% AEP and PMF.

Figure A16 to Figure A20 presents the Flood Function for the 20% AEP up to the PMF. Flood function has only been defined for locations with depths over 0.1 m.

6.8 Climate Change

The hydrologic and hydraulic models were adjusted to assess the effect of climate change on design flood behaviour. Climate change is expected to worsen flood risk over time as higher greenhouse gas concentrations lead to increases in high intensity rainfall and sea levels. The assessment used the IPCC (Intergovernmental Panel on Climate Change) greenhouse gas concentration scenarios and subsequent modelling estimating each scenario's effect on rare rainfall events. There are four IPCC greenhouse gas concentration projections named RCP 2.5, 4.5, 6.0 and 8.5, with the RCP 2.5 being the most optimistic (emissions plateau and then decline) and 8.5 the least optimistic (emissions continue to grow). For the RCP4.5 and 8.5 scenarios, the projected increase in precipitation intensity were obtained from the ARR Data Hub and shown in Table 9 for the 2090 estimate. The table also shows the 2150 estimate, from The Ocean and Cryosphere in a Changing Climate – Summary for Policymakers, IPCC WGI and II, September 2019.

Table 9: Climate Change Factors – Percentage Increase in Rainfall Intensity

Year	RCP 4.5	RCP 8.5
2050	+6.4%	+9.0%
2090	+9.5%	+19.7%
2150	+11.5%	+28.5%

Sea level rise as a result of climate change affects the catchment's tailwater conditions at the Parramatta River and can affect flood behaviour in the lower catchment. An estimate of sea level rise is 0.4 m by 2050 and 0.9 m by 2100, as set out in the NSW government Practical Consideration of Climate Change guideline (2007). A further estimate of 1.5 m sea level rise has been used, from The Ocean and Cryosphere in a Changing Climate – Summary for Policymakers, IPCC WGI and II, September 2019. Based on these estimated changes the following scenarios were assessed for the 20% AEP, 5% AEP and 1% AEP, for the no blockage scenario:

- "CC1" RCP4.5 2050 rainfall increase of 6.4%, with 0.4 m sea level rise (SLR) on tailwater
- "CC2" RCP8.5 2050 rainfall increase of 9%, with 0.4 m SLR
- "CC3" RCP4.5 2090 rainfall increase of 9.5%, with 0.9 m SLR
- "CC4" RCP8.5 2090 rainfall increase of 19.7%, with 0.9 m SLR
- "CC5" 0.4 m SLR
- "CC6" 0.9m SLR
- "CC7" RCP4.5 2150 rainfall increase of 11.5% with 1.5 m SLR
- "CC8" RCP8.5 2150 rainfall increase of 28.5% with 1.5 m SLR
- "CC9" 1.5 m SLR

For each scenario the peak flood levels were then tabulated and compared to the base case (i.e., no climate change). The average increase in flood level for a scenario indicates how sensitive the results are to that particular change, while the list of locations shows areas where climate change will cause a relatively large difference, or where there will be little increase. The results of the assessment are shown in Table 10 (CC1 and CC2), Table 11 (CC3 and CC4) and Table 12 (CC5 and CC6).

Table 10: Water Levels for Climate Change 1 and 2 Scenarios

ID	Location	Base Case			CC1			CC2		
		20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP
1	Duck River: Confluence with Duck Creek	1.86	2.64	3.92	2.10	2.82	4.10	2.15	2.86	4.14
2	Duck River: Upstream Parramatta Road	2.48	3.46	4.72	2.71	3.66	4.82	2.76	3.72	4.86
3	Duck Creek: Upstream M4	4.35	4.85	5.58	4.46	4.96	5.65	4.50	4.99	5.68
4	Duck Creek: Upstream Parramatta Road	4.51	5.08	6.02	4.63	5.21	6.08	4.68	5.25	6.10
5	ABC: Confluence with Duck Creek	3.99	4.52	5.41	4.10	4.64	5.50	4.14	4.69	5.53
6	ABC: East end of A'Beckett Street	4.35	4.87	5.78	4.47	5.00	5.87	4.52	5.05	5.89
7	ABC: Upstream Arthur Street Bridge	4.42	4.93	5.85	4.54	5.06	5.93	4.59	5.10	5.96
8	ABC: Upstream Alfred Street Bridge	4.47	4.97	5.91	4.59	5.10	6.00	4.64	5.14	6.03
9	ABC: Upstream Good Street Bridge	4.66	5.11	6.2	4.78	5.25	6.28	4.84	5.30	6.31
10	ABC: Upstream Harris Street footway	5.13	5.60	6.78	5.27	5.77	6.86	5.33	5.83	6.89

ID	Location	Base Case			CC1			CC2		
		20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP
11	ABC: U/S railway near Duke Street	6.49	7.16	8.67	6.64	7.33	8.84	6.71	7.41	8.91
12	ABC: Upstream Woodville Road Bridge	8.99	9.56	10.63	9.11	9.67	10.71	9.16	9.73	10.75
13	Overland Flow: Woodville Road Underpass	9.47	10.12	10.56	9.59	10.25	10.57	9.63	10.30	10.59
14	Overland Flow: P'matta Road Underpass east of Mort Street	6.42	6.75	8.6	6.51	6.87	8.61	6.55	6.91	8.65
15	Overland Flow: Good St near Prince St	5.63	5.65	5.97	5.64	5.65	6.07	5.64	5.65	6.10

CC1 increases design levels by around 0.10 to 0.15 m, on average. As with all climate change scenarios, the largest areas of increase are outside the study area, on Duck River where sea level rise has the greatest effect. Flood levels in the study area are around 0.1 m higher than the base case. CC2 shows a similar effect with slightly greater average, around 0.15 to 0.20 m relative to the base case.

Table 11: Water Levels for Climate Change 3 and 4 Scenarios

ID	Location	Base Case			CC3			CC4		
		20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP
1	Duck River: Confluence with Duck Creek	1.86	2.64	3.92	2.26	2.93	4.26	2.42	3.08	4.41
2	Duck River: Upstream Parramatta Road	2.48	3.46	4.72	2.84	3.77	4.90	3.04	3.97	5.04
3	Duck Creek: Upstream M4	4.35	4.85	5.58	4.52	5.00	5.69	4.68	5.14	5.78
4	Duck Creek: Upstream Parramatta Road	4.51	5.08	6.02	4.70	5.27	6.11	4.88	5.45	6.19
5	ABC: Confluence with Duck Creek	3.99	4.52	5.41	4.16	4.70	5.55	4.32	4.86	5.64
6	ABC: East end of A'Beckett Street	4.35	4.87	5.78	4.53	5.06	5.91	4.70	5.22	6.00
7	ABC: Upstream Arthur Street Bridge	4.42	4.93	5.85	4.61	5.12	5.98	4.77	5.27	6.07
8	ABC: Upstream Alfred Street Bridge	4.47	4.97	5.91	4.66	5.16	6.04	4.83	5.31	6.14
9	ABC: Upstream Good Street Bridge	4.66	5.11	6.2	4.85	5.31	6.32	5.05	5.49	6.42
10	ABC: Upstream Harris Street footway	5.13	5.60	6.78	5.34	5.85	6.90	5.55	6.08	7.01
11	ABC: U/S railway near Duke Street	6.49	7.16	8.67	6.72	7.42	8.90	6.98	7.70	9.20
12	ABC: Upstream Woodville Road Bridge	8.99	9.56	10.63	9.17	9.75	10.77	9.36	9.97	10.93

ID	Location	Base Case			CC3			CC4		
		20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP
13	Overland Flow: Woodville Road Underpass	9.47	10.12	10.56	9.64	10.31	10.60	9.81	10.41	10.67
14	Overland Flow: P'matta Road Underpass east of Mort Street	6.42	6.75	8.6	6.56	6.92	8.67	6.70	7.09	8.77
15	Overland Flow: Good St near Prince St	5.63	5.65	5.97	5.64	5.66	6.11	5.64	5.67	6.21

CC3 increases design flood levels by around 0.15-0.25 m, with increases larger for the more common flood events. The increase for CC4 is around 0.4 m along the creek channel for the 20% AEP and 5% AEP events, and around 0.2 m for the 1% AEP event. The results show that CC4 has the greatest effect on flood levels of CC1-CC4, which is to be expected given it has the highest rainfall increase and sea level rise, and there will be a significant change in flood behaviour, especially along the A'Becketts Creek floodplain.

Table 12: Water Levels for Climate Change 5 and 6 Scenarios

ID	Location	Base Case			CC5			CC6		
		20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP
1	Duck River: Confluence with Duck Creek	1.86	2.64	3.92	1.99	2.69	3.99	2.11	2.76	4.11
2	Duck River: Upstream Parramatta Road	2.48	3.46	4.72	2.57	3.49	4.74	2.64	3.53	4.78
3	Duck Creek: Upstream M4	4.35	4.85	5.58	4.35	4.86	5.59	4.36	4.86	5.60
4	Duck Creek: Upstream Parramatta Road	4.51	5.08	6.02	4.52	5.09	6.02	4.53	5.09	6.03
5	ABC: Confluence with Duck Creek	3.99	4.52	5.41	4.00	4.53	5.42	4.01	4.54	5.44
6	ABC: East end of A'Beckett Street	4.35	4.87	5.78	4.35	4.87	5.79	4.36	4.88	5.80
7	ABC: Upstream Arthur Street Bridge	4.42	4.93	5.85	4.43	4.93	5.86	4.43	4.94	5.87
8	ABC: Upstream Alfred Street Bridge	4.47	4.97	5.91	4.47	4.98	5.92	4.48	4.98	5.93
9	ABC: Upstream Good Street Bridge	4.66	5.11	6.2	4.66	5.12	6.21	4.67	5.12	6.22
10	ABC: Upstream Harris Street footway	5.13	5.60	6.78	5.13	5.61	6.79	5.13	5.61	6.80
11	ABC: U/S railway near Duke Street	6.49	7.16	8.67	6.47	7.14	8.67	6.47	7.14	8.68
12	ABC: Upstream Woodville Road Bridge	8.99	9.56	10.63	8.99	9.52	10.58	8.99	9.52	10.59

ID	Location	Base Case			CC5			CC6		
		20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP
13	Overland Flow: Woodville Road Underpass	9.47	10.12	10.56	9.47	10.12	10.56	9.47	10.12	10.56
14	Overland Flow: P'matta Road Underpass east of Mort Street	6.42	6.75	8.6	6.42	6.75	8.60	6.42	6.75	8.60
15	Overland Flow: Good St near Prince St	5.63	5.65	5.97	5.63	5.65	5.98	5.63	5.65	5.99

The CC5 and CC6 scenarios have very minimal effect on flood levels in the study area, with most locations showing less than 0.1 m increase in flood level. Under CC6 the 20% AEP levels are up to 0.1 m higher but this reduces to a 0.01-0.03 m increase in the 1% AEP event. This shows that flood levels in the catchment are relatively insensitive to sea level rise.

Table 13: Water Levels for Climate Change 7 and 8 Scenarios

ID	Location	Base Case			CC7			CC8		
		20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP
1	Duck River: Confluence with Duck Creek	1.86	2.64	3.92	2.50	3.08	4.46	2.71	3.30	4.67
2	Duck River: Upstream Parramatta Road	2.48	3.46	4.72	3.02	3.88	5.01	3.31	4.16	5.22
3	Duck Creek: Upstream M4	4.35	4.85	5.58	4.57	5.04	5.73	4.81	5.24	5.87
4	Duck Creek: Upstream Parramatta Road	4.51	5.08	6.02	4.75	5.31	6.14	5.03	5.62	6.25
5	ABC: Confluence with Duck Creek	3.99	4.52	5.41	4.22	4.75	5.60	4.48	4.98	5.73
6	ABC: East end of A'Beckett Street	4.35	4.87	5.78	4.59	5.11	5.94	4.85	5.34	6.08
7	ABC: Upstream Arthur Street Bridge	4.42	4.93	5.85	4.66	5.16	6.01	4.92	5.40	6.15
8	ABC: Upstream Alfred Street Bridge	4.47	4.97	5.91	4.71	5.20	6.08	4.97	5.44	6.22
9	ABC: Upstream Good Street Bridge	4.66	5.11	6.2	4.91	5.36	6.35	5.21	5.65	6.50
10	ABC: Upstream Harris Street footway	5.13	5.60	6.78	5.39	5.89	6.92	5.72	6.26	7.07
11	ABC: U/S railway near Duke Street	6.49	7.16	8.67	6.78	7.47	8.93	7.18	7.93	9.32
12	ABC: Upstream Woodville Road Bridge	8.99	9.56	10.63	9.21	9.80	10.81	9.52	10.17	11.04
13	Overland Flow: Woodville Road Underpass	9.47	10.12	10.56	9.67	10.34	10.61	9.94	10.46	10.79

ID	Location	Base Case			CC7			CC8		
		20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP
14	Overland Flow: P'matta Road Underpass east of Mort Street	6.42	6.75	8.6	6.59	6.95	8.70	6.81	7.28	8.85
15	Overland Flow: Good St near Prince St	5.63	5.65	5.97	5.64	5.66	6.14	5.65	5.69	6.29

The CC7 and CC8 have the greatest effect on flood levels of the RCP4.5 and RCP8.5 scenarios tested. Most locations are around 0.2-0.4 m higher for CC7, while CC8 is around 0.5-0.7 m higher in the 20% AEP and 5% AEP, and 0.2-0.4 m higher in the 1% AEP.

Table 14: Water Levels for Climate Change 9 Scenario

ID	Location	Base Case			CC9		
		20% AEP	5% AEP	1% AEP	20% AEP	5% AEP	1% AEP
1	Duck River: Confluence with Duck Creek	1.86	2.64	3.92	2.35	2.90	4.31
2	Duck River: Upstream Parramatta Road	2.48	3.46	4.72	2.81	3.61	4.86
3	Duck Creek: Upstream M4	4.35	4.85	5.58	4.38	4.88	5.63
4	Duck Creek: Upstream Parramatta Road	4.51	5.08	6.02	4.54	5.11	6.04
5	ABC: Confluence with Duck Creek	3.99	4.52	5.41	4.04	4.56	5.48
6	ABC: East end of A'Beckett Street	4.35	4.87	5.78	4.38	4.90	5.82
7	ABC: Upstream Arthur Street Bridge	4.42	4.93	5.85	4.46	4.96	5.89
8	ABC: Upstream Alfred Street Bridge	4.47	4.97	5.91	4.50	5.00	5.95
9	ABC: Upstream Good Street Bridge	4.66	5.11	6.2	4.69	5.14	6.24
10	ABC: Upstream Harris Street footway	5.13	5.60	6.78	5.14	5.61	6.81
11	ABC: U/S railway near Duke Street	6.49	7.16	8.67	6.47	7.14	8.67
12	ABC: Upstream Woodville Road Bridge	8.99	9.56	10.63	8.99	9.52	10.61
13	Overland Flow: Woodville Road Underpass	9.47	10.12	10.56	9.47	10.12	10.56
14	Overland Flow: P'matta Road Underpass east of Mort Street	6.42	6.75	8.6	6.42	6.75	8.60
15	Overland Flow: Good St near Prince St	5.63	5.65	5.97	5.63	5.65	6.00

As with CC5 and CC6, CC9 has very minimal effect on flood levels in the study area, with most locations showing less than 0.1 m increase in flood level. The locations of increase above 0.1 m in the 1% AEP from the base case are the two Duck River locations.

6.9 Preliminary Flood Planning Area

The Flood Planning Area is an area of land within which flood planning controls apply to development, based on the 1% AEP flood extent plus freeboard. The release of new LEP clauses 5.21 and 5.22 mean controls now also apply up to the PMF flood extent. At this flood study stage, a Preliminary Flood Planning Area has been mapped based on the 1% AEP with climate change (specifically 'CC8' in the previous section) and a freeboard of 0.5 m. The Preliminary FPA is shown on Figure A 115. The FPA is limited to areas of significant overland and mainstream flow and so does not include the very shallow flowpaths (i.e. ~0.1 m in 1% AEP) on the edge of the catchment.

6.10 Model Comparison – ARR87 and Previous Studies

Table 15 presents the design flood levels and flows from multiple previous studies which used ARR87 (see details in Section 3.1.9), in comparison to those from the current study. Results have been included for Duck Creek and Duck River on the basis that these determine the A'Becketts Creek flood level in the lower catchment in certain events. It is noted that the current study will not supersede the Duck Creek and Duck River flood levels.

Table 15: Comparison to Previous Studies

Location	5% AEP – Previous	5% AEP - Current	1% AEP – Previous	1% AEP - Current	PMF - Previous	PMF - Current
	Peak Flood Levels (mAHD)					
Duck River: Confluence Duck Creek & Duck River*	3.7	2.6	4.2	3.9	6.8	6.3
Duck River: Confluence with Parramatta River**	3.2	0	3.2	1.8	5.5	2.8
Duck Creek: Upstream M4	4.6	4.9	5.0	5.6	7.3	7.2
A'Becketts Creek: Arthur Street Bridge	5.2	4.9	5.7	5.9	-	7.5
A'Becketts Creek: Harris Street Footbridge	5.8	5.6	6.1	6.8	-	8.4
	Peak Flows (m3/s)					
Duck River: Upstream Parramatta Road	133	94	168	159	225	312
Duck Creek: Upstream Parramatta Road	62	32	82	65	203	197
A'Becketts Creek at Dalley Street	98	69	118	90	-	-
A'Becketts Creek at Rail Bridge near Duck Creek	104	57	127	108	-	-

*Note: Grey rows are for comparison only and these locations will not be superseded or updated by the current study. The current study is only producing design flood information for A'Becketts Creek.

**Note: This location is at the model downstream boundary so will be strongly influenced by the boundary conditions

The current study produces levels and flows that are both lower and higher than previous estimates, depending on the location and the flood event. For the 5% AEP, Duck River levels are 1.1-3.2 m lower, Duck Creek is 0.3 m higher, and A'Becketts Creek is 0.1-0.2 m lower, and all flows are around 30-50% lower than the previous estimates. For the 1% AEP, Duck River is 0.2-1.4 m lower, Duck Creek is 0.6 m higher, and A'Becketts Creek 0.2 m higher in the lower catchment, and 0.7 m higher under the M4 at Harris Street footbridge, while flows are around 10-30% lower. The most likely causes of the changes are:

- Lower IFD estimates for the catchments under ARR2019, compared to ARR87 (this is offset by the upscaled 1% AEP rainfall and temporal pattern, for that event).
- Similarly, flow changes as a result of revised temporal patterns from ARR2019
- Model changes, as the current study is based on relatively new models, and the previous A'Becketts Creek hydraulic model was a 1D model
- Tailwater changes, as the Duck River study used tailwater levels of 2.66 and 3.18 mAHD for the 5% AEP and 1% AEP, whereas the current study uses normal depth boundary for the 5% AEP and 1.75 mAHD for the 1% AEP.

Comparison of 1% AEP flood extents between the current study and the 2009 A'Becketts Creek study shows:

- Flood extents under the M4 are largely the same between the studies, with neither showing significant out-of-bank flooding.
- Flood extents in the lower section around Arthur Street and Alfred Street are slightly larger in the previous study. In the 2009 study, the 1% AEP flood levels at these locations were lower than the current study. This is likely a result of the model schematisation with the previous model in 1D.
- Downstream of James Ruse Drive the current study shows wider flood extents particularly to the north of the creek, which is likely due to improved representation of the interaction with Duck Creek and Duck River flooding.

6.11 Model Comparison – ROG Model

The ROG model was used as a check of the peak flows produced by WBNM and TUFLOW, and to confirm the TUFLOW model captures all relevant overland flowpaths in the study area. The 1% AEP results of the ROG model are shown on Figure 14. The ROG model ran the same two critical storm durations as the TUFLOW model. A comparison of peak flow rates is presented in Table 16. The flow rate comparison is made against TUFLOW as WBNM channel flows are only applied at the model boundary and are not representative of design flows inside the TUFLOW model area.

Table 16: ROG and WBNM/TUFLOW Flow Comparison

Location	Flow (m^3/s)			
	5% AEP - TUFLOW	5% AEP - ROG	1% AEP - TUFLOW	1% AEP - ROG
Harris Street Pedestrian Bridge (30min in 5% AEP, 60min in 1%)	67.9	27.8	107.7	78.4

Duck Creek: Downstream Parramatta Road (30min in 5% AEP, 60min in 1%)	31.8	33.0	57.9[3]	54.3
Duck River: Upstream Parramatta Road (360min in 5% AEP, 720min in 1%)	94.0	97.7	131.4	178.6

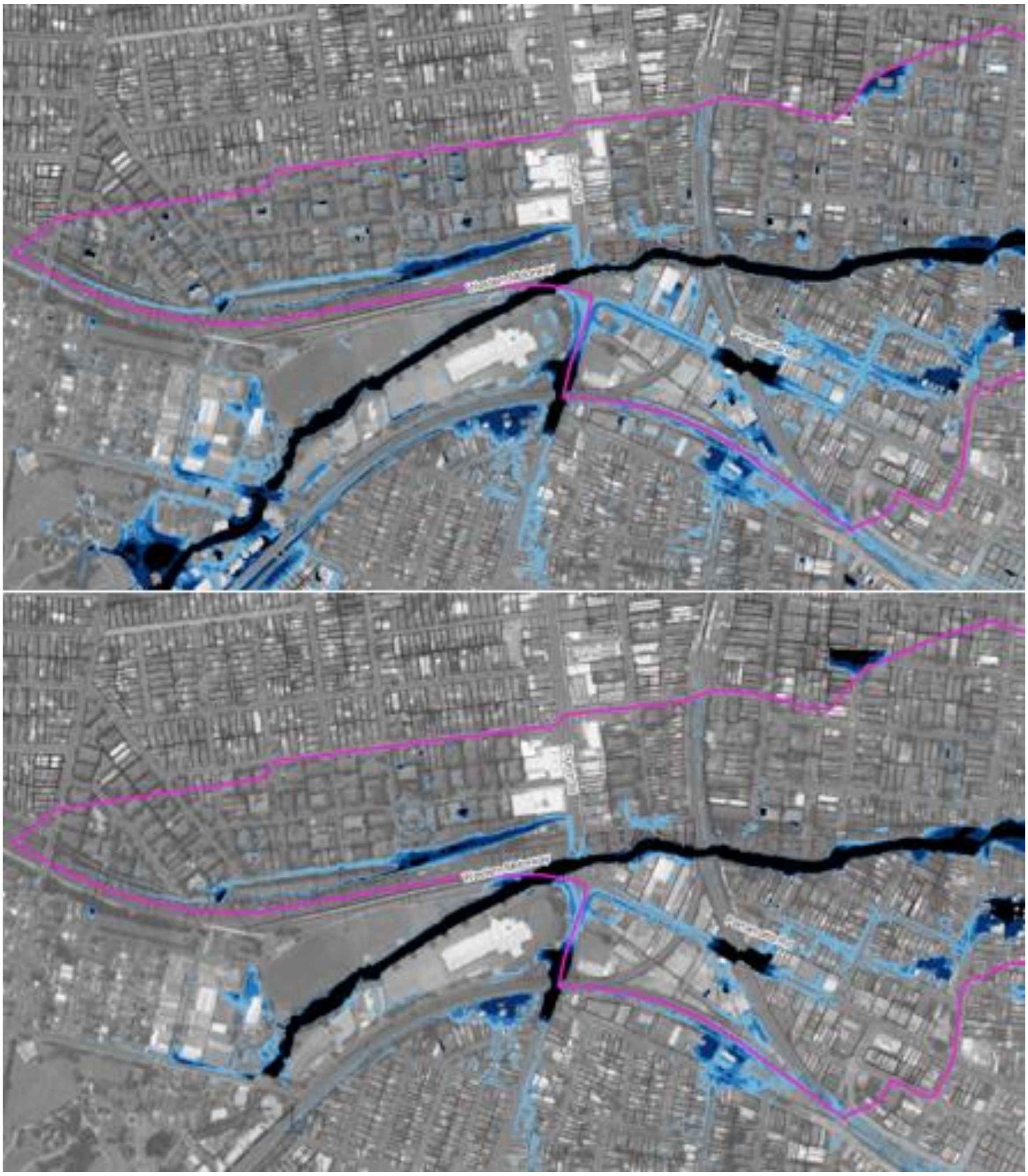
The comparison shows that the TUFLOW/WBNM and ROG models differ significantly in some areas. In A'Becketts Creek the ROG model shows significant attenuation and is not considered a reliable estimate of mainstream flood behaviour. The Duck Creek estimates are similar between the two models. Duck River is around 35% higher in the 1% AEP and has similar flows in the 5% AEP.

Sketch 25 below compares the mapping of overland flowpaths by the TUFLOW and ROG models, for the 1% AEP 60 minute duration event. The ROG model is used to confirm that the TUFLOW model has included all significant flowpaths, in the study area. The figure shows:

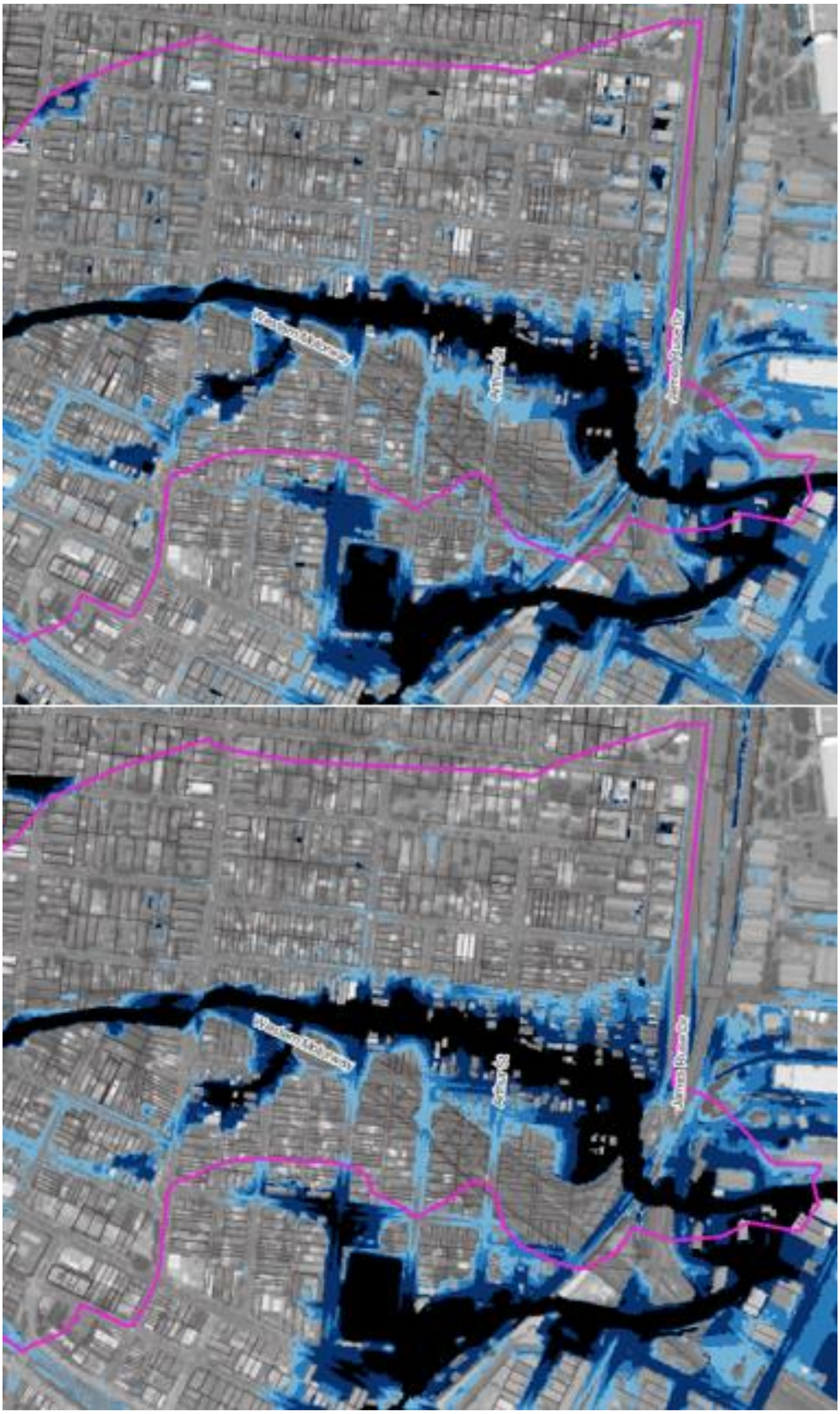
- On the north side of the creek, in the north-west area, both models show ponding against the road embankment but neither shows any significant overland flowpaths.
- Similarly on the remaining area on the north side of the creek, there are no prominent topographic depressions where a flowpath forms. Flow upstream/north of Alfred Street bridge appears in both models.
- South of the creek, in the Granville station area, both models show the prominent sag points where flow accumulates.
- Both show the significant overland flowpath that flows generally north-east and enters the creek between Good Street and Alfred Street.

The comparison confirms the TUFLOW captures all overland flowpaths of interest to the study. The TUFLOW model uses fine-scale inflow locations (based on the small subcatchments used in WBNM) and so represents overland flow to a high resolution.

[3] Separately to the ROG comparison, the table shows the TUFLOW peak flow estimates are significantly lower in Duck Creek than A'Becketts Creek despite the catchments having similar size. The main reason for this is Granville Park detention basin attenuating flow, and similar attenuating features in the lower Duck Creek catchment including Scout Memorial Park where the two tributaries meet, William Street just downstream, and the backwater effect in the lower catchment from A'Becketts Creek and Duck River inflows.



Sketch 25 TUFLOW (bottom) and ROG (top) comparison of overland flowpaths, west half of study area



Sketch 26 TUFLOW (bottom) and ROG (top) comparison of overland flowpaths, east half of study area

6.12 Model Sensitivity Analysis

Sensitivity analysis describes the sensitivity of model results to changes in the modelling parameters. These parameters include structure blockage, hydraulic roughness and tailwater. Each parameter is estimated based on the available data, but, due to the complexity of the catchment and flood-producing rainfall, the estimate will involve a series of assumptions and therefore has a degree of uncertainty. The sensitivity analysis therefore qualifies the assumptions by measuring their effect on the modelled flood behaviour. Large changes in the flood behaviour indicates a higher degree of uncertainty in the model results.

The sensitivity is tested by varying each parameter within a reasonable estimate range, and then re-running the hydraulic models to determine the peak flood level results for each scenario, for two design events (5% and 1% AEP). The sensitivity is then quantified by measuring the impact on the peak flood level at a series of reporting locations.

The parameters tested and the results of the sensitivity analysis are presented below in Table 17. Note that structure blockage is also included in the design event modelling which uses multiple blockage scenarios.

Table 17: Parameter Sensitivity - Results

Parameter	Approach	Results
Hydraulic roughness	Hydraulic roughness was increased by 20%, and decreased by 20%, in TUFLOW	Increased roughness showed similar sensitivity in both 5% AEP and 1% AEP events, with an average increase in flood level of around 0.25 m along the channel and around 0.16 m in the upper study area. Along overland flow paths the increase is around 0.07 m. Decreased roughness showed similar sensitivity in both 5% AEP and 1% AEP events, with an average decrease in flood level of round 0.22 m around the channel and 0.2 m in the upper study area. Along overland flow paths the decrease is around 0.1 m.
Blockage (1)	50% blockage applied to all pits, pipes, and the two A'Becketts Creek structures <6.1 m in size. 100% blockage applied to all pipes and the two A'Becketts Creek structures <6.1 m in size.	Increased blockage under the first scenario showed both higher and lower flood levels along A'Becketts Creek, depending on the location. Blockage at the railway line resulted in upstream increase of 0.22 m for both 5% and 1% AEP events, and slight decrease of 0.02 m downstream. The lower creek area around Arthur Street showed no significant change in flood level. The second scenario showed similar results with areas of both increase and decrease long the creek. Similarly upstream of the railway line showed increases of up to 2 m in flood level and a corresponding decrease of 0.65 m downstream. Flood levels in the lower study area had no significant change. The main overland flowpath was around 0.2 m higher in the 5% AEP event and 0.1 m higher in the 1% AEP event.
Blockage (2)	Blockage of individual structures on A'Becketts Creek to test whether blockage of one structure in isolation produced higher flood levels than blocking both structures (only two	Blockage of only the Church Street culvert was compared to the blockage of both structures (at Church Street and Duke Street). Model results showed flood levels were insensitive to the individual blockage, which is expected as the peak flow arriving at Church Street is unchanged.

	structures have design blockage applied).	Blockage of only the Duke Street culvert was compared to the blockage of both structures. Model results showed flood levels were insensitive to the individual blockage. Although marginally more flow arrives at Duke Street relative to the blockage of both structures, the increase in flood level was only 0.006 m, i.e. negligible. The same process was repeated for the three Council nominated structures (M4 to Woodville Road Cycleway, Church Street Bridge, and M4 to James Ruse Drive exit ramp). None of the three produced a design level 0.01 m above the combined blockage run, i.e. there was no sensitivity to individual blockage. Based on these results the design scenarios do not involve blockage of individual structures.
Downstream Boundary Conditions	The adopted design flood level, which uses an elevated Parramatta River level, was increased by 0.3 m.	An increase in the adopted tailwater did not show any significant change in flood level along the creek, or overland flowpaths. There was an increase of around 0.01 m in the creek flood level and up to 0.02 m in some areas.
Cumulative Development	The cumulative effect of potential future development is modelled by increasing imperviousness in areas where zoning permits significant future development, e.g. a large cleared site with residential or commercial/industrial zoning. No such areas were identified for A'Becketts Creek, which is fully developed aside from parks and open space areas. Discussion is ongoing with Council regarding potential future development.	No significant impacts identified (TBC).

In summary, the analysis found that the model results are largely insensitive to the adopted tailwater levels, while higher and lower roughness values did show some sensitivity in the model results. The blockage scenarios showed the areas of potential blockage along the creek can significantly affect flood levels, and that while overland flow is affected by pit and pipe blockage, the effect is not large.

6.13 Model Stability Checks

The following model stability checks were made of the TUFLOW model of the 1% AEP and PMF runs:

- 1D negative depths. Result: None
- Warnings during simulation. Result: None
- Final Cumulative Mass Error: 0.01% (1% AEP) and -0.01% (PMF)
- Tlf.hpc and tlf.dt files review. Result: No repeated timesteps or negative depths, no NaN warnings. Minimum timestep and control numbers are reasonable.

This data and related stability outputs are included in the TUFLOW .tlf files in the log subfolder.

7. REFERENCES

1. Australian Disaster Resilience Handbook 7 – Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia, 2017, Australian Institute for Disaster Resilience.
2. Australian Rainfall and Runoff, 2016, Commonwealth of Australia.

8.GLOSSARY

annual exceedance probability (AEP)	the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. Eg, if a peak flood discharge of 500 m3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m3/s or larger events occurring in any one year.
Australian Height Datum (AHD)	a common national surface level datum approximately corresponding to mean sea level.
average annual damage (AAD)	depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
average recurrence interval (ARI)	the long-term average number of years between the occurrence of a flood as big as or larger than the selected event. For example, floods with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
catchment	the land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	the council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the council, however legislation or an EPI may specify a Minister or public authority (other than a council), or the Director General of DIPNR, as having the function to determine an application.
development	is defined in Part 4 of the EP&A Act infill development: refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development new development: refers to development of a completely different nature to that associated with the former land use. Eg, the urban subdivision of an area previously used for rural purposes. New developments involve re-zoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. redevelopment: refers to rebuilding in an area. Eg, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either re-zoning or major extensions to urban services.

disaster plan (DISPLAN)	a step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	the rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
effective warning time	the time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	a range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	the remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	is synonymous with flood prone land (ie) land susceptible to flooding by the PMF event. Note that the term flood liable land covers the whole floodplain, not just that part below the FPL (see flood planning area).
flood mitigation standard	the average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.

floodplain	area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	the measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	a management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at state, division and local levels. Local flood plans are prepared under the leadership of the SES.
flood planning area	the area of land below the FPL and thus subject to flood related development controls. The concept of flood planning area generally supersedes the "flood liable land" concept in the 1986 Manual.
flood planning levels (FPLs)	are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the "standard flood event" in the 1986 manual.
flood proofing	a combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	land susceptible to flooding by the PMF event. Flood prone land is synonymous with flood liable land.
flood readiness	Readiness is an ability to react within the effective warning time.
flood risk	potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below: <u>existing flood risk:</u> the risk a community is exposed to as a result of its location on the floodplain. <u>future flood risk:</u> the risk a community may be exposed to as a result of new development on the floodplain. <u>continuing flood risk:</u> the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

flood storage areas	those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
freeboard	provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	in a residential situation: a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. in an industrial or commercial situation: an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	a source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community.
hydraulics	term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	a graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

major drainage	councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purposes of this manual major drainage involves: • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or • water depths generally in excess of 0.3m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or • major overland flowpaths through developed areas outside of defined drainage reserves; and/or • the potential to affect a number of buildings along the major flow path.
mathematical/computer models	the mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	the merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into council plans, policy, and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local flood risk management policy and EPIs.
minor, moderate and major flooding	both the SES and the BoM use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: <u>minor flooding:</u> causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. <u>moderate flooding:</u> low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. <u>major flooding:</u> appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

modification measures	measures that modify either the flood, the property or the response to flooding.
peak discharge	the maximum discharge occurring during a flood event.
probable maximum flood	the PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
probable maximum precipitation	the PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	a statistical measure of the expected chance of flooding (see AEP).
risk	chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	the amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	equivalent to water level (both measured with reference to a specified datum).
stage hydrograph	a graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	a plan prepared by a registered surveyor.
water surface profile	a graph showing the flood stage at any given location along a watercourse at a particular time.

REPORT FIGURES

APPENDIX A – DESIGN FLOOD MAPS

APPENDIX B – COMMUNITY QUESTIONAIRE

The following questions were asked on the questionnaire.

- First Name
- Last Name
- Phone
- Email
- Do you live, work or own property in the A'Becketts Creek flood study catchment area?
- What is the address of the property that you live, work or own within the A'Becketts Creek flood study catchment area?
- How long have you lived, worked or owned property at this address?
- Have you seen or experienced flooding in the A'Becketts Creek flood study catchment area?
    - When did you see or experience flooding in the A'Becketts Creek flood study catchment area?
    - Do you have any photographs or video of the flooding?
    - If yes, please upload your photos here.
    - What was affected by flooding?
    - My property is: (free-standing, semi-detached, etc.)
    - If your business address is not the same as your home address, please provide it below.
    - Where did the water come from?
    - How deep was the flood water?
    - How long did the flooding last?
    - Can you tell us a little about the damage that was caused by flood water?
- I have other flood events to report:
    - When did you see or experience flooding in the A'Becketts Creek flood study catchment area?
    - Do you have any photographs or video of the flooding?
    - If yes, please upload your photos here.
    - What was affected by flooding?
    - My property is:
    - If your business address is not the same as your home address, please provide it below.
    - Where did the water come from?
    - How deep was the flood water?
    - How long did the flooding last?
    - Can you tell us a little about the damage that was caused by flood water?
- Do you know where to go for flood information or to find out if your property is flood affected?
    - If yes, which of these services/organisations have you used to find out if your home is flood affected?

APPENDIX C – ARR2019 BLOCKAGE ASSESSMENT

Blockage was assessed using a combination of the ARR2019 and Council's preferred method.

Specifically:

- ARR2019 Blockage Form was used for each structure (listed below)
- Catchment data on blockage debris was not used to estimate the L10 parameter. The parameter instead used the value of 1.5 m instructed by Council.
- For structures greater than 6.1 m diagonal width no blockage was applied for any event. This differs from the ARR2019 Blockage Form which estimates a 15% blockage for events rarer than 0.5% AEP.

The blockage assessment results shown below. The blockage at each structure is in Table C1.

DEBRIS TYPE / MATERIAL / L_{10} / SOURCE AREA

Debris Type/Material	L_{10}	Source Area	How Assessed
Non-urban Floating	1.5 m based on Council instruction	Parks and other areas with vegetation.	Aerial/Google Maps & Street View, previous studies
Urban Floating	1.5 m based on Council instruction	Urban areas surrounding the creek.	Aerial/Google Maps & Street View, previous studies
Non-floating	Sand and silts – 0.002	From road surface	Aerial/Google Maps & Street View, previous studies

DEBRIS AVAILABILITY (HML) – *for the selected debris type/size and its source area*

Availability	Typical Source Area Characteristics	Notes
High	• *Dense forest, thick vegetation, extensive canopy, difficult to walk through with considerable fallen limbs, leaves and high levels of floor litter.* • *Streams with boulder/cobble beds and steep bed slopes and banks showing signs of substantial past bed/bank movements.* • *Arid areas, where loose vegetation and exposed loose soils occur and vegetation is sparse.* • *Urban areas that are not well maintained and/or old paling fences, sheds, cars and/or stored loose material etc., are present on the floodplain close to the water course.*	
Medium	• *State forest areas with clear understory, grazing land with stands of trees* • *Source areas generally falling between the High and Low categories.*	Non-Urban Floating, based on previous studies and site visit.
Low	• *Well maintained rural lands and paddocks, with minimal outbuildings* • *Streams with moderate to flat slopes and stable beds and banks.* • *Arid areas where vegetation is deep rooted and soils resistant to scour* • *Urban areas that are well maintained with limited debris present in the source area.*	Urban Floating, based on previous studies and site visit. Non-floating: based on previous studies and site visit.

DEBRIS MOBILITY (HML) - *for the selected debris type/size and its source area*

Mobility	Typical Source Area Characteristics	Notes
High	• *Steep source area with fast response times and high annual rainfall and/or storm intensities and/or source areas subject to high rainfall intensities with sparse vegetation cover.* • *Receiving streams that frequently overtop their banks.* • *Main debris source areas close to streams*	
Medium	• *Source areas generally falling between the High and Low categories.*	Non-Urban Floating: fast urban catchment response, high vegetation cover Non-floating
Low	• *Low rainfall intensities and large, flat source areas.* • *Receiving streams that Infrequently overtop their banks.* • *Main source areas well away from streams*	Urban Floating: Source areas are often away from creek

DEBRIS TRANSPORTABILITY (HML) - *for the selected debris type/size and stream characteristics*

Transportability	Typical Transporting Stream Characteristics	Notes
High	• *Steep bed slopes (> 3%).and/or high stream velocity (V>2.5m/sec)* • *Deep stream relative to vertical debris dimension (D>0.5L_{10})* • *Wide streams relative to horizontal debris dimension. (W>L_{10})* • *Streams relatively straight and free of constrictions/snag points.* • *High temporal variability in maximum stream flows*	
Medium	• *Streams generally falling between High and Low categories*	Non-Urban Floating: Shallow and narrow drain. Velocity close to 2.5m/s Floating: Shallow and narrow drain. Velocity close to 2.5m/s Non-floating: Shallow and narrow drain. Velocity close to 2.5m/s
Low	• *Flat bed slopes (< 1%).and/or low stream velocity (V<1m/sec)* • *Shallow stream relative to vertical debris dimension (D<0.5L10)* • *Narrow streams relative to horizontal debris dimension. (W<L10)* • *Streams meander with frequent constrictions/snag points.* • *Low temporal variability in maximum stream flows*	

SITE BASED DEBRIS POTENTIAL 1%AEP (HML) - *for the selected debris type/size arriving at the site*

Debris Potential	Combinations of the Above (any order)	Notes
High	*HHH or HHM*	
Medium	*MMM or HML or HMM or HLL*	MMM
Low	*LLL or MML or MLL*	LLM LMM

AEP ADJUSTED SITE DEBRIS POTENTIAL (HML) - *for the selected debris type/size*

Event AEP	At Site 1% AEP Debris Potential			AEP Adjusted at Site Debris Potential		
	High	Medium	Low			
AEP > 5% (frequent)	*Medium*	*Low*	*Low*	Low	Low	Low
AEP 5% - AEP 0.5%	*High*	*Medium*	*Low*	Medium	Low	Low
AEP < 0.5%	*High*	*High*	*Medium*	High	Medium	Medium

MOST LIKELY DESIGN INLET BLOCKAGE LEVEL (B_{DES}%) *for the selected debris type/size*

Control Dimension Inlet Width W (m)	At Site 1% AEP Debris Potential		
	High	Medium	Low
$W < L_{10}$	*100%*	*50%*	*25%*
$W \geq L_{10} \leq 3L_{10}$	*20%*	*10%*	*0%*
$W > 3L_{10}$	*10%*	*0%*	*0%*

Event AEP	Bdes% Floating
AEP > 5% (frequent)	*25%*
AEP 5% - AEP 0.5%	*50%*
AEP < 0.5%	*100%*

LIKELIHOOD OF SEDIMENT BEING DEPOSITED IN WATERWAY (HML)

Peak Velocity through Structure (m/s)	Particle Type				
	Clay/Silt	Sand	Gravel	Cobbles	Boulders
>= 3	*L*	*L*	*L*	*L*	*M*
1.0 to 3	*L*	*L*	*L*	*M*	*M*
0.5 to 1	*L*	*L*	*L*	*M*	*H*
0.1 to 0.5	*L*	*L*	*M*	*H*	*H*
< 0.1	*L*	*M*	*H*	*H*	*H*

Note: V~2.4m/s

MOST LIKELY DEPOSITIONAL BLOCKAGE LEVELS – B_{DES}%

Likelihood that deposition will occur	AEP Adjusted Debris Potential		
	High	Medium	Low
High	*100%*	*60%*	*25%*
Medium	*60%*	*40%*	*15%*
Low	*25%*	*15%*	*0%*

Event AEP	Bdes% Non-Floating
AEP > 5% (frequent)	*See table*
AEP 5% - AEP 0.5%	*See table*
AEP < 0.5%	*See table*

Table C1 – Blockage Applied

Structure Location	L_{10}	Width (if less than 6.1 m)	FLOATING B_{DES}%			NON-FLOATING B_{DES}%		
			AEP > 5%	AEP 5% - AEP 0.5%	AEP < 0.5%	AEP > 5%	AEP 5% - AEP 0.5%	AEP < 0.5%
A'Becketts Creek starting from upstream end								
Pedestrian bridge approximately 80 m west of Parramatta Road/Woodville Road intersection	1.5		0%	0%	0%	0%	0%	0%
M4 ramp at same location, immediately downstream	1.5		0%	0%	0%	0%	0%	0%
Church Street bridge	1.5		0%	0%	0%	0%	0%	0%
Culvert running parallel to the creek under Church Street bridge pedestrian path	1.5	2.5	0%	10%	20%	0%	0%	0%
Railway crossing near the north end of Duke Street	1.5		0%	0%	0%	0%	0%	0%
Pedestrian bridge at the same location	1.5	3.5	0%	10%	20%	0%	0%	0%
Pedestrian bridge at Harris Street	1.5		0%	0%	0%	0%	0%	0%
Good Street bridge	1.5		0%	0%	0%	0%	0%	0%
Alfred Street bridge	1.5		0%	0%	0%	0%	0%	0%
Arthur Street bridge	1.5		0%	0%	0%	0%	0%	0%
Motorway bridge joining M4 and James Ruse Drive, near east end of A'Beckett Street	1.5		0%	0%	0%	0%	0%	0%
Rail bridge approximately 50 m downstream (old Carlingford line)	1.5		0%	0%	0%	0%	0%	0%
Fleet Street bridge, immediately downstream of the rail bridge	1.5		0%	0%	0%	0%	0%	0%
Unwin Street bridge	1.5		0%	0%	0%	0%	0%	0%
Duck Creek starting from upstream end								
William Street bridge/culverts	1.5	3.35	0%	10%	20%	0%	0%	0%
Memorial Drive bridge	1.5		0%	0%	0%	0%	0%	0%
Train line immediately downstream of Memorial Drive	1.5	5.6	0%	0%	10%	0%	0%	0%
Bridge at end of East Street	1.5		0%	0%	0%	0%	0%	0%
Parramatta Road bridge	1.5		0%	0%	0%	0%	0%	0%
Rail bridge near Arthur Street	1.5		0%	0%	0%	0%	0%	0%
Driveway bridge near George Street	1.5		0%	0%	0%	0%	0%	0%
James Ruse Drive bridge	1.5		0%	0%	0%	0%	0%	0%
M4 (multiple elevated roadways)	1.5		0%	0%	0%	0%	0%	0%
Kay Street bridge	1.5		0%	0%	0%	0%	0%	0%
Duck River starting from upstream end								
Rail bridge near Clyde Station	1.5		0%	0%	0%	0%	0%	0%

Unnamed road bridge immediately downstream	1.5		0%	0%	0%	0%	0%	0%
Parramatta Road bridge	1.5		0%	0%	0%	0%	0%	0%
Pedestrian bridge just upstream of M4	1.5		0%	0%	0%	0%	0%	0%