# Lovers Jump Creek Flood Study

Ku-ring-gai Council

Review Report

Version B

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# Lovers Jump Creek Flood Study

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| A | 23/02/2018 | For public exhibition | L Chong | A Hossain | L Chong |
| B | 14/11/2018 | Updated flood planning area mapping. Updated details on community consultation | L Chong | A Hossain | L Chong |
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## Executive Summary

A Floodplain Risk Management Study and Plan (FRMSP) is being conducted for the 9.7km$^2$ Lovers Jump Creek catchment, including the waterways of Lovers Jump Creek and a number of tributaries in the suburbs of Turramurra, North Turramurra, Warrawee, Wahroonga and North Wahroonga in the Ku-ring-gai Local Government Area. The overall purpose of the FRMSP is to define the flood risk to existing development in the catchment, to identify feasible structural and non-structural mitigation measures to reduce the flood risk to people and property and to develop a plan for their implementation in accordance with the NSW Government's *Floodplain Development Manual*.

As a part of the FRMSP the Lovers Jump Creek Flood Study (Jacobs, 2016) has been reviewed and the Flood Study has subsequently been updated. The flood mapping and results contained in this current Flood Study Review Report supersedes the 2016 Flood Study.

The catchment is comprised primarily of residential land use and forested areas. The terrain is such that flooding is generally confined to the well-defined flow paths and watercourses. In developed areas the watercourses are often piped and filled-in for development to occur, hence floodwaters may pass through properties and over roads causing relatively shallow overland flooding. There are some locations where flows may be obstructed, for example by road and railway embankments, causing flows to pond on the upstream side to greater depths which may then overtop the road embankment.  Some properties in the catchment are situated on low areas in close proximity to the creeks and flow paths that regularly experience flooding which encroaches on and surrounds the dwelling.

The flood study assessment is based on a detailed TUFLOW 1D/2D dynamic hydraulic model developed specifically for this study. The model has been set up at a 2m resolution of the floodplain, which allows determination of flooding behaviour through properties and between buildings and other obstructions. The model includes all stormwater pits and pipes identified in Council's asset database, in addition to other identified major waterway structures and minor crossings such as footbridges. Appropriate levels of blockage have been applied to stormwater pits, culvert inlets and bridges, consistent with industry guidelines. Hydrologic modelling of has been undertaken based on a DRAINS stormwater model provided by Council to establish inflow hydrographs at numerous local sub-catchments in the study area. The modelling has been verified against flooding observations provided by local residents of the February 2010 storm event.

Design flood events between the 20% AEP event up to the PMF event, for a range of event durations up to 2 hours have been simulated. The critical event durations are observed to be the 25 minute and 1.5 hour events for events up to the 1% AEP. The critical duration for the PMF varies throughout the catchment, but is typically the 45 minute duration event in most parts of the catchment, with the 1 hour event critical in large flood storage areas. Flood mapping of depth, flood level, flood hydraulic categories and provisional flood hazard has been undertaken for selected event AEPs.

The number of properties affected by varying maximum flood depths is summarised in **Table 1**. The maximum flood depth typically occurs within a flow path or watercourse which passes through the property, and may not reflect the flood depth at the dwelling. The analysis is based on the land parcels spatial layer provided by Council and includes both private property as well those occupied by Ku-ring-gai Chase National Park and other reserves and open space.

Table 1 Count of properties by maximum flood depth on each property

| Depth (m) | AEP | | | | | |
|---|---|---|---|---|---|---|
| | 20% | 10% | 5% | 2% | 1% | PMF |
| 0.1 – 0.2 | 48 | 56 | 103 | 107 | 109 | 112 |
| 0.2 – 0.5 | 174 | 171 | 290 | 306 | 338 | 391 |
| 0.5 – 1.0 | 89 | 101 | 154 | 191 | 229 | 425 |
| 1.0 – 2.0 | 69 | 61 | 59 | 65 | 68 | 264 |
| >2.0 | 148 | 138 | 148 | 151 | 157 | 239 |
| Total | 528 | 527 | 754 | 820 | 901 | 1,431 |

The flood planning area mapping has been conducted for areas deemed to be affected by active flows in the 1% AEP event. This has been determined by consideration of flooding depth, continuity of the mapped flood inundation, presence of incised gullies in the flow path terrain and susceptibility of existing development. The flood planning area is defined by the area below the 1% AEP flood level plus a specified freeboard. In this study a 0.3m freeboard has been adopted for areas affected by overland flooding, and a 0.5m freeboard for those affected by mainstream flooding. The number of properties to which the mainstream and overland flood planning areas apply are summarised in **Table 2**.

Table 2 Number of Properties with Flood Planning Area

| Flood Planning Area | Number of Properties |
|---|---|
| Mainstream only (0.5m freeboard above 1% AEP flood) | 197 |
| Overland only (0.3m freeboard above 1% AEP flood) | 831 |
| Both Mainstream and Overland | 36 |
| Total | 992 |

Properties within the study area were classified for flood emergency response based on NSW Government floodplain risk management guidelines. The classification indicates the relative vulnerability of different areas of the catchment and considers the ability to evacuate certain parts of the community. The classification is denoted preliminary and subject to update in the subsequent Floodplain Risk Management Study.

Sensitivity testing indicates that peak flood levels are not overly sensitive to the varied rainfall loss and hydraulic roughness scenarios tested, with increases in 1% AEP flood levels typically less than 150mm in developed areas. However, some significant flood level increases of up to 1m were observed for the fully blocked hydraulic structures scenario, due to the height of the waterway structures which would need to be overtopped by floodwaters in the case of a fully blocked scenario. Existing development would be impacted by these increases. A fully blocked scenario is considered to be a highly conservative assumption as some amount of flow would likely be conveyed through the structure even in a highly blocked condition.

Climate change impact modelling indicates that existing development would be affected by increases in peak flood levels in overland flow paths of up to 0.25m in the 30% rainfall intensity increase scenario. Some locations along watercourses would be affected by increases of up to 0.75m at certain locations. Flood levels increase by up to 0.35m at some road crossings.

A number of flooding “hot spots” have been identified based on the modelling, confirming several problem areas previously identified by Council, and identifying a number of additional locations. These are described in **Table 3**.

Table 3 Description of Flooding Hot Spots

| Location | Description |
|---|---|
| Properties on The Chase Road, including upstream properties near Eastern Road (along Lovers Jump Creek tributary) | Access may be cut-off due to creek overflows over private driveway crossings. High hazard flows around some dwellings on the northern side of the creek. |
| On Cudgee Street and Tennyson Avenue | Access cut-off due to creek overflows over private driveway crossings. Risk to dwelling and occupants on Cudgee Street property where the dwelling is immediately adjacent to left creek bank, due to high hazard flooding surrounding the dwelling in frequent events (e.g. 20% AEP). |
| Properties on Chilton Parade near Raymond Avenue and Davidson Avenue | Risk to dwelling and occupants due to high hazard flooding encroaching on the dwelling in frequent events (e.g. 20% AEP). |
| Properties near the Burns Road crossing | Access from Burns Road cut-off and high hazard flooding encroaching on dwellings. |
| Properties between Challis Avenue and The Chase Road | Risk to dwelling and occupants due to high hazard flooding encroaching on the dwelling in events as frequent as the 10% AEP. |
| Properties in sag points on Eastern Road north and south of Karuah Road | Properties on high side of the road affected by flood depths of 0.8 – 1m in frequent events (e.g. 20% AEP) and up to 1.2m in the 1% AEP. |
| Properties upstream of North Shore Railway embankment | Properties affected by flood depths at the dwelling of up to 1.3m in the 1% AEP and up to 4.8m in the PMF.<br>In a high culvert inlet blockage scenario (75% blockage) for the railway culvert near Brentwood Avenue, properties would be affected by flood depths at the dwelling of up to 2m in the 1% AEP. |
| Banks Avenue, North Turramurra | Sag point would not be passable in the 20% AEP event due to depths of flow exceeding 300mm, cutting off access to properties at the northern end of Banks Avenue. Could be potentially considered a drainage issue rather than a flooding issue. |
| **Roads*** | |
| Eastern Road near Chilton Parade | Road cut off in 20% AEP event with depths up to 0.4m. High hazard flooding in 1% AEP with depths up to 0.9m. |
| Challis Avenue sag point | Road cut off in 20% AEP event with depths exceeding 0.3m. High hazard flooding in 1% AEP with depths up to 0.9m. |
| Tennyson Avenue sag point | High hazard flooding over the road in 10% AEP with depths to 0.4m. High hazard flooding over the road in 1% AEP with depths exceeding 0.7m. |
| Burns Road sag point | Road cut off in 10% AEP event with depths exceeding 0.3m. High hazard flooding over the road in 1% AEP event with depths to 0.8m. |

* Further detailed assessment of road flooding will be undertaken during the FRMS.

The impacts of ARR 2016 on flood behaviour for the 1% AEP event in Lovers Jump Creek have been considered as a part of this flood study review. An assessment of at-site design rainfall estimates has also been undertaken. Based on the ARR 2016 design rainfall assessment findings it is recommended that ARR 1987 design rainfall and flood levels be adopted in the flood study review and FRMSP (i.e. no update to flood modelling), noting that ARR 1987 provides a conservative estimate of flooding in the study area.

This Flood Study Review Report has been placed on public exhibition in April 2018. It is recommended that Ku-ring-gai Council considers the adoption of this flood study review and the outputs such as the Flood Planning Levels (FPLs) to guide floodplain management and land use planning in the Lovers Jump Creek catchment. The FRMSP should consider the management of flood risk in the catchment, particularly at the identified flooding “hot spots”, which may include the development of flood mitigation strategies.

## Important note about this report

The sole purpose of this report and the associated services performed by Jacobs is to document the assessment undertaken for the Lovers Jump Creek Flood Study Review and the Floodplain Risk Management Study and Plan in accordance with the scope of services set out in the contract between Jacobs and Ku-ring-gai Council (“the Client”). That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client (if any) and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

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# 1. Introduction

## 1.1 General

Ku-ring-gai Local Government Area (LGA) encompasses an area of 85.4km$^2$ on Sydney's North Shore with a number of separate catchments draining to the Lane Cove River, Middle Harbour and Cowan Creek systems. Lovers Jump Creek is one creek system within the LGA which drains to Cowan Creek and is rated as a high priority catchment in terms of risk of flooding to existing development.

Patterns of urbanisation and associated construction of drainage infrastructure dating back to as early as the 1940's, have resulted in a number of watercourses being piped or crossed by road embankments and development occurring in sometimes unsuitable locations, putting this development at risk to flooding during heavy rainfall events. Flood events have occurred in recent history in 1984, 1988, 1990, 1991, 2010, 2011 and 2012, leading to flooding and damage to properties.

Hydrologic and drainage studies have been undertaken in the study area in the past, though some of these studies are up to 10 years old and most do not define the flood behaviour to the level of detail required in the NSW Government's *Floodplain Development Manual* (2005), which forms the current guidance for management of development and flood risk in NSW. Further, a significant amount of urban redevelopment has occurred in the catchment in recent years which has the potential to increase rainfall-runoff and hence flooding.

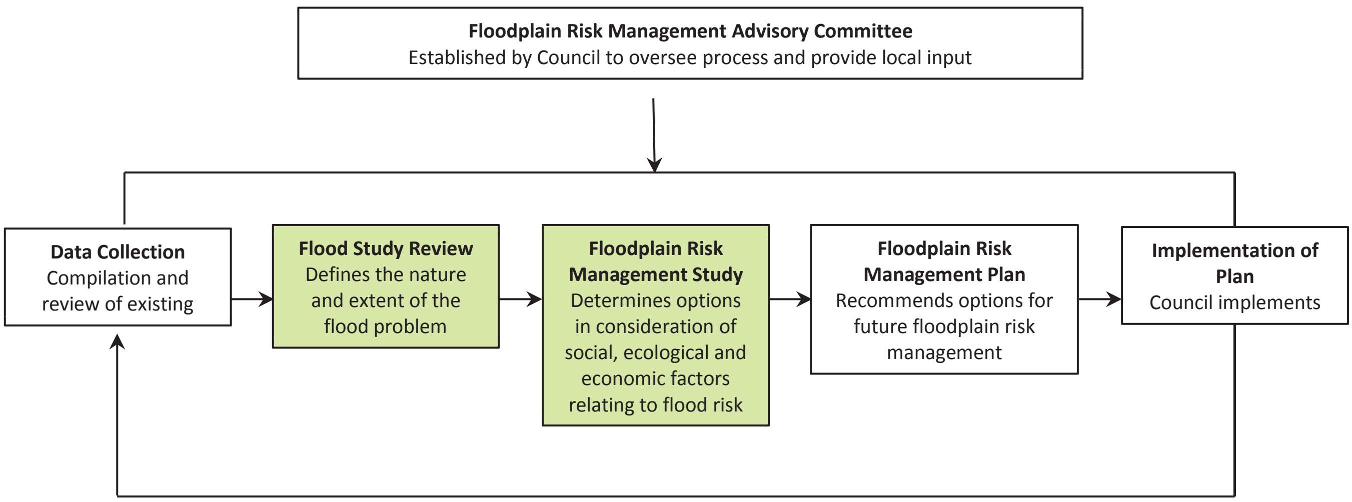
Ku-ring-gai Council ("Council") commissioned Jacobs to undertake a Floodplain Risk Management Study and Plan (FRMSP) for the Lovers Jump Creek catchment. As a part of the FRMSP the previous Lovers Jump Creek Flood Study (Jacobs, 2016) has been reviewed and updated.  This report documents the development and outcomes of the flood study review to define the existing nature of flooding in the study area. The flood mapping and results contained in this current Flood Study Review Report supersedes the 2016 Flood Study.

## 1.2 Floodplain Risk Management

Council is responsible for managing the existing, continuing and future flood risk for its Local Government Area (LGA). The floodplain risk management planning process, as set out in the *Floodplain Development Manual* (NSW Government, 2005) has a number of steps which are illustrated in **Figure 1-1**.

The Floodplain Risk Management Advisory Committee for Council was established in 2015 and includes a number of Council Representatives, staff from the Office of Environment and Heritage (OEH), the State Emergency Services (SES), in addition to local stakeholders including community representatives.

Figure 1-1 Floodplain Risk Management Process



## 1.3 Purpose of this Flood Study Review

The purpose of this flood study review is to provide an updated understanding of the existing and future flood risks in the study area and to provide information for the development of the subsequent floodplain risk management study and plan in accordance with the NSW Government's *Floodplain Development Manual*.

Key objectives of this flood study review are to:

- Develop and calibrate/verify hydrologic and hydraulic models for the estimation of overland and mainstream flood behaviour in the study area, taking into account the performance of the stormwater drainage network including overflows from the drainage network. The overflows contribute to overland flooding in some areas.
- Determine flooding behaviour and flood risk in the study area for a range of flood events between the 20% Annual Exceedance Probability (AEP) event and the Probable Maximum Flood (PMF) event.
- Map the flood hydraulic and hazard categories.
- Determine the flood planning areas for the 1% AEP event.
- Identify the flood emergency response categories for different parts of the catchment and community.
- Assess the sensitivity of flood behaviour to changes in hydrologic and hydraulic characteristics in the catchments.
- Assess the impact of climate change on flood levels in the study area.

The outcomes from this flood study review will form the basis for the identification, assessment and prioritisation of management measures in the FRMSP.

# 2. Background on Study Area

## 2.1 Catchment Description

The catchment has a total area of 9.7km$^2$ and includes Lovers Jump Creek and a number of tributaries in the suburbs of Turramurra, North Turramurra, Warrawee, Wahroonga and North Wahroonga in the Ku-ring-gai Local Government Area. The catchment is approximately bounded by the Pacific Highway to the south, Bobbin Head Road to the east and Grosvenor Road to the west. Burns Road crosses east-west through the southern half of the catchment, while the North Shore Railway Line traverses the far southern portion of the catchment. Eastern Road passes north-south through the centre of the study area. Lovers Jump Creek joins Cockle Creek (also known as Spring Gully Creek) at the northern end of the study area, and then Cowan Creek further to the north. The study area is depicted in **Figure 2-1**.

Ground elevations range from 30m AHD at the catchment outlet up to and exceeding 210m AHD at the southern end of the catchment. The catchment is generally gently to moderately sloped in developed parts of the catchment, and steep to very steep in most forested portions of the catchment. The watercourses themselves are very steep in some sections, including a number of waterfalls up to 20m high. The catchment terrain is shown on **Figure 2-2**.

Watercourses were observed during site inspections to experience some low levels of baseflow but would otherwise be expected to be dry during periods of low rainfall. Overland flow paths through developed areas are a mix of having being filled/piped and developed, or have been retained as more natural watercourses.

## 2.2 Existing Development

Land use in the catchment is predominantly low-density residential housing, with allotment size ranging from typical-sizes lots up to large lots over 2000m$^2$. There are some apartment developments along the Pacific Highway and railway line, and main commercial areas in Turramurra and Wahroonga villages. Development is generally confined to the southern two-thirds of the study area as well as to the ridge tops and upper hillsides as the valleys are generally too steep for development. The valleys are vegetated with natural bushland.

Overland flow paths and watercourses in the catchment flow through a number of private properties and are crossed by driveway culverts and bridges in addition to minor footbridges. A number of roads cross the watercourses with culvert structures. Burns Road, which crosses the main arm of Lovers Jump Creek, is the main waterway crossing in the catchment. Several roads, including Eastern Road have been constructed in fill over the overland flow paths, which have been piped under the roads. In some locations the road embankments pose significant obstructions to flow and cause ponding of floodwaters on private properties on the upstream side of the roads. The railway embankment also crosses several flow paths with the potential to pose a constraint on flows in extreme storm events.


GIS MAP file : LJCFSReview_R02_Fig2-1_Study_area_02

**Legend**

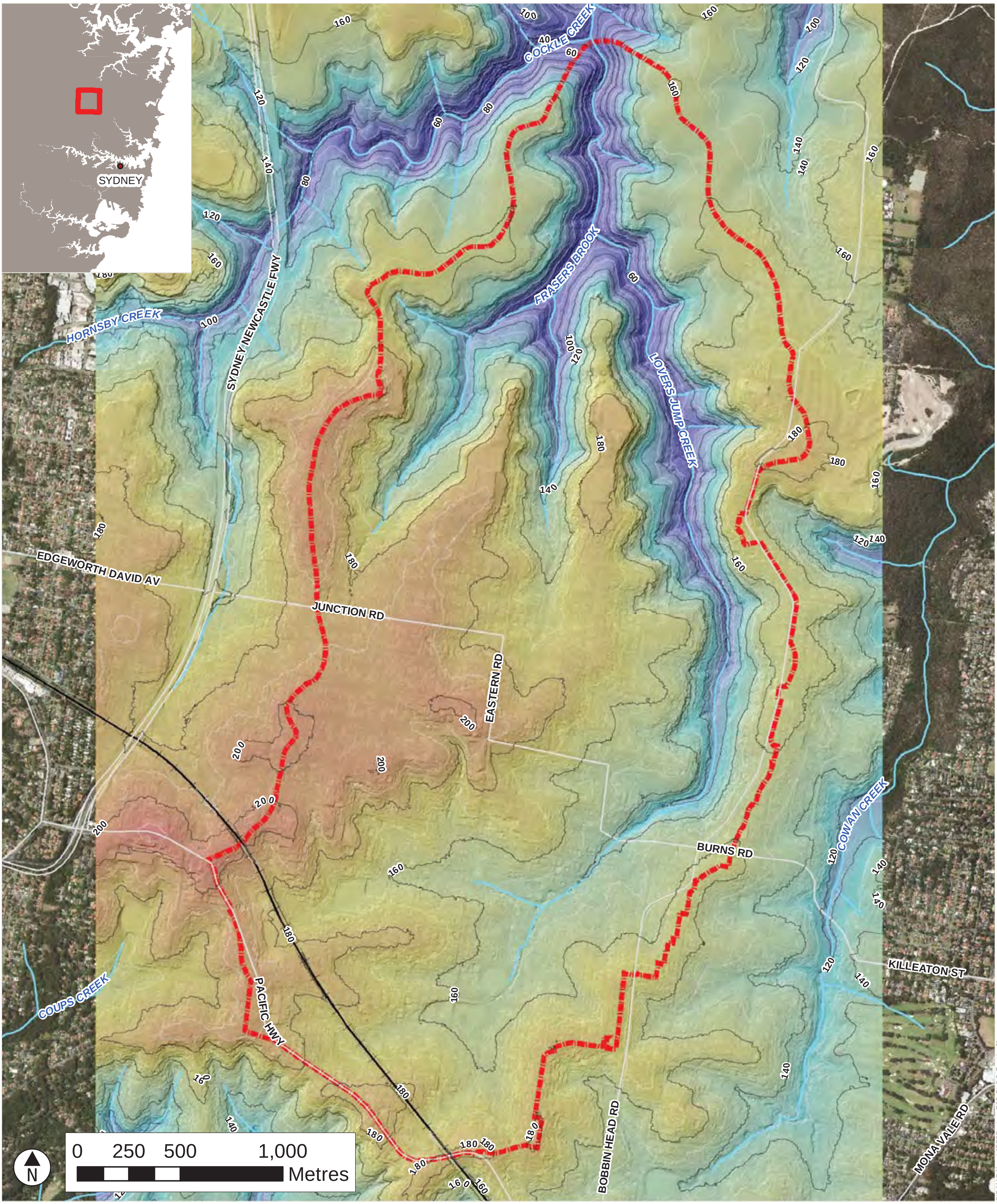
- Study Area
- Watercourse
- Railway
- Railway Station
- Main Road

JACOBS



A3

| | | | | | | |
|---|---|---|---|---|---|---|
| SHEET | 1 of 1 | | GDA 1994 MGA Zone 56 | | | |
| TITLE | Study Area | | | | | |
| PROJECT | Lovers Jump Creek Flood Study Review | | | | | |
| DRAWN | MR | PROJECT # | IA159900 | MAP # FIGURE 2-1 | REV 1 | VER 1 |
| CHECK | LC | DATE | 26/02/2018 | | | |




**Legend**

**Elevation m AHD**

High : 201.509

Low : 138.546

Elevation 20m contour

Elevation 10m contour

Watercourse

Main Road

Railway

Study Area

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A3

| | |
|---|---|
| SHEET | 1 of 1 — GDA 1994 MGA Zone 56 |
| TITLE | Catchment Terrain |
| PROJECT | Lovers Jump Creek Flood Study Review |

| DRAWN | PROJECT # | MAP # | REV | VER |
|---|---|---|---|---|
| MR | IA159900 | FIGURE 2-2 | 1 | 1 |
| CHECK LC | DATE 21/02/2018 | | | |

## 2.3 History and Nature of Flooding

Given the nature of the terrain in the study area, flooding is generally confined to the well-defined flow paths and watercourses. In developed areas the watercourses are often piped and filled-in for development to occur, hence floodwaters may pass through properties and over roads causing relatively shallow overland flooding. There are some locations where flows may be obstructed, for example by road and railway embankments, causing flows to pond on the upstream side to greater depths which may then overtop the road embankment. Some properties in the catchment are situated on low areas in close proximity to the creeks that regularly experience flooding which encroaches on and surrounds the dwelling. Once flows reach the deeply-incised, forested valleys, the floodwaters are confined to within the creeks and with no risk to properties.

According to Council’s flooding complaints database and feedback from the community, significant flooding in the catchment has occurred during February 1984, April 1988, February 1990, June 1991 and February 2010, among other smaller flood events. The 1984 and 1991 flood events were particularly large, considering the high number of flooding complaints logged by Council, with the 1984 event estimated to exceed the 1% AEP event in parts of northern Sydney, including in the study area (Riley et al, 1986). It is understood from consultation with long term residents that numerous road waterway crossings were upgraded to provide greater flow capacity following the 1991 storm event.

The February 2010 event is thought to be one of the largest recent flood events, based on regular observations of flooding events by local residents. **Plates 2-1 to 2-5** show flooding on properties in various parts of the catchment.

Potential flooding trouble spots identified by Council, based on flooding behaviour and development patterns, include:

1. Properties on The Chase Road
2. Properties on Cudgee Street and Tennyson Avenue
3. Properties near the Burns Road crossing.

Plate 2-1. Floodwaters overtop a private footbridge (approximately in line with corner of brick wall) on a residential property. 6 February 2010 event (photograph courtesy S. O’Malley).

Plate 2-2. Debris caught on same footbridge as previous photograph. 6 February 2010 flood (photograph courtesy S. O'Malley).

Plate 2-3. Lovers Jump Creek on morning after 6 February 2010 flood, showing flood debris caught in tree. The flood level peaked at approximately the top of bank on the right bank.

Plate 2-4. March 2011 flood overtopping private footbridge, and breaking creek bank (photograph courtesy S. O'Malley).

Plate 2-5. December 2014 event, showing overtopping of a driveway crossing with property cut-off from vehicular access.

# 3. Available Data

## 3.1 Background

Details on the data available to this study are provided in the following sections.

## 3.2 Previous Studies

### 3.2.1 Lovers Jump Creek Flood Study

Jacobs prepared the *Lovers Jump Creek Flood Study* (Jacobs, 2016) which involved the development and calibration of a TUFLOW hydraulic model to estimate design flooding behaviour in the catchment. Details on the model development and calibration and the design flood estimation are reproduced in this current report.

Review of the Flood Study during this FRMSP identified issues with the flood mapping. Specifically, the mapping and analysis did not pick up on peak flood conditions (levels, depths, velocities etc.). Hence, the full risk of flooding in the catchment was not characterised in the Flood Study. This Flood Study review therefore is required to update the flood behaviour and flood risk in the study area.

### 3.2.2 Cowan Creek Catchments Sub-Catchment Stormwater Analysis and Planning, Final Report

Jacobs reviewed the *Cowan Creek Catchments Sub-Catchment Stormwater Analysis and Planning, Final Report*, prepared by WP Brown & Partners and Boyden & Partners, October 2004. Analysis of drainage and flooding issues in a number of catchments draining to Cowan Creek and provides details on the set up of existing DRAINS models for the study area, including Lovers Jump Creek.

- The report identifies likely flood problem areas and potential mitigation options for these areas. Stormwater quality is also analysed using the MUSIC model including identification of possible stormwater treatment options.
- Levels for pits and pipes were based on available 2m contour data, which were not considered by WP Brown & Partners to be accurate.
- Data associated with this study was also provided, including DRAINS and MUSIC models, CAD and GIS layers derived from the models and CAD models of the study area, incorporating road and property boundaries, pit and pipe network and stormwater sub-catchment boundaries.

## 3.3 Topographic Data

Council provided the following data for use in this study. Comments on the data set are provided where there are particular findings with respect to the data.

- Topographic data:
  - LiDAR data captured by NSW Government Land and Property Information (LPI) with a vertical accuracy of approximately +/-0.15m (one standard deviation) that encompasses the Lovers Jump Creek catchment and adjacent areas. The LiDAR data was reviewed and was considered unlikely to be accurate along the watercourses due to the dense vegetation cover and tree canopy present in much of the study area. Ground elevations presented by the LiDAR were up to several metres higher than actual elevations particularly in watercourses, based on observations during the site inspection. This justified the collection of additional ground survey in selected locations.
- GIS layers
  - Drainage pipes and pits
  - Main creek catchments.

- Gross pollutant trap locations.
- Riparian corridors.
- Endangered ecological communities vegetation mapping.
- Cadastre.

## 3.4 Aerial Photography

AUSIMAGE aerial photography dated 2016 was obtained by Jacobs for the study area, and has been used in this flood study review.

## 3.5 Streamflow Data

No streamflow data was available for Lovers Jump Creek.

## 3.6 Rainfall Data

### 3.6.1 Historic Rainfall

Historic rainfall data was obtained from a number of Sydney Water and Bureau of Meteorology rain gauge sites in the vicinity of the study area for model calibration and verification. Refer to **Section 6.2**.

### 3.6.2 Intensity-Frequency-Duration Data

Design Intensity-Frequency-Duration (IFD) rainfall information is contained in the existing DRAINS model of the catchment. The IFD data is based on Australian Rainfall and Runoff 1987 (Engineers Australia, 1987) as the flood study and modelling pre-dates the recent ARR 2016 IFD updates.

The ARR 1987 IFD parameters at Turramurra Railway Station are summarised in **Table 3-1**.

Table 3-1 IFD Parameters for Study Area

| Parameter | 2 year ARI | 50 year ARI |
|---|---|---|
| 1hr Event Intensity (mm/h) | 37.91 | 76.12 |
| 12hr Event Intensity (mm/h) | 8.95 | 19.44 |
| 72hr Event Intensity (mm/h) | 2.99 | 6.7 |
| Frequency Factor | 4.3 | 15.85 |
| Skewness | 0.00 | |

## 3.7 Flooding Complaints Database

This database of flooding complaints lodged with Council includes 365 entries from historic storm events from 1969 to 2008. Significant storm events, based on the number of entries per event, occurred in November 1984, April 1988, July 1988 and February 1990. Only 12 complaints were made between 1991 and 2008, with no complaints present in this particular register following 2008. Flood complaints made subsequent to 2008 have been dealt with through Council's main customer request management system, data from this system was not available for the study.

## 3.8 Site Inspections

A site visit was undertaken following project inception on 24 November 2015. The purposes of the site inspection was to gain a further understanding of the catchment characteristics, the nature of existing development and hydraulic constraints, and likely flood risk. Jacobs' project manager was accompanied by officers from Council and Office of Environment and Heritage (OEH). Locations inspected on the site visit included potential trouble spots identified in the project brief, road crossings and potential obstructions to overland flow.

Observations made during the site visit included:

- The upper reaches of the watercourses are generally undefined and consist of informal overland flow paths passing through existing development. In the middle reaches the watercourses are more defined and typically consist of formalised channels or natural and more incised flow paths through existing development. The lower reaches are located within well-incised valleys with steep sides within Ku-ring-gai Chase National Park outside of the existing urbanised area.
- The watercourses flow through a number of properties, with numerous hydraulic structures including driveway culvert crossings and footbridges crossing the watercourses.
- The dwellings on an extensive number of properties are situated in close proximity to the watercourses.
- The North Shore Railway Line is built on embankment in some sections and may pose a significant obstruction to flood flows in the far upper (southern) portion of the catchment.
- Works have been undertaken recently to a few sections of the watercourses including construction of a retaining wall for bank stabilisation near Katina Avenue and installation of a Gross Pollutant Trap (GPT) near Karuah Road.

Further site inspections were undertaken following model verification for locations where there remained uncertainty or queries about the flooding behaviour, and to follow up on queries made during community consultation. Observations and measurements of key hydraulic structures were taken at these locations as these features were not previously represented in the hydraulic model. The likely flood behaviour at critical locations in the study area was also validated during the ground truthing.

## 3.9 Ground Survey

Survey was collected in February/March and June 2015 of ground elevations along watercourses, driveway crossings, culverts, bridges and other hydraulic structures at key locations in the study area. The locations were selected based on the proximity of properties to watercourses and road crossing culverts, which were not represented in the available spatial data from Council. Features including footbridges, retaining walls and free-standing brick walls on private property were also surveyed.

The survey also picked up the details of stormwater pipe outlets into the surveyed sections of the watercourses, as well as one pit and pipe section upstream of the outlet, for validation of the modelled pit and pipe levels. Other features were also surveyed, such as a large 1.1m diameter water mains pipe crossing the creek at the cross-drainage culvert outlet at The Chase Road, Turramurra, see **Plate 3-1**.

Survey of drainage structures crossing the North Shore Railway was not collected due to foreseen difficulties in obtaining approval and clearance to collect this data from within the railway corridor. However, visual inspection of key culvert inlets within the rail corridor was undertaken from adjacent private property by the project team during site inspection to offset the inability to undertaken ground survey in the corridor.

Plate 3-1 Water mains pipe partially obstructing The Chase Road culverts

## 3.10 Community Consultation

### 3.10.1 2015 Flood Study

In February 2015 questionnaires were distributed to property owners within the study area, with approximately 70 responses received. Twenty-four responses included observations of flood behaviour from storms between 1970 and 2015. Storm events with greater than five respondents reporting flooding included April 1988 (7 observations), July 1988 (6) February 1990 (7), June 1991 (6) and February 2010 (8).

A community forum was held at Council' Chambers on 21st October 2015. Approximately 30 residents attended the forum and were briefed on the objectives and progress of the flood study and invited to provide feedback on preliminary modelling results. Initial modelling and mapping results were laid out for participants to view. A presentation from the Insurance Council of Australia was also given on how the flood study results are used by insurers to refine their pricing and provide fairer insurance outcomes for residents.

The forum attendees generally agreed with the preliminary model calibration results. Residents were contacted following the forum to gather further information and provide clarification on recent flooding. The project team reviewed and updated the model in some locations to obtain a better agreement with residents' feedback.

#### 3.10.2 2018 Flood Study Review

The flood modelling and mapping was updated as a part of this flood study review, as described in Section 3.2.1. The Flood Study Review Report was placed on public exhibition in April 2018, with nine submissions received from the community. The flood planning area mapping was updated in response to site-specific queries, and is presented in Appendix I of this report.

# 4. Hydrologic Modelling

## 4.1 Overview

The existing DRAINS model (WP Brown & Partners, 2004) represents the entire stormwater pit and pipe system in the Lovers Jump Creek catchment, which was divided into 800 sub-catchments. The model was reviewed and updated for use in this study primarily to estimate sub-catchment runoff hydrographs for subsequent input into the hydraulic model.

## 4.2 Sub-Catchment Data

Mapping of the sub-catchment boundaries is shown on **Figure 4-1**. Sub-catchments within the urbanised parts of the study area were previously delineated for the DRAINS modelling study and were available from Council. Details on these sub-catchments within the DRAINS model, including area and imperviousness, were reviewed and generally found to be consistent with the topographic and aerial imagery data for existing conditions. There is also minimal or no difference between the existing development conditions and the Ku-ring-gai Local Environmental Plan 2015, meaning that there is not expected to be any change in catchment hydrologic behaviour as a result of changing development patterns in the catchment in the near future.

An additional 32 sub-catchments for the undeveloped parts of the catchment located within the Ku-ring-gai Chase National Park were delineated in this study and included in the flood modelling for completeness. These areas were assumed to have an impervious percentage of 10%, given the common presence of exposed rocky outcrops in these areas.

## 4.3 Hydrologic Parameters

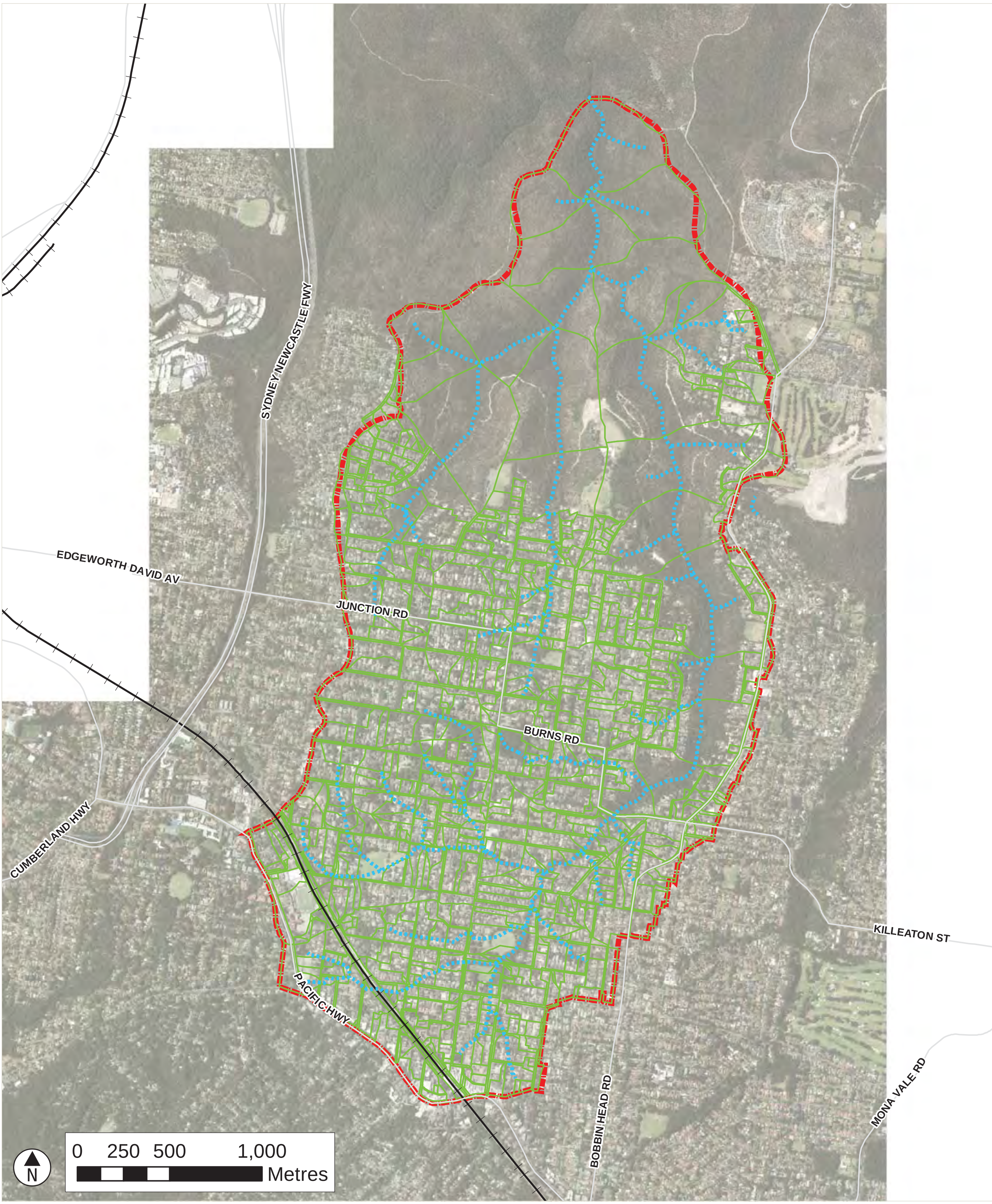
The following parameter values were adopted in the DRAINS modelling for the design storms:

- Depression storage: Paved areas – 1mm; Grassed areas – 5mm.
- Soil type: Type 3, which represents a not-particularly well drained soil landscape.
- Antecedent Moisture Condition: This represents the degree of soil wetness at the onset of a storm, which affects its infiltration capacity. A value of 3 was adopted for storms up to and including the 1% AEP event, which represents “rather wet” (but not saturated) soil conditions due to total rainfall of between 12.5 and 25mm in the preceding 5 days prior to the modelled storm event (DRAINS User Manual, Watercom, 2017). It was assumed that the ground would be completely saturated during extreme storm events, therefore, a value of 4 was adopted for the PMP event.

## 4.4 Design Rainfall

The storm events including the 20%, 10%, 5%, 2% and 1% Annual Exceedance Probability (AEP) events were modelled as Australian Rainfall and Runoff 1987 (ARR 1987) Zone 1 storms in DRAINS.

Design rainfall time series were derived for the Probable Maximum Precipitation (PMP) events, based on the Generalised Short Duration Method (GSDM) in *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method* (BOM, 2003).




**Legend**

- Study Area
- Sub-catchment
- Drainage Line
- Railway
- Main Road

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|---|---|---|---|---|
| SHEET 1 of 1 | | GDA 1994 MGA Zone 56 | | |
| TITLE | Hydrologic Model Sub-Catchments | | | |
| PROJECT | Lovers Jump Creek Flood Study Review | | | |
| DRAWN LC | PROJECT # IA159900 | MAP # FIGURE 4-1 | REV 1 | VER 1 |
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# 5. Hydraulic Modelling

## 5.1 Model Selection

A TUFLOW combined one-dimensional (1D) and two-dimensional (2D) hydrodynamic model has been developed for this study. TUFLOW is an industry-standard flood modelling platform, which was selected for this assessment as it has:

- Capability in representing complex flow patterns on the floodplain, including flows through street networks and around buildings.
- Capability in representing the stormwater drainage network, including pit inlet capacities and interflows between the network and floodplain including system surcharges.
- Capability in accurately modelling flow behaviour in 1D channel, bridge and culvert structures and interflows with adjacent 2D floodplain areas.
- Easy interfacing with GIS and capability to present the flood behaviour in easy-to-understand visual outputs.

The model was developed and run in TUFLOW 2013-12-AD-iDP-w64, in double-precision mode.

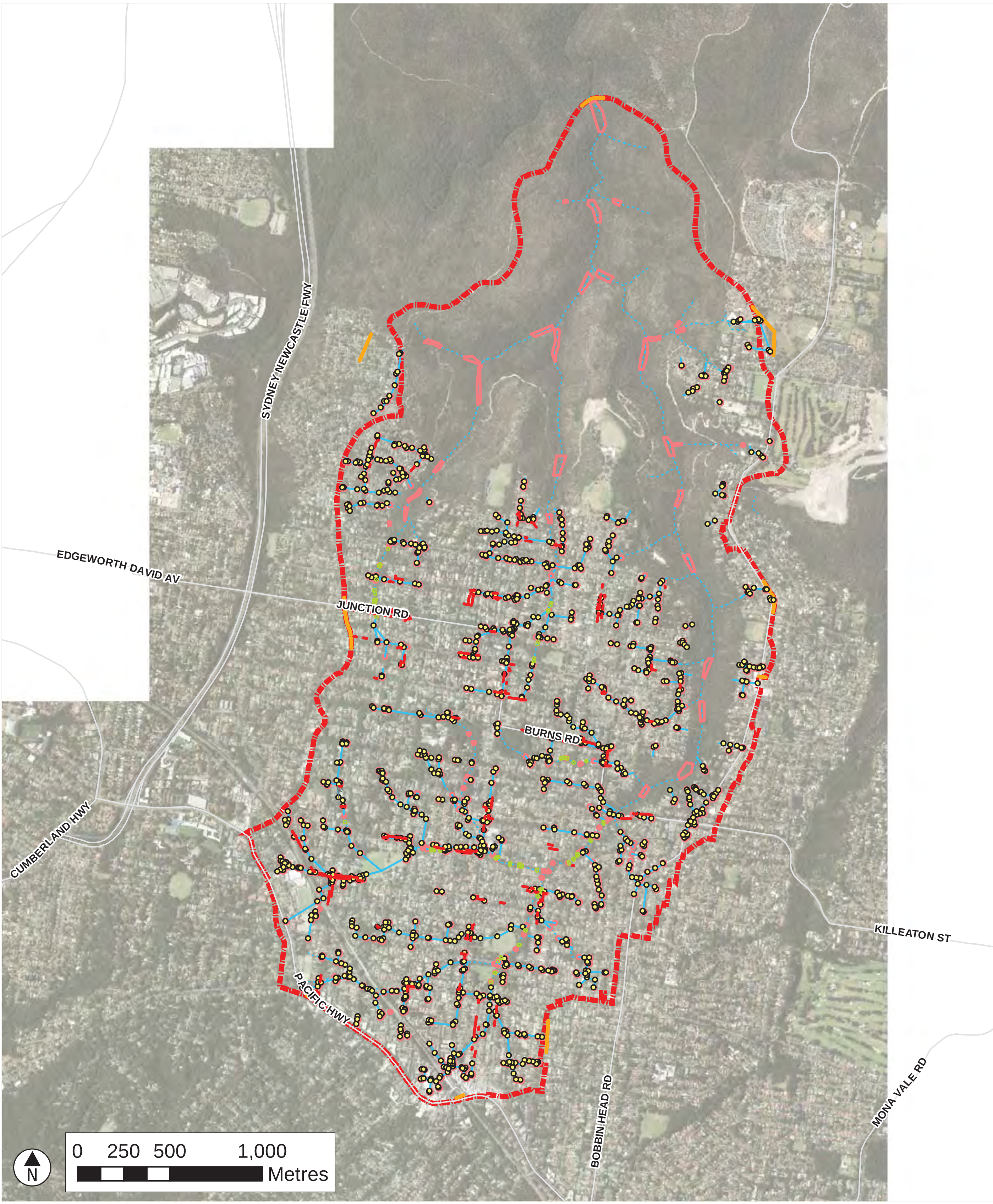
## 5.2 Configuration of Hydraulic Model

### 5.2.1 Extent and Structure

The TUFLOW model is comprised of:

- A 2D domain of the catchment surface reflecting the catchment topography, with varying roughness as dictated by land use. The watercourses are in general modelled in 2D.
- A 1D network of pits and pipes representing the stormwater network. The pits have a defined inflow capacity as dictated by their type and size.
- Additional hydraulic structures including culverts (1D) and footbridges (2D).
- Obstructions to flow are represented as 2D objects, including existing buildings and visually identified free-standing walls.

Refer to the following report sections for details on these features. The locations of various features in the TUFLOW model are shown on **Figure 5-1**.




**Legend**

- Stormwater Pit
- Stormwater Pipe or Culvert
- Downstream or Outflow Boundary
- Solid wall obstruction
- Bridge/Footbridge
- Inflow Location
- Drainage Line
- Main Road
- Study Area

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SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE TUFLOW Hydraulic Model Configuration

PROJECT Lovers Jump Creek Flood Study Review

| DRAWN | PROJECT # | MAP # | REV | VER |
|---|---|---|---|---|
| LC | IA159900 | FIGURE 5-1 | 1 | 1 |
| CHECK | DATE | | | |
| AH | 21/02/2018 | | | |

#### 5.2.2 Model Topography

The topography of the catchment is represented in the model using a 2m grid. This level of precision in the grid is considered necessary in order to represent detailed flood behaviour in a fully developed catchment. Finer model grid sizes such as 1m grid are not considered practical given the large size and expected excessively long computing times. The basis of the topographic grid used in the TUFLOW model is the LiDAR data set in addition to ground survey.

#### 5.2.3 Stormwater Pits

The stormwater pits provide a dynamic linkage between the underground drainage network and the 2D TUFLOW model domain, representing the floodplain. Water is able to flow between the drainage network and floodplain, depending on the hydraulic conditions.

The location of the stormwater pits and associated attributes were available from Council in GIS format. Locations of structures were updated based on survey where available. Pit inflow relationships were defined in terms of flow depths versus pit inflow. The pit types and inflow relationships adopted in the DRAINS model were also used in the TUFLOW model.

TUFLOW automatically calculates hydraulic energy losses in the pits based on the alignment of pipes connected to each pit and the flows in each pipe. The calculations are based on the Engelhund manhole loss approach (*TUFLOW User Manual*, BMT WBM, 2017).

#### 5.2.4 Stormwater Conduits

Each of the stormwater pits and pipes in the DRAINS models are also modelled in the TUFLOW models. Several pipes down to a diameter of 150mm are represented, but are typically larger than 300mm. The conduits are represented as circular pipes or rectangular culverts with dimensions matching those adopted in the DRAINS models.

Details of additional pipes and culverts which were not in the DRAINS model were collected during ground survey. This included culverts at road crossings and driveway crossings.

#### 5.2.5 Building Polygons

This study considers buildings as solid objects in the floodplain. This means that buildings form impermeable boundaries within the model, and while water can flow around buildings, it cannot flow across their footprint. The building footprints in the TUFLOW model were digitised based on the 2014 aerial imagery. The building polygons were superimposed on the model grid to make model computational cells under the footprints inactive.

#### 5.2.6 Property Fencelines

Fencelines have typically not been explicitly represented in the model and floodwaters are allowed to flow across them freely. Although fences may obstruct overland flood flows in some parts of the catchment, experience indicates that representing fences in the hydraulic model requires making unvalidated assumptions about depths at which fences overflow or fail.

Hence, the potential obstruction to flow caused by fences was represented in the model by increasing the cell roughness (Manning's n values) for certain land uses, as described in **Section 5.2.7**. The limitation of this approach is that the flood levels may be slightly overestimated and flow velocities slightly underestimated for flooding within properties depending on the actual locations of obstructions and the interaction of flood flows with these obstructions. However, this approach does preserve the likely typical flooding behaviour, in which floodwaters use the road corridor as the preferential flow path.

Where observed, free-standing brick walls such as those along property boundaries were modelled as solid obstructions to flow.

### 5.2.7 Surface Roughness

All parts of the study area within the TUFLOW model were assigned hydraulic roughness values according to the LEP zoning and ground cover. These are based on engineering experience and typical values used in previous flood studies undertaken in the Sydney Region by Jacobs and other consultants. The relatively high Manning's n values for the residential land use accounts for expected obstructions such as minor structures (sheds, etc.) and fences.

There are numerous large residential properties in the study area (approximately 2,000m$^2$) with large areas of lawns and pavement, such as tennis courts and driveways. The surface roughness of these areas has been represented separately from the overall land use type.

Note that road pavement areas were delineated based on spatial data available from Council for Lovers Jump Creek and are represented separately from road verge areas.

Table 5-1 TUFLOW Model Grid Hydraulic Roughness Values

| Land Use Type | Manning's n | Comment |
|---|---|---|
| Paved area | 0.02 | Includes parking areas and large paved areas on private property |
| Grassed area | 0.03 | Large grassed areas including sporting fields, parks and large lawns on private property, road verges. |
| Commercial/Industrial/High Density Residential | 0.035 | Assumed mainly paved |
| Watercourse | 0.05 | Generally uneven bedrock base, no vegetation. Accounts for irregularities in channel |
| Residential (low density) | 0.08 | Accounts for landscaping and fences |
| Natural vegetation | 0.12 | |
| Railway Corridor | 0.05 | |

### 5.2.8 Footbridges

Details of identified footbridges in the study area were obtained from survey, including soffit, deck and hand railing levels. Footbridges were modelled as 2D structures and their locations are indicated on **Figure 5-1**.

## 5.3 Boundary Conditions and Initial Conditions

### 5.3.1 Model Inflows

Runoff generated in the sub-catchments from the DRAINS model was input to the TUFLOW model via one of two methods:

- At the pits located at the outlet of each sub-catchment. Sealed pits are not assigned an inflow. The amount of surface flow entering the pit is dictated by the pit inflow relationship. Flows in excess of the pit inlet capacity remain in the 2D model domain as point inflows, subsequently forming overland flow.
- At the outlet to the sub-catchment if there are no pits in that sub-catchment, for example, in forested sub-catchments. Flows are initially input at the lowest point of the sub-catchment and then distributed to wet areas in the catchment as the storm progresses.

Pit surcharge flows are caused when flows in the drainage network exceed network capacity and spill out of the pits and into the 2D domain. Pit surcharges would similarly form overland flow in the model. Depending on the hydraulic conditions in the pipe system, overland flows can re-enter the pipe system via the stormwater pits.

# 6. Model Calibration and Verification

## 6.1 Overview

Rigorous model calibration of overland flood models cannot generally be carried out because direct measurements of overland flows and accurate measurements of flood levels are usually not available. Hence, overland flood models are often verified using observations of flood depths and flood behaviour as a way of "sanity-checking" the modelling and confirming its reliability.

This study has relied mainly on observed depths of flooding during past flood events given by local residents. This anecdotal information is considered indicative as only the general location of the observation is usually given, with the observer unlikely to have measured actual depths and may have estimated the depth of flow in the watercourse from a distance, and the depths are often rounded up to the nearest 0.1m. However, the reported flood depths are still useful information for validating the general behaviour of flooding predicted by the flood models.

The general approach involved running the hydrologic and hydraulic models and comparing the flood depths and flow patterns to reported observations. The model configuration and parameter values were adjusted as necessary with the aim of achieving a satisfactory fit to the observations.

## 6.2 Selection of Verification Events

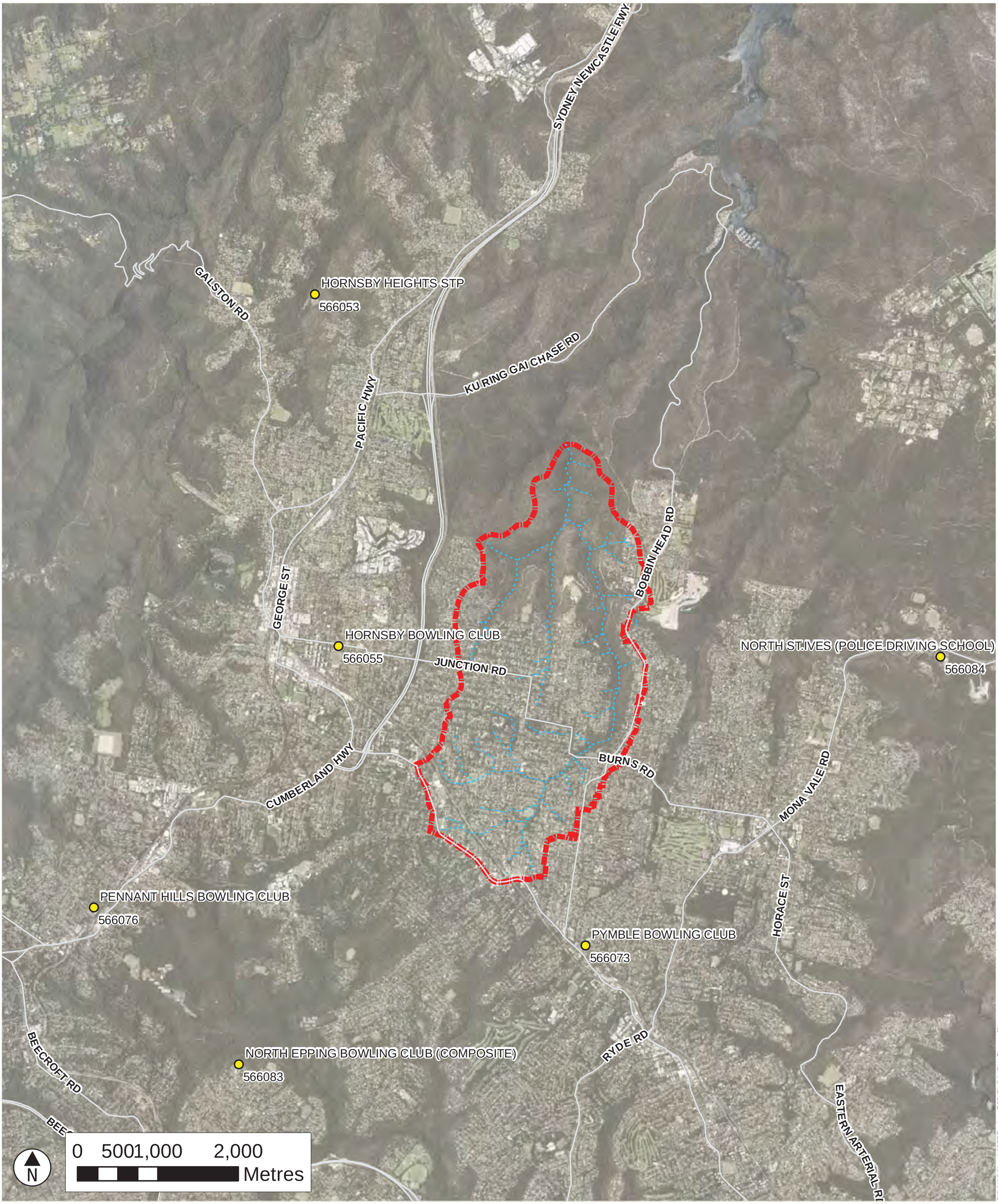
Three storm events were initially identified for model calibration/verification based on the relatively high number of observations from the questionnaire responses and their more recent occurrence. The storm events considered for investigation included:

- 6 – 7 February 2010
- 10 June 1991
- 2 – 4 February 1990.

Rainfall data at 5 minute intervals was obtained from six Sydney Water rainfall gauges in the vicinity of the study area. Locations of the selected rainfall gauges and other gauges are shown on **Figure 6-1**.

Review of the rainfall data record indicated a good coverage of data for the 2010 and 1991 events (5 gauges with recorded data) but poor coverage for the 1990 storm (one gauge). Sydney Water advised that their network of rainfall gauges in the area was installed progressively in the early 1990s, which explains the poor data coverage during the 1990 event. The February 1990 event was therefore discarded as a suitable calibration event, and the February 2010 and June 1991 events were selected for model calibration/verification. The February 2010 event also has the advantage of being a recent event, hence the observations are expected to be fresh in people's memories.

Archived Bureau of Meteorology (BOM) rainfall radar images from the Terrey Hills radar, available online at www.theweatherchaser.com, was reviewed. Out of the identified verification events, data was only available for the 2010 storm. The images showed an east-to-west movement of the rainfall bands during the storm event, and that the heaviest rainfall occurred to the south and north of Lovers Jump Creek catchment, with the catchment receiving only a portion of the rainfall recorded at adjacent rainfall gauges. The radar images indicated that that the recorded rainfall from the Hornsby Bowling Club gauge (station 566055) was most representative rainfall in the catchment. The radar image at the peak of the storm in the study area is shown on **Figure 6-2**.




**Legend**

- Sydney Water Rain Gauge
- Drainage Line
- Main Road
- Study Area

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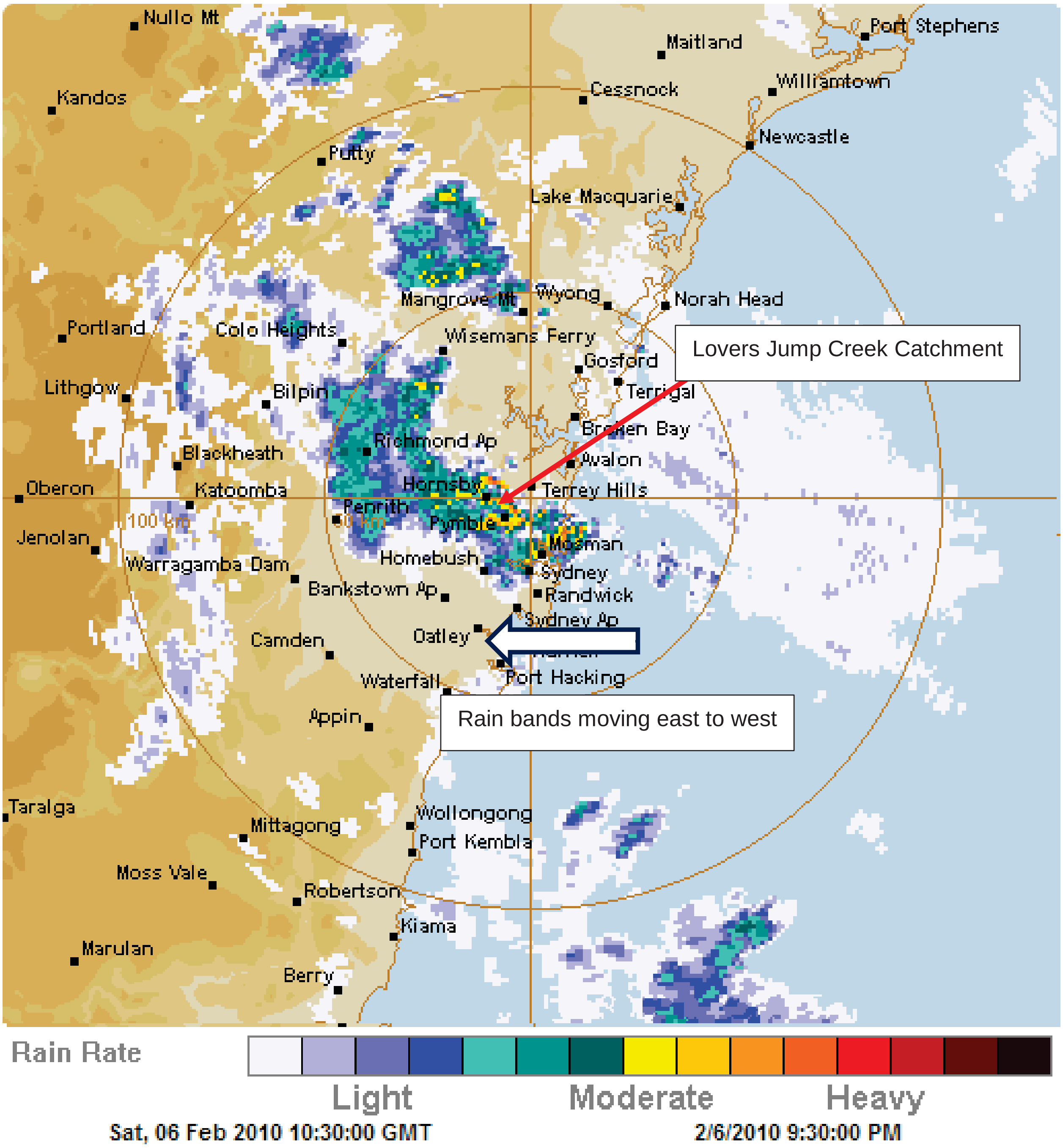
|---|---|---|---|
| SHEET | 1 of 1 | GDA 1994 MGA Zone 56 | |
| TITLE | Sydney Water Rain Gauges | | |
| PROJECT | Lovers Jump Creek Flood Study Review | | |
| DRAWN LC | PROJECT # IA159900 | MAP # FIGURE 6-1 | REV 1 VER 1 |
| CHECK AH | DATE 21/02/2018 | | |

GIS MAP file : LJCFSReview_R02_Fig6-1_RainGauge_01

Figure 6-2 Rainfall radar image at peak of 6 February 2010 storm




http://www.theweatherchaser.com/radar-loop/IDR713-sydney-terrey-hills/2010-02-06-09/2010-02-06-12

Radar data was not available for the June 1991 event. The recorded rainfall data indicated significant rainfall depths at the Pymble gauge (566073), however, no data was recorded at the Hornsby Bowling Club gauge (566055) and the recorded data from the Hornsby Heights STP gauge (566055) was used to infill the data record. For this reason the Pymble gauge data was considered the most reliable for the Lovers Jump Creek catchment for this storm event and was therefore adopted for the model verification.

Characteristics of the selected storm events are provided in **Table 6-1**. The cumulative rainfall depths are plotted in **Appendix A**. Comparison of the recorded rainfall against the design IFD is also shown on **Figure A-3 in Appendix A** for the February 2010 event.

Table 6-1 Calibration storm event characteristics

| Event Date | Daily Rainfall Depth | Main Storm Burst Rainfall Depth and Duration | Approximate Event AEP | Comment |
|---|---|---|---|---|
| 6 February 2010 | 118mm | 47mm/2 hours | More freq. than 20% | **Hornsby gauge (566055) data adopted.** Heaviest rainfall occurred to south of catchment – Pymble gauge (566073) recorded 96mm/2hrs (2 – 5% AEP) |
| 10 June 1991 | 261mm | 45mm/2 hours<br>109mm/6 hours | More freq. than 20% (2hr dur.)<br>10 – 20% (6hr dur.) | Less certainty about spatial distribution due to no archived rainfall radar. Hornsby gauge not operational. **Pymble gauge (566073) data adopted. Significant drainage and culvert upgrades have occurred in the catchment in key flooding areas since this storm.** |

## 6.3 Recent Storm Events

A recent East Coast Low storm event occurred on 21 – 22 April 2015 which caused extremely heavy rainfall in parts of the Sydney and Hunter Region. The storm occurred after all questionnaire responses were received. Although it was observed that while significant regional flooding was produced by the East Coast Low in a number of river systems in the Sydney and Hunter Regions, the archived rainfall radar imagery indicated that the Lovers Jump Creek catchment generally received more moderate rainfall over a longer duration, with more intense bursts only occurring over periods of up to 25 minute duration. The April 2015 storm therefore is not believed to have caused as significant flooding as previous events. Further, review of rainfall data for this event indicated generally lower rainfall intensities at the each of the six Sydney Water gauges reviewed for this study. This storm event was not analysed further in this study.

## 6.4 Adopted Parameter Values for Model Verification

### 6.4.1 Rainfall Losses

An Antecedent Moisture Condition (AMC) value of 3, representing fairly wet soils, was adopted for both calibration/verification event runs in the DRAINS hydrologic model. This is based on guidance in the *DRAINS User Manual* (Watercom, 2017) which suggests this value for an accumulated rainfall depth between 12.5mm and 25mm over the preceding 5 days.

Other hydrologic parameter values used in the model verification included:

- Depression storage: Paved areas – 1mm; Grassed areas – 5mm.
- Soil type: Type 3, which represents a not-particularly well drained soil landscape.

#### 6.4.2 Blockages

Guidance on blockage of hydraulic structures has generally been sought from *Australian Rainfall and Runoff Revision Project 11– Blockage of Hydraulic Structures Stage 2* (Engineers Australia, 2013).

Culverts were assumed to be 50% blocked for the model calibration events. There were reports from the questionnaire responses of blockages by large boulders being washed down in the creek in one of the historic events, and recurring blockage due to debris.

Footbridges were modelled with a blockage of typically 10 – 25% to provide a good calibration fit at key locations. Most bridges were observed from site inspection to have no piers (single spans only) and high-set above the creek invert and appeared to be relatively averse to blockage by flood debris. This was supported by residents' photographs during high flow conditions. Other bridges are relatively low and with piers, and a blockage of 50% was adopted.

Stormwater pit inlets were assumed to be 20% blocked for on-grade pits and 50% blocked for sag pits, consistent with the adopted values proposed for the design runs.

#### 6.4.3 Initial Water Levels

There are no storages (ponds, dams, etc.) in the catchment. The catchment and waterways were assumed to be dry for the calibration/verification runs.

#### 6.4.4 Tailwater Conditions

A normal depth condition has been assumed at the downstream boundary for the calibration events. Given the steep terrain of the Lovers Jump Creek valley and that the existing urbanised area is situated at least 100m higher than the Creek near its outlet, the flooding conditions on private properties and at calibration points are not considered to be sensitive to this assumed tailwater condition.

### 6.5 Comparison to Observed Flooding

The questionnaire responses were analysed to determine the dates of historic flooding and the number of respondents experiencing flooding in each event. A total of 53 reports of flooding were made. Some respondents made multiple observations. The questionnaire stated the dates when particularly large storm events occurred in Ku-ring-gai, with a relatively large number of respondents confirming that they experienced flooding during those storms, compared to other storms not suggested on the questionnaire.

The 2010 storm event was modelled in greater detail given greater certainty about the condition of the watercourses and hydraulic structures at that time. The 1991 event was initially assessed but later discarded following knowledge of significant upgrades of drainage and hydraulic structures following the 1991 storm, and hence less certainty about the drainage conditions.

The modelled flood behaviour was compared to the residents' observations, and were generally found to be consistent with the observations. Refer to **Appendix C**. The TUFLOW model provides a satisfactory match to the observed flood depths and flow behaviour in the historic events and is therefore considered to be suitable for the estimation of design flood behaviour in the study area.

# 7. Estimation of Design Floods

## 7.1 Hydraulic Model Parameters for Design Events

### 7.1.1 Blockages

The blockage factors adopted in the calibration runs were also adopted for the design runs. These are summarised below:

- Culvert inlets: 50% blocked
- Footbridges: 10% to 50% based on site observations and likelihood of blockage (depending on bridge opening height, presence/absence of piers, availability of debris)
- Stormwater pits: 20% for on-grade pits, 50% for sag pits.

### 7.1.2 Tailwater Conditions

A normal depth condition was adopted at the downstream boundary, as per the calibration event modelling. As previously mentioned, the urbanised parts of the catchment are situated at least 100m higher than the Creek near its outlet, the flooding conditions on private properties are not considered to be sensitive to this assumed tailwater condition.

## 7.2 Simulated Design Events

The storm events modelled include the 20%, 10%, 5%, 2%, 1% and PMF events. The storm durations initially assessed include the 15, 25, 60, 90,120 and 180 minute duration for the 20% to 1% AEP events, with the 25 minute and 90 minute events observed to be the critical durations and adopted for the final model runs. The 15, 30, 45, 60, 90 and 120 minute durations were modelled for the PMF event, with the maximum envelope derived from the model results for these individual runs. The critical event durations are observed to be the 25 minute and 1.5 hour events for events up to the 1% AEP. The critical duration for the PMF varies throughout the catchment, but is typically the 45 minute duration event in most parts of the catchment, with the 1 hour event critical in large flood storage areas.

## 7.3 Comparison of Results with Previous Studies

The modelling results for peak flows estimated using the TUFLOW model have been compared with those estimated using the DRAINS model in the *Cowan Creek Catchments Sub-Catchment Stormwater Analysis and Planning* study (WP Brown & Partners, 2004). The comparison has been made for the 1% AEP flood event at selected locations along the main branch of Lovers Jump Creek, from the North Shore Railway down to the Burns Road crossing, and is summarised in **Table 7-1**.

Table 7-1 Comparison of 1% AEP Peak Flows at Selected Locations to Previous Studies

| Location | Total Peak Flow ($m^3/s$) | | % Difference |
|---|---|---|---|
| | TUFLOW[1] | DRAINS[2] | |
| Burns Road crossing | 89.2 | 114.0 | 22% |
| Upstream of Tennyson Avenue | 82.5 | 104.0 | 21% |
| The Chase Road | 41.0 | 51.8 | 21% |
| Downstream of Karuah Road | 26.4 | 33.8 | 22% |
| Railway crossing near Brentwood Avenue | 6.0 | 11.0 | 46% |

1. This current study.

2. From WP Brown & Partners, 2004.

The comparison of peak flows indicates marked differences in the estimated peak flows between the two studies, ranging from 20% to 46%. This is attributed to the different nature of the types of models used in this study and the previous study. The DRAINS model is a simplified 1D model which does not account for the storage of floodwaters in most of the drainage features in the model (e.g. overflow routes, sags, etc.) and assumes that runoff is generally conveyed in the flow paths without being attenuated. Flood storage in the Lovers Jump Creek model only occurs at user-specified locations, usually upstream of road crossings, using a “detention basin” node object.

In contrast, TUFLOW models typically represent the floodplain and overland flow areas in 2D. This allows the modelled flows to spread out and become temporarily stored in an area as the flows are conveyed through that area. This temporary storage has the effect of slowing down the flow and reducing the peak flow rate, particularly in the upper sections of the catchment where there is no defined channel or watercourse and the surface runoff is typically shallow, sheet flow. The 46% difference in peak flows between the two studies at the railway crossing near Brentwood Avenue reflects this. Its upstream area is a residential area with no defined channel. Additionally, the flood storage upstream of the railway embankment was not represented in the DRAINS model, which would have had a significant attenuation effect.

Given that the Lovers Jump Creek catchment TUFLOW model accounts for the flood storage in the catchment, and in addition has been verified against historic flooding observations, it is considered to provide more reliable estimates of flow and flooding behaviour in the study area.

Note that flood levels have not been compared between the current and previous studies, due to the previous studies being based on models developed using coarse topographic data. The current study utilises field survey of watercourses and waterway crossings, which was observed to be several metres different to the data in the DRAINS model. The estimated flood levels between the two studies would reflect this variance in waterway and structures levels.

# 8. Results Mapping and Analysis

## 8.1 Foreword on the Flood Mapping

The maximum envelope of flood behaviour parameters (depth, level, velocity, velocity x depth, flood hazard) was derived for each event AEP, considering the maximum values over each combination of storm event duration.

By nature, overland flood modelling using two-dimensional hydraulic models often produce results which display large areas of shallow sheet flow which are of minor significance to the study objectives. Areas of greater flow and depth which pose a risk to people and property are of greater concern. Post-processing of the raw model 2D results is therefore undertaken to remove the shallow sheet flow areas from the data set, retaining the main areas of flow.

Several filters were applied to the 2D model results on the flood mapping, based on thresholds on depth, flow velocity and depth-velocity product. These are described in **Table 8-1**.

Table 8-1 Flood Mapping Filters

| Criteria | Comment |
|---|---|
| Depth ≥ 0.3m | Includes areas of significant flooding depths. |
| Depth ≥ 0.1m AND Velocity x Depth > 0.1m$^2$/s | Includes areas with depth 0.1 – 0.3m but only with some flow component. |
| Depth ≥ 0.05m AND Velocity x Depth > 0.025m$^2$/s | Includes areas of shallower flow between areas of more significant flow. These areas have been included on the mapping to illustrate continuity of flow paths. |

Further manual trimming of the flow spatial extents was then undertaken to remove broad, shallow sheet flow areas and isolated ponding areas located away from the flow paths. This has been conducted for all events mapped.

Note that the floodplain within the study area is depicted as being the area below Council's most upstream stormwater pits in the catchments. Local drainage issues may still occur in the areas above the most upstream pits, which have not been assessed in this study.

## 8.2 Flood Depth and Flood Level Mapping

Flood depth mapping is presented in **Appendix B** for the 20%, 10%, 5%, 2% and 1% AEP events and the PMF event.

Flood level mapping is presented in **Appendix E** for the 5% and 1% AEP events and the PMF event.

The number of properties affected by varying maximum flood depths is summarised in **Table 8-2** for the various design AEP events in addition to the February 2010 event, which was a smaller event than the 20% AEP. The maximum flood depth typically occurs within a flow path or watercourse which passes through the property, and may not reflect the flood depth at the dwelling.

The analysis is based on the land parcels spatial layer provided by Council and includes both private property as well those occupied by Ku-ring-gai Chase National Park and other reserves and open space.

Table 8-2 Count of properties by maximum flood depth on each property

| Depth (m) | AEP | | | | | |
|---|---|---|---|---|---|---|
| | 20% | 10% | 5% | 2% | 1% | PMF |
| 0.1 – 0.2 | 48 | 56 | 103 | 107 | 109 | 112 |
| 0.2 – 0.5 | 174 | 171 | 290 | 306 | 338 | 391 |
| 0.5 – 1.0 | 89 | 101 | 154 | 191 | 229 | 425 |
| 1.0 – 2.0 | 69 | 61 | 59 | 65 | 68 | 264 |
| >2.0 | 148 | 138 | 148 | 151 | 157 | 239 |
| Total | 528 | 527 | 754 | 820 | 901 | 1,431 |

The number of properties affected by flooding may appear to be high in comparison to the number of flooding complaints in Council's register (refer **Section 3.7**), however, it should be noted that the count of properties in **Table 8-2** includes those with relatively shallow flooding, and additionally, flooding which did not affect the dwelling on the property, and hence did not warrant a flooding complaint from the resident.

## 8.3 Summary of Peak Flows

Peak overland, piped and total flows are tabulated and mapped for selected locations in **Appendix F** for each storm AEP and for both the all clear and partial pipe/structure blockage scenarios.

## 8.4 Hydraulic Categories Mapping

The three flood hydraulic categories identified in the *Floodplain Development Manual* (NSW Government, 2005) are:

- Floodway, where the main body of flow occurs and blockage could cause redirection of flows. Generally characterised by relatively high flow rates; depths and velocities;
- Flood storage, characterised by deep areas of floodwater and low flow velocities. Floodplain filling of these areas can cause adverse impacts to flood levels in adjacent areas; and
- Flood fringe, areas of the floodplain characterised by shallow flows at low velocity.

There is no firm guidance on hydraulic parameter values for defining these hydraulic categories, and appropriate parameter values may differ from catchment to catchment. For example, the minimum threshold flows and depths which might define a floodway in an urban overland flow catchment may be markedly lower than those for a large lowland river due to the different scale of flooding.

Various combinations of flow, depth and velocity were trialled for appropriate threshold values for the hydraulic categories. For the purposes of this study, the hydraulic categories were defined as per the criteria in **Table 8-3**. These criteria are consistent with those adopted by Council in other similar catchments in Ku-ring-gai LGA.

Table 8-3 Hydraulic Categories Criteria

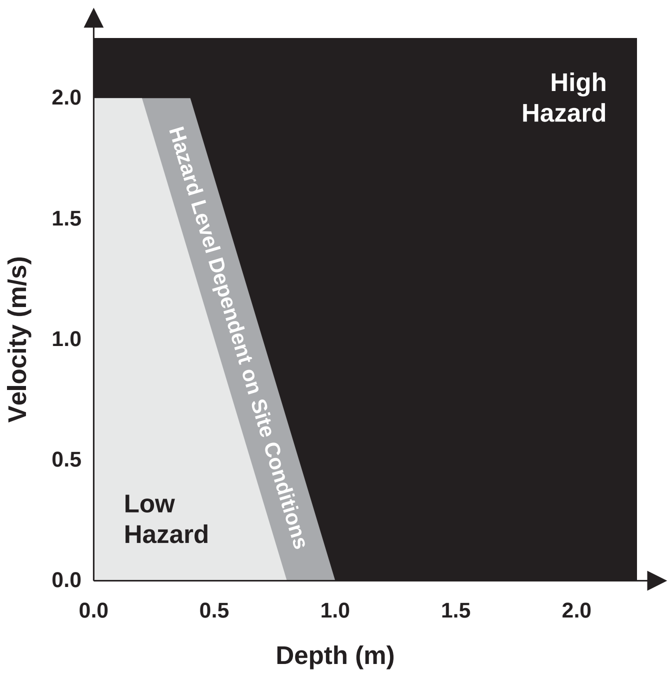
| Hydraulic Category | Criteria |
|---|---|
| Floodway | Area within the flood extent where: • Velocity x Depth > 0.3m$^2$/s AND • Velocity > 0.5m/s AND • Depth > 0.15m |
| Flood Storage | Remaining area within 1% AEP flood extent where Depth > 0.15m |
| Flood Fringe | Remaining area in the floodplain (i.e. area within PMF extent) outside the Floodway and Flood Storage areas. |

The hydraulic categories mapping is presented in **Appendix F**.

## 8.5 Provisional Flood Hazard Mapping

The TUFLOW modelling results were used to delineate the preliminary flood hazard areas for the study area from interpretation of the 20%, 5%, 1% AEP and PMF event results, based on the hydraulic hazard category diagram presented in the *Floodplain Development Manual* (NSW Government, 2005), shown in **Figure 8-1**, and from discussion with Council. The TUFLOW model calculates the hazard rating at each cell and computational time step, rather than calculating the rating based on the peak depth and peak velocity. The “transitional” hazard areas (hazard level dependent on site conditions) have been nominally classified as areas affected by high hazard flooding.

Figure 8-1 Hydraulic Hazard Category Diagram (reproduced from Figure 6-1 in *NSW Floodplain Development Manual*)




Hazard categories delineated in this study are based on depths and velocities of floodwaters and do not consider evacuation, isolation, flood damages and social impacts of flooding, hence, these categories are considered provisional. The provisional flood hazard mapping is presented in **Appendix H**.

## 8.6 Provisional Flood Planning Area

The flood planning area is defined by the extent of the area below the flood planning level (usually the 1% AEP flood plus freeboard) and delineates the area and properties where flood planning controls are proposed, for example, minimum floor levels to ensure that there is sufficient freeboard of building habitable floor levels above the 1% AEP flood. Other controls may be considered, such as policies on fence construction or rezoning.

A freeboard of 0.5m is often selected for defining the flood planning level on mainstream floodplains, however, a reduced freeboard of 0.3m may be more appropriate in areas affected by overland flows. In this study, a freeboard of 0.3m has been adopted for areas affected by overland flooding, and a 0.5m freeboard for areas of mainstream flooding. Areas affected by mainstream flooding are considered as those affected by flooding emanating from defined watercourses.

It was considered appropriate to delineate the flood planning area on the more significant flow paths and not on those with shallow flows which are unlikely to pose a risk to private property. These shallow flow paths are presented on other flood mapping to show continuity of flow paths through the catchment area.

The areas for delineation of the flood planning area were selected via the following steps:

1) Filter out areas with depth <150mm. Such shallow flow depths are unlikely to pose a risk.
2) Identify areas of isolated ponding <100m$^2$ for potentially filtering out.
3) If there are a number of small “ponds” almost connecting up then this indicates an active flow path and hence should be included (the ponds are to be joined up for the flood planning area).
4) Cross-check against the ground level contours. Gullies in the contours would indicate active flow paths.
5) A sanity check was undertaken of whether particular properties should/shouldn’t have a flood planning level attached to it, considering the susceptibility or resilience of the property to flood damage, such as whether the existing dwelling is located in a low point.

The flood planning area mapping is provided in **Appendix I** and indicates the overland and mainstream flood planning areas where the 0.3m and 0.5m freeboard above 1% AEP flood level are recommended, respectively. The number of properties to which the mainstream and overland flood planning areas apply are summarised in **Table 8-4**. Open space, public lands and transport corridor land parcels have not been removed from this count.

Table 8-4 Number of Properties with Flood Planning Area

| Flood Planning Area | Number of Properties |
|---|---|
| Mainstream only (0.5m freeboard above 1% AEP flood) | 197 |
| Overland only (0.3m freeboard above 1% AEP flood) | 831 |
| Both Mainstream and Overland | 36 |
| Total | 992 |

## 8.7 Preliminary Emergency Response Classification of Communities

Areas within the catchment have been classified based on the floodplain risk management guideline *Flood Emergency Response Planning – Classification of Communities* (DECC, 2007). The classification indicates the relative vulnerability of different areas of the catchment and considers the ability to evacuate certain parts of the community. It is considered preliminary and subject to update in the subsequent Floodplain Risk Management Study. The classification has been undertaken for the 1% AEP and PMF events, with mapping provided in **Appendix J**.

The categories identified included:

- Indirectly Affected: Areas which are not flood affected and whose access is not cut-off, but may be affected by flood impacts to services and infrastructure in the area.
- Rising Road Access: Areas that become inundated by flooding which can be evacuated by vehicles on roads with continuously rising grade to high ground.
- Overland Escape Route: Areas where vehicular access is cut-off but can be evacuated on foot to high ground.
- High Trapped Perimeter: Areas which are partially or wholly above the peak flood level but whose evacuation routes are cut-off. These areas are not surrounded by flood waters but there may be a physical barrier preventing evacuation overland.
- High Trapped Island: Areas which are above the peak flood level but surrounded by flood waters and whose evacuation routes are cut-off.
- Low Trapped Island: Areas which are surrounded by flood waters during early stages of the flood, and which become submerged as the flood peaks.

The guideline is largely geared towards classification of communities in mainstream floodplains with longer flooding response times, hence some assumptions were made to suit the shorter-duration flash flooding in the Lovers Jump Creek catchment:

- Given the relatively shallow flows in the majority of overland flow paths which would not necessarily be hazardous, areas of high flood hazard were used to indicate where flooding may pose a risk to life and hence where evacuation would be required.
- Access routes were deemed to be cut-off if fully crossed by areas of high flood hazard. Roads with patchy high hazard areas were considered to be accessible by heavy vehicle or on foot on the road verge.
- Property boundary fences were assumed to be barriers to overland escape routes on foot as they may be too high for some members of the community to climb.
- Some properties are located in depressions in the terrain and their dwellings become surrounded by high hazard flooding. While there may be a rising road evacuation route available, due to the rapid rise in flood level, there may be insufficient warning time before the dwelling is surrounded by deep floodwaters and subsequently inundated. These areas were treated as Low Level Islands since there was no information available on habitable floor levels of these dwellings.
- Properties where the dwelling is surrounded by floodwaters but have some dry land adjoining the dwelling, were deemed to be High Flood Islands.
- Properties whose street frontage is fully blocked off by high flood hazard areas in the street but which were otherwise not affected by high flood hazard areas, were classed High Trapped Perimeter. Similarly, properties located on a cul-de-sac which is cut off by high flood hazard areas, were classed as High Trapper Perimeter.
- Properties with either vehicular or foot access to the street were classed **Indirectly Affected**.

## 8.8 Sensitivity Analysis

A number of scenarios have been assessed for the 1% AEP flood event to test the sensitivity of the model results to changes in the adopted parameter values. The scenarios are described and the impacts summarised in **Table 8-5**. The sensitivity runs assume the same blockage condition of stormwater pits and waterway structures as per the design runs, with exception of the fully blocked sensitivity run.

The modelling indicates that peak flood levels are generally not overly sensitive to the varied rainfall loss and hydraulic roughness scenarios tested, with increases in 1% AEP flood levels typically less than 150mm in developed areas. There are several locations where impacts approach or exceed 200mm, such as The Chase Road and Burns Road.

The flooding behaviour is sensitive to the full blockage scenario, with a number of locations experiencing up to 1m increases in flood levels (typically 0.3 – 0.5m). This is due to the overtopping height of the waterway structure, requiring the floodwaters to build to high depths before overflowing the structure. Existing development would be impacted by these increases. A fully blocked scenario is considered to be a highly conservative assumption as some amount of flow would likely be conveyed through the structure even in a highly blocked condition.

Flood conditions in the developed areas of the catchment were considered to be insensitive to tailwater levels in Cowan Creek, given the large drop in elevation (minimum 100m vertical drop) from the existing development to the Creek at the catchment outlet. Hence, an elevated tailwater condition scenario was not assessed in the hydraulic model.

## 8.9 Impact of Climate Change on Flooding

The impact of climate change on flooding in the study area has been assessed for increases in 1% AEP storm rainfall intensity of 10%, 20% and 30%. The DRAINS model was rerun with the increased rainfall intensities, and the resulting sub-catchment hydrographs input into the TUFLOW model.

The climate change impacts on flood depths are mapped in **Appendix K** at the study area scale, and summarised in **Table 8-6**. Existing development would be affected by increases in peak flood levels in overland flow paths of up to 0.2m in the 30% rainfall intensity increase scenario. Development along watercourses would be affected by increases of typically up to 0.3m. Impacts would be up to 0.6m at The Chase Road, which indicates that the existing drainage structure at this location is a significant constraint.

The impact of sea level rise on flooding was not assessed, as the lowest developed areas within the study area are located well above the influence of sea level increases of 0.9m at the year 2100 horizon. The developed areas in the catchment are located at elevations of 130m AHD and higher.

Table 8-5 Sensitivity Analysis Description and Results

| Scenario | Description | Change in Flood Level[1] |
| --- | --- | --- |
| Rainfall losses – increase | Updated DRAINS hydrology - adopt AMC[2] of 2 and double the depression storage (2mm for paved areas; 10mm for grassed areas) | • Typically 0 – 30mm decrease in most flow paths adjacent to existing development. Some areas up to -70mm.<br>• 200mm decrease in flood storage areas in developed areas (e.g. upstream of railway). -30mm at Eastern Road storage areas.<br>• Decreases in the main branch of Lovers Jump Creek of 200mm at Challis Ave; 130mm at The Chase Rd; 140mm at Tennyson Ave, 330mm at Alice Street and 140mm at Burns Rd. |
| Rainfall losses – decrease | Updated DRAINS hydrology - adopt AMC of 4 and 0mm in the depression storage | • Typically 0 – 30mm increase in most flow paths adjacent to existing development.<br>• Typically 50 – 80mm increases in watercourses. Increases exceed 150mm in localised sections of some watercourses<br>• Up to 110mm increase in flood storage areas in developed areas (e.g. upstream of railway).<br>• Increases in the main branch of Lovers Jump Creek of 110mm at Challis Ave; 100mm at The Chase Rd; 90mm at Tennyson Ave, 230mm at Alice Street and 80mm at Burns Rd. |
| Friction – increase | Increase Manning's n in TUFLOW 2D domain by 20% | • Typically 20 – 40mm increase in most flow paths adjacent to existing development.<br>• 50 – 190mm increases in the main branch of Lovers Jump Creek between Karuah Ave and Burns Rd, and its tributary between Eastern Rd and Cudgee St. |
| Friction – decrease | Decrease Manning's n in TUFLOW 2D domain by 20% | • Typically 20 – 40mm decrease in most flow paths adjacent to existing development. Up to 150mm decrease in the main branch of Lovers Jump Creek between Karuah Ave and Burns Rd.<br>• Some localised increases up to 40mm as smoother flow paths provide greater conveyance of flows to certain locations. |
| Blockage | Full blockage at culverts, bridges and pits in TUFLOW | Increases in flood levels at selected locations include:<br>• Lawrence Ave footbridge: 0.23m increase<br>• Challis Ave: 0.23m<br>• The Chase Rd: 0. 43m.<br>• Tennyson Ave: 0.33m<br>• Burns Rd: 0.44m<br>• Footbridges on tributary between Eastern Rd and Cudgee St: 0.45m<br>• Driveway crossings along Morris Ave: 0.2m<br>• Carrington Rd between Wahroonga Ave and Grosvenor Rd: 0.74m<br>• Boundary Rd between Wahroonga Ave and Grosvenor Rd: 0.27m<br>• Low point upstream of railway embankment: up to 0.95m<br>• Trapped low points in vicinity of Eastern Rd: up to 0.06m.<br>The relatively high (e.g. > 1m) increases in flood levels in the 100% blocked scenarios at a number of locations are attributed to the high crossing embankments or bridge decks which would be overtopped by floodwaters.<br>The sensitivity assessment assumes 100% blockage of all waterway structures, **except for the railway culvert near Brentwood Ave where a 75% blockage was assumed. A 100% blockage was considered too conservative and would trap all flows upstream of the railway embankment**. The increase in flood levels are likely to differ depending on the degree of blockage of individual structures at any one time. |

1. Comparison of sensitivity case to design case peak flood level in 1% AEP event. 2. Antecedent Moisture Condition.

Table 8-6 Climate Change Impact Summary

| Increase in Rainfall Intensity[1] | Typical Increase in Flood Depth[2] | | | |
|---|---|---|---|---|
| | Overland Flow Paths | Watercourses | In Main Storages | At Catchment Outlet |
| 10% | Typically up to 0.03m, some locations up to 0.06m<br>Up to 0.08m at Eastern Road shops and to the west. | Typically 0.1 – 0.2m on main Lovers Jump Creek, some locations higher<br>• Up to 0.22m at The Chase Rd<br>• Up to 0.27m at Alice St<br>• Up to 0.12m at Burns Rd<br>Up to 0.1m on minor tributaries. | Up to 0.03m at Eastern Rd low points near Karuah Rd<br>Up to 0.19m upstream of railway. | 0.3m |
| 20% | Typically 0.04m to 0.1m, some locations exceeding 0.15m<br>0.15 – 0.2m at Eastern Road shops and to the west. | Typically 0.15 – 0.25m on main Lovers Jump Creek, some locations higher<br>• Up to 0.25m at The Chase Rd<br>• Up to 0.53m at Alice St<br>• Up to 0.22m at Burns Rd<br>0.1 – 0.2m on minor tributaries. | Up to 0.06m at Eastern Rd low points near Karuah Rd<br>Up to 0.38m upstream of railway. | 0.6m |
| 30% | Typically 0.05m to 0.12m, some locations exceeding 0.1m<br>0.15 – 0.25m at Eastern Road shops and to the west. | Typically 0.25 – 0.5m on main Lovers Jump Creek, some locations higher<br>• Up to 0.35m at The Chase Rd<br>• Up to 0.75m at Alice St<br>• Up to 0.3m at Burns Rd<br>0.15 – 0.25m on minor tributaries. | Up to 0.09m at Eastern Rd low points<br>Up to 0.55m upstream of railway embankment | 0.85m |

1 Increase from 1% AEP design rainfall intensity.
2 Change from existing conditions.

# 9. Flooding Hot Spots

This flood study review confirms the flooding problem areas identified by Council and listed in **Section 2.3**. It also identifies a number of additional locations where there is elevated potential for flooding to cause a hazard to people, damage to properties and disruption to transportation routes. These are described in **Table 9-1**.

Table 9-1 Description of Flooding Hot Spots

| Location | Description |
|---|---|
| Properties on The Chase Road, including upstream properties near Eastern Road (along Lovers Jump Creek tributary) | Access may be cut-off due to creek overflows over private driveway crossings. High hazard flows around some dwellings on the northern side of the creek. |
| On Cudgee Street and Tennyson Avenue | Access cut-off due to creek overflows over private driveway crossings. Risk to dwelling and occupants on Cudgee Street property where the dwelling is immediately adjacent to left creek bank, due to high hazard flooding surrounding the dwelling in frequent events (e.g. 20% AEP). |
| Properties on Chilton Parade near Raymond Avenue and Davidson Avenue | Risk to dwelling and occupants due to high hazard flooding encroaching on the dwelling in frequent events (e.g. 20% AEP). |
| Properties near the Burns Road crossing | Access from Burns Road cut-off and high hazard flooding encroaching on dwellings. |
| Properties between Challis Avenue and The Chase Road | Risk to dwelling and occupants due to high hazard flooding encroaching on the dwelling in events as frequent as the 10% AEP. |
| Properties in sag points on Eastern Road north and south of Karuah Road | Properties on high side of the road affected by flood depths of 0.8 – 1m in frequent events (e.g. 20% AEP) and up to 1.2m in the 1% AEP. |
| Properties upstream of North Shore Railway embankment | Properties affected by flood depths at the dwelling of up to 1.3m in the 1% AEP and up to 4.8m in the PMF.<br>In a high culvert inlet blockage scenario (75% blockage) for the railway culvert near Brentwood Avenue, properties would be affected by flood depths at the dwelling of up to 1m in the 1% AEP. |
| Banks Avenue, North Turramurra | Sag point would not be passable in the 20% AEP event due to depths of flow exceeding 300mm, cutting off access to properties at the northern end of Banks Avenue. Could be potentially considered a drainage issue rather than a flooding issue. |
| **Roads*** | |
| Eastern Road near Chilton Parade | Road cut off in 20% AEP event with depths up to 0.4m. High hazard flooding in 1% AEP with depths up to 0.9m. |
| Challis Avenue sag point | Road cut off in 20% AEP event with depths exceeding 0.3m. High hazard flooding in 1% AEP with depths up to 0.9m. |
| Tennyson Avenue sag point | High hazard flooding over the road in 10% AEP with depths to 0.4m. High hazard flooding over the road in 1% AEP with depths exceeding 0.7m. |
| Burns Road sag point | Road cut off in 10% AEP event with depths exceeding 0.3m. High hazard flooding over the road in 1% AEP event with depths to 0.8m. |

* Further detailed assessment of road flooding will be undertaken during the FRMS.

# 10. Impact of ARR 2016 Design Rainfall and At-Site Design Rainfall on Flood Behaviour

## 10.1 Overview

The Lovers Jump Creek Flood Study (Jacobs, 2016) was prepared on the basis of the guidelines from the 1987 Australian Rainfall and Runoff (ARR 1987). These guidelines were updated in 2016 (ARR 2016), including design rainfall estimates which are based on a more extensive database, using more than 30 years of additional rainfall records and inclusion of data from an extra 2,300 rainfall stations across Australia than ARR 1987. The ARR 2016 design rainfalls were derived by combining contemporary statistical analysis and techniques with this expanded rainfall database.

Apart from the updated design rainfall depths, ARR 2016 includes revised temporal and spatial distribution of design rainfall, rainfall losses, blockage of pits and pipes etc. These changes have the potential to alter the flood behaviour adopted in the Lovers Jump Creek Flood Study.

The impacts of ARR 2016 on flood behaviour for the 1% AEP event in Lovers Jump Creek have been considered as a part of this flood study review. An assessment of at-site design rainfall estimates has also been undertaken. The findings are discussed in the following sections.

## 10.2 Comparison of At-Site Design Rainfall Estimates

A comparison between rainfall frequency derived using data recorded at a nearby rain gauge and design rainfall depths from ARR 1987 and ARR 2016 has been undertaken. Rainfall data recorded at Sydney Water's rainfall station at Pymble (Station 566073) was obtained for the assessment to determine if there are major differences to the ARR 1987 and ARR 2016 design rainfall. The data consists of tipping bucket rainfall data (0.5mm intervals) for the period 30 September 1987 to 1 September 2017 (i.e. nearly 30 years of data). Annual maximum rainfall depths recorded over various storm durations were calculated in order to derive the at-site rainfall depths. The at-site rainfall depths were ranked and the Cunnane plotting position for a simple distribution free formula ($P_i = (i-0.4)/(n+0.2)$, where the smallest data value is assigned a rank i =1 and n is the sample size of the data set) was used to assign a plotting position to each annual maximum rainfall. The at-site data is plotted against both ARR 1987 and ARR 2016 design rainfalls on **Figures L-1 to L-5 in Appendix L** for 30, 60, 90, 120 and 180 minute storm durations, respectively. The plots show how the design rainfall varies with AEP for each duration. The following key observations are made from attached **Figures L-1 to L-5**:

- ARR 1987 design rainfall is generally greater than ARR 2016 design rainfall (although they are similar for 30 minute duration only),
- The at-site design rainfall is generally greater than ARR 2016, except for 180 minute duration where it is similar or lower than ARR 2016.
- The ARR 1987 and ARR 2016 plots are smooth, as the design rainfall estimates were derived based on regional pooling of recorded rainfall data and fitting a theoretical probability distribution to the recorded data. The at-site data plot on the other hand is fairly irregular due to the variability of observed rainfall data.
- The at-site design rainfall estimates are generally similar to, or less than, the ARR 1987 design rainfall, particularly for the 60 minute and longer durations. By not pooling the data from a number of sites, the at-site data is less likely to capture rarer storm events which would raise the design rainfall estimates.
- The at-site design rainfall estimates are up to 15% higher for the 30 minute storm for up to 5% AEP, although noting that this is not the critical storm duration for the catchment (90 minute duration is critical based on ARR 1987).

In recognition of uncertainties involved in rainfall frequency analysis, ARR 2016 design rainfall estimates are considered similar to the at-site estimates, and generally lower than ARR 1987 design rainfall estimates. The ARR 2016 design rainfall estimates are based on a more extensive database, with more than 30 years of additional rainfall records and inclusion of data from an extra 2300 rainfall stations across Australia than ARR 1987.

## 10.3 Impact of ARR 2016 on 1% AEP Peak Flood Levels

The impact of ARR 2016 hydrology on peak flood levels was assessed for the 1% AEP event in comparison to the ARR 1987 hydrology, which was adopted in the flood study. Assessment of ARR 2016 design rainfalls involves consideration of the design rainfall depths for various storm durations, with the rainfall depth distributed temporally based on 10 design temporal patterns for each storm duration. The temporal patterns can have an influence on peak flood levels, depending on catchment characteristics.

The flood study modelling consists of a DRAINS hydrologic model for estimating sub-catchment inflow hydrographs, which are then input as distributed inflows into a TUFLOW hydraulic model of the catchment. ARR 1987 design rainfalls were input in the flood study DRAINS model.

For the sensitivity assessment, the design rainfalls were replaced with ARR 2016 design rainfall depths for various storm durations, and the DRAINS model run for 10 design temporal patterns for each storm duration. The resultant inflow hydrographs were input into the TUFLOW model. The median flood level value of each storm duration is determined from the TUFLOW model results and then the maximum flood level envelope derived from the medians of all storm durations. Storm durations of 15, 30, 60, 90 and 120 minutes were assessed. The critical duration for the 1% AEP event was observed to typically be the 60 minute duration in most of the catchment.

The difference between the ARR 2016 and ARR 1987 1% AEP design flood levels are mapped on **Map L-1**, in **Appendix L**. Flood levels are generally observed to be lower than the ARR 1987 flood levels, with in-stream flood level differences of -0.2m to -0.4m on the reach of Lovers Jump Creek upstream of Burns Road. Flood levels in several flood storage areas and trapped drainage points such as adjacent to Knox Grammar School and in-channel upstream of Carrington Road, Wahroonga, are approximately 1m lower, although these drainage features are localised and not on the main overland flow areas. The differences in flood levels are a result of lower design rainfall depths for ARR 2016 (refer **Figures L-1 to L-5**) and resulting reduced flood volumes. There are some localised minor increases in flood levels, however, these do not impact on existing properties.

## 10.4 Consideration of ARR 2016 parameters

### 10.4.1 Design Rainfalls

The design rainfall depths for ARR 1987 and ARR 2016 are compared in **Table 10-1** for the assessed 1% AEP storm events. It is observed that there are minor increases for the 15 and 30 minute duration events of up to +3%, although for the critical storm durations of the 60 and 90 minute events there are reductions in rainfall depths of -5% and -10%, respectively.

Table 10-1 Comparison of ARR 1987 and ARR 2016 design rainfall for 1% AEP event

| Duration | Rainfall depth (mm) | | Difference |
|---|---|---|---|
| | ARR 1987* | ARR 2016 | |
| 15m | 43.3 | 44.8 | 3% |
| 30m | 60.4 | 61.9 | 2% |
| 60m | 84.9 | 80.4 | -5% |
| 90m | 103 | 92.2 | -10% |
| 120m | 117 | 104 | -11% |

* ARR 1987 rainfall depths from BOM website

#### 10.4.2 Areal Reduction Factor

Areal reduction factors are often applied in hydrologic assessments of catchment areas larger than 1km$^2$ to reduce the relatively high point-location design rainfall depths and intensities in order to reflect the lower, catchment-averaged depth or intensity. Flooding in the Lovers Jump Creek study area is primarily concerned with overland flooding of properties with up to a 3km$^2$ (typically less than 1km$^2$) upstream catchment area. The areal reduction factor associated with these catchment areas is estimated at 0.96 – 1.0. Therefore, with minimum reduction factor values being relatively close to 1.0 for the local catchments in the study area, no areal reduction factor has been applied to the hydrologic assessment of the local catchments for this study.

#### 10.4.3 Rainfall Losses

The rainfall losses for pervious areas adopted in the flood study hydrologic modelling with ARR 1987 (DRAINS modelling) are based on the Horton infiltration model, which assumes an initial (depression storage) rainfall loss and subsequently an exponential-decay continuing loss rate. This is shown on **Figure L-6**. A soil type of C and an Antecedent Moisture Condition (AMC) of 3 was adopted. These parameters have been retained and only the design rainfalls changed to ARR 2016 for this sensitivity assessment, as mentioned in the task scope in Jacobs' proposal and discussed in the project inception meeting.

ARR 2016 recommendations for rainfall losses are based on an initial loss – continuing loss model, with storm loss depths (pre-burst + burst losses) prescribed by the ARR Datahub for the study area as:

- Storm initial loss: 38mm, with median pre-burst loss of 1mm for a 1% AEP 1 hour storm. Therefore, burst loss = 37mm.
- Continuing loss: 2mm/hr.

These rainfall losses apply to pervious areas.

It is difficult to conduct a direct comparison between the traditional DRAINS rainfall losses (Horton model) and the ARR 2016 IL-CL model. Estimated runoff volumes from the DRAINS model for the entire catchment area (combined pervious and impervious areas) for the 1% AEP 60 minute event were therefore compared to the design rainfall depths to determine an effective rainfall loss depth in mm. In the DRAINS modelling, the ARR 1987 design rainfalls were paired with the traditional Horton loss model, while the ARR 2016 design rainfalls were paired with the IL-CL model and loss values. The results are summarised in **Table 10-2**. Comparison to the scenario which has been analysed in the TUFLOW model (ARR 2016 design rainfall with DRAINS Horton loss model) has also been made.

Table 10-2 Effective rainfall losses for Lovers Jump Creek catchment for ARR 1987 and ARR 2016

| Rainfall and Losses | Design Rainfall (mm) | Rainfall Volume (m$^3$) | Runoff Volume (m$^3$) | % Volume conversion to runoff | Rainfall Excess (mm) | Catchment-Averaged Rainfall Loss (mm) |
|---|---|---|---|---|---|---|
| ARR 1987 | 84.9 | 825,228 | 682,000 | 83% | 70 | 14.7 |
| ARR 2016 | 80.4 | 781,488 | 538,000 | 69% | 55 | 25.4 |
| ARR 2016 (rainfall only) | 80.4 | 781,488 | 640,000 | 82% | 65 | 15.4 |

Applying ARR 2016 guidelines (design rainfall and losses) results in 70% higher rainfall losses for the 1% AEP 60 minute storm, a lower conversion rate of rainfall to runoff and a 25% lower runoff volume than with ARR 1987 guidelines.

Applying the ARR 2016 design rainfall only (retaining the original DRAINS model losses) results in similar rainfall losses to ARR 1987, with an 6% reduction in runoff volume. This reduction is consistent with the difference in rainfall intensity in **Table 10-1**.

Based on the estimated storm rainfall losses and the runoff volumes, the modelled flows in Lovers Jump Creek appear to be more sensitive to the application of the ARR 2016 IL-CL loss model and values than to the ARR 2016 design rainfalls. Adopting the ARR 2016 design rainfall and losses is likely to result in marked reductions in peak flows and flood levels.

The ARR 2016 guidelines states that the IL-CL loss values are for assessment of rural catchments and are not for use in urban catchments. The loss values were estimated based on analysis of gauged rural catchments, which are different in characteristics to even the pervious portions of urban catchments in terms of vegetation cover and soil moisture conditions, and this is likely to reflect in high initial losses in rural catchments versus urban catchments. Further, the high initial loss depth of 37mm (burst only) appears exceedingly high compared to values previously used for pervious areas in urban catchments (typically up to 15mm). It is also inconceivable that in a storm event an urban pervious area would only begin to generate runoff after the first 37mm of rainfall. For these reasons the ARR 2016 IL-CL losses are not considered appropriate for the Lovers Jump Creek catchment and the traditional DRAINS (Horton) losses have been retained for the flood study review.

## 10.5 Rainfall Temporal Patterns – analysis of ARR 2016 ensemble peak flow rates

Box plots of the 1% AEP peak flow rates at 10 selected key locations (refer **Figure L-7**) in the catchment are shown on **Figures L-8 to L-17** for the assessed storm durations. The peak flow rates were extracted from the TUFLOW model after the ARR 2016 design rainfall (with Horton losses) DRAINS inflow hydrographs were routed through the model. The box plots show the variability of the peak flows for the ensemble of 10 temporal patterns for each storm duration at each location. The peak flood study model flow (ARR 1987 design rainfall) is also plotted on the graphs. The ARR 2016 critical event peak flows are summarised on **Table 10-3**.

The key locations were selected at various points along overland flow paths and main watercourses in the developed parts of the catchment. A location near the outlet of Lovers Jump Creek is also selected.

Findings of this assessment are:

- The 60 minute duration event is typically the critical event on the main watercourses and main overland flow paths (Sites 3, 6, 7 and 10), based on the median of each ensemble.
- The 15 minute and 30 minute duration events are critical on the upper sections of overland flow paths (Sites 1, 2, 4, 5, 8 and 9).
- The critical event peak flows (maximum of ensemble medians) and the critical event duration are summarized on Table 3. The cutoff flow between the 15 and 30 minute events and the 60 minute event as the critical event is around 20m$^3$/s.
- Although the peak flows indicate variability of the critical event duration, this generally did not translate to a significant difference in peak flood level between the 60 minute event and the 15 or 30 minute event, where these latter events were critical. The typical variance is up to 0.03m.
- The peak ARR 1987 flows adopted in the flood study exceed the critical (i.e. maximum of ensemble medians) ARR 2016 (with DRAINS model losses) peak flows at all locations. The maximum of ensemble maximum ARR 2016 peak flows equal or exceed the ARR 1987 peak flows in only a couple of instances (Site 2, 15 and 30 minute event, and Site 9, 30 and 60 minute event). The difference between the ARR 1987 and the critical ARR 2016 peak flows is shown on **Table 10-3**. With the difference in flows of 5 – 10% due to the difference in design rainfall depth (based on rainfall depths and runoff volumes in Table 2) this indicates that the ARR 2016 temporal patterns have a similar or greater influence on the resultant peak flows as the difference in rainfall depth only.

Table 10-3 Summary of ARR 2016 critical event peak flow and storm duration at selected locations

| Location | Critical duration | Critical event peak flow ($m^3/s$) | Difference from ARR 1987 |
|---|---|---|---|
| Site 1 | 30min | 9.27 | -16% |
| Site 2 | 15min | 5.93 | -11% |
| Site 3 | 60min | 29.81 | -27% |
| Site 4 | 30min | 5.06 | -26% |
| Site 5 | 30min | 10.22 | -21% |
| Site 6 | 60min | 30.72 | -25% |
| Site 7 | 60min | 69.44 | -27% |
| Site 8 | 30min | 8.1 | -17% |
| Site 9 | 15min | 17.81 | -18% |
| Site 10 | 60min | 165.36 | -22% |

## 10.6 Conclusions and Recommendations on ARR 2016

- ARR 2016 design rainfall estimates are based on a more extensive database, with more than 30 years of additional rainfall records than ARR 1987, and has been derived with contemporary statistical analysis and techniques with this expanded rainfall database.
- ARR 1987 design rainfall estimates are generally higher than ARR 2016 estimates. The at-site estimates based on Sydney Water's rainfall station at Pymble (Station 566073) are generally lower than ARR 1987 and generally higher than ARR 2016.
- ARR 2016 design rainfall depths are not expected to have a significant influence on peak flows compared to ARR 1987 (approximately -5% to -10% difference). Based on the critical (maximum of ensemble medians) peak flows, the temporal patterns are expected to have a greater influence on peak flows (approximately -10% to -20% difference).
- The ARR 2016 IL-CL rainfall losses are not recommended for use in urban catchments such as Lovers Jump Creek due to limitations in the estimation approach for these losses, but would be expected to result in a significant reduction in peak flows mainly due to the very high pervious area initial losses. The traditional DRAINS (Horton loss model) losses adopted in the flood study are recommended to be retained in the flood study review.
- Flood levels simulated for the 1% AEP event using ARR 2016 (design rainfalls only) are typically lower than the ARR 1987 flood levels by -0.2m to -0.4m on main flow paths and watercourses due to lower design rainfall depths and resultant lower flood flows and volumes.
- Based on the ARR 2016 design rainfall assessment findings it is recommended that ARR 1987 design rainfall and flood levels be adopted in the flood study review and FRMS (i.e. no update to flood modelling). ARR 1987 provides a conservative estimate of flooding in the study area.

# 11. Conclusions and Recommendations

An analysis of existing flooding conditions in the Lovers Jump Creek catchment has been undertaken using a two- dimensional, unsteady flow TUFLOW hydraulic model which has been developed for this flood study. The model is based on LiDAR-derived terrain data and ground survey data of watercourses, and includes the stormwater pit and pipe drainage network and surveyed waterway structures. Inflows have been estimated at numerous locations throughout the catchment using an existing DRAINS stormwater model provided by Ku-ring-gai Council.

The models have been verified against the February 2010 flood event, which is the most significant flood event in recent times in the study area. The verified DRAINS and TUFLOW models present flood behaviour which is consistent with the reported observations to the precision offered by the available historic flood observations.

Design flood events between the 20% AEP event up to the PMF event, for a range of event durations up to 2 hours have been simulated. Flood mapping of depth, flood level, flood hydraulic categories and provisional flood hazard has been undertaken for selected event AEPs.

The flood planning area mapping has been conducted for areas deemed to be affected by active flows in the 1% AEP event. This has been determined by consideration of flooding depth, continuity of the mapped flood inundation, presence of incised gullies in the flow path terrain and susceptibility of existing development. The flood planning area is defined by the area below the 1% AEP flood level plus a specified freeboard. In this study a 0.3m freeboard has been adopted for areas affected by overland flooding, and a 0.5m freeboard for those affected by mainstream flooding.

Properties within the study area were classified for flood emergency response based on NSW Government floodplain risk management guidelines. The classification indicates the relative vulnerability of different areas of the catchment and considers the ability to evacuate certain parts of the community.

Sensitivity testing indicates that peak flood levels are not overly sensitive to the varied rainfall loss and hydraulic roughness scenarios tested, with increases in 1% AEP flood levels typically less than 150mm in developed areas. However, some significant flood level increases of up to 1m were observed for the fully blocked hydraulic structures scenario, due to the height of the waterway structures which would need to be overtopped by floodwaters in the case of a fully blocked scenario. Existing development would be impacted by these increases. A fully blocked scenario is considered to be a highly conservative assumption as some amount of flow would likely be conveyed through the structure even in a highly blocked condition.

Climate change impact modelling indicates that existing development would be affected by increases in peak flood levels in overland flow paths of up to 0.25m in the 30% rainfall intensity increase scenario. Some locations along watercourses would be affected by increases of up to 0.75m at certain locations. Flood levels increase by up to 0.35m at some road crossings.

Based on the ARR 2016 design rainfall assessment findings it is recommended that ARR 1987 design rainfall and flood levels be adopted in the flood study review and FRMS (i.e. no update to flood modelling). ARR 1987 provides a conservative estimate of flooding in the study area.

It is recommended that Ku-ring-gai Council considers the adoption of this Flood Study Review and the outputs such as the Flood Planning Levels (FPLs) to guide floodplain management and land use planning in the Lovers Jump Creek catchment. The subsequent Floodplain Risk Management Study should consider the management of flood risk in the catchment, particularly at the identified flooding “hot spots”, which may include the development of flood mitigation strategies.

# 12. Acknowledgements

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- Residents of the study area;
- Members of the floodplain management committee;
- Council officers; and
- Office of Environment and Heritage.

# 13. References


BMT WBM (2017) TUFLOW User Manual 2017.

Bureau of Meteorology (2003) The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method, Bureau of Meteorology, Melbourne, Australia, June 2003, (39pp).

Commonwealth of Australia (Geoscience Australia) (2016). Australian Rainfall and Runoff, a Guide for Flood Estimation.

Department of Environment and Climate Change (2007) Flood Emergency Response Planning – Classification of Communities

Department of Environment and Climate Change (2007) Floodplain Risk Management Guideline – Practical Consideration of Climate Change.

Department of Environment and Climate Change (2009) Draft Sea Level Rise Policy.

Engineers Australia (2003). Australian Rainfall and Runoff, a Guide for Flood Estimation. Vol. I and II. The Institution of Engineers, Australia.

Engineers Australia (2013). Australian Rainfall and Runoff Revision Projects – Project 11 Blockage of Hydraulic Structures Stage 2. The Institution of Engineers, Australia.

Jacobs (2016) Lovers Jump Creek Flood Study. Prepared for Ku-ring-gai Council.

NSW Government (2005) Floodplain Development Manual.

S. J. Riley , G. B. Luscombe & A. J. Williams (1986) Urban stormwater design: lessons from the 8 November 1984 Sydney storm, Australian Geographer, 17:1, 40-50, DOI: 10.1080/00049188608702899

Watercom (2017) DRAINS User Manual.

WP Brown & Partners (2004) Cowan Creek Catchments Sub-Catchment Stormwater Analysis and Planning, Final Report. Prepared for Ku-ring-gai Council.

# 14. Glossary

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| 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. In this study AEP has been used consistently to define the probability of occurrence of flooding. It is to be noted that design rainfalls used in the estimation of design floods up to and including 100 year ARI (ie. 1% AEP) events was derived from 1987 Australian Rainfall and Runoff. Hence the flowing relationship between AEP and ARI applies to this study.<br><br>20% AEP = 5 year ARI; 10% AEP = 10 year ARI; 5% AEP = 20 year ARI; 2% AEP = 50 year ARI; 1% AEP = 100 year ARI. |
| 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 occurrences 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. |
| Development | Is defined in Part 4 of the EP&A Act<br><br><u>In fill development</u>: 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.<br><br>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 exiting urban services, such as roads, water supply, sewerage and electric power.<br><br>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. |
| DRAINS | DRAINS is a computer program which is used to simulate local catchment rainfall-runoff and stormwater system hydraulics and is widely used across Australia. |

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| Effective Warning Time | The time available after receiving advise 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. |
| 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 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 (i.e.) land susceptibility to flooding by the PMF event. Note that the term flooding liable land covers the whole floodplain, not just that part below the FPL (see flood planning area) |
| 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 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 include both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defines 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 levels (FPLs) | Are the combination 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 "designated flood" or the “flood standard” used in earlier studies. |
| Flood proofing | A combination of measures incorporated in the design, construction and alteration of individual buildings and structures subject to flooding, to reduce or eliminate flood damages. |
| 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 |

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| | floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below.<br><br>Existing flood risk: the risk a community is exposed to as a result of its location on the floodplain.<br><br>Future flood risk: the risk a community may be exposed to as a result of new development on the floodplain.<br><br>Continuing flood risk: 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 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. |
| Hazard | A source of potential harm or 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. |
| Local overland flooding | Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam. |
| m AHD | Metres Australian Height Datum (AHD) |
| m/s | Metres per second. Unit used to describe the velocity of floodwaters. |
| $m^3/s$ | Cubic metres per second or "cumecs". A unit of measurement of creek or river flows or discharges. It is the rate of flow of water measured in terms of volume per unit time. |
| Mainstream flooding | Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam. |
| Modification measures | Measures that modify either the flood, the property or the response to flooding. |

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| Overland flow path | The path that floodwaters can follow as they are conveyed towards the main flow channel or if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads. |
| Probable Maximum Flood (PMF) | The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation couplet 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. |
| Probable Maximum Precipitation (PMP) | 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. |
| 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 a streamflow, also known as rainfall excess. |
| Stage | Equivalent to water level (both measured with reference to a specified datum) |
| TUFLOW | TUFLOW is a computer program which is used to simulate free-surface flow for flood and tidal wave propagation. It provides coupled 1D and 2D hydraulic solutions using a powerful and robust computation. The engine has seamless interfacing with GIS and is widely used across Australia. |