# GRETA FLOOD STUDY

# FINAL REPORT – VOLUME 1


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# GRETA FLOOD STUDY

FINAL REPORT

| **Project**<br>**Greta Flood Study** | **Project Number**<br>**117053** |
|---|---|
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| | |
|---|---|
| AEP | Annual Exceedance Probability |
| AHD | Australian Height Datum |
| ARR | Australian Rainfall and Runoff |
| BoM | Bureau of Meteorology |
| CCC | Cessnock City Council |
| ERP | Emergency Response Classification |
| EY | Exceedances per Year |
| GSAM | General Southeast Australia Method |
| GSDM | Generalised Short Duration Method |
| IFD | Intensity, Frequency and Duration of Rainfall |
| IPCC | Intergovernmental Panel on Climate Change |
| LEP | Local Environmental Plan |
| LiDAR | Light Detection and Ranging (also known as ALS) |
| LPI | Land and Property Information |
| MCC | Maitland City Council |
| MHL | Manly Hydraulics Laboratory |
| $m^3/s$ | cubic metres per second (flow measurement) |
| m/s | metres per second (velocity measurement) |
| NOW | NSW Office of Water |
| OEH | Office of Environment and Heritage |
| PMF | Probable Maximum Flood |
| PMP | Probable Maximum Precipitation |
| TUFLOW | one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model) |
| WBNM | Watershed Bounded Network Model (hydrologic computer model) |
| 1D | One dimensional hydraulic computer model |
| 2D | Two dimensional hydraulic computer model |

# TERMINOLOGY USED IN REPORT

Australian Rainfall and Runoff (ARR, ed Ball et al, 2016) recommends terminology that is not misleading to the public and stakeholders. Therefore the use of terms such as "recurrence interval" and "return period" are no longer recommended as they imply that a given event magnitude is only exceeded at regular intervals such as every 100 years. However, rare events may occur in clusters. For example there are several instances of an event with a 1% chance of occurring within a short period, for example the 1949 and 1950 events at Kempsey. Historically the term Average Recurrence Interval (ARI) has been used.

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

ARR 2016 recommends the use of Annual Exceedance Probability (AEP). Annual Exceedance Probability (AEP) is the probability of an event being equalled or exceeded within a year. AEP may be expressed as either a percentage (%) or 1 in X. Floodplain management typically uses the percentage form of terminology. Therefore a 1% AEP event or 1 in 100 AEP has a 1% chance of being equalled or exceeded in any year.

ARI and AEP are often mistaken as being interchangeable for events equal to or more frequent than 10% AEP. The table below describes how they are subtly different.

For events more frequent than 50% AEP, expressing frequency in terms of Annual Exceedance Probability is not meaningful and misleading particularly in areas with strong seasonality. Therefore events more frequent than 50% AEP should be expressed as X Exceedances per Year (EY). For example, 2 EY is equivalent to a design event with a 6 month recurrence interval where there is no seasonality, or an event that is likely to occur twice in one year.

The Probable Maximum Flood is the largest flood that could possibly occur on a catchment. It is related to the Probable Maximum Precipitation (PMP). The PMP has an approximate probability. Due to the conservativeness applied to other factors influencing flooding a PMP does not translate to a PMF of the same AEP. Therefore an AEP is not assigned to the PMF.

This report has adopted the approach recommended by ARR and uses % AEP for all events rarer than the 50 % AEP, 1 in X AEP for events rarer than the 1% AEP and EY for all events more frequent than the 50% AEP.

# FOREWORD

The NSW State Government's Flood Prone Land Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through four sequential stages:

***1. Flood Study***
- Determine the nature and extent of the flood problem.

***2. Floodplain Risk Management Study***
- Evaluates management options for the floodplain in respect of both existing and proposed development.

***3. Floodplain Risk Management Plan***
- Involves formal adoption by Council of a plan of management for the floodplain.

***4. Implementation of the Plan***
- Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

# EXECUTIVE SUMMARY

The Anvil Creek catchment is located in the Hunter Valley, approximately 45 km west of Newcastle, with an area of 36.5 km$^2$. The catchment boundary lies 5 km upstream from Greta (intersection of Anvil and Sawyers Creek) extending to downstream of the Cessnock City Council (CCC) LGA. The catchment lies within CCC with minor portions of the upper Anvil Creek catchment lying within the Maitland City Council (MCC) and Singleton Council (SC) LGA.

The primary objective of this Flood Study is to develop a robust hydrologic and hydraulic modelling system that defines flood behaviour for the study area (comprising of most of the populous areas within the catchment) for a range of design flood events. While flooding in the lower Anvil Creek catchment can occur in large Hunter River flood events, the focus of this study is on flooding resulting from runoff within the Anvil Creek catchment. Anvil Creek and the tributaries within the townships of Greta and East-Branxton have a history of significant flooding, with notable events occurring in June 2007 (the “Pasha Bulker” storm), June 2011, February-March and November 2013, April 2015 and January 2016 over the entire catchment.

The available data for this study was collected, including topographic data and survey data. Community consultation was also undertaken, where residents were asked to provide information on their experiences of flooding. Of those that responded, 79% were aware of flooding issues within the catchment, with a total of 32 respondents having their properties affected by flooding and of those, 18 properties flooded above floor level. A number of flood marks were provided as part of the consultation, with several others being collected by WMAwater on a fieldtrip at the conclusion of the consultation period.

A WBNM hydrologic model with 140 subcatchments was developed to simulate rainfall runoff. A linked one-dimensional (1D) and two-dimensional (2D) TUFLOW hydraulic model was also developed to simulate flood behaviour. The model adopts a 2 m grid cell size and a new TUFLOW version that uses Heavily Parallelised Computing (HPC) Graphical Processor Unit (GPU) model support for significantly faster model run-times. Inflows from the WBNM model were used and a downstream boundary applied downstream of the model, at the Hunter River.

The models were calibrated to the June 2007, April 2015 and January 2016 flood events. The approach to model calibration was to adjust the rainfall loss parameters and the stream routing parameter in the WBNM (hydrologic) model and adjust the Manning’s ‘n’ roughness values in the TUFLOW hydraulic model. No water level gauge was available to calibrate to. As such, both the WBNM and TUFLOW model investigated multiple combinations of these parameters until the best fit to the recorded flood marks in the study area could be achieved across the whole range of calibration events. The results indicate that a good calibration was achieved.

Design flood events were then simulated using the calibrated models. Australian Rainfall and Runoff (ARR) 2016 methodology was employed to model the 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% Annual Exceedance Probability (AEP) events as well as the Probable Maximum Flood (PMF). The critical pattern duration was selected based upon the temporal pattern that consistently produced the average peak flood levels across the catchment for both Anvil Creek and smaller flow paths within Greta and East-Branxton. This assessment was undertaken using the WBNM hydrologic model where the critical duration pattern for each design flood was run in the TUFLOW model. These flood results were used to map results and present the flood behaviour for the catchment. Results presented include flood levels, depths, velocities, hazard categories, hydraulic categories, classification of communities, information to support emergency management, advice of land-use planning considering flooding and the flood planning area.

A sensitivity analysis was also undertaken to assess the sensitivity of results to climate change, rainfall losses, catchment lag, Manning's 'n', blockage of structures and downstream boundary conditions.

# 1. INTRODUCTION

## 1.1. Background

The Greta Flood Study covers the Anvil and Red House Creek catchments, which are located in the Hunter Valley, approximately 45 km north-west of Newcastle. The study area includes the urbanised areas of Greta, East-Branxton and adjacent rural areas. The location of the study area catchment is shown in Figure 1. The total area of the catchment is approximately 36.5 $km^2$.

The catchment lies predominately within the Local Government Area (LGA) of Cessnock City Council (CCC). A minor portion of the upper Anvil Creek catchment is within the Maitland City Council (MCC) LGA, and the upper part of Red House Creek lies within the Singleton Council LGA.

Flooding in the lower Anvil creek can occur as a large Hunter River flood. CCC has previously undertaken flood studies in 1998 and 2010 focussing on riverine flooding from the Hunter River.

Flooding in the upper portion of the Anvil Creek catchment is dominated by localised rainfall events, and the major flood mechanism within the townships of Greta and East-Branxton is from local tributary creeks draining water from the northern portion of the catchment into Anvil Creek. CCC has previously undertaken small drainage studies throughout the study area along these overland flow paths. These studies were completed in the 1980s and are now outdated.

A comprehensive study of the local catchment flooding mechanisms throughout the catchment has not yet been undertaken. There has been increasing development of residential properties and transport infrastructure across the catchment in recent years. The Hunter Expressway was opened in 2015; linking the F3 Freeway (now M1) at Newcastle to Branxton creating a bypass for the townships of Maitland, Lochinvar, Greta and Branxton. The dual carriageway passes through the study area (as seen on Figure 2) remaining on the left on Anvil Creek for its entire length. Some tributaries including Sawyers Creek cross the Hunter Expressway, eventually draining into Anvil Creek.

There has been rezoning of a large portion of rural land around North Rothbury, which will be developed to form a new township called Huntlee. It is located at the south-western portion of the study area, bounded by the Hunter Expressway to the north and east and Wine Country Drive to the east. Staged development of Huntlee is underway, but at the time of this study, full design and subdivision approval for the entire Huntlee area was not yet complete. Flood mapping in North Rothbury is not within the scope of this flood study, however the land usage is integral to the development of the hydrological model, and full development of this area has been assumed for this study. It will be necessary for Council to understand the potential flood affectation of these areas, and to mitigate against flood risks for future development in the area.

During the progress of the Flood Study, development was occurring in the upper catchment draining to the West Street Tributary. In the current flood model the catchment was considered rural in nature with hydraulic structures only at Branxton Road and New England Highway. Current development in catchment consists of a residential subdivision and associated detention basin in the upper reaches, along with a road and associated culverts bisecting the catchment. The flood modelling does not reflect these changes in the catchment conditions and it may be necessary for Council to consider further flood analysis to understand the potential flood affectation in this catchment and to mitigate against flood risk and ongoing development.

The extent of the study area is shown in Figure 2. The study covers an area of approximately 36.5 km$^2$ from 5 km upstream from Greta (intersection of Anvil and Sawyers Creek), and 9 km upstream of East-Branxton (intersection of Anvil Creek at Maitland Street) extending to the confluence with the Hunter River.

## 1.2. Study Objectives

The primary objective of this Flood Study is to develop a robust hydrologic and hydraulic modelling system that defines flood behaviour for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2%, 0.1% AEP, and the Probable Maximum Flood design events. This will be used to assist CCC in determining existing flood risk, peak flood levels, inundation extents and velocities along with hazard and hydraulic categorisation within the study area. The system may subsequently be used within a Floodplain Risk Management Study and Plan to assess the effectiveness and suitability of potential flood risk mitigation measures.

This Flood Study includes:

- a description of the study area;
- a summary of available historical flood-related data;
- analysis of rainfall data;
- outcomes of the community consultation program;
- identification of suitable historical events for calibration and verification;
- the modelling methodology adopted;
- description of the hydrological and hydraulic model set up;
- the calibration methodology and results;
- design flood event results;
- sensitivity analysis including climate change; and
- preliminary outputs for implementation of Council's flood related planning controls.

# 2. BACKGROUND

## 2.1. Study Area

The study area comprises the majority of the populous areas of the Anvil and Red House Creek catchment as shown in Diagram 1 below and also in Figure 2. Anvil Creek generally runs in a north-westerly direction and parallel to the Northern Railway (remaining on the north side). The upper portion of the Anvil Creek catchment is predominately made up of rural properties with small pockets of residential development. Several tributaries drain water from the south-western portion of the catchment, crossing the Hunter Expressway before joining Anvil Creek.

Further downstream, the terrain levels out through the lower reaches comprising of a mixture of rural and residential development. The creek passes Greta along the south of the township. The New England Highway is situated between Anvil Creek and Greta.

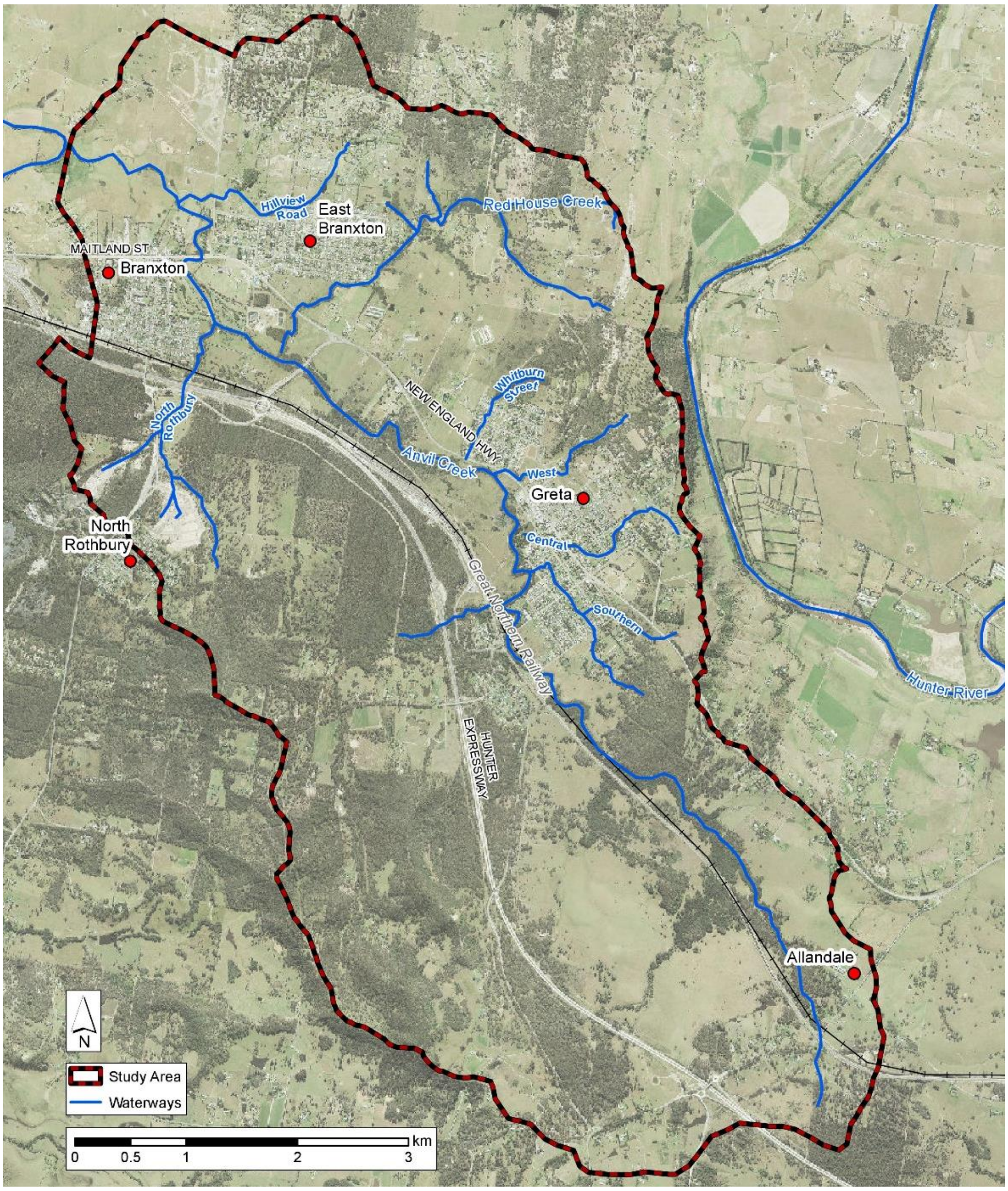


Diagram 1: Greta Study Area

Flow in the tributary creeks is the principal flooding mechanism within the townships of Greta and East-Branxton. There are four main flow paths within Greta, draining water from the eastern portion of the catchment and discharging into Anvil Creek. East-Branxton has main two flow paths. The location of these flow paths is shown in Diagram 1 and a description of them is detailed below:

- **Whitburn Catchment, Greta –** has a catchment area of approximately 0.9 km$^2$. Flow originates upstream of the Whitburn residential estate and travels in a south-westerly direction between residential properties. The flow path runs perpendicular to York Street, Kent Street and Whitburn Street before flowing beneath the New England Highway and spilling into Anvil Creek.

- **West Street Catchment, Greta** – has a catchment area of approximately 0.9 km$^2$. Residential development is currently occurring in the upper reaches of the catchment, which has not been considered in this Flood Study. The overland flow path covering the west catchment is mostly made of up rural land with an influence from the residential subdivision and detention basin current being constructed in the upper reaches. The flowpath runs parallel to the new Reginald Street (extension of West Street), crossing two new hydraulic structures along the new street, as wells at Branxton Road and the New England Highway before discharging into Anvil Creek. Several farm dams are also located along this flow path. The flow path runs along a naturally vegetated channel. Council will need to consider the changed catchment terrain and land use conditions in this catchment and may carry out a future flood analysis to mitigate against flood risk and ongoing development.

- **Central Catchment, Greta** – has a catchment area of approximately 1.1 km$^2$. The central catchment flow path originates east of Orient Street, where a detention basin and built-up bank controls the discharge of flow further downstream. In large events where the detention basin is exceeded, flow travels north-west before turning west running parallel to Hunter Street. The flow path continues in a south-west direct, travelling between properties along Branxton Street and Evans Street. Between Branxton Street and Hunter Street, the naturally vegetated channel becomes a concrete lined channel until it discharges into an old mine dam adjacent to Anvil Street. Hydraulic structures (such as bridges and culverts) built from timber materials are located along this section of channel, crossing Wyndham Street, High Street and Anvil Street.

- **Southern Catchment, Greta –** has a catchment area of approximately 1.45 km$^2$. The main flow path occurs as a result of the convergence of two smaller flow paths: one originating upstream of Park Street, and one upstream of White Street. These two paths converge in the rear of properties between Anvil Street and Sale Street. This flow path continues in a north-west direction before discharging into Anvil Creek at Sale Street. A hydraulic structure is located Nelson Street and causeways are located at Station Street and Hunter Street.

- **Red House Creek, East-Branxton –** has a catchment area of approximately 5.7 km$^2$.The upper portion of the Red House Creek catchment is rural land. The creek runs parallel to

Dalwood Road for approximately 1 km, crossing the road on two occasions. Several minor tributaries feed into the upper Red House Creek. The creek then runs along the south-east boundary of East-Branxton in close proximity to residential properties along Preston Close, Spring Street, Church Street and Yates Street. Flow continues in a south-west direction, crossing the New England Highway and discharging into Anvil Creek. The creek is a heavily vegetated natural channel.

- **Hillview Road, East-Branxton** – has a catchment area of approximately 1.57 km$^2$. The flow path originates to the north, within the Singleton Council LGA. The land usage within the Singleton Council LGA is generally made up of rural land. The flow path crosses Hillview Road (in CCC LGA) and travels along a formalised channel with concrete lining until McMullins Road before becoming a naturally vegetated channel. Flow continues in an easterly direction before spilling into Anvil Creek.

## 2.2. Historical Flooding

### 2.2.1. Flood Mechanisms in Greta and East-Branxton

Flooding in the townships of Greta and East Branxton can occur when intense local rainfall causes runoff exceeding the capacity of creeks and drainage channels, producing over bank flow. The key flow paths are described above.

### 2.2.2. Flood Mechanisms in the lower Anvil Creek

1. Anvil Creek Flooding – Flooding on the Anvil Creek River can occur due to heavy rainfall over the Anvil and Red House Creek catchments. This mechanism influences flooding the entire length of the Anvil Creek.
2. Hunter River Flooding – Flooding on the Hunter River can be caused by rainfall over the broader Hunter River and Goulburn River catchments. This mechanism influences backwater flooding on the lower reaches and floodplains of the Anvil Creek. The extent of flooding during a large Hunter River flood event can extend upstream to the township of Greta. Greta is on higher ground above the floodplain so widespread flooding within the town as a result of the Hunter River is unlikely.

Flooding on the Anvil Creek and Hunter Rivers can occur independently of one another or concurrently. Concurrent flooding has a significant influence on flood levels on the lower reaches of the Anvil River and floodplains.

### 2.2.3. Historical Events

Both Anvil and Red-House Creeks have a history of significant flooding, with notable events occurring in June 2007 (the “Pasha Bulker” storm), June 2011, February-March 2013, November 2013, April 2015 and January 2016 over the entire catchment.

This study focusses on three major recent events – June 2007, April 2015 and January 2016. The June 2007 and April 2015 events in particularly were major storms that caused widespread inundation, damage and loss. A selection of photos following the April 2015 event are shown below.


Photo 1: Greta Public School - 2015

Photo 2: Bridge at New England Highway crossing Anvil Creek - 2015

Photo 3: Branxton Street Bridge 2015

Photo 4: Sports field at Wyndham St, Greta 2015

# 3. AVAILABLE DATA

## 3.1. Topographic Data

Light Detection and Ranging (LiDAR) survey of the study area and its immediate surroundings was provided for the study by LPI (see Figure 3). LiDAR is aerial survey data that provides a detailed topographic representation of the ground with a survey mark approximately every square metre. The data for the Maitland area was collected in 2012. The accuracy of the ground information obtained from LiDAR survey can be adversely affected by the nature and density of vegetation, the presence of steeply varying terrain, the vicinity of buildings and/or the presence of water. The accuracy is typically ± 0.15 m for clear terrain. The data extent is shown in Figure 3.

## 3.2. Hydraulic Structures

Structures including bridges and culverts can have a significant impact on flood behaviour. Therefore, appropriate representation of these structures is essential for the accuracy of the hydraulic model. Data for hydraulic structures was supplied by Council on the inception of the Flood Study from:

- Council Reports (WAE Designs and previous studies);
- WMA measurements; and
- Hunter Expressway Alliance

### 3.2.1. WMA Hydraulic Structure Inspection

During the catchment inspection (22nd September 2017), WMAwater measured key hydraulic structures along Anvil Creek and the several flow paths within Greta and East-Branxton. During the inspection, the structure dimensions as well as the height from the structure obvert to road level were estimated. The inverts of the structures were estimated by subtracting the structure obvert to road level height from the road level (estimated from LiDAR). In some cases, the hydraulic structure inverts were taken from previous studies (Section 3.8.1). The locations of these structures are shown on Figure 3. A summary of the details is provided in Table 1. Photos of the structures are provided in Appendix B.

Table 1: Hydraulic Structures Measured by WMAwater

| ID | Location | Structure Type | Width/ Diameter (m) | Height (m) | Number |
|---|---|---|---|---|---|
| CENTRAL01 | Orient St, Greta | Pipe | 0.45 | | 2 |
| CENTRAL02 | Branxton St, Greta | Pipe | 1.35 | | 2 |
| CENTRAL03 | Hunter St, Greta | Box Culvert | 3.03 | 1.35 | 1 |
| CENTRAL04 | High St, Greta | Box Culvert | 3.60 | 1.65 | 1 |
| CENTRAL05 | High St, Greta | Box Culvert | 3.75 | 1.25 | 1 |
| CENTRAL06 | Wyndham St, Greta | Box Culvert | 3.15 | 2.60 | 1 |
| CENTRAL07 | Anvil St, Greta | Box Culvert | 2.70 | 2.20 | 1 |
| HVIEW01 | Hillview Rd, East Branxton | Box Culvert | 2.10 | 0.73 | 3 |
| HVIEW2 | McMullins Rd, East Branxton | Box Culvert | 2.50 | 1.70 | 2 |
| HVIEW3 | Elderslie Rd, East Branxton | Box Culvert | 6.00 | 0.75 | 1 |
| NEHWY01 | New England Hwy, Greta | Pipe | 0.60 | | 2 |
| RHILL01 | Dalwood Rd, East Branxton | Arch | 2.70 high | | 1 |
| RHILL02 | Dalwood Rd, East Branxton | Box Culvert | 0.60 | 0.60 | 1 |
| RHILL03 | Maitland St, East Branxton | Box Culvert | 4.00 | 3.80 | 3 |
| SOUTH01 | New England Hwy, Greta | Pipe | 1.20 | 0.00 | 1 |
| SOUTH02 | Park St, Greta | Box Culvert | 1.35 | 3.03 | 1 |
| SOUTH03 | Anvil St, Greta | Box Culvert | 1.20 | 0.75 | 3 |
| SOUTH04 | Nelson St, Greta | Box Culvert | 2.10 | 2.00 | 1 |
| WBURN01 | York St, Greta | Box Culvert | 2.50 | 0.60 | 3 |
| WBURN02 | Kent St, Greta | Box Culvert | 1.20 | 0.60 | 4 |
| WBURN03 | New England Hwy, Greta | Box Culvert | 2.70 | 0.90 | 3 |
| WEST01 | Branxton St, Greta | Box Culvert | 3.00 | 1.64 | 1 |
| WEST2 | New England Hwy, Greta | Pipe | 1.65 | | 3 |
| WEST23 | Devon St, Greta | Box Culvert | 1.80 | 0.90 | 2 |
| Bridge1 | Nelson Street, Greta | Bridge | See Note[1] | | |
| Bridge2 | Wine Country Drive (Becan Bridge) | Bridge | See Note[1] | | |
| Bridge3 | Maitland Street, Branxton | Bridge | See Note[1] | | |

<u>Notes:</u>

[1] large bridge structures crossing Anvil Creek – LiDAR data was used to define the flow area under the bridge structure.

## 3.3. Hunter Expressway

The Hunter Expressway Alliance and the NSW Roads and Maritime Services (RMS) have constructed the Hunter Expressway; linking the F3 Freeway at Newcastle to Branxton creating a bypass for the townships of Maitland, Lochinvar, Greta and Branxton. The freeway is dual carriageway with two lanes running in each direction, and crosses over several tributaries that flow into Anvil Creek, including Sawyers Creek.

This study involved the incorporation of data supplied by the Hunter Expressway Alliance. This included;

- Survey of the designed levels
- WAE Drawings of cross drainage structures (culverts and bridges)

A total of 13 hydraulic structures were identified within the study area, with locations indicated on Figure 3. Details of the structures are provided in
Table 2.

Table 2: Hydraulic Structures for the Hunter Expressway

| ID | Structure Type | Width/ Diameter (m) | Height (m) | Number | U/S Invert (mAHD) | D/S Invert (mAHD) |
|---|---|---|---|---|---|---|
| **C32.20** | Pipe | 1.35 | | 2 | 55.00 | 54.49 |
| **C32.60_A** | Box Culvert | 2.40 | 2.10 | 1 | 49.41 | 49.18 |
| **C32.60_B** | Irregular shaped Box Culvert | 2.35 | 2.80 | 1 | 49.11 | 48.88 |
| **C32.60_C** | Box Culvert | 2.40 | 2.10 | 1 | 49.41 | 49.19 |
| **C34.04** | Pipe | 1.20 | | 2 | 43.65 | 41.62 |
| **C34.53** | Pipe | 1.50 | | 4 | 35.05 | 34.02 |
| **C34.99** | Pipe | 0.38 | | 1 | 34.94 | 34.79 |
| **C35.00** | Pipe | 0.68 | | 2 | 32.00 | 31.78 |
| **C35.04** | Pipe | 0.45 | | 1 | 41.70 | 41.49 |
| **C35.88** | Pipe | 1.05 | | 1 | 34.80 | 34.44 |
| **C35.90_B** | Irregular shaped Box Culvert | 2.40 | 1.80 | 1 | 34.50 | 34.14 |
| **C35.90_C** | Box Culvert | 2.40 | 1.80 | 1 | 32.66 | 31.22 |
| **C36.00** | Pipe | 0.90 | | 1 | 30.24 | 30.09 |

## 3.4. Great Northern Railway

At several locations, tributaries cross the Great Northern Railway. The geometries of the structures were assumed based on aerial imagery and LiDAR.

Table 3: Hydraulic Structures for the Great Northern Railway

| ID | Structure Type | Width/ Diameter (m) | Height (m) | Number |
|---|---|---|---|---|
| **R_01** | Pipe | 1.2 | | 1 |
| **R_02** | Box Culvert | 3 | 1.8 | 2 |
| **R_03** | Box Culvert | 1.5 | 1.5 | 2 |
| **R_04** | Box Culvert | 1.8 | 1.5 | 1 |
| **R_05** | Box Culvert | 2.4 | 1.8 | 1 |
| **R_06** | Pipe | 1.35 | | 2 |
| **R_07** | Box Culvert | 2.8 | 1.2 | 2 |
| **R_08** | Pipe | 1.5 | | 1 |
| **R_09** | Box Culvert | 3 | 3 | 2 |
| **R_10** | Pipe | 1.8 | | 1 |
| **Railway** | Bridge | See Note[1] | | |

Notes:
[1]Railway is a large bridge structure crossing a tributary – LiDAR data was used to define the flow area under the bridge structure.

## 3.5. Flood Marks

In order to calibrate and validate the models, data from historical events is required. Council identified that calibration/validation should include the February/March 2013, April 2015 and January 2016 events. Flood mark data was collected via the community consultation and a site visit completed by WMAwater post the 2015 April Event. This data was consolidated to produce a database of potential calibration / validation events.

### 3.5.1. Community Consultation

As part of this study, a community consultation process was undertaken in collaboration with Cessnock City Council. As part of the process, community members were asked to provide details about flood events. It was found that 32 respondents had reported their properties being affected by flooding. Of those who reported flooding, 10 properties were flooded above floor level, of which 6 provided a flood mark. These are detailed in Table 4. A list of all flood marks (including those not flooded above flood level) is presented in Section 4 with details about the community consultation.

Table 4: Flood Marks for properties affected above floor level – community consultation

| ID | Address | Event | Flood Level (mAHD) | Comment |
|---|---|---|---|---|
| **G28** | 100 Hillview St, East Branxton | April 2015 | 38.4 at driveway | 0.56m Above Floor Level* |
| **G10** | 3 Branxton St, Greta | April 2015 | 54.1 | 2" Above Floor Level |
| **G32** | 1 Durham Rd, East Branxton | April 2015 | 41.05 | Covered Carpets - 0.2m |
| **G46** | 21 Hunter St, Greta | April 2015 | 50.15 | 1m at Lowest Point in Yard (49.15mAHD) |
| **G47** | 17C Evans St, Greta | April 2015 | 58.7 | 0.1m Above Floor Level |
| **G38** | 11 Hunter St, Greta | April 2015 | 49.6 | 6" Deep - About ankle height |

** Debris mark in photo shows ~6.5 bricks. Assuming 86 mm per brick height, a total of 0.56 m flood depth was determined (see Photo 5). This was the flood level on the upstream side of the building, which was subject to direct overland flows and hence localised increases in flood levels at the building. Water depths through the house are lower. The flood level has been estimated at the driveway based on the available photographs and the factors discussed.*

Photo 5: Debris mark at 100 Hillview St, East-Branxton

### 3.5.2. Site Visit

Subsequent to the finalisation of the community consultation period, WMAwater spoke with community members about their flood observations to gather further information (i.e. flood marks, photos). This process included a secondary site visit to gather information. A further 6 flood marks were collected including flood marks that had been surveyed. The flood marks are detailed in the calibration chapter of this report (see Section 8). Example photos from this visit are shown in Photo 6 and Photo 7.

Photo 6: 6-8 Dalwood St, Greta – Pegs for 2015, 2007 event

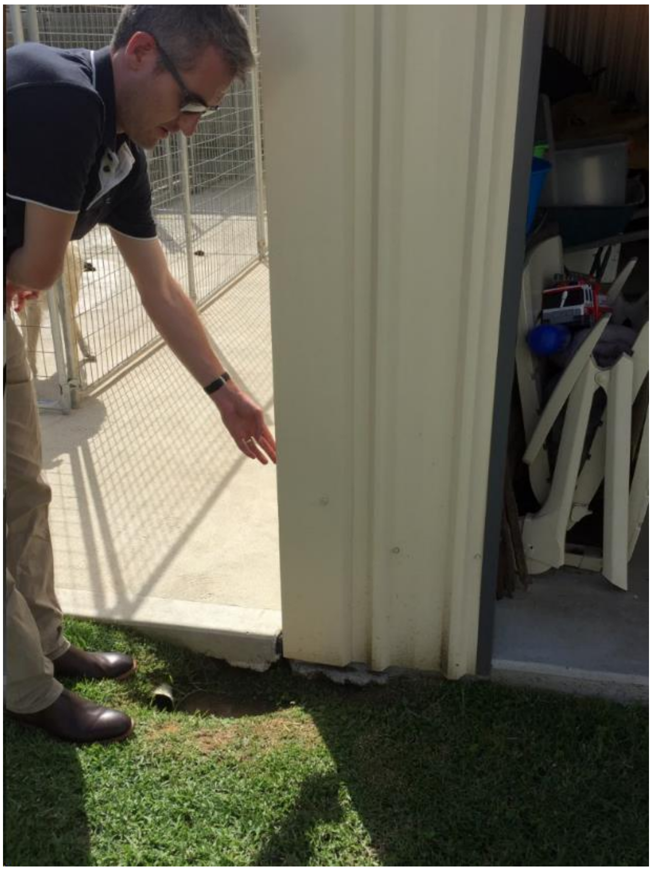


Photo 7: 5 Katerina Close, Greta 2015

Table 5: Flood Marks collected during the site visit – April 2015

| ID | Address | Source | Comment | Estimated Flooding Depth (m) | Observed Flood Level (mAHD) |
|---|---|---|---|---|---|
| **16** | 5 Katerina Close, Greta | Fieldtrip | Flooding through shed at rear of property | 0.3 | 55.8 |
| **17** | 6-8 Dalwood St, Greta | Fieldtrip | Surveyed Flood Level on light pole between 6-8 Dalwood St, Greta | 0.6 (2015)<br>0.1 (2007) | 54.26 (2015)<br>53.72 (2007) |
| **18** | 67 High Street, Greta | Fieldtrip | Shallow flooding observed in the carpark | 0.1 | 48.7 |

### 3.5.3. 2015 Flood Database Collection – WMAwater

WMAwater undertook data collection in Greta on the 30$^{th}$ April 2015 in the aftermath of the extreme storm event of April 2015, as part of a broader data collection exercise throughout the Maitland and Cessnock Council areas. Three flood marks were collected within the study area. The flood marks were observed as debris lines on residential dwellings. A summary of the flood marks is listed in Table 6.

During the April 2015 flood, the residential property at 78 Sale Street, Greta was knocked off its footings, which would have required a significant depth and velocity of flow. The property is shown in Photo 8.

Table 6: Flood Marks for the April 2015 Event Measured by WMAwater

| ID | Address | Flood Level (mAHD) | Comment |
|---|---|---|---|
| S-01 | 76 Sale Street, Greta | 47.75<br><br>(Ground Level estimated at 46.5 mAHD) | The mark is situated on the right-hand side of the house on the back sun room. The mark measures 1.25 m from the ground at the interface of the brickwork and sun room as shown in Photo 9 and Photo 11. |
| S-02 | 1 Wyndham Street, Greta | 47.45*<br><br>(Ground Level estimated at 46.9 mAHD) | The mark is situated on the front of the house on the left-hand side of the door. The mark measures 0.4 m from the front veranda as shown in Photo 10. |
| S-03 | 9 Hunter Street, Greta | 48.2 | The mark is situated at the bottom of the driveway next to the letterbox as shown in Photo 11. |

**The estimated flood level takes into account the distance between the ground level at the front of the house and the front veranda which was estimated to be 150 mm.*

Photo 8: 78 Sale Street, Greta – House knocked off foundations, 2015

Photo 9: 76 Sale Street, Greta, 2015

Photo 10: 1 Wyndham Street, Greta, 2015

Photo 11: 9 Hunter Street, Greta, 2015

## 3.6. Historical Rainfall Data

### 3.6.1. Overview

The rainfall data described in the following sections pertains to information that was used in calibration of the hydraulic models as well as validation of the hydrologic models (via joint calibration).

There are a number of rainfall stations located across the Hunter Valley area, although none of them are located within the study area catchment. These include daily read stations and continuous pluviometer stations.

The daily read stations record total rainfall for the 24 hours to 9:00 am of the day being recorded. For example the rainfall received for the period between 9:00 am on 3 February 2008 until 9:00 am on 4 February 2008 would be recorded on the 4 February 2008.

The continuous pluviometer stations record rainfall in sub-daily increments (with output typically reported every 5 or 6 minutes). These records were used to create detailed rainfall hyetographs, which form a model input for historical events against which the model is calibrated. Table 7 and Table 8 present a summary of the available continuous pluviometer and daily rainfall gauges respectively. The availability of historical records is also listed. “Y” indicates that data are available from that gauge for the respective historical event. The locations of these gauges are shown in Figure 4 and Figure 5. These gauges are operated by Hunter Water Corporation (HWC) and Bureau of Meteorology (BoM).

Table 7: Continuous read rainfall stations

| Station Number | Station Name | Authority | Jun-07 | Mar-13 | Apr-15 | Jan-16 |
|---|---|---|---|---|---|---|
| **210458** | Maitland Belmore Bridge | BOM | Y | Y | Y | |
| **61250** | Paterson (Tocal AWS) | BOM | | Y | Y | Y |
| **R21** | Abermain BC Rain Gauge | HWC | Y | Y | Y | Y |
| **R31** | Branxton WWTW Rain Gauge | HWC | Y | Y | Y | Y |
| **R4** | Cessnock BC Rain Gauge | HWC | Y | Y | Y | |
| **R6** | Maitland 7 WWPS Rain Gauge | HWC | Y | | Y | Y |
| **R29** | Bolwarra 1A WWPS Rain Gauge | HWC | | Y | Y | Y |
| **R35** | West Wallsend Community Centre Rain Gauge | HWC | | | | |
| **R30** | Maitland 18 WWPS Rain Gauge | HWC | | | | Y |
| **R36** | Maryland Rain Gauge | HWC | | | | |
| **R16** | Farley WWTW | HWC | | | Y | Y |
| **61260** | Cessnock Airport AWS | BOM | | Y | Y | Y |

Table 8: Daily read rainfall stations

| Station Number | Station Name | Operating Authority | Opened | Closed |
|---|---|---|---|---|
| **61014** | Branxton (Dalwood Vineyard) | BoM | 1863 | Current |
| **61424** | Brunkerville (Sunrise B&B) | BoM | 2009 | Current |
| **61242** | Cessnock (Nulkaba) | BoM | 1966 | 2012 |
| **61260** | Cessnock Airport AWS | BoM | 1994 | Current |
| **61393** | Edgeworth WWTP | BoM | 1990 | Current |
| **61414** | Kurri Kurri Golf Club | BoM | 2007 | Current |
| **61268** | Maitland Belmore Bridge | BoM | 2006 | Current |
| **61388** | Maitland Visitors Centre | BoM | 1997 | 2016 |
| **61046** | Morpeth Post Office | BoM | 1884 | 2011 |
| **61048** | Mulbring (Stone Street) | BoM | 1932 | 2007 |
| **61295** | Nulkaba (O'Connors Rd) | BoM | 1970 | Current |
| **61250** | Paterson (Tocal AWS) | BoM | 1967 | Current |
| **61329** | Pokolbin (Jacksons Hill) | BoM | 1961 | Current |
| **61238** | Pokolbin (Somerset) | BoM | 1962 | Current |
| **61405** | Woodville (Clarence Town Rd ) | BoM | 2004 | Current |
| **61152** | Congewai (Greenock) | BoM | 1959 | Current |
| **61322** | Toronto WWTP | BoM | 1972 | Current |
| **61133** | Bolton Point (The Ridge Way) | BoM | 1962 | Current |

### 3.6.2. Analysis of Daily Read Data

The daily rainfall gauges within 20 km of the centroid of the study area were analysed for each of the four significant recent events identified in Section 2.2.3. Each event was analysed for the individual days and entire event totals. The results of the analysis are shown in Table 9 to Table 11.

The rainfall totals for each event at each available rain gauge were used to create rainfall isohyets for the entire catchment. These rainfall isohyets were used to determine the rainfall depths for each individual subcatchment in the hydrological model, and are shown in Figure 9 to Figure 11. The rainfall isohyets were developed using the natural neighbour interpolation technique.

Table 9: Daily Rainfall Depths (mm) for the June 2007 Event

| Station Number | Station Name | 8/06/2007 | Total |
|---|---|---|---|
| | | From 9 am | 1 Day |
| **61014** | Branxton (Dalwood Vineyard) | 193.4 | **193.4** |
| **61242** | Cessnock (Nulkaba) | 189.8 | **189.8** |
| **61260** | Cessnock Airport AWS | 178.4 | **178.4** |
| **61414** | Kurri Kurri Golf Club | 203 | **203** |
| **61268** | Maitland Belmore Bridge | 161 | **161** |
| **61388** | Maitland Visitors Centre | 175 | **175** |
| **61046** | Morpeth Post Office | 165.8 | **165.8** |
| **61048** | Mulbring (Stone Street) | 280 | **280** |
| **61295** | Nulkaba (O'Connors Rd) | 186 | **186** |
| **61250** | Paterson (Tocal AWS) | 200.2 | **200.2** |
| **61329** | Pokolbin (Jacksons Hill) | 204.2 | **204.2** |
| **61238** | Pokolbin (Somerset) | 202.8 | **202.8** |
| **61405** | Woodville (Clarence Town Rd) | 200.8 | **200.8** |
| **61298** | Pokolbin (Bellevue) | 204 | **204** |
| **61327** | Pokolbin (Myrtledayle) | 191 | **191** |
| **61056** | Pokolbin (Ben Ean) | 245 | **245** |
| **61397** | Singleton Stp | 79.4 | **79.4** |
| **R21** | Abermain BC | 115 | **115** |
| **R4** | Cessnock BC | 230.8 | **230.8** |
| **R29** | Bolwarra 1A WWPS | 100.6 | **100.6** |
| **R31** | Branxton WWTW | 198.6 | **198.6** |

Table 10: Daily Rainfall Depths (mm) for the April 2015 Event

| Station Number | Station Name | 21/04/2015 | Total |
|---|---|---|---|
| | | From 9 am | 1 Day |
| **61014** | Branxton (Dalwood Vineyard) | 199.4 | **199.4** |
| **61260** | Cessnock Airport AWS | 126.6 | **126.6** |
| **61414** | Kurri Kurri Golf Club | 246 | **246** |
| **61268** | Maitland Belmore Bridge | 307.5 | **307.5** |
| **61295** | Nulkaba (O'Connors Rd) | 138 | **138** |
| **61250** | Paterson (Tocal AWS) | 176 | **176** |
| **61329** | Pokolbin (Jacksons Hill) | 147.8 | **147.8** |
| **61238** | Pokolbin (Somerset) | 150.4 | **150.4** |
| **61405** | Woodville (Clarence Town Rd) | 275.4 | **275.4** |
| **61092** | Elderslie | 109 | **109** |
| **61298** | Pokolbin (Bellevue) | 145.8 | **145.8** |
| **61327** | Pokolbin (Myrtledayle) | 132 | **132** |
| **61397** | Singleton Stp | 70.8 | **70.8** |
| **R21** | Abermain BC | 171.2 | **171.2** |
| **R29** | Bolwarra 1A WWPS | 239.4 | **239.4** |
| **R30** | Maitland 18 WWPS | 270.4 | **270.4** |
| **R31** | Branxton WWTW* | 100.6 | **100.6** |

**Gauge failed during the events*

Table 11: Daily Rainfall Depths (mm) for the January 2016 Event

| Station Number | Station Name | 5/01/2016 | Total |
|---|---|---|---|
| | | From 9 am | 1 Day |
| **61014** | Branxton (Dalwood Vineyard) | 160 | **160** |
| **61260** | Cessnock Airport AWS | 99.4 | **99.4** |
| **61414** | Kurri Kurri Golf Club | 143.2 | **143.2** |
| **61268** | Maitland Belmore Bridge | 165 | **165** |
| **61388** | Maitland Visitors Centre | 167.8 | **167.8** |
| **61295** | Nulkaba (O'Connors Rd) | 100 | **100** |
| **61250** | Paterson (Tocal AWS) | 178.6 | **178.6** |
| **61329** | Pokolbin (Jacksons Hill) | 95 | **95** |
| **61238** | Pokolbin (Somerset) | 94.4 | **94.4** |
| **61405** | Woodville (Clarence Town Rd) | 229.6 | **229.6** |
| **61092** | Elderslie | 94 | **94** |
| **61298** | Pokolbin (Bellevue) | 84 | **84** |
| **61327** | Pokolbin (Myrtledayle) | 115 | **115** |
| **61397** | Singleton STP | 67 | **67** |
| **R21** | Abermain BC | 96.8 | **96.8** |
| **R29** | Bolwarra 1A WWPS | 185.8 | **185.8** |
| **R30** | Maitland 18 WWPS | 214.8 | **214.8** |
| **R16** | Farley WWTW | 195.3 | **195.3** |
| **R31** | Branxton WWTW* | 89.6 | **89.6** |

**Gauge failed during the events*

### 3.6.3. Analysis of Pluviometer Data

The pluviometer gauges were analysed for the historical events that had corresponding rainfall data. This data was used to determine the temporal patterns of each storm event that were subsequently used in the model calibration process. The temporal patterns for the historical event are shown in Figure 6 to Figure 8.

## 3.7. Design Rainfall Data

The design rainfall intensity frequency duration (2016 ARR IFD) for the centroid of the study area are shown in Table 12. The comparisons of rainfall IFD between historical rainfall events to design events are shown in Figure 12 to Figure 14. For AEPs of 1 in 200 AEP and 1 in 500 AEP the Bureau of Meteorology does not provide design rainfall for durations shorter than 24 hours. Therefore, growth factors were derived for these AEPs at the 24-hour duration. This involves dividing the rainfalls of AEPs of 1 in 200 AEP and 1 in 500 AEP by the 1% AEP. These growth factors were then applied to the 1% AEP design rainfalls for durations shorter than 24 hours.

Table 12: IFD (mm) table for the centroid of the study area

| Storm Duration | 50% AEP | 20% AEP | 10% AEP | 5% AEP | 2% AEP | 1% AEP | 0.5% AEP | 0.2% AEP |
|---|---|---|---|---|---|---|---|---|
| **30 minutes** | 19.9 | 27.8 | 33.5 | 39.5 | 48.1 | 55.1 | 61.6 | 72.3 |
| **1 hour** | 25.5 | 35.3 | 42.5 | 50 | 60.3 | 68.7 | 76.8 | 90.2 |
| **2 hour** | 31.8 | 43.9 | 52.7 | 61.7 | 74.2 | 84.3 | 94.2 | 110.7 |
| **3 hour** | 36.2 | 50.1 | 60.1 | 70.3 | 84.6 | 96.1 | 107.4 | 126.2 |
| **6 hour** | 45.9 | 63.8 | 76.8 | 90.3 | 109 | 125.0 | 139.7 | 164.1 |
| **12 hour** | 59.4 | 83.6 | 101.0 | 120.0 | 147.0 | 169.0 | 188.8 | 221.9 |
| **24 hour** | 77.3 | 110.0 | 135.0 | 161.0 | 199.0 | 230.0 | 257.0 | 302.0 |
| **48 hour** | 98.3 | 142.0 | 175.0 | 211.0 | 259.0 | 299.0 | 352.0 | 421.0 |
| **72 hour** | 110.0 | 160.0 | 198.0 | 237.0 | 290.0 | 333.0 | 382.0 | 451.0 |

## 3.8. Previous Studies

### 3.8.1. Greta Drainage Study – Ian H. Marshall & Associates – March 1985

This study (Reference 1) was commissioned by CCC to determine the 100 year ARI flood levels and flood extent of Anvil and Red House Creek. This investigation used the rational method to produce the 100 year ARI flood hydrographs, whilst adopting the slope-area method based on Mannings formula to determine the water surface levels and flood extents. Cross sections of creek bathymetry are used in this study throughout the length of Anvil and Red House Creek, as they are used in the calculations for the slope-area method.

The following flows were estimated along Anvil Creek (refer to Diagram 3 for the surveyed cross section locations)

- Section 1 – 165 $m^3/s$
- Section 3 – 158 $m^3/s$
- Section 4 – 148 $m^3/s$
- Section 6 – 141 $m^3/s$
- Section 8 – 133 $m^3/s$
- Section 9 – 109 $m^3/s$

The following flows were estimated along Red House Creek (refer to Diagram 3 for the surveyed cross section locations)

- Section 1 – 37.0 $m^3/s$
- Section 3 – 38.35 $m^3/s$
- Section 6 – 42.4 $m^3/s$

Diagram 2: Plan of Anvil Creek - Greta Drainage Study

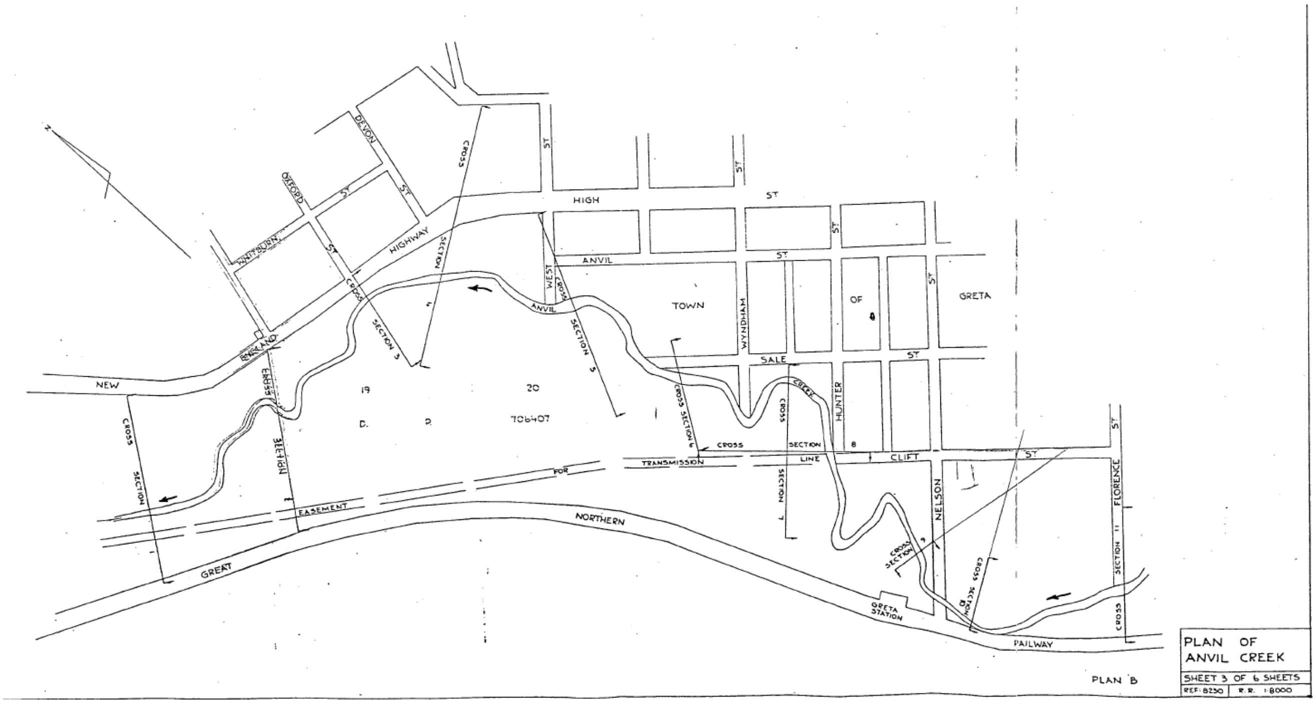
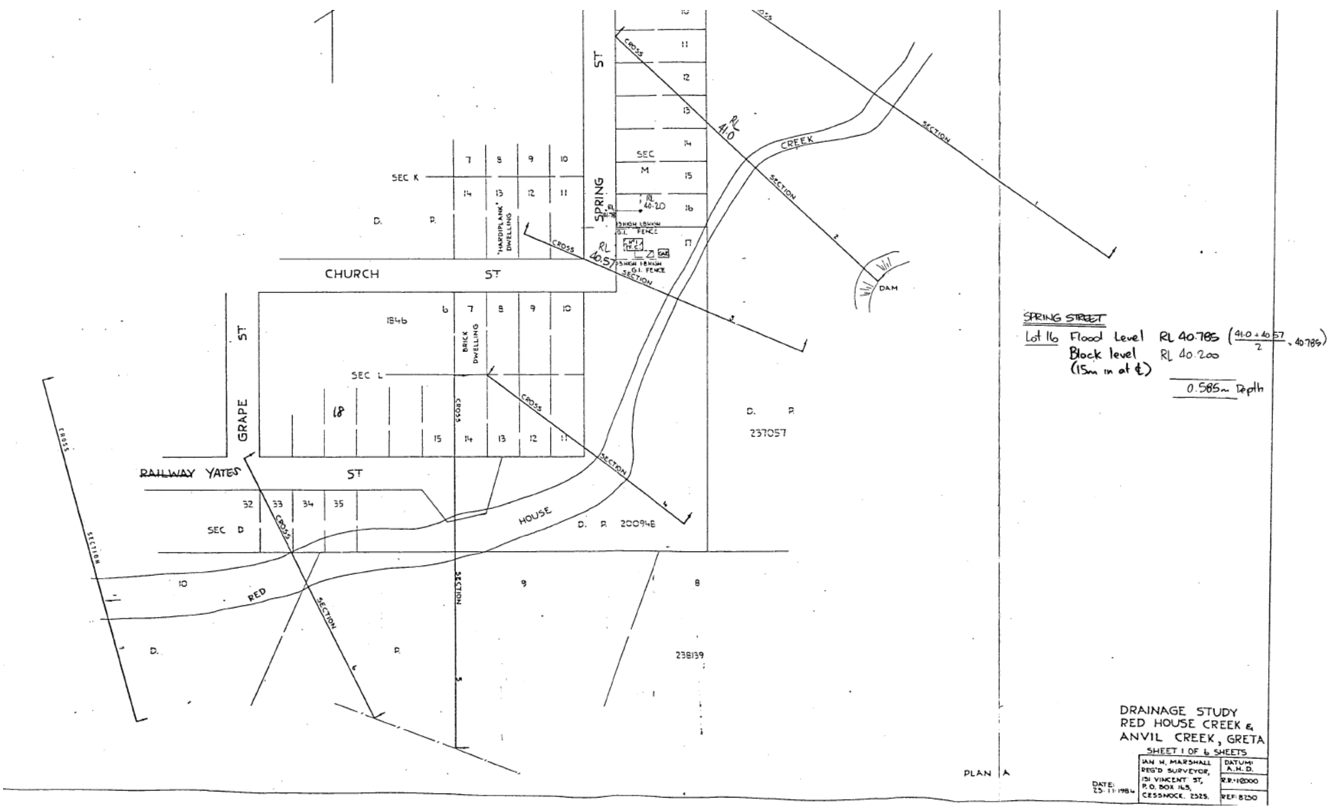



Diagram 3: Plan of Red House Creek - Greta Drainage Study



### 3.8.2. Hunter River: Branxton to Green Rocks Flood Study – WMAwater 2010

WMAwater was commissioned by Maitland City Council (MCC) to undertake a flood study of the Lower Hunter River between Braxton and Green Rocks (Reference 2). The study area included the lower reaches of Anvil Creek.

TUFLOW modelling software was used to undertake 2D hydraulic modelling for this study, and WBNM software was used for hydrologic modelling. This study provides the most recent design flood information for Hunter, using up-to-date modelling techniques, and provides information about Hunter River flooding and associated tailwater levels that affect flooding at the lower reaches of Anvil Creek.

The design flood mapping from the Study indicates the following:

- In the 0.5%, 1%, 2% and 5% AEP events there is significant discharge from the Hunter River upstream of Oakhampton, which passes the entrance to Black Creek (Anvil Creek spills into Black Creek north of Branxton).
- The extent inundation during a 50% flood event in the Hunter River is observed at the lower reaches of Anvil Creek, extending up to the bridge along the New England Highway. This flood extent continues further upstream during rarer flood events.

### 3.8.3. Hunter River: Review of Branxton Flood Levels – WMAwater 2013

Cessnock City Council engaged WMAwater to review design flood levels at Branxton to determine whether there is justification for adjusting the design levels at Branxton for flood-related development control purposes, and if so, whether adjustments should be made to design levels for the full 2010 Flood Study TUFLOW model extent downstream to Green Rocks (Reference 3).

As a result of the study, the June 2007 calibration event produced a good fit to the water level hydrograph at Greta and mapped extent at Branxton. The estimated 1% AEP flood level at Branxton from the WMAwater (2010) study was 34.8 mAHD.

Concluding remarks on the study included:

- Flood Planning Levels for development should be determined as part of a Floodplain Risk Management Study at Branxton including consideration of appropriate Flood Planning Levels for commercial development (possibly based on smaller floods than the 1% AEP event or a merits-based approach).
- Until the Floodplain Risk Management Study at Branxton is undertaken, a freeboard of 0.7 m above the 1% AEP flood level should be adopted for residential development at Branxton, giving an Interim Flood Planning Level equivalent to the recorded February 1955 peak flood level of 34.2 mAHD, using a revised 1% AEP level of 33.5 mAHD.

### 3.8.4. Cessnock City Council LGA Assessment of the April 2015 Flood Event – Royal Haskoning DHV

This study (Reference 4) was an investigation of the April 2015 storm event across the Cessnock City Council Area, specifically as a means to approximate the severity of the flood event in terms of Average Recurrence Interval (ARI). The study identified a key hotspot in Sale Street and Wyndham Street Greta that had been affected during the rainfall event. 76 Sale Street was flooded above floor level (estimated flood level of 48.0 mAHD) and 78 Sale Street was knocked off its foundations.

A 10 m rainfall on grid TUFLOW model was developed to simulate the April 2015 event and the 1% AEP Event (using ARR 2013 data). The hydraulic model extent covered the whole Anvil Creek Catchment using 2012 LPI LiDAR data. Photographs and data were provided by CCC.

The flood events run through the TUFLOW model included;

- April 2015 – 1-hour rainfall pattern with a total of 150 mm of rainfall (recorded at Belmore Bridge Maitland) was scaled to a 1987 Temporal Pattern due to the absence of pluviograph data.
- 100 year ARI event – 1-hour rainfall pattern with a total of 85 mm.

The results from the April 2015 TUFLOW model produced a flood level of 48.3 mAHD at 76 Sale Street (0.3 m higher than observed). Further, the velocity depth product (flood hazard) exceeded 3 $m^2/s$ at 78 Sale Street. This value corresponds to High Hazard (as per the NSW Floodplain Development Manual).

A peak discharge of 450 $m^3/s$ and 165 $m^3/s$ from the TUFLOW model was determined for the April 2015 and 100 year ARI event (ARR 2013) respectively. As such, it was estimated that the April 2015 event was between a 1000 to 2000 year ARI event.

Other key hotspots identified as areas affected by overland flow include York Street Greta, 60 High Street Greta and Hillview Road East Branxton.

# 4. COMMUNITY CONSULTATION

## 4.1. Information Brochure and Survey

In collaboration with Cessnock City Council a questionnaire was distributed to residents in the study area. The purpose of the questionnaire was to identify what residents had experienced, problems with flooding and to collate as much historical flood data as possible. From this, 86 responses were received. Of those that responded, 79% were aware of flooding issues within the catchment, with a total of 32 respondents having their properties affected by flooding and of those, 18 properties flooded above floor level. There is a relatively high level of flood awareness and preparedness generally in the area, as several major floods have occurred in the last ten years.

The locations of the community consultation respondents are shown in Figure 15. Properties identified as having been affected by flooding and flooded above floor level are shown in Figure 16. The location of reported flood marks is also displayed on Figure 16. Details related to these are provided in Section 3.5.1. The full set of results from the community consultation questionnaire are summarised in Figure 17.

## 4.2. Community Responses

Several photographs of historical flooding were provided by the community. A selection of these are presented below.

Photo 12: 6 The Barracks Close, Greta 2015

Photo 13: Durham Road, East Branxton 2015

Photo 14: 1 Durham Road, East Branxton 2015

Photo 15: 1 Durham Road, East Branxton 2015

Photo 16: 1 Durham Road, East Branxton 2015

Photo 17: Hillview Street East Branxton 2015

Photo 18: 100 Hillview Street East Branxton 2015

Photo 19:  51 York Street Greta 2015

Photo 20: 49 York Street Greta 2015

Photo 21: York Street Greta 2015

Photo 22: 20 Anvil Street Greta 2015

Photo 23: Anvil Street Greta 2015

The responses to the community survey are summarised in charts in Figure 15 and the flood marks are shown in Figure 16. The following issues were raised by the respondents:

- Residents in Greta and East Branxton described the April 2015 super storm as the biggest they have witnessed. The 2007 Pasha Bulker Storm also affected some residents however not as severely;
- The majority of residents are aware of flooding risks and believe they are generally prepared for flood events;
- Some residents believe that better drainage systems need to be implemented to account for larger flood events within both Greta and East Branxton;
- Most residents are concerned with maintenance of both Anvil Creek and Red House Creek, believing that cleaning out the creek from debris and rubbish may help the water to drain more quickly during floods. Residents have suggested a regular maintenance program; and
- Various residents are also concerned about future development in areas that are isolated during flood events. Residents have also blamed the increased rate of rise in flood waters to be as a result of the residential developments in surrounding areas within East Branxton, specifically along Dalwood Rd. They are concerned that this will be dangerous to new residents and stretch the resources of community and emergency services during flood events.

## 4.3. Public Exhibition

The Draft Greta Flood Study was placed on public exhibition for comment from 3 December 2018 to 19 January 2019.

Public notices were placed in the local newspaper and on Council's website. The Draft Study was available for inspection at Council's Administration Centre, Greta Newsagency and all libraries.

One submission was received during the exhibition period associated current catchment conditions and flood modelling in the West Street Catchment. The submission highlighted:

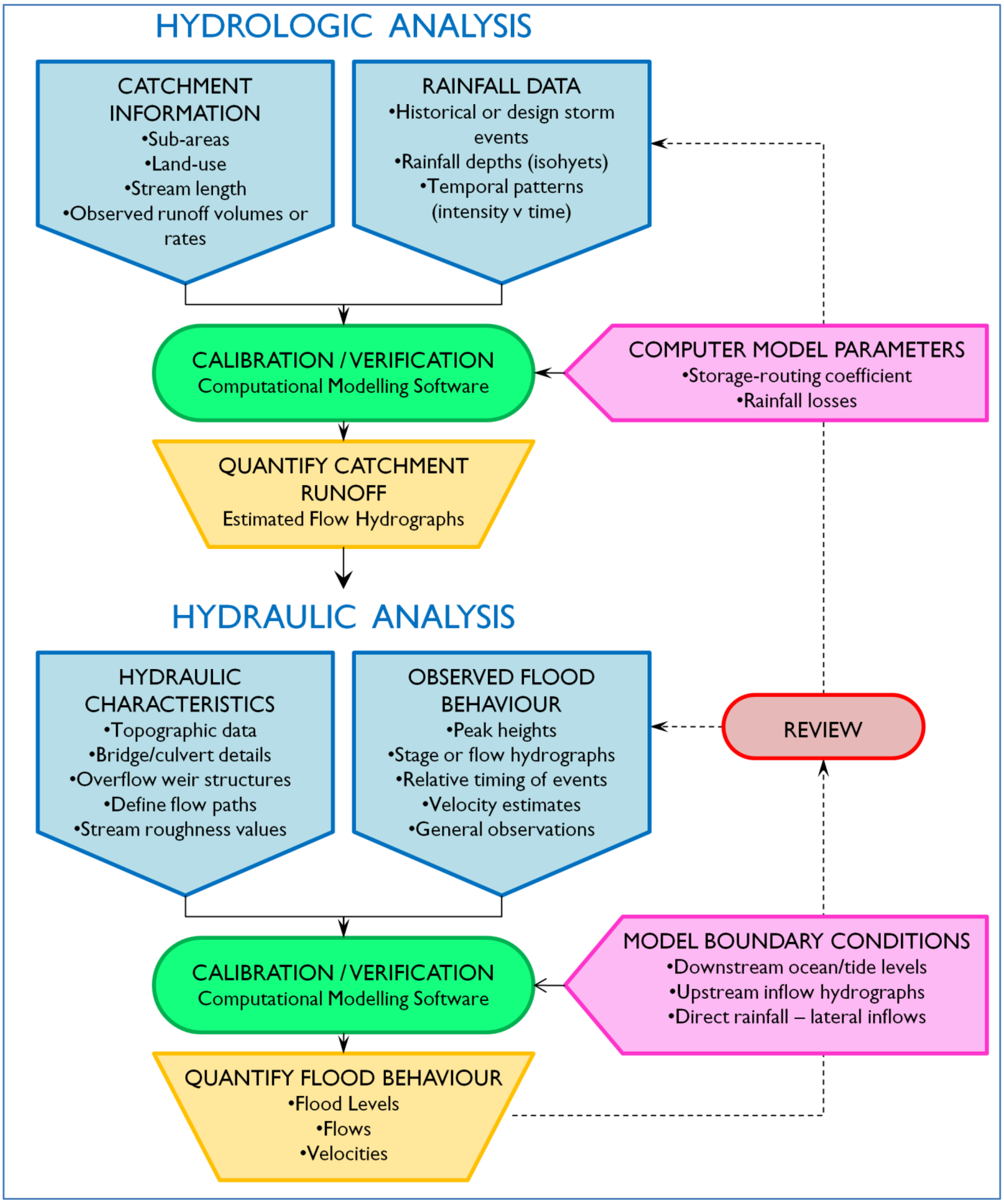
- A current rezoning application at 71 Branxton Street, Greta (Lot 1 / DP 873220);
- The subdivision construction (Windham Ridge) in the upper reaches of the catchment;
- The new road construction, Reginald Street, bisecting the catchment;
- Construction of two new culverts on Reginald Street; and
- An existing undersized bridge on Branxton Street, at the catchment outlet.

The Flood Study Report has been subsequently updated to highlight the difference in the modelled and current catchment condition within the West Street Catchment. No remodelling of this catchment has been undertaken as part of this Study, however the need for future flood analysis to reflect the changing catchment terrain and land use conditions is highlighted.

# 5. MODELLING METHODOLOGY

The approach adopted in flood studies to determine design flood levels largely depends upon the objectives of the study and the quantity and quality of the data (survey, flood, rainfall, flow etc.). There is a thorough record of daily rainfall data for the catchment and some sub-hourly rainfall data from pluviometer gauges and stream gauges with sufficient record length, which can be used for event-based model calibration. For this study, a rainfall-runoff approach was adopted, using a hydrologic model to estimate the runoff flows from rainfall, and a detailed hydraulic model to determine the flood levels, depths, velocities and extents produced by the runoff flows throughout the study area. A diagrammatic representation of the flood study process undertaken in this manner is shown below.

Diagram 4: Rainfall-runoff modelling process



# 6. HYDROLOGIC MODEL

## 6.1. Introduction

Inflow hydrographs serve as inputs at the boundaries of the hydraulic model. In a flood study where long-term gauged streamflow records are not available, a rainfall-runoff hydrologic model (converts rainfall to runoff) is generally used to provide these inflows. A range of runoff routing hydrologic models is available as described in Australian Rainfall and Runoff (ARR) 2016 (Reference 5). These models allow the rainfall depth to vary both spatially and temporarily over the catchment and readily lend themselves to calibration against recorded data.

The WBNM hydrologic run-off routing model was used to determine flows from each sub-catchment. The WBNM model has a relatively simple but well supported method, where the routing behaviour of the catchment is primarily assumed to be correlated with the catchment area. If flow data is available at a stream gauge, then the WBNM model can be calibrated to this data through adjustment of various model parameters including the stream lag factor, storage lag factor, and/or rainfall losses.

A hydrological model for the entire Anvil Creek catchment was created and used to calculate the flows for each individual sub-catchment and tributary creek for inclusion in the TUFLOW model.

## 6.2. Sub-catchment delineation

In total, the catchment represented by WBNM is 45.6 km$^2$. This area was represented by a total of 140 sub-catchments. The sub-catchment delineation is shown in Figure 18. The sub-catchments were derived from LiDAR topographic data and consideration of hydraulic controls such as bridge crossings and road/rail embankments.

## 6.3. Impervious Surface Area

Runoff from connected impervious surfaces such as roads, gutters, roofs or concrete surfaces occurs significantly faster than from vegetated surfaces. This results in a faster concentration of flow within the downstream area of the catchment, and increased peak flow in some situations. This is less important in rural studies as they consist of relatively few impervious areas, and those areas are typically not hydraulically connected to the waterway (i.e. the water flows across pervious areas on the route between the impervious surface and the receiving waterway).

The assumed effective imperviousness of each sub-catchment varied from 0 to 60%, depending on the land use. A large majority of the catchment is undeveloped and has an imperviousness of 0% to 5%. Slightly higher values were applied where there was low-density development, whilst higher imperviousness percentages were applied in the denser urban areas of Greta, Branxton and East-Branxton.

WMAwater used the Mannings layers (discussed in Section 7.4) to estimate the effective impervious surface area for each sub-catchment. For each of the Mannings type, an impervious percentage was assigned to it. The details of each category and the total catchment area assumed is provided in Table 13.

Table 13: Assumed percentage of effective impervious surface area

| Type | Percent Impervious | Total Area (km²) |
|---|---|---|
| Railway | 90% | 0.41 |
| Paved Areas (roads, carparks, pavement) | 80% | 0.75 |
| Urban Lots | 30% | 0.63 |
| Impervious areas outside hydraulic model | 85% | 2.14 |
| Pervious Areas (vegetation, waterways, open area) | 0% | 0 |

## 6.4. Rainfall Losses

Methods for modelling the proportion of rainfall that is "lost" to infiltration are outlined in ARR 2016 (Reference 5). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data is available. The method most typically used for design flood estimation is to apply an initial and continuing loss to the rainfall. The initial loss represents the wetting of the catchment prior to runoff starting to occur and the filling of localised depressions, and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

## 6.5. Adopted Hydrologic Model Parameters

The model input parameters for each subcatchment are:

- A lag factor (termed C), which can be used to accelerate or delay the runoff response to rainfall;
- A stream flow routing factor, which can accelerate or decelerate in-channel flows occurring through each subcatchment;
- An impervious area lag factor;
- An areal reduction factor;
- The percentage of catchment area with a pervious/impervious surface; and
- Rainfall losses calculated by initial and continuing losses to represent infiltration.

A typical regional value of 1.7 for the lag factor 'C' hydrologic model parameter was found to be appropriate. The percentage of the impervious area in the whole catchment is roughly 8.5%. A value of 1.0 was used for the stream flow routing which is standard for natural catchments. The areal reduction factor will be discussed in the design modelling process.

# 7. HYDRAULIC MODEL

## 7.1. Introduction

The availability of high quality LiDAR as well as detailed aerial photographic data enables the use of 2D hydraulic modelling for the study. Various 2D software packages are available (SOBEK, TUFLOW, RMA-2), and the TUFLOW package was adopted as it meets requirements for best practice, and is currently the most widely used model of this type in Australia for riverine flood modelling.

The TUFLOW modelling package includes a finite difference or finite volume numerical model for the solution of the depth averaged shallow water equations in two dimensions. The TUFLOW software has been widely used for a range of similar floodplain projects both internationally and within Australia and is capable of dynamically simulating complex overland flow regimes.

The TUFLOW model version used in this study was 2017-09-AC-w64 (using the finite volume HPC solver). Further details regarding TUFLOW software can be found in the User Manual (Reference 6).

In TUFLOW the ground topography is represented as a uniform grid with a ground elevation and Mannings ‘n’ roughness value assigned to each grid cell. The size of grid is determined as a balance between the model result definition required and the computer processing time needed to run the simulations. The greater the definition (i.e. the smaller the grid size) the greater the processing time need to run the simulation.

## 7.2. TUFLOW Hydraulic Model Extent

The model extent starts 4.4 kilometres upstream of Nelson Street, Greta at Anvil Creek (where the upstream boundary lies to the east of Allandale Road). The model includes the townships of Greta, East-Branxton and Branxton where the model extent begins upstream of the towns. The model continues along Anvil Creek where the downstream boundary is located approximately 1 km downstream of the New England Highway at Anvil Creek and 80 m downstream of the CCC boundary. The hydraulic model covers an area of 15.6 km$^2$ and its extent is shown in Figure 19.

Anvil Creek catchment is largely rural with development concentrated around the townships of Greta, Branxton and East-Branxton. Typically, developed areas require a grid resolution of no more than 2 m to capture the various flow mechanisms characteristic of a built-up environment. However, a grid resolution of that size for an area 15.6 km$^2$ using the TUFLOW Classic would result in large model run-times. In 2017, a new TUFLOW version was released with Heavily Parallelised Computing (HPC) Graphical Processor Unit (GPU) model support. The new GPU models are significantly faster than the traditional Central Processing Unit (CPU). As such, the GPU model was used for this study, although the models can be run over a longer timeframe using CPU.

## 7.3. Boundary Locations

Design floods have two main components. The first is the inflows, comprised of rainfall-runoff generated in the hydrological model. The second is the tailwater condition, which in the case of Anvil Creek, is the Hunter River. The combination of the probabilities of these two events is what defines the design flood events.

### 7.3.1. Inflows

For sub-catchments within the TUFLOW model domain, local runoff hydrographs were extracted from the WBNM model (see Section 6). These were applied to the downstream end of the sub-catchments within the 2D domain of the hydraulic model. External inflows from outside of the hydraulic model domain (i.e. Upstream of the Hunter Expressway) were applied to the boundary of the model. The inflow boundaries are shown in Figure 20.

### 7.3.2. Downstream Boundary

The downstream boundary is located approximately 1 km downstream of Maitland Street, Branxton and 80 m downstream of the Cessnock LGA. This is located sufficiently downstream from points of interest (i.e. hydraulic structures, properties) to limit any influence on the hydraulic performance of the flood model. The downstream boundary is shown in Figure 20.

For calibration, a constant water level (equivalent to the lowest ground elevation) was applied to the downstream boundary. Following this, a sensitivity analysis was completed to take into account backwater flooding effects from the Hunter River using data from the Hunter River and Branxton Flood Studies (Reference 2). The results of this are discussed in Section 11.5.

This study adopted coincident Hunter River flood assumptions for the design flood events consistent with the approach used for the Paterson River Flood Study (Reference 7). The design flood combinations adopted are detailed in Table 14.

Table 14: Design Flood Combinations

| Design Flood AEP | Rainfall AEP | Hunter River AEP |
|---|---|---|
| **50% AEP** | 50% AEP | 50% AEP |
| **20% AEP** | 20% AEP | 50% AEP |
| **10% AEP** | 10% AEP | 50% AEP |
| **5% AEP** | 5% AEP | 50% AEP |
| **2% AEP** | 2% AEP | 20% AEP |
| **1% AEP** | 1% AEP | 10% AEP |
| **0.5% AEP** | 0.5% AEP | 5% AEP |
| **0.2% AEP** | 0.2% AEP | 2% AEP |
| **PMF** | PMF | 2% AEP |

## 7.4. Mannings 'n' Roughness

Table 15: Adopted Mannings '*n'* values – TUFLOW model

| Surface | Mannings 'n' |
|---|---|
| General | 0.04 |
| Light Vegetation | 0.04 |
| Thick Vegetation | 0.07 |
| Waterways (Light Vegetation) | 0.05 |
| Waterways (Heavy Vegetation) | 0.1 |
| Paved | 0.02 |
| Urban Lots | 0.1 |
| Wetland | 0.05 |
| Railway | 0.04 |
| Concrete Channel | 0.014 |
| Lakes | 0.1 |

Roughness, represented by the Mannings 'n' coefficient, is an influential parameter in hydraulic modelling. As part of the calibration process roughness values are adjusted within ranges defined in the literature so that the model better matches observed peak flood levels at a variety of locations. Chow (Reference 8) provides the definitive reference work in regards to the setting of the of the roughness values for hydraulic calculations.

Mannings 'n' values are also discussed in Project 15 of ARR 2016 – *Two Dimensional Modelling in Urban and Rural Floodplains* (Reference 9). The values adopted for this study were based on consideration of the above references, and the model calibration process. The Mannings 'n' values adopted for this flood study are shown in Table 15 while Figure 21 shows their spatial distribution.

## 7.5. Creeks/ Overland Flow paths

The creek channels were mostly defined in the 2D grid domain, as the 2 m resolution was sufficient to resolve the creek geometry effectively. The DEM was modified in various locations of the model to provide a continuous flow path using data available from previous studies or from site investigation.

For the central overland flow path in Greta, the concrete lined open channel was modelled within the 1D Domain to capture the conveyance of flow more efficiently. The open channel begins at Branxton Street and continues south west until it discharges into an artificial lake. Data for the hydraulic structures were collected during the site visit. Invert level data for these structures was available from Reference 1. This information was used to define the open channel invert. During the fieldtrip, WMAwater identified two structures had a steep invert drop directly downstream of a hydraulic structure – Hunter Street and New England Highway. These are shown in Photo 24 and Photo 25. This information was used to supplement the open channel invert gradient. The cross sections for the open channel system were obtained during fieldtrips.

Photo 24: New England Highway – steep slope downstream of the hydraulic structure

Photo 25: Hunter Street - steep gradient drop directly downstream of the hydraulic structure

## 7.6. Levees, Roads and Railway

The roads and railway were all modelled using break lines which alter the topography of the DEM. The elevations of the road and railway system were determined using the high resolution 1 m DEM from the LiDAR dataset. The Hunter Expressway and the hydraulic structures on it were modelled as per data supplied by RMS.

## 7.7. Hydraulic Structures

### 7.7.1. Bridges

The bridges traversing Anvil Creek at Nelson Street, Wine Country Drive (Becan Bridge) and Maitland Street are shown in Figure 3. These bridges were modelled in the 2D domain for the purpose of maintaining continuity in the model, and because the 2 m resolution was generally sufficient to resolve the waterway area accurately. The modelling parameter values for the bridges were based on the geometrical properties of the structure, which were obtained from measurements, ALS and photographs taken during site inspections and previous experience modelling similar structures. Examples of bridges included in the model are shown in Photo 26 and Photo 27.

Photo 26: Nelson Street Bridge

Photo 27: Wine Country Drive (Becan Bridge)

### 7.7.2. Culverts

The road culverts were modelled in the 1D domain. The modelling parameter values for the culverts/bridges were based on the geometrical properties of the structure, which were obtained from measurements and photographs taken during site inspections and previous experience modelling similar structures. For several of the culverts, invert levels had to be estimated from topographic information due to lack of available detailed survey data or plans. An example of a culvert included in the model is shown in Photo 28.

Photo 28: Road Culverts underneath New England Hwy, Greta

# 8. MODEL CALIBRATION

## 8.1. Objectives

The objective of the calibration process is to build a robust hydrologic and hydraulic modelling system that can replicate historical flood behaviour in the catchment being investigated. If the modelling system can replicate historical flood behaviour then it can more confidently be used to estimate design flood behaviour. The resulting outputs from design flood modelling are used for planning purposes and for infrastructure design. For this study, several relatively recent historical events were available to use for calibration purposes. Some of these, such as April 2015 and June 2007, were quite large events. The historical events chosen for calibration were:

- June 2007
- April 2015
- January 2016

## 8.2. Methodology

Surveyed flood marks were available from Reference 10 and from the community consultation process for this study.

The rainfall depths for each event across the catchment were derived from the gauge data, with the interpolated isohyets shown in Figure 9 and Figure 10. The rainfall inputs for the hydrologic model were varied spatially according to these isohyets. For each flood event, different temporal patterns were tested based on available sub-daily gauge data. Generally, the temporal pattern adopted was from the pluviograph at either Maitland, 18 WWP (R30), Bolwarra 1A WWPS (R29), Abermain BC (R21) or Branxton WWTW (R31). The adopted temporal pattern for each event varies with the specific historical rainfall scenario, depending on the available data.

The approach to model calibration was a joint calibration process. Rainfall loss parameters and the Mannings ‘n’ roughness values were adjusted in the TUFLOW hydraulic model until a strong match to the known flood level marks was achieved.

For most events, the peak flood levels were found to be most sensitive to assumptions about the historical rainfall depths and temporal pattern, rather than model parameters to the other model parameters available for tuning the model calibration. This indicates that it is unreasonable to try and obtain a perfect fit in the model calibration results, since the available rainfall data is inherently unable to reflect the true spatial and temporal rainfall distribution across the catchment for the floods investigated. In light of this consideration, the adopted model parameters were not varied significantly from typical values used in similar studies in the region.

## 8.3. Hydrologic Model Parameters

The adopted hydrologic model parameters for the study are listed in Table 16.

Table 16: Adopted WBNM model parameters

| Parameter | Value |
|---|---|
| C (Catchment Routing) | 1.7 |
| Impervious Catchment Area | 8.6% |
| Stream Routing Factor | 1.0 |
| Impervious Area Lag Factor | 0.1 |
| Initial loss | 10 mm |
| Continuing loss | 2 mm/hr |

## 8.4. Rainfall Losses

The initial loss / continuing loss model was used to estimate rainfall losses over the catchment. The approach taken was to vary the initial loss across the calibration events and to use an identical continuing loss for all the events in order to provide the best fit to recorded water levels. This can be justified as there would be different antecedent conditions in the catchment for the historical events. Antecedent conditions in the catchment may change but the rate of ongoing infiltration of water into the saturated soil (continuing loss) should theoretically be relatively consistent in the historical events.

A continuing loss that provided the best average fit for all the historical events was determined through multiple model runs. A better fit to recorded levels could have been achieved by changing the continuing loss values across the historical events but it was deemed to be an exercise in curve fitting rather an accurate representation of catchment conditions. The rainfall loss values applied to the historical events are shown in Table 16.

## 8.5. Calibration Results

### 8.5.1. April 2015

The April 2015 flood event was a significant event for the Anvil Creek Catchment and its tributaries, producing some of the highest flood levels on record across the catchment. The flood was a result of extremely intense rainfall (approximately 180 mm within a 24-hour period, falling primarily on the morning of 21st April. There was also significant rainfall of in the preceding 24 hours. For calibration purposes the models were run for 1 day – from 9am on the 21st April to 9am on the 22nd of April. The temporal pattern from the Maitland 18 WWP (R30) pluviometer produced a similar peak flow and hydrograph shape to other nearby pluviometer gauges. The temporal pattern from the Bolwarra 1A WWPS (R39) produced the largest peak flow. Both temporal patterns were input into the model to assess the variation across the catchment.

A comparison between the observed flood depths and modelled flood depths is shown Table 17. A map of the peak flood depths as well as the difference between observed and modelled flood levels for gauge Maitland 18 WWP (R30) and Bolwarra 1A WWPS (R39) is in shown in Figure C1 and Figure C2.

Table 17: Observed and modelled peak flood levels – April 2015 Event

| ID | Address | Source* | Comment | Estimated Flood Depth (m) | Estimated Flood Level (mAHD) | Pattern 1 - Maitland 18 WWP (R30) | | Pattern 2 - Bolwarra 1A WWPS (R39) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Modelled Peak Flood Level | Difference | Modelled Peak Flood Level | Difference |
| 1 | 3 Branxton St, Greta | CC | Flooding Above Floor Level | 0.05 | 54.1 | 54.2 | 0.1 | 54.3 | 0.1 |
| 2 | 30 Hunter St, Greta | CC | Flooding Above Floor Level - Shed | 0.2 | 50.8 | 50.7 | -0.1 | 50.9 | 0.1 |
| 3 | 1 Sale St, Greta | CC | Flooding above top of gully bank ant property rear. Fence destroyed. | 0.5 | 57.1 | 57.2 | 0.1 | 57.2 | 0.1 |
| 4 | 6 The Barracks Close, Greta | CC | Flooding in Backyard | 0.5-0.6 | 50.8 | 50.1 | -0.9 | 50.4 | -0.6 |
| 5 | 76 Sale Street, Greta | CC | Flooding at 1.25m depth through property | 1.25 | 47.75 | 47.5 | -0.3 | 47.9 | 0.2 |
| 6 | 9 Hunter St, Greta | CC | Flooding at bottom of driveway next to the letterbox | - | 48.2 | 48.4 | 0.2 | 48.5 | 0.3 |
| 7 | 21 Hunter St, Greta | CC | Flood Depth at lowest point within the property | 1 | 50.15 | 50.0 | -0.2 | 50.0 | -0.1 |
| 8 | 17C Evans St, Greta | CCC | Flooding Above Floor Level | 0.1 | 58.7 | 58.7 | 0.0 | 58.7 | 0.0 |
| 9 | 1 Wyndham St, Greta | CC | Flooding Above Floor Level | 0.55 | 47.45 | 47.3 | -0.2 | 47.8 | 0.3 |
| 10 | 11 Hunter St, Greta | CC | Flooding at ankle level above floor | 0.15 | 49.6 | 49.6 | 0.0 | 49.7 | 0.1 |
| 11 | 20 Anvil St, Greta | CC | Flooding in front of the house (taken from photo supplied) | 0.15 | 56.2 | 56.4 | 0.2 | 56.5 | 0.2 |
| 12 | 51 York St, Greta | CC | Flooding in property (knocked down back fence) | 0.2 | 49.4 | 49.4 | 0.0 | 49.4 | 0.0 |
| 13 | 78 Sale St, Greta | CC | Flooding in property (knocked house off piers) | 1.6 | 47.7 | 47.3 | -0.4 | 47.8 | 0.1 |
| 14 | 19 Mansfield St, Greta | CC | Flooding at the side of the house | 0.15 | 58.4 | 58.3 | 0.0 | 58.4 | 0.0 |
| 15 | 43 Sale St, Greta | CC | Flood Mark on DIP road sign in Sale Street, Greta | 0.4 | 51.1 | 51.1 | 0.0 | 51.2 | 0.1 |
| 16 | 5 Katerina Close, Greta | FT | Flooding through shed at rear of property | 0.3 | 55.8 | 55.8 | 0.0 | 55.9 | 0.1 |
| 17 | 6-8 Dalwood St, Greta | FT | Surveyed Flood Level on light pole between 6-8 Dalwood St, Greta | 0.3 | 54.26 | 54.2 | -0.1 | 54.3 | 0.1 |
| 18 | 67 High Street, Greta | FT | Shallow flooding observed in the carpark | 0.1 | 48.7 | 48.8 | 0.1 | 49.0 | 0.3 |
| 19 | 100 Hillview St, East Branxton | CC | Flooding Above Floor Level | 0.4 | 38.4 | 38.3 | -0.1 | 38.3 | -0.1 |
| 20 | 1 Durham Rd, East Branxton | CC | Flooding Above Floor Level | 0.2 | 41.1 | Not Flooded | Not Flooded | Not Flooded | Not Flooded |
| 21 | 7 Preston Close, East Branxton | CC | Surveyed Flood Level along north boundary | - | 42.8 | 42.7 | -0.2 | 42.9 | 0.0 |

** CC = Community Consultation, FT = Fieldtrip*

### 8.5.2. January 2016

The January 2016 flood was a result of heavy rain from the 3rd to 6th January, with the most intense falls on 5th January. For calibration purposes, the models were run for a period of 1 day. The modelled rainfall depths across the catchment are shown in Figure 11. The temporal pattern from the Maitland 18 WWPS (R30) and Bolwarra 1a WWPS (R29) pluviometers were modelled to assess the variation across the catchment. One observed flood mark was available for this event. The difference between the observed and modelled flood level is shown on Figure C3 and Figure C4. The peak flood depths are also shown on these figures.

### 8.5.3. June 2007

The June 2007 event occurred as a result of an east coast low that provided sustained heavy rainfall over a period of 2 days on 7th and 8th June. The models for this event were run for a period of 1 day. The modelled rainfall depths across the catchment are shown in Figure 9. The temporal pattern from the Abermain BC (R21) and Branxton WWTW (R31) pluviometers were modelled to assess the variation across the catchment. Three observed flood marks were available for this event. The difference between the observed and modelled flood level is shown on Figure C5 and Figure C6. The peak flood depths are also shown on these figures.

## 8.6. Discussion of Results

The TUFLOW model was primarily calibrated to the April 2015 Event by comparing the modelled peak flood levels and observed flood levels across the catchment. The modelled results are a relatively good match across Greta as seen in in Figure C1 and Figure C2.

The following is observed:

- The differences between observed and modelled peak flood levels in the central flow path of Greta were -0.1 m to 0.2 m for the Maitland 18 WWP (R30) station and 0 m to 0.3 m for the Bolwarra 1A WWPS (R39) gauge.
- Differences in flood levels along the southern flow path in Greta were also reasonable with ±0.3 m for both temporal patterns tested.
- The modelled flood levels at Sale Street for the April 2015 Event (using the Bolwarra 1A WWPS (R39) rainfall gauge) are a very good match to the observed flood levels. At 76 & 78 Sale Street, the difference between modelled and observed levels are 0.1 m.

The models did not produce some flooding reported by the community in East Branxton. The primary reason suspected for this is that these issues were caused by overland flow mechanisms rather than mainstream flooding. Modelling overland flow is not a part of this study and the models were not established to model these mechanisms. An investigation was made into the flood marks provided to WMAwater from the community consultation that were not flood affected based on the April 2015 modelling. The flood marks reviewed include;

- **1 Durham Rd, East Branxton** - Based on communication with the property owner, flood affectation during the April 2015 event was due to flow entering the property from the rear of the property (between 112 Hillview Rd and 3 Durnham Rd) where water looked like a waterfall coming off a neighbours retaining wall. Further, water entered the house through drains in the house. As such, was determined not to be due to mainstream or major overland flow and outside the scope of the flood modelling.

- **7 Preston Close, East-Branxton** – Based on communication with property owner, it was found that these flood marks were due to sheet flow travelling south along Preston Close and travelling between 4 & 5 Preston Close before converging with flow along Red House Creek. As such, was determined not to be due to mainstream or major overland flow and outside the scope of the flood modelling.

It is possible that the assumed rainfalls are too low for the western part of the study area. Based on the rainfall isohyets for the event (Figure 10), the rainfall applied to the sub-catchments varies from 110 mm – 180 mm – where the lowest rainfall is applied at the western portion of the catchment. The sub-catchments around East-Branxton and Branxton are highly influenced by the lower rainfalls recorded at Singleton STP (70.8 mm) and Elderslie Station (109 mm). As such, the rainfall applied to these catchments may have been too low, where the 199.4 mm of rainfall recorded at Branxton (Dalwood Vineyard) may be more realistic.

The assumed losses for this event included an initial loss of 10 mm and a continuing loss of 2 mm/h. For the preceding 24 hours prior to rainfall event, 160mm of rainfall was recorded at Branxton (Dalwood Vineyard) rainfall station which is location approximately 5.2 km to the north east of Greta. As such, the antecedent conditions of the catchment would have been saturated, suggesting a relatively low initial loss of 10 mm was appropriate for this event.

Calibration of the model was not undertaken for the June 2007 and January 2016 events due to a limited availability of observed flood marks. A more limited verification of the modelling was undertaken for these events, after calibrating to the April 2015 event. For the June 2007 event, two of the observed flood marks were assumed to be overland flood affected, rather than part of mainstream flooding (one of these included 7 Preston Close, East-Branxton).

For the observed flood marks that were available, modelling of both the June 2007 and January 2016 events produced good matches.

The calibration match for the model to historical events is considered to be good. Given that the April 2015 event was an extreme storm, likely more intense than a 1% AEP event for the catchment, this calibration provides a relatively high level of confidence in the 1% AEP design flood levels produced by the study.

# 9. DESIGN FLOOD MODELLING INPUTS

## 9.1. Overview

The principal flow paths in the study area are Anvil Creek, four tributaries through the township of Greta and two tributaries through East-Branxton. The lower reaches of the catchment are flood affected in the event of a Hunter River flood. This study assessed "mainstream" flooding from these creeks, but not shallow overland flow in the urban areas.

ARR2016 guidelines (Reference 5) were adopted for this study, including design rainfalls, losses, areal reduction factors and temporal patterns. These inputs were used for a range of AEPs including the 50%, 20%, 10%, 5%, 2%, 1%, 0.2% and 0.5% AEP. The PMF flows were derived using the Bureau of Meteorology's Generalised Short Duration Method (Reference 11) for durations up to 360 minutes (6 hours) and the Bureau of Meteorology's Generalised Southeast Duration Method (Reference 12) for durations greater than 360 minutes.

The ARR2016 data inputs, the procedure for the selection of the critical pattern duration, and adopted hydrologic model parameters are discussed in the following sections.

## 9.2. Whitburn Estate

The hydraulic model was updated to include the Greta Trunk Drainage and Road Realignment for the Whitburn Estate (Reference 13 ). The construction of the drainage upgrade was still underway during WMAwater's site visit in November 2017, and had not commenced when the calibration events occurred. Photos taken from the site visit are shown below.

Photo 29: Culverts (2m x 2.7m x 0.9m) installed at the New England Highway

Photo 30: Construction at the New England Highway

Photo 31: Drainage reserve looking from New England Highway towards Whitburn Street

Photo 32: Culvert inlet (2m x 2.7m x 0.75m) installed between Kent St and Whitburn St

For the purposes of this study, the existing situation as at June 2018 was assumed. This included an overland flow swale from York Street to downstream of Kent Street, with existing culvert structures at York St and Kent St, before entering into an upgraded underground trunk drain from downstream of Kent Street to downstream of the New England Highway. This culvert travels southwards through the drainage easement, flowing underneath Whitburn Street and New England Highway, before discharging towards Anvil Creek on the southern side of the New England Highway. At these road crossings, the culvert sizes are 2 x 2.7 m x 0.9 m RCBC. The model modifications included:

## 9.3. Downstream Boundary Conditions - Hunter River Tailwater

The lower reach of the Anvil Creek catchment is dominated by Hunter River Flooding. Flood extents for major Hunter River flooding were defined in Reference 2 and Reference 3. The main purpose of this study was to define flood extents for localised storm events over the Greta/Branxton area (similar to April 2015), which may or may not occur in conjunction with Hunter River flooding. Generally, localised storms would be expected to coincide with only minor Hunter River flooding, or the timing of the flood peaks would not be coincident. There is not enough historical data to do a comprehensive joint probability analysis of the two flood mechanisms.

The assumptions for joint Hunter River flooding probability in this study were consistent with other similar tributary studies undertaken in area in recent years (see Section 7.3.2 for the AEP combinations). The corresponding design flood levels for the downstream boundary from Reference 2 are shown in Table 18.

Table 18: Hunter River Design Flood Levels

| Hunter River Flood Event | Peak Downstream Flood Level (mAHD) |
|---|---|
| **50% AEP** | 25.1 |
| **20% AEP** | 28.1 |
| **10% AEP** | 29.8 |
| **5% AEP** | 31.2 |
| **2% AEP** | 33.1 |
| **1% AEP** | 33.5 |

## 9.4. ARR 2016 Data Inputs

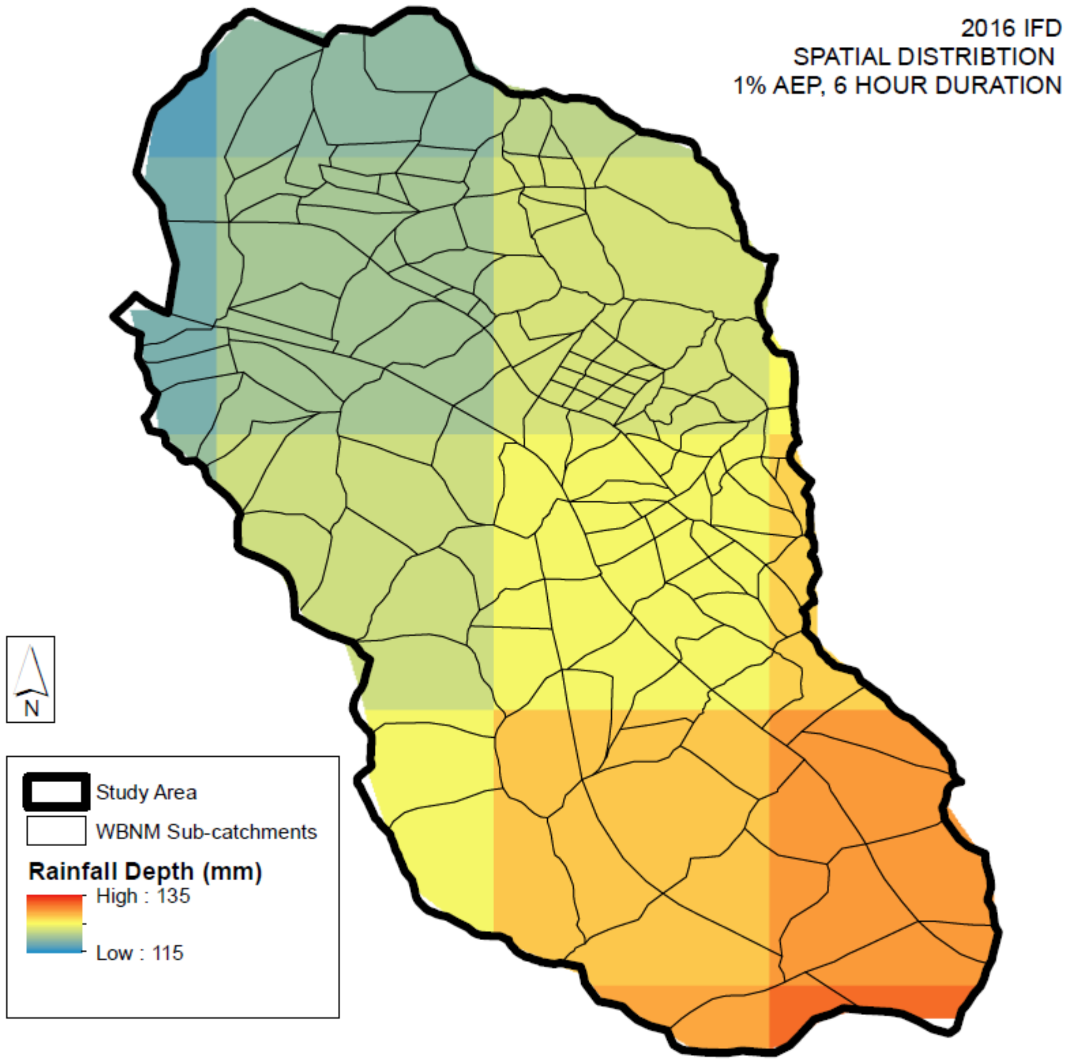
### 9.4.1. Rainfall

The design rainfall intensity frequency duration (2016 ARR IFD) for the centroid of the study area was discussed in Section 3.7. However the design rainfall data varies spatially over the catchment, and this spatial variation was included in the modelling.

The spatial distribution for the 6 hour 1% AEP event (critical duration of the 2016 ARR assessment as derived in Section 9.5) is shown in Diagram 5, as per the gridded data provided by the Bureau of Meteorology. A similar surface grid was generated for each AEP / duration combination by interpolating point values.

It is noted that across all durations and AEPs, that the southern portion of the catchment has higher design rainfall depths compared to the rest of the catchment. That is, the long-term rainfall records indicate that the southern portion of the catchment has higher rainfall depths compared to the northern catchment. For the 1% AEP event, the spatial variability was 11%. This trend is consistent with observations from recent major storms such as April 2015 and June 2007.

Diagram 5: 1% AEP design rainfall spatial distribution comparison: 6 hour duration




### 9.4.2. Temporal Patterns

In real storms there is a wide variety of how a given amount of rain fall over time (whether more heavily at the start or the end of the storm, or with multiple bursts). This variation in temporal pattern can result in significant effects on the peak flow for a given amount of rainfall. For design storms, temporal pattern assumptions are required to describe how rain falls over time, while capturing the average peak behaviour of this inherent variability. Previously, with ARR1987 guidelines (Reference 14), a single temporal pattern was adopted for each rainfall event duration.

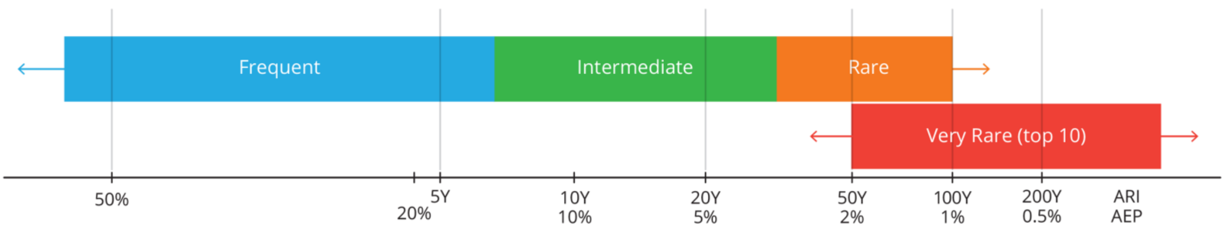
However, ARR2016 (Reference 5) identified the potential inaccuracies with adopting a single temporal pattern and recommends an approach where an ensemble of different temporal patterns are investigated.

Temporal patterns for this study were obtained from ARR2016 (Reference 5). The revised temporal patterns have adopted an ensemble of ten different temporal patterns for a particular design rainfall magnitude and duration. Given the rainfall-runoff response can be quite catchment specific, using an ensemble of temporal patterns attempts to produce the average catchment response.

The ARR2016 temporal patterns look at the entirety of the storm including pre-burst rainfall, the burst and post-burst rainfall. There can be significant variability in the burst loading distribution (i.e. depending on where 50% of the burst rainfall occurs an event can be defined as front, middle or back loaded). The 2016 method divides Australia into 12 temporal pattern regions, with the Anvil Creek catchment falling within the East Coast South region.

ARR2016 provides 30 patterns for each duration and are sub-divided into three temporal pattern bins based on the frequency of the events. Diagram 6 shows the three categories of bins (frequent, intermediate and rare) and corresponding AEP groups. The "very rare" bin is currently in the experimental stage and was not used in this flood study.

Diagram 6: Temporal Pattern Bins




### 9.4.3. Design Losses

The Australian Rainfall and Runoff Data Hub (Reference 15 and Attachment A) specifies at the Anvil Creek catchment centroid a storm initial loss of 18 mm, and a continuing loss rate of 2.0 mm/hr. These recommendations are based on prediction equations and were based on 35 catchments with a standard error between 20% and 50% (Reference 5).

As per ARR 2016 modelling methodology, pre-burst (the portion of rainfall that precedes the critical burst of the storm event) is subtracted from the storm initial loss to calculate the burst initial loss. The burst loss is applied to the hydrological model. The formula for deriving the burst initial loss is:

Burst Initial Loss = Storm Initial Loss – Pre-Burst

The median pre-burst rainfall depth varies for AEP and duration. That is, the initial loss applied to the hydrological model varies for each AEP/ duration combination. Appendix A includes the catchment median pre-burst information for the Anvil Creek catchment used in this study.

For this study, the ARR 2016 design losses were adopted. Incorporating pre-burst rainfall, at the catchment centroid the applied initial losses range from 8 mm (1% AEP) to 16 mm (50% AEP) depending on AEP. The continuing loss at the catchment centroid is 2 mm/hr. These adopted initial and continuing losses are consistent with the values used for the calibration events.

### 9.4.4. Areal Reduction Factors

An Areal Reduction Factor (ARF) is an estimate of how the intensity of a design rainfall event varies over a catchment, based on the assumption that large catchments will not have a uniform depth of rainfall over the entire catchment. As part of the revised ARR 2016 methodology (Reference 5), ARFs are available for short durations (12 hours and less) and long durations (durations larger than 12 hours). The equations utilised for this study along with applicable regional parameters are presented in Attachment A (as part of the Data Hub dataset). The areal reduction factors to be applied using the 2016 IFD are presented in Table 19.

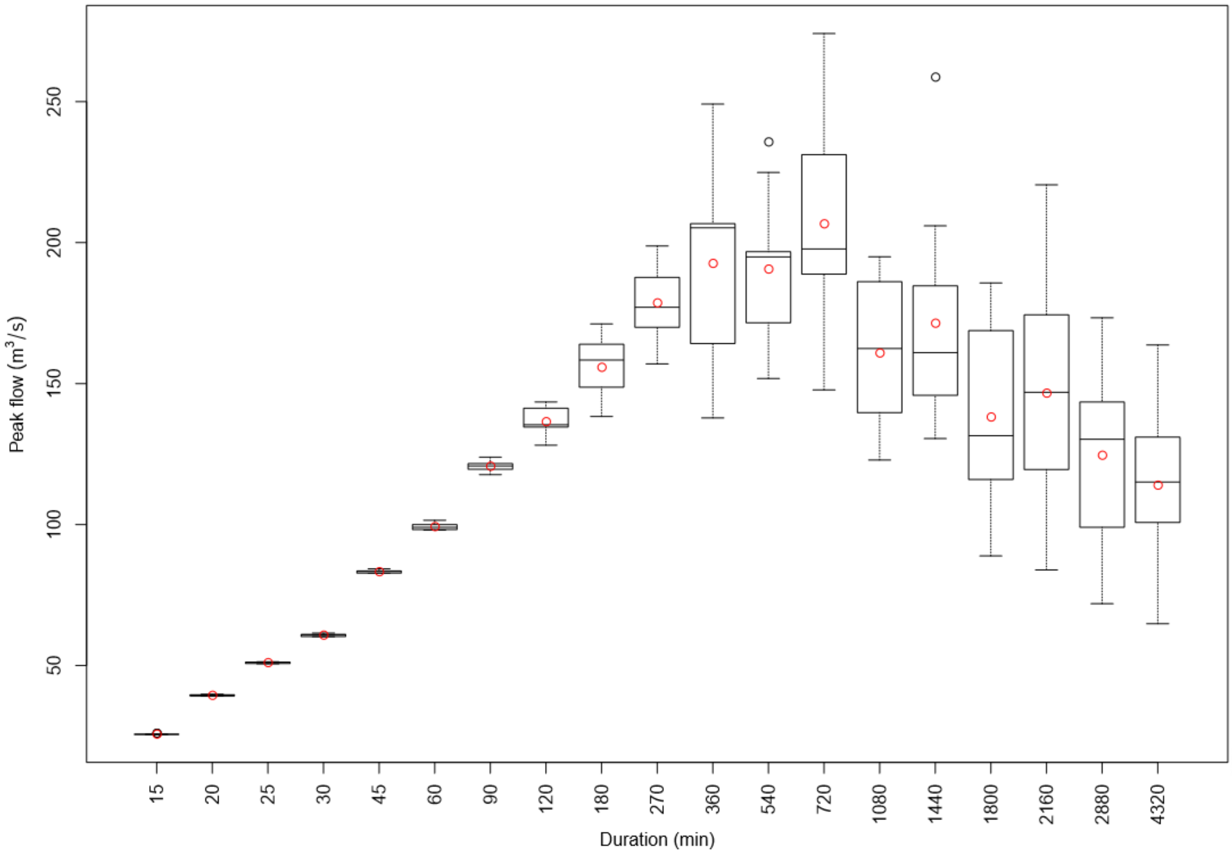
Table 19: Areal Reduction Factors (2016) for a range of AEP / duration combinations

| Storm Duration | 50% AEP | 20% AEP | 10% AEP | 5% AEP | 2% AEP | 1% AEP | 0.5% AEP | 0.2% AEP |
|---|---|---|---|---|---|---|---|---|
| **30 minutes** | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 |
| **1 hour** | 0.87 | 0.86 | 0.85 | 0.84 | 0.83 | 0.82 | 0.81 | 0.80 |
| **2 hour** | 0.91 | 0.89 | 0.88 | 0.87 | 0.85 | 0.84 | 0.83 | 0.81 |
| **3 hour** | 0.92 | 0.91 | 0.89 | 0.88 | 0.86 | 0.85 | 0.84 | 0.82 |
| **6 hour** | 0.94 | 0.94 | 0.93 | 0.92 | 0.91 | 0.91 | 0.90 | 0.89 |
| **12 hour** | 0.96 | 0.95 | 0.95 | 0.95 | 0.94 | 0.94 | 0.94 | 0.93 |
| **24 hour** | 0.98 | 0.98 | 0.98 | 0.98 | 0.97 | 0.97 | 0.97 | 0.97 |
| **48 hour** | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 |
| **72 hour** | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 |

## 9.5. Critical Duration and Temporal Pattern Assessment

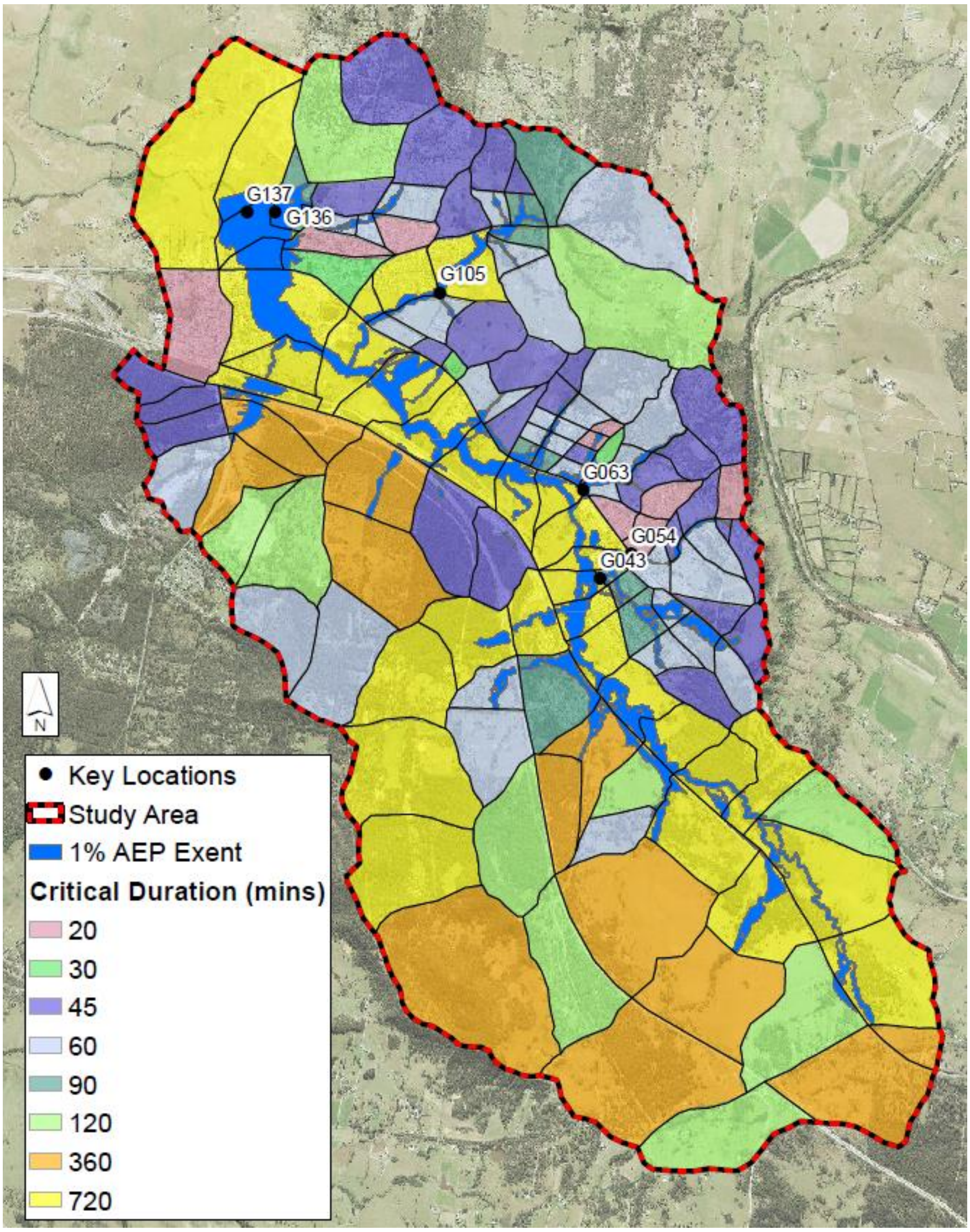
The temporal patterns for durations between 15 minutes and 72 hours were run through the WBNM models. The critical duration across the catchment was assessed by a box and whiskers plot of the peak flow from the ensembles of all durations for the 1% AEP peak flow (as recommended in Book 2 Chapter 5 Section 5.9.2, Reference 5). The boxplot for the catchment outlet is shown in Diagram 7. The box and whiskers for each duration indicate the spread of results obtained from the ensemble of temporal patterns. The box defines the first quartile to the third quartile of the results and the bottom and top line (also called 'whiskers') represent the maximum and minimum values. The black circles beyond these lines are statistical outliers. The black line within the box represents the median value. The red circle is the mean value. The critical duration at the catchment outlet, as identified by the peak mean flow, is 720 minutes.

Diagram 7: Box plot of the peak flow at downstream end of study area – 1% AEP




The same principle was applied to all subcatchments in order to spatially identify the critical duration across the catchment. The result of this is shown in Diagram 8. As seen, the critical duration across the catchment varies from 120 minutes to 720 minutes. For the townships and minor tributaries, various durations (45, 60, 90, 120 min) are critical, whilst larger tributaries (Red House Creek, Sawyers Creek) and Anvil Creek had a larger critical duration of 360 minutes and 720 minutes. A number of key locations throughout the catchment were analysed to determine the critical duration flows and to investigate other potential durations or temporal patterns which result in similar peak flows. These key locations are shown on Diagram 8.

Diagram 8: Spatial distribution of critical duration for the 1% AEP event.




Despite this range of critical durations for different sub-catchment sizes across the study area, it was found that a single representative 360 minute storm pattern could be found for each AEP, which reproduced the critical duration flow response for each of the key subcatchments. Table 20 shows the 1% AEP peak flow for the selected design storm (360 minutes, using temporal pattern TP4694), compared to the 1% AEP peak flow for each major subcatchment derived from the critical duration analysis. In each case, the chosen storm produces a peak flow within a few percent of the critical duration peak flow, and generally slightly higher. For example, even though the critical duration for the southern flow path was found to be 120 minutes (mean peak flow of 10.0 $m^3/s$), the selected 360 minute storm produces a peak flow of 10.6 $m^3/s$, which is within reasonable bounds.

Table 20: Comparison of the peak flow ($m^3/s$) for the representative storm (360 minute) compared to the local critical duration at key subcatchments – 1% AEP

| Catchment | Location | Critical Duration (mins) | Mean Peak Flow ($m^3/s$) | Peak Flow ($m^3/s$) for 360 min TP4694 design storm | Difference (%) |
|---|---|---|---|---|---|
| **G137** | Anvil Creek | 720 | 206.7 | 206.3 | 0% |
| **G136** | Hillview Road, East Branxton | 360 | 18.9 | 19.9 | 5% |
| **G105** | Red House Creek, East Branxton | 720 | 25.7 | 27.5 | 7% |
| **G043** | Southern flowpath, Greta | 120 | 10.0 | 10.6 | 6% |
| **G053** | Central flowpath, Greta | 90 | 8.6 | 8.5 | -2% |
| **G063** | West St flowpath, Greta | 90 | 10.4 | 10.3 | -1% |

Table 21 and Table 22 show similar comparisons for the selected storms for the 5% AEP and 20% AEP respectively.

Table 21: Comparison of the peak flow ($m^3/s$) for the representative storm (360 minute) compared to the local critical duration at key subcatchments – 5% AEP

| Catchment | Location | Critical Duration (mins) | Mean Peak Flow ($m^3/s$) | Peak Flow ($m^3/s$) for 360 min TP4694 design storm | Difference (%) |
|---|---|---|---|---|---|
| **G137** | Anvil Creek | 360 | 132.3 | 137.9 | 4% |
| **G136** | Hillview Road, East Branxton | 360 | 12.9 | 14.0 | 9% |
| **G105** | Red House Creek, East Branxton | 360 | 17.9 | 18.7 | 5% |
| **G043** | Southern flowpath, Greta | 360 | 7.0 | 7.2 | 3% |
| **G053** | Central flowpath, Greta | 180 | 5.7 | 6.1 | 7% |
| **G063** | West St flowpath, Greta | 180 | 6.8 | 7.2 | 5% |

Table 22: Comparison of the peak flow ($m^3/s$) for the representative storm (360 minute) compared to the local critical duration at key subcatchments – 20% AEP

| Catchment | Location | Critical Duration (mins) | Mean Peak Flow ($m^3/s$) | Peak Flow ($m^3/s$) for 360 min TP4694 design storm | Difference (%) |
|---|---|---|---|---|---|
| **G137** | Anvil Creek | 540 | 70.8 | 73.0 | 3% |
| **G136** | Hillview Road, East Branxton | 270 | 7.8 | 8.0 | 2% |
| **G105** | Red House Creek, East Branxton | 360 | 10.3 | 10.8 | 5% |
| **G043** | Southern flowpath, Greta | 270 | 4.1 | 4.2 | 2% |
| **G053** | Central flowpath, Greta | 180 | 3.5 | 3.4 | -3% |
| **G063** | West St flowpath, Greta | 180 | 4.2 | 4.3 | 1% |

The same procedure was used to determine the critical duration and the critical temporal pattern for each AEP bin. That is, the 1% AEP, 5% AEP and 20% AEP were assessed for critical duration and critical pattern and these were applied to other AEPs within the same AEP bin.

Table 23 summarises the critical durations and representative storm patterns selected for the different design events, whilst Table 24 shows the peak flows for these storm patterns.

Table 23: Selected Critical Durations and Representative Storm Patterns

| Event | AEP Bin | Critical Duration (min) | Critical Pattern |
|---|---|---|---|
| **50% AEP** | Frequent | 360 | TP4740 |
| **20% AEP** | Frequent | 360 | TP4740 |
| **10% AEP** | Intermediate | 360 | TP4731 |
| **5% AEP** | Intermediate | 360 | TP4731 |
| **2% AEP** | Rare | 360 | TP4694 |
| **1% AEP** | Rare | 360 | TP4694 |
| **0.5% AEP** | Rare | 360 | TP4694 |
| **0.2% AEP** | Rare | 360 | TP4694 |
| **PMF** | Not applicable | 180 | Not applicable |

Table 24: Peak flows ($m^3/s$) for the representative temporal pattern at key locations

| Sub-catchment | Location | 50% AEP | 20% AEP | 10% AEP | 5% AEP | 2% AEP | 1% AEP | 0.5% AEP | 0.2% AEP |
|---|---|---|---|---|---|---|---|---|---|
| **G137** | Anvil Creek | 38 | 72 | 108 | 137 | 171 | 206 | 239 | 293 |
| **G136** | Hillview Road, East-Branxton | 5 | 7 | 11 | 13 | 17 | 19 | 22 | 26 |
| **G105** | Red House Creek, East-Branxton | 6 | 10 | 15 | 18 | 23 | 27 | 31 | 37 |
| **G043** | Southern flow path, Greta | 2 | 4 | 5 | 7 | 9 | 10 | 11 | 14 |
| **G053** | Central flow path, Greta | 2 | 3 | 5 | 6 | 7 | 8 | 9 | 11 |
| **G063** | West St flow path, Greta | 2 | 4 | 5 | 7 | 8 | 10 | 11 | 13 |

## 9.6. Blockage of Culverts and Bridges

For the modelled bridges and culverts, a methodology in accordance with the ARR Blockage Guidelines (Reference 5) was incorporated into design event modelling. The Reference 5 methodology considers blockage due to various sources and takes into account the:

- Debris Type and Dimensions - Whether floating, non-floating or urban debris present in the source area and its size;
- Debris Availability – The volume of debris available in the source area;
- Debris Mobility – The ease with which available debris can be moved into the stream;
- Debris Transportability – The ease with which the mobilised debris is transported once it enters the stream; and
- Structure Interaction – The resulting interaction between the transported debris and the bridge or culvert structure.

Debris characteristics were considered to be similar for each of the culverts assessed (i.e. uniform across the catchment), due to both similar catchment and stream characteristics. The applied blockage varies with opening size, on the basis that for the available debris in this catchment, inlet of smaller pipes are more likely to be affected by significant blockage than larger culverts or bridge structures. A summary of the adopted design blockage levels is provided in Table 25.

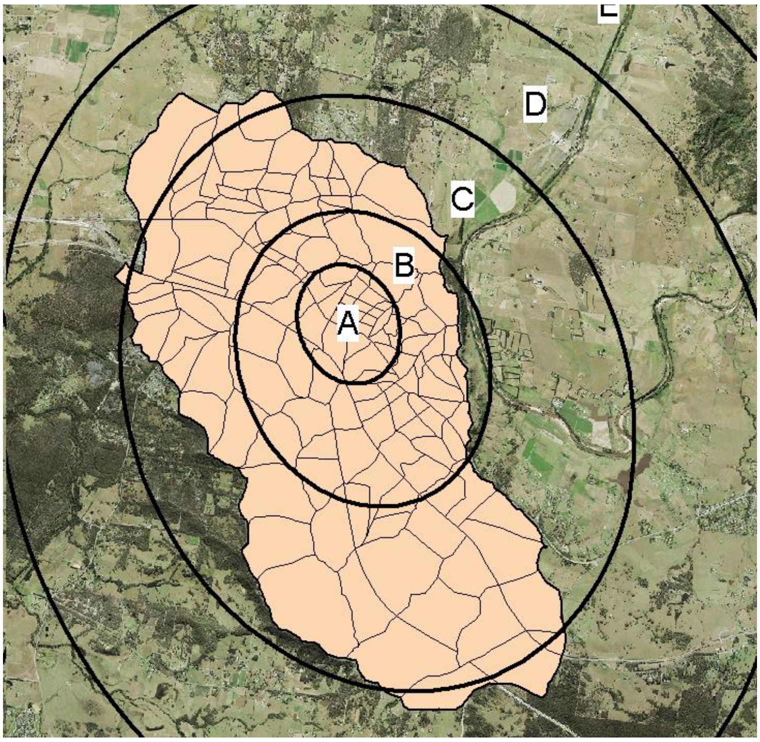
Table 25: Adopted Bridge/Culvert Design Blockage Factors

| Culvert size (largest dimension) | Selected Design Blockage |
|---|---|
| Less than 0.9 m | 50% |
| 0.9 m to 1.5 m inclusive | 25% |
| Larger than 1.5 m | 10% |

## 9.7. Probable Maximum Precipitation

The Probable Maximum Precipitation (PMP) is used to determine the Probable Maximum Flood (PMF). Anvil Creek has a catchment area of less than 1,000 km$^2$ and accordingly PMP depth calculation for this catchment was calculated by the Generalised Short Duration Method (GSDM) for durations up to 6 hours. An initial loss of 0 mm and a continuing loss of 1 mm/hr were adopted as recommended in Book 7, Chapter 4 of Reference 5). As per the Generalised Short Duration Method (GSDM), PMP estimates were derived using the ellipses with Zone A (the highest rainfall depths) distributed over the township of Greta. The storm durations run for the PMF model were 1, 1.5, 2, 2.5, 3, 4, 5, and 6 hour. The figures below show the distribution of ellipses and rainfall depths (mm). It was found the 3 hour duration event produced the largest flood levels across the catchment and was adopted for this study.

Diagram 9: Ellipses derived for the Generalised Short Duration Method (GSDM)



# 10. Design Flood Modelling Results

The results for the design flood events are presented in the following maps:

- Peak flood depth and level contours in Figure D1 to Figure D9
- Peak flood velocities in Figure D10 to Figure D18
- Provisional hydraulic hazard based on the NSW Floodplain Development Manual in Figure D19 to Figure D22
- Hydraulic hazard based on the Australian Disaster Resilience Handbook in Figure D23 to Figure D26
- Hydraulic categories in Figure D27 to Figure D30
- SES Flood Emergency Response Classifications in Figure D31 to Figure D34
- Provisional Flood Planning Area in Figure D35

Additional results are presented in the following tables and graphs:

- Peak flood depths and flows at road crossings in Table E1 and Table E2;
- Peak flood level profiles in Figure E1 to Figure E7; and
- Stage hydrographs at road crossings in Figure E8 to Figure E10.

Discussion of these results is provided in the following sections.

## 10.1. Summary of Results

The flood behaviour across the catchment can be seen in the peak flood depth and water level contour maps (Figure D1 to Figure D9), the peak velocity maps (Figure D10 to Figure D18) and peak water level profile graphs (Figure E1 to Figure E7). These results are presented for the range of design flood events modelled from the 50% AEP to the PMF event.

Through Anvil Creek, flooding is mostly contained within the channel banks in the 50% AEP event with floodwaters beginning to break out of bank just upstream of Maitland Street (New England Highway), inundating Branxton Golf Course. Flooding along tributary flow paths is generally contained to defined waterway areas, with only minor overbank flooding occurring. On the Southern Tributary, there are a series of flow paths which flow through properties on High Street and Anvil Street. Shallow overland flooding also occurs along a minor flow path between the Whitburn Street and West Street Tributaries, adjacent to Devon Street. The Whitburn Street Tributary trunk drainage system contains the 50% AEP event.

In the 20% and 10% AEP events there is more extensive flooding. This is most noticeable in the downstream portion of Anvil Creek. There is extensive flooding on the Branxton Golf Course and downstream of Maitland Road (New England Highway). There is additional overbank flooding on the Southern Tributary, affecting properties on Anvil Street and Sale Street. Shallow inundation occurs adjacent to the Central Tributary upstream of Branxton Street and also on the Whitburn Street Tributary, particularly upstream of Kent Street. The extent of flooding along Red House Creek is increased in the vicinity of properties in East Branxton. Shallow flows first occur on the New England Highway between Greta and Branxton in the 10% AEP event.

In the 5% AEP event, additional shallow overland flows occur on the Central Tributary immediately downstream of Branxton Street and the flow path adjacent to Devon Street. Maitland Street (New England Highway) is just overtopped. In the 2% AEP event, flows begin to break out of Anvil Creek in the vicinity of Greta. Shallow overland flows occur around Mansfield Street, between the Hunter Expressway and railway line. The basin located at the lower end of Water Street overflows, sending water along Anvil Street toward the Greta Workers Sports and Recreation Club. Shallow flows are more extensive on the flow path adjacent to Devon Street and on the Whitburn Street Tributary between Kent Street and Whitburn Street. The Hunter Expressway has flooding on the sag point between the Bridge Street overpass and Wine Country Drive interchange. The extent of inundation downstream of Maitland Street (New England Highway) due to the adopted Hunter River tailwater level affects a significant portion of land, including some areas upstream of Elderslie Road.

In the 1% AEP event, overland flooding from the Southern Tributary around Sale Street and Centre Street is more extensive. Along the Whitburn Street Tributary, water overtops York Street and Whitburn Street. Inundation of a large portion of Elderslie Road occurs and flooding extends into East Branxton.

In the 0.5% and 0.2% AEP events, additional shallow overland flooding occurs along most of the tributaries. Again, flooding in the downstream portion is much larger than the 1% AEP event, inundating the Miller Park Sporting Fields and reaching properties at the end of Fleet Street, upstream of the New England Highway. A large number of properties are also affected along the Maitland Street (New England Highway) and downstream of this in East Branxton, with flooding reaching Wyndham Street in the 0.2% AEP event.

In the PMF event, flooding along Anvil Creek in the vicinity of Greta is extensive, being approximately 300 to 400 m wide, causing inundation from Hunter Street, up to Anvil Street and the New England Highway. Along the Southern Tributary, there are substantial overbank flows along the northern side of the flow path up to Florence Street and on the southern side of the flow path downstream of this. Flooding along the other tributaries is also extensive and causes inundation of properties. Significant inundation of the New England Highway and Hunter Expressway occurs. Inundation downstream of Red House Creek remains largely the same as the 0.2% AEP event due to the adopted tailwater conditions for Hunter River flooding.

## 10.2. Road Inundation

An analysis of road inundation has been undertaken at key locations in the study area. These locations can be seen in Figure 22. Tabulated results of peak flood levels, depths and flows can be found in Table E1 and Table E2. Bridge deck levels or the top of road embankments are also plotted on the peak water level profiles in Figure E1 to Figure E7. Stage hydrographs showing the depth for each major crossing of Anvil Creek are shown in Figure E8 to Figure E11. Further information pertaining to access considerations is provided in Section 10.7.2.

## 10.3. Provisional Flood Hazard Categorisation

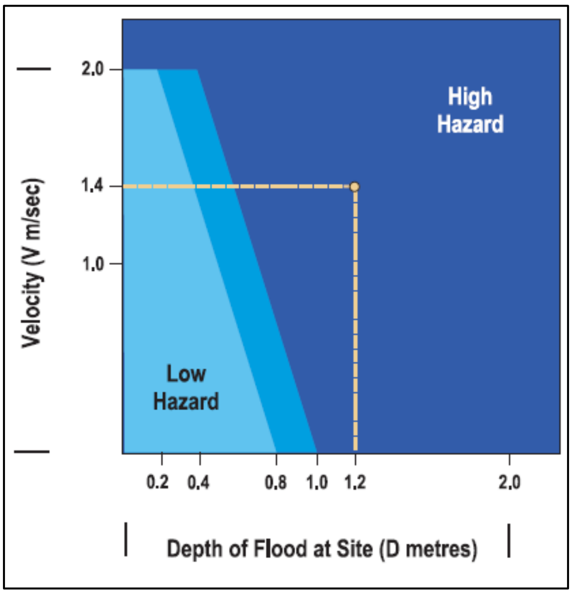
Hazard classification plays an important role in informing floodplain risk management in an area.

Provisional hazard categories have been determined for the Anvil Creek catchment by two methods – one in accordance with the NSW Floodplain Development Manual (Reference 16), and the other in accordance with the Australian Disaster Resilience Handbook Collection (Reference 17). Each is discussed below. These flood hazards are considered provisional. Note that this mapping does include consideration of the Hunter River Design Flood Events (Reference 2), which should also be considered for development control planning.

### 10.3.1. Floodplain Development Manual

Provisional hazard categories have been determined in accordance with Appendix L of the NSW Floodplain Development Manual (Reference 16) the relevant section of which is shown in Diagram 10. For the purposes of this report, the transition zone presented in Diagram 10 was considered to be high hazard.

Diagram 10: Provisional "L2" Hydraulic Hazard Categories (Source: Reference 16)




The provisional flood hazard maps utilising the Floodplain Development Manual (FDM) hazard categorisation are shown in Figure D19 to Figure D22 for the 5% AEP, 1% AEP, 0.2% AEP and PMF events. The FDM hazard categorisation has been included for applicability to exiting council policy documents that may refer to this hazard classification.

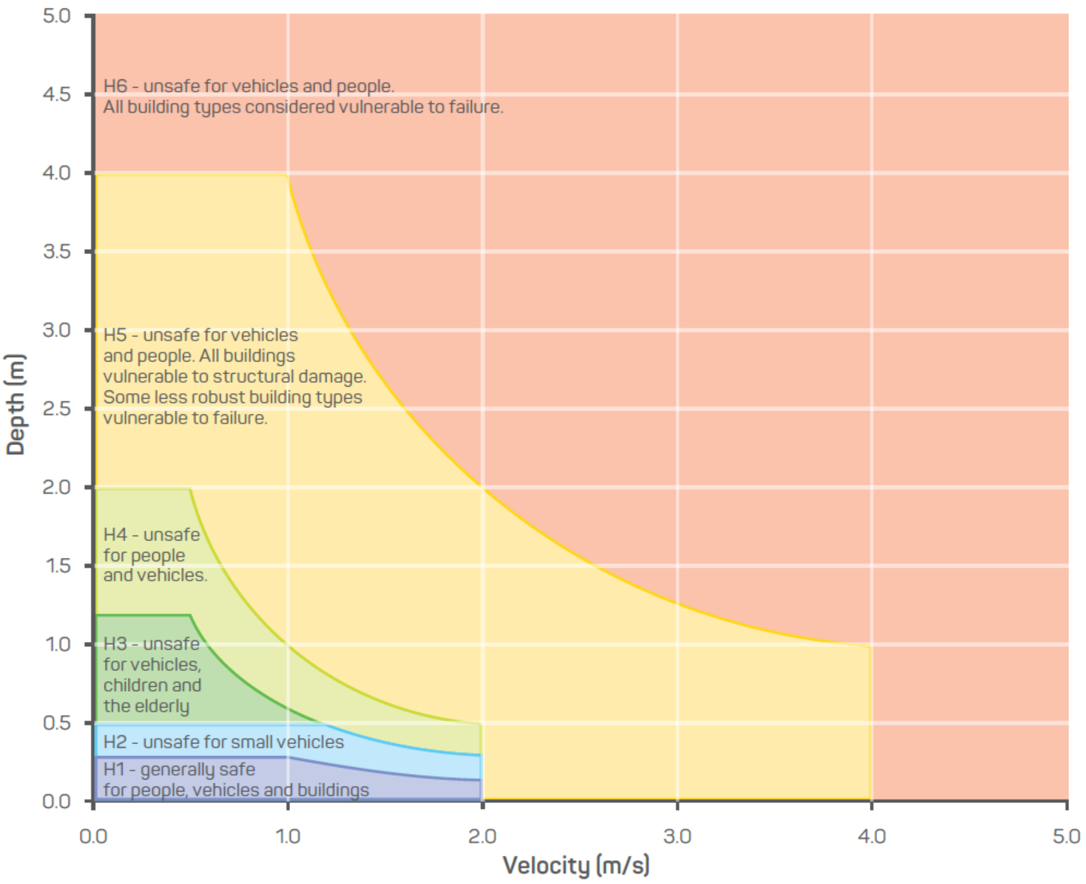
The results indicate that the high hazard areas are primarily within the channels on the floodplain upstream of Wine Country Drive in the 5% AEP event. This includes Anvil Creek, Red house Creek and the tributaries originating from the western portion of the catchment flowing under the Hunter Expressway and Railway and discharging into Anvil Creek. The flow paths through Greta and East-Branxton are typically within the low hazard area, apart from the channels themselves. A similar pattern can be seen in the 1% and 0.2% AEP events, except high hazard areas on the tributaries become more continuous and a large proportion of the areas inundated downstream are high hazard. In the PMF event, it is only the very fringes of the Anvil Creek flood extent that are low hazard, or in areas of shallow flow such as the overbank areas of the Southern Tributary through Greta and upstream of Mansfield Street (between the Railway Line and the Hunter

Expressway) with the remaining area being high hazard.

### 10.3.2. Australian Disaster Resilience Handbook Collection

In recent years, there have been a number of developments in the classification of hazards. Research has been undertaken to assess the hazard to people, vehicles and buildings based on flood depth, velocity and velocity depth product. The Australian Disaster Resilience Handbook Collection deals with floods in Handbook 7 (Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia). The supporting guideline 7-3 (Reference 17) contains information relating to the categorisation of flood hazard. A summary of this categorisation is provided in Diagram 11.

Diagram 11: General flood hazard vulnerability curves (Source: Reference 17)




This classification provides a more detailed distinction and practical application of hazard categories, identifying the following 6 classes of hazard:

- H1 – No constraints, generally safe for vehicles, people and buildings;
- H2 – Unsafe for small vehicles;
- H3 – Unsafe for all vehicles, children and the elderly;
- H4 – Unsafe for all people and all vehicles;
- H5 – Unsafe for all people and all vehicles. All building types vulnerable to structural damage. Some less robust building types vulnerable to failure. Buildings require special engineering design and construction; and

- H6 – Unsafe for all people and all vehicles. All building types considered vulnerable to failure.

The hazard maps using the Australian Disaster Resilience (ADR) classification are presented in Figure D23 to Figure D26 for the 5% AEP, 1% AEP, 0.2% AEP and PMF events. In the 5% and 1% AEP event, Anvil Creek are in the H4 and H5 category. Within the townships, the hydraulic hazard is mostly H1 with small pockets of H2. However, Red House Creek reaches the H3 and H4 category. In the 0.2% AEP event, a majority of Anvil Creek including the downstream area affected by the adopted Hunter River tailwater are in the H6 category, whilst sections of the central flow path in Greta are in the H5 category. In the PMF event, a large portion of the floodplain is covered by H5 and H6, with very small proportion of the flooded area being classified as H4 or lower.

## 10.4. Provisional Hydraulic Categorisation

The NSW Governments Floodplain Development Manual (Reference 16) defines three hydraulic categories which can be applied to different areas of the floodplain depending on the flood function:

- Floodways;
- Flood Storage; and
- Flood Fringe

Floodways are areas of the floodplain where a significant discharge of water occurs during flood events and by definition, if blocked would have a significant effect on flood levels and/or distribution of flood flow. Flood storages are important areas for the temporary storage of floodwaters and if filled would result in an increase in nearby flood levels and the peak discharge downstream may increase due to the loss of flood attenuation. The remainder of the floodplain is defined as flood fringe.

There is no quantitative definition of these three categories or accepted approach to differentiate between the various classifications. The delineation of these areas is somewhat subjective based on knowledge of an area and flood behaviour, hydraulic modelling and previous experience in categorising flood function. A number of approaches, such as that of Howells *et al* (Reference 18) rely on combinations of velocity and depth criteria to define the floodway.

For this study, hydraulic categories were defined by the following criteria, which was tested and is considered to be a reasonable representation of the flood function of this catchment.

- Floodway is defined as areas where:
  - the peak value of velocity multiplied by depth (V x D) > 0.25 $m^2$/s, **AND** peak velocity > 0.25 m/s, **OR**
  - peak velocity > 0.6 m/s **AND** peak depth > 0.3 m, or
  - areas within 10 m of a creek or tributary centreline (riparian zone).

  The remainder of the floodplain is either Flood Storage or Flood Fringe;
- Flood Storage comprises areas outside the floodway where peak depth > 0.5 m; and
- Flood Fringe comprises areas outside the Floodway where peak depth < 0.5 m.

The provisional hydraulic categories have been mapped in Figure D27 to Figure D30 for the 5% AEP, 1% AEP, 0.2% AEP and PMF events. As expected, the creeks and tributaries are classified as floodways, with flood storage areas mostly located at the downstream boundary and smaller pockets throughout the catchment.

## 10.5. Flood Emergency Response Planning Classification of Communities

To assist in the planning and implementation of response strategies, the NSW State Emergency Service (SES) in conjunction with the NSW Office of Environment and Heritage (OEH) has developed guidelines to classify communities according to the impact that flooding has upon them. These Emergency Response Planning (ERP) classifications (Reference 19) consider flood affected communities as those in which the normal functioning of services is altered, either directly or indirectly, because a flood results in the need for external assistance. This impact relates directly to the operational issues of evacuation, resupply and rescue, which is coordinated by the SES. Based on the guidelines (Reference 19), communities are classified to assist in emergency response planning (refer to Table 26).

Table 26: Emergency Response Planning Classification of Communities

| Classification | Response Required | | |
|---|---|---|---|
| | Resupply | Rescue/Medivac | Evacuation |
| **High flood island** | Yes | Possibly | Possibly |
| **Low flood island** | No | Yes | Yes |
| **Area with rising road access** | No | Possibly | Yes |
| **Area with overland escape route** | No | Possibly | Yes |
| **Low trapped perimeter** | No | Yes | Yes |
| **High trapped perimeter** | Yes | Possibly | Possibly |
| **Indirectly affected areas** | Possibly | Possibly | Possibly |

Key considerations for flood emergency response planning in the Anvil Creek catchment include:

- Cutting of external access isolating an area;
- Key internal roads being cut;
- Transport infrastructure being shut down or unable to operate at maximum efficiency;
- Flooding of any key response infrastructure such as hospitals, evacuation centres, emergency service sites;
- Risk of flooding to key public utilities such as gas, electricity and sewerage; and
- The extent of the area flooded and the duration of inundation.

Flood liable land within the study area where there are habitable areas (identified as buildings on the aerial imagery) have been classified according to the ERP classification above. The high flood island and high trapped perimeter areas have been combined, since they have the same emergency response planning considerations. Similarly, the low flood island and low trapped perimeter categories have also been combined. When classifying communities, consideration was given to flood depths for the purpose of being able to move through floodwaters on foot or in a vehicle, drawing on hazards presented in the Australian Disaster Resilience Handbook Collection (Reference 17 see Section 10.3.2). The ERP classifications for the study area are shown in Figure D31 to Figure D34 for the 5% AEP, 1% AEP, 0.2% AEP and PMF events. These figures also show major access roads that are cut in each event.

There are a number of properties affected by flooding in the 5% AEP event. These are primarily on the tributary flow paths and typically have rising road access. The depth of flooding is also expected to be reasonably shallow. There are several areas that are high flood islands, in particular the Greta Train Support Facility, the end of Florence Street (and John Street) and several houses along the New England Highway in north Greta. In East Branxton there are also several properties that are affected by flooding, with rising road access. This remains fairly similar in the 1% AEP event, with the most significant changes occurring west of the railway line, around Sale / Centre Street in Greta and on the Central Tributary upstream of Branxton Street (as flows break out of the channel and impact properties along the flow path) and downstream of the New England Highway adjacent to Anvil Creek, where a number of properties are identified as flood islands. In the 0.2% AEP event, there are a number of additional properties in the downstream portion through Branxton and East Branxton that are identified as low flood islands.

In the PMF event, the suburbs of Dalwood, Leconfield and an area in north Greta become isolated along with a portion of southern Greta. A number of properties along the tributaries through Greta also become low flood islands. The downstream area remains similar to the 0.2% AEP event.

## 10.6. Preliminary Flood Planning Area

The preliminary Flood Planning Area (FPA) is the area under the Flood Planning Level (FPL). The FPL was determined by adding 0.5 m freeboard to the 1% AEP flood level (the flood planning Level), and "stretching" this surface across the topography to form the FPA. The preliminary FPA is shown in Figure D35. The extent of the FPA was trimmed to the extent of the PMF, since areas outside the PMF are not expected to be impacted by flooding.

## 10.7. Information to support emergency management activities

### 10.7.1. Properties

The townships of Greta and East Branxton are affected by flooding from Anvil Creek and a number of smaller tributaries that run from east to west through the towns. The storm durations producing peak flood levels are short to medium duration storms ranging from less than 1 hour in the upper catchment areas to 12 hours along Anvil Creek. These storm durations and the response of the catchment to rainfall generally do not provide adequate time for widespread evacuations. Given the extent of flooding affecting properties within the towns is relatively minor, widespread evacuations are not considered necessary for events up to the 1% AEP event. In the 1% AEP event, there are expected to be a number of properties affected by shallow overland flooding (up to approximately 0.3 m). Generally, given the relatively short duration of flooding and shallow inundation experienced by the town, most residents will be able to shelter in place up in events up to and including the 1% AEP.

There are, however, several properties at the downstream end of the study area which are severely affected by flooding in the 1% AEP event. These properties are located in the vicinity of the New England Highway and Elderslie Road, adjacent to Anvil Creek. Some of these properties have been identified as ‘low flood islands’ and may require evacuation. These properties are primarily affected by the adopted Hunter River tailwater level, so it is assumed that more reasonable warning time would be given for Hunter River flood events.

In the PMF event, there are a number of properties affected by flooding and several areas are isolated such as southern Greta, northern Greta and the rural areas of Dalwood and Leconfield. Some deep flooding can be experienced even on the smaller tributaries such that evacuation may be required. Given the short critical duration of the PMF event, adequate warning time is unlikely.

### 10.7.2. Access

A number of local roads experience inundation in frequent events, such as White Street, High Street, Station Street, Kent Street, Devon Street and McMullins Road. The inundation, however, is shallow and access is unlikely to be cut off. For most of these, there are also alternative flood free routes.

There are a number of major roads that provide access into and out of Greta and East Branxton to other towns and city centres. These include the Hunter Expressway at the Branxton Interchange (via New England Highway, Bridge Street and Wine Country Drive) for access to the west and south east; New England Highway to the west and south east; Elderslie Road to the North; and Mansfield Street / Nelson Street over the railway to the south and west. Dalwood Road and Leconfield Road also provide the only access to the rural areas of Leconfield and Dalwood. The New England Highway also acts as a main thoroughfare within the study area, particularly between Greta and Branxton.

Major roads that experience inundation are discussed below:

- The Hunter Expressway is shown as flooded at the low point between the Branxton Interchange and overpass of Bridge Street. This occurs in the 2% AEP event and greater. This renders the Hunter Expressway inaccessible to vehicles west of the Branxton Interchange. It should be noted that the road drainage on the Hunter Expressway has not been included and the flood immunity of the road is likely to be greater than what has been modelled. The railway culverts downstream of the Hunter Expressway at this location were inaccessible and were estimated from aerial photos and nearby structures, so modelling may be inaccurate at this location. In the PMF event, the Hunter Expressway to the east of the Branxton Interchange is also modelled flooded, and may not be accessible as an evacuation route for Greta and Branxton. In this instance, Wine Country Drive is also cut off, so the Hunter Expressway is inaccessible in any case.
- New England Highway is first inundated in the 10% AEP event between Greta and Branxton, however, the road should only cut off in the 1% AEP event along Maitland Street at the Anvil Creek crossing. In events from the 10% AEP to the 1% AEP, however, there is expected to be congestion and an increased risk to road users as traffic moves through shallow floodwaters (<0.3 m deep) along the New England Highway. In the 1% AEP event, alternative access between Branxton and East Branxton/Greta should be available via

Bridge Street and Wine Country Drive, over the Hunter Expressway. The inundation of Maitland Street is due to the adopted Hunter River tailwater level, as demonstrated in Figure E10. In the PMF event, the New England Highway is not only cut at Maitland Street, but also between East Branxton and Greta, and at the Central Tributary crossing in Greta. Some residents within Greta who are not cut off will have access along the New England Highway to the south-east (toward Lochinvar and Maitland), through shallow floodwaters.

- Mansfield Street and Nelson Street provide access from Greta, over the railway, to roads leading to the south and west. Mansfield Road is first inundated in the 2% AEP event, though should remain trafficable up to the 0.2% AEP event. This access is only cut off in the PMF event, being inundated at both Mansfield Street and Nelson Street. This isolates The Barracks Close and a portion of southern Greta. This access is expected to be cut for approximately 4 hours (Figure E8 and Figure E9).
- Elderslie Road provides access from the New England Highway to the north. This road is inundated by the adopted Hunter River tailwater level in the 1% AEP event. An alternate route via McMullins Road should still be trafficable in all events except the PMF. When this is the case, access to the north via Vintage Row should be open to some residents (not inundated within the study area, however, this route may be cut off outside the study area, potentially by the Hunter River, which would isolate East Branxton completely), however the remaining residents of East Branxton would be isolated.
- Dalwood Road and Branxton Street Road are cut off only in the PMF event. These two roads, in combination with flooding on the New England Highway isolate Dalwood, Leconfield and north Greta.

In the 1% AEP event, the best access routes into and out of Branxton include the New England Highway to the west, and Hunter Expressway to the east. For East Branxton and Greta, the New England Highway to the east should be trafficable, although subject to shallow inundation. The Hunter Expressway to the east should also be accessible via the New England Highway and Wine Country Drive.

The railway line should be flood free in the 1% AEP event (within the study area).

### 10.7.3. Community and Emergency Facilities

Knowledge of the location of community facilities (for evacuation of large numbers of people, evacuation of less mobile people or for potential evacuation centres) and emergency services (police, fire, ambulance, SES) are important in the event of a flood. The community facilities and emergency services present within the study area are shown in Table 27. The table also outlines in what event the facility is inundated and potential issues.

Table 27 Community Facilities and Emergency Services within the Study Area

| Type | Name | Location | Comment |
|---|---|---|---|
| Child Care Centre | Tilly's Play and Development Centre | 4A Nelson St, Greta | Not flooded, isolated in PMF. |
| School | Greta Public School | 2 Wyndham St, Greta | Flooded in PMF only. |

| Type | Name | Location | Comment |
|---|---|---|---|
| Church | St Marys Anglican Church | Anvil St, Greta | Flooded in PMF only. |
| Community Hall | Greta Community Hall | Water St, Greta | Flooded in PMF only. |
| Medical Centre | Greta Medical Centre | 29 High St, Greta | Affected by PMF, access most likely cut off. |
| Church | St Catherine's Greta Church | Branxton St, Greta | Not flooded. |
| Club | Greta Workers Sports and Recreation Club | 2 West St, Greta | Affected by flooding in the 2% AEP event and greater. |
| Club | Miller Park Sports Club | 6 Maitland St, East Branxton | Property affected in the 0.2% AEP, however, building and access should be flood free up to the PMF. |
| Church | St John the Divine Anglican Church | 45 Cessnock Rd, Branxton | Not flooded in PMF. |
| Fire Department | Greta Fire Station | 2 Drinan St, Branxton | Not flooded, but cannot access East Branxton/Greta via New England Highway in the 1% AEP event. Wine Country Drive should be accessible up to the 0.2% AEP event. |
| Police Station | Branxton Police Station | 52 Cessnock Rd, Branxton | Not flooded, but cannot access East Branxton/Greta via New England Highway in the 1% AEP event. Wine Country Drive should be accessible up to the 0.2% AEP event. |
| School | Branxton Public School | 12 King Street, Branxton | Not flooded in PMF. |

Emergency services facilities (including SES) are present in towns to the east of the study area (such as Lochinvar, Maitland and Rutherford) and also Singleton to the north-west. The majority of the community facilities are not flooded in events except the PMF and could potentially be used as evacuation points if required. Branxton has a number of suitable locations and available emergency facilities. East Branxton has Millers Park Sports Club which should be flood free and accessible in the PMF event. Greta has a number of locations available in events smaller than the PMF. In the PMF event, central Greta could utilise St Catherines Church, and southern Greta, which is isolated, could use Tilly's Child Care Centre. An area in north Greta along with the suburbs of Dalwood and Leconfield are isolated in the PMF and do not have suitable evacuation centre locations. The Greta Medical Centre (a small private facility) begins to be affected by flooding in the PMF event and would most likely not be accessible for vehicles. The medical centre would be able to service the areas of Greta in events smaller than this. Access to major regional hospitals would probably be limited in extreme events.

## 10.8. Advice on land-use planning considering flooding

It is considered good practice to permit land use and development that is compatible with the nature of flooding in a particular area. For example, it is wise to limit use and development of land that is classified as floodway, since these are areas of conveyance and not only pose significant risks to humans, but any development in these areas can shift flood risks to other areas.

Land use planning should consider the flood hazard (Figure D23 to Figure D26), flood function (Figure D27 to Figure D30) and evacuation potential (Figure D31 to Figure D34) of the land. Guideline 7-5 of the Australian Disaster Resilience Handbook Collection (Reference 20) recommends using flood planning constraint categories (FPCCs) to better inform land-use planning activities. An outline of these categories is provided below:

- FPCC1: Flow conveyance (floodway) and storage areas in the defined flood event (DFE - typically the 1% AEP) and H6 hazard areas in the DFE. The majority of developments and uses have adverse impacts on flood behaviour. Consider limiting uses and development to those compatible with the flood behaviour.
- FPCC2: Flow conveyance (floodway) areas in events larger than the DFE, H5 hazard category in the DFE, H6 in floods larger than the DFE and areas that are isolated by floodwaters. Consider compatibility of developments and users with rare flood flows in the area. Many uses and developments will be vulnerable to flood hazard. Consider limiting new uses to those compatible with the flood hazard. Consider treatments to reduce the flood hazard which will not adversely affect flood behaviour. Consider evacuation difficulties.
- FPCC3: Outside FPCC2, generally below the DFE and the freeboard. Hazardous conditions may exist creating issues for vehicles, people and buildings. Standard land-use and development controls aimed at reducing damage and exposure of the development to flooding in the DFE are likely to be suitable. Consider the need for additional conditions for emergency response facilities, key community infrastructure and vulnerable users.
- FPCC4: Outside FPCC3, but within the PMF extent. Consider the need for conditions for emergency response facilities, key community infrastructure and land uses with vulnerable users.

There are no known planned major subdivision development or redevelopment areas within the study area. Any changes in land use or new developments should be compatible with the nature of flooding in the area. The information contained in the flood study regarding the flood hazard, flood function and evacuation potential should be used in land use planning activities to ensure that proposed land uses do not increase the flood risk to people.

# 11. SENSITIVITY ANALYSIS

A sensitivity analysis was conducted using historical events or the 1% AEP flood event by varying model parameters and observing the relative impact on peak flows or peak flood levels. The results are presented in the following sections.

## 11.1. Climate Change

The sensitivity of the simulated peak flood levels to climate change was investigated. Climate change is expected to have adverse impacts upon sea levels and rainfall intensities. Sensitivity analysis of sea level rise was not undertaken for this study as the tidal limit of the Hunter River does not extend up to the study area. Sensitivity analysis was undertaken by increasing the rainfall by 10%, 20% and 30% for the 1% AEP Event. The same downstream boundary conditions were applied to all events. That is, climate change in the Hunter River was not included as part of this sensitivity testing.

Table 28 shows the change in peak flows at the main subcatchment outlets for each of the rainfall increase scenarios.

Table 28: Sensitivity of peak flow to rainfall increases

| Sub-catchment | Location | 1% AEP | 1% AEP (10% increase in rainfall) | | 1% AEP (20% increase in rainfall) | | 1% AEP (30% increase in rainfall) | |
|---|---|---|---|---|---|---|---|---|
| | | Peak Flow ($m^3/s$) | Peak Flow ($m^3/s$) | Change (%) | Peak Flow ($m^3/s$) | Change (%) | Peak Flow ($m^3/s$) | Change (%) |
| **G137** | Anvil Creek | 206 | 236 | 15% | 265 | 29% | 296 | 44% |
| **G136** | Hillview Road, East-Branxton | 19 | 22 | 16% | 24 | 26% | 26 | 37% |
| **G105** | Red House Creek, East-Branxton | 27 | 30 | 11% | 34 | 26% | 37 | 37% |
| **G043** | Southern flow path, Greta | 10 | 11 | 10% | 12 | 20% | 14 | 40% |
| **G053** | Central flow path, Greta | 8 | 9 | 13% | 10 | 25% | 11 | 38% |
| **G063** | West St flow path, Greta | 10 | 11 | 10% | 12 | 20% | 13 | 30% |

A comparison of flood levels is provided from Figure F1 to Figure F3, with results also shown in Table F1 for the reporting locations for the study (see Figure 22)

Across the catchment, the increase in flood levels are generally;

- 10% Rainfall increase: up to 0.15 m
- 20% Rainfall increase: up to 0.3 m
- 30% Rainfall increase: up to 0.6 m

For each of the sensitivity runs, there were localised areas where flood levels increased more than the above ranges. This is typically in locations where flood storage and volume is a driver of the flood level (such as upstream of road crossings and lakes). There are also newly flooded areas that were previously not flood affected. This includes flow paths in Greta (Central and Southern flow path) and East-Branxton (Red House creek) in areas of shallow flow as well as the fringe along Anvil Creek.

## 11.2. Rainfall Losses

An assessment of rainfall losses was undertaken during the calibration process. The initial loss is highly dependent on the antecedent catchment conditions. The initial loss values adopted during the calibration process are tied to the historic storm. Initial loss values between 10 mm and 30 mm were tested for each of the calibration events, and were adopted based upon calibration to flood marks. A constant continuing loss value of 2 mm/hr was adopted for all calibration events.

A sensitivity analysis was conducted for the April 2015 event, with varying the rainfall losses. These tests included;

- Continuing loss sensitivity (0 mm/hr versus 2 mm/hr); and
- Initial loss sensitivity (30 mm versus 10 mm).

The results indicate that if the continuing loss were set to 0 mm/hr, there would be a small increase in flood levels across the catchment, generally between 0.01 and 0.1 m. This is shown in Figure F8. If the initial losses were set to 30 mm, then there is a larger variation in peak flood levels across the catchment, up to 0.5 m within Anvil Creek, 1 m in storage areas (upstream of the Hunter Expressway), and between a 0.01 and a 0.1 m change in the flow paths through the towns. This is shown in Figure F9.

It was found that the modelled flood levels are sensitive to the assumed initial loss, whilst not as sensitive to the continuing loss.

## 11.3. Manning's 'n'

The Manning's 'n' parameter in the TUFLOW model represents the surface roughness, and the adopted values are outlined in Table 15. A sensitivity analysis was conducted with both an increase and decrease in these values by 20%. The peak flood level impacts can be seen in Figure F4 and Figure F5 with results also in Table F1 for the reporting locations for the study (see Figure 22).

Across the catchment, the increase in flood level with the increase in Manning's 'n' of 20% is approximately 0.01 to 0.25 m. There is also an increase in flood extent along the flood fringe in Anvil Creek and Central flow path in Greta. With a decrease in Manning's 'n', the flood, the difference in flood levels reduces by the same amount, around 0.01 to 0.25 m. There is also a large reduction in flood extent along the Central flow path in Greta, where a majority of the flow no longer floods out-of-bank (i.e. floodwaters remain within the concrete lined channel). Flood levels are also seen to reduce in flood storage areas, such as upstream of the Hunter Expressway, and the dam at the outlet of the Central flow path in Greta.

## 11.4. Blockage of Structures

A sensitivity analysis was undertaken for the blockage of structures in the TUFLOW model. The base design results include an assumption of blockage as specified in Section 9.6. The sensitivity assessment was undertaken for no blockage, and for a "high blockage" scenario as indicated in Table 29.

Table 29: "High Blockage" Sensitivity Bridge/Culvert Blockage Factors

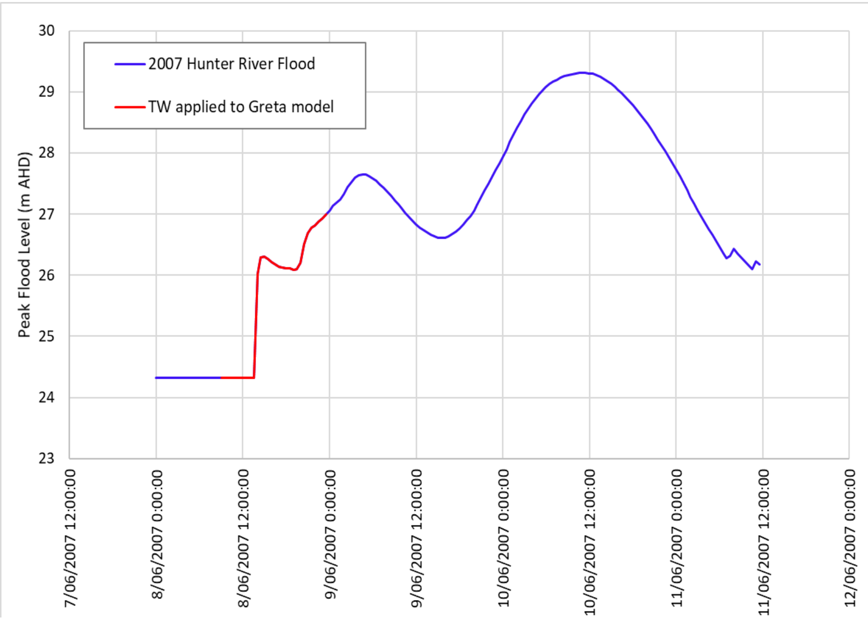
| Culvert size (largest dimension) | Selected Design Blockage |
|---|---|
| Less than 0.9 m | 90% |
| 0.9 m to 1.5 m inclusive | 50% |
| Larger than 1.5 m | 20% |

The decrease in flood level is up to 0.3 m for the no blockage scenario.

The increase in flood level is generally up to 0.1 m with higher blockage, with some structures increasing between 0.25 m and 0.5 m. In the higher blockage scenario, there are minor reductions in peak flood levels immediately downstream of the affected structures.

## 11.5. Downstream Boundary Conditions

Diagram 12: Dynamic downstream boundary conditions applied to the June 2007 Event.




The assumed downstream boundary condition for the calibration events was set to the lowest ground level across the boundary (23.5 mAHD). The lower reaches of Anvil Creek is affected during Hunter River flooding, particularly during the 2007 event where flooding from the Hunter River was observed upstream of Anvil Creek, almost reaching Greta. As a sensitivity assessment, the 2007 event was run using a dynamic tailwater from the 2007 event, where the timing of the Anvil Creek catchment rainfall event was matched to the Hunter River flooding. This is shown in

Diagram 12. As seen, the rainfall event that passed over Anvil Creek catchment finished prior to the Hunter River flooding.

There were no other available historical flood modelling results from the Hunter River: Branxton to Green Rocks Flood Study (Reference 2). However, these events were allocated a flood classification using the BOM Flood Classifications for Belmore Bridge (Hunter River). The April 2015 event was found to be a moderate flood event - corresponding to a 20% AEP flood. As such, the 5-year ARI peak flood level of 28.14 mAHD (taken from Reference 2) was adopted for the downstream boundary for sensitivity testing.

The peak flood level impacts of the June 2007 and April 2015 event are shown in Figure F10 and Figure F11. Whilst there are increases in flood level as well as an increased flood extent near the downstream boundary, these are mostly contained to downstream of Maitland Street, where the hydraulic structure acts as a control structure for backflow of flood waters.

## 11.6. Catchment Lag

The catchment lag factor (termed ‘C’ in the WBNM model) can be used to accelerate or delay the runoff response to rainfall. By varying the adopted C parameter of 1.7 by ±20%, the effect on peak flow and peak flood levels was observed at several key locations across the catchment. The peak flow and percentage differences for key locations across the catchment are shown in Table 30. These locations are shown in Diagram 8.

Table 30: Sensitivity of peak flow to “C” catchment lag parameter

| Sub-catchment | Location | 1% AEP | 1% AEP (20% decrease in C) | | 1% AEP (20% increase in C ) | |
|---|---|---|---|---|---|---|
| | | Peak Flow ($m^3/s$) | Peak Flow ($m^3/s$) | Difference (%) | Peak Flow ($m^3/s$) | Difference (%) |
| **G137** | Anvil Creek | 206 | 245 | 19% | 180 | -13% |
| **G136** | Hillview Road, East-Branxton | 19 | 21 | 11% | 18 | -5% |
| **G105** | Red House Creek, East-Branxton | 27 | 30 | 11% | 24 | -11% |
| **G043** | Southern flow path, Greta | 10 | 11 | 10% | 9 | -10% |
| **G053** | Central flow path, Greta | 8 | 9 | 13% | 7 | -13% |
| **G063** | West St flow path, Greta | 10 | 11 | 10% | 9 | -10% |

Decreasing the catchment lag produces a peakier hydrograph, in turn, increasing the peak flow. There is a 10% to 19% increase in the peak flow across the catchment using a smaller lag factor. This is also reflected in the peak flood levels, where an increase of 0.01 to 0.1 m is generally observed (Figure F12). In comparison, increasing the catchment lag attenuates the hydrograph, reducing the peak flow. There is a 5% to 13% reduction at key locations across the catchment. This corresponds to 0.01 to 0.1 m decrease generally (see Figure F13).

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Appendix A **Glossary of Terms**

Appendix A

Taken from the Floodplain Development Manual (April 2005 edition)

| | |
|---|---|
| **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. For example, if a peak flood discharge of 500 $m^3/s$ has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 $m^3/s$ or larger event occurring in any one year (see 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 occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. |
| **catchment** | The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location. |
| **consent authority** | The Council, Government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application. |
| **development** | Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act).<br><br>**infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development.<br>**new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.<br>**redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services. |
| **disaster plan (DISPLAN)** | A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies. |
| **discharge** | The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second ($m^3/s$). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s). |
| **effective warning time** | The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions. |

| | |
|---|---|
| **emergency management** | A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding. |
| **flash flooding** | Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain. |
| **flood** | Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami. |
| **flood awareness** | Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures. |
| **flood education** | Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness. |
| **flood fringe areas** | The remaining area of flood prone land after floodway and flood storage areas have been defined. |
| **flood liable land** | Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area). |
| **flood mitigation standard** | The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding. |
| **floodplain** | Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land. |
| **floodplain risk management options** | The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options. |
| **floodplain risk management plan** | A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives. |
| **flood plan (local)** | A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service. |
| **flood planning area** | The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the “flood liable land” concept in the 1986 Manual. |
| **Flood Planning Levels (FPLs)** | FPL’s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the “standard flood event” in the 1986 manual. |
| **flood proofing** | A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages. |
| **flood prone land** | Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land. |
| **flood readiness** | Flood readiness is an ability to react within the effective warning time. |

| | |
|---|---|
| **flood risk** | Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below.<br><br>**existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain.<br>**future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain.<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 the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas. |
| **floodway areas** | Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels. |
| **freeboard** | Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level. |
| **habitable room** | **in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom.<br>**in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood. |
| **hazard** | A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual. |
| **hydraulics** | Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity. |
| **hydrograph** | A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood. |
| **hydrology** | Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods. |
| **local overland flooding** | Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam. |
| **local drainage** | Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary. |
| **mainstream flooding** | Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam. |
| **mathematical/computer models** | The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain. |

| | |
|---|---|
| **minor, moderate and major flooding** | Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood:<br><br>**minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.<br>**moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.<br>**major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated. |
| **modification measures** | Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual. |
| **peak discharge** | The maximum discharge occurring during a flood event. |
| **Probable Maximum Flood (PMF)** | The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study. |
| **Probable Maximum Precipitation (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. |
| **probability** | A statistical measure of the expected chance of flooding (see AEP). |
| **risk** | Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment. |
| **runoff** | The amount of rainfall which actually ends up as streamflow, also known as rainfall excess. |
| **stage** | Equivalent to "water level". Both are measured with reference to a specified datum. |
| **stage hydrograph** | A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum. |
| **survey plan** | A plan prepared by a registered surveyor. |
| **water surface profile** | A graph showing the flood stage at any given location along a watercourse at a particular time. |

# Appendix B


Image 1: CENTRAL02


Image 2: CENTRAL03


Image 3: CENTRAL04


Image 4: SOUTH04


Image 5: RHILL03


Image 6: BRIDGE2

Image 7: CENTRAL07

Image 8: SOUTH03

Image 9: WBURN01

Image 10: WBURN02

Image 11: WEST23

Image 12: WEST2

Image 13: NEHWY01

Image 14: SOUTH01

Image 15: CENTRAL01

Image 16: HVIEW2

Image 17: HVIEW01

Image 18: RHILL02

Image 19: RHILL01

Image 20: Bridge1

# ATTACHMENT A: ARR2016 DATAHUB METADATA

Attachment A

# Australian Rainfall & Runoff Data Hub - Results

## Input Data

| | |
|---|---|
| Longitude | 151.381 |
| Latitude | -32.684 |
| **Selected Regions** | |
| River Region | |
| ARF Parameters | |
| Temporal Patterns | |
| Areal Temporal Patterns | |
| Interim Climate Change Factors | |
| Baseflow Factors | |

## Region Information

| Data Category | Region |
|---|---|
| River Region | Hunter River |
| ARF Parameters | SE Coast |
| Temporal Patterns | East Coast South |

## Data

### River Region

| | |
|---|---|
| **division** | South East Coast (NSW) |
| **rivregnum** | 10 |
| **River Region** | Hunter River |

### Layer Info

| | |
|---|---|
| **Time Accessed** | 29 March 2018 03:04PM |
| **Version** | 2016_v1 |

**ARF Parameters**

**Long Duration ARF**

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

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

**Short Duration ARF**

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

**Layer Info**

| **Time Accessed** | 29 March 2018 03:04PM |
|---|---|
| **Version** | 2016_v1 |

### Storm Losses

**Note: Burst Loss = Storm Loss - Preburst**

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

| | |
|---|---|
| **Storm Initial Losses (mm)** | 18.0 |
| **Storm Continuing Losses (mm/h)** | 2.0 |

### Layer Info

| | |
|---|---|
| **Time Accessed** | 29 March 2018 03:04PM |
| **Version** | 2016_v1 |

### Temporal Patterns

| | |
|---|---|
| **code** | ECsouth |
| **Label** | East Coast South |

### Layer Info

| | |
|---|---|
| **Time Accessed** | 29 March 2018 03:04PM |
| **Version** | 2016_v2 |

### Areal Temporal Patterns

| | |
|---|---|
| **code** | ECsouth |
| **arealabel** | East Coast South |

### Layer Info

| | |
|---|---|
| **Time Accessed** | 29 March 2018 03:04PM |
| **Version** | 2016_v2 |

**BOM IFD Depths**

Click here to obtain the IFD depths for catchment centroid from the BoM website

**Layer Info**

| | |
|---|---|
| **Time Accessed** | 29 March 2018 03:04PM |
| **Version** | 2016_v2 |

## Median Preburst Depths and Ratios

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

| min (h)\AEP (%) | 50 | 20 | 10 | 5 | 2 | 1 |
|---|---|---|---|---|---|---|
| **60 (1.0)** | 0.8 (0.031) | 1.0 (0.029) | 1.2 (0.027) | 1.3 (0.026) | 1.4 (0.023) | 1.5 (0.022) |
| **90 (1.5)** | 0.7 (0.023) | 0.7 (0.018) | 0.7 (0.016) | 0.8 (0.014) | 1.2 (0.017) | 1.5 (0.019) |
| **120 (2.0)** | 0.0 (0.0) | 0.1 (0.003) | 0.2 (0.004) | 0.3 (0.004) | 1.1 (0.015) | 1.8 (0.021) |
| **180 (3.0)** | 1.4 (0.04) | 1.8 (0.036) | 2.0 (0.034) | 2.2 (0.032) | 2.0 (0.023) | 1.8 (0.019) |
| **360 (6.0)** | 1.6 (0.035) | 5.0 (0.078) | 7.3 (0.095) | 9.4 (0.104) | 9.5 (0.087) | 9.6 (0.077) |
| **720 (12.0)** | 2.8 (0.047) | 6.3 (0.076) | 8.6 (0.085) | 10.9 (0.091) | 13.2 (0.09) | 14.9 (0.088) |
| **1080 (18.0)** | 0.3 (0.004) | 6.2 (0.063) | 10.2 (0.085) | 14.0 (0.098) | 15.1 (0.086) | 15.9 (0.078) |
| **1440 (24.0)** | 0.0 (0.0) | 3.2 (0.029) | 5.3 (0.039) | 7.3 (0.045) | 9.8 (0.049) | 11.7 (0.051) |
| **2160 (36.0)** | 0.2 (0.003) | 2.1 (0.016) | 3.3 (0.021) | 4.5 (0.024) | 6.6 (0.028) | 8.1 (0.03) |
| **2880 (48.0)** | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.2 (0.001) | 0.4 (0.001) |
| **4320 (72.0)** | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) |

## Layer Info

| | |
|---|---|
| **Time Accessed** | 29 March 2018 03:04PM |
| **Version** | 2016_v2 |

### 10% Preburst Depths

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

### Layer Info

| | |
|---|---|
| **Time Accessed** | 29 March 2018 03:04PM |
| **Version** | 2016_v2 |

### 25% Preburst Depths

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

### Layer Info

| | |
|---|---|
| **Time Accessed** | 29 March 2018 03:04PM |
| **Version** | 2016_v2 |

### 75% Preburst Depths

| min (h)\AEP (%) | 50 | 20 | 10 | 5 | 2 | 1 |
|---|---|---|---|---|---|---|
| **60 (1.0)** | 15.3 (0.6) | 15.2 (0.429) | 15.1 (0.354) | 15.0 (0.3) | 16.1 (0.267) | 16.9 (0.246) |
| **90 (1.5)** | 14.8 (0.51) | 14.5 (0.362) | 14.4 (0.298) | 14.2 (0.251) | 21.6 (0.317) | 27.1 (0.351) |
| **120 (2.0)** | 9.2 (0.291) | 11.9 (0.27) | 13.6 (0.258) | 15.3 (0.247) | 19.5 (0.263) | 22.7 (0.27) |
| **180 (3.0)** | 27.0 (0.746) | 31.6 (0.631) | 34.6 (0.576) | 37.5 (0.533) | 32.2 (0.381) | 28.3 (0.294) |
| **360 (6.0)** | 25.6 (0.557) | 39.2 (0.614) | 48.2 (0.627) | 56.9 (0.63) | 66.6 (0.609) | 73.9 (0.592) |
| **720 (12.0)** | 27.7 (0.467) | 33.7 (0.403) | 37.7 (0.371) | 41.5 (0.346) | 49.8 (0.34) | 56.1 (0.332) |
| **1080 (18.0)** | 18.0 (0.259) | 29.4 (0.298) | 36.9 (0.307) | 44.2 (0.309) | 53.3 (0.304) | 60.2 (0.297) |
| **1440 (24.0)** | 5.7 (0.074) | 20.3 (0.183) | 29.9 (0.221) | 39.1 (0.242) | 50.1 (0.252) | 58.4 (0.254) |
| **2160 (36.0)** | 8.2 (0.091) | 15.3 (0.118) | 20.0 (0.126) | 24.4 (0.129) | 32.6 (0.14) | 38.8 (0.143) |
| **2880 (48.0)** | 1.5 (0.015) | 3.6 (0.026) | 5.1 (0.029) | 6.4 (0.03) | 16.4 (0.063) | 23.9 (0.08) |
| **4320 (72.0)** | 0.0 (0.0) | 2.6 (0.016) | 4.4 (0.022) | 6.0 (0.026) | 8.7 (0.03) | 10.8 (0.032) |

### Layer Info

| | |
|---|---|
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**90% Preburst Depths**

| min (h)\AEP (%) | 50 | 20 | 10 | 5 | 2 | 1 |
|---|---|---|---|---|---|---|
| **60 (1.0)** | 47.1 (1.847) | 48.2 (1.364) | 49.0 (1.152) | 49.7 (0.995) | 69.5 (1.153) | 84.4 (1.229) |
| **90 (1.5)** | 53.5 (1.841) | 54.7 (1.362) | 55.5 (1.151) | 56.3 (0.995) | 67.1 (0.987) | 75.3 (0.974) |
| **120 (2.0)** | 51.4 (1.615) | 60.0 (1.365) | 65.7 (1.246) | 71.2 (1.152) | 78.8 (1.062) | 84.5 (1.003) |
| **180 (3.0)** | 55.8 (1.539) | 75.3 (1.505) | 88.3 (1.47) | 100.7 (1.432) | 98.7 (1.167) | 97.1 (1.011) |
| **360 (6.0)** | 64.2 (1.399) | 79.7 (1.249) | 89.9 (1.171) | 99.8 (1.105) | 119.9 (1.097) | 135.0 (1.082) |
| **720 (12.0)** | 48.7 (0.821) | 72.1 (0.863) | 87.6 (0.864) | 102.4 (0.854) | 110.2 (0.751) | 116.1 (0.688) |
| **1080 (18.0)** | 39.5 (0.57) | 57.0 (0.579) | 68.6 (0.571) | 79.8 (0.558) | 102.0 (0.581) | 118.7 (0.586) |
| **1440 (24.0)** | 43.5 (0.562) | 55.0 (0.498) | 62.6 (0.463) | 69.9 (0.433) | 95.5 (0.48) | 114.7 (0.499) |
| **2160 (36.0)** | 32.9 (0.368) | 43.7 (0.339) | 50.8 (0.32) | 57.6 (0.303) | 80.1 (0.342) | 97.0 (0.359) |
| **2880 (48.0)** | 17.4 (0.177) | 29.0 (0.203) | 36.6 (0.209) | 44.0 (0.209) | 61.4 (0.237) | 74.4 (0.249) |
| **4320 (72.0)** | 4.9 (0.044) | 20.0 (0.125) | 30.0 (0.152) | 39.5 (0.167) | 35.8 (0.123) | 33.0 (0.099) |

**Layer Info**

| | |
|---|---|
| **Time Accessed** | 29 March 2018 03:04PM |
| **Version** | 2016_v2 |

### Interim Climate Change Factors

**Values are of the format temperature increase in degrees Celcius (% increase in rainfall)**

| | **RCP 4.5** | RCP6 | **RCP 8.5** |
|---|---|---|---|
| **2030** | **0.892 (4.5%)** | 0.775 (3.9%) | **0.979 (4.9%)** |
| **2040** | **1.121 (5.6%)** | 1.002 (5.0%) | **1.351 (6.8%)** |
| **2050** | **1.334 (6.7%)** | 1.28 (6.4%) | **1.765 (8.8%)** |
| **2060** | **1.522 (7.6%)** | 1.527 (7.6%) | **2.23 (11.2%)** |
| **2070** | **1.659 (8.3%)** | 1.745 (8.7%) | **2.741 (13.7%)** |
| **2080** | **1.78 (8.9%)** | 1.999 (10.0%) | **3.249 (16.2%)** |
| **2090** | **1.825 (9.1%)** | 2.271 (11.4%) | **3.727 (18.6%)** |

### Layer Info

| | |
|---|---|
| **Time Accessed** | 29 March 2018 03:04PM |
| **Version** | 2016_v1 |
| **Note** | ARR recommends the use of RCP4.5 and RCP 8.5 values |

### Baseflow Factors

| | |
|---|---|
| **downstream** | 9811 |
| **area_sqkm** | 18056.3513454 |
| **catch_no** | 9739 |
| **Volume Factor** | 0.156654 |
| **Peak Factor** | 0.034763 |

### Layer Info

| | |
|---|---|
| **Time Accessed** | 29 March 2018 03:04PM |
| **Version** | 2016_v1 |