MAITLAND CITY COUNCIL &
CESSNOCK CITY COUNCIL

WALLIS AND SWAMP FISHERY CREEK FLOOD STUDY

VOLUME 1: FINAL REPORT

FEBRUARY 2019

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Project **Wallis and Swamp Fishery Creek Flood Study**	**Project Number** **117039**
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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
ALS	Airborne Laser Scanning
ARR	Australian Rainfall and Runoff
BOM	Bureau of Meteorology
DECC	Department of Environment and Climate Change (now OEH)
DNR	Department of Natural Resources (now OEH)
DRM	Direct Rainfall Method
DTM	Digital Terrain Model
FRMS	Floodplain Risk Management Study
FRMP	Floodplain Risk Management Plan
GIS	Geographic Information System
GPS	Global Positioning System
IFD	Intensity, Frequency and Duration (Rainfall)
mAHD	meters above Australian Height Datum
OEH	Office of Environment and Heritage
PMF	Probable Maximum Flood
SRTM	Shuttle Radar Topography Mission
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software (hydraulic model)
WBNM	Watershed Bounded Network Model (hydrologic model)

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 (see Reference 1):

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.

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A number of organisations and individuals have contributed both time and valuable information to this study. The assistance of the following in providing data and/or guidance to the study is gratefully acknowledged:

- Maitland Floodplain Risk Management Committee
- Residents of the study area
- Maitland City Council
- Cessnock City Council
- Office of Environment and Heritage
- State Emergency Service

EXECUTIVE SUMMARY

The Wallis and Swamp-Fishery Creek catchment is located in the Hunter Valley, approximately 30 km west of Newcastle, with an area of some 400 square kilometres. The headwaters of the catchment extend to Heaton State Forest in the south and Aberdare State Forest in the west, and flows into the Hunter River at Maitland. The catchment lies within the Local Government Areas of Maitland City Council and Cessnock City Council.

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 Wallis Creek catchment can occur in large Hunter River flood events, the focus of this study is on flooding resulting from runoff within the Swamp-Fishery and Wallis Creek catchment. Both Wallis and Swamp-Fishery Creeks have a history of significant flooding, with notable events occurring in February 1990, 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, survey data and gauged data. Community consultation was also undertaken, where residents were asked to provide information on their experiences of flooding. Of the 191 respondents, 87% were aware of flooding issues within the catchment and 35% have properties affected by flooding. A number of flood marks were subsequently surveyed.

A WBNM hydrologic model with 108 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 16 m regular grid with a 4 m nested grid for the urban areas of Abermain, Weston and Kurri Kurri. Inflows from the WBNM model were used and a downstream boundary applied downstream of the Wallis Creek floodgates, at the Hunter River.

The models were calibrated to the June 2007, March 2013, 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. The water level gauges in the lower catchment reflect the total catchment runoff volume, so these were used to calibrate the rainfall loss parameters. Mannings ‘n’ roughness and stream routing parameters were primarily used to calibrate to flood marks in the upper catchment areas, where conveyance rather than storage is the primary flood characteristic. Multiple combinations of these parameters were investigated until the best fit to the recorded water levels 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. ARR2016 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 durations were selected based upon the two distinct flood behaviours within the catchment – the areas upstream of the Hunter Expressway which are dominated by conveyance of floodwater, and the downstream areas which are driven by the volume of floodwater in the storage areas. Peak flows were used to determine the critical pattern duration for the upstream areas and peak runoff volumes were used to determine the critical pattern duration for the downstream areas. This assessment was undertaken using the WBNM hydrologic model and the two resulting storms for each event were run in the TUFLOW model. The maximum envelope of flood results was used for each flood event 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 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 tailwater conditions.

NOTE: Flooding due to the Hunter River has not been investigated in this study. Flood behaviour due to the Hunter River has been modelled and documented in the Hunter River: Branxton to Green Rocks Flood Study (Reference 6). In the 5% AEP event and greater, there is significant discharge from the Hunter River down the Oakhampton Floodway, which passes to the west of Maitland. While flood levels in the downstream storage areas are similar for the 5% AEP Hunter River and 5% AEP Wallis and Swamp-Fishery Creek flood events, in events less frequent than this, Hunter River flooding dominates (i.e. the 1% AEP Hunter River flood produces higher peak flood levels than the 1% AEP Wallis and Swamp-Fishery Creek storm event). The results produced herein are for the Wallis and Swamp-Fishery Creek local storm events only and do not include Hunter River flooding.

1. INTRODUCTION

1.1. Background

The Wallis and Swamp-Fishery Creek catchment is located in the Hunter Valley, approximately 30 km west of Newcastle, with an area of some 400 square kilometres. The headwaters of the catchment extend to Heaton State Forest in the south and Aberdare State Forest in the west, and flows into the Hunter River at Maitland. The catchment lies within the Local Government Areas (LGA) of Maitland City Council (MCC) and Cessnock City Council (CCC). The location the catchment is shown in Figure 1.

Flooding in the lower Wallis Creek catchment can occur in large Hunter River flood events. MCC has previously undertaken flood studies in 1998 and 2010 focussing on riverine flooding from the Hunter River. CCC has previously undertaken flood studies of the upper parts of Swamp Creek. However, a comprehensive study of the local catchment flood mechanisms throughout the entire catchment has not yet been undertaken. There has been increasing development of residential in lower catchment areas over the past 15 years, for example at Gillieston Heights and Cliftleigh. It is therefore necessary to understand the potential flood affectation of these areas and to mitigate flood risks for future development in the area.

The extent of the study area is shown in Figure 2. The study covers an area of approximately 119 km^2 from 2 km upstream of William Street, Abermain on Swamp-Fishery Creek and 5.5 km upstream of John Renshaw Drive, Buchanan on Wallis Creek, extending to the Wallis Creek floodgates at the confluence with the Hunter River east of Maitland.

1.2. Objectives

The primary objective of this Flood Study is to develop a robust hydrologic and hydraulic modelling system that defines flood behaviour for a range of design flood events including the 1% annual exceedance probability (AEP) the Probable Maximum Flood (PMF).

This process involves calibration of the models to ensure they can adequately reproduce historical flood behaviour. Design flood events are simulated using the calibrated models according to the Australian Rainfall and Runoff (ARR) 2016 guidelines (Reference 2).

This information will be used to assist MCC and CCC in determining existing flood risk, peak flood levels and inundation extents within the study area. The models may subsequently be used within a Floodplain Risk Management Study and Plan (FRMS/P) to assess the effectiveness and suitability of potential flood risk mitigation measures. This report documents key components of the study, using the structure outlined below:

- Section 1: introduction to the study;
- Section 2: a description of the Study Area;
- Section 3: a summary of available historical flood-related data and analysis of rainfall and river level data;
- Section 4: outcomes of the community consultation program;
- Section 5: the modelling methodology adopted;

- Section 6: development of the hydrologic model;
- Section 7: development of the hydraulic model;
- Section 8: the calibration methodology and results;
- Section 9: design flood event modelling and results, including preparation of a range of outputs for use by planners and emergency services personnel for the management of flood risk; and
- Section 10: sensitivity analysis including climate change.

2. BACKGROUND

2.1. Study Area

The study area comprises the majority of the populated areas of the Wallis and Swamp-Fishery Creek catchment as shown in Figure 2, and the full lower floodplain. Both creeks generally run south to north, draining forested steeper sections of the catchment towards farmland that spreads across the floodplains. The majority of both creek catchments are within Cessnock LGA with the remaining portion, generally to the north, within the Maitland LGA.

Wallis Creek has its headwaters in Heaton State Forest and is fed by runoff from Brunkerville, Church, Surveyors and Buttai Creeks, which drain the north-western slopes of the Sugarloaf Range. The creek is an ephemeral stream, although the lower reach holds water permanently due to tidal influence projecting upstream of the creek's confluence with the Hunter River. The lower section of the Wallis Creek catchment widens to form a fertile floodplain on the fringe of the Hunter River.

Swamp Creek rises in the Broken Back Range and travels downstream through Aberdare State Forest, before passing through the undulating and mostly timbered area of Kearsley and Neath. Downstream of Neath, Swamp Creek passes through generally flat and open terrain along the southern-eastern portion of the Abermain township, before being joined by Deep Creek at Weston. The channel then follows a path through the centre of the urban area of Weston and the western suburbs of Kurri Kurri, before draining to Wentworth Swamp. The other major catchment tributaries, namely Bishops and Black Waterholes Creeks, also drain to Wentworth Swamp, which is the major natural water storage within the lower catchment (refer to Figure 2).

Fishery Creek is the name given to the section of Swamp Creek that continues downstream of the swamps, as the channel reforms near Gillieston Heights (refer to Figure 2). The creek follows a meandering path for a further five kilometres where it discharges to Wallis Creek at Louth Park.

2.2. Land Use

The Wallis and Swamp-Fishery Creek catchment is a significant social resource in terms of its history, population and influence on agricultural productivity. It lies within the heart of the Lower Hunter coalfields and has undergone significant changes since European settlement as a consequence of natural resource extraction, clearing for agricultural development and urban expansion. The floodplain is used for cultivation and grazing, and is flanked by the urban and commercial centres of Maitland and East Maitland along the catchment boundaries. The steep upper portion of the catchment comprises a number of smaller residential communities including Buchanan, Abermain, Kurri Kurri and Weston before it levels out through the lower section comprising the rural areas of Louth Park and Cliftleigh, used primarily for grazing and cropping.

A number of coal mines are also located within the catchment including both active open cut operations such as at Shamrock Hill, and derelict mines. There is a former aluminium smelter in the vicinity of Swamp Creek at Loxford. Uncleared land, including Cessnock State Forest, Aberdare State Forest, and Heaton State Forest, covers a large portion of the upper section of both catchments at levels above 70 mAHD.

2.3. Existing Flood Mitigation Infrastructure

A major levee system was constructed in the Lower Hunter Valley in the 1950s, 1960s and 1970s by the Department of Public Works. The levee system is primarily associated with protection from major flooding from the Hunter River and larger tributaries such as the Paterson and Williams Rivers. However there are several levees along smaller tributaries, particularly Fishery Creek and Wallis Creek in the vicinity of Louth Park and Maitland. The levee system has a considerable influence on flood behaviour, especially in smaller events.

2.4. Historical Flooding

Both Wallis and Swamp-Fishery Creeks have a history of significant flooding, with notable events occurring in February 1990, June 2007 (the “Pasha Bulker storm”), June 2011, February-March and November 2013, April 2015 and January 2016 over the entire catchment. Cessnock Road at Testers Hollow is inundated relatively frequently, resulting in significant detours between Maitland and Cessnock and restricted access to the Hunter Expressway via Cessnock Road. In larger events Cessnock Road is also inundated at Mount Dee, isolating several thousand residents in Gillieston Heights. The April 2015 event resulted in the isolation of the town for more than a week, and the death of a driver whose car was washed off Cessnock Road at Mount Dee.

This study will focus on four major recent events - June 2007, February-March 2013 (herein March 2013), April 2015 and January 2016. The June 2007 and April 2015 events in particularly were major floods that caused widespread inundation, damage and loss.

2.5. Previous Studies

2.5.1. Swamp Creek Flood Study – Public Works Department (1992)

The Swamp Creek Flood Study (Reference 3) provided estimates of peak flood levels and mean velocities along Swamp Creek from about 800 m upstream of the William Street road bridge at Abermain to Norton Road, Loxford. The study was based on a hydrologic model of the catchment upstream of Loxford and a linked hydraulic model extending as a single branch along the main channel of Swamp Creek between Abermain and Loxford.

The RAFTS rainfall-runoff flood routing software package was used to develop the hydrologic model for the catchment. The US Army Corps HEC–2 software package was used to develop a hydraulic model of the floodway between Abermain and Loxford. Peak discharges generated by the RAFTS model were used as boundary conditions for the HEC-2 hydraulic model. Design flood profiles were generated for the floodway for the design 1%, 2%, 5% and 10% AEP events, as well as for an extreme flood.

In each design event, flood levels were predicted at 53 locations along the main channel corresponding to the locations of channel cross-sections that were surveyed for the study.

This study provided predicted peak flood levels for a substantial length of Swamp Creek, although the modelling was relatively limited by current standards.

2.5.2. Deep Creek Flood Study, Lawson & Treloar (2002)

The Deep Creek Flood Study (Reference 4) included the assessment of flood characteristics along Deep Creek and South Deep Creek, tributaries of Swamp Creek that discharge to the creek approximately 1200 m and 500 m downstream of the Cessnock Road Bridge at Abermain, respectively.

The assessment involved XP-RAFTS hydrologic modelling of the local catchments and one-dimensional (1D) hydraulic modelling using MIKE-11 software.

2.5.3. Lower Hunter River Flood Study (Oakhampton to Green Rocks), Public Works Department (1996)

The Lower Hunter Valley (Oakhampton to Green Rocks) Flood Study (Reference 5), covers the Lower Hunter floodplain and its tributaries between Oakhampton and Green Rocks (downstream of Hinton). This area also included floodplains that are considered the lower reaches of Wallis Creek, upstream of its junction with the Hunter River at the Wallis Creek Floodgates.

The flood study used the MIKE-11 hydraulic modelling software package to generate design flood water surface profiles and mean velocities for a range of flood events. The primary objective of the study was to simulate flood behaviour in the Hunter River and across its floodplain for flood events generated by rainfall in the upper Hunter catchment. The lower reaches of Wallis and Fishery Creeks were included in the model to provide a definition of flood levels and velocities within the Louth Park and Dagworth Swamp areas, which act as backwater storages when floodwaters from the Hunter River overtop the levee system upstream of Maitland.

The hydraulic model extended along Wallis Creek upstream of its confluence with the Hunter River to Dagworth Bridge, and along Fishery Creek upstream of its confluence with Wallis Creek to just downstream of Wentworth Swamps.

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

WMAwater was commissioned by Maitland City Council to undertake a flood study of the Lower Hunter River between Braxton and Green Rocks (Reference 6). The study area included the lower reaches of Swamp Creek and Wallis Creek.

TUFLOW modelling software was used to undertake two-dimensional (2D) hydraulic modelling for this study, and WBNM software was used for hydrologic modelling. This study uses up-to-date modelling techniques and provides the most recent design flood information for this reach of the Hunter River, including the associated tailwater levels that affect flooding along Swamp Creek and Wallis 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 down the Oakhampton Floodway, which passes to the west of Maitland.
- Significant ponding and storage occurs in the Wentworth and Dagworth Swamp areas to the south of Maitland due to this flow down the Oakhampton Floodway, and also potentially due to overtopping of the Wallis Creek floodgates and Pitnacree levees in larger events.
- In moderate Hunter River floods such as the 20% and 10% AEP, the Hunter River water level is significantly higher than the water level in the Wentworth and Dagworth Swamp areas produced by local runoff. The Wallis Creek floodgates prevent backflow into these areas from the Hunter River, but also prevent drainage until the Hunter River levels have subsided.

2.5.5. Wallis and Swamp/Fishery Creeks Flood Study – Worley Parsons 2011

Worley Parsons was commissioned by Cessnock City Council to undertake a flood study covering the entire catchment of Wallis and Swamp-Fishery Creeks (Reference 7). RMA-2 modelling software was used to undertake hydraulic modelling for this study, while XP-RAFTS software was used for hydrologic modelling. Swamp Creek, from Abermain to Loxford, was modelled using HEC-RAS. The key outcomes were as follows:

- The Wentworth Swamp provides a significant flood storage area which has the capacity to hold a volume of nearly 11 million cubic meters, enough capacity to store flows in a design 1% AEP event. This storage provides substantial attenuation of flows carried by Swamp Creek, reducing peak flood levels downstream of the Swamp to Wallis Creek. Therefore, it is important that the Wentworth Swamp storage be retained so that flooding downstream in the Louth Park and South Maitland area is not exacerbated.
- Flooding damage at Abermain can be severe, as evidenced by the June 2007 event. Floodwater from the upper catchment is concentrated in the main channel of Swamp Creek. This reach of Swamp Creek experiences steeper flood surface gradients than further downstream, with greater potential for flood damage and risk to life.
- The lower Wallis Creek Valley can be influenced by backwater flooding from the Hunter River. The worst flooding conditions downstream of John Renshaw Drive typically occur when flooding of Wallis Creek occurs concurrently with flooding of the Hunter River. In events rarer than 5% AEP event in the Hunter River, levees around Maitland within the Lower Hunter Flood Mitigation System will be overtopped and begin to fill backwater storages. As these backwater storages fill, floodwater backs up in a southerly direction along Wallis Creek, generating higher flood levels than would occur with local runoff alone.

2.5.6. Swamp/Fishery Creek Floodplain Risk Management Study – Worley Parsons 2013

The Swamp/Fishery Creek Floodplain Risk Management Study (Reference 8) focussed on Swamp/Fishery Creek from Abermain to Loxford. This portion of the creek was previously modelled in a one-dimensional HEC-RAS model as part of the Wallis and Swamp/Fishery Creek Flood Study (Reference 7). This was updated to a two-dimensional RMA-2 model for this study, due to the availability of additional LiDAR survey data. The model was calibrated to the June 2007 event, with a good calibration achieved. The flood levels, however, were up to 1 m higher than those predicted by the HEC-RAS model. The model was used to assess the effectiveness of flood mitigation measures for Swamp Creek from Abermain to Loxford.

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 NSW Land and Property Information (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 vertical accuracy is typically ± 0.15 m for clear terrain. The accuracy within creek channels is typically much less, and the LiDAR must be supplemented with detail survey and bathymetric survey. The data extent is shown in Figure 3.

3.2. Bathymetric and Structure Survey

The bathymetry of Swamp Creek from York Street, Abermain to Hunter Expressway is available from the Swamp Creek Flood Study (Reference 3). The additional cross-sections in the south of the previous survey extent were collected by Carman Surveyors in July 2008. Details were also collected for three bridge crossings in Abermain, including culvert sizes and invert levels and adjacent channel geometry. Further survey was undertaken by Carman Surveyors in January 2010 to gather 10 additional cross-sections along Wallis Creek, upstream of John Renshaw Drive.

WMAwater also measured some key dimensions of hydraulic structures along Wallis and Swamp-Fishery Creeks and their tributaries. The details are listed in Table 1.

Table 1: Hydraulic Structures Measured by WMAwater

ID	Location	Creek	Type	No	Width / Diameter (m)	Height (m)	Thickness of Deck (m)	Height of Handrail (m)
1	Cessnock Rd, Weston	Swamp	Bridge	1			0.9	1.1
2	Near Date Ave, upstream of Swamp Ck	Swamp	Arch	3	3.6	3.6		
3	Kline St, Weston	Swamp	Bridge	1			0.5	1.0
4	Fourth St, Weston	Swamp	Bridge	1			0.7	1.0
5	Government Rd, Weston	Swamp	Bridge	1			0.7	1.0
6	Unnamed Rd, Loxford	Swamp						
7	Hydro Aluminium, Loxford	Black Waterholes	Pipe	3	1.2			
8	Downstream of Hydro Aluminium, Loxford	Black Waterholes	Pipe	3	0.8			
9[1]	Carrington St, Horseshoe Bend	Wallis						
10	Pedestrian Bridge, Weston	Wallis	Bridge	1			0.1	1.1
11	Boundary St, Kurri Kurri	Tributary of Swamp Ck	Box Culvert	3	1.2	0.6	0.3	0.7

ID	Location	Creek	Type	No	Width / Diameter (m)	Height (m)	Thickness of Deck (m)	Height of Handrail (m)
12	Aberdare St, Kurri Kurri	Tributary of Swamp Ck	Pipe	3	1.2			
13	Deakin St, Kurri Kurri	Tributary of Swamp Ck	Box Culvert	2	2.4	0.9	0.8	1.0
14	Northcote St, Kurri Kurri	Tributary of Swamp Ck	Box Culvert	3	2.2	1.5	0.7	1.3
15	Mitchell Ave, Kurri Kurri	Tributary of Swamp Ck	Bridge	2			0.4	1.2
16	Northcote St, Kurri Kurri	Tributary of Swamp Ck	Box Culvert	1	3.6	0.6	0.4	
17	Lismore St, Abermain	Tributary of Swamp Ck	Box Culvert	3	1.85	0.9	0.2	0.8
18	Northcote St, Kurri Kurri	Tributary of Swamp Ck	Box Culvert	2	0.9	0.9		
19	Alexandra St, Kurri Kurri	Tributary of Swamp Ck	Box Culvert	5	1.8	0.6	0.1	
20	Near Date Ave, Weston	Tributary of Swamp Ck	Culvert/ Pipe	2	1.6 / 0.6	0.6		
21	Near McLeod Rd, Loxford	Tributary of Swamp Ck	Pipe	3	1.2			
22	Wermol St, Kurri Kurri	Tributary of Swamp Ck	Cause way					

[1]Located on private property and inaccessible during the site visit, drawings provided by Office of Environment and Heritage (OEH).

3.3. Flood Level Survey

Flood marks for the June 2007 event were surveyed at Abermain and Weston by Carman Surveyors in November 2007. As shown in Figure 26, recorded flood marks are concentrated in the urbanised areas adjacent to Swamp Creek. Flood marks were commonly observed as debris lines on residential dwellings, trees, roadways and bridges. A summary of the flood marks is listed in Table 2.

Table 2: Flood Marks for the June 2007 Surveyed by Carman Surveyors

ID	Location	Flood Level (m AHD)	Comment
S07-01	29 Elizabeth St, Abermain	25.65	Flood level on the front wall as indicated by owner
S07-02	3 Mary St, Abermain	25.40	Flood level on the front wall as indicated by Surveyor
S07-03	1 Mary St, Abermain	25.65	Distinct debris line visible on the front and side wall
S07-04	25 Elizabeth St, Abermain	25.59	Flood level on the front wall as indicated by Surveyor
S07-05	23 Elizabeth St, Abermain	25.36	Flood level on the back wall as indicated by Surveyor
S07-06	16 - 18 William St, Abermain	25.12	Distinct debris line visible on the back wall
S07-07	12 William St, Abermain	25.20	Flood level on the front wall as indicated by Surveyor
S07-08	13 William St, Abermain	24.90	Flood level on the front wall as indicated by Surveyor
S07-09	9 Elizabeth St, Abermain	24.74	Distinct debris line visible on the side wall
S07-10	11 Elizabeth St, Abermain	24.56	Distinct debris line visible on window
S07-11	3 Elizabeth St, Abermain	24.30	Debris line indicated by Surveyor

ID	Location	Flood Level (m AHD)	Comment
S07-12	Footbridge near Elizabeth St, Abermain	23.52	Build-up of debris visible over footbridge
S07-13	169 Harle St, Abermain	22.94	Distinct debris line visible along front porch wall
S07-14	173 Harle St, Abermain	22.13	Distinct debris line visible on furniture within garage
S07-15	Kline St (South of Bridge), Weston	17.06	Debris line visible on overturned fence
S07-16	53 Swanson St, Weston	17.11	Debris lines visible on the wall
S07-17	44 Fourth St, Weston	17.13	Distinct debris line visible on front and side wall of dwelling
S07-18	42 and 43 Fourth St, Weston	17.17	Debris on the exterior and interior walls
S07-19	38 Fourth St, Weston	16.95	Debris line visible on side fence
S07-20	31 Ninth St, Weston	15.82	Distinct debris line visible on front and side wall of dwelling
S07-21	Downstream of Government Road Bridge, Weston	13.01	Estimated from level of observed scour line along embankment
S07-22	Government Road Bridge, Weston	13.32	Debris line visible along the bridge embankment
S07-23	153 Mitchell Ave, Weston	13.30	Debris line visible along the fence line
S07-24	16 - 18 William St, Abermain	24.93	Distinct debris line visible on the side wall
S07-25	43 Fourth St, Weston	17.17	Debris on the side and inside walls
S07-26	Peace Park, Cessnock Rd	18.72	Debris on the roof of gazebo
S07-27	Cessnock Rd, Chinamans Hollow Bridge	17.83	Debris under the deck
S07-28	Cessnock Rd, Chinamans Hollow Bridge	18.08	Debris south eastern side
S07-29	47 Fourth St, Weston	17.21	Debris on the front wall
S07-30	40 Fourth St, Weston	16.92	Debris line visible on the wall
S07-31	Cul-De-Sac near Brisbane St, Abermain	21.48	Debris on Slope

3.4. Road Survey

The New South Wales Roads and Maritime Services (RMS) provided Works as Executed drawings of the newly constructed Hunter Expressway, which crosses Wallis Creek, Surveyor Creek and Swamp Creek. The location and extent are shown in Figure 3.

3.5. Stream Gauges

In order to calibrate the hydraulic model, water level recorders (stream gauges) are required in a creek or river. Data suitable for calibration was available from four stream gauges located in or adjacent to the Study Area. They are listed with availability of historical records in Table 3 and their locations are shown in Figure 4. The Belmore Bridge gauge is only relevant as an indication of Hunter River flood levels, and therefore backwater interactions if levels in the Hunter River are high enough.

Table 3: Stream Gauges

Station Number	Station Name	Jun-07	Mar-13	Apr-15	Jan-16
210428	Wallis Creek Upstream	Not Available	Available	Available	Available
210457	Wallis Creek Downstream	Not Available	Available	Available	Available
210453	Louth Park	Not Available	Available	Available	Available
210458	Belmore Bridge	Available	Available	Available	Available

The stream gauge records were analysed for four significant recent events. The stage hydrographs are shown in Figure 5 to Figure 8.

3.6. Rainfall Stations

There are a number of rainfall stations in the vicinity of the Study Area. These include continuous pluviometer stations and daily read stations. Continuous pluviometer stations record rainfall in sub-daily increments (with output typically reported every 5 or 6 minutes). These records are used to create detailed rainfall hyetographs, which form a model input for historical events against which the model is calibrated. The daily read stations record total rainfall for the 24 hours to 9:00 am of the day being recorded.

Table 4 and Table 5 present a summary of the continuous pluviometer and daily rainfall gauges available for use in this study. The availability of historical records for the events of interest is also listed. “Y” indicates that data is available for the respective event. The locations of these gauges are shown in Figure 9 and Figure 10. These gauges are operated by Hunter Water Corporation (HWC) and Bureau of Meteorology (BoM).

Table 4: Continuous read rainfall stations

Station Number	Station Name	Operating Authority	Within Catchment	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	Yes	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	Yes			Y	Y
61260	Cessnock Airport AWS	BoM			Y	Y	Y
R32	Dora Creek WWTW	HWC		Y			
R12	Toronto WWTW	HWC					Y
R33	Wangi BC	HWC					Y

Table 5: Daily read rainfall stations

Station Number	Station Name	Operating Authority	Opened	Closed	Within Catchment
61014	Branxton (Dalwood Vineyard)	BoM	1863	Current	
61424	Brunkerville (Sunrise B&B)	BoM	2009	Current	Yes
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	Yes
61268	Maitland Belmore Bridge	BoM	2006	Current	
61388	Maitland Visitors Centre	BoM	1997	2016	Yes
61046	Morpeth Post Office	BoM	1884	2011	
61048	Mulbring (Stone Street)	BoM	1932	2007	Yes
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	

3.6.1. 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. Each event was analysed for the individual days and entire event totals. The results of the analysis are shown in Table 6 to Table 9.

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 19 and Figure 20. The rainfall isohyets were developed using the natural neighbour interpolation technique. Daily rainfall bar charts for a selection of gauges in each event are also shown in Figure 11 to Figure 14. The selection of gauges was based on the spatial rainfall distribution pattern, and gauges in the heaviest rainfall area and lightest rainfall area were selected to compare the daily rainfall patterns between them.

Table 6: Daily Rainfall Depths (mm) for the June 2007 Event

Station No.	Station Name	6/06/2007 From 9am	7/06/2007 From 9am	8/06/2007 From 9am	9/06/2007 From 9am	Total 4 Days
61014	Branxton (Dalwood Vineyard)	13.4	115	193.4	5.8	327.6
61424	Brunkerville (Sunrise B&B)					
61242	Cessnock (Nulkaba)	9.2	53.8	189.8	12	264.8
61260	Cessnock Airport AWS	10.4	56.6	178.4	11.4	256.8
61393	Edgeworth WWTP	21.2	54.6	0	254.8	330.6
61414	Kurri Kurri Golf Club	0	63.5	203	18	284.5
61268	Maitland Belmore Bridge	21.5	95.5	161	8.5	286.5
61388	Maitland Visitors Centre	22.8	85	175	5	287.8
61046	Morpeth Post Office	32	100	165.8	10.4	308.2
61048	Mulbring (Stone Street)	14	66	280	16.2	376.2
61295	Nulkaba (O'Connors Rd)	0	61	186	13	260
61250	Paterson (Tocal AWS)	12.2	112	200.2	5.8	330.2
61329	Pokolbin (Jacksons Hill)	5.2	37	204.2	12.8	259.2
61238	Pokolbin (Somerset)	9.8	47.8	202.8	12.6	273
61405	Woodville (Clarence Town Rd)	13.4	119.2	200.8	7.6	341
61152	Congewai (Greenock)	17	60	200	40	317
61322	Toronto WWTP	23	35	251.2	30	339.2

Table 7: Daily Rainfall Depths (mm) for the March 2013 Event

Station No.	Station Name	20/02/2013 From 9 am	21/02/2013 From 9 am	22/02/2013 From 9 am	23/02/2013 From 9 am	24/02/2013 From 9 am	28/02/2013 From 9 am	1/03/2013 From 9 am	2/03/2013 From 9 am	3/03/2013 From 9 am	Total 12 Days
61014	Branxton (Dalwood Vineyard)	1.6	1.4	46	88.8	0	53	45.6	15	0.2	253
61424	Brunkerville (Sunrise B&B)	8	3.8	64.4	0	61.4	66.2	74.2	34.4	1	314
61242	Cessnock (Nulkaba)										
61260	Cessnock Airport AWS	10	3.8	21	38.2	0	44.2	51.4	17.6	0	186.2
61393	Edgeworth WWTP	3.2	5.2	0	0	86	63.8	0	0	120.2	280.8
61414	Kurri Kurri Golf Club	3.2	8.6	0	0	77.6	0	0	0	90	179.4
61268	Maitland Belmore Bridge	0	1	39	27	0	42.5	36.5	10.5	0	156.5
61388	Maitland Visitors Centre	1.4	2.4	32	29.4	0.1	32	33.6	11	0.1	142
61046	Morpeth Post Office										
61048	Mulbring (Stone Street)										
61295	Nulkaba (O'Connors Rd)	15	0	29	46.6	0	43	52.4	20	0	206
61250	Paterson (Tocal AWS)	4	3	40	89.6	0.9	50.9	56.8	16.2	2	265.6
61329	Pokolbin (Jacksons Hill)	7.4	2	34	47.2	0.4	30	47	24.6	0	192.6
61238	Pokolbin (Somerset)	0	2	24.2	35.6	0	38.8	39.2	19.2	0	159
61405	Woodville (Clarence Town Rd)	5.2	2	38.4	27.2	0.2	46.4	51	11	1.6	183
61152	Congewai (Greenock)	6	0	50	0	0	50	44	10	0	160
61322	Toronto WWTP	16.5	0	0	0	77	72	0	0	96	264.1

Table 8: Daily Rainfall Depths (mm) for the April 2015 Event

Station Number	Station Name	20/04/2015 From 9 am	21/04/2015 From 9 am	22/04/2015 From 9 am	Total 3 Days
61014	Branxton (Dalwood Vineyard)	160	199.4	13.2	372.6
61424	Brunkerville (Sunrise B&B)	167	187	29.6	383.6
61242	Cessnock (Nulkaba)				
61260	Cessnock Airport AWS	84.6	126.6	19.2	230.4
61393	Edgeworth WWTP	156	153	35	344
61414	Kurri Kurri Golf Club	0	246	24	270
61268	Maitland Belmore Bridge	128.5	307.5	14	450
61388	Maitland Visitors Centre	0	0	277.3	277.3
61046	Morpeth Post Office				
61048	Mulbring (Stone Street)				
61295	Nulkaba (O'Connors Rd)	92	138	17	247
61250	Paterson (Tocal AWS)	242.6	176	21	439.6
61329	Pokolbin (Jacksons Hill)	64.8	147.8	16	228.6
61238	Pokolbin (Somerset)	66.2	150.4	12.8	229.4
61405	Woodville (Clarence Town Rd)	234.2	275.4	25.2	534.8
61152	Congewai (Greenock)	0	260	11	271
61322	Toronto WWTP				
61133	Bolton Point (The Ridge Way)	135	123	40	298

Table 9: Daily Rainfall Depths (mm) for the January 2016 Event

Station Number	Station Name	3/01/2016 From 9 am	4/01/2016 From 9 am	5/01/2016 From 9 am	6/01/2016 From 9am	Total 4 Days
61014	Branxton (Dalwood Vineyard)	15.2	64	160	11.4	239.2
61424	Brunkerville (Sunrise B&B)	23.6	56.8	143.6	25.8	224
61242	Cessnock (Nulkaba)					
61260	Cessnock Airport AWS	22.4	35.2	99.4	16.2	157
61393	Edgeworth WWTP	44	25	208	33	277
61414	Kurri Kurri Golf Club	26	25.6	143.2	21	194.8
61268	Maitland Belmore Bridge	13	33	165	31.5	211
61388	Maitland Visitors Centre	13.8	37.8	167.8	30.6	219.4
61046	Morpeth Post Office					
61048	Mulbring (Stone Street)					
61295	Nulkaba (O'Connors Rd)	22	37	100	20	159
61250	Paterson (Tocal AWS)	18	69	178.6	36	265.6
61329	Pokolbin (Jacksons Hill)	25.4	34.6	95	39.4	155
61238	Pokolbin (Somerset)	21.8	37	94.4	21.4	153.2
61405	Woodville (Clarence Town Rd)	17.4	69	229.6	11.4	316
61152	Congewai (Greenock)	30	58	74	18	180
61322	Toronto WWTP	36	33	0	166	235

3.6.2. 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 events are shown in Figure 15 to Figure 18.

3.7. Design Rainfall

The design rainfall intensity frequency duration (IFD) data for the centroid of the Study Area are shown in Table 10. The comparisons of rainfall IFD between historical rainfall events to design events are shown in Figure 21 to Figure 24.

Table 10: IFD (mm/hr) table for the centroid of the Study Area

Storm Duration	1EY	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
1 hour	24.1	27.5	38.9	47.2	55.8	67.9	77.7
2 hour	15.1	17.3	24.4	29.6	35	42.5	48.6
3 hour	11.5	13.1	18.7	22.7	26.8	32.6	37.3
6 hour	7.3	8.38	12	14.6	17.4	21.3	24.5
12 hour	4.74	5.45	7.88	9.71	11.6	14.4	16.7
24 hour	3.09	3.56	5.21	6.48	7.84	9.73	11.3
48 hour	1.97	2.27	3.35	4.19	5.11	6.31	7.31
72 hour	1.47	1.7	2.51	3.14	3.83	4.7	5.41

4. COMMUNITY CONSULTATION

4.1. Information Brochure and Survey

In collaboration with Cessnock City Council (CCC) and Maitland City Council (MCC) an information brochure with survey was distributed to residents in the Study Area. The function of this was to describe the role of the Flood Study in the flood plain risk management process and to request records of historical flooding. In total, 191 responses were received from the questionnaire. From the survey:

- 87% of respondents were aware of flooding issues in the catchment.
- A total of 66 respondents' properties had been affected by flooding.
- Of those, 16 properties had been flooded above floor level.

A selection of submitted photos is shown below.

Photo 1 – Fourth Street, Weston 2015

Photo 2 – Woodbury Lane, Abermain 2015

Photo 3 – Deakin Street, Kurri Kurri 2015

Photo 4 – Charles Street, Abermain 2015

Photo 5 – Northcote Street, Kurri Kurri 2015

Photo 6 – Simpsons Lane, Telarah 2015

The responses are summarised in graphs in Figure 25 and the flood marks are shown in Figure 26. The following issues were raised by the respondents:

- Residents on the Wallis and Fishery Creek described the April 2015 super storm as the biggest they have witnessed;
- The 2007 Pasha Bulker Storm, also affected many residents however not as severely;
- The majority of landowners were acutely aware of flooding risks and are generally prepared for flood events and the potential for isolation until the floodwaters recede. Even with this knowledge and preparedness some residents were caught off guard by the rapidly rising floodwaters of the April 2015 event which prevented them from buying additional supplies or implementing their flood plans in time;
- Many residents believed that both the Testers Hollow bridge upgrade and raising the road at Testers Hollow (Cessnock Road) will be highly beneficial for the community, as it will improve access for residents during flooding;
- Some residents were concerned with maintenance of the creek as well as the flood gates, believing that cleaning out the creek from debris and rubbish may help the water to drain quicker during floods. Residents have suggested a regular maintenance program;
- Some residents are 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 a result of the residential developments in surrounding areas such as Gillieston Heights. They are concerned that this will be dangerous to new residents and stretch the resources of community and emergency services during flood events;
- Some residents feel that creating a further access road to Maitland will prevent the isolation of many.

4.2. Public Exhibition

The Wallis and Swamp Fishery Creek Draft Flood Study was placed on public exhibition for comment by both Maitland City Council and Cessnock City Council. The dates of public exhibition were as follows:

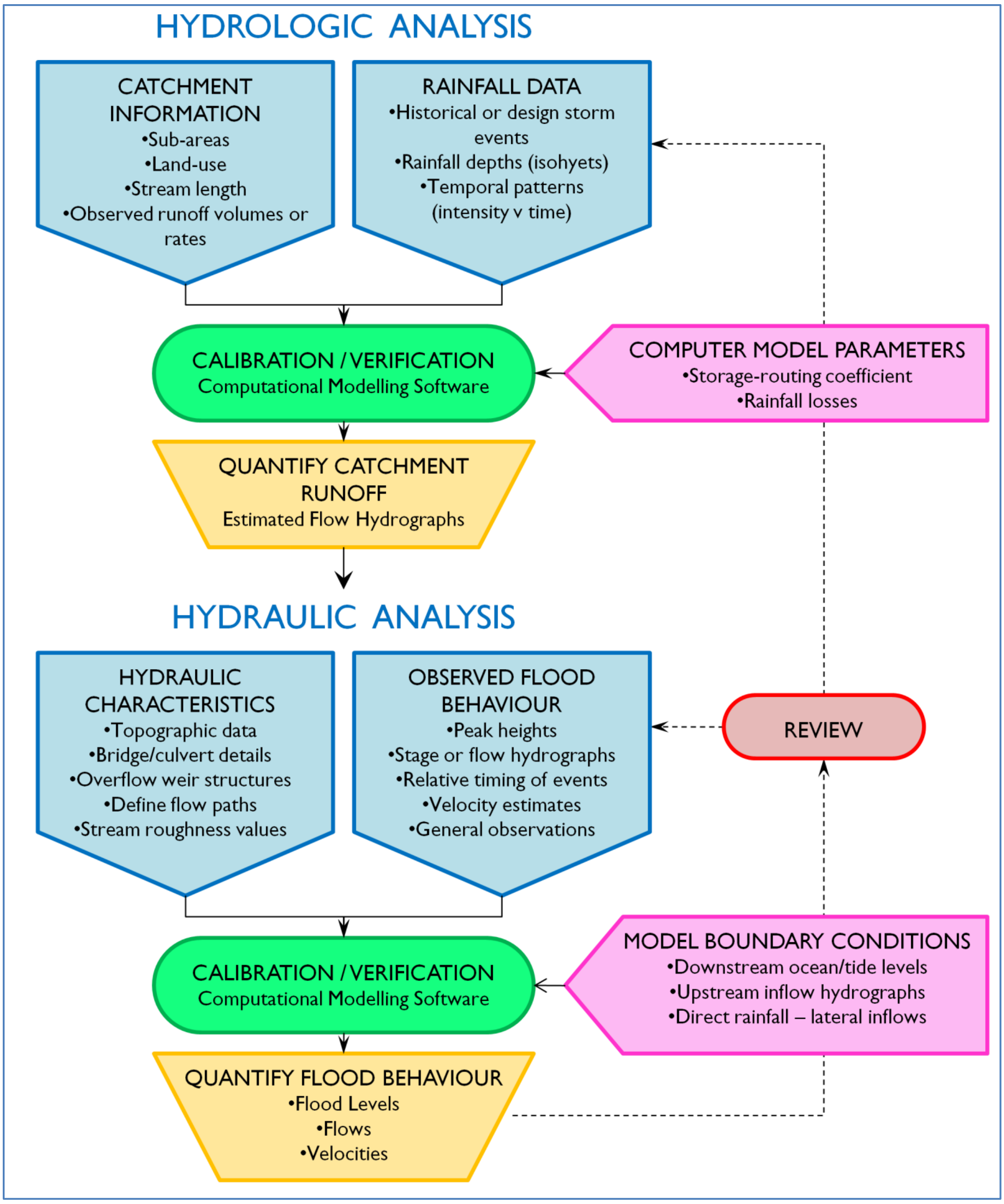
- Maitland City Council: 22 October 2018 – 20 November 2018 (4 weeks)
- Cessnock City Council: 3 December 2018 – 25 January 2019 (8 weeks)

During the public exhibition period there were no submissions received by either Maitland City Council or Cessnock City Council.

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 1: 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 used to provide these inflows. A range of runoff routing hydrologic models is available as described in ARR2016 (Reference 2). 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 runoff 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 Wallis and Swamp-Fishery Creek catchment was created and used to calculate the flows for each individual subcatchment and tributary creek for inclusion in the TUFLOW model.

6.2. Sub-catchment delineation

The total catchment represented by the WBNM model is 400 km^2, split into two principal zones: the section of the catchment upstream of the hydraulic model boundary, and the section within the hydraulic model. Each section was then split into subcatchments, with 25 subcatchments in the upstream section and 83 in the downstream section, resulting in a total of 108 subcatchments. The subcatchment delineation is shown in Figure 27. The subcatchment boundaries were derived using LiDAR topographic data and the location of bridge crossings.

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).

WMAwater analysed the proportion of pervious surfaces in each subcatchment using aerial imagery and estimated the effective impervious surface areas. Each subcatchment was assigned one of four categories. The details of each category and the total area covered by each subcatchment type is provided in Table 11.

Table 11: Assumed percentage of effective impervious area in each subcatchment type

Type	Percent Impervious	Total Area (km²)
1	5	340
2	15	15
3	30	36
4	50	9

The most widespread category was Type 1, with only 5% effective impervious area. This essentially corresponds to the waterways and riparian zone, as there are negligible infiltration losses from these areas during flood events.

6.4. Rainfall Losses

Methods for modelling the proportion of rainfall that is “lost” to infiltration are outlined in ARR2016 (Reference 2). 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 WBNM 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 1.6 for the 'C' lag parameter was found to be appropriate. The percentage of the impervious area in the whole catchment is roughly 8.5%. A value of 0.8 was used for the stream flow routing factor in order to speed up in-channel flows, relative to a typical value of 1.0 for natural channels. This was found to be required to correctly produce the rate of rise and time to peak of the historical flood hydrographs, and is considered reasonable due to the relatively steep gradient of the river and tributaries, and the incised nature of the channel. The areal reduction factor will be discussed in the design process. This stream flow routing factor was determined through the calibration process and is discussed in Section 8.

Table 12: WBNM model parameters

Parameter	Value
C (Catchment Routing)	1.6
Impervious Catchment Area	8.5%
Stream Routing Factor	0.8
Impervious Area Lag Factor	0.1
Initial loss	Varies (see Section 8.3)
Continuing loss	5 mm/hr

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 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 2016-03-AD-w64, and further details regarding TUFLOW software can be found in the User Manual (Reference 9).

In TUFLOW the ground topography is represented as a uniform grid with a ground elevation and Manning's '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 TUFLOW hydraulic model commences 5.5 kilometres upstream of John Renshaw Drive, Buchanan on Wallis Creek and 2 kilometres upstream of William Street, Abermain on Swamp Fisher Creek. The model covers the catchment downstream of these locations, extending to the north of Wallis Creek floodgates at its confluence with the Hunter River, enabling interactions with the Hunter River to be assessed. The hydraulic model covers an area of 119 km^2 and the extent is shown in Figure 28.

The Wallis and Swamp-Fishery catchment is largely rural and development is concentrated around the Swamp Creek and the towns namely Abermain, Weston, Kurri Kurri, and Loxford.

Typically, developed areas require a grid resolution of no more than 4 metres to capture the various flow mechanisms characteristic of a built-up environment. However, such a grid resolution over the 119 km^2 covered by the Wallis Creek and Swamp-Fishery Creek catchment would result in excessive model runtimes. Splitting the two catchments into separate models would reduce run-times, but was not deemed to be feasible due to a lack of suitable locations for separating the two models. Therefore, a nested approach to the hydraulic modelling was adopted, whereby the urbanised areas of the upper catchment was modelled with a finer grid resolution than the downstream storage areas. The model adopts a 16 m x 16 m grid resolution, which is refined to a resolution of 4 m x 4 m for the nested grid where development is concentrated. These two extents are shown in Figure 28.

7.3. Boundary Locations

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 upstream of the model extent are applied at the upstream boundary of the model. The locations of these inflows can be seen in Figure 28.

7.3.2. Downstream Boundary

Dynamic tailwater levels were applied as the downstream boundary condition for the Hunter River, downstream of Wallis Creek floodgates, where there is a stream gauge. The stage hydrographs of historical events at that gauge were adopted as the downstream tailwater levels.

7.4. Mannings ‘n’ Roughness

Surface roughness, represented by the Manning’s ‘n’ coefficient, is an influential parameter in hydraulic modelling. As part of the calibration process, roughness values are adjusted within acceptable ranges defined in the literature so that the model better matches observed peak flood levels at a variety of locations. Chow (Reference 10) provides the definitive reference work regarding roughness values for hydraulic calculations.

The Manning’s ‘n’ values are also discussed in Project 15 of ARR2016: Two Dimensional Modelling in Urban and Rural Floodplains (Reference 11). The values adopted for this study were based on consideration of the above references and the model calibration process. The Manning’s ‘n’ values adopted for this flood study are shown in Table 13.

Table 13: Adopted Mannings *n* values – TUFLOW model

Surface	Mannings n
General	0.04
Light Vegetation	0.04
Thick Vegetation	0.08
Waterways (Light Vegetation)	0.04
Waterways (Medium Vegetation)	0.06
Waterways (Heavy Vegetation)	0.08
Lots	0.05
Paved	0.02
Railway	0.04
Wetland	0.05

7.5. Creeks

The creek channels are defined in the 2D grid domain. The digital elevation model (DEM) was modified to provide a continuous flow path with the gradient determined from available topographic data. Available LiDAR data provided elevation of the creek channels above the water level on the day of the survey. Creek channel topographic data was supplemented where possible with segments of bathymetric survey available from previous studies.

7.6. Levees, Roads and Railway

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

7.7. Hydraulic Structures

7.7.1. Bridges

Photo 7 – Cessnock Road Bridge

Photo 8 – Railway Bridge

The bridges traversing Wallis Creek, Swamp-Fishery Creek and the Hunter River are shown in Figure 28. The bridges were modelled in the 2D domain for the purpose of maintaining continuity in the model. The modelling parameter values for the bridges were based on the geometric properties of the structure, which were obtained from measurements and photographs taken during site inspections and previous experience modelling similar structures. Examples of bridges included in the model are shown in Photo 7 and Photo 8.

7.7.2. Culverts

The road culverts were modelled as 1D structures. The modelling parameter values for the culverts were based on the geometric 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 9.

Photo 9 – Road Culverts underneath Northcote St, Kurri Kurri

7.7.3. Buildings

Buildings within floodplain were removed from the computational grid ("blocked out"). As such, it was assumed that all the buildings would be solid obstructions to floodwaters and not provide any flood storage during an event. This is in line with guidance from Reference 11, which found that the flow paths through built up areas were more accurately resolved by using the "block out" method, than by alternative mechanisms where flow through the buildings is assumed.

8. 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;
- March 2013;
- April 2015; and
- January 2016.

8.2. Methodology

Two automatic water level gauges within the study area were suitable for model calibration (Louth Park and Wallis Creek Flood Gates Upstream). The gauge locations are shown in Figure 4. Surveyed flood marks were also available from Reference 7 and from the community consultation process for this study.

The rainfall depths for each event across the catchment were derived from the daily read rainfall data, with the interpolated isohyets shown in Figure 19 and Figure 20. 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 Belmore Bridge, Abermain Bowling Club, Cessnock Bowling Club or a combination of these. Where a combination was used, different patterns were applied to the corresponding parts of the catchment (for example, the Belmore Bridge pattern in the northern catchment and the Cessnock Bowling Club pattern for the southern catchment. 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 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. The stream gauges in the lower catchment reflect the total catchment runoff volume, so these were used to calibrate the rainfall loss parameters. Mannings 'n' roughness and stream routing parameters were primarily used to calibrate to flood marks in the upper catchment areas, where conveyance rather than storage is the primary flood characteristic. Multiple combinations of these parameters were investigated until the best fit to the recorded water levels in the study area could be achieved across the whole range of calibration events.

For most events, the adopted rainfall depths and temporal patterns were found to have the most influence on the calibration results. The modelled levels obtained at the gauges were more sensitive to the rainfall assumptions than 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.

Floodwaters take a relatively long time to drain from Wallis Creek into the Hunter River through the flood gates near Horseshoe Bend. This extended drainage time is mainly a function of the very large flood storage volume within the lower parts of the catchment and the relatively flat water level gradient to drive the water out through the gates. Drainage times can be exacerbated if there is coincident flooding in the Hunter River, which can restrict or prevent outflow through the flood gates. For calibration of the models in this study, it was necessary to run the models for a relatively long time after the rainfall ceased, to determine whether the model could reproduce drawdown in flood levels resulting from drainage out through the Wallis Creek flood gates.

8.3. Rainfall Losses (WBNM)

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 across 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 14.

Table 14: Calibration Event Rainfall Losses

Event	Initial Loss	Continuing Loss
June 2007	80 mm	5 mm/h
March 2013	10 mm	5 mm/h
April 2015	10 mm	5 mm/h
January 2016	20 mm	5 mm/h

8.4. Stream Routing Parameter (WBNM)

The typical stream routing value in WBNM is 1.0 for natural channels. An increase to this parameter will reduce stream velocity and a decrease will increase stream velocity. A stream routing value of 0.8 was applied to provide to best fit to historical events. This is considered reasonable due to the relatively steep and incised channels in the upper catchment, and the formalised nature of the channels through the urbanised areas such as Abermain.

8.5. Manning's 'n'

Multiple combinations of Manning's 'n' parameters were modelled in order to determine the values that provided the best fit to recorded water levels. The values modelled were consistent with ranges specified in literature (see Section 7.4). The adopted Manning's 'n' value can be seen in Table 13.

8.6. Calibration Results

8.6.1. 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 8 days. The modelled rainfall depths across the catchment are shown in Figure 19. The temporal pattern from the Cessnock BC (R4) pluviometer produced the best fit to recorded levels. A comparison between the recorded and modelled stage hydrographs at two gauges (Louth Park and Wallis Creek Upstream) is shown in Figure B1. A comparison between the surveyed and modelled flood levels is shown in Table 15.

Table 15: Peak Flood Level Comparison June 2007

ID	Location	Surveyed Flood Level (mAHD)	Modelled Flood Level (mAHD)	Difference (m)
S07-01	29 Elizabeth St, Abermain	25.65	25.32	-0.33
S07-02	3 Mary St, Abermain	25.40	25.12	-0.28
S07-03	1 Mary St, Abermain	25.65	25.11	-0.54
S07-04	25 Elizabeth St, Abermain	25.59	25.21	-0.38
S07-05	23 Elizabeth St, Abermain	25.36	25.12	-0.24
S07-06	16 - 18 William St, Abermain	25.12	25.04	-0.08
S07-07	12 William St, Abermain	25.20	24.97	-0.24
S07-08	13 William St, Abermain	24.90	24.80	-0.09
S07-09	9 Elizabeth St, Abermain	24.74	24.71	-0.03
S07-10	11 Elizabeth St, Abermain	24.56	24.71	0.15
S07-11	3 Elizabeth St, Abermain	24.30	24.59	0.29
S07-12	Footbridge near Elizabeth St, Abermain	23.52	23.72	0.20
S07-13	169 Harle St, Abermain	22.94	23.00	0.06
S07-14	173 Harle St, Abermain	22.13	22.20	0.07
S07-15	Kline St (South of Bridge), Weston	17.06	17.37	0.31
S07-16	53 Swanson St, Weston	17.11	16.95	-0.16
S07-17	44 Fourth St, Weston	17.13	16.88	-0.24
S07-18	42 and 43 Fourth St, Weston	17.17	16.87	-0.30
S07-19	38 Fourth St, Weston	16.95	16.76	-0.19
S07-20	31 Ninth St, Weston	15.82	15.66	-0.16
S07-21	Downstream of Government Road Bridge, Weston	13.01	13.40	0.39
S07-22	Government Road Bridge, Weston	13.32	14.26	0.93
S07-23	153 Mitchell Ave, Weston	13.30	13.42	0.11
S07-24	16 - 18 William St, Abermain	24.93	24.97	0.04
S07-25	43 Fourth St, Weston	17.17	16.84	-0.33
S07-26	Peace Park, Cessnock Rd	18.72	17.98	-0.73
S07-27	Cessnock Rd, Chinamans Hollow Bridge	17.83	17.96	0.13
S07-28	Cessnock Rd, Chinamans Hollow Bridge	18.08	17.99	-0.09
S07-29	47 Fourth St, Weston	17.21	16.89	-0.32
S07-30	40 Fourth St, Weston	16.92	16.88	-0.04
S07-31	Cul-De-Sac near Brisbane St, Abermain	21.48	21.48	0.00

A comparison between the observed flood depths from community consultation and modelled flood depths is show in Table 16. A map of recorded and modelled flood levels and depths is shown in Figure B5.

Table 16: Peak Flood Depth Comparison June 2007

ID	Location	Observed Flood Depth (m)	Modelled Depth (m)	Difference (m)	Comment From Community Consultation
WSC99	27 Elizabeth St, Abermain	2.06	2.08	0.02	2.06 m deep
WSC140	24 Charles St, Abermain	1.20	1.23	0.03	1 m up laundry walls and 1.2 m up shed wall
WSC53	37 Gullivers Rd, Louth Park	1.00	1.98	0.98	1 m deep around the outside of the house
WSC156	44 Fourth St, Weston	1.70	1.69	-0.01	House: 1.2 m deep inside Garage: 2.1 m deep inside Caravan parked in yard: 2.4 m deep

8.6.2. March 2013

The March 2013 flood was a result of two distinct storms in the order of 100 mm rainfall each, separated by a period of a week. There was relatively little flooding recorded in the upper areas of the catchment, but there was significant filling and flooding of the lower catchment flood storage areas. A period of 12 days was modelled for calibration purposes. The modelled rainfall depths across the catchment are shown in Figure 19. The temporal pattern from the Maitland Belmore Bridge (210458) pluviometer produced the best fit to recorded levels. A comparison between the recorded and modelled stage hydrographs at two gauges (Louth Park and Wallis Creek Upstream) is shown in Figure B2. There were no observed flood level of depth marks available for this event.

8.6.3. April 2015

The April 2015 flood was a result of extremely intense rainfall (approximately 300 mm within a period of about 3 hours), falling primarily on the morning of 21st April. There was also significant rainfall of approximately 100 mm in the preceding 24 hours. For calibration purposes the models were run for a period of 5 days. The modelled rainfall depths across the catchment are shown in Figure 20. A combination of the temporal patterns from the Cessnock Bowling Club (for southern areas) and Maitland Belmore Bridge (for northern areas) pluviometer produced the best fit to recorded levels. A comparison between the recorded and modelled stage hydrographs at two gauges (Louth Park and Wallis Creek Upstream) is shown in Figure B3. A comparison between the observed flood depths from community consultation and modelled flood depths is show in Table 17. A map of recorded and modelled flood depths is shown in Figure B6.

Table 17: Peak Flood Depth Comparison April 2015

ID	Location	Observed Flood Depth (m)	Modelled Depth (m)	Difference (m)	Comment From Community	Notes
WSC99	27 Elizabeth St, Abermain	0.90	1.74	0.84	0.9 m deep	
WSC20	58 Third St, Weston	0.10	0.14	0.04	3 m from house on lot 5	
WSC156	44 Fourth St, Weston	1.50	1.63	0.13	House:0.6m Garage:1.5m Caravan:1.8m	
WSC152	45 Fourth St, Weston	1.50	1.39	-0.11	1 m above floor level	
WSC153	34 Fourth St, Weston	0.30	0.00	-0.30	0.3 m in and around front yard	Maybe local runoff
WSC22	376 Lang St, Kurri Kurri	1.10	0.00	-1.10	0.6 m above floor level	Property outside flood extent
WSC182	145 Deakin St, Kurri Kurri	0.60	0.29	-0.31	0.6 m at back fence	
WSC190	1575 George Booth Dr, Buchanan	1.00	1.56	0.56	0.15 m through house, 1 m through shed	
WSC9	14 Cascade Cl, Louth Park	0.10	0.00	-0.10	0.09 m above garage floor level for 6 hours	Property outside flood extent
WSC127	24 Reflection Dr, Louth Park	0.15	0.00	-0.15	0.15 m deep at back of house area	Property outside flood extent
WSC53	37 Gullivers Rd, Louth Park	2.00	2.03	0.03	2 m deep around house	
WS128	40 O'Connels Rd, Louth Park	0.70	0.72	0.02	0.7m depth over whole block	
WSC107	197 Louth Park Rd, Louth Park	0.13	0.51	0.39	0.127m deep over shed floor	
WSC61	9 Mt Dee Rd, Maitland	2.50	2.24	-0.26	2-3m in bottom of paddock	
WSC158	16 Simpsons Ln, Telarah	1.20	1.56	0.36	1.2m depth	
WSC156x	Fourth St, Weston	1.00	1.10	0.10	Approx. at top of handrail on bridge (1m above GL)	
WSC150	17 Woodbury Ln, Abermain	0.20	0.00	-0.20	Water pooling on road approx. 0.2m above GL	Property outside model extent
WSC169	21 Woodbury Ln, Abermain	0.20	0.00	-0.20	Backyard underwater approx0.2m above GL	Property outside model extent
WSC117	42 Charles St, Abermain	0.10	0.29	0.19	Flooding came up to approx. 20m mapping contour in backyard	

8.6.4. 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 4 days. The modelled rainfall depths across the catchment are shown in Figure 20. The temporal pattern from the Bolwarra 1A WWPS pluviometer produced the best fit to recorded levels. A comparison between the recorded and modelled stage hydrographs at two gauges (Louth Park and Wallis Creek Upstream) is shown in Figure B4. Apart from the automatic water level recorders, there are no reliable observed flood depth marks for calibrating to this event.

8.7. Discussion of Results

The TUFLOW model was calibrated by mainly considering two areas:

- The conveyance of the system in upper urbanised areas, and particularly the portion of Swamp Creek running from Abermain to Loxford; and
- The significant flood storage volumes in the lower parts of the system around Wentworth Swamp, Mount Dee and Louth Park.

The modelled results are a relatively good match with observed flood marks for both the upstream areas and the lower flood storage areas. In the upstream conveyance areas there were flood marks available through Abermain, Weston and Kurri Kurri. There are a number of flood marks in this area from the June 2007 flood that were surveyed for the previous flood study (Reference 7) and flood depths responded from community consultation.

As can be seen on Figure B5, the modelled flood levels are generally lower than the surveyed flood levels upstream of William Street, Abermain. Reference 7 discussed the presence of a shipping container in the vicinity of the William Street bridge, which may have provided a localised obstruction to flow, and would have affected the peak flood levels upstream of William Street. The matches are generally within a range of 0.3 m from William Street, Abermain to Fourth Street, Weston. WMAwater considers this to be a reasonable match. There is one flood mark location at Peace Park near Cessnock Road which appears to be an erroneous observation, as it is 0.9m higher than nearby flood marks. The model also does not produce a close match to flood mark ID S07-22 (see Table 2) on Government Road Bridge, Weston. The modelled level of 14.26 m AHD is over 0.9 m higher than the recorded observation of 13.32 m AHD. The description of this flood mark was "*debris line visible along the bridge embankment*". The obvert of the bridge embankment is above 14.5m AHD, indicating that the surveyed flood mark does not accord with the description provided. For the other observed flood depths in the vicinity of this mark, the modelled depths are within a range of 0.1 m compared to recorded levels, which is considered a good match.

Other issues for consideration of the model calibration are as follows:

- For events with no data from the Abermain pluviometer, there is significant uncertainty about the temporal distribution of rainfall across most of the study area, since the available pluviometers at Cessnock and Belmore Bridge are at the edges or outside of the study area catchment.
- Some of surveyed flood levels may not be accurate and it is noted that the previous flood study (reference 7) had similar issues in calibrating to the flood levels upstream of William Street, Abermain.
- Sensitivity analysis indicates that the modelled flood levels are highly sensitive to the assumed rainfall depths. Even though there is a reasonable density of rainfall gauges in and around the catchment, errors in the total interpolated rainfall depth across the catchment of +/-20% could be expected.

The modelled results have a very good match to the continuous automatic water level recorders in the lower parts of the system around Wentworth Swamp, Mount Dee and Louth Park, for all of the calibration events (June 2007, March 2013, April 2015 and January 2016). The comparison between the recorded and modelled stage hydrographs at the two gauges is shown from Figure B1 to Figure B4. These levels are representative of the total runoff volume from the catchment, since the outflow rates through the Wallis Creek flood gates are relatively small. The primary model assumptions affecting the runoff volume are the total rainfall depths and the assumed losses. The model produces a good match to the observed hydrographs with reasonable values for losses that are consistent with losses adopted for other studies in the region. The modelled peak flood levels are similar to recorded levels and the model produces a good match to the rising and falling limbs. The falling limb in particular shows a very close match for the gauge at the Wallis Creek flood gates, indicating that the modelling of the flood gates accurately reflects the outflow as the flood recedes.

9. DESIGN EVENT MODELLING

9.1. Overview

There are two distinct types of flood behaviour in the study area:

- Conveyance dominated flood behaviour in upper urbanised areas, and particularly the portion of Swamp Creek running from Abermain to Loxford; and
- Storage volume dominated flood behaviour in the lower parts of the system around Wentworth Swamp, Mount Dee and Louth Park.

These two types of flood behaviour were assessed separately for the critical pattern duration analysis. ARR2016 guidelines were adopted for this study, including the use of ARR2016 IFD information and temporal patterns for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events. The PMF flows were derived using the Bureau of Meteorology's Generalised Short Duration Method (Reference 13) for durations up to 360 minutes (6 hours) and the Bureau of Meteorology's Generalised Southeast Duration Method (Reference 14) for durations greater than 360 minutes.

The flows generated by the WBNM model for the critical pattern duration for the two distinct flood behaviour types were then used as inflows in the calibrated TUFLOW model to define the flood behaviour across the catchment by taking an envelope of the two durations for each event. A discussion of the ARR2016 temporal patterns, the procedure for the selection of the critical pattern duration and adopted hydrologic model parameters are discussed in the following sections. The resulting flood behaviour simulated in the TUFLOW model is subsequently presented.

NOTE: Flooding due to the Hunter River has not been investigated in this study. Flood behaviour due to the Hunter River has been modelled and documented in the Hunter River: Branxton to Green Rocks Flood Study (Reference 6). In the 5% AEP event and greater, there is significant discharge from the Hunter River down the Oakhampton Floodway, which passes to the west of Maitland. While flood levels in the downstream storage areas are similar for the 5% AEP Hunter River and 5% AEP Wallis and Swamp-Fishery Creek flood events, in events less frequent than this, Hunter River flooding dominates (i.e. the 1% AEP Hunter River flood produces higher peak flood levels than the 1% AEP Wallis and Swamp-Fishery Creek storm event). This is demonstrated graphically in Figure 30. The results produced herein are for the Wallis and Swamp-Fishery Creek local storm events only and do not include Hunter River flooding.

9.2. ARR2016 Temporal Patterns

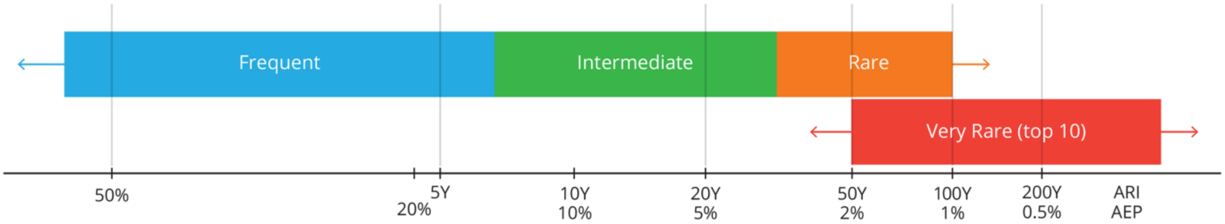
Temporal patterns are a hydrologic tool that describe how rain falls over time and are often used in hydrograph estimation. Previously, with ARR1987 guidelines (Reference 12), a single temporal pattern was adopted for each rainfall event duration. However, ARR2016 (Reference 2) discusses the potential inaccuracies with adopting a single temporal pattern and recommends an approach where an ensemble of different temporal patterns is investigated.

Temporal patterns for this study were obtained from ARR2016 (Reference 2). The revised 2016 temporal patterns attempt to address the key concerns practitioners found with the ARR1987 temporal patterns. It is widely accepted that there are a large variety of temporal patterns possible for rainfall events of similar magnitude. This variation in temporal pattern can result in significant effects on the estimated peak flow. As such, the revised temporal patterns have adopted an ensemble of ten different temporal patterns for a particular design rainfall event. Given the rainfall-runoff response can be quite catchment specific, using an ensemble of temporal patterns attempts to produce the median catchment response.

As hydrologic modelling has advanced, it is becoming increasingly important to use realistic temporal patterns. The ARR1987 temporal patterns only provided a pattern of the most intense burst within a storm, whereas the 2016 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 Wallis and Swamp-Fishery 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 2 shows the three categories of bins (frequent, intermediate and rare) and corresponding AEP groups. The “very rare” bin is in the experimental stage and was not used in this flood study. There are ten temporal patterns for each AEP/duration in ARR2016.

Diagram 2: Temporal Pattern Bins



9.3. Critical Duration

The critical duration is the temporal pattern and duration that can best represents the flood behaviour for a specific design event.

In ARR2016, the adopted temporal pattern out of the ensemble of 10, is the pattern which produces the peak values just greater than the average of the 10 peak values for the critical duration. Thus the temporal pattern adopted does not produce the largest peak values for that storm duration. The critical storm duration for a location is then the design storm duration which produces the highest average value across the full range of durations at that location of interest. The peak values can be peak flows or peak volumes and they depend on the most relevant aspect of flood behaviour. The hydrologic model (WBNM) was used to assess the peak flows or volumes at key locations, depending on whether the primary flood driver was conveyance or storage.

Three subcatchment outlet locations were chosen to assess the peak flows or peak volumes. The chosen subcatchments are shown on Figure C1. Two subcatchments (3E and 3T) are located in upper urbanised areas, where conveyance is the primary consideration. Subcatchment 3AC is the outlet of the whole catchment, where runoff from the whole Wallis and Swamp-Fishery catchment drains to, and represents the flood level in the swamp area that is primarily storage driven.

9.3.1. Conveyance-Dominated Flood Behaviour

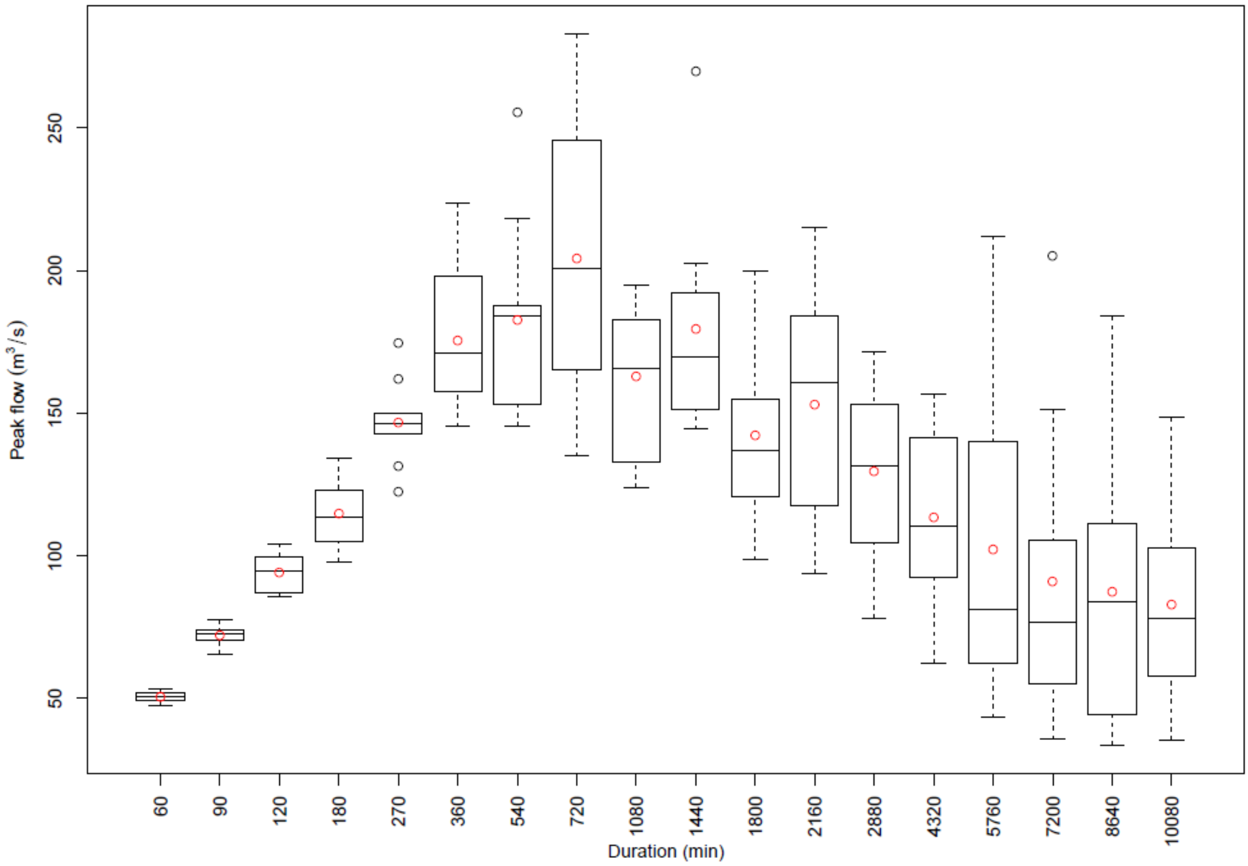
In the upper urbanised areas, particularly the portion of Swamp Creek running from Abermain to Loxford, conveyance of the creek dominates the flood behaviour. Therefore, the critical pattern duration analysis focussed on the peak flow.

Subcatchment 3E outlet is located at the William Street crossing with Swamp Creek. It is a reasonable reference location to assess the critical pattern duration for urbanised areas since:

- It includes Swamp Creek itself;
- It is upstream of urbanised areas; and
- There are historical flooding problems near William Street.

A box plot of the 1% AEP peak flows at subcatchment 3E for the various durations is shown on Diagram 3 and Figure C2.

Diagram 3: Box Plot of Peak Flows at 3E – 1% AEP



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 horizontal line within the box represents the median value. The red circle is the mean value.

It can be observed from Diagram 3 that patterns of 720 minutes produce the highest mean flow for the 1% AEP design storm event at 3E. Therefore, 720 minutes is the critical duration and the pattern that produces peak flow just above this mean flow is the critical pattern.

The same methodology was adopted to assess critical pattern durations for design storm events ranging from 50% AEP to 0.2% AEP and the results are shown in Table 18.

Table 18: Critical Pattern Durations at 3E for Various Design Storm Events

Event	Critical Duration (min)	Critical Pattern ID	Mean peak flow (m^3/s)	Peak flow of representative pattern (m^3/s)
50% AEP	1440	TP4882	25	28
20% AEP	1080	TP4855	56	62
10% AEP	540	TP4764	84	88
5% AEP	540	TP4764	113	116
2% AEP	720	TP4785	167	171
1% AEP	720	TP4785	204	206
0.5% AEP	720	TP4785	236	237
0.2% AEP	720	TP4751	289	344

Subcatchment 3T outlet is located at the Hunter Expressway crossing with Swamp Creek. The reasons for choosing this location are as follows:

- It includes Swamp Creek itself;
- It is the outlet of upstream urbanised areas;
- The Hunter Expressway was constructed in 2014 and it is a new flow constriction.

The box plot of the 1% AEP peak flows at 3T for the various durations is shown on Figure C3. The results of critical pattern durations are shown in Table 19.

Table 19: Critical Pattern Durations at 3T for Various Design Storm Events

Event	Critical Duration (min)	Critical Pattern ID	Mean peak flow (m^3/s)	Peak flow of representative pattern (m^3/s)
50% AEP	1080	TP4846	39	44
20% AEP	720	TP4809	94	94
10% AEP	720	TP4791	138	146
5% AEP	720	TP4793	186	196
2% AEP	720	TP4787	274	279
1% AEP	720	TP4787	335	339
0.5% AEP	720	TP4787	387	391
0.2% AEP	720	TP4787	476	478

The flows by the representative patterns selected from locations 3E and 3T were compared and it was found that the two locations are similar, but the patterns from 3E produced marginally higher flows overall. Consequently, the critical pattern durations at 3E were used to assess the flood behaviour for design storms upstream of Hunter Expressway.

For the PMF event, the peak flows for duration ranging from 60 minutes to 360 minutes at 3E and 3T were analysed. It was found that the 180 minute storm produced the highest flow at both locations, and hence was selected as the critical storm duration.

9.3.2. Volume-Dominated Flood Behaviour

Flood behaviour in the lower parts of the system around Wentworth Swamp, Mount Dee and Louth Park is dominated by flood storage volume. Therefore, the critical pattern duration analysis focussed on the total runoff volume.

Subcatchment 3AC is the outlet of the whole catchment, where runoff from the whole Wallis and Swamp-Fishery catchment drains to. The location of this subcatchment is shown on Figure C1. Runoff from the entire catchment drains to this outlet at the Wallis Creek floodgates. The total volume of runoff modelled to this subcatchment represents the total volume of runoff generated by the whole catchment.

The box plot of the 1% AEP peak volumes at subcatchment 3AC for the various durations is shown on Figure C4. The resulting critical duration and pattern for various AEPs are shown in Table 20.

Table 20: Critical Durations at Catchment Outlet for Various Design Storm Events

Event	Critical Duration (min)	Critical Pattern	Mean Volume (m³)	Volume or Representative Pattern (m³)
50% AEP	1440	TP4879	10,000	10,000
20% AEP	1440	TP4882	22,000	23,000
10% AEP	2160	TP4915	34,000	35,000
5% AEP	2160	TP4714	48,000	48,000
2% AEP	4320	TP4960	67,000	67,000
1% AEP	4320	TP4961	84,000	86,000
0.5% AEP	2880	TP4937	104,000	105,000
0.2% AEP	2880	TP4937	134,000	134,000

In the PMF, the peak volumes for durations from 360 minutes to 5760 minutes were assessed and the results are shown in Table 21. The duration producing highest volume is 2160 minutes, so this has been adopted as the critical PMF duration for the storage driven areas.

Table 21: Total runoff volumes from various durations for PMF Event

PMF Duration	Volume (m³)
360m	192,000
540m	219,000
720m	231,000
1440m	255,000
2160m	263,000
2880m	259,000
4320m	246,000
5760m	224,000

9.3.3. Summary of Critical Pattern Duration

The critical pattern durations vary with different flood behaviour mechanisms. Table 22 summarises the critical durations and representative storm durations selected for the different flood behaviour areas. For each AEP, the design flood results presented in this report are an envelope of the results from the storms identified below.

Table 22: Selected Critical Durations and Representative Storm Patterns

Event	Conveyance Dominated Areas		Volume Dominated Areas	
	Critical Duration (min)	Critical Pattern	Critical Duration (min)	Critical Pattern
50% AEP	1440	TP4882	1440	TP4879
20% AEP	1080	TP4855	1440	TP4882
10% AEP	540	TP4764	2160	TP4915
5% AEP	540	TP4764	2160	TP4714
2% AEP	720	TP4785	4320	TP4960
1% AEP	720	TP4785	4320	TP4961
0.5% AEP	720	TP4785	2880	TP4937
0.2% AEP	720	TP4751	2880	TP4937
PMF	180	N/A	2160	N/A

As expected, the critical durations in volume dominated areas are longer than those in conveyance dominated areas. The longer storm durations generally have a lower rainfall intensity, but larger overall rainfall volume, which is of interest in the lower catchment. In the upper catchment, the critical storms are generally shorter duration, since these are dominated by peak flows.

9.4. Rainfall Losses

Table 23: Median Pre-Burst Depths at the Centroid of the Study Area (mm)

Duration	AEP					
(min)	50%	20%	10%	5%	2%	1%
60	0.6	1.3	1.8	2.3	1.6	1.0
90	0.3	1.5	2.2	3.0	1.7	0.7
120	1.2	1.6	1.8	2.0	3.6	4.8
180	0.6	2.6	3.9	5.1	5.8	6.2
360	4.7	5.7	6.4	7.0	11.7	15.1
720	4.8	9.5	12.6	15.6	17.3	18.6
1080	1.6	7.5	11.4	15.2	16.8	17.9
1440	2.0	5.6	8.1	10.4	14.6	17.8
2160	0.5	2.3	3.4	4.5	7.0	8.8
2880	0.0	0.0	0.0	0.0	1.0	1.8
4320	0.0	0.0	0.0	0.0	0.0	0.0

The initial losses for this area from the ARR2016 data hub range from 20 mm to 37 mm, and continuous losses range from 2.7 mm/hr to 3.3 mm/hr. The ARR2016 data hub provides pre-burst depths for all storm durations and the median depths at the centroid of the study area are shown on Table 23.

The pre-burst rainfall depths are storm rainfall depths before the main burst and vary with AEP and duration. It is assumed that the hydrologic model is only simulating the main rainfall burst, and hence the true initial loss used in the model is the ARR2016 initial loss minus the pre-burst rainfall depth (negative losses are taken as zero). Therefore, all design storms modelled have a different applied burst initial loss.

Table 23 indicates that the durations up to 180 minutes and 2160 minutes and longer have a relative small pre-burst depth, thus resulting in a true initial loss that is similar to or greater than 10 mm. From 360 to 1440 minutes, the pre-burst depths increase sharply with decreasing AEPs, which means the rarer events will have greater pre-burst depths and smaller applied burst initial losses.

Pre-burst depths only play an important role in short duration events (generally less than 180 minutes) as the initial losses take a relatively larger portion of the total rainfall depths in these short storms compared to those in the long storms. For the modelled design events, the applied burst initial losses were used in conjunction with the ARR continuing loss values, which are slightly lower than the calibrated value of 5 mm/hr.

9.5. Areal Reduction Factors

Areal Reduction Factors (ARF) were applied in the WBNM model for the design storm events based on ARR2016. The design rainfall estimates are based on point rainfalls and in reality, the catchment-average rainfall depth will be less. It allows for the fact that larger catchments are less likely than smaller catchments to experience high intensity storms simultaneously over the whole catchment area. The ARF varies with AEP and duration and the resulting matrix of ARFs for the design storms are shown in Table 24.

Table 24: Areal Reduction Factors for the Design Storm Events

Duration (min)	AEP							
	50%	20%	10%	5%	2%	1%	0.5%	0.2%
60	0.73	0.71	0.70	0.68	0.67	0.65	0.64	0.62
90	0.77	0.75	0.73	0.72	0.70	0.68	0.66	0.64
120	0.80	0.77	0.75	0.74	0.71	0.69	0.67	0.65
180	0.83	0.80	0.78	0.76	0.73	0.71	0.69	0.67
270	0.85	0.83	0.81	0.80	0.78	0.76	0.74	0.72
360	0.87	0.86	0.85	0.83	0.82	0.81	0.80	0.79
540	0.89	0.88	0.88	0.87	0.86	0.86	0.85	0.84
720	0.90	0.89	0.89	0.88	0.87	0.87	0.86	0.85
1080	0.93	0.92	0.92	0.91	0.91	0.90	0.90	0.90
1440	0.95	0.95	0.95	0.94	0.94	0.94	0.94	0.94
1800	0.95	0.95	0.95	0.95	0.95	0.94	0.94	0.94
2160	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.94
2880	0.96	0.96	0.96	0.95	0.95	0.95	0.95	0.95
4320	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.95
5760	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.96
7200	0.97	0.97	0.97	0.96	0.96	0.96	0.96	0.96
8640	0.97	0.97	0.97	0.97	0.96	0.96	0.96	0.96
10080	0.97	0.97	0.97	0.97	0.97	0.97	0.96	0.96

9.6. Coincident Hunter River Flooding and Tailwater Levels

As part of the Hunter River (Branxton to Green Rocks) Flood Study (Reference 6), it was found that Hunter River Flooding is the dominant flood mechanism in the lower Wallis and Swamp-Fishery catchment for events rarer than 5% AEP. In large Hunter River floods (greater than about a 15 year Average Recurrence Interval, or ARI), floodwaters will overtop the Oakhampton spillways north of long Bridge, flow down the Oakhampton Floodway, southwards to Louth Park in the east and Loxford in the west, inundating the swamp areas in the lower floodplains of Wallis and Swamp-Fishery Creeks. In larger events, the levees around the Hunter River banks and Wallis Creek Flood Gate can also be overtopped. While the 5% AEP levels in the swamp areas are similar for both the Hunter River and local catchment flooding, in events rarer than this, the Hunter River flood levels in the study area are much higher than those generated by local catchment runoff for rainfalls with the same exceedance probability.

There is not enough information to undertake a full joint probability analysis of the Hunter River and Wallis and Swamp-Fishery Creek catchment flooding. Instead, an alternative approach has been adopted to define the local Wallis and Swamp-Fishery Creek catchment flood behaviour, separate to Hunter River flooding (defined in Reference 6). For all design flood events, a static tailwater level in the Hunter River of 4.5 mAHD has been adopted for the rising limb of the storm event. This tailwater level does not overtop the levees, but is high enough to restrict flow out of the catchment through the Wallis Flood Gates while the flood storage areas in the lower floodplain are being filled, generating peak flood levels in the lower catchment. On the receding limb of the flood event, the tailwater level in the Hunter River was assumed to reduce to a static level of 1 mAHD over a period of 3 days, to allow the water to drain out and assess the duration of inundation for these swamp areas. This assumed tailwater behaviour was based on analysis of typical Hunter River flow behaviour during large storm events over the study area, and in particular the observed Hunter River behaviour for the calibration flood events.

9.7. 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 D31;
- SES Flood Emergency Response Classifications in Figure D32; and
- Provisional Flood Planning Area in Figure D36.

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 and Figure E2; and
- Stage hydrographs at road crossings in Figure E3 to Figure E15.

A discussion of these results is provided in the following sections.

9.7.1. 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 and Figure E2). These results are presented for the range of design flood events modelled from the 50% AEP to the PMF event.

Through Abermain and Weston, flows are generally within the channel banks in the 50% AEP event. Floodwaters start to break out of the channel in the 20% AEP event, and impact the urban areas in the 10% AEP event. Up to the 1% AEP event, the most affected areas include those in the vicinity of the Cessnock Road crossing and Fourth Street crossing of Swamp Creek. In the PMF event a large number of properties are affected in Abermain and Weston. These areas, upstream of the Hunter Expressway, are dominated by conveyance of floodwaters. Upstream of the Hunter Expressway on Wallis Creek, there are very few properties and most are located on high ground and are unaffected by flooding up to and including the 1% AEP event.

As can be seen in the flood profile graphs (Figure E1 and Figure E2), approximately 3 km to 5 km downstream of the Hunter Expressway, the swamp areas are reached and a fairly constant water level is evident that persists downstream on both Swamp-Fishery Creek and Wallis Creek. The larger the event, the higher the peak flood level and the broader the area inundated by this relatively constant peak flood level. It is in this location that the flooding is dominated by storage. The flood levels in the lower catchment are primarily influenced by the volume of runoff that enter the storage areas.

The change in flood extent between the design flood events up to and including the 1% AEP local storm event is reasonably small when compared to that of the upstream areas. The storage areas on Wallis Creek and Swamp-Fishery Creek are significant and have the potential to store a large volume of water. The difference in flood depth between the 50% AEP event and 1% AEP (local storm) event is approximately 3 m. These storage areas discharge to the Hunter River via Wallis Creek, which is a relatively narrow and meandering channel that makes inundation times in the swamp areas significant. It is only in the downstream areas of Mount Dee and Louth Park that experience a significant increase in flood extent up to the 1% AEP event. In the PMF event a significant portion of the downstream areas is inundated, including Maitland, South Maitland and East Maitland.

9.7.2. Road Inundation

An analysis of road inundation was undertaken at key locations in the study area. These locations can be seen in Figure 29. Tabulated results of peak flood levels, depths and flows can be found in Appendix E. Bridge deck levels or the top of road embankments are also plotted on the peak water level profiles in Figure E1 and Figure E2. Stage hydrographs showing the depth and duration of inundation for each major crossing of Swamp-Fishery Creek and Wallis Creek is also shown in Figure E3 to Figure E15.

Many of the local roads crossing Swamp Creek in Abermain have a flood immunity up to and including the 10% AEP event. In events larger than this, roads begin to be inundated. Some of the roads on tributaries of Swamp Creek in Kurri Kurri have less than 50% AEP flood immunity. The duration of inundation for these upstream areas is generally reasonably short, being approximately 5 to 10 hours.

John Renshaw Drive crossing Wallis Creek has flood immunity for events up to and including the 0.2% AEP. The Hunter Expressway is only inundated in the PMF event, with the largest depths at the Swamp Creek crossing at Loxford (although inundation from local runoff on the road itself may cause traffic issues in more frequent events, but this flood mechanism was not considered in this study).

Main Road / Cessnock Road at Testers Hollow is inundated in events of around a 20% AEP or larger, and is subject to significant depths of flooding. The duration of inundation can be reasonably long, being between 3 and 10 days. The road is inundated in the 1% AEP event and larger at another location closer to Fishery Creek near Maitland. For other road crossings in the lower catchment area, the primary flood mechanism for inundation is Hunter River flooding via the Oakhampton floodway. The swamp areas take a long time to drain out, with durations of inundation being in the order of two weeks.

9.7.3. Duration of Inundation

In addition to looking at inundation of roads, a general assessment of the duration of inundation of the downstream flood storage areas was undertaken. The areas such as Wentworth Swamp, Mount Dee and Louth Park hold a large volume of water which is slowly discharged through the Wallis Creek channel downstream of Louth Park, though the flood gates and into the Hunter River (when the Hunter River water level is low enough to allow discharge). The duration of inundation in these areas can be quite long.

The assessment considered the upper Wallis Creek swamp areas, in the vicinity of Testers Hollow, where road closures from inundation can isolate the Gillieston Heights area. An approximate curve was fitted to the data available from the model results and is presented in Figure E16. The figure indicates the indicative time to drain to a level of 3 mAHD from various peak flood levels.

As an example, it takes approximately 30 hours to drain from the 50% AEP peak level of 3.35 mAHD to a level of 3 mAHD. In the 1% AEP event, the flood takes approximately 220 hours to drain from the peak level of 6.4 mAHD to 3 mAHD. The PMF event takes approximately 330 hours to drain to a level of 3 mAHD.

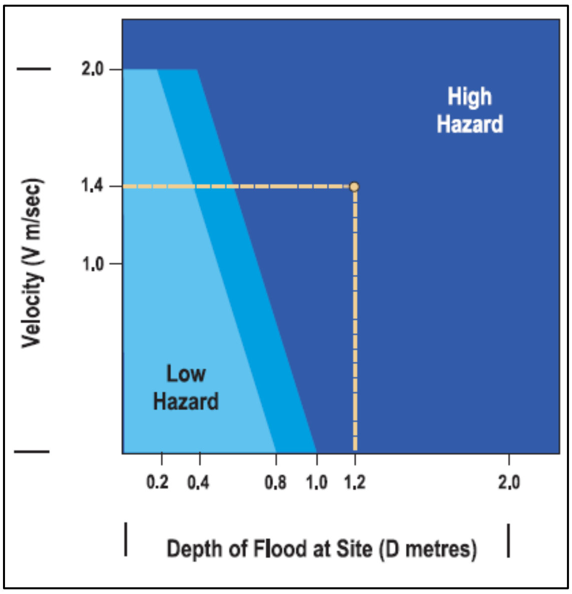
9.7.4. Provisional Flood Hazard Categorisation

Hazard classification plays an important role in informing floodplain risk management in an area. Provisional hazard categories have been determined for the Swamp-Fishery and Wallis Creek catchment by two methods – one in accordance with the NSW Floodplain Development Manual (2005), and the other in accordance with the Australian Disaster Resilience Handbook Collection (2017). Each is discussed below. Note that this mapping does not include consideration of the Hunter River Design Flood Events (Reference 6), which should also be considered for development control planning.

9.7.4.1. Floodplain Development Manual

Provisional hazard categories have been determined in accordance with Appendix L of the NSW Floodplain Development Manual (Reference 1), the relevant section of which is shown in Diagram 4. For the purposes of this report, the transition zone presented in Diagram 4 was considered to be high hazard.

Diagram 4: Provisional “L2” Hydraulic Hazard Categories (Source: Reference 1)

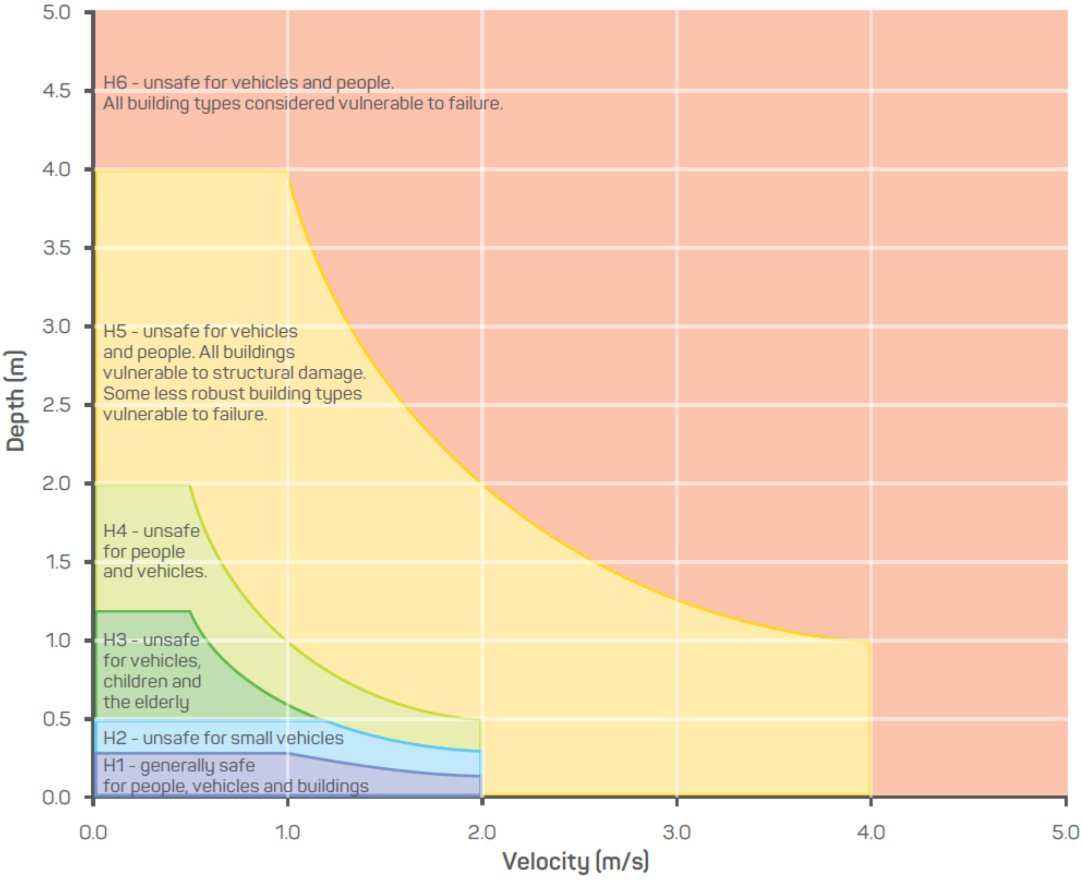


The provisional flood hazard maps utilising the Floodplain Development Manual (FDM) hazard categorisation are shown in Figure D19 to Figure D22 for the 10% AEP, 5% AEP, 1% AEP and PMF events. The FDM hazard categorisation has been included for applicability to exiting council policy documents that may refer to this hazard classification. The results indicate that the high hazard areas are primarily within the channels on the floodplain upstream of the Hunter Expressway in the 10% AEP event. The large storage areas in the downstream areas of the catchment are primarily high hazard in the 10% AEP event. There are some storage areas around Louth Park which only have a portion of the storage in the high hazard category in the 10% AEP event. A similar pattern can be seen in the 5% AEP event. In the 1% AEP event, the majority of flood conveyance and flood storage areas are high hazard, with only the fringes and areas of shallow overland flow being low hazard. In the PMF event, it is only the very fringes of the flood extent that are low hazard, with the remaining area being high hazard.

9.7.4.2. 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 15) contains information relating to the categorisation of flood hazard. A summary of this categorisation is provided in Diagram 5.

Diagram 5: General flood hazard vulnerability curves (Source: Reference 15)



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 10% AEP, 5% AEP, 1% AEP and PMF events. In the 10% and 5% AEP event, the creek channels in the upstream areas and flood storage areas in the downstream areas are classified as H5 and H6. In the 1% AEP event the H5 category extends beyond the channel and a large portion of the flood storage areas are in the H6 category. In the PMF event, a significant area of the floodplain is covered by H6, with very small proportion of the flooded area being classified as H4 or lower.

9.7.5. Provisional Hydraulic Categorisation

The 2005 NSW Government's Floodplain Development Manual (Reference 1) 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 16) rely on combinations of velocity and depth criteria to define the floodway.

For this study, hydraulic categories were defined by the following criteria, which has been 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) > 1.5 m^2/s, **AND** peak velocity > 0.5 m/s, **OR**
  - peak velocity > 1.5 m/s **AND** peak depth > 0.5 m, **OR**
  - defined channels (from bank to bank) on creeks or tributary flow paths

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 D31 for the 10% AEP, 5% AEP, 1% AEP, 0.5% AEP and PMF events. As expected, the majority of the creeks are classified as floodways, with significant flood storage areas throughout the catchment. Note that this mapping does not include consideration of the Hunter River Design Flood Events (Reference 6), which should also be considered for development control planning.

9.7.6. 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 17) 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 17), communities are classified as either; Flood Islands; Trapped Perimeter Areas; Areas Able to be Evacuated (Rising Road Access or Overland Escape Route) or Indirectly Affected Areas. The ERP classification can identify the type and scale of information required by the SES to assist in emergency response planning (refer to Table 25).

Table 25: 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 Wallis and Swamp-Fishery 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 15, see Section 9.7.4.2). The ERP classifications for the study area are shown in Figure D32 to Figure D35, for the 10% AEP, 5% AEP, 1% AEP and PMF events. These figures also show major access roads that are cut in each event.

The majority of areas affected in the 10% AEP event are around Abermain and Weston, however most have rising road access or overland escape routes. There are some areas around Farley / Bishops Bridge which have road access cut off. In the 5% AEP event, there are areas around Cliftleigh, Gillieston Heights and Louth Park that are high flood islands. In the 1% AEP there are additional areas that are high flood islands, including the entire suburb of Gillieston Heights, since Cessnock Road at Testers Hollow and Maitland are both cut off. In the PMF event there are a number of low flood island areas, particularly the areas of South Maitland and Louth Park. There is also a large area including Gillieston Heights, Cliftleigh, Heddon Greta, Kurri Kurri and Weston which are marked as a high flood island, since road access is cut off in all directions from this area, including the Hunter Expressway and New England Highway.

Note that this emergency response planning does not include consideration of the Hunter River Design Flood Events (Reference 6), which should also be considered for flood emergency response planning, and which produce the more significant flood risk for rarer events.

9.7.7. 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 planning level flood), and “stretching” this surface across the topography to form the FPA. The preliminary FPA can be found in Figure D36. The freeboard does not extent the flood surface much further than the 1% AEP event, with the FPL being similar to the 0.5% AEP level in the lower catchment, and typically between the 0.5% AEP and 0.2% AEP event levels in the upper catchment. The FPA mapping also includes the adopted FPA from Maitland City Council for the Hunter River Flooding (based on modelling undertaken for Reference 6, presented in the Maitland Local Environmental Plan 2011). For the areas downstream of the Hunter Expressway on the lower floodplain, it is the 1% AEP Hunter River Flood that dominates, hence the FPA for the Hunter River is more extensive.

9.8. Flooding Hotspots

A number of flooding ‘hotspots’ were investigated within the study area. These areas are where there is a particular risk to people or property from potential flood conditions. Each of these areas are discussed in the following sections.

9.8.1. William Street Hotspot

The William Street hotspot covers both upstream and downstream of the William Street crossing of Swamp Creek in Abermain. A flood depth map and hazard map of the hotspot for the 1% AEP event are shown in Figure D37. Flood depths of approximately 1 m to 1.5 m occur at a number of houses located adjacent to the creek. Upstream of William Street, these houses are generally located within the H4 hazard category, while downstream of William Street, the houses are typically within the H3 category. The William Street bridge is inundated by approximately 0.6 m, and isolates the population to the east of the crossing.

9.8.2. Fourth Street Hotspot

The Fourth Street hotpot is located in the vicinity of the Fourth Street crossing of Swamp Creek in Weston, between the Kline Street crossing and Fifth Street. A flood depth map and hazard map of the hotspot for the 1% AEP event are shown in Figure D38. Houses located on the western side of Swamp Creek are impacted by flooding in the 1% AEP event, with depths of approximately 1 m to 2 m. The hazard is generally within the H4 and H5 categories at the properties. In the 1% AEP event, both Kline Street and Fourth Street crossings are cut off, being inundated by approximately 0.6 m and 1.3 m respectively. This isolates the area to the north west of Swamp Creek, creating a low trapped area in the PMF event.

9.8.3. Government Road Hotspot

The Government Road hotspot occurs in the vicinity of the Government Road crossing of Swamp Creek in Weston. A flood depth map and hazard map of the hotspot for the 1% AEP event are shown in Figure D39. The 1% AEP flood event does not overtop Government Road, however sensitivity analyses presented in Section 10 show that water levels at this crossing are particularly sensitive to changes in flows and blockage of the bridge. While flooding remains fairly contained in the 0.2% AEP event (used to assess potential increases in rainfall intensity due to climate change), in the 0.5% AEP event, water breaks out of the channel and inundates a large area to the south of Swamp Creek, where a number of properties are impacted (see Figure F2). The flood level upstream of the bridge is increased by approximately 1.2 m in this scenario.

When considering a 25% blockage of the Government Road crossing, flood levels are raised approximately 0.9 m upstream of the bridge, and water breaks out of the channel and inundates Government Road and affects some nearby properties (see Figure F5) in the 1% AEP event. With a 50% blockage of the bridge, flood levels upstream of the bridge increase by approximately 1.7 m and a large area to the south of the creek is inundated, including a number of houses (see Figure F6).

9.8.4. Gillieston Heights Hotspot

Gillieston Heights, located to the west of Wallis Creek, can be isolated due to road inundation for extended periods of time. A flood depth map and hazard map of the hotspot for the 1% AEP event have been provided in Figure D40. The houses located within the suburb of Gillieston Heights are not affected by flooding in Wallis Creek up to and including the PMF event, however the entire suburb is cut off from road access to neighbouring areas in the 1% AEP event and greater. The suburb relies on Cessnock Road (also referred to as Main Road south of Testers Hollow) for access to Maitland and the New England Highway to the north, and Heddon Greta, Kurri Kurri and the Hunter Expressway to the south. Cessnock Road crosses Swamp-Fishery Creek to the north, and crosses Testers Hollow to the south. When Cessnock Road is cut off at both of these locations, the suburb is isolated (as it was in the 2015 flood event).

Cessnock Road at Testers Hollow has flood immunity up to the 20% AEP event (as demonstrated in Figure E9), while at Swamp-Fishery Creek the road has a higher flood immunity, being just overtopped in the 1% AEP event from local flooding (see Figure E13), but more frequently from Hunter River flooding. The duration of inundation can also be quite long, approximately 9 days at Testers Hollow and 6 days at Swamp-Fishery Creek for a large local catchment event (noting that the draining of the swamp depends on Hunter River levels). The

5% AEP Hunter River flood event (as larger) can also cause inundation of these roads and isolate Gillieston Heights.

9.8.5. Flood Storages Hotspot

The flood storages hot spot includes all the downstream flood storage areas including Wentworth Swamp and the flood storages on Wallis Creek, particularly around Louth Park. A flood depth map and hazard map of the hotspot for the 1% AEP event have been provided in Figure D41. These areas experience high flood depths, typically over 4 m in the 1% AEP event, and are hazardous (categories H4 and H5). Much of the land is used for agricultural purposes and does not pose a significant risk to people, however, there are a number of properties which are surrounded by deep floodwaters in the 1% AEP event around Louth Park and Mount Dee. These areas are inundated to a significant depth in the PMF event, and this extends into South Maitland. Flooding from the Hunter River can also inundate these areas to an even greater depth, and is the primary flood risk mechanism for these areas.

9.9. Comparison of Results with Previous Studies

The design flood results of this study were compared to previous studies. The comparison was completed for the 1% AEP event results, comparing with the Wallis and Swamp Fishery Creek Flood Study (Reference 7) for Wallis Creek, and with the Swamp/Fishery Creek Floodplain Risk Management Study (Reference 8) for Swamp/Fishery Creek.

A comparison of the 1% AEP flood levels along Wallis Creek is shown in Figure E17. The Wallis Creek RMA-2 model extends from approximately 5 km upstream of the Hunter Expressway, and continues to just downstream of the New England Highway. The Worley Parsons results presented in Figure E17 adopted a tailwater level of 5.0 mAHD, which corresponds to a 5 year ARI Hunter River Flood Event, assuming the Wallis Creek floodgates are open. The Flood Study Report also states that LiDAR data was only available for the Dagworth Swamp area within the Maitland City Council LGA (downstream of approximately chainage 13 km in Figure E17. Upstream of this, the terrain was based on 2 m contour data and limited surveyed cross sections. The Hunter Expressway was also not included in the model. The hydrology for the model is based on an XP-RAFTS model that utilises ARR 1987 (Reference 12).

Upstream of John Renshaw Drive, the current study 1% AEP flood level tends to be lower than the 2011 flood study, by approximately 0.5 m. At the John Renshaw Drive crossing, however, the differences are within 0.1 m. Downstream of John Renshaw Drive, the flood levels are typically within ±0.2 m to Dagworth Swamp. Water levels in the swamp are heavily influenced by the assumed downstream boundary conditions, with the current study levels being approximately 0.2 m lower than the previous study upstream of Dagworth Road. Downstream of this, the simulated flood levels are within ±0.3 m of each other.

A comparison of the 1% AEP flood levels along Swamp-Fishery Creek is shown in Figure E18. The Wallis and Swamp/Fishery Creek RMA-2 model was extended for the 2013 Floodplain Risk Management Study and covers the same extent as the current study along Swamp Creek. The topography was based upon 2012 LiDAR data, with surveyed cross sections used within the Swamp Creek channel. The Worley Parsons peak water level profile results presented in Figure E18 are for a tailwater level of 4.0 mAHD downstream of the New England Highway, representing a 10% AEP Hunter River Flood Event.

There is generally good agreement between the simulated 1% AEP flood levels of the models, with flood levels typically being within ±0.1 m. There are some larger differences which occur at the crossings. Around the William Street, Railway and Cessnock Road Crossings in Abermain, the current study has flood levels approximately 0.2 to 0.4 m lower than the 2013 study. In the vicinity of the Fourth Street crossing, flood levels are approximately 0.3 m lower. The Government Road crossing, however, presents a significant constriction in the current study, and modelled flood levels are up to 0.6 m higher. Downstream of this, flood levels are within approximately ±0.2 m of each other, and the difference in flood levels in Wentworth Swamp are less than 0.1 m.

The source of these differences can be attributed to the following:

- Different topographic data used, particularly for the upstream portion of Wallis Creek
- The introduction of the Hunter Expressway (completed in 2014). It is assumed that the Hunter Expressway is not included in the 2011 study, but it is unclear whether it is included in the 2013 study. The Hunter Expressway is included in the current study.
- Different hydraulic models used – RMA-2 versus TUFLOW.
- Different hydrologic models used – XP-RAFTS versus WBNM.
- Different IFD data used. The previous studies utilised ARR 1987 IFD data, whereas the current study utilises ARR 2016 IFD data. A comparison of the IFD data has been undertaken at the centroid of the Wallis and Swamp-Fishery Creek catchment and the results indicated that there is generally a reduction in rainfall intensity of approximately 5% for the 20% AEP event for durations longer than 1 hour. For the 5% AEP event, there are increases of between 0 and 10% in rainfall intensity, and between 5% and 16% for the 1% AEP event when looking at durations longer than 1 hour.
- Different temporal patterns used. The previous studies utilised ARR 1987 temporal patterns, which are a single representative temporal pattern for each zone and duration with 2 AEP categories. The ARR 2016 approach uses the mean temporal pattern of an ensemble of 10.
- Different storm durations were simulated. The previous studies simulated critical durations of 12 and 24 hours, while the current study uses 12 and 72 hours (for the 1% AEP event).

10. SENSITIVITY ANALYSIS

A sensitivity analysis was conducted using 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.

10.1. 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. Although the tidal limit of the Hunter River extends to Oakhampton, just upstream of the study area, the impact of sea level rise is expected to be negligible at Maitland (Reference 6). Moreover, the focus of this study is on local flooding from Wallis and Swamp-Fishery Creeks, rather than Hunter River flooding, and the tidal influence is not significant upstream of the Wallis Creek floodgates. A discussion on the adopted tailwater levels is provided in Section 10.6.

Sensitivity analysis of an increase in rainfall intensity was undertaken by comparing the 0.5% and 0.2% AEP events with the 1% AEP event. These events are commonly used as proxies to assess an increase in rainfall intensity. Within the Wallis and Swamp/Fishery Creek catchment, these events correspond to an increase in rainfall intensity of approximately 12% to 15% for the 0.5% AEP event and 32% to 36% increase for the 0.2% AEP event. The peak flood depth and level results of the 1%, 0.5% and 0.2% AEP events are shown in Figure D6, Figure D7 and Figure D8, respectively. A comparison of flood levels has been provided in Figure F1 and Figure F2, with results also shown in Table F1 for the reporting locations for the study (see Figure 29).

The 0.5% AEP event flood level is approximately 0.2 m higher than the 1% AEP level in the upper reaches of the catchment. In the lower catchment, the flood level increase is approximately 0.3 m to 0.4 m and a large area near Louth Park is now flooded. In the 0.2% AEP event, the increase in peak flood level is approximately 0.5 m to 1 m in the upper reaches for the catchment, and approximately 1 m in the flood storage areas of the lower catchment. There are large areas around Louth Park, South Maitland and Weston that are now flooded.

10.2. Rainfall Losses

An assessment of rainfall losses was undertaken during the calibration process (Section 8.3). 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 80 mm were tested for each of the calibration events, and were adopted based upon calibration to water level gauges and flood marks. A constant continuing loss value of 5 mm/hour was adopted for all calibration events. It was found that the modelled flood levels are highly sensitive to the assumed rainfall depths, which are dependent on the initial and continuing loss rates to some extent. For the design events, the initial and continuing loss rates were adopted from ARR2016, which vary based on the event, duration and subcatchment. They are generally in the order of 0 mm to 30 mm for initial loss, and approximately 3 mm/hour for continuing loss. These are considered reasonable and conservative given the calibrated values for the catchment.

A sensitivity analysis was conducted for the 1% AEP event, with varying the rainfall losses. The results indicate that if the initial losses were set to zero, then the increase in mean flows for the critical duration in the upstream catchments results in an increase of approximately 5% in peak flows. The rainfall losses are more likely to influence the flood levels in the storage driven areas, where runoff volume is the primary driver. The results of the changes in volume are shown in Table 26.

When the initial loss is set to zero, the increase in volume is approximately 7%. The continuing loss values adopted influence the total volume of runoff, particularly for the long duration storms. A sensitivity analysis was undertaken for the 1% AEP event using continuing loss values of 0 mm/hour and 5 mm/hour. The resulting change in total runoff volume for the whole catchment is an increase of approximately 85% with a zero continuing loss and a reduction of approximately 25% for a continuing loss of 5 mm/hour. Moreover, the adopted continuing loss value influences the critical duration, with a lower continuing loss value resulting in an increase in the critical duration, and vice versa. These results indicate that the results are most sensitive to the adopted continuing rainfall losses, which affect the total rainfall depth that results in runoff.

Table 26 Sensitivity of 1% AEP volumes to the rainfall losses

Rainfall Losses		Subcatchment 3AC (Total Catchment Runoff)	
Initial Loss	Continuing Loss	Mean Volume (m^3/s)	Critical Pattern Volume (m^3/s)
ARR	ARR	84,000	86,000
0 mm	ARR	90,000	92,000
ARR	0 mm/hr	155,000	155,000
ARR	5 mm/hr	62,000	63,000

10.3. Catchment Lag

The catchment lag factor (termed ‘C’ in the WBNM model) can be used to accelerate or delay the runoff response to rainfall. This will have the largest impact on peak flows for the upstream ‘conveyance’ dominated areas. This will have a minimal impact on the peak flood levels in the downstream storage areas since these are driven by total flood volume, rather than the timing of the runoff. By varying the adopted C parameter of 1.6 by ±20%, the effect on the peak flows was observed at subcatchments 3E and 3T, which were used to assess the critical storm patterns for Swamp Creek upstream of the Hunter Expressway. The critical storm duration does not change and remains the 720 minute duration for the 1% AEP. The change in the mean peak flows and the critical temporal pattern flows can be seen in Table 27.

Table 27 Sensitivity of 1% AEP catchment flows to the lag factor

Lag Factor (C)	Subcatchment 3E		Subcatchment 3T	
	Mean Flow (m^3/s)	Critical Pattern Flow (m^3/s)	Mean Flow (m^3/s)	Critical Pattern Flow (m^3/s)
1.6 (Design Runs)	204	206	335	339
1.92 (+20%)	182	183	295	300
1.28 (-20%)	232	233	389	405

An increase in the lag factor results in a decrease in flows, of approximately 10 to 12%. Conversely, a decrease in the lag factor increases the catchment flows by up to 20%.

10.4. Manning's 'n'

The Manning's 'n' parameter in the TUFLOW model represents the surface roughness, and the adopted values are outlined in Table 13. A sensitivity analysis was conducted with both an increase and decrease in these values by 20%. The results can be found in maps in Figure F3 and Figure F4, with results also tabulated in Table F1 for the reporting locations for the study (see Figure 29).

In the steep upper parts of the catchment, the increase in flood level with the increase in Manning's 'n' of 20% is approximately 0.1 to 0.3 m. In the lower parts of the catchment that are dominated by storage, the increase in flood level is within 0.01 to 0.03 m. With a decrease in Manning's 'n', the flood level reduces by approximately the same magnitude, being 0.1 to 0.3 m in the upper parts of the catchment and 0.01 to 0.03 m in the lower storage areas.

10.5. Blockage of Structures

A sensitivity analysis was undertaken for the blockage of structures in the TUFLOW model. This assessment was undertaken for 25% and 50% blockage of culverts and bridges for the 1% AEP event. Culverts were assumed to have a reduced capacity while bridges were assumed to have a reduction in the available waterway area. The results of this assessment can be found in Figure F5 and Figure F6, with results tabulated in Table F1 for the reporting locations for the study (see Figure 29). This blockage did not include the floodgates at the Wallis Creek outlet, since this would primarily just increase the duration of inundation in the lower swamps.

The results indicate that there is generally an increase in water level upstream of the hydraulic structures with a decrease on the downstream side. The largest impact occurs at the Government Road crossing of Swamp Creek in Weston. The increase in flood level is approximately 0.8 m with 25% blockage and 1.5 m with 50% blockage. At other structures (especially upstream of the Hunter Expressway), there is typically an increase in flood level up to approximately 0.3 m with 25% blockage and 0.8 m with 50% blockage. In the Swamp Creek storage areas, there is an increase in flood level of just over 0.01 m.

10.6. Tailwater Conditions

The assumed tailwater condition for the design flood events is described in Section 9.6. The adopted tailwater level of 4.5 mAHD during the rising stages of the flood restrict the outflow from Wallis Creek through the floodgates. The reduced tailwater level of 1 mAHD enables water to drain from the catchment, discharging into the Hunter River. A sensitivity analysis was conducted for the 1% AEP event. A tailwater level of 1 m AHD for the entire duration of the storm resulted in a reduction in flood levels primarily within the lower catchment flood storage areas. The peak flood level is reduced by approximately 0.1 m in the Wallis Creek storage areas and by approximately 0.2 m within the Swamp-Fishery Creek storage areas. A raised tailwater level of 4.5 mAHD for the entire duration of the model simulation results in peak water levels for the 1% AEP event being within ±0.1 m of the modelled design storm event. The only material difference is in the duration of inundation. For example, with the persistent raised tailwater level, the duration of inundation at Testers Hollow increases indefinitely until the Hunter River level reduces to allow drainage. The draining of the swamp areas is heavily influenced by the water levels in the Hunter River, since the only outlet for the storage areas is the Wallis Creek floodgates.

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Appendix A

APPENDIX A. GLOSSARY OF TERMS / FLOOD TERMINOLOGY

A.1. Flood Terminology

Australian Rainfall and Runoff 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	

ARR2016 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 the term Exceedances per Year (EY) is recommended. Statistically a 0.5 EY event is not the same as a 50% AEP event, and likewise an event with a 20% AEP is not the same as a 0.2 EY event. For example an event of 0.5 EY is an event which would, on average, occur every two years. A 2 EY event is equivalent to a design event with a 6 month Average 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.

A.2. Glossary

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).

infill development: refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development.

new development: refers to development of a completely different nature to that associated with the former land use. 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.

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 Aflood 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 Astandard 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.
existing flood risk: the risk a community is exposed to as a result of its location on the floodplain.
future flood risk: the risk a community may be exposed to as a result of new development on the floodplain.
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.
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.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: $ the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or $ water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or $ major overland flow paths through developed areas outside of defined drainage reserves; and/or $ the potential to affect a number of buildings along the major flow path.
mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
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: **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. **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. **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 a 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.