MAITLAND CITY COUNCIL

LOCHINVAR FLOOD STUDY

VOLUME 1

wma water

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LOCHINVAR FLOOD STUDY

FINAL REPORT

Project **Lochinvar Flood Study**	**Project Number** **117077**
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EXECUTIVE SUMMARY

This flood study provides information about existing flood risk in the Lochinvar Creek catchment. Flood modelling tools were developed that can be used by Council for decision-making about land-use planning, and in future studies to assess the effectiveness of potential measures to reduce flood risk.

There is a history of significant flooding over the entire catchment. Recent local storm events that caused flood damage and loss included February 1990, June 2007 (the “Pasha Bulker” storm), April 2015 and January 2016. April 2015 in particular resulted in significant flood damages, with several homes flooded above floor level. This event was estimated to be larger than a 1% AEP event (that is, less than 1% chance of similar flooding occurring in any given year).

The lower part of Lochinvar Creek can also be affected by Hunter River flooding, for example in February 1955 and also in June 2007 to a lesser degree. A previous study focussing on flooding from the Hunter River was completed in 2010. This study focussed on the flood behaviour from local catchment rainfall, and should be used in conjunction with the 2010 Hunter River study.

In the 20% AEP event, flows are generally contained within Lochinvar Creek and Greedy Creek upstream of Lochinvar. There are overland flows modelled through the properties on Freeman Drive, however, the flows are generally very shallow (less than 0.1 m). On the Robert Road Tributary, the road crossings of Robert Road, Gregory Road and New England Highway cause floodwaters to pond behind these crossings. Floodwaters also spread out along the tributaries in the vicinity of the New England Highway, where defined creek channels do not exist. Downstream of Lochinvar, flooding is dominated by the adopted Hunter River tailwater level.

Hunter Close floods in the 5% AEP event (along the street) and the New England Highway is overtopped at the Robert Road Tributary. Flooding begins to affect properties in Hunter Close in the 2% AEP event, with floodwaters surrounding all properties on the eastern side of Hunter Close in the 1% AEP event. Hunter Close is the most affected area in the 0.5% and 0.2% AEP events, with floodwaters reaching 0.3 to 0.5 m at a number of properties. Overland flooding along Freeman Drive remains fairly shallow (generally less than 0.1 m).

In events up to the 2% AEP (a 2% chance of happening in a given year), flood damage in Lochinvar is primarily attributed to external damages (landscaping, fencing, sheds, etc.). In the 1% AEP event there are a couple of properties flooded above floor level. In the 0.2% AEP event, there are estimated to be 7 properties flooded above floor, and 33 affected in total. In the PMF event, there are 52 properties flooded above floor, with 75 affected by flooding altogether.

The average annual damages from flooding are relatively low, at approximately $13,400. This equates to an average property damage value of $200, averaged across the 75 properties affected in the PMF event. Damages for smaller to moderate events range from approximately $17,000 in the 20% AEP event, to approximately $25,000 in the 2% AEP event. When floor levels begin to be inundated in the 1% AEP event, the flood damages rise to approximately $90,000 for that event. In the 0.2% AEP, flood damages reach over $500,000 and in the PMF event they reach almost $4.5 million.

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LIST OF ACRONYMS

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

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 2):

1. Flood Study

- Determines 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
- Office of Environment and Heritage
- State Emergency Service

1. INTRODUCTION

The Lochinvar Flood Study covers the Lochinvar Creek catchment, which is located in the Hunter Valley, approximately 40 km north-west of Newcastle. The study area includes the urbanised township of Lochinvar and adjacent rural areas. The location of the catchment is shown in Figure 1. The catchment lies within the Local Government Area (LGA) of Maitland City Council (MCC).

This flood study provides information about existing flood risk in the catchment. Flood modelling tools were developed that can be used by Council for decision-making about land-use planning, and in future studies to assess the effectiveness of potential measures to reduce flood risk. The models were calibrated using observations from historical floods, and used to estimate the impacts of flooding for a range of standardised “design” flood probabilities. This modelling was completed in accordance with the guidelines in Australian Rainfall and Runoff (Reference 1)

Flooding in the lower Lochinvar creek can occur from either local rainfall or a large Hunter River flood. A previous study focussing on flooding from the Hunter River was completed in 2010. This study is focussed on the flood behaviour from local catchment rainfall, and is intended to be used in conjunction with the 2010 Hunter River study.

Flooding in the upper portion of the catchment is dominated by localised rainfall events, and the major flood mechanism within Lochinvar is from local tributary creeks that break out of bank and flood adjacent areas. MCC has previously undertaken flood studies and floodplain management studies along these overland flow paths. These studies were completed in the 1990’s and are now outdated.

Maitland Council is responsible for managing development in accordance with flood risk, as per the NSW Floodplain Development Manual (Reference 2). The Lochinvar Structure Plan (LSP), which identifies potential land for future development across the catchment, was adopted by MCC on the 9th October 2007 (Reference 3). As part of this, the Urban Release Area was defined – as seen in Figure 1. The urban release area is predominately located in the upper portion of the catchment, bounded by the Northern Railway to the south, roughly following the Lochinvar Creek catchment boundary to the east and west and extending approximately 650 m north of the New England Highway. The information in this study can be used to ensure that development of the urban release area includes appropriate management of flood risk.

2. CATCHMENT BACKGROUND

2.1. Study Area

The area studied was the Lochinvar Creek catchment as shown in Figure 2. The total area of the catchment is approximately 16.6 km^2, extending from approximately 2.4 km upstream of Lochinvar (where the New England Highway crosses Lochinvar Creek) to the confluence with the Hunter River.

Lochinvar Creek is the main waterway that conveys water from the catchment to the Hunter River. The creek generally runs in a northerly direction, originating in the vicinity of the Northern Railway Line. The upper portion of the Lochinvar Creek catchment predominately consists of rural properties – primarily cleared farmland with some remnant stands of trees. The creeks have been completely cleared of vegetation for large reaches in the upper parts of the catchment, and there are signs of erosion in these areas. Along this section, several tributaries drain water from the south-east portion of the catchment joining Lochinvar Creek, with Greedy Creek being the largest of these tributaries. Lochinvar Creek continues north, before turning east running parallel to (and between) the New England Highway and Freeman Drive. Just upstream of Hunter Close, Greedy Creek joins Lochinvar Creek. Lochinvar Creek continues in a north direction, crossing under the New England Highway and meandering approximately 3.6 km before discharging into the Hunter River. Along this section, four tributaries discharge into Lochinvar Creek.

Greedy Creek is a tributary of Lochinvar Creek and has a catchment area of approximately 2.2 km^2. Flow originates in the south-eastern part of the study area, where it flows parallel to Station Lane and crosses this road at two locations. The flow path continues north where it passes through the front of several properties, before flowing under Freeman Drive and converging with Lochinvar Creek just upstream of Hunter Close. Several farm dams are located along this flow path and the catchment has been almost completely cleared of bushland vegetation.

There are three other smaller flow paths covering the eastern catchment that are mostly made up of rural land, crossing the New England Highway at three locations. One of these tributaries flows underneath and then parallel to Robert Road before flowing under the New England Highway. This tributary is referred to as the Robert Road Tributary in this report and is the largest tributary that crosses the New England Highway. At this location, the flow path runs adjacent (on the east side) to both St Patrick's Primary School (upstream of the New England Highway) and St Josephs College (downstream of the New England Highway). At the north-east boundary of St Josephs College, these three tributaries converge.

2.2. Flood Mechanisms

Flooding within the Lochinvar Creek catchment can occur as a result of different weather patterns:

1. Intense local rainfall on the Lochinvar Creek catchment– Flooding can occur when intense local rainfall causes runoff exceeding the capacity of creeks and drainage channels, producing over bank flow. This mechanism can produce flooding over the whole catchment, including shallow overland flow in steep upper catchment areas. April 2015

was a recent example of this type of flooding.

2. Hunter River Flooding – Flooding on the Hunter River can be caused by rainfall over the upper Hunter River and Goulburn River catchments. Flow in the Hunter River can overtop the banks and cause backwater flooding on the lower reaches and floodplains of Lochinvar Creek. In a large Hunter River flood event, inundation across the lower portion of the Lochinvar catchment can be extensive. This may or may not coincide with local rainfall in the upper Lochinvar creek catchment. The February 1955 Hunter River flood is an example of this type of flooding. It caused inundation backing up to the vicinity of the New England Highway.

Flooding in Lochinvar Creek and Hunter River can occur independently of one another or concurrently. Concurrent flooding has a significant influence on flood levels on the lower reaches of Lochinvar Creek and its floodplains. Hunter River flooding was investigated in Reference 7. This report generally refers to local catchment flooding in Lochinvar Creek unless otherwise specified.

2.3. Previous Flood Mitigation Works

Previous flood studies in the area have led to mitigation works to reduce flood risk. The New England Highway Bridge at Lochinvar Creek was rebuilt in 1978 by Roads and Maritime Services (RMS). The new design incorporated an increased waterway area and channel works as a measure to reduce flood affectation upstream of the bridge. The channel works included widening of the creek for 30 m upstream of the bridge, as well as vegetation management. The new bridge and creek widening had a considerable influence on flood behaviour, especially in the areas upstream around Hunter Close. More details are provided in 3.7.1.

2.4. Historical Flooding

Lochinvar Creek has a history of significant flooding, with notable events occurring in March 1977, February 1990, June 2007 (the “Pasha Bulker” storm), April 2015 and January 2016 over the entire catchment. Properties in Hunter Close have been inundated in a number of flood events, namely April 2015 where several properties were affected above floor level, as well as the 1977 event. This was due to flow in Lochinvar Creek breaking out of bank and affecting the adjacent properties.

Further, flooding in Freeman Drive has been observed in a number of flood events, where properties have been directly affected by overland sheet flow, Lochinvar Creek flow or a combination of these at the interface of these flooding mechanisms.

Flooding has also affected residents along Windermere Rd, with some residents reporting being isolated for 6 and 8 days with no power for the June 2007 and April 2015 event respectively.

The June 2007 and April 2015 events in particular were major floods that caused widespread inundation, damage and loss. A selection of photos following the April 2015 event are shown below (Photo 1 to Photo 4).

Photo 1: Freeman Drive - 2015

Photo 2: 80 New England Highway – Flooding over New England Highway - 2015

Photo 3: 80 New England Highway - 2015

Photo 4: 9 Freeman Drive - 2015

3. AVAILABLE DATA

3.1. Topographic Data

Aerial survey of the catchment was the only topographic data used for this study. This aerial survey, known as Light Detection and Ranging (LiDAR), was obtained from the NSW department of Land and Property Information (LPI). LiDAR provides a detailed topographic representation of the ground with a survey mark approximately every square metre. The data for the Maitland region (including Lochinvar) was collected in 2012. The accuracy of the ground information obtained from LiDAR survey can be adversely affected by the nature and density of vegetation, the presence of steeply varying terrain, the vicinity of buildings and/or the presence of water. The accuracy is typically ± 0.15 m for clear terrain. The ground levels are shown in Figure 2.

3.2. Hydraulic Structures

Hydraulic structures, including bridges and culverts, can have a significant impact on flood behaviour. Therefore, appropriate representation of these structures is essential for the accuracy of the hydraulic model. Data for hydraulic structures were collected from:

- Previous studies; and
- WMA field measurements during a site visit at project inception;

A summary of the hydraulic structures along Lochinvar Creek and its tributaries is provided in Table 1 (locations shown in Figure 2). Examples of structures measured during the initial site investigation for the project are shown in Photo 5 and Photo 6. Structure lengths were measured in a GIS program based on aerial photography.

Table 1: Hydraulic Structures

ID	Location	Structure Details	No.	U/S Invert (mAHD)	D/S Invert (mAHD)	Source of Data
NEH_02	New England Highway at Unnamed Creek	1.2 m (W) x 0.9 m (H) RCBC	3	30.45 A	30.4 A	Site Visit
WDM_01	Wyndella Road at Unnamed Creek	0.9 m diameter RCP	3	33.4 A	33.3 A	Site Visit
NEH_03	New England Highway at Unnamed Creek	1 m diameter RCP	1	33.2 A	33.1 A	Site Visit
STATION	Station Lane at Greedy Creek	1.5 m diameter RCP	2	32.205 B	32.17 B	1997 Study (Reference 5)
FREEMAN	Freeman Drive at Greedy Creek	1.65 m diameter RCP	4	27.665 B	27.425 B	1997 Study (Reference 5)
NEH_04	New England Highway at Unnamed Creek	1.2 m (W) x 0.9 m (H) RCBC	3	38.75 A	38.65 A	Estimated from Site Visit (Photo 5)
NEH_01	New England Highway at Lochinvar Creek	LiDAR data and aerial imagery was used to define the flow area under the bridge structure.				

Note: A. Estimated using LiDAR data
B. Surveyed invert levels

Photo 5: New England Highway Culverts (NEH_04)

Photo 6: Wyndella Road Culverts (WDM_01)

3.3. Floor Level Survey

Building floor levels are required in order to undertake an assessment of potential flood damage and to estimate Average Annual Damages (AAD). A database of estimated building floor levels was produced for all properties (residential and commercial) that were within a Preliminary Probable Maximum Flood (PMF) extent. Floor levels were compiled by using LiDAR to estimate ground levels at each building and adding a height-above-ground estimate for floor level heights above ground. These height-above-ground estimates were determined via visual inspection using techniques such as counting the number of bricks or steps from ground level to floor level, or other approximation methods – this technique provides a sufficient level of accuracy for undertaking flood damages. Google StreetView, in conjunction with photographs taken during a site visit, were used to estimate the height of the floor above ground. In total, 254 properties were identified within the Lochinvar Study Area, with floor levels of 76 properties being estimated that were within the PMF extent. These are shown in Figure 3.

3.4. Flood Marks

In order to calibrate and validate the models, data from historical events is required. Council identified that calibration/validation should include the June 2007, April 2015 and January 2016 events. Flood mark data was collected via the community consultation process and a data collection exercise completed by WMAwater following the 2015 April event.

3.4.1. Community Consultation and Site Visit

A community consultation process was undertaken in collaboration with Maitland City Council (see Section 4 for full details). Some respondents provided an estimated flood depth that could be used as a flood mark. WMAwater spoke with community members about their flood observations and carried out a second site visit to gather information. Example photos from this visit are shown in Photo 9 to Photo 12. A further 4 flood marks were collected during this phase. A summary of all flood marks collected during the community consultation and accompany site visit are presented in Table 2 (locations shown on Figure 16).

Table 2: Flood Marks – April 2015 – community consultation and site visit

ID	Address	Comment	Estimated depth (m)	Flood Level (mAHD)
FM01	47A Station Lane	Flood levels reached the front entrance to the property - reached first step. ~2.5 bricks.	0.22	31.8
FM02	80 New England Highway	200 mm up to first step. Sheds at north east part of the property were not inundated (they are about 100 mm above ground level)	0.20	28.4
FM03	New England Highway	100 mm of sheet flow flowing across the New England Highway.	0.10	29.5
FM04	2 Wyndella Road	1 m of water over the driveway	1.00	35.8
FM05	9 Freeman Drive	The house was surrounded by water almost 30cm deep, and the house garage was affected above floor levels.	0.30	30.6
FM06	13 Freeman Drive	Tools and equipment, stored in sheds etc. were destroyed by mud and water. 300mm flooding observed	0.30	31.4
FM07	33 Freeman Drive	Flooding of building by a couple inches on his property. Granny flat at rear of property was also affected.	0.10	34.7
FM08	19 Freeman Drive	House was structurally damaged due to runoff from Freeman Drive. Estimated 100mm of rainfall as house is on ground level	0.10	32.8
FM09	28 Freeman Drive	Shed had 300mm of water. Equipment damaged in shed	0.30	35.6
FM10	15 Hunter Close	Both the house and granny flat at the rear of the property were affected above floor levels. Both properties had to be demolished.	See Section 3.4.2	
FM11	13 Hunter Close	House inundated with approximately 18 inches (0.5 m) of water. Causing complete loss of contents and rebuild of inside dwelling. Floor level is estimated at 0.6 m above ground level (estimated from Photo 10).	1.0	29.5

Note: Flood levels were estimated using flood depths provided by the resident from the consultation or subsequent site visit and adding the estimated ground level (taken from 1 m LiDAR data).

Photo 7: 28 Freeman Drive – Flood almost reaching house - 2015

Photo 8: 9 Freeman Drive – Flooding at shed at rear of property - 2015

Photo 9:47A Station Lane – Flooding reached the mark as shown - 2015

Photo 10: 13 Hunter Close - 2015

Photo 11: 33 Freeman Drive – Flooding reached fence line – 2015

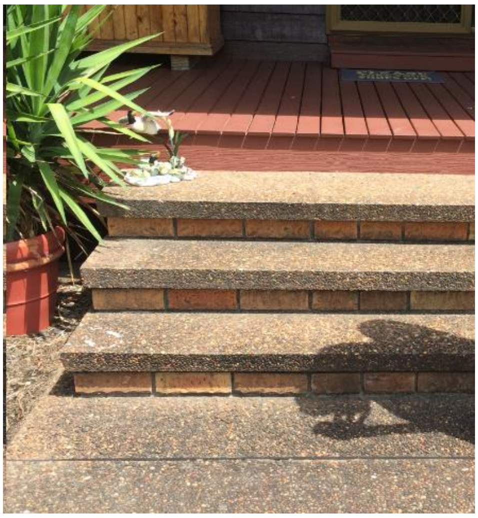


Photo 12: 80 New England Highway – Flooding reached 200mm up to first step – 2015

3.4.2. 2015 Flood Database Collection – WMAwater

WMAwater undertook data collection in Lochinvar on the 30th April 2015 in the aftermath of the extreme storm event of April 2015, as part of a broader data collection exercise throughout the Maitland and Cessnock Council areas (Reference 4). Four flood marks were collected within the study area. The flood marks were observed as debris lines on residential dwellings or fences. A summary of the flood marks is listed in Table 3 (see Figure 16 for location).

Table 3: Flood Marks for the April 2015 Event Measured by WMAwater

ID	Address	Comment	Flood Level (mAHD)
FM10	15 Hunter Close	The mark is situated on the front right hand side of the house next to the air conditioning unit. The mark measures 1.03 m from the bottom of the cladding. Adding 4 bricks at 76 mm each between ground and cladding (Photo 13)	29.6 mAHD (Ground level estimated at 28.3 mAHD)
FM12	5 Hunter Close	The mark is situated at the front right hand corner of the house near the air conditioning unit. The mark measured 0.92 m from the ground level. (Photo 16)	29.6 mAHD (Ground level estimated at 28.7 mAHD)
FM13	1 Hunter Close	The mark is situated in the backyard on the metal frame wall. The mark measures 1.17 m from the concrete slab. (Photo 14)	29.6 mAHD (Ground level estimated at 28.5 mAHD)
FM14	4 Hunter Close	The mark is situated on the front veranda. The mark is at the bottom of the facia board. Estimated to be 1.1 m from ground level to the debris line (Photo 15)	29.6 mAHD (Ground level estimated at 28.5 mAHD)

Photo 13: 15 Hunter Close - Debris Line, 2015

Photo 14: 1 Hunter Close - Debris Line, 2015

Photo 15: 4 Hunter Close - Debris Line, 2015

Photo 16: 5 Hunter Close - Debris Line, 2015

3.5. Historical Rainfall Data

3.5.1. Rainfall Stations within the Catchment

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

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

The daily read stations record total rainfall for the 24 hours to 9:00 am of the day being recorded. For example, the rainfall received for the period between 9:00 am on 21 April 2015 until 9:00 am on 22 April 2015 would be recorded on the 22 April 2015.

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

Table 4: Continuously read rainfall stations

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

Table 5: Daily read rainfall stations

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

3.5.2. Analysis of Daily Read Data

The daily rainfall gauges within 20 km of the centroid of the study area were analysed for each of the three significant recent events identified in Section 2.4 Each event was analysed for the individual days and entire event totals. The results of the analysis are shown in Table 6 to Table 8.

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 sub-catchment in the hydrological model, and are shown in Figure 9 to Figure 11. The rainfall isohyets were developed using the natural neighbour interpolation technique.

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

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

Table 7: Daily Rainfall Depths (mm) for the April 2015 Event

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

Table 8: Daily Rainfall Depths (mm) for the January 2016 Event

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

3.5.3. Analysis of Pluviometer Data

The pluviometer gauges were analysed for the historical events that had corresponding rainfall data. This data was used to determine the temporal patterns of each storm event that were subsequently used in the model calibration process. An analysis of these temporal patterns using the available pluviometer gauge data for the June 2007, April 2015 and January 2016 events can be found in Figure 6, Figure 7 and Figure 8, respectively.

The June 2007 storm event (Figure 6) displayed two distinct rainfall bursts, one short and intense burst occurring from approximately 9 am to 2 pm on the 8th June, and one longer and less intense burst, resulting in a higher rainfall depth from approximately 4:30 pm on the 8th June through to 2 am the next day. The total rainfall depth recorded at the gauges ranges from 100 mm to 230 mm.

The April 2015 storm event (Figure 7) consisted of a single rainfall burst occurring between approximately 9 am and 9 pm on the 21st April, with between 60% and 80% of the rain falling in the first 5 hours and some low intensity rainfall following the burst. The total rainfall recorded is between approximately 100 mm and 370 mm.

The main burst of the January 2016 storm event (Figure 8) occurred between approximately 3 pm on 5th January and 9 am on 6th January. A small amount of rainfall (typically less than 30 mm recorded) also preceded the main burst, resulting in a total rainfall depth of approximately 100 mm to 240 mm across the two days.

3.6. Design Rainfall Data

The design rainfall intensity frequency duration (IFD) for the centroid of the study area was obtained for Australian Rainfall and Runoff (ARR) 2016 (Reference 1), and are shown in Table 9. The comparisons of rainfall IFD between historical rainfall events to design events are shown in Figure 12 to Figure 14.

Table 9: Rainfall depths (mm) for given durations and frequencies, for the catchment centroid

Storm Duration	1EY	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
1 hour	23	26	36.1	43.4	51	61.7	70.3
2 hour	28.7	32.5	45	54	63.3	76.3	86.8
3 hour	32.6	37	51.3	61.6	72.3	87.2	99.2
6 hour	41.2	46.8	65.4	79	93	113	129
12 hour	52.9	60.4	85.6	104	124	151	175
24 hour	68.4	78.5	113	139	166	205	237
48 hour	86.4	99.7	145	180	217	267	308
72 hour	96.7	112	163	202	244	299	343

3.7. Previous Studies

3.7.1. Lochinvar Floodplain Management Study (WMAwater 1997) and Plan (WMAwater 1998)

WMAwater were engaged by MCC and the Department of Land and Water Conservation (DLWC) to undertake a Floodplain Management Study and Plan for Lochinvar (Reference 5 and 6 respectively). The study involved investigating the flood behaviour and flood hazards as well as identifying potential mitigation options. The study included Lochinvar Creek, Greedy Creek as well tributaries downstream that join the main flow path.

The model adopted a WBNM hydrological model and a RUBICON hydraulic model. No calibration was completed due to lack of flood data. The model adopted an initial loss of 0 mm and a continuing loss of 2.5 mm/hr. The critical duration was found to be between 1 and 3 hours.

The study found that the replaced bridge at New England Highway improved flood conveyance due to the waterway area and mitigation of the creek upstream.

- The existing bridge had two openings at 5 m each, whilst the rebuilt bridge has two openings at 8.2 m wide – 60% extra flow area.
- Widening and realigning of Lochinvar Creek was completed for a 30 m section upstream of the bridge.

Hydraulic modelling results also showed that the existing bridge acted as a hydraulic restriction and upstream of the bridge, half the properties in Hunter Close were inundated during the 1% AEP event. Results also showed that the rebuilt bridge reduced upstream flood levels such that no properties were inundated during the 1% AEP event.

The study found that there were mitigation measures that could be implemented to reduce flood severity. Some of these include;

1. Levees around Hunter Close – this would reduce high velocity flow and deflect flow
2. Maintaining a clear creek to increase efficiency of the waterway
3. Development restrictions – setting minimum floor levels for new development in flood liable areas

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

WMAwater was commissioned by Maitland City Council (MCC) to undertake a flood study of the Lower Hunter River between Braxton and Green Rocks (Reference 7). The study area included the lower reaches of Lochinvar Creek.

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

The design flood mapping from the Study indicates the following:

- In the 50% AEP event and greater, there is significant discharge from the Hunter River upstream of Oakhampton, which inundates the lower reaches of the Lochinvar Creek catchment.
- The extent of inundation during a 5% AEP flood event in the Hunter River is observed at the lower reaches of Lochinvar Creek, extending up to the northern end of the Urban Release Area. This flood extent continues further upstream during rarer flood events, where the 1% AEP event extends to approximately 150 m downstream of the New England Highway Bridge and the 0.5% AEP event extends up into Greedy Creek.

3.7.3. Lochinvar Urban Release Area (ADW Johnson Pty Ltd, 2015)

ADW Johnston Pty Ltd was commissioned by MCC to undertake a study of Lochinvar and adjacent rural areas to analyse what impact the proposed development (using the Urban Release Area) will have on the flood behaviour (Reference 8). Both the existing and developed options were modelled for the 10% and 1% AEP event.

The study area extended from the Northern Railway in the south to approximately 500 m downstream of the New England Highway, and included the extent of the Urban Release Area.

XP-RAFTS software was used for hydrologic modelling and HEC-RAS software was used to undertake 1D hydraulic modelling. An analysis of the existing flood behaviour was undertaken, including peak flows, peak flood levels and the flood immunity of road crossings. With the potential development within the Lochinvar Urban Release Area, it was found that peak flows through the Lochinvar township would increase and it was recommended that three new regional detention basins within the Greedy Creek catchment be implemented, in addition to existing farm dams in other areas, to attenuate peak flows from the new development to pre-development flows. Culvert upgrades were also recommended at Station Lane, Roberts Road, Gregory Road, Wyndella Road and Winders Lane to provide flood free access for the Urban Release Area.

4. COMMUNITY CONSULTATION

4.1. Information Brochure and Survey

In collaboration with Maitland City Council a questionnaire was distributed to residents in the study area. The purpose of the questionnaire was to identify flooding that residents had experienced, problems with flooding and to collate as much historical flood data as possible. From this, 25 responses were received. Of those that responded, 92% were aware of flooding issues within the catchment, with a total of 15 respondents having their properties affected by flooding and of those, 5 properties flooded above floor level. There is a relatively high level of flood awareness and preparedness generally in the area, as multiple floods have occurred in the last ten years.

The locations of the community consultation respondents are shown in Figure 15. Properties identified as having been affected by flooding and flooded above floor level are shown in Figure 16. The location of reported flood marks is also displayed on Figure 16. Details about the flood marks are documented in Section 3.4.1. The results from the community consultation questionnaire are summarised in Figure 17.

4.2. Community Responses

Several photographs of historical flooding were provided by the community. A selection of these are presented below in Photo 17 to Photo 21.

Photo 17: 80 New England Highway - 2015

Photo 18: 25 Station Lane - 2015

Photo 19: 28 Freeman Drive - 2015

Photo 20: 13 Freeman Drive - 2015

Photo 21: 13 Freeman Drive - 2007

The following issues were raised by the respondents:

- Residents described the April 2015 storm as the biggest they have witnessed. The 2007 Pasha Bulker Storm and 2016 rainfall event also affected some residents however not as severely;
- The majority of residents are aware of flooding risks and believe they are generally prepared for flood events;
- Some residents believe that better drainage systems need to be implemented to account for larger flood events within the township;
- Most residents are concerned with maintenance of both Lochinvar Creek and Greedy Creek, believing that cleaning out the creek from debris and rubbish may help the water to drain more quickly during floods. Residents have suggested a regular maintenance program; and
- Various residents are also concerned about future development. Residents have also blamed the increased rate of rise in flood waters to be as a result of increasing residential development in surrounding areas – specifically upstream of Lochinvar. They are concerned that this will be dangerous to new residents and stretch the resources of community and emergency services during flood events.

4.3. Public Exhibition

The Draft Lochinvar Flood Study was placed on public exhibition for comment from 1 April 2019 to 3 May 2019. Public notices were placed in the local newspaper and on Council's website, and residents affected by the study were directly notified by Council. The Draft Study was available for inspection at Council's Administration Centre, and via download from the website.

A community drop-in information session was held on 16 April 2019 at Maitland Town Hall between 1.00pm to 5.00pm. Attendees at the session were able to ask questions about the study to Council officers and WMAwater staff. Instructions for making formal written submissions were provided to those wishing to comment on the study.

Two written submissions were received from residents in the study area. Residents at the workshops and in the two submissions were primarily concerned with control of runoff from future development upstream of existing flood prone areas. This is a valid concern, given the plan for a substantial increase in development within Lochinvar. Under the NSW State Government's Flood Prone Land Policy, the management of flood liable land remains the responsibility of local government. The Policy provides a means of ensuring that any new development does not create additional flooding problems in other areas. It is Council's responsibility to ensure that future development does not exacerbate flooding problems in downstream areas. This study provides an important foundation that enables Council to perform this responsibility, in the following ways:

- The study defines the existing flood risk for the catchment, under development conditions at the time of writing. Council therefore has a benchmark to ensure that future flood risk is not worsened by future developments.
- The flood models prepared for this study are available to prospective developers under a licence agreement with Council. Development applications will need to demonstrate, by incorporating the proposed developments and mitigation measures in the models, that the flood risk will not be exacerbated.

At the workshops and in the written submissions, some residents expressed concern that detention/retarding basins may not perform adequately, or will become a future maintenance liability for Council, as well as potentially becoming a breeding site for snakes and vermin. Detention basins can play an effective role in mitigating the impacts of increasing urbanisation, but it is important that the following questions are addressed as part of the development application:

- Has the detention basin been adequately designed to mitigate flood impacts for the full range of storm durations (including the critical duration for the whole catchment, not just the local development site)?
- Has the cumulative impact of all proposed detention basins in the catchment been considered on a system-wide basis?
- Who will own and maintain the basin, and have the maintenance costs been provisioned?
- What is the effective design life of the basin and will remediation works be required? and
- Will the New South Wales Dam Safety Committee need to be notified about potential risks of basin failure?

5. HYDROLOGIC MODEL

5.1. Introduction

A hydrologic model is a tool for estimating the amount of runoff that flows from a catchment for a given amount of rainfall, and the timing of this runoff flow. Stream gauges (which measure water level in a stream) are a way of directly measuring this information, but they are expensive to setup and maintain. They also require a long record (several decades) to be of most use for flood estimation. Most of the smaller creeks in NSW are not gauged, and there are no stream gauges in the Lochinvar Creek catchment. In such cases, using a computer-based hydrologic model is the best practice method for determining how much flow occurs from rainfall information (which is more widely available from rain gauges) to flow information in creeks. This type of hydrologic model is referred to as a runoff-routing model.

A range of runoff-routing hydrologic models is available as described in ARR 2016 (Reference 1). These models allow the rainfall to vary in both space and time over the catchment and will calculate the runoff generated by each subcatchment. The generated flow hydrographs then serve as inputs at the boundaries of the hydraulic model, which provides details about flood levels and velocities.

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 Lochinvar Creek catchment was created and used to calculate the flows for each individual sub-catchment and tributary creek for inclusion in the TUFLOW hydraulic model. The hydraulic model is discussed in Section 6.

5.2. Sub-catchment delineation

In total, the catchment represented by WBNM is 16.6 km^2, consisting of 152 sub-catchments. The sub-catchment delineation is shown in Figure 18. The sub-catchments were derived from LiDAR topographic data and consideration of hydraulic controls such as bridge crossings and road/rail embankments.

5.3. Impervious Surface Area

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

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

WMAwater used the Mannings layers (discussed in Section 6.4) to estimate the effective impervious surface area for each sub-catchment. For each of the Mannings ID, an impervious percentage was assigned to it. The details of each category and the total catchment area assumed is provided in Table 10.

Table 10: Assumed percentage of effective impervious surface area

Type	Percent Impervious	Total Area (km²)
Railway	80%	0.01
Paved Areas (roads, carparks, pavement)	100%	0.36
Urban Lots	40%	0.73
Pervious Areas (vegetation, waterways, open area)	0%	15.5

5.4. Rainfall Losses

Methods for modelling the proportion of rainfall that is “lost” to infiltration are outlined in ARR 2016 (Reference 1). 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. The initial/continuing loss method was adopted for this study.

5.5. Adopted Hydrologic Model Parameters

The model input parameters for each sub-catchment 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 sub-catchment;
- An impervious area lag factor;
- An areal reduction factor;
- The percentage of catchment area with a pervious/impervious surface; and
- Rainfall losses calculated by initial and continuing losses to represent infiltration.

A typical regional value of 1.7 for the lag factor ‘C’ hydrologic model parameter was found to be appropriate. The percentage of the impervious area in the whole catchment is roughly 7%. A stream flow routing value of 1.0 which is the typical value for natural channels.

6. HYDRAULIC MODEL

6.1. Introduction

Hydraulic modelling is the simulation of how floodwaters move through across the terrain. A hydraulic model can estimate the flood levels, depths, velocities and extents across the floodplain. It also provides information about how the flooding changes over time. The hydraulic model can simulate floodwater both within the creek banks, and when it breaks out and flows overland, including flows through structures (such as bridges and culverts), over roads and around buildings.

2D hydraulic modelling is currently the best practice standard for flood modelling. It requires high resolution information about the topography, which is available for this study from the LiDAR aerial survey. Various 2D software packages are available (SOBEK, TUFLOW, RMA-2). The TUFLOW package was adopted as it meets requirements for best practice, and is currently the most widely used model of this type in Australia for riverine flood modelling.

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

The TUFLOW model version used in this study was 2017-09-AC-w64 (using the finite volume HPC solver), 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 Mannings ‘n’ roughness value assigned to each grid cell. The size of grid is determined as a balance between the model result definition required and the computer processing time needed to run the simulations. The greater the definition (i.e. the smaller the grid size) the greater the processing time need to run the simulation.

6.2. TUFLOW Hydraulic Model Extent

The model extent starts 2.4 kilometres upstream of New England Highway at Lochinvar, where the upstream boundary lies just to the north of the Northern Railroad. The model continues along Lochinvar Creek where the downstream boundary is located approximately 3.2 km downstream of the New England Highway at the confluence of the Hunter River. The hydraulic model covers an area of 15.5 km^2 and its extent is shown in Figure 19. The extent essentially covers the catchment area, apart from a small area upstream (south) of the Northern Railway Line. It was determined during the site inspection and liaison with Council that detailed mapping of flow paths upstream of the railway line would not be required.

The Lochinvar Creek catchment is largely rural with development concentrated around the township of Lochinvar (either side of the New England Highway). Typically, developed areas require a grid resolution of no more than 2 m to capture the various flow mechanisms characteristic of a built-up environment. However, a grid resolution of that size for an area 15.5 km^2 using the TUFLOW Classic Engine would result in large model run-times. In 2017, a new TUFLOW version was released with High-Performance Computing (HPC) Graphical Processor Unit (GPU) model support. The new HPC GPU models are significantly faster than the traditional Central Processing Unit (CPU). As such, the HPC Engine with GPU was used for this study, although the HPC models can be run over a longer timeframe using CPU. A grid size of 2 m was adopted for the entire 15.5 km^2 area.

6.3. Boundary Locations

6.3.1. Inflows

For sub-catchments within the TUFLOW model domain, local runoff hydrographs were extracted from the WBNM model (see Section 5). These were applied to the downstream end of the sub-catchments within the 2D domain of the hydraulic model. External inflows from outside of the hydraulic model domain (i.e. Just downstream of the Northern Railway) were applied to the boundary of the model. The inflow boundaries are shown in Figure 20.

6.3.2. Downstream Boundary

The downstream boundary is located approximately 4 km downstream of the New England Highway at Lochinvar Creek. The downstream boundary is shown in Figure 20. The Hunter River flood behaviour that was used in the calibration and design modelling was sourced from 7.

For the June 2007 calibration event, backwater flooding from the Hunter River affected flood levels in the Lochinvar catchment. Concurrent flood levels using modelled flood data from Reference 7 were applied as the downstream boundary for this event.

There is no available flood data in the Hunter River at Lochinvar for the other calibration events used in this study. These events were allocated a flood classification using the BOM Flood Classifications for Belmore Bridge (Hunter River). April 2015 was classified as a moderate flood event at Belmore Bridge, - corresponding to a 20% AEP flood or less. Therefore, the 20% AEP peak flood level of 17.5 m AHD was adopted for the downstream boundary (using design flood results from Reference 7). January 2016 was found to be below the minor flood level in the Hunter River – as such, the lowest ground level across the downstream boundary was applied.

For this study, the main objective was to define local catchment flooding, as Hunter River flood extents in the lower catchment have already been assessed. Furthermore, significant local flooding can occur within the catchment in isolation of Hunter River flooding, as was particularly apparent in April 2015. In order to understand local flood behaviour, a downstream boundary condition was adopted in the Hunter River that would not produce significant backwater effects. A static flood level of 22.25 mAHD was assumed for all design flood events, corresponding to a 5% AEP Hunter River flood level (Reference 7).

6.4. Mannings 'n' Roughness

Roughness, represented by the Mannings 'n' coefficient, is an influential parameter in hydraulic modelling. As part of the calibration process roughness values are adjusted within ranges defined in the literature so that the model better matches observed peak flood levels at a variety of locations. Chow (Reference 10) provides some information with regards to the setting of the of the roughness values for hydraulic calculations.

Mannings 'n' values are also discussed in Project 15 of ARR 2016 – *Two Dimensional Modelling in Urban and Rural Floodplains* (Reference 11). The values adopted for this study were based on consideration of the above references, and the model calibration process. The Mannings 'n' values adopted for this flood study are shown in Table 11 while Figure 21 shows their spatial distribution.

Table 11: Adopted Mannings '*n*' values – TUFLOW model

Surface	Mannings 'n'
General	0.04
Waterways - Thick Vegetation	0.1
Waterways - Minimal Vegetation	0.07
Riparian Vegetation	0.08
Medium Vegetation	0.055
Thick Vegetation	0.08
Roads	0.02

6.5. Creeks

The creek channels were defined in the 2D grid domain, as the 2 m resolution was sufficient to resolve the creek geometry effectively.

6.6. Road Crest Elevations

The model topography was refined to improve representation of road crests. Road crests were schematised as breaklines where the road elevation was sourced from high resolution 1 m DEM from the LiDAR dataset. These are displayed in Figure 19.

6.7. Model Schematisation Methodology for Hydraulic Structures

6.7.1. Bridges

Photo 22: New England Highway Bridge at Lochinvar Creek

The New England Highway Bridge over Lochinvar Creek (shown in Photo 22) was modelled in the 2D domain. The purpose of this was to maintain continuity in the model, and because the 2 m resolution was generally sufficient to resolve the waterway area accurately. The modelling parameter values for the bridges were based on the geometrical properties of the structure, which were obtained from measurements, ALS and photographs taken during site inspections and previous experience modelling similar structures.

6.7.2. Culverts

The road culverts were modelled using 1D elements. The modelling parameter values for the culverts/bridges were based on the geometrical properties of the structure, which were obtained from measurements and photographs taken during site inspections and previous experience modelling similar structures. For several of the culverts, invert levels had to be estimated from LiDAR information due to lack of available detailed survey data or plans.

6.7.3. Buildings

Buildings within the floodplain were removed from the computational grid ("blocked out"). As such, it was assumed that all the buildings would not provide any storage during a flood event, and that they could be treated as obstructions to floodwaters. 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.

7. MODEL CALIBRATION

The aim of the calibration process is to ensure the modelling system can replicate historical flood behaviour. There are assumptions in the modelling inputs, such as the effect of vegetation on flow and the amount of infiltration into the soil, which can be adjusted to improve the match between observed and modelled flood levels. A good match to historical flood behaviour provides confidence that the modelling methodology and schematisation can accurately represent the important flood processes in the catchment.

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/verification were:

- June 2007
- April 2015
- January 2016

Due to the widespread availability of flood marks from the April 2015 flood, this event was the main focus of the calibration process. A more limited verification process was used for the other flood events, where only limited marks were available. The verification involved using the calibrated model parameters from the April 2015 event and simulating the other flood events to check that the model replicated the observed flood behaviour for those other events.

7.1. Methodology

Surveyed flood marks were available from Reference 4 and from the community consultation process for this study (see Section 3.4).

The rainfall depths for each event across the catchment were derived from the gauge data, with the interpolated isohyets shown in Figure 9, Figure 10 and Figure 11 for the 2007, 2015 and 2016 events, respectively. 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 pluviometer at either Maitland Belmore Bridge (210458), Maitland 18 WWPS (R30), Bolwarra 1A WWPS (R29), or Branxton WWTW (R31). The adopted temporal pattern for each event varies with the specific historical rainfall scenario, depending on the available data (refer to Table 4).

The approach to model calibration was a joint calibration process of both the WBNM hydrologic model and TUFLOW hydraulic model. Rainfall loss parameters in WBNM and the Mannings 'n' roughness values in TUFLOW were adjusted until a reasonable match to the known flood level marks was achieved.

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

7.2. Hydrologic Model Parameters

The adopted hydrologic model parameters for the study are listed in Table 12.

Table 12: Adopted WBNM model parameters

Parameter	Value
C (Catchment Routing)	1.7
Impervious Catchment Area	See Section 5.3
Stream Routing Factor	1.0
Impervious Area Lag Factor	0.1
Initial loss	See Table 13
Continuing loss	2.5 mm/hr

7.3. Rainfall Losses

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

A continuing loss that provided the best average fit for all the historical events was determined through multiple model runs. A better fit to recorded levels could have been achieved by changing the continuing loss values across the historical events but it was deemed to be an exercise in curve fitting rather an accurate representation of catchment condition is. The rainfall loss values applied to the historical events are shown in Table 13.

Table 13: Calibration Event Rainfall Losses

Event	Initial Loss	Continuing Loss
April 2015	20 mm	2.5 mm/h
June 2007	10 mm	2.5 mm/h
January 2016	10 mm	2.5 mm/h

7.4. Calibration Results

7.4.1. April 2015

The April 2015 flood event was a significant event for the Lochinvar Creek Catchment and its tributaries, producing some of the highest flood levels on record across the catchment. The flood was a result of extremely intense rainfall (approximately 180 mm within a 24-hour period, falling primarily on the morning of 21st April). There was also significant rainfall in the preceding 24 hours. For calibration purposes the models were run for 1 day – from 9am on the 21st April to 9am on the 22nd of April. The temporal pattern from the Belmore Bridge (210458) gauge produced a representative peak flow and hydrograph shape compared to other nearby pluviometer gauges.

A comparison between the observed flood depths and modelled flood depths is shown in Table 14. A map of the peak flood depths as well as the difference between observed and modelled flood levels is shown in Figure B1.

Table 14: Observed and modelled peak flood levels for the April 2015 Event

Location ID	Address	Flood Level (m AHD)	Modelled Flood Level (m AHD)	Difference (m)
FM01	47A Station Lane	31.8	31.9	0.1
FM02	80 New England Highway	28.4	28.3	-0.1
FM03	New England Highway	29.5	29.6	0.1
FM04	2 Wyndella Road	35.8	35.3	-0.5
FM05	9 Freeman Drive	30.6	30.6	0.0
FM06	13 Freeman Drive	31.4	31.3	-0.1
FM07	33 Freeman Drive	34.8	34.7	-0.1
FM08	19 Freeman Drive	32.8	32.7	-0.1
FM09	28 Freeman Drive	35.6	35.4	-0.2
FM11	13 Hunter Close	29.6	29.6	0.0
FM10	15 Hunter Close	29.5	29.6	0.1
FM12	5 Hunter Close	29.6	29.6	0.0
FM13	1 Hunter Close	29.6	29.6	0.0
FM14	4 Hunter Close	29.6	29.6	0.0

The flood level upstream of the New England Highway was estimated to be approximately 29.5 to 29.6 mAHD, and the modelled flood levels are generally within this range. The modelled flood level on Greedy Creek was approximately 0.1 m higher than observed, however the model generally underestimated flood levels at properties along Freeman Drive that were subject to shallow inundation (up to 0.2 m below the observed levels).

7.4.2. January 2016

The January 2016 flood was a result of heavy rain from the 3rd to 6th January, with the most intense falls on 5th January. For calibration purposes, the models were run for a period of 1 day. The modelled rainfall depths across the catchment are shown in Figure 11. The temporal patterns from the Maitland 18 WWPS (R30) and Bolwarra 1a WWPS (R29) pluviometers were modelled to assess the potential variation in the distribution of rainfall. The peak depths are mapped in Figure B2 and Figure B3, for the Maitland and Bolwarra patterns respectively.

The January 2016 event was relatively minor in comparison with the other calibration events. This assertion is based on the rainfall analysis and limited community consultation responses provided for this event. The only anecdotal evidence provided was that the New England Highway flooded as the capacity of culverts was exceeded on the Robert Road Tributary. Modelling supports this, as seen in Figure B2 and Figure B3. Further, the flood event caused a spa to be uplifted at 60 Robert Road, at a location adjacent to these culverts.

7.4.3. June 2007

The June 2007 event occurred as a result of an east coast low that provided sustained heavy rainfall over a period of 2 days on 7th and 8th June. The models for this event were run for a period of 1 day. The modelled rainfall depths across the catchment are shown in Figure 9. The temporal patterns from the Maitland Belmore Bridge (210458) and Branxton WWTW (R31) pluviometers were modelled to assess the variation in the potential distribution of rainfall. The peak depths are mapped in Figure B4 and Figure B5, for the results using the Belmore Bridge and Branxton gauges respectively.

No flood marks were available for this event. However, anecdotal reports indicate that the lower reaches of Lochinvar Creek were heavily affected due to Hunter River Flooding. It should be noted that flood levels in the Hunter River for the 2007 event have been adopted from the previous study (Reference 7), however, the localised rainfall event across the Lochinvar catchment produces the maximum flood levels in the Lochinvar township well before the peak of the Hunter River flood. Accordingly, the time of peak Hunter River flood levels have not been modelled for this study (as this occurred significantly later than the local flooding).

Flooding in the upper reaches of the catchment was observed along Freeman Drive, where properties were isolated for one day (assumed to be due to access being cut off at the Freeman Drive crossing of Greedy Creek).

7.5. Discussion of Results

The TUFLOW model was primarily calibrated to the April 2015 flood event by comparing the modelled peak flood levels and observed flood levels across the catchment. The modelled results are a good match across Lochinvar as seen in Figure B1. The following is observed:

- The differences between modelled and observed peak flood levels upstream of the New England Highway (Hunter Close in particular) are within a ±0.1 m. High confidence is placed in the observed flood mark at 15 Hunter Close (FM10), as the property was inspected and the mark measured by WMAwater in the days after the flood event. The flows observed to overtop the New England Highway at Hunter Close resulted in a depth of inundation of approximately 0.1 m (FM03). Using the available LiDAR data, both of these flood marks were estimated to be 29.6 mAHD. Since these two flood marks are at either end of Hunter Close, there is a high level of confidence that the flood level reached 29.6 mAHD. The other flood marks located in Hunter Close indicate a flood level between 29.5 and 29.6 mAHD. The modelled flood level at each of these locations, including one mark immediately downstream of the New England Highway, indicate a very good match to these levels, being within ±0.1 m of the observed flood levels.

- Flooding observed along Freeman Drive was due to mixture of overland and mainstream flooding. Where shallow flow was reported at flood marks FM05 to FM09, the modelling results reflect this. The simulated flood level, however, was up to 0.2 m lower than that observed.
- A good match of the observed and modelled flood level is seen along Greedy Creek, where the flood mark measured at 47A Station Lane was within 0.1m of the modelling.
- The modelled flood level at 2 Wyndella Road underestimated the reported flood level by 0.5 m. This could be due to a number of possibilities, such as that:
  - the estimated spatial distribution of rainfall does not accurately reflect the actual distribution of rain that fell on the eastern portion of the catchment, and a more intense local burst occurred in this subcatchment; and/or
  - the reported flood depth at that location could have been was overestimated. Due to the nature of the driveway crossing the creek, a flood depth at the lowest point of the crossing would be difficult to estimate.

Calibration of the model was not undertaken for the June 2007 and January 2016 events due to a limited availability of observed flood marks. A more limited verification of anecdotal reports of the modelling was undertaken for these events, after calibrating to the April 2015 event.

January 2016 was not considered to be a major flood event, and there were not many reports of damage or inundation of property. It is useful to include this event as a calibration event, to ensure the model does not over-predict flood levels in smaller events. The only report of flood damage for this event was uplift of a spa in a property on Robert Road, and the modelling reproduced inundation at this location.

June 2007 was a major flood event for the Hunter River which is supported by anecdotal evidence provided by residents at the lower reaches of the catchment. Localised rainfall was also considered to be extreme, with residents reporting flooding in backyards along Freeman Drive.

The match of the model to historical events is considered to be good. There is a relatively high level of confidence in this study's 1% AEP design flood levels as the April 2015 calibration event was an extreme storm, likely more intense than a 1% AEP event. The hydrologic and hydraulic models are considered 'fit for purpose' for modelling design flood events with a high level of confidence.

8. DESIGN FLOOD EVENT MODELLING

8.1. Overview

ARR 2016 guidelines for design flood modelling were adopted for this study, including the use of ARR 2016 IFD information and temporal patterns for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP events. The PMF flows were derived using the Bureau of Meteorology's Generalised Short Duration Method (Reference 12) to estimate the probable maximum precipitation (PMP).

The flows generated by the WBNM model for the critical pattern duration for each design flood event were then used as inflows in the calibrated TUFLOW model to define the flood behaviour across the catchment using the representative pattern. 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, including an analysis of the results.

Flooding due to the Hunter River was not investigated in this study, beyond consideration of the results from the Hunter River: Branxton to Green Rocks Flood Study (Reference 7). In the 5% AEP flood event, the Hunter River causes inundation in the lower reaches of Lochinvar Creek, at the northern end of the Urban Release Area. This flood extent continues further upstream during rarer flood events, where the 1% AEP event extends to approximately 150 m downstream of the New England Highway Bridge and the 0.5% AEP event extends partially up into Greedy Creek. Across the majority of the Lochinvar township, the local catchment flooding produces higher peak flood levels, up to the 0.5% AEP. In events larger than this, the Hunter River dominates (produces higher peak levels) in areas near the New England Highway adjacent to Lochinvar Creek.

8.2. ARR 2016 IFD

ARR 2016 IFD information was obtained from the Bureau of Meteorology (BoM). IFD information was sourced for each subcatchment individually from the BoM's gridded IFD data and applied in the WBNM hydrologic model. For AEPs of 0.5% and 0.2%, the BoM does not provide design rainfall for durations shorter than 24 hours. Therefore, growth factors were derived for these AEPs for the 24 hour storm duration relative to the 1% AEP event. These factors were applied to the 1% AEP design rainfalls to derive the 0.5% and 0.2% AEP rainfalls for storm durations less than 24 hours. A summary of average design rainfall depths across the Lochinvar Creek catchment is provided in Table 15.

Table 15: Average design rainfall depths (mm) for the Lochinvar Creek catchment

Duration	AEP						
(min)	20%	10%	5%	2%	1%	0.5%	0.2%
60	36.4	43.9	51.6	62.4	71.2	79.7	93.7
90	41.5	49.9	58.6	70.7	80.5	90.2	106.0
120	45.5	54.7	64.2	77.4	88.1	98.7	116.0
180	51.9	62.5	73.4	88.7	101.0	113.2	133.0
360	59.8	72.2	84.9	102.8	117.4	131.6	154.6
720	66.5	80.4	94.9	115.2	131.9	147.9	173.7
1080	77.8	94.6	112.0	136.8	157.3	176.3	207.1
1440	87.4	106.6	126.7	155.3	179.1	200.7	235.8
2160	103.1	126.5	151.2	186.1	215.2	241.2	283.4
2880	115.7	142.5	171.0	210.9	244.2	273.7	321.5
4320	126.2	155.8	187.4	231.3	267.8	310.6	371.2

8.3. ARR 2016 Temporal Patterns

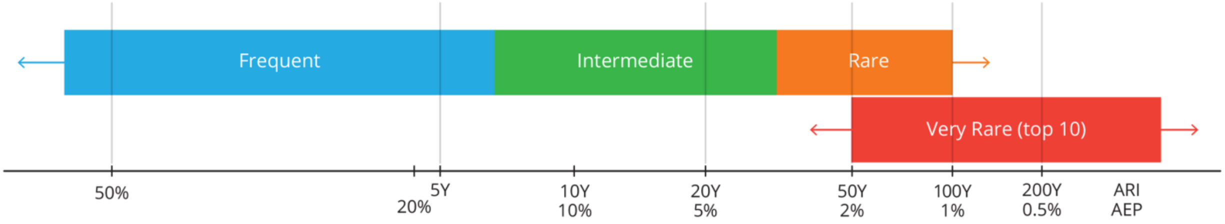
Temporal patterns are a hydrologic tool that describe how rain falls over time and are used in hydrograph estimation. Previously, with ARR 1987 guidelines (Reference 13), a single temporal pattern was adopted for each rainfall event duration. However, ARR 2016 (Reference 1) discusses the potential inaccuracies 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 the ARR 2016 data hub (Reference 1, http://data.arr-software.org/). A summary of the data hub information at the catchment centroid is presented in Attachment A. The revised 2016 temporal patterns attempt to address the key concerns practitioners found with the ARR 1987 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 ARR 1987 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 Lochinvar Creek catchment falling within the East Coast South region.

ARR 2016 provides 30 patterns for each duration and are sub-divided into three temporal pattern bins based on the frequency of the events. Diagram 1 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 ARR 2016 that have been utilised in this study for the 20% AEP to 0.2% AEP events.

Diagram 1: Temporal Pattern Bins



The method employed to estimate the PMP utilises a single temporal pattern (Reference 12).

8.4. Critical Duration Assessment

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

With ARR 2016 methodology, the adopted temporal pattern out of the ensemble of 10, is the pattern which produces the peak flows just greater than the average of the 10 peak flows for the critical duration. Thus, the temporal pattern adopted does not produce the largest peak flows for that storm duration. The critical storm duration for a location is then the design storm duration which produces the highest average flow across the full range of durations at that location of interest. The hydrologic model (WBNM) was used to assess the peak flows at key locations to select the critical duration and representative temporal pattern to run in the TUFLOW model.

Four key subcatchment outlet locations were chosen to assess the peak flows. The chosen subcatchments are listed below and can be seen on Figure 18.

- L032 – Upstream of urban areas on Lochinvar Creek
- L061 – Upstream of urban areas on Greedy Creek
- L036 – Catchment draining to New England Highway crossing Lochinvar Creek
- L083 – Catchment draining to New England Highway crossing Robert Road Tributary

A range of storm durations and the ensemble of temporal patterns were run in WBNM and the results were analysed at each of these locations. A box plot of 1% AEP flows for each of these locations can be seen in Diagram 2 to Diagram 5.

Diagram 2: Box Plot of Peak Flows at L032 – 1% AEP Event

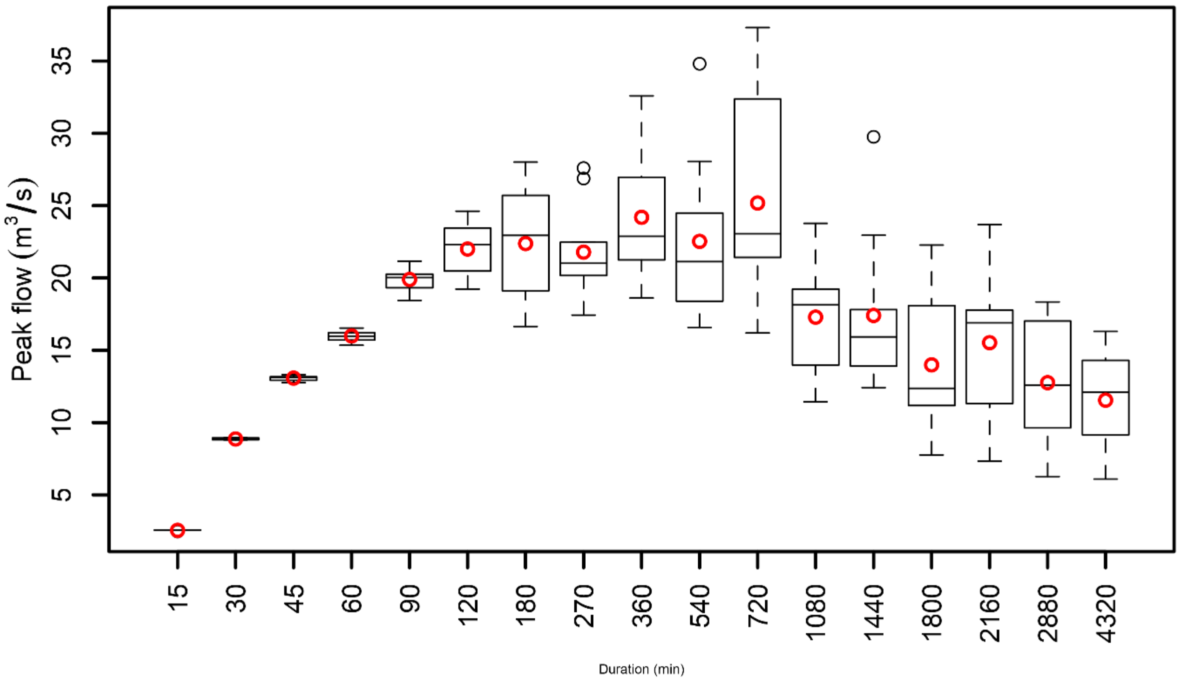


Diagram 3: Box Plot of Peak Flows at L036 – 1% AEP Event

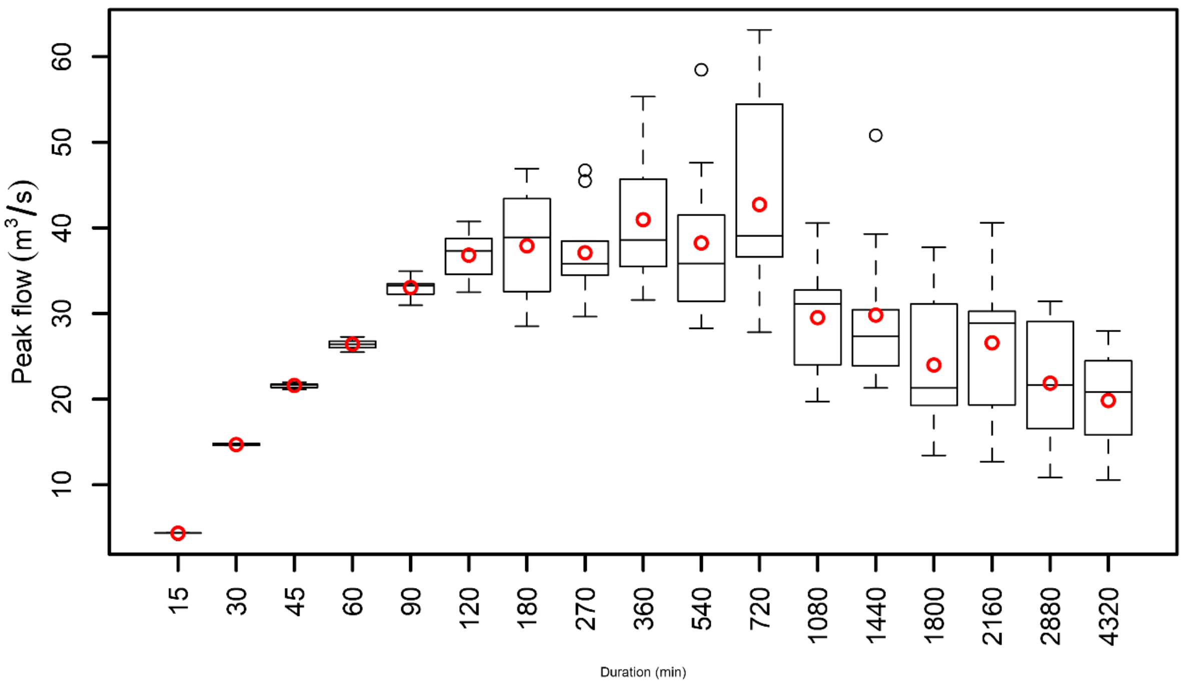


Diagram 4: Box Plot of Peak Flows at L061 – 1% AEP Event

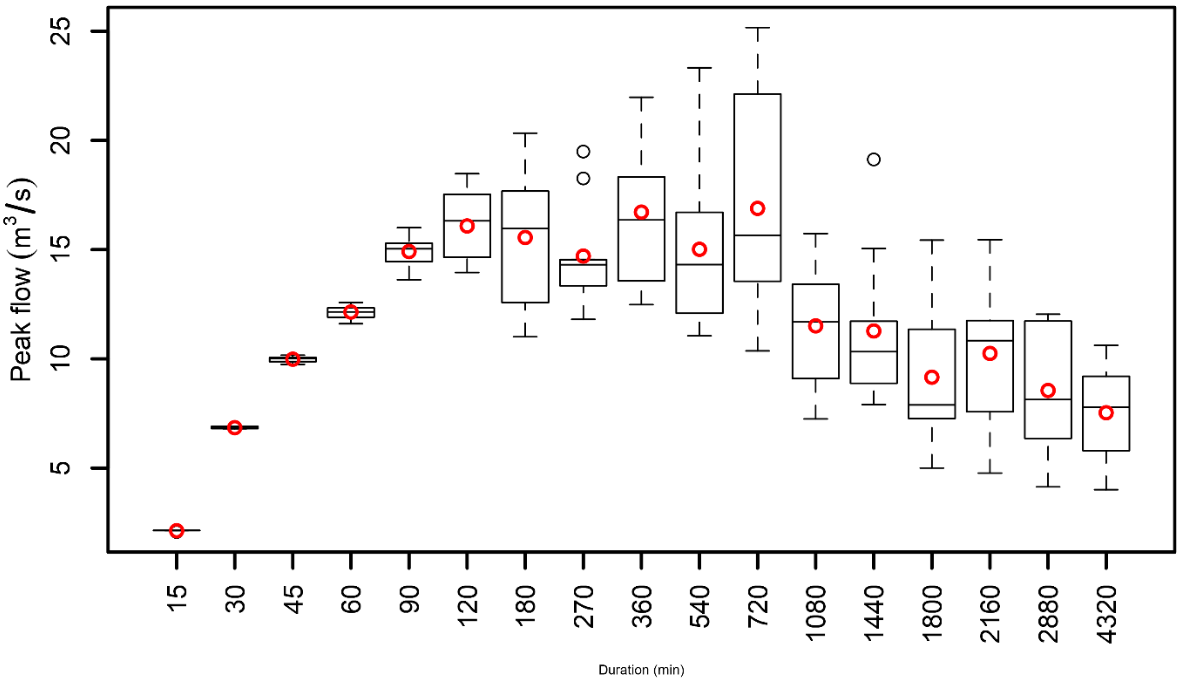
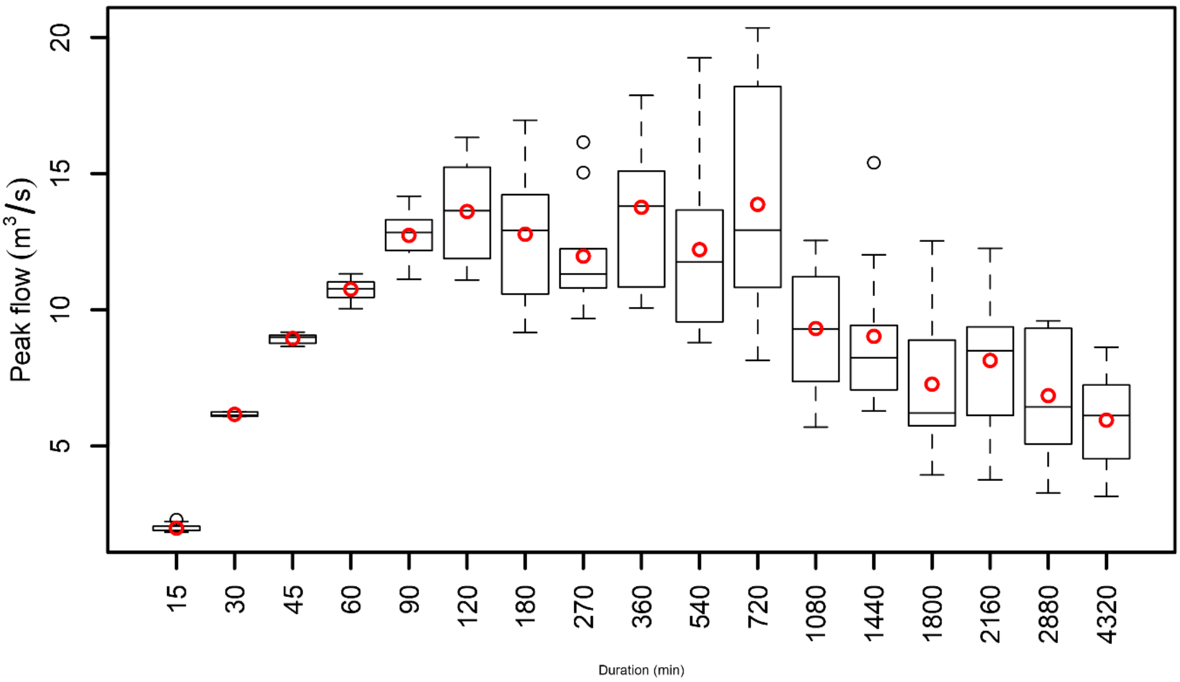


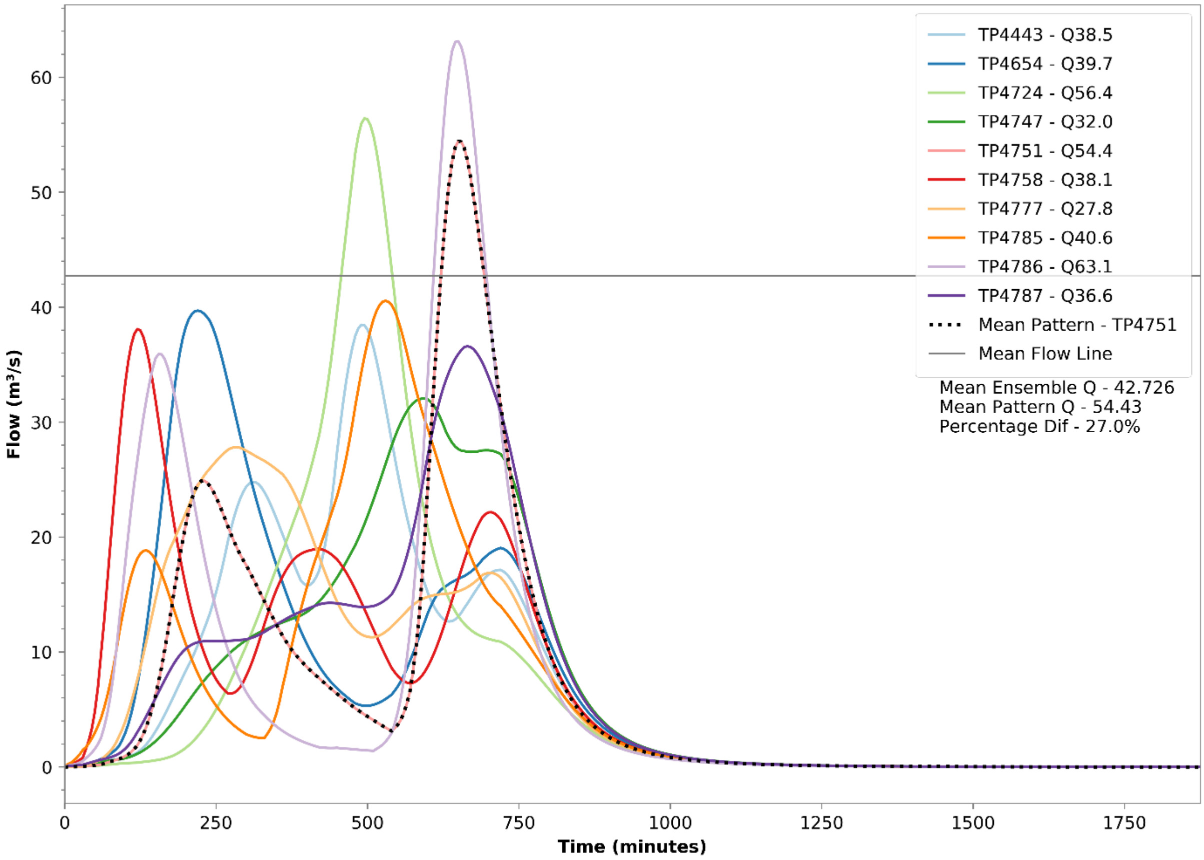
Diagram 5: Box Plot of Peak Flows at L083 – 1% AEP Event



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.

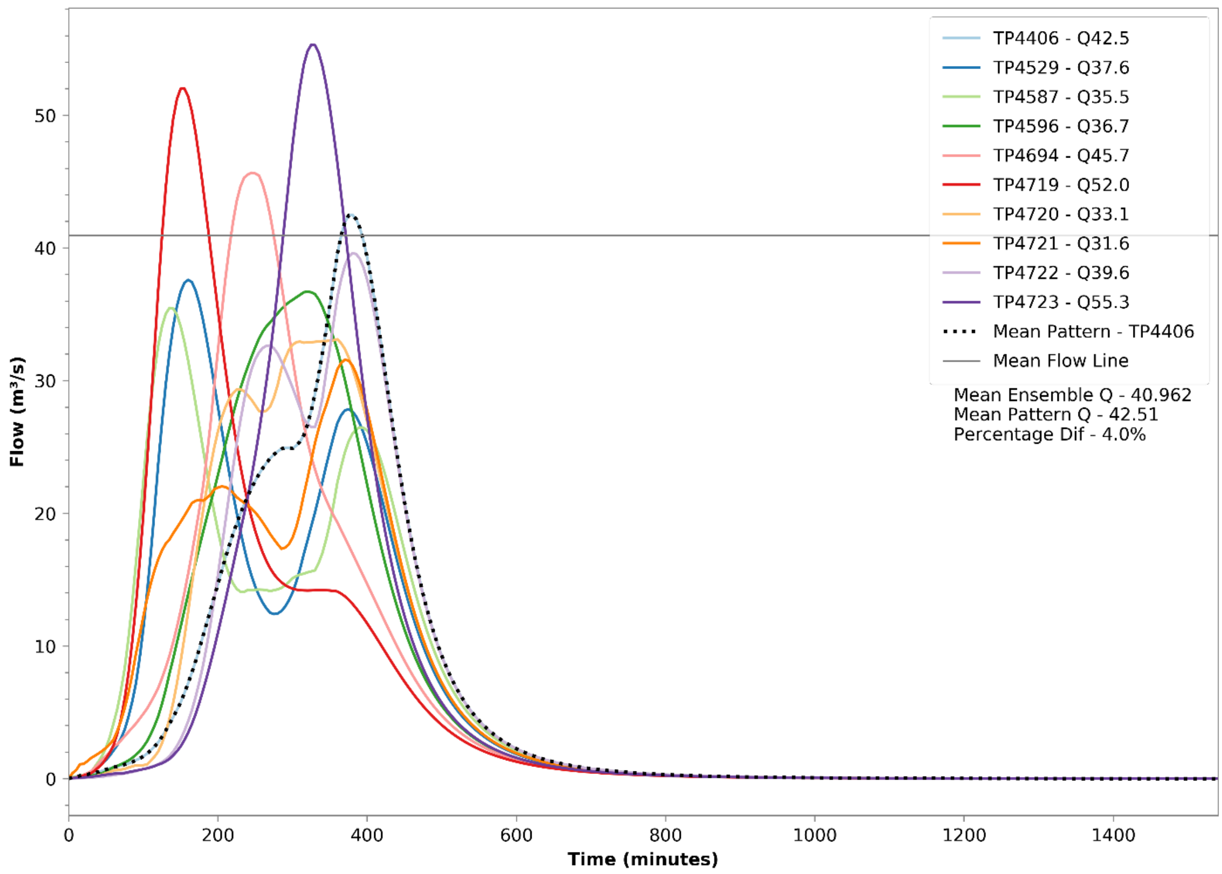
It can be observed that for the 1% AEP event, similar mean peak flows occur for a range of durations from 120 minutes up to 720 minutes. The 720 minute (9 hour) storm is critical at all of the key locations (highest mean flows from the ensemble of temporal patterns). The range of flows, however, produced by the 720 minute storm is quite large, and selecting the temporal pattern which produces the peak flow just above the mean flow results in peak flows being up to 30% higher than the mean critical flow. This is demonstrated visually in Diagram 6.

Diagram 6: 720 minute 1% AEP flow hydrographs for subcatchment L036



It can be seen from the box plot in Diagram 3 (for subcatchment L036), that the mean flow from the 720 minute storm (the critical flow) is within range of flows produced in other storm durations – from 120 minutes to 720 minutes. This means that there is likely to be a temporal pattern in other durations that closely matches the critical flow. Using the information contained in the box plots and the flow hydrographs, a representative duration and temporal pattern was selected that closely matches the critical flow across the key subcatchments. For example, at catchment L036, the 360 minute (6 hour) storm event has a temporal pattern with a peak flow that is within 1% of the critical flow, and is a more reasonable storm to simulate to represent the critical flow. This can be seen in Diagram 7 below.

Diagram 7: 360 minute 1% AEP flow hydrographs for subcatchment L036



This analysis was undertaken for all the design storm events, considering the key flow locations described above. A single duration and temporal pattern was adopted for each bin (see Diagram 1), being representative across the range of events and locations. The adopted representative temporal pattern and a summary of the flows can be found in Table 16.

The probable maximum precipitation (PMP) uses a single temporal pattern (Reference 12). In this case, the peak flows at each of the key subcatchments were analysed to determine the critical duration (duration which produces the peak flows). At all the locations of interest, the 90 minute storm was the critical duration and was adopted for the PMF design flood event.

Table 16: Summary of ensemble flows and the adopted flows

Catchment ID	Ensemble Results		Adopted Representative Results			
	Critical Duration (mins)	Mean (Critical) Flow (m^3/s)	Duration (mins)	Temporal Pattern ID	Peak Flow (m^3/s)	% Difference (Peak Flow minus Critical Flow)
20% AEP Event						
L032	360	8.6	360	4737	9.2	6.5%
L061	360	6.1	360	4737	6.3	3.9%
L036	360	14.7	360	4737	15.8	7.7%
L083	360	5.0	360	4737	5.1	1.9%
10% AEP Event						
L032	360	12.6	360	4660	12.7	0.7%
L061	360	8.7	360	4660	8.9	2.2%
L036	360	21.4	360	4660	21.5	0.6%
L083	360	7.0	360	4660	7.0	0.3%
5% AEP Event						
L032	360	16.5	360	4660	17.3	5.1%
L061	360	11.3	360	4660	11.9	5.4%
L036	360	28.0	360	4660	29.4	5.2%
L083	360	9.0	360	4660	9.4	3.5%
2% AEP Event						
L032	720	21.0	360	4406	21.3	1.5%
L061	720	14.1	360	4406	14.9	5.8%
L036	720	35.6	360	4406	36.2	1.6%
L083	720	11.6	360	4406	12.3	6.5%
1% AEP Event						
L032	720	25.2	360	4406	25.0	-0.8%
L061	720	16.9	360	4406	17.5	3.7%
L036	720	42.7	360	4406	42.5	-0.5%
L083	720	13.9	360	4406	14.5	4.4%
0.5% AEP Event						
L032	720	28.9	360	4406	28.5	-1.2%
L061	720	19.3	360	4406	19.9	3.2%
L036	720	49.0	360	4406	48.5	-1.1%
L083	120	15.9	360	4406	16.5	3.4%
0.2% AEP Event						
L032	720	35.0	360	4406	34.4	-1.8%
L061	120	23.6	360	4406	23.9	1.3%
L036	720	59.5	360	4406	58.5	-1.6%
L083	120	19.8	360	4406	19.8	0.0%

A summary of the adopted durations and temporal patterns for this study are shown in Table 17 below.

Table 17: Adopted durations and temporal patterns for design flood events

Event	AEP Bin	Adopted Duration (mins)	Adopted Temporal Pattern
20% AEP	Frequent	360	4737
10% AEP	Intermediate	360	4660
5% AEP	Intermediate	360	4660
2% AEP	Rare	360	4406
1% AEP	Rare	360	4406
0.5% AEP	Rare	360	4406
0.2% AEP	Rare	360	4406
PMF	Not applicable	90	Not applicable

8.5. Rainfall Losses

Design rainfall losses were obtained from the ARR 2016 data hub (http://data.arr-software.org/). The catchment straddles two loss regions – one to the north of the New England Highway and one to the south of the New England Highway. The initial losses are 18 mm in the north and 27 mm in the south. The continuing losses are 2.0 mm/hr for the north and 2.9 mm/hr in the south. A summary of the datahub output at the catchment centroid (lies just within the northern region) is presented in Attachment A.

As per ARR 2016 modelling methodology (Reference 1), pre-burst (the portion of rainfall that precedes the critical burst of the storm event) is subtracted from the storm initial loss to calculate the burst initial loss. The burst loss is applied to the hydrological model. The formula for deriving the burst initial loss is as follows (with negative losses assumed to be zero):

Burst Initial Loss = Storm Initial Loss – Pre-Burst Depth

The median pre-burst rainfall depth varies for each AEP and duration combination. That is, the initial loss applied to the hydrological model varies for each design storm modelled. Median pre-burst depths for all storm durations and AEPs were obtained from the ARR 2016 data hub (Attachment A) and the median pre-burst depths at the centroid of the Lochinvar Creek catchment are provided in Table 18.

Table 18 indicates that for the adopted critical duration of 360 minutes, the pre-burst depths range from 5.0 mm in the 20% AEP event to 9.6 mm in the 1% AEP event. With these pre-burst depths, the burst initial losses adopted in the hydrologic model range from approximately 8.4 mm to 22 mm.

Table 18: Median Pre-Burst Depths at the Centroid of the Study Area (mm)

Duration	AEP						
(min)	50%	20%	10%	5%	2%	2%	1%
60	0.8	1.0	1.2	1.3	1.4	1.4	1.5
90	0.7	0.7	0.7	0.8	1.2	1.2	1.5
120	0.0	0.1	0.2	0.3	1.1	1.1	1.8
180	1.4	1.8	2.0	2.2	2.0	2.0	1.8
360	1.6	5.0	7.3	9.4	9.5	9.5	9.6
720	2.8	6.3	8.6	10.9	13.2	13.2	14.9
1080	0.3	6.2	10.2	14.0	15.1	15.1	15.9
1440	0.0	3.2	5.3	7.3	9.8	9.8	11.7
2160	0.2	2.1	3.3	4.5	6.6	6.6	8.1
2880	0.0	0.0	0.0	0.0	0.2	0.2	0.4
4320	0.0	0.0	0.0	0.0	0.0	0.0	0.0

8.6. Areal Reduction Factors

Areal Reduction Factors (ARF) were applied in the WBNM model for the design storm events based on ARR 2016 (Reference 1). 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 19. The equation used to derive these reduction factors can be found in Attachment A.

Table 19: Areal Reduction Factors for the Design Storm Events

Duration	AEP							
(min)	50%	20%	10%	5%	2%	1%	0.5%	0.2%
60	0.91	0.90	0.90	0.89	0.88	0.87	0.87	0.86
90	0.93	0.92	0.91	0.90	0.89	0.88	0.88	0.86
120	0.94	0.93	0.92	0.91	0.90	0.89	0.88	0.87
180	0.95	0.94	0.93	0.92	0.90	0.89	0.88	0.87
270	0.96	0.95	0.94	0.93	0.92	0.91	0.90	0.89
360	0.97	0.96	0.95	0.95	0.94	0.94	0.93	0.92
540	0.97	0.97	0.97	0.96	0.96	0.96	0.95	0.95
720	0.98	0.97	0.97	0.97	0.96	0.96	0.96	0.95
1080	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97
1440	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
1800	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
2160	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98
2880	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
4320	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

8.7. Coincident Hunter River Flooding and Tailwater Levels

For the design flood events for Lochinvar Creek, a coincident static Hunter River flood level of 22.25 mAHD was adopted. This is equivalent to a 5% AEP Hunter River flood level at Lochinvar (Reference 7). This flood level extends up Lochinvar Creek to approximately the last property (number 51) on Cantwell Road. This is at the northern extent of the Urban Release Area.

The lower Lochinvar Creek catchment is dominated by Hunter River Flooding. Flood extents for major Hunter River flooding were defined in Reference 7. This study defines flood extents for localised storm events over the Lochinvar Creek catchment (similar to April 2015), which may or may not occur in conjunction with Hunter River flooding. Generally, localised storms would be expected to coincide with only minor Hunter River flooding and the timing of the flood peaks are unlikely to coincide. There is not enough historical data to undertake a comprehensive joint probability analysis for the two flood mechanisms.

8.8. Initial Water Level Assumptions

The only initial water levels specified in the model were for water in the Hunter River, using the adopted tailwater level (Section 8.7).

Localised initial water levels were not widely used in other parts of the catchment area, such as in the creek channels or for farm dams in the catchment. This is because the LiDAR data used to define the terrain in the model does not penetrate standing water, and the DEM levels typically reflect the water level in storages at the time of the survey. There are a number of farm dams located upstream of Lochinvar where this is the case. The majority of dams were reasonably full at the time of LiDAR capture, with approximately 0.1 m of freeboard between the water level and crest level of the dam. The dams are therefore assumed to be almost full for the purposes of this study.

There were two dams with water levels more than 0.1 m below the overtopping level of the dam with considerable storage available. One dam is located adjacent to the New England Highway at the ‘Aird’s’ property (on a small tributary) and the other is located on the Robert Road Tributary just upstream of Robert Road. For these dams, the initial water level in the dam was set to be just below the overtopping level of the dam.

8.9. Blockage

Design blockage for hydraulic structures was adopted in accordance with Reference 1. The debris availability, debris mobility and debris transportability was deemed to be in the Low to Medium categories for the Lochinvar Creek catchment, due to the large amount of cleared land upstream of Lochinvar. The overall debris potential was classified as Low. With this classification, an inlet headwall blockage of 25% was applied to all road crossing culvert structures in the model. The New England Highway Bridge over Lochinvar Creek had a debris blockage of 5% applied.

9. DESIGN FLOOD EVENT MODELLING RESULTS

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

- Peak flood depth and level contours in Figure C1 to Figure C8;
- Peak flood velocities in Figure C9 to Figure C16;
- Provisional hydraulic hazard based on the NSW Floodplain Development Manual in Figure C17 to Figure C19;
- Hydraulic hazard based on the Australian Disaster Resilience Handbook in Figure C20 to Figure C22;
- Provisional hydraulic categories in Figure C23 to Figure C25;
- Flood Emergency Response Classifications in Figure C26 to Figure C28; and
- Provisional Flood Planning Area in Figure C29.

Additional results are presented in the following tables and graphs:

- Peak flood level profiles in Figure D1 to Figure D3;
- Stage hydrographs at road crossings in Figure D4 to Figure D15; and
- Peak flood depths and flows at road crossings and key locations in Table D1 and Table D2.

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

9.1. Summary of Results

The flood behaviour across the Lochinvar catchment can be seen in the peak flood depth and water level contour maps (Figure C1 to Figure C8), the peak velocity maps (Figure C9 to Figure C16) and peak water level profile graphs (Figure D1 to Figure D3). These results are presented for the range of design flood events modelled from the 20% AEP to the PMF event.

In the 20% AEP event, flows are generally contained within Lochinvar Creek and Greedy Creek upstream of Lochinvar. There are overland flows modelled through the properties on Freeman Drive, however, the flows are generally very shallow (less than 0.1 m). Floodwater also begins to encroach onto the floodplain upstream of the New England Highway. On the Robert Road Tributary, the road crossings of Robert Road, Gregory Road and New England Highway cause floodwaters to pond behind these crossings. Floodwaters also spread out along the tributaries in the vicinity of the New England Highway, where defined creek channels do not exist. Downstream of Lochinvar, flooding is dominated by the adopted Hunter River tailwater level.

A similar pattern of flooding occurs in the 10% and 5% AEP events. Hunter Close floods in the 5% AEP event and the New England Highway is overtopped at the Robert Road Tributary. Flooding begins to affect properties in Hunter Close in the 2% AEP event, with floodwaters surrounding all properties on the eastern side of Hunter Close in the 1% AEP event. Hunter Close is the most affected area in the 0.5% and 0.2% AEP events, with floodwaters reaching 0.3 to 0.5 m at a number of properties. Overland flooding along Freeman Drive remains fairly shallow (generally less than 0.1 m).

In the PMF event, there is significant flooding through Lochinvar, particularly due to Lochinvar

Creek. The flooding in the creek is approximately 150 m to 180 m wide, causing inundation of most properties on the northern side of Freeman Drive, with depths of approximately 0.5 m to 1 m. Shallow overland flooding still occurs on the southern side of Freeman Drive. Floodwaters also reach a number of properties on the western side of Greedy Creek. Upstream of the New England Highway, flooding completely inundates Hunter Close and several properties to the west located on the New England Highway and Occupation Lane. Flood depths in Hunter Close are between 2 m and 3 m. The PMF extent also reaches to properties to the east of Lochinvar Creek on Station Lane. Flooding in Lochinvar Creek is approximately 300 m wide as it overtops the New England Highway and inundates properties located on the northern side of the highway. Flooding on the Robert Road Tributary is only slightly more extensive than the 0.2% AEP event, with a significant stretch of the New England Highway being inundated by the Robert Road Tributary and the smaller tributaries to the east.

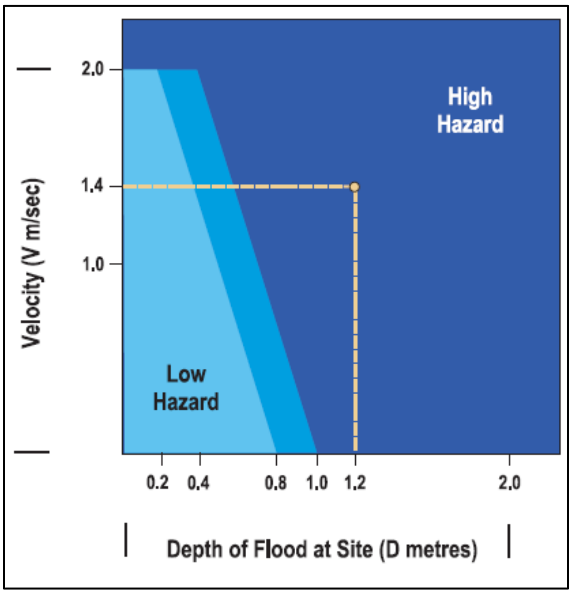
9.2. Hydraulic Hazard Categorisation

Hydraulic hazard is a measure of potential risk to life and property damage from flood. Hydraulic hazard is typically determined by considering the depth and velocity of floodwaters. 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.

Hydraulic hazard categories were determined for the Lochinvar Creek catchment by two methods – one in accordance with the NSW Floodplain Development Manual (Reference 2), and the other in accordance with the Australian Disaster Resilience Handbook Collection (Reference 14). Each is discussed below. Note that this mapping does not include consideration of the Hunter River Design Flood Events (Reference 7), which should also be considered for development control planning.

9.2.1. Floodplain Development Manual Categorisation

Diagram 8: Provisional “L2” Hydraulic Hazard Categories (Source: Reference 2)



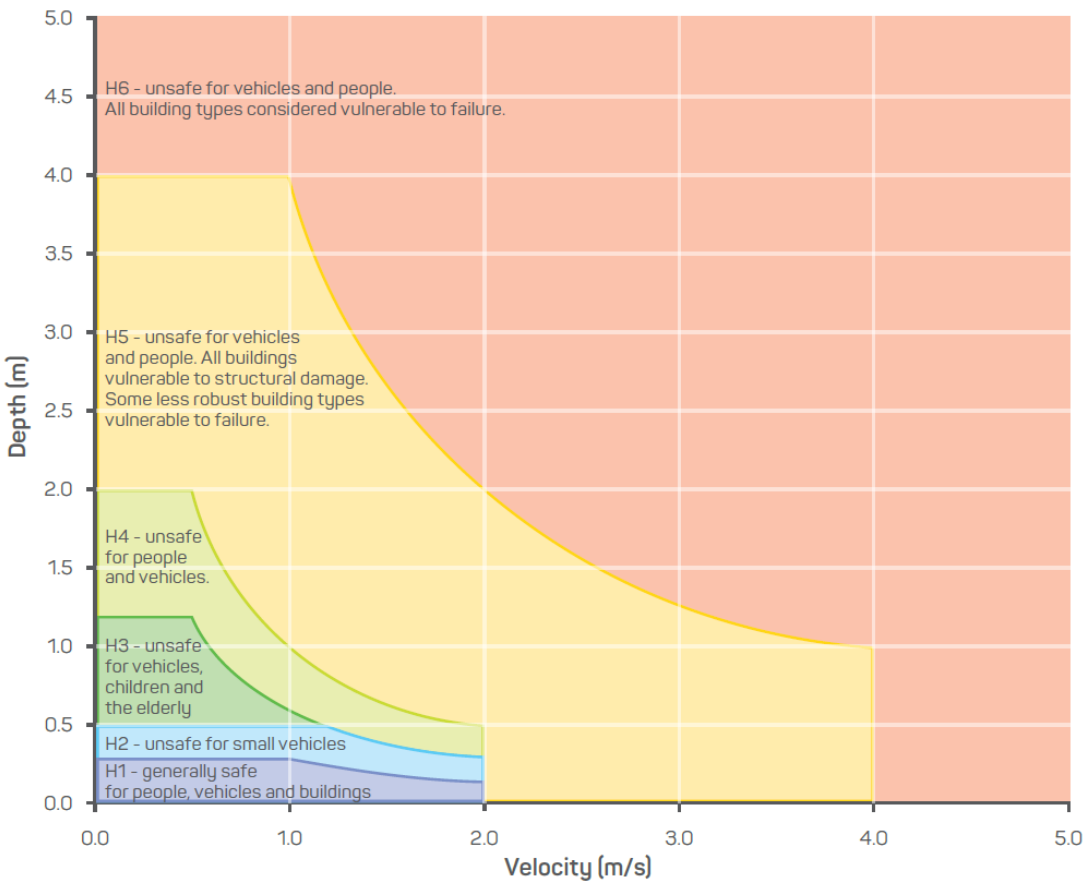
Appendix L of the NSW Floodplain Development Manual (FDM, Reference 2) gives one method for hydraulic hazard, which is shown in Diagram 8. In this study, the transition zone was considered to be high hazard.

The hydraulic hazard utilising the FDM categorisation is mapped on Figure C17 to Figure C19 for the 5% AEP, 1% AEP and PMF events respectively. The FDM hazard categorisation has been included for applicability to existing council policy documents that may refer to this hazard classification.

The high hazard areas are primarily within the channels on Lochinvar Creek and Greedy Creek upstream of the New England Highway in the 5% AEP event. There are some areas of high hazard in storage areas on the Robert Road Tributary. Downstream of Lochinvar the depth from the adopted Hunter River tailwater level causes much of the floodplain to be classified as high hazard. High hazard areas in the 1% AEP event follow a similar pattern, with greater continuity on the tributary flow paths. In the PMF event, much of the floodplain is classified as high hazard.

9.2.2. Australian Disaster Resilience Categorisation

Diagram 9: General flood hazard vulnerability curves (Source: Reference 14)



The Australian Disaster Resilience (ADR) 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 14) contains information relating to the categorisation of flood hazard. A summary of this categorisation is provided in Diagram 9.

This classification provides a more detailed distinction and practical application of hazard categories than the FDM method, 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 categories using the ADR classification are mapped in Figure C23 to Figure C25 for the 5% AEP, 1% AEP and PMF events respectively. In the 5% AEP event, Lochinvar Creek and Greedy Creek are in the H4 and H5 category. The Robert Road Tributary is primarily up to the H3 category. Much of the overland flow areas are classified as H1. Downstream of the Lochinvar Creek and Robert Road Tributary confluence, the hazard reaches H6 due to the depth of the adopted Hunter River tailwater level. In the 1% AEP event, the H5 category is more prominent in Lochinvar Creek and Greedy Creek, with other areas remaining similar to the 5% AEP event. In the PMF event, the hazard reaches H6 in Lochinvar Creek and Greedy Creek, with the majority of the remaining flooded area (including Robert Road Tributary) being up to H5 category.

9.3. Provisional Hydraulic Categorisation

Hydraulic categorisation involves mapping the floodplain to indicate which areas are most important for the conveyance of floodwaters, and the temporary storage of floodwaters. This can help in planning decisions about which parts of the floodplain are suitable for development, and which areas need to be left as-is to ensure that flooding impacts are not worsened compared to existing conditions.

The NSW Governments Floodplain Development Manual (Reference 2) 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 15), rely on combinations of velocity and depth criteria to define the floodway.

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

- Floodway is defined as areas where:
  - the peak value of velocity multiplied by depth (V x D) > 0.25 m^2/s, **AND** peak velocity > 0.25 m/s, **OR**
  - peak velocity > 1.0 m/s **AND** peak depth > 0.3 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 > 0.4 m; and
- Flood Fringe comprises areas outside the Floodway where peak depth < 0.4 m.

The provisional hydraulic categories have been mapped in Figure C23 to Figure C25 for the 5% AEP, 1% AEP and PMF events. As expected, the creeks and major tributaries are classified as floodways in the 5% AEP and 1% AEP events, with flood storage areas mostly located where there are farm dams, or where road embankments cause ponding of water (for example, on the Robert Road Tributary). The adopted Hunter River tailwater level causes backwater which results in a large area downstream of the Lochinvar township being classified as flood storage. In the PMF event, the majority of flooded areas are classified as floodways, with only some small farm dams and areas near the Hunter River being flood storage areas, and flood fringe areas being located where there is shallow overland flow.

9.4. Flood Emergency Response Planning

9.4.1. Property Inundation

The properties with the highest flood risk are located in Hunter Close. Floodwaters begin to encroach onto properties in the 5% AEP event. In the 1% AEP event there are flood depths of approximately 0.3 m at the houses located closest to Lochinvar Creek and flood depths of up to 0.6 m on the road. In the PMF event, flood depths of 2 to 3 m occur at the properties in Hunter Close.

Generally, other properties located in the Lochinvar township are not inundated in events up to and including the 0.2% AEP event. Properties located along Freeman Drive are subject to shallow overland flooding in these events. This area has been modelled in this way to replicate the numerous reports of flooding for these properties in the April 2015 flood event. The depth due to overland flooding in this area is generally less than 0.1 m and not considered to be a significant flood risk. This is also the case for one property located on the New England Highway opposite

Hunter Close.

In the PMF event, however, the properties located on the northern side of Freeman Drive are subject to inundation depths of approximately 0.5 to 1 m. Floodwaters also reach a number of properties on the western side of Greedy Creek. In addition to significant flooding in Hunter Close, the adjacent Lochinvar Public School and several properties in Occupation Lane are also subject to flooding in the PMF event. Properties on the northern side of the new England Highway in this location are also inundated.

9.4.2. Road Inundation

Inundation of roads has been recorded at a number of key locations across the catchment. The resulting depth of inundation over these roads for each of the design flood events can be seen in Table D1. Peak flows at key structures and overtopping roads can also be seen in Table D2. Peak water level profiles along Lochinvar Creek, Greedy Creek and Robert Road Tributary can be found in Figure D1 to Figure D3, and water level hydrographs at each of the major road crossings (identified in Figure 22) can be found in Figure D4 to Figure D15.

There are several road crossings within the study area that do not have cross drainage structures and hence are flooded even in minor flood events. This includes Station Lane at the upstream extent of Greedy Creek (D01), Station Lane at Christopher Road (D03), Robert Road and Gregory Road crossing the Robert Road Tributary (D08 and D09), and Wyndella Road to the north (D12). The flooding is generally shallow (up to 0.4 m in the 0.2% AEP event). When the depth of flooding reaches 0.3 m, it has been assumed that these roads will be cut off (based on Diagram 9 for small vehicles).

Other road crossings with cross drainage structures have varying levels of flood immunity. Station Lane at downstream Greedy Creek (D02) is first overtopped in the 2% AEP event, and should remain trafficable up to the 0.2% AEP event. The duration of inundation is approximately 1 hour. Freeman Drive at Greedy Creek (D04) is inundated in the 2% AEP event and begins to be untrafficable in the 1% AEP event. Again, the duration of inundation is only approximately one hour. The Freeman Drive sag point (D05) is also modelled to be inundated due to overland flooding of less than 0.1 m in events up to and including the 0.2% AEP event. The New England Highway at the Robert Road Tributary (D10) is first inundated in the 5% AEP event, but flooding remains shallow (up to 0.2 m) up to the 0.2% AEP event. Wyndella Road south (D11) is overtopped in the 2% AEP event, but should remain trafficable up to the 0.2% AEP event.

Hunter Close at the cul-de-sac (D06) begins to be affected by floodwater in the 10% AEP event, and is too deep for small cars in the 5% AEP event, although this varies along the road as it rises to the New England Highway. The duration of inundation is up to 4 hours. The New England Highway itself at this location (D07) is only overtopped in the PMF event, for approximately 2 hours.

In the PMF event, all these roads have flood depths exceeding 0.3 m, and are considered to be cut off, although the duration of inundation is less than 4 hours.

9.4.3. 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 16) 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 16), communities are classified to assist in emergency response planning (refer to Table 20).

Table 20: Emergency Response Planning Classification of Communities

Classification	Description	Response Required		
		Resupply	Rescue/Medivac	Evacuation
High flood island	Area not flooded, but surrounded by floodwaters (cut off).	Yes	Possibly	Possibly
Low flood island	Area first surrounded by floodwaters (limiting evacuation) and is then inundated.	No	Yes	Yes
High trapped perimeter	Area not flooded, but is cut off by floodwaters and impassable terrain/structures.	Yes	Possibly	Possibly
Low trapped perimeter	Area first cut off by floodwaters and impassable terrain/structures, and is then inundated.	No	Yes	Yes
Area with overland escape route	Areas affected by flooding and where vehicle access is cut off, but evacuation on foot is possible.	No	Possibly	Yes
Area with rising road access	Areas affected by flooding, but where roads are accessible to vehicles, rising away from floodwaters.	No	Possibly	Yes
Indirectly affected areas	Areas not inundated, but may be subject to disruptions to utility supply, transport links or communications.	Possibly	Possibly	Possibly

Key considerations for flood emergency response planning in the Lochinvar 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 into a single category, 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 14). Properties were assumed to be fenced at the rear and sides, and that these form barriers for access. The ERP classification of communities for the study area are shown in Figure C26 to Figure C28 for the 5% AEP, 1% AEP and PMF events. These figures also show major access roads that are cut in each event (discussed in Section 9.4.2).

In the 5% AEP event, there are two areas that are cut off and classified as high flood islands. One is located along Station Lane, between two crossings of Greedy Creek. Although the depth of inundation on Station Lane is small (up to approximately 0.3 m at the lowest point of these crossings), this is considered to be cut off for small vehicles. This isolates several properties located south of Lochinvar. The other area includes a number of properties located off Station Lane near Freeman Drive. The local driveway has flooding exceeding 0.3 m depth, due to a lack of cross drainage. An area opposite this on Station Lane is classified as having an overland escape route in the 5% AEP event. Even though Station Lane is inundated where these properties are located (and may not be trafficable for small vehicles), residents would be able to walk north along Station Lane if access is required. This is the same situation for a couple of properties located at the end of Hunter Street, where although vehicle access may not be possible, residents will be able to evacuate on foot. Properties located along Freeman Drive that are subject to shallow overland flooding have rising road access. This is also the case for properties located on the northern side of the New England Highway adjacent to Lochinvar Creek.

In the 1% AEP event, a similar classification can be found to the 5% AEP event. The only notable change is the increased extent of inundation of Hunter Close, which now classifies the entire street as having an overland escape route. While the road has substantial inundation and is not trafficable, residents would be able to walk north to the New England Highway, alongside the road and through front yards, which are flood free, or subject to only shallow inundation. An additional property located on Wyndella Road is identified as a high flood island, since the driveway access is assumed to be cut off.

In the PMF event, there are several large areas affected by flooding or access routes being cut. The northern side of Freeman Drive, Hunter Close, Lochinvar Public School and properties on the northern side of the New England Highway opposite Hunter Close are low flood islands, being inundated to a substantial depth. The remaining properties in the vicinity of Freeman Drive are isolated due to Freeman Drive being cut off at Greedy Creek. Floodwaters overtop the New England Highway and cut off access between Hunter Close and west of Robert Road. This isolates a large area both to the north and south of the New England Highway, considering Station Lane is also cut off.

Some of the areas identified as high flood islands may have their access improved in a future redevelopment of Lochinvar. The raising of roads and/or upgrading cross drainage at tributary crossings may improve accessibility during flood events (as recommended in Reference 8). Station Lane in particular is a key access route that can be cut in frequent flood events and would benefit from upgrade works.

9.4.4. Community and Emergency Facilities

Knowledge of the location of community facilities (for evacuation of large numbers of people that may be present, evacuation of less mobile people – such as children or the elderly, or for potential evacuation centre locations) and emergency services (police, fire, ambulance, SES) are important in the event of a flood. The community facilities and emergency services present within the study area are shown in Table 21. The table also outlines in what event the facility is inundated and potential issues.

Table 21: Community Facilities and Emergency Services within the Study Area

Type	Name	Location	Comment
Hotel	Lochinvar Hotel	114 New England Highway	Not flooded in PMF, access only to west of Lochinvar Creek
Medical Centre	Lochinvar Medical Centre	101 New England Highway	Not flooded in PMF, access only to west of Lochinvar Creek
School	Lochinvar Public School	95 New England Highway	Flooded in PMF event only, access only to the west of Lochinvar Creek
Police Station	Lochinvar Police Station	24 Station Lane	Not flooded in PMF, isolated in between Lochinvar Creek, Greedy Creek and Robert Road Tributary
School / Church	St Patricks Church and Primary School	113 Gregory Road	Not flooded in PMF, isolated in between Lochinvar Creek, Greedy Creek and Robert Road Tributary
School	St Joseph's College	New England Highway	Not flooded in PMF, isolated in between Lochinvar Creek, Greedy Creek and Robert Road Tributary
Church	Holy Trinity Anglican Church	New England Highway	Not flooded in PMF, isolated in between Lochinvar Creek, Greedy Creek and Robert Road Tributary

Emergency services facilities are present in towns to the east of the study area. This includes SES in Metford (17 km), Fire and Rescue in Rutherford (6 km) and a Hospital in Maitland (10 km). These would be accessible via the New England Highway in all events except the PMF. In this case, there is an area of Lochinvar which is isolated, including the Police Station, two schools and two churches. These premises could be used for potential evacuation locations for the isolated area if required. Lochinvar Public School is only flooded in the PMF event, while the Lochinvar Hotel remains flood free for areas to the west of Lochinvar Creek along the New England Highway. This area also has the Lochinvar Medical Centre, which is also flood free in all events.

9.5. Preliminary Flood Planning Area

The preliminary Flood Planning Area (FPA) was determined by adding 0.5 m freeboard to the 1% AEP flood level, and "stretching" this surface across the topography to form the FPA. Flood depths less than 0.1 m, and small areas of ponding were removed from the 1% AEP flood extent prior to determining the FPL. The resulting FPA was trimmed to the extent of the PMF. The preliminary FPA is shown in Figure C29.

The preliminary FPA is generally slightly more extensive than the 0.2% AEP flood event. The previously derived FPA for the Hunter River (Reference 7) is also shown on the map. The Hunter River FPA dominates in areas downstream of the Lochinvar township, in the lower catchment area.

9.6. Advice on Land-Use Planning Considering Flooding

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

9.6.1. Existing Flood Planning Controls

Maitland Council implements flood-related planning controls via the Local Environment Plan (LEP) and Development Control Plan (DCP). The LEP specifies that land is subject to flood-related restrictions on development if it is

- shown as "Flood planning area" on the Flood Planning Map [in the LEP], or
- other land at or below the flood planning level [defined in the LEP to be the 1% AEP flood level plus 0.5 m freeboard].

The LEP outlines the nature of these restrictions, and more detailed requirements are specified in the DCP for different land uses. The LEP and DCP refer to mapping outputs that have been produced as part of this and other flood studies undertaken for Council. Land use planning in Maitland Council considers the flood hazard (Figure C17 to Figure C22), flood function (Figure C23 to Figure C25) and evacuation potential (Figure C26 to Figure C28) of the land.

9.6.2. Recommended Updates

This is a typical approach for consideration of flooding in land use planning, although WMAwater recommends that Council consider the following refinements:

- The time required to modify mapping in the LEP is significant, due to the consultation and exhibition requirements, and the approval requirements from state government departments. This means that the flood maps in the LEP will usually not reflect studies that have been recently undertaken. Council should therefore consider revising the LEP so that mapping of the Flood Planning Area (FPA) is either provided in the DCP, or via some other method (for example by referring to a mapped Flood Planning Area from any flood study adopted by Council). The preliminary FPA for the Lochinvar Creek catchment is provided in Figure C29 of this study (see Section 9.5 below for details).

- The DCP currently refers to the "Hunter River Floodplain," but there are other areas of the Maitland LGA that are flood-prone which are not part of the Hunter River floodplain, including the upper parts of the Lochinvar Creek catchment. The DCP should be updated so that appropriate development controls are applied across all flood prone areas of the LGA.
- The current Lochinvar Structure Plan (Reference 3) identifies the Lochinvar area as an opportunity for expansion of the existing community in the lower Hunter region. The structure plan identifies flooding and drainage as a current constraint, however this is primarily based upon maintaining existing drainage lines and riparian buffer zones. Any future development in Lochinvar should consider this flood study when determining potential areas to be developed. Any changes in land use or new developments should be compatible with the nature of flooding in the area. The information contained in the flood study regarding the flood hazard, flood function and evacuation potential should be used in land use planning activities to ensure that proposed land uses do not increase the flood risk to people. As a preliminary assessment of flood constraints for land use planning activities, Flood Planning Constraint Categories can be considered and are discussed in the following section.

9.6.3. Flood Planning Constraint Categories

Guideline 7-5 of the Australian Disaster Resilience Handbook Collection (Reference 17) recommends using Flood Planning Constraint Categories (FPCCs) to better inform land use planning activities. These categories condense the wealth of flood information produced in a flood study and classify the floodplain into areas with similar degrees of constraint. These FPCCs can be used in high level assessments of land use planning to inform and support decisions. For detailed land use planning activities, it is recommended that the flood behaviour across the range of flood events be considered, depending on the level of constraint.

The Australian Disaster Resilience Handbook Collection (Reference 17) recommends the use of four constraint categories. It is recommended that isolation potential also be considered for the high constraint category. This could include areas classified as 'low flood island', 'low trapped perimeter', 'high flood island' and 'high trapped perimeter' (see Section 9.4.3 for details). Isolation has not been considered in the FPCCs defined for Lochinvar, since it is not considered to be a significant constraint in this catchment for local catchment flooding. In land use planning for greenfield areas, it is assumed that any development would be accompanied by new roads and access routes which would change the isolation potential of the land (given that Lochinvar is affected by small creeks, tributaries and overland flow which new roads could easily cross). In areas that are already developed, the isolation potential has been defined using Emergency Response Planning classifications, and land use planning activities should consider these in addition to the FPCCs.

The constraints have been adapted to suit the Lochinvar Creek catchment and are outlined in Table 22. The associated FPCC map can be found in Figure C30.

Table 22: Flood Planning Constraint Categories for the Lochinvar Creek Catchment

FPCC	Constraints	Implications	Considerations
FPCC 1	Floodway and flood storage areas in the 1% AEP event H6 hazard in the 1% AEP event	Any development is likely to affect flood behaviour in the 1% AEP event and cause impacts elsewhere. Hazardous conditions considered unsafe for vehicles and people, all types of buildings considered vulnerable to structural failure.	Majority of developments and uses have adverse impacts on flood behaviour or are vulnerable. Consider limiting uses and developments to those that are compatible with flood function and hazard.
FPCC 2	Floodway in the 0.2% AEP event H5 flood hazard in the 1% AEP event H6 flood hazard in the 0.2% AEP event	People and buildings in these areas may be affected by dangerous floodwaters in rarer events. Hazardous conditions considered unsafe for vehicles and people, and all buildings vulnerable to structural damage. Hazardous conditions develop in rare events which may have implications for the development and its occupants.	Many uses and developments will be vulnerable. Consider limiting new uses to those compatible with flood function and hazard (including rarer flood flows) or consider treatments to reduce the hazard (such as filling). Consider the need for additional development control conditions to reduce the effect of flooding on the development and its occupants.
FPCC 3	Within the FPA	Hazardous conditions may exist creating issues for vehicles and people. Structural damage to buildings is unlikely.	Standard land use and development controls aimed at reducing damage and the exposure of the development to flooding are likely to be suitable. Consider additional conditions for emergency response facilities, key community infrastructure and land uses with vulnerable users.
FPCC 4	Within the PMF extent	Emergency response may rely on key community facilities such as emergency hospitals, emergency management headquarters and evacuation centres operating during an event. Recovery may rely on key utility services being able to be readily re-established after an event.	Consider the need for conditions for emergency response facilities, key community infrastructure and land uses with vulnerable users.

It should be noted that these FPCCs account for local catchment flooding of Lochinvar Creek and that any land use planning activities should also consider flooding from the Hunter River, particularly in those areas to the north of the New England Highway.

10. SENSITIVITY ANALYSIS

10.1. Climate Change

The sensitivity of the simulated 1% AEP 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. The tidal limit of the Hunter River extends to Oakhampton (Reference 7), downstream of the study area, and hence is not expected to influence flood levels at Lochinvar.

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 Lochinvar Creek catchment, these events correspond to an increase in rainfall intensity of approximately 12% for the 0.5% AEP event and 32% increase for the 0.2% AEP event (see Table 15). The peak flood depth and level results of the 1%, 0.5% and 0.2% AEP events are shown in Figure C5, Figure C6 and Figure C7, respectively. A comparison of flood levels has been provided in Figure E1 and Figure E2, with results also shown in Table E1 and Table E2 for the reporting locations for the study (see Figure 22).

The 0.5% AEP event flood level is approximately 0.05 to 0.08 m higher along Lochinvar Creek. The increase in flood level along the tributary flow paths is typically less than this. The largest increase in flood level is immediately upstream of the New England Highway on Lochinvar Creek, where flood levels increase by up to 0.13 m. In the 0.2% AEP event, the increase in flood level on Lochinvar Creek and Greedy Creek through the town is approximately 0.1 to 0.2 m. The increase in flood level on the tributary flow paths is typically less than 0.1 m. The largest increase in flood level occurs immediately upstream of the New England Highway crossing of Lochinvar Creek, where the increase in flood level is up to 0.35 m.

In both cases there is no change downstream of the town where the adopted Hunter River tailwater level dominates.

10.2. Temporal Patterns

The method for selecting the representative temporal pattern is outlined in Section 8.4. The adopted duration and temporal pattern was selected based on the most representative peak flow (closest to the peak mean flow) across all events within the temporal pattern bin, at the locations of interest. The resulting durations and temporal patterns selected are identified in Table 17. At each individual key location, however, there may have been a duration and temporal pattern that better represented the peak mean flow. Therefore, a sensitivity analysis was conducted by selecting an alternative duration and/or temporal pattern that may have better represented the peak mean flow for each event at the locations of interest. For example, the 1% AEP adopted duration and temporal pattern resulted in an over-estimation of flows at L061 and L083, but slightly underestimating flows at L032 and L036. An alternative duration and temporal pattern for the 1% AEP resulted in a closer match at L083, with the other flows being overestimated, but within 5%

of the peak mean flow. This is summarised in Table 23 below.

Table 23: Summary of the sensitivity of the temporal pattern flows for the 1% AEP event

Catchment	Mean (Critical) Flow (m^3/s)	Adopted Storm 360m TP4406		Sensitivity Storm 180m TP4652	
		Peak Flow (m^3/s)	% Difference (Peak Flow – Critical Flow)	Peak Flow (m^3/s)	% Difference (Peak Flow – Critical Flow)
L032	25.2	25.0	-0.8%	25.7	2.1%
L061	16.9	17.5	3.7%	17.7	4.7%
L036	42.7	42.5	-0.5%	43.4	1.6%
L083	13.9	14.5	4.4%	14.2	2.6%

A similar approach was undertaken for each of the design flood events. The storms for the sensitivity analysis of the adopted duration and temporal pattern are outlined in Table 24 below. For the PMF event, the 120 minute storm was close to being critical at the downstream extent of the Lochinvar township. The PMP relies on a single temporal pattern, so only the duration was changed for the PMF.

Table 24: Summary of the temporal pattern sensitivity runs for all events

Event	Adopted duration (mins) and temporal pattern	Sensitivity duration (mins) and temporal pattern
20% AEP	360m TP4737	540m TP4775
10% AEP	360m TP4660	360m TP4696
5% AEP	360m TP4660	360m TP4696
2% AEP	360m TP4406	180m TP4652
1% AEP	360m TP4406	180m TP4652
0.5% AEP	360m TP4406	180m TP4653
0.2% AEP	360m TP4406	180m TP4653
PMF	90m	120m

The results indicate that across the majority of events, the change in flood level is generally within ±0.02 m, indicating that the adopted duration and temporal pattern is not overly sensitive, as long as the peak flows are reasonably close the peak mean flow. The largest difference was seen in the 10% AEP event, where the peak flood levels immediately upstream of the New England Highway were 0.05 to 0.09 m higher than the adopted storm. This is because the flows for this storm were up to 7% higher than the peak mean flow at the locations of interest, while the adopted temporal pattern were more representative of the peak mean flows.

The 120 minute PMP storm resulted in a reduction in flood levels of up to 0.08 m through the Lochinvar township, indicating that the adopted critical duration results in the peak flood levels through Lochinvar.

10.3. Hydrologic Model Parameters

10.3.1. Rainfall Losses

Rainfall losses were adopted from the ARR 2016 data hub (see Section 8.5). As a sensitivity analysis, the calibrated rainfall losses (for the 2007 and 2016 events) were run for the 1% AEP event using the WBNM hydrologic model. A comparison of flows was undertaken at the key subcatchments of L032, L061, L036 and L083, which were used to assess the critical storm patterns for the Lochinvar Creek catchment.

The calibrated initial loss value (for the 2007 and 2016 flood events) of 10 mm was used for the sensitivity analysis. The adopted data hub initial losses also relied on the pre-burst depth that varied with duration and AEP. In setting the initial loss values to 10 mm across the entire catchment for all durations for the 1% AEP event, the catchment runoff was increased. A comparison of the resulting critical duration and peak mean flows for the initial loss sensitivity analysis at key subcatchment locations is shown in Table 25.

Table 25: Sensitivity Analysis Results for Initial Losses for the 1% AEP Event

Catchment	Adopted Data Hub Initial Losses		Sensitivity Analysis – 10 mm Initial Loss		Difference in Peak Mean Flows	
	Critical Duration (mins)	Peak Mean Flow (m^3/s)	Critical Duration (mins)	Peak Mean Flow (m^3/s)	(m^3/s)	(%)
L032	720	25.2	120	27.5	2.3	9%
L061	720	16.9	90	19.5	2.6	16%
L036	720	42.7	120	46.2	3.4	8%
L083	720	13.9	90	16.4	2.6	18%

On Lochinvar Creek (L032 and L036), the increase in the peak mean flow is approximately 9%, and the critical duration reduces from 720 minutes to 120 minutes. On Greedy Creek and the Robert Road Tributary, the increase is much greater, being 16 to 18%, with the critical duration now being the 90 minute storm. The magnitude of the increase in flows at these key locations is approximately 2 m^3/s to 3 m^3/s.

The calibrated continuing loss value (for the all calibration events) of 2.5 mm was used for the sensitivity analysis. The adopted data hub continuing losses range from 2.0 mm/hr to 2.9 mm/hr. In setting the initial loss value to 2.5 mm across the entire catchment for all durations for the 1% AEP event, the catchment runoff was increased for the subcatchments south of the New England Highway. This is because these subcatchments generally had a continuing loss of 2.9 mm/hr adopted from the data hub, while catchments to the north of the New England Highway generally had a continuing loss of 2.0 mm/hr. A comparison of the resulting critical duration and peak mean flows for the continuing loss sensitivity analysis at key subcatchment locations is shown in Table 26.

Table 26: Sensitivity Analysis Results for Continuing Losses for the 1% AEP Event

Catchment	Adopted Data Hub Continuing Losses		Sensitivity Analysis – 2.5 mm/hr Continuing Loss		Difference in Peak Mean Flows	
	Critical Duration (mins)	Peak Mean Flow (m^3/s)	Critical Duration (mins)	Peak Mean Flow (m^3/s)	(m^3/s)	(%)
L032	720	25.2	720	25.6	0.4	1.6%
L061	720	16.9	720	17.1	0.2	1.4%
L036	720	42.7	720	43.4	0.7	1.5%
L083	720	13.9	720	14.1	0.2	1.3%

There is no change in the critical duration with the change in continuing loss. The increase in peak mean flows is minimal, being within 1% to 2% of the adopted peak mean flows at the key subcatchments of interest.

10.3.2. Catchment Lag

The catchment lag factor (termed 'C' in the WBNM model) can be used to accelerate or delay the runoff response to rainfall. By varying the adopted C parameter of 1.7 by ±20%, the effect on the peak flows was observed at the key subcatchments of L032, L061, L036 and L083, which were used to assess the critical storm patterns for the Lochinvar Creek catchment. This assessment was undertaken for the 1% AEP event.

An increase in catchment lag of 20% results in a reduction in catchment flows. A comparison of the resulting critical duration and peak mean flows for this sensitivity analysis at key subcatchment locations is shown in Table 27.

Table 27: Sensitivity Analysis Results for Increase in Catchment Lag for the 1% AEP Event

Catchment	Adopted Catchment Lag (C) of 1.7		Sensitivity Analysis – 20% Increase in Catchment Lag		Difference in Peak Mean Flows	
	Critical Duration (mins)	Peak Mean Flow (m^3/s)	Critical Duration (mins)	Peak Mean Flow (m^3/s)	(m^3/s)	(%)
L032	720	25.2	720	22.9	-2.3	-9%
L061	720	16.9	720	15.4	-1.5	-9%
L036	720	42.7	720	38.8	-4.0	-9%
L083	720	13.9	720	12.8	-1.1	-8%

The critical storm duration does not change and remains the 720 minute duration for the 1% AEP event. The decrease in the mean peak flows is approximately 9% for the key locations of interest.

A decrease in catchment lag of 20% results in an increase in catchment flows. A comparison of the resulting critical duration and peak mean flows for this sensitivity analysis at key subcatchment locations is shown in Table 28.

Table 28: Sensitivity Analysis Results for Decrease in Catchment Lag for the 1% AEP Event

Catchment	Adopted Catchment Lag (C) of 1.7		Sensitivity Analysis – 20% Decrease in Catchment Lag		Difference in Peak Mean Flows	
	Critical Duration (mins)	Peak Mean Flow (m^3/s)	Critical Duration (mins)	Peak Mean Flow (m^3/s)	(m^3/s)	(%)
L032	720	25.2	720	28.1	2.9	12%
L061	720	16.9	120	19.0	2.1	13%
L036	720	42.7	720	47.7	5.0	12%
L083	720	13.9	120	16.0	2.1	15%

The critical storm duration remains the same for Lochinvar Creek (L032 and L036), while it decreases for Greedy Creek and Robert Road Tributary (L061 and L083) to 120 minutes. The increase in peak flows is in the range of 12 to 15% across the key subcatchments.

10.4. Hydraulic Model Parameters

10.4.1. Manning's 'n'

The Manning's 'n' parameter in the TUFLOW model represents the surface roughness, and the adopted values are outlined in Table 11. A sensitivity analysis was conducted with both an increase and decrease in these values by 20%. The results can be found in the maps in Figure E3 and Figure E4, with results also shown in Table E1 and Table E2 for the reporting locations for the study (see Figure 22).

There is an increase in peak flood levels with an increase in the Manning's 'n' values. The 1% AEP flood levels increase by approximately 0.05 to 0.1 m through the Lochinvar town. With a decrease in Manning's 'n', there is a decrease in flood levels of a similar magnitude. The largest decrease is seen around Hunter Close, where peak flood levels reduce by up to 0.12 m. There is no change downstream of the town where the adopted Hunter River tailwater level dominates.

A summary of the change in flood levels and flows at key locations within the study area can be found in Table E1 and Table E2, respectively.

10.4.2. Blockage

A sensitivity analysis was undertaken for the blockage of structures in the TUFLOW model. For the design events, a blockage factor of 25% was applied to all culvert structures, with a nominal 5% blockage for the New England Highway Bridge over Lochinvar Creek. For the sensitivity analysis, a no blockage scenario was run (all structures clear) and an increased blockage scenario was run (50% for culverts and 10% for Lochinvar Creek Bridge) for the 1% AEP event. The results of this assessment can be found in Figure E5 and Figure E6, with results also shown in Table E1 and Table E2 for the reporting locations for the study (see Figure 22).

The results indicate that with a no blockage scenario, there is a decrease in flood level upstream of the hydraulic structures. This decrease is up to 0.02 m at the Lochinvar Creek bridge, and typically up to 0.04 m at other crossings of the New England Highway and local roads. The largest decrease is at Freeman Drive crossing Greedy Creek, where the decrease in flood level is approximately 0.08 m. There is generally a negligible increase downstream of these crossings.

With the increased blockage scenario, there is an increase in flood levels upstream of the hydraulic structures. Upstream of the Lochinvar Creek Bridge, this is up to approximately 0.02 m. Blockage of other smaller culverts result in an increase in peak flood level larger than this, up to 0.13 m at the most easterly culvert crossing on the New England Highway. There are some small reductions in flood levels downstream of the smaller culvert crossings.

10.4.3. Tailwater Level

For all the design flood events, a 5% AEP Hunter River tailwater level was adopted (RL 22.25 mAHD). This assumption influences results downstream of the Lochinvar township, north of the New England Highway, where the backwater extends to the northern extent of the Lochinvar Urban Release Area. The Hunter River flood levels in the vicinity of Lochinvar have already been defined in the Hunter River: Branxton to Green Rocks Flood Study (Reference 7), so it was not considered necessary to reassess that behaviour for a wide range of events. The Hunter River peak levels are the dominant flood mechanism for the lower reaches of Lochinvar Creek, and need to be taken into consideration for strategic planning and floodplain management decisions. The Flood Planning Area is generally set by the Hunter River 1% AEP levels north of Cantwell Road (see Figure C29).

There is insufficient data to undertake a full joint probability analysis of flooding on the Hunter River and Lochinvar Creek catchment together. Typically, the different response times of the catchments will produce flood peaks that are asynchronous. It is not appropriate to assume a 1% AEP flood peak on the Hunter River at the same time as a local 1% AEP storm, as this will produce flood levels that are rarer than 1% AEP in parts of the catchment.

In the areas through the Lochinvar township, flood levels are not heavily influenced by the adopted tailwater level, and are dominated by the local catchment runoff. This local catchment runoff has been modelled and presented in this report, which is largely independent of the adopted tailwater level.

11. Flood Damage Assessment

The average annual tangible damage for Lochinvar was estimated to be approximately $13,400. This is driven by external damage at a number of properties in events up to the 2% AEP. In the 1% AEP event, one house is estimated to be flooded above floor and the estimated tangible flood damage is approximately $90,000. This increases to almost $4.5 million in the PMF event. The methodology for estimating flood damages is outlined below.

11.1. Introduction

The quantification of flood damages is an important part of the floodplain risk management process. It helps identify whether the benefits from various flood mitigation measures will outweigh the costs to implement those measures, and to prioritise which measures will be most cost-effective.

While flood damage assessment does not include all impacts or costs associated with flooding, it provides a basis for assessing the economic loss due to flooding, and also a non-subjective means of assessing the merit of flood mitigation works such as detention basins, levees, drainage enhancements, etc. By quantifying flood damages for a range of design events, appropriate management measures can be evaluated in terms of their benefits (reduction in flood damage) versus the cost of implementation.

The cost of flood damage and disruption to a community depends on a number of factors which include:

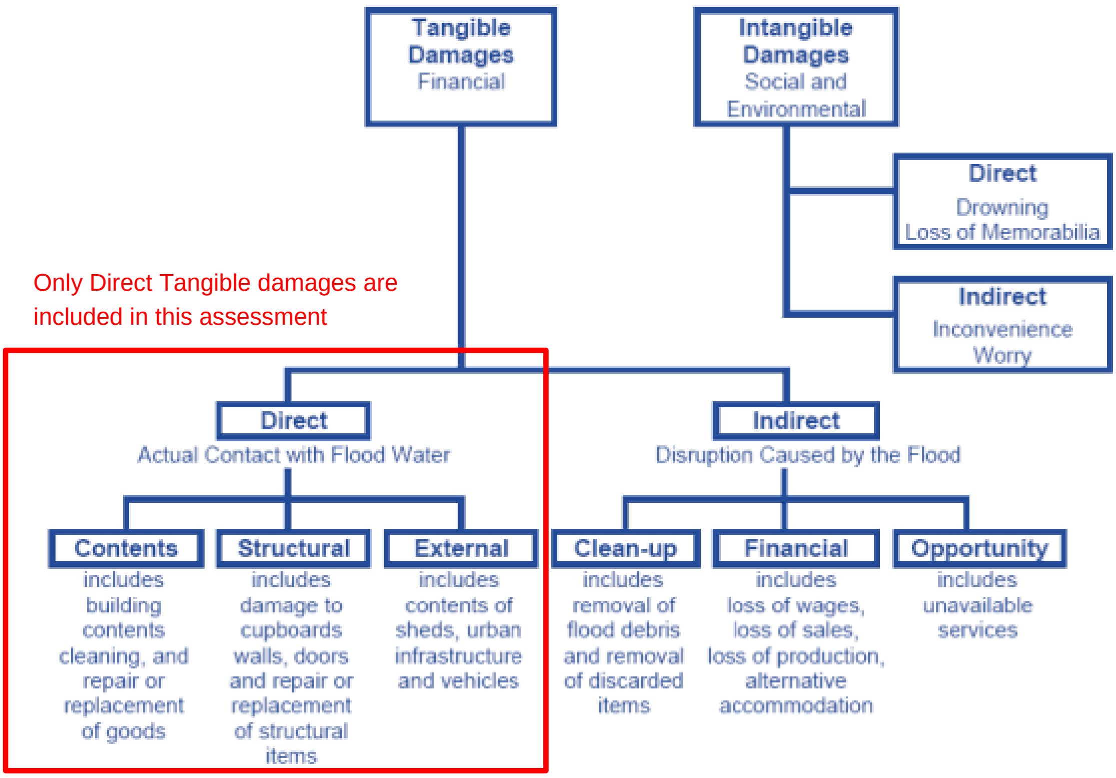
- Flood magnitude (depth, velocity and duration);
- Type of structures at risk and their susceptibility to damage;
- Nature of the development at risk (residential, commercial, industrial);
- Physical factors such as failure of services (e.g. utilities), flood borne debris, sedimentation, etc.;
- Awareness and readiness of the community to flooding;
- Effective warning times; and
- Availability of Evacuation Plans

The potential damage associated with a particular flood event can be divided into a number of components, which are grouped into two major categories;

- Tangible damages – financial costs of flooding quantified in monetary terms
- Intangible damages – social costs of flooding reflected in increased levels of mental stress, loss of sentimental items, inconvenience to people, injury or loss of life, etc.

Intangible damages are difficult to measure and impossible to meaningfully quantify in dollar terms. For this reason, intangible damages have not been assessed for Lochinvar and the following damage assessment focuses on tangible damages only. Tangible damages can be further sub-divided into two categories, direct and indirect damages, as illustrated in Diagram 10.

Diagram 10: Types of flood damages (Source: Reference 2)



The total likely damages in any given flood event is difficult to quantify, given the variable nature of flooding and the property and content values of houses affected. Nonetheless, flood damages are estimated to obtain an indication of the magnitude of the flood problem and compare the economic effectiveness of proposed mitigation options. Understanding the total damages prevented over the life of a mitigation option in relation to current damages, or to an alternative option, can assist in the decision making process.

11.2. Approach

Flood damage estimation procedures have been formulated using data collected following real flood events. Information collected includes identification of properties flooded, the extent of flooding, depth of flooding experienced, flooding mechanism etc. This information can then be used to guide and calibrate models used to calculate flood damages for a particular area. One of the most thoroughly studied flood damage assessments was that undertaken at Nyngan, following the flood in 1990.

Estimation of flood damage has focussed on residential and community buildings in the study area using guidelines issued by the NSW Government (Reference 18) and recognised damage assessment methodologies. The most common approach to present flood damage data is in the form of flood-damage curves for a range of property types, i.e. residential, commercial, public property, public utilities etc. These relate flood damage to depth of flooding above a threshold level (usually floor level). The estimation of damage is based upon a flood level relative to the floor level of a property.

11.2.1. Property Database

A property database was assembled using available aerial imagery and cadastre information for the study area. Floor levels were estimated using the LiDAR data to estimate ground levels, and adding a height-above-ground estimate for floor level heights. This process is outlined in Section 3.3. The level of accuracy for the estimated floor heights is considered suitable for two reasons. Firstly, the estimation of property damage due to flooding is inherently difficult to estimate, given the large variation in building types, their contents, the duration of flooding and other factors, and so the accuracy of floor heights should be in line with the accuracy and applicability of the flood damage curves. Secondly, the economic damages assessment is only intended to be used as an estimate of the LGA-wide flood affectation and not on a per-property basis.

A total of 254 properties were identified within the Lochinvar Study Area, with 76 being identified within the PMF extent (see Figure 3). Floor levels for these 76 properties were estimated using techniques outlined in Section 3.3. Of these 76 properties identified, the following is noted:

- One property identified in the aerial imagery had been demolished when inspected on-site. This property is located at 19 Freeman Drive;
- Two dwellings were identified at 33 Freeman Drive (main dwelling plus a granny flat);
- Three buildings were identified as part of Lochinvar Public School;
- One property only had a large shed located on it; and
- One property identified on the New England Highway (located near St Patrick's Primary School) appears to have been demolished and a church building constructed. This was retained as a single property.

Flood levels were assigned to each property based on the modelled flood surface at the building. The database was used to determine the number and extent of properties inundated above protection level for the range of flood events modelled (20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and the PMF). No freeboard was included in these estimates.

11.2.2. Residential Damage

Flood damage of residential buildings was calculated using a residential damage spreadsheet developed by the NSW Department of Environment, Climate Change and Water (DECCW, now NSW Office of Environment and Heritage) in 2007. This includes a representative stage-damage curve derived for a typical house on a floodplain to estimate structural, contents and external damage. The amount of damage is based on the flood inundation depth for a given flood event. The AEP of the PMF event for Lochinvar was estimated to be 1 in 10^7.

A number of input parameters are required to determine which stage-damage curve will be adopted. The key parameters used in this assessment are shown in Table 29.

Table 29: Parameters adopted for Residential Damages Assessment

Parameter	Adopted Value	Comment
Post Flood Inflation Factor	1.10	Suggested range of 1.0 to 1.5 depending on the scale of impacts. Raise to 1.1 assuming that similar areas within the Hunter Valley region are also affected (for example the April 2015 event).
Typical Duration of Immersion	2 hours	Short duration flooding.
Building Damage Repair Limitation Factor	0.85	Suggested range of 0.85 to 1.00 (short to long duration events). Duration of flooding is expected to be short in Lochinvar.
Contents Damage Repair Limitation Factor	0.75	Suggested range of 0.75 to 0.90 (short to long duration events). Duration of flooding is expected to be short in Lochinvar.
Effective Warning Time (hrs)	0	Due to the size of the Lochinvar Creek catchment and the short duration of flooding, it has been conservatively assumed that no warning time would be given for residents.
Level of flood awareness	Low	Guidelines suggest 'low' is adopted unless 'high' can be justified. While flooding has been experienced in Lochinvar, it is assumed that the level of awareness of the extent of flooding for large events is low.
House size	240m^2	House size was taken to be the recommended average size.

The DECCW stage-damage curves within the spreadsheet are derived for late 2001, and have been updated using an Average Weekly Earnings (AWE) factor to August 2007. AWE is used to update residential flood damage curves rather than the inflation rate measured by the Consumer Price Index (CPI). The most recent AWE value from the Australian Bureau of Statistics (ABS) at the time of the assessment was May 2018, and a factor of 1.79 was applied to all ordinates in the residential stage-damage curves based on the increase from November 2001. Similarly, the spreadsheet was developed for the Sydney urban area. A regional cost variation factor of 1.05 was applied for Lochinvar based on an interpolation between the value at Newcastle (1.01) and Singleton (1.08), as presented in Rawlinson's Australian Construction Handbook (Reference 19).

The external flood damages that occur when flooding reaches the property, but does not inundate the floor of the dwelling, was reduced to approximately $600 per property (prior to adjustment factors). This is because many of the properties within Lochinvar can be subject to shallow overland flows (for example, properties along Freeman Drive), and the cost of this damage is expected to be minor landscaping and fencing costs, rather than any structural or contents damage. Hence, external damage can occur with or without inundation above floor level. Other default parameters and values within the spreadsheet were retained, including clean-up costs of $4,000 and accommodation costs of $220 per week for a period of 3 weeks (prior to adjustment factors).

The resulting flood damage curves (including adjustment factors) indicate maximum internal (contents) damages of approximately $83,000 occurring at a depth of 2 m above the building floor level. Structural damages vary depending on whether the property is slab/low set or high set. For the purpose of this study, properties were assumed to be low set, since floor levels were within 0.5 m of the ground. For two storey properties, damages (apart from external damages) are reduced by a factor of 70% where only the ground floor is flooded as it is assumed that some contents will be on the upper floor and unaffected by flooding, and that structural damage will be less. No damages were assumed to be incurred for Lochinvar in the 50% AEP event.

11.2.3. Non-residential Building Damage

While the majority of development at risk from flooding in Lochinvar is residential, there are a several community facilities and other buildings impacted by flooding. To account for the non-residential flood damages in Lochinvar, a representative number of residential dwellings were adopted for each building type. These multiplication factors were then applied to the damage curve for each building type. These factors are presented in Table 30 below.

Table 30: Parameters adopted for Residential Damages Assessment

Building type	Equivalent Residential Houses	Comment
Large shed	0.5	There is one large shed located on a property without a dwelling. Other smaller sheds/garages located on properties with dwellings are assumed to be part of the residential flood damage curve.
Lochinvar Public School – Fixed classrooms	1.5	Series of classrooms located on the eastern side of the site.
Lochinvar Public School – Demountable classrooms	0.5	Classrooms located on the western side of the site.
Lochinvar Public School – other buildings	0.5	Additional buildings at the rear of the site.

These buildings are only impacted by flooding in the PMF event, and hence their contribution to average annual damages (AAD) is minimal.

11.2.4. Vehicle Damage

An estimation of vehicle damage has been excluded from this assessment. Significant damage can be attributed to vehicles (see Photo 23), but these damages are difficult to quantify due to the mobility of the vehicles and the ability to remove them from the path of flood waters. The damages associated with vehicles can be highly variable depending on the time of day, flood warning times, and other factors. These may need to be considered for inclusion in the damages assessment if they are likely to affect assessment of flood mitigation measures for a subsequent Floodplain Risk Management Study and Plan.

Photo 23: Flood damaged car in Hunter Close following the April 2015 flood event

11.3. Estimated Tangible Flood Damages

An estimation of the number of properties impacted (flooding occurring on the property up to the dwelling/building), number of properties with above floor flooding and total damage costs for each modelled flood event for the Lochinvar township was undertaken. Residential external damages are assumed to start accumulating when floodwater is within 0.5m of the dwelling floor level for single storey buildings. (i.e. the property is impacted).

The most convenient way to express flood damage for a range of flood events is by calculating the Annual Average Damage (AAD). AAD represents the equivalent average damages that would be experienced by the community on an annual basis, by taking into account the probability of a flood occurrence. The AAD value is determined by multiplying the damages that can occur in a given flood by the probability of that flood actually occurring in a given year, and then summing across a range of floods. This method allows smaller floods, which occur more frequently to be given a greater weighting than the larger catastrophic floods. The AAD for the existing case then provides a benchmark by which to assess the merit of flood management options. The AAD for Lochinvar is $2.51 Million.

A summary of the tangible flood damages for Lochinvar is provided in Table 31. There is a large difference in the average tangible damages per property between the frequent and rare flood events. This is reflective of the rarer floods, the PMF in particular, having a far wider flood extent than the frequent events, and of these rare events being more costly, even after their rarity has been accounted for. There is estimated to be only one property affected above floor in the 1% AEP event, with no properties flooded above floor for events more frequent. There are a number of properties with floodwaters up to the dwelling, resulting in external damages. In the PMF event a large number of properties are affected, including 52 with above floor flooding.

Table 31: Estimated Tangible Flood Damages for Lochinvar

Flood Event	No. Properties Affected[1]	No. Properties Flooded Above Floor Level	Total Damages for Event[2]	Average Damage Per Flood Affected Property[2]
20% AEP	16	0	$17,100	$1,100
10% AEP	16	0	$17,100	$1,100
5% AEP	19	0	$20,300	$1,100
2% AEP	23	0	$24,600	$1,100
1% AEP	28	1	$91,700	$3,300
0.5% AEP	30	1	$205,800	$6,900
0.2% AEP	33	7	$581,700	$17,600
PMF	75	52	$4,463,800	$59,500
Average Annual Damages (AAD)			**$13,400**	**$200**

1 - Floodwaters reach the dwelling and are within 0.5 m of the floor level

2 - Rounded to the nearest $100

The average annual damages for Lochinvar is approximately $13,400, being approximately $200 per property affected (in the PMF).

11.4. Intangible Flood Damages

The intangible damages associated with flooding, by their nature, are inherently more difficult to estimate in monetary terms. In addition to the tangible damages discussed above, additional costs/damages are incurred by residents affected by flooding, such as stress, injury, loss of life, loss of sentimental items, etc. It is not possible to put monetary values on these intangible damages as they are likely to vary dramatically between each flood (from a negligible amount to significantly more than tangible damages) and depend on a range of factors such as size of flood, the individuals affected and community preparedness. However, it is still important that the consideration of intangible damages is included when assessing the impacts of flooding on a community.

Post flood damage surveys have linked flooding to stress, ill-health and trauma for residents. For example, the loss of memorabilia, pets, important documents and other items without fixed costs and of sentimental value may cause stress and subsequent ill-health. In addition, flooding may affect personal relationships and lead to stress in domestic and work situations. The actual flood event, resulting property damage, risk to life for the individuals or their family and the clean-up process can also add to the stress. In addition to the stress caused during an event, many residents who have experienced a major flood are fearful of the occurrence of another flood event and the associated damage and loss. The extent of stress depends on the individual and although the majority of flood victims recover, these effects can lead to a reduction in quality of life for the flood victims.

During any flood event, these is the potential for injury as well as loss of life due to causes such as drowning, floating debris or illness from polluted water. Generally, the higher the flood velocities and depths, the higher the risk. Section 9.2 categorises the flood hazard through in the Lochinvar Creek catchment. However, there will always be localised areas of high risk where flows may be concentrated around buildings or other structures within low hazard areas. The intangible damages for Lochinvar may be substantial, due to the lack of warning time for a potential flood event.

11.5. Summary

Flood damage in Lochinvar is primarily attributed to external damages (landscaping, fencing, sheds, etc.) in events up to the 0.5% AEP, with between 16 and 30 properties being affected. Only in the 1% AEP event are properties flooded above floor level. In the 0.2% AEP event, there are estimated to be 7 properties flooded above floor, and 33 affected in total. In the PMF event, there are 52 properties flooded above floor, with 75 affected by flooding altogether.

The average annual damage, however, is reasonably low, at approximately $13,400. This equates to an average property damage value of just $200, considering the 75 properties affected in the PMF event. Damages for smaller to moderate events range from approximately $17,000 in the 20% AEP event, to approximately $25,000 in the 2% AEP event. When floor levels begin to be inundated in the 1% AEP event, the flood damages rise to approximately $90,000. In the 0.2% AEP, flood damages reach over $500,000 and in the PMF event they reach almost $4.5 million.

While flood damage estimates for Lochinvar are indicative only, they are useful in the evaluation of flood management options, aimed at reducing flood damage estimates while being economically viable to implement. It is recommended that these flood damage estimates be revised at the subsequent Floodplain Risk Management Study phase, in order to use the latest available information and incorporate any new developments in the flood damage assessment.

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Attachment A: ARR2016 Datahub Metadata

Attachment A

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	151.45
Latitude	-32.696
Selected Regions	
River Region	
ARF Parameters	
Storm Losses	
Temporal Patterns	
Areal Temporal Patterns	
Interim Climate Change Factors	

Region Information

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

Data

River Region

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

Layer Info

Time Accessed	06 August 2018 04:03PM
Version	2016_v1

ARF Parameters

Long Duration ARF

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

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

Short Duration ARF

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

Layer Info

Time Accessed	06 August 2018 04:03PM
Version	2016_v1

Storm Losses

Note: Burst Loss = Storm Loss - Preburst

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

id	29260.0
Storm Initial Losses (mm)	18.0
Storm Continuing Losses (mm/h)	2.0

Layer Info

Time Accessed	06 August 2018 04:03PM
Version	2016_v1

Temporal Patterns

code	ECsouth
Label	East Coast South

Layer Info

Time Accessed	06 August 2018 04:03PM
Version	2016_v2

Areal Temporal Patterns

code	ECsouth
arealabel	East Coast South

Layer Info

Time Accessed	06 August 2018 04:03PM
Version	2016_v2

BOM IFD Depths

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

No data	No data found at this location!

Layer Info

Time Accessed	06 August 2018 04:03PM

Median Preburst Depths and Ratios

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

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.8 (0.030)	1.0 (0.028)	1.2 (0.027)	1.3 (0.025)	1.4 (0.023)	1.5 (0.021)
90 (1.5)	0.7 (0.023)	0.7 (0.018)	0.7 (0.015)	0.8 (0.013)	1.2 (0.017)	1.5 (0.019)
120 (2.0)	0.0 (0.000)	0.1 (0.003)	0.2 (0.004)	0.3 (0.004)	1.1 (0.015)	1.8 (0.020)
180 (3.0)	1.4 (0.039)	1.8 (0.035)	2.0 (0.033)	2.2 (0.031)	2.0 (0.023)	1.8 (0.018)
360 (6.0)	1.6 (0.034)	5.0 (0.077)	7.3 (0.092)	9.4 (0.101)	9.5 (0.084)	9.6 (0.074)
720 (12.0)	2.8 (0.046)	6.3 (0.074)	8.6 (0.083)	10.9 (0.088)	13.2 (0.087)	14.9 (0.085)
1080 (18.0)	0.3 (0.004)	6.2 (0.062)	10.2 (0.083)	14.0 (0.095)	15.1 (0.083)	15.9 (0.076)
1440 (24.0)	0.0 (0.000)	3.2 (0.028)	5.3 (0.038)	7.3 (0.044)	9.8 (0.048)	11.7 (0.049)
2160 (36.0)	0.2 (0.003)	2.1 (0.016)	3.3 (0.021)	4.5 (0.023)	6.6 (0.027)	8.1 (0.029)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.2 (0.001)	0.4 (0.001)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	06 August 2018 04:03PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

Interim Climate Change Factors

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

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

Layer Info

Time Accessed	06 August 2018 04:03PM
Version	2016_v1
Note	ARR recommends the use of RCP4.5 and RCP 8.5 values

Appendix A Glossary of Terms

Appendix A

Terminology used in Report

Australian Rainfall and Runoff (ARR, Reference 1) 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.

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

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

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

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

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

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	

Glossary – from the NSW 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 “flood liable land” concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL’s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the “standard flood event” in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.

flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **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.

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 “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.