COOTAMUNDRA-GUNDAGAI REGIONAL COUNCIL

COOTAMUNDRA FLOOD STUDY

FINAL

JANUARY 2021

Level 2, 160 Clarence Street
Sydney, NSW, 2000

Tel: (02) 9299 2855
Fax: (02) 9262 6208
Email: wma@wmawater.com.au
Web: www.wmawater.com.au

COOTAMUNDRA FLOOD STUDY

FINAL

JANUARY 2021

Project Cootamundra Flood Study	**Project Number** 119039
Client Cootamundra-Gundagai Regional Council	**Client's Representative** Mike Brearley
Project Manager Erin Askew	

Revision History

Revision	Description	Distribution	Authors	Reviewed by	Verified by	Date
0	Stage 1 – Data Collection	CGRC DPIE	CW, DB	EA	EA	AUG 19
1	Stage 2- Model Build and Calibration	CGRC DPIE	DB	EA	EA	JUN 20
2	Stage 3 – Draft Flood Study Report	CGRC DPIE	DB, EA	EA	EA	AUG 20
3	Draft for Public Exhibition	CGRC DPIE	DB, EA	EA	EA	NOV 20
4	Final	CGRC DPIE	EA	EA	EA	JAN 21

Cover photo: Bradman Oval and Cutler Avenue Causeway, September 2016, (Photo B Cant)

Cootamundra-Gundagai Regional Council
PO Box 420, COOTAMUNDRA NSW 2590
mail@cgrc.nsw.gov.au
1300 459 689

COOTAMUNDRA FLOOD STUDY

TABLE OF CONTENTS

PAGE

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF DIAGRAMS

LIST OF ACRONYMS

AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
ALS	Airborne Laser Scanning
ARR	Australian Rainfall and Runoff
BOM	Bureau of Meteorology
DPIE	NSW State Government Department of Planning, Industry and Environment
DEM	Direct Elevation Model
GIS	Geographic Information System
IFD	Intensity, Frequency and Duration (Rainfall)
LiDAR	Light Detection and Ranging
mAHD	meters above Australian Height Datum
NSW SES	New South Wales State Emergency Service
OEH	Office of Environment and Heritage (now DPIE)
PMF	Probable Maximum Flood
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software (hydraulic model)
WBNM	Watershed Bounded Network Model (hydrologic model)

ADOPTED TERMINOLOGY

Australian Rainfall and Runoff (ARR, ed Ball et al, 2016 and its 2019 revision (ARR 2019)) 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 2019 recommends the use of Annual Exceedance Probability (AEP). Annual Exceedance Probability (AEP) is the probability of an event being equalled or exceeded within a year. AEP may be expressed as either a percentage (%) or 1 in X. Floodplain management typically uses the percentage form of terminology. Therefore a 1% AEP event or 1 in 100 AEP has a 1% chance of being equalled or exceeded in any year.

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

For events more frequent than 50% AEP, expressing frequency in terms of Annual Exceedance Probability is not meaningful and misleading particularly in areas with strong seasonality. Therefore the term Exceedances per Year (EY) is recommended. Statistically a 0.5 EY event is not the same as a 50% AEP event, and likewise an event with a 20% AEP is not the same as a 0.2 EY event. For example an event of 0.5 EY is an event which would, on average, occur every two years. A 2 EY event is equivalent to a design event with a 6 month Average Recurrence Interval where there is no seasonality, or an event that is likely to occur twice in one year.

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

This report has adopted the approach recommended by ARR 2019 and uses % AEP for all events rarer than the 50 % AEP and EY for all events more frequent than this. The only exception is when reference is made to a previous assessment, the terminology used in that assessment has remained.

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	

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 studies investigating flood risk and 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 five sequential stages:

1. Data Collection
- Compilation of existing data and collection of additional data.

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

3. Floodplain Risk Management
- Determines options in consideration of social, ecological and economic factors relating to flood risk.

4. Floodplain Risk Management Plan
- Preferred options are publicly exhibited and subject to revision in light of responses. Formally approved by Council after public exhibition and any necessary revisions due to public comments.

5. Implementation of the Plan
- Implementation of flood, response and property modification measures (including mitigation works, planning controls and flood warnings for example) by Council.

The Cootamundra Flood Study constitutes the first two stages of the floodplain management process. This study has been completed without state government funding but has had state government technical assistance and is compliant with the state government guidelines for flood studies.

This study has been prepared by WMAwater for Cootamundra – Gundagai Regional Council.

1. INTRODUCTION

The Cootamundra Flood Study provides information about existing flood risk in the study area, which covers the urbanised township of Cootamundra. Flooding can occur as a result of rainfall in the upper catchments of Muttama, Jindalee and Cootamundry Creeks (mainstream). In addition, flooding can occur in parts of town as a result of local rainfall (local overland flow) , particularly the Southee Circle Area. These mechanisms can also combine for example, where the drainage network capacity can be significantly hampered by high levels in Muttama Creek downstream. The Study Area lies within the Local Government Area (LGA) of Cootamundra – Gundagai Regional Council (CGRC) (Council).

Council is responsible for managing development of flood prone land under guidance provided in the NSW Floodplain Development Manual (Reference 2). The flood modelling tools and outputs developed as part of this study can be used by Council for informed decision-making about land-use planning, for emergency management, and in future studies to assess the effectiveness of potential measures to reduce flood risk. The models have been calibrated using observations from historical floods and subsequently 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).

Cootamundra has been subject to a number of previous Flood Study investigations, as early as the Cootamundra Flood Study in 1986 by the NSW Water Resources Commission (Reference 5), which used the Rational Method to define design peak flood discharges, and a HEC-2 hydraulic model to determine corresponding design peak flood levels. Since then, a further study was completed in 2001 and hydrologic modelling has been undertaken using RAFTS rainfall-runoff hydrologic model (e.g. Reference 6 and 7), while the HEC-2 hydraulic model was retained from the 1986 Flood Study. Since the completion of these studies there has been a range of significant advancements in the modelling tools available, development of industry guidelines, and the availability of considerably more detailed topographic data (i.e. LiDAR data). In addition, there has been a range of developments and changes within the catchment over the years, including the implementation of a number of formerly recommended mitigation works. As such, Council seeks to use the latest available tools and data to define flood risk in Cootamundra under current catchment conditions.

2. BACKGROUND

2.1. Study Area

Cootamundra is located on the western slopes of the Great Dividing Range. The catchment is generally rural in nature, with considerable clearing of the lower slopes and flat land immediately upstream of the town. The land use within the catchment consists primarily of rural agricultural land, supporting livestock (cattle and sheep) and cereal crops (wheat and other grain) with low or medium density residential development in town. Elevations in the upper catchment are between 400 to 500 mAHD, reducing to 300 to 350 mAHD, closer to town. Slopes of between 1% and 3% are present in the upper catchment however this slope reduces to 0.5% and lower immediately upstream and through the town.

The Study Area, shown on Figure 1, covers Muttama Creek, which runs north to south through the centre of Cootamundra, Jindalee Creek in the northeast and Cootamundry Creek in the town's southwest. Jindalee Creek has a catchment area of 54 km^2 to its confluence with Muttama Creek upstream of Cootamundra. Cootamundry Creek joins Muttama Creek downstream of town with a catchment area of 62 km^2; Muttama Creek has a catchment area of 116 km^2 to this confluence. Muttama Creek then flows south to join the Murrumbidgee River upstream of Gundagai.

Jindalee, Muttama and Cootamundry Creeks have well defined channels, particularly in the upper reaches. Muttama Creek becomes less well defined as the slope flattens towards and through the township. The lower reaches of Jindalee Creek have also been modified to direct flooding around the airstrip.

With Muttama Creek effectively bisecting Cootamundra, there are a number of creek crossings through town. Four bridges span Muttama Creek, located (from downstream to upstream) on Sutton Street, Mackay Street, Parker Street and Wallendoon Street. There are also several causeways that cross the creek at Nash's Lane, Cowcumbla Street, Lloyd Conkey Avenue, Hovell Street, Thompson Street, Poole Street, Cutler Avenue, Adams Street and Temora Street, with pedestrian bridges also at a number of these causeways.

Local rainfall is conveyed through the town via a drainage system consisting of kerb and gutters, dish drains and a pit and pipe network.

Three railway lines traverse the Study Area, including the Cootamundra-Tumut line (towards Gundagai), Cootamundra-Lake Cargelligo line (towards Stockinbingal), and the Main Southern Railway, which runs northeast towards Harden, and southeast towards Junee. Where the railway lines intersect the creek there are substantial bridge and culvert structures. The Olympic Highway between Cootamundra and Junee crosses Cootamundry Creek at three separate points, each with bridge structures. There are several railway and road culverts included within the Study Area that cross Jindalee Creek, including the quadruple box culvert bridge located on the Main Southern Railway line.

Council's water treatment and reuse storage facility is located adjacent to the confluence of Muttama and Cootamundry Creeks at the downstream end of the study area.

2.2. Nature of Flooding at Cootamundra

Flooding in Cootamundra due to Muttama, Jindalee and Cootamundry Creeks is reported to fall into two broad regimes upstream and downstream of Wallendoon Street. Upstream of Wallendoon Street, flooding is typically widespread but shallow in most areas, except for the intersections at Adams Street and Cutler Avenue and the surrounding areas. On the flatter areas upstream of Adams Street including the airstrip and the Jindalee Creek floodplain, inundation of the overbank areas commences in a more frequent storm (e.g. 2 to 5 year ARI events, 1986 Flood Study, Reference 5).

Downstream of Wallendoon Street to the confluence of Muttama and Cootamundry Creeks, flood flows in events up to the 1% AEP flood are contained within the channel and the adjacent banks and/or open reserves, with shallow overland inundation being experienced in three locations:

- At the caravan park on Mackay Street;
- Across the area surrounding Southee Circle; and
- At Hovell Street where low-lying land can be inundated.

In addition to mainstream flood affectation, overland flooding exists in the Southee Circle area. Southee Circle is subject to flooding when local runoff exceeds the limited capacity of the existing piped drainage system, causing overland flow to pond around Southee Circle, and to discharge overland to Muttama Creek (primarily along existing roads). Elevated tailwater levels in Muttama Creek reduce the ability of the local drainage system to convey local runoff to the creek.

Flooding within Cootamundra occurs when short intense local rainfall causes runoff exceeding the capacity of the creeks. Thus, flooding duration tends to not exceed 3 to 6 hours. Flood peaks within the Cootamundra township occur a few hours after the rainfall burst, creating a relatively short warning period.

2.3. Historic Flood Events

Cootamundra has a long history of flooding since its colonist settlement in 1825. The majority of the annual 500 – 600mm of rainfall falls in the winter and spring months, it is during these months that flooding tends to occur. Events have also occurred over the summer months resulting from short-duration thunderstorms. The town was first gazetted as a municipality in 1884, and the earliest records available describe a catastrophic flood in 1885 and significant events thereafter in 1903, 1919, 1952, 1956, 1974, 1983 and 1984. More recently the town experienced flooding in March 2010 and September 2016, reigniting the community's interest in flooding after a long period of no floods. Smaller events have also occurred in December 2010 and March 2012. A brief overview of each event is provided below based on available records (Figure 2). It is noted that this is not an exhaustive list of flood events, as details were not available for all historical floods.

2.3.1. January 1885

Flooding of Cootamundry Creek caused a Melbourne to Sydney passenger train to derail just outside of Cootamundra, killing six and injuring around twenty people (Reference 12). The high flows in the creek washed the earth fill out from around the culvert at the foot of Bethungra Hill, leaving the rails unsupported. One account described the incident:

"Here the earthwork had been washed away, leaving the rails and fishplates alone standing. The whole of the train must have been on the rails at one time before they gave way. The engine got to the edge of the creek on the far side, and was then immediately embedded. The second class carriage, which was next to the engine, being thrown at right angles to the former and nearly submerged. The sleeping car was next, and it, with the second class carriage, was in the centre of the creek, the engine in front just showing above the water. The sleeping car as well as the second class carriage was a total wreck. Behind the sleeping car the first-class carriage which I was in was thrown on to the brick culvert, over which water to a depth of 4ft was rushing, and this carriage with others was damming back the water." (Reference 13).

A second flood occurred on 17th February of this year where 21.2 mm of rain fell in the morning and another 33.5 mm of rain fell later that afternoon. This caused damage to the train lines, causing all trains to stop (Reference 14).

2.3.2. April 1903

Rising "*2ft above the level of the 1885 flood, with 4ft of water in the main street",* the 1903 flood inundated the gasworks and left the town in darkness. Twenty inches (508 mm) of rain fell in the Jindalee Valley north-west of Cootamundra, and caused the town to flood very quickly: *"The water came down in torrents and in 10 minutes a large craft could easily float from the Commercial Bank to the Albion Hotel, and through Parker Street".* Cootamundra suffered significant damage, with roads and bridges being washed away, gasworks damaged, and several stores and hotels inundated and needing to pump water out of their cellars (Reference 15).

2.3.3. December 1919

The flood of December 1919 is described to have reached within a foot of the 1903 flood, though a reference location is not provided in historic newspaper reports. The costs were estimated at £1000, and included damage to roads, footbridges (Reference 16), houses (some having 3 foot of water in them), and loss of cattle and sheep livestock (Reference 17).

The Flood Study (Reference 5) noted that the 1903 and 1919 floods were mainly driven by floodwaters from the Jindalee Valley and most significantly affected the business centre. After the 1919 flood, the then Department of Railways constructed a dam on Jindalee Creek, and the 1986 Flood Study commented that, since then, the business centre has been flood free. This dam was initially designed as a water supply for steam locomotives but was abandoned due to the salinity of the water. It now acts as a retarding basin and diversion point for flood flows from Jindalee Creek.

2.3.4. Floods of the 1950s

The Flood Study (Reference 5) notes that in 1956, the Muttama Creek channel between Olney Street and Parker Street was relocated, and channel works carried out on several other sections of the creek as well. Information from Council also indicates a significant flood occurred in 1952, however no further details were available at the time of writing. There are some disputed reports that the 1956 flood was larger than the 1974 event but local records suggest the two floods were of similar magnitude.

2.3.5. January 1974

The flood of 1974 was a significant event and is reasonably well documented, Cootamundra received approximately 140 mm of rain over two days, causing creeks to burst their banks, flooding houses and overtopping many minor roads in the area (Reference 18). The large flood of 1974 was used to calibrate the previous flood model developed for the Cootamundra Flood Study (Reference 5). The 1986 Flood Study (Reference 5) provided six flood marks based on photographs of the flood and anecdotes from local residents. The photos or their source are not available. Photos of flooding can have large amounts of uncertainty as it is often unknown if the photo has been captured at the peak of the event. The estimated levels as reported in Reference 5 have been documented in Table 1. The flood marks are quite similar to those estimated in the September 2016 flood event (Table 4) considering during 1974 approximately 140mm fell in comparison to less than 60mm in the 2016 event. An analysis of the rainfall records shows that conditions preceding the 1974 event were much drier and the infiltration rate likely to be higher.

The Flood Study also notes that 'further clearing of the channel was carried out after the 1974 flood.

Table 1 Estimated Peak Flood Depths on Muttama Creek, January 1974 (from Reference 5)

Location	Observed Peak Flood level (m AHD)
Mackay Street	325.08
Thompson Street	325.82
Olney Street	328.92
Poole Street	329.68
Cutler Avenue	330.30
McGowan Street	330.70

2.3.6. August 1983 and January 1984

The previous Floodplain Management Study and Plan (Reference 7) notes that Cootamundra experienced flooding in 1983 and 1984 and presents various images of the flood, which occurred after 77 mm of rain was received over 2 days. Photos from the event are very blurry and of low quality but show that Muttama Creek flooded Poole Street up to the intersection of Poole St and Bourke St, and that Southee Circle was inundated to depths of approximately 200 mm.

2.3.7. December 2010

Council reported that on the 3rd December 2010 water from Jindalee Creek overtopped the railway dams and flooded across the aerodrome and down into properties fronting Yass Road. The flow then travelled along the railway line before going under the line and eventually flooding houses at the northern end of Hay St (email from Mark Ellis, received on the 7th of February 2020). A combination of factors may have impacted on flood behaviour during this event:

- The bank along the fence line at the railway dams had been lowered or removed (rebuilt up to old level after the event),
- The open drain along the northern side of the aerodrome was in poor condition (maintenance has been undertaken following the event),
- The culvert under the airport entrance road was under capacity (this has now been enlarged to 1200 mm x 400 mm box culvert)
- The concrete lined drain in the aerodrome along the railway line was poorly maintained. It was cleaned out after the event and is now better managed.
- Poorly maintained drainage along the aerodrome near Hay Street (also cleaned out after the event).

2.3.8. September 2016

The September 2016 flood resulted in evacuations of properties located along Muttama Creek through town. It was reported that approximately twelve (12) properties experienced overfloor flooding during this event.

There were several reports of flood related property damage caused by this event, particularly at the Poole St causeway on Muttama Creek where residents reported water levels exceeding the flood depth markers and peaking at around 2.2 m in the late afternoon (around 5 pm) on the 22nd September 2016. Residents of properties located near this crossing reported flood waters within backyards, garages and underneath some houses. Upstream of town at the Muttama Creek Berthong Road (Gauge No. 41000207) a peak water level of 2.141 m was recorded at 3:15 pm (Gauge Zero: 342.069 mAHD), this equates to a peak flow of approximately 50m^3/s. This is the highest level recorded at the gauge, which was commissioned in July 2004, and is 0.657 m above the second highest recorded level at the site (1.484 m, recorded in December 2010).

Within Cootamundra itself, peak flood depths were observed at key creek crossings and causeways (Table 4). Reports from residents and the NSW SES indicated however that Muttama Creek did not peak in town until about 7:30 pm that night. In addition, Council staff provided a sketch of the extent of inundation during the September 2016 event, which is useful information for validation of the developed hydraulic model, discussed in Section 8.4.1.

The NSW SES reported an incident involving an intoxicated individual who attempted to cross the Thompson Street causeway (with approximately 1.2 m of water over the causeway) when the water level had reached approximately 150 mm over the pedestrian bridge. This individual had to be rescued by the swift-water tech who was on patrol at the time. An incident was also reported involving a car that was swept from the Hovell Street causeway and washed over 200 m downstream. Fortunately, the driver was able to escape the vehicle before it was washed away however the car remained in the creek.

3. PREVIOUS STUDIES

A number of flood studies and assessments have been previously undertaken at Cootamundra. A brief overview of the more significant studies is provided below. Australian Rainfall and Runoff (ARR) is a national guideline document that can be used for the estimation of design flood characteristics in Australia. Design methodologies applied in these previous studies have generally been obtained using ARR 1977 or ARR 1987, while the current study considers the terminology, methodology and data described in ARR 2019, the event terminology used in previous reports has been maintained in the following section.

3.1. Cootamundra Flood Study Report, NSW Water Resources Commission, 1986 (Reference 5)

The Cootamundra Flood Study report details the results of flood investigations carried out under the 1977 NSW Government flood policy, which aimed to define flood conditions (particularly the 100 year ARI (1% AEP) design flood) for Cootamundra Shire Council for Muttama and Jindalee Creeks. Flooding in Cootamundry Creek was not assessed as part of the Flood Study.

The Cootamundra Flood Study used the Pilgrim-McDermott Method to establish design flows. This procedure is based on a statistical interpretation of the 'Rational Method' and is suitable for catchments less than 250 km^2 in area. The method has since been replaced by alternative techniques with the release of ARR 2019. The suitability of the approach was confirmed at the time by producing a frequency curve of peak flows. The estimated 1974 flood flow of 76 m^3/s fitted the curve at about the expected recurrence interval (approximately 1 in 25 years). The report does not document the source of the 1974 flow estimate. The 100 year ARI peak discharge was estimated at 126 m^3/s at the Wallendoon Street bridge, and the 20 year ARI at 65 m^3/s at the same location.

A HEC-2 1D hydraulic model (Hydrologic Engineering Centre (1981)) was developed to determine design peak flood levels in the Study Area. The floodplain topography was defined by a series of surveyed cross-sections across the channel (Muttama Creek) and adjacent floodplain, at right angles to the direction of flow. Cross sections were spaced at 150 to 250 m, with a survey taken at each bridge or culvert crossing (including details of the structure itself).

The hydraulic model was calibrated to the January 1974 flood event. This was the highest flood for which reasonable records were available, including numerous flood mark estimates along the creek channel and floodplain. An estimate of the peak discharge was made at the Wallendoon Street bridge as there were no flow records or gauging of the flow during the event. The inundation extents for the 20 year ARI and 100 year ARI events were located with field survey.

The Cootamundra Flood Study went on to define the floodway using an iterative encroachment analysis approach. The floodway is the part of the floodplain which, if it were to be blocked or partially blocked, would result in redistribution of flood flows causing some areas to receive 'deeper and swifter floodwaters than previously'. The encroachment analysis iteratively reduced the extent of the floodplain (from the fringe towards the channel) until the peak flood levels in the 100 year ARI event increased by more than 0.1 m as the trigger for adjustment. The Flood Study determined that the extent of the floodway was approximately equivalent to the 20 year ARI design flood extent. In 1983, Council resolved to exclude all areas within the 20 year ARI design flood extent (as a proxy for the floodway) from development, for consistency with the NSW Government's 1977 Flood Prone Land Policy.

The Flood Study also contained an assessment of flood hazard, flood damages and various flood mitigation measures. Amongst the outcomes was a recommendation to install a series of peak height indicators along the creek, and management of flood risk using selective stream clearing and zoning measures rather than structural options such as levees, basins or channel modifications.

3.2. Cootamundra Lake Flood Study, Maunsell Pty Ltd, 1997 (Reference 6)

Maunsell Pty Ltd were commissioned by the Cootamundra Lake Development Committee to investigate existing flood conditions through Cootamundra, and report on the impacts (or flood mitigation benefits) of constructing an artificial lake upstream of Cootamundra at the confluence of Muttama and Jindalee Creeks. Maunsell developed a RAFTS hydrologic model and utilised the existing HEC-2 hydraulic model developed in the Cootamundra Flood Study (Reference 5) to define existing flood behaviour. The study aimed to reproduce previously reported peak flood flows and levels rather than independently determining. To achieve this the model parameters were adjusted to reproduce peak flood flows and levels. A consistent initial loss of 25mm was adopted, while the adopted continuing loss varied from 1.5 mm/hr to 4.5 mm/hr, increasing with event size. The storage delay time modifier (Bx) was also varied from 1.25 – 1.8. The default Bx is typically 1.0.

The study considered a flood frequency analysis at the Coolac gauge approximately 50km downstream of Cootamundra. The report states that the analysis was discounted as the frequency estimate for the 1974 event was inconsistent with the estimate of frequency made for the event at Cootamundra in the 1986 report. Additionally, the report states that the period of record was insufficient. Considering this the study adopted the 1986 design flows for calibration purposes.

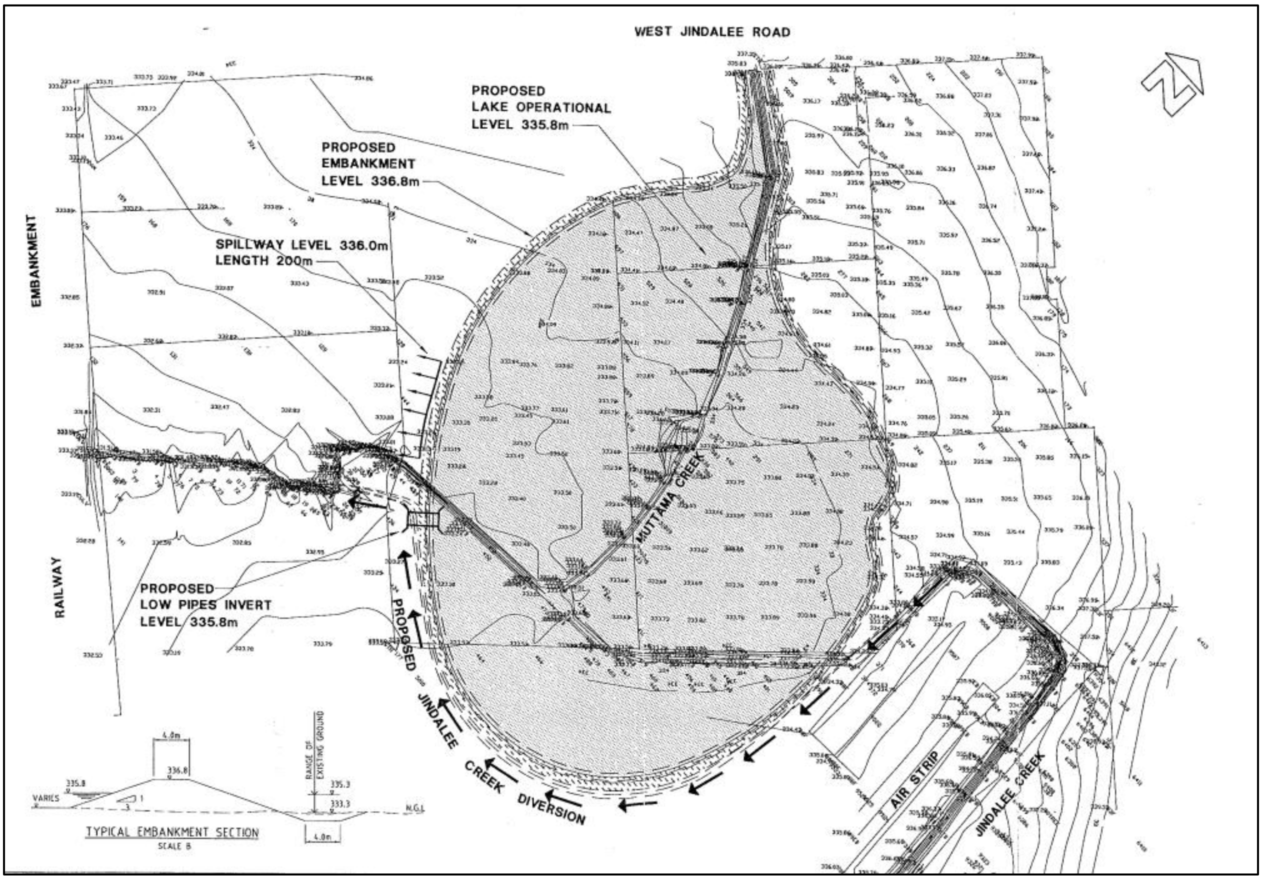
Several lake options were considered, with various spillway lengths of 50, 100 and 200 m tested. The report recommended the following:

- Construction of a spillway length of 200 m at an elevation of 336.0 mAHD, proposed embankment at 336.8 mAHD and a proposed operational top water level of 335.8 mAHD;
- Maintain operating water level with two 0.5 m diameter low flow pipes (invert 335.8 mAHD);
- Alternatively, an open channel could be provided through the centre of the spillway to pass low flows, avoiding problems of blockage in the pipes.

The installation of such a lake would increase flood levels by 1.5 m at the lake inlet, extending approximately 1 km upstream of the lake, where water levels return to existing levels. Jindalee Creek would be diverted to the south to allow for the construction of the lake embankment. This would increase flood levels in the vicinity of the aerodrome from the Muttama/Jindalee Creek confluence. However, the report noted that 'the construction of the proposed lake upstream of town decreases flood levels in the township marginally'

The proposed lake layout is shown in Diagram 1. It is noted that at the time of writing, the lake and embankments had not been constructed.

Diagram 1 Proposed Layout - Muttama Creek Lake (Fig B1 Reference 6)



3.3. Cootamundra Floodplain Management Study and Plan, Willing & Partners, 2001 (Reference 7)

The Cootamundra Floodplain Management Study and Plan followed on from the 1986 Cootamundra Flood Study (Reference 5), and included an extension of the existing hydrologic and hydraulic models for the study area, development of an estimate of the Probable Maximum Flood and the assessment of mitigation strategies. The study revisited the hydrological assessment, extending the existing XP-RAFTS rainfall-runoff hydrologic model. Once again, the study aimed to reproduce the flows identified in Reference 5 rather than reassessing the flow rates. The XP-RAFTS modelling found that the critical storm durations for the creek catchment were 9 hours for the 2 and 5 year ARI events, and 6 hours for the 10 year, 20 year, 50 year, 100 year and 200 year ARI events. In the case of the PMP a 3 hour storm was modelled. The results produced a peak flow of 136 m^3/s at the Wallendoon St bridge for the 100 year ARI event, and a 20 year ARI peak discharge of 72.9 m^3/s at the same location.

In addition, the Study undertook a flood frequency analysis at Coolac (despite being discounted in the previous Flood Study). Muttama Creek at Coolac is estimated to have a catchment of 1,025 km^2, approximately 5 times greater than its catchment at Cootamundra. Peak flows at Cootamundra were estimated by transposing Coolac flows using an areal transposition equation for each design flood event. However, there were significant differences between the transposed flows and the XP-RAFTS results (e.g. the 100 year transposed flow was found to be 50.6 m^3/s at Wallendoon Street), suggesting either high transmission losses between Cootamundra and Coolac, or an uneven distribution of the catchment area that contributes to flows at Coolac compared to Cootamundra. The transposed flows were subsequently discounted, and the XP-RAFTS design hydrographs adopted for the hydraulic analysis. The report states that the extended models were not calibrated and adopted the same model parameters (including higher storage delay time modifier (Bx)) to be consistent with the previous assessments.

The existing HEC-RAS model developed in the Flood Study (Reference 5) was extended downstream along Muttama Creek to its confluence with Cootamundra Creek (also referred to as Cootamundry Creek), and along Jindalee Creek to upstream of Binowee Road. In addition, a detailed model of the Southee Circle drainage system was assembled using XP-SWMN, with downstream tailwater conditions defined by the peak level in Muttama Creek for the same design storm event, in accordance with advice from the Cootamundra Floodplain Management Committee.

The Study assessed flood risk due to Muttama Creek and Jindalee Creek, as well as overland flood risk in the Southee Circle area that occurs when the capacity of the piped drainage system is exceeded, causing runoff to pond around Southee Circle and to discharge overland to Muttama Creek (primarily along existing roads). The pipe network in the Southee Circle area was identified as having a capacity of no more than a 5 year ARI flood, as is typical of most stormwater drainage systems. The Study reviewed Council's planning policies and instruments and assessed a range of options aimed at reducing the social, environmental and economic impacts of flooding over the full range of potential flood events.

Table 2 describes the options that were investigated (as documented in the Study) and the conclusions/recommendation for each (as documented in the Plan).

Table 2 Floodplain Risk Mitigation Options Assessed in the 2001 FRMS&P***

Type	Measure ID	Description	Recommended
Retarding Basins	B1	Cootamundra Lake Option 7D (Reference 6) at confluence of Muttama and Jindalee Creeks.	No
	B2	Dry retarding basin at same site.	No
	B3	Pair of cascading basins with slotted outlets at Temora Street and Adams Street, aiming to contain up to the 100 year ARI flood without hydraulically interfering with the upstream Railway Line.	No
	B4	Single basin with slotted outlet at Adams Street that would inundate Temora Street from time to time, aimed at containing up to the 100yr ARI flood without hydraulically interfering with the upstream Railway Line.	No
	S3	Installation of flap gates on stormwater outfalls into Muttama Creek and the excavation of Southee Circle to create either a (dry) retarding basin (S3A) or a pond/wetland with an operating level equal to the existing invert level of the piped drain that exits Southee Circle (S3B)	No
	S4	Golf course basins	No, however two basins have been constructed*
Channel and Bridge Improvements	A1	Reconstruction and widening of the existing channel around the northern end of the airstrip (Jindalee Creek).	Yes**
	R1	50% amplification of the railway crossing just downstream of Hovell Street	No
	R2	100% amplification of the railway crossing just downstream of Hovell Street	No
Pipe Drainage Improvements	S1	Installation of flap gates on stormwater outfalls into Muttama Creek	Yes (Implementation TBC)***
	S2	Installation of flap gates on stormwater outfalls into Muttama Creek and augmentation of piped drains at Southee Circle, and from Southee Circle to Muttama Creek.	No
Levee Banks	L1	Combined earthen levee and concrete wall along the eastern side of Muttama Creek between Temora Street and Crown Street.	No
	L2	Concrete ring wall along the eastern side of Muttama Creek between Adams Street and Cutler Avenue (difficulties noted with access to residential dwelling driveways, drop boards needed).	No

Type	Measure ID	Description	Recommended
	J1	Low earthen levee to protect two flood affected residences immediately downstream of Binowee Road, incorporating a 300 mm freeboard.	Yes – Constructed in 2006
Vegetation Management	M1	Scenario in which Council significantly reduced its maintenance of Muttama Creek, and allowed the creek to revegetate (i.e. increase hydraulic roughness)	Recommendation for Council to continue maintenance program
Options to Reduce Residual Hazard		Flood warning gauge upstream of Cootamundra	Yes
		Flood awareness and education (S149 certificates, articles, historic flood marks, flood awareness days)	Yes

*Clarification on the implementation of these mitigation measures has been requested from council

**The study recommended that flood warning be improved by installing an automatic gauging station on Muttama Creek upstream of the town – suggested at the Berthong Road crossing, approximately 5 km upstream of Adams Street, which would provide 1-1.5 hours of warning ahead of the flood peak. The Muttama Creek at Berthong gauge was subsequently installed and commissioned in July 2004, site No. 41000207.

***The Study also identified opportunities to improve local flood awareness via periodic public awareness and community education campaigns, inclusion of flood information with rates notices, notifications on S149 Planning Certificates (now Section 10.7).

The Plan also recommended that Council consider a range of controls for redevelopment and new development in the area defined by the extent of the 1% AEP event + 0.5 m (i.e. Flood Planning Area), pertaining in particular to flood planning levels for dwellings and commercial/retail developments. The plan also recommended a requirement for dividing fences within the Floodway to be subject to a Development Application. No houses were identified for house raising or voluntary purchase.

3.4. Jindalee Creek Levee, Cootamundra, Preliminary Design Report, Cardno Willing, August 2004, (Reference 8)

Council commissioned Cardno Willing to investigate and design a levee bank at Jindalee Creek immediately west of Binowee Road. The study recommended the building of a levee to protect three households from potential flooding.

Work as executed plans from September 2006 show that the levee crest level was set to the 1% AEP flood level + 500 mm (from 344.5m AHD to 343.65 m AHD). The levee height varies from 0.5 m to 1.0 m, with a 2 m wide crest and 3 to 1 m slope on the creek side (2.5 m to 1 m on the outer face).

3.5. Cootamundra Local Flood Plan, NSW SES, June 2007, (Reference 9)

The Cootamundra Local Flood Plan (LFP) is a subplan of the Cootamundra Local Disaster Plan (DISPLAN). The plan covers preparedness measures, the conduct of response operations and the coordination of immediate recovery measures from flooding within the Cootamundra Shire Council area. It addresses operations for all levels of flooding and covers the entire former Cootamundra Shire Council area. The Local Flood Plan (LFP) outlines the general responsibility of emergency service organisations and supporting services ahead of, during and following a flood event. In Cootamundra, responsible agencies include the NSW SES Local Controller, NSW SES Unit Members, Council Local Emergency Operations Controller, NSW Police Force, Council Local Emergency Management Officer, Council, BOM, NSW Fire Brigades, RFS, amongst others.

Annex A of the LFP provides flood information specific to Cootamundra, including a description of flood behaviour, and identification of roads that may experience inundation, including Rodeo Drive, Temora Road within Cootamundra, and a number of roads outside of town within the former Cootamundra Shire LGA, including Gundagai Road at Muttama and Burley Griffin Way at Stockinbingal.

The Cootamundra LFP identified the Cootamundra Showgrounds (on Pinkerton and Berthong Streets) as the preferred evacuation centre in town.

3.6. Stormwater Priority Assessment Report, Brearley & Hansen, 2018 (Reference 10)

Council engaged Brearley & Hansen to identify possible stormwater management projects using a risk based approach, and to propose a priority list for expenditure and implementation. The report focussed on urban drainage systems within both Cootamundra and Gundagai.

In particular, Option C5 was listed as a high priority stormwater improvement project. Option C5 involved the construction of a small levee or grassed earth bank along the fence line on Adams Street and McGowan Street, for the purpose of separating mainstream flood waters from urban runoff. Reference 10 however noted that further consideration of this project should be deferred until the Cootamundra Floodplain Risk Management Study had been completed.

Other recommendations for Cootamundra included vegetation management and desilting of minor flowpaths, installation of concrete “V” drains and reshaping grass channels to improve conveyance, CCTV inspection of pipes within the Southee Circle area (suspected blockage) and consideration of upgrading/ enlarging the piped network or formalisation of overland flow paths.

3.7. Survey and Design of Six Stormwater Improvement Projects, Design Report, 2019, (Reference 11)

Council engaged Cardno to develop designs for stormwater drainage improvements to mitigate the risks from flooding at six specified locations, five in Gundagai and one in Cootamundra at Southee Circle. Southee Circle was a low-lying swamp prior to urban development and the area is not free draining. Stormwater is currently drained to Muttama Creek via a 1050/1800 mm diameter pipeline.

The scope of services included:

- CCTV inspection of pipes,
- Analyse stormwater capacity and overland flow paths,
- Design improvements to minimise flooding risk.

Hydrological and hydraulic 1D modelling was undertaken using the xpswmm stormwater modelling package.

The design report recommends waiting for Cootamundra Flood Study and Cootamundra Floodplain Risk Management Study and Plan before proposing large scale stormwater improvement works.

The report recommends constructing two flap gates on the Muttama Creek outlet as an interim measure to prevent backwatering from Muttama Creek. The preliminary cost was estimated to $26,730.

4. AVAILABLE DATA

4.1. Aerial Imagery

Aerial imagery available on SIXMaps was provided for the study by Council. This included two aerial images, one covering the town area of Cootamundra captured in 2009, and one covering the area to the east of Cootamundra captured in 2008. Since Nearmap does not offer any service in this region these aerial images are the best available for the area.

4.2. Topographic Data

4.2.1. LiDAR

Light Detection and Ranging (LiDAR) topographic survey of the study area and its immediate surroundings was provided for the study by NSW Government Spatial Services, freely available from Geosciences Australia (ELVIS). LiDAR is aerial survey data that provides a detailed topographic representation of the ground with a survey mark approximately every square metre. The LiDAR data used in this study was collected in 2014 with a resolution of 1 m, covering an area of 120 km^2 over the town itself. Beyond this extent, 5 m LiDAR data was obtained from NSW Department of Land and Property Information (LPI). The extents of the two LiDAR data sets are shown on Figure 3.

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 horizontal accuracy of the data is 0.8 m at 95% confidence interval (CI), while the vertical accuracy is 0.3 m at 95% CI.

The LiDAR survey was checked against the surveyed road level of the Olympic Highway. The LiDAR indicates a road level of 325.78 m AHD and is consistent with the surveyed level of 325.75 m AHD

4.2.2. Muttama Creek Cross Section Survey

In the 1986 Flood Study (Reference 5), the floodplain topography used in the HEC-2 model was defined by a series of surveyed cross-sections across the channel (Muttama Creek) and adjacent floodplain, at right angles to the direction of flow. Cross sections were spaced at 150 to 250 m, with a survey taken at each bridge or culvert crossing. Within Cootamundra, Muttama Creek is typically 80/100 m wide and 3.5 – 4.0 m deep. The surveyed cross sections have been compared to the available LiDAR data as a way to validate the LiDAR data.

The comparison showed reasonable similarity between the two cross section sources (DEM and HEC-2) (see Figure 4), particularly considering the 30 year period between measurement, resolution of the more recent survey and the relative uncertainty of the location of the HEC-2 sections.

4.2.3. Boundary Road Subdivision

Council provided design details for the subdivision located on Boundary Road, including road layout, and drainage details including an on site detention basin. At the time of writing, Stage 1, adjacent to Dillon Avenue was currently under construction and due for completion in the coming months. Other stages will be constructed in the future. This information can be used to define existing conditions as well as to assess future development scenarios in subsequent studies.

4.3. GIS Layers

Upon commencement of this Flood Study, Council provided WMAwater with a range of GIS layers used for figures and various elements of the analysis. The handover included the following:

- Road centrelines and corridors;
- Town planning information and various layers from the Cootamundra Local Environmental Plan 2013 and 2006;
- Cadastre;
- Town boundaries within the Cootamundra-Gundagai LGA;
- Creeks and wet areas location;
- Gundagai Flood Study area and 1% AEP flood extent.

4.4. Hydraulic Structures

4.4.1. In-Field Measurements

A comprehensive site visit was undertaken in August 2019 to identify and measure key hydraulic structures, including culverts, bridges, and elements of the pit and pipe network. In total, 59 structures were measured during the two-day field trip. Dimensions of hydraulic structures located along the railway lines in the Cootamundra area were provided by ARTC. Photographs of hydraulic structures within the Study Area are shown on Figure 5A, 5B and 5C. Appendix B provides a summary of these structures.

4.4.2. Previous Survey

In the 1986 Flood Study (Reference 5), a survey was taken at the following bridge or culvert crossing (including the structure itself):

- Mackay Street bridge
- Thompson Street
- Olympic Highway
- Hovell Street
- Railway Bridge

These cross-sections are presented in Appendix C.

4.4.3. Notes about upgraded structures

The Stockinbingal railway crossing, upstream of Temora Street, has been upgraded since the 1974 flood. The original box culverts (44 No. 3.15 m width x 1.0 m depth) were replaced with pipe culverts (36 No. 1.5 m diameter, 1 No. 1.6 m width x 2.4 m depth).

It is also noted that the following structures have also changed:

- Wallendoon Street was converted from a causeway to a bridge structure after the 1974 event;
- Temora Road culverts have been upgraded; and
- Parker Street pedestrian bridge has been constructed more recently.

4.4.4. Pit and Pipe Network

Details of the stormwater network in the vicinity of Southee Circle, including inlet information and pipe inverts and diameters, was provided by Council. The survey had been collected in 2018 by Cardno as part of the Southee Circle stormwater improvement project and focused on drainage in the Southee Circle Area and the open channel to Muttama Creek. This dataset was provided in GIS format and checked for accuracy during the August 2019 site visit, with on-site measurements used to validate the provided dimensions and locations of stormwater inlets and pipes in this area.

A drainage reticulation master plan from 1997 was also provided by Council (as a scan of the hardcopy). Pit and pipe locations, and pipe diameters, were marked on the map with handwritten annotations, covering most of the urban area. This dataset was digitized in-house by WMAwater, georeferenced and cross checked with the Cardno survey and measurements from the site visits. Pit locations were also confirmed via aerial imagery and Google Street View. The annotated map did not include invert levels, and thus inverts were estimated based on LiDAR data using the following principles:

- Pipes were modelled as having 0.30 m cover below the recorded ground level (taken from the available LiDAR) at pits and junctions;
- Pit inlets were modelled as having an invert at recorded ground level (taken from the available LiDAR); and
- Pit inlet dimensions of 1.2 m x 0.15 m were assumed for all inlet pits for consistency, cross-checked with measurements during the site visit.

It is noted that two culverts were significantly damaged during the September 2016 event and have since been replaced. These two culverts labelled A22 and E14 on Figure 5 and include:

- An existing culvert on Berthong Road 200 m south of Dinyah Farm was damaged during the event. The road pavement of the three existing culverts was resealed after the event but the culverts remained. An additional culvert (1.8 m x 0.8 m rectangular box culvert) located between the two southern culverts was installed to reduce flood impact on Berthong Road; and

- The low level causeway at Cowcumbla Street was upgraded to the current three-cell rectangular box culverts, with the causeway deck now sitting 2.9 m above the creek bed. Details of the original culvert were not available. However, as this structure is 1.1 km south of town in the downstream portion of model extent, the dimensions of this structure are not considered critical to the calibration of the model (described in Section 8) in the area of interest.

4.4.5. Details of railway structures from ARTC

Comprehensive details of the railway culverts were provided by ARTC for the Main Southern Line (Wallendbeen to Bethungra) and the Cootamundra to Tumut Railway, and the disused Cootamundra – Lake Cargelligo Railway, which crosses Muttama Creek north of town. The details provided included Equipment Number, distance from Central Station (in kilometres), structure type, status (in service or closed), deck width, barrel length, culvert shape and dimensions, and the distance from the rail to invert level. These details were used to ensure railway culverts were represented appropriately in the hydraulic model and were particularly useful as it was not generally safe or possible to access and measure these structures in the field. During the field trip (see Section 4.4.1), the location of culverts was verified, and matched to the data from ARTC, as many of the culverts were stencilled with their 'ID' – which corresponds to their distance from Central Station.

4.5. Site Visit

Two site visits were conducted as part of the data collection process. The first was completed on Tuesday 18th June 2019 by WMAwater staff. The purpose of this site visit was to gain a broad understanding of the Cootamundry, Muttama and Jindalee Creeks and their interactions, and become more familiar with the area in general. WMAwater staff walked along Muttuma Creek through town where access allowed, noting the catchment conditions, vegetation and crossings. In addition, staff drove out to the airport (public access roads only), and out to see the Jindalee Levee, accessed via Rodeo Drive.

The second site visit was conducted by WMAwater staff on Wednesday 7th and Thursday 8th August 2019. The main purpose was to measure hydraulic structures (mainly culverts and bridges) within the Study Area and identify any other important features that may be required for modelling purposes. The hydraulic structure dimensions obtained from this site visit are shown on Figure 5, and have been used in the modelling process.

A community drop-in session was also conducted during the second site visit, where residents were able to provide valuable information regarding significant flood events that have occurred in Cootamundra. The community consultation activities are detailed in Section 5. On the Thursday morning, WMAwater staff were joined by the Local NSW SES Commander, who shared experiences from the September 2016 event and directed the team to key locations including the Muttuma Creek gauge on Berthong Road, and the area downstream of Lloyd Conkey Drive, where a car was washed away.

The insight provided by the NSW SES was particularly valuable and included a description of observed peak flood depths at various locations, and the identification of key structures that had been upgraded since the 2016 flood (on Berthong Road and Cowcumbla Street).

4.6. Land Use in the Study Area

Land use zoning is defined by the Cootamundra Local Environment Plan (LEP 2013). The majority of residential development within Cootamundra is comprised of lots zoned *R1 General Residential* with areas of *B3 Commercial Core* around Olympic Highway and areas of *IN1, IN2 and IN3 General, Light and Heavy Industrial* south of the town. There is a relatively small amount of lots zoned *R3 Medium Density Residential* in the western part of the town. Land use outside of the township of Cootamundra is generally zoned *RU1 Primary Production*.

4.7. Floor Level Database

A key outcome of the current study is a flood damages assessment. To complete this aspect of the study, floor level estimates are required to undertake a broad assessment of flood affectation across the suite of design flood events. While the assessment uses floor level data for individual properties, the results are not intended as an indicator of individual flood risk exposure but part of a regional assessment of flood risk exposure. For each property, the floor level estimation captured the following descriptors:

- Ground Level (in mAHD);
- An indication of house size (number of storeys);
- Location of the front entrance to the property; and
- Local Environmental Plans (LEP) land use (residential, commercial, industrial, primary production, or public recreation and infrastructure).

The floor level database includes all properties within the PMF extent. WMAwater used LiDAR data and visual inspection to estimate floor levels for these properties. A floor level survey was undertaken as part of the 2001 Floodplain Risk Management Study (Reference 7). The floor level estimates from the current study compared well, providing greater confidence to the estimated dataset. This method of determining floor levels is appropriate particularly considering the other uncertainties present in the damages assessment procedure and its use as a comparative tool. A summary of the floor level estimates is provided in Table 3 below.

Table 3 Floor Level Database

Property Type	No. Included in Damages Assessment
Residential	**1306**
Non-Residential	117
Total	**1423**

4.8. Flood Marks for Calibration

Calibration of a hydraulic model relies on recorded flood information from past events. Anecdotal information is available for a number of events and more so in recent history. A small number of estimated flood marks are also available for the 1974 event (Table 1). The 1986 Flood Study (Reference 5) describes the flood marks as being estimated from photos.

The September 2016 flood event has a number of readily available flood marks. Peak flood depths were also estimated based on photos taken at the peak of the event or as reported by NSW SES and residents. They have been documented in Table 4.

It should be noted that observed peak flood depth have not been surveyed and thus are subject to significant uncertainties. The photos (and their metadata, especially time taken and location) were used to derive flood marks. Uncertainties can come from the timing of the photo that may not have been taken at the exact time of the peak and from the fact that the reading of the flood depth was made by eye.

Table 4 Observed Peak Flood Depths on Muttama Creek, September 2016

Id	Location	Observed Peak Flood Depth* (m)	Source
1	Berthong Road Gauge	2.1	SES
2	West Jindalee Road Culvert	0.40	Local Resident
3	Adams Street / McGowan Street Crossroad	0.10	Local Resident
4	Cutler Ave causeway	1.90	Local Resident
5	Cutler Ave causeway	2.10	SES
6	Poole St causeway and pedestrian bridge	2.10	Local Resident
7	Poole St causeway and pedestrian bridge	2.00	SES
8	Olney Street pedestrian bridge	1.82	Local Resident
9	Parker Street bridge	2.50	Local Resident
10	Thompson St causeway	2.10	SES
11	Sutton Street Bridge	2.57	Local Resident
12	Hovell Street Causeway	2.10	SES
13	Main Southern Railway Culverts	3.00	Local Resident

*Observed peak flood depths are approximate only and have been taken from photos or as reported by the NSW SES and residents.

Council staff also provided a sketch of the extent of inundation in the September 2016 event (Figure 26).

4.9. Gauge Data in the Study Area

4.9.1. Stream Gauges

There are two stream gauges located across the Jindalee and Muttama Creek catchments operated by WaterNSW, located at Jindalee and Berthong Road (Figure 7). The details of these gauges are shown in Table 5. The Jindalee Creek gauge opened in 1975 while the Berthong Road gauge opened in 2004.

Table 5: Stream Gauges

Station	Name	Operating Authority	Opened	Closed
410112	Jindalee Creek @ Jindalee	WaterNSW	1975	-
4100207	Muttama Creek @ Berthong	WaterNSW	2004	-

The Jindalee Creek gauge is out of hydraulic model extent and cannot be used for hydraulic calibration purpose. The Berthong Road stream gauge has a short data record and has only been rated for low flows and has significant uncertainties for higher levels when the creek overtops the banks.

4.9.2. Rainfall Gauges

There are two working continuous pluviometers located across the study area catchment, operated by WaterNSW, located at Jindalee and Berthong Road. These records were used to create rainfall hyetographs (a temporal representation of rainfall), which forms the model input for historical events against which the model is calibrated. The details of the continuous pluviometers are shown in Table 6.

The locations of theses gauges are shown on Figure 7.

Table 6: Pluviometer Rainfall Stations

Station	Name	Operating Authority	Opened	Closed
410112	Jindalee Creek @ Jindalee	WaterNSW	1975	-
4100207	Muttama Creek @ Berthong	WaterNSW	2004	-

There are also a number of daily read rainfall stations located within or close to the catchment. Rainfall totals derived from these daily stations in addition to the pluviometer stations for historical events have been used to construct a representation of the rainfall depth across the catchment for modelled calibration events. This in turn informs the modelled spatial distribution of rainfall across the catchment for calibration events. Details of these gauges are summarised in Table 7 and also mapped on Figure 7.

The gauge at Cootamundra Airport operated by the Bureau of Meteorology (previously located at Cootamundra Post Office 1960 - 2000) has a recording interval of 3 hours and was included in the daily rainfall station analysis.

Table 7: Daily Rainfall Stations

Station	Name	Operating Authority	Opened	Closed
73009	Cootamundra Post Office	BOM	1889	2000
73142*	Cootamundra Airport	BOM	1995	-
73085	Cootamundra 1	BOM	1885	1911
73118	Cootamundra Aero	BOM	1940	1943
73053	Woddburn 3	BOM	1897	1970
73119	Gilgal	BOM	1888	1915
73022	Cootamundra Landgrove	BOM	1891	-
73092	Stockingbal 1	BOM	1896	1938
73003	Berthong	BOM	1886	1952
73042	Wallendoon	BOM	1911	1952
73011	Dunollie	BOM	1936	1953
73073	Eulomo	BOM	1904	1918
73137	Muttama (Grovene)	BOM	1987	-
73063	Bongalong	BOM	1899	1919
73043	Wallendbeen (Corang)	BOM	1914	-
73004	Bethungra Post Office	BOM	1889	1968
73103	Bethungra Park	BOM	1884	1917
73036	Stockinbingal Post Office	BOM	1903	-
73150	Stockinbingal (Sunnydale)	BOM	1949	-

* 3 hour recording interval

4.9.3. Analysis of September 2016 Rainfall Event

An analysis of the available pluviometer data at Berthong Road and Jindalee (Figure 7) indicated that on the 21th September, the total recorded rainfall at Jindalee between 3:20 AM and 6:04 PM was 53.0 mm. At Berthong Road, the total recorded rainfall between 1:12 AM and 9:07 PM was 54.0 mm. Temporal patterns of the rainfall burst were very consistent between the two gauges (Figure 8). Thus, the Jindalee pluviometer was considered representative of the temporal pattern of rain falling around the catchment for the purpose of calibration.

In addition to the pluviometers and daily rain gauges, a private rainfall gauge located at 4 Poole Street in Cootamundra recorded a total rainfall depth of 48 mm. This gauge data was also used in the calibration process.

The rainfall totals at each available pluviometer and daily rain gauges were used to create rainfall isohyets for the entire catchment and subsequently the rainfall depths for each individual sub-catchment in the hydrologic model. The rainfall isohyets were developed using natural neighbour interpolation technique. In cases where a subcatchment was situated outside the interpolated isohyets, rainfall depths were taken to be equal to the average rainfall depth for the nearest adjacent subcatchments.

A review of available pluviometer and daily rainfall gauges confirmed that the main burst of rainfall occurred within a 24 hour period, with similar rainfall recorded at the gauges in the region (Table 8).

Table 8: Recorded Rainfall (24 hour totals) – September 2016

Station Number	Station Name	Type	19-Sep	20-Sep	21-Sep	22-Sep
73022	Cootamundra (Landgrove)	Daily	15	0	15	40
73036	Stockinbingal Post Office	Daily	16.4	0	31	39
73043	Wallendbeen (Corang)	Daily	3.2	0	48.2	2.2
73137	Muttama (Grovene)	Daily	14	0	23	19
73142	Cootamundra Airport	Daily	13.1	0	27	30
410112	Jindalee	Pluvi	0	0	22	31
41000207	Muttama Creek at Berthong Road	Pluvi	0	0	25	29

The rainfall records also showed that a relatively wet period preceded the event on the 21st September (approximately 150mm over 30 days), resulting in saturated catchment conditions when the event occurred.
An analysis of the equivalent AEP Rainfall Design Intensities (ARR 2019) on the Jindalee and Muttama Creek pluviometers for the September 2016 event is presented in Table 9.

The total duration of the event was confirmed to be between 15 and 18 hours and the rainfall intensity was mostly constant during this duration (3 or 4 mm/hr). For shorter durations (< 6 hours) the equivalent AEP was less than a 1 EY, which is considered to be fairly frequent. However, at the 18 hours duration the equivalent AEP was 50% AEP. For a 24 hour period, this event was found to be equivalent AEP to a 50% AEP for both stations.

Table 9: Equivalent AEP Rainfall Design Intensities (ARR 2019) – September 2016

Station Number	Station Name	Operating Authority	Rainfall Depth (mm) (Equivalent Design Rainfall Event)				
			3 hrs	**6 hrs**	**12 hrs**	**18 hrs**	**24 hrs**
410112	Jindalee Creek @ Jindalee	WaterNSW	16(3EY)	29 (1EY)	48 (50% AEP)	52 (50% AEP)	52 (50% AEP)
4100207	Muttama Creek @ Berthong Road	WaterNSW	17 (2EY)	29 (1EY)	48 (50% AEP)	54 (50% AEP)	54 (50% AEP)

4.9.4. Analysis of March 2012 Rainfall event

The March 2012 event is the second highest recorded level at the Muttama Creek Berthong Road gauge after the September 2016 event. The main event burst occurred between 10:00 AM and 3:00 PM on the 3rd March, with a much more intense burst of rainfall over a shorter duration than the September 2016 event. In comparison to September 2016, which displayed fairly consistent rainfall over the catchment, the March 2012 showed greater total rainfall in the southern part of the catchment as recorded at Cootamundra Airport (Table 10). The catchment experienced several days of preceding rain with earlier peaks being experienced on the 29th February and 1st March.

Table 10: Recorded Rainfall (24 hour totals) – March 2012

Station Number	Station Name	Type	02-Mar	03-Mar	04-Mar
73022	Cootamundra (Landgrove)	Daily	17	1	36
73043	Wallendbeen (Corang)	Daily	20	1	39
73142	Cootamundra Airport	Daily	19.4	0.4	53
73137	Muttama (Grovene)	Daily	20	0.2	0
410112	Jindalee	Pluvi	12	1.2	43.2
41000207	Muttama Creek at Berthong Road	Pluvi	10.6	0	39.2

The rainfall totals at each available pluviometer and daily rain gauge were used to create rainfall isohyets for the entire catchment and subsequently the rainfall depths for each individual sub-catchment in the hydrologic model. The rainfall isohyets were developed using natural neighbour interpolation technique. In cases where a subcatchment was situated outside the interpolated isohyets, rainfall depths were taken to be equal to the average rainfall depth for the nearest adjacent subcatchments.

Rainfall at the two available pluviometers did not exceed a magnitude of 1 EY for 3 and 6 hour events and a magnitude of 2 EY for the 12 hours event (Figure 9). At both stations, the event was found to be comparable to a 3 EY event for a daily period. This is consistent with the lack of significant flooding within Cootamundra. The event does provide useful data for the validation of the model performance at the Berthong Road gauge for more frequent events.

Table 11: Equivalent AEP Rainfall Design Intensities (ARR 2019) – March 2012

Station Number	Station Name	Operating Authority	Rainfall Depth (mm) (Equivalent Design Rainfall Event)				
			3 hrs	**6 hrs**	**12 hrs**	**18 hrs**	**24 hrs**
410112	Jindalee Creek @ Jindalee	WaterNSW	24.2(1 EY)	29.6((1 EY)	29.8(2 EY)	32.2(2 EY)	43.2 (2 EY)
4100207	Muttama Creek @ Berthong Road	WaterNSW	22.6(1 EY)	28.6(1 EY)	29.2(2 EY)	31.6(2 EY)	39.2 (2 EY)

4.9.5. Analysis of December 2010 Rainfall event

The December 2010 event was again a relatively minor event with some inundation being experienced over the airport. The majority of rainfall occurred in the northern and eastern portions of the catchment. The Berthong Road streamflow gauge recorded an event on the 3rd December following a few days of rainfall. A review of the available rainfall gauges shows the event occurred over a period of a week with fairly steady rainfall falling. The total rainfall over the week was 153 mm at Jindalee and 124 mm at Berthong Road gauge (Figure 10).

Table 12: Recorded Rainfall (24 hour totals) – – December 2010

Station Number	Station Name	Type	28-Nov	29-Nov	30-Nov	01-Dec	02-Dec	03-Dec	04-Dec
73022	Cootamundra (Landgrove)	Daily	7	->	104	31	4.6	85	5
73043	Wallendbeen (Corang)	Daily	6	78	24	31.2	2	38	7
73137	Muttama (Grovene)	Daily	->	80.2	19.4	32.8	19.4	0	0
73142	Cootamundra Airport	Daily	9	50	23.4	26.6	1.6	31	3
410112	Jindalee	Pluvi	11	63	20	23.5	1.5	17	16
41000207	Muttama Creek at Berthong Rd	Pluvi	13	38.8	16.6	24.6	0.2	31	0

The rainfall totals at each available pluviometer and daily rain gauge were used to create rainfall isohyets for the entire catchment and subsequently the rainfall depths for each individual sub-catchment in the hydrologic model. The rainfall isohyets were developed using natural neighbour interpolation technique. In cases where a subcatchment was situated outside the interpolated isohyets, rainfall depths were taken to be equal to the average rainfall depth for the nearest adjacent subcatchments.

On the 3rd December, Jindalee received 13 mm of rainfall and Berthong Road station 30.6 mm. This was found to be more frequent than a 12 EY event for a daily period at Jindalee station and comparable to a 4 EY event at Berthong Road.

An analysis of the equivalent AEP Rainfall Design Intensities (ARR 2019) on the Jindalee and Berthong Road pluviometers for the December 2010 event is presented in Table 13. At the Jindalee and Berthong Road gauges, the maximum intensity was recorded on the 3rd of December but was too low to lead to a significant equivalent design rainfall.

Table 13: Equivalent AEP Rainfall Design Intensities (ARR 2019) – December 2010

Station Number	Station Name	Operating Authority	Rainfall Depth (mm) (Equivalent Design Rainfall Event)				
			3 hrs	6 hrs	12 hrs	18 hrs	24 hrs
410112	Jindalee Creek @ Jindalee	WaterNSW	3.0 (< 12 EY	5.5 (< 12 EY)	10.0 (< 12 EY)	13.5 (< 12 EY)	16.0 (< 12 EY)
4100207	Muttama Creek @ Berthong Road	WaterNSW	17(2 EY)	18 (4 EY)	24.6 (4 EY)	28.6 (4 EY)	30.6 (4 EY)

4.9.6. Analysis of March 2010 Rainfall event

The March 2010 rainfall event was a localized storm with a significant intensity recorded at the Berthong Road and Airport gauges (Table 14). At Berthong Road, the event is estimated to be of a 10% AEP magnitute for a 1hr duration and a 20% AEP magnitute for 3 hr / 6 hr events. At Jindalee, the recorded rainfall was more frequent (≈12 EY). For a 24 hour period, the event was found to be comparable to a 50% AEP event at the Berthong Road gauge but was too low to lead to a significant equivalent design rainfall at the Jindalee gauge (Figure 11).

Table 14: Recorded Rainfall (24 hour totals) – – March 2010

Station Number	Station Name	Type	06-Mar	07-Mar	08-Mar	09-Mar
73022	Cootamundra (Landgrove)	Daily	19.4	11.4	26.4	1.2
73043	Wallendbeen (Corang)	Daily	22.4	0.6	28.4	0
73137	Muttama (Grovene)	Daily	25.8	27.8	32.8	0
73142	Cootamundra Airport	Daily	24.2	35.6	61.6	0
410112	Jindalee	Pluvi	14.5	12	18.5	0
41000207	Muttama Creek at Berthong Rd	Pluvi	3.4	39.8	46.8	0

At Berthong Road for the 1 hour duration the event was considered moderate (10% AEP), this event however did not lead to any significant flooding within Cootamundra and Muttama Creek did not overtop its banks. The critical duration for the catchment at town is in the 6 to 12 hour range, a much longer event than the 1 hour duration of this event.

The event does provide useful data for the validation of the model performance at the Berthong Road gauge for more frequent events.

Table 15: Equivalent AEP Rainfall Design Intensities (ARR 2019) – March 2010

Station Number	Station Name	Operating Authority	Rainfall Depth (mm) (Equivalent Design Rainfall Event)				
			1 hr	2 hrs	3 hrs	6 hrs	24 hrs
410112	Jindalee Creek @ Jindalee	WaterNSW	5.5 (< 12 EY)	6.5(< 12 EY)	7.0(< 12 EY)	13(< 12 EY)	14(< 12 EY)
4100207	Muttama Creek @ Berthong Road	WaterNSW	30.6(10 %AEP)	31.8(20 %AEP)	34.6(50 %AEP)	42.8(50 %AEP)	47.0(50 %AEP)

4.9.7. Analysis of January 1984 Rainfall Event

An analysis of the available pluviometer data at Jindalee (Table 16) indicated that between the 25th January at 7.45pm and the 26th January at 10:30am, the total recorded rainfall at Jindalee was 77.0 mm. The Berthong Road gauge did not commence operation until 2004.

Cootamundra Post Office gauge recorded a total of 82 mm on the 25th and 26th January 1984. Nearby stations recorded similar rainfall on the same days, 84 mm at Cootamundra Landgrove, 79 mm at Wallendbeen in Corang and 84 mm at Stockinbingal Post Office.

An analysis of the equivalent AEP Rainfall Design Intensities (ARR 2019) at Jindalee for the January 1984 event is presented in Table 16. The total duration of the event was around 15 hours. The rainfall intensity peaked between 6 am and 7 am (18 mm/hr). Mean rainfall intensity over the event was 5.2 mm/hr. The event equated to a 20%AEP for a 6 hour duration event and a 5% AEP for a 12hr duration event.

Table 16: Equivalent AEP Rainfall Design Intensities (ARR 2019) – January 1984

Station Number	Station Name	Operating Authority	Rainfall Depth (mm)			
			3 hrs	6 hrs	12 hrs	18 hrs
410112	Jindalee Creek @ Jindalee	WaterNSW	34(0.5 EY)	53(20% AEP)	71(5% AEP)	/

4.9.8. Analysis of January 1974 Rainfall Event

Jindalee and Berthong Road rainfall gauges were commissioned in 1975 and 2004, respectively; thus no pluviometer data are available for this flood event for the study area catchment. Cootamundra Post Office rainfall gauges records rainfall depth on a 3-hourly interval but the data is patchy and there is a large period of missing data between 1965 and 1988, including the 1974 rainfall event.

Cootamundra Post Office station however recorded a daily total of 125.2 mm on the 11th January 1974. Nearby stations recorded similar rainfall on the same day, 136 mm at Cootamundra Landgrove, 118 mm at Wallendbeen in Corang and 170 mm at Stockinbingal Post Office.

There is limited information available to determine the duration of the event, although little rain was recorded at the Cootamundra Post Office station on both the 10th (6.4mm) and 12th (0mm) January suggesting the event may have been around 24 hours or less. The Cootamundra Herald from January 14th 1974 references rain falling at 3am and the creek dropping at 10am, suggesting the duration of the event may have been shorter than 24 hours. At the 24 hour duration the rainfall total is equivalent to the approximately the 1% AEP and could be considered rarer if the rainfall did in fact fall over a shorter period. In comparison to the 2016 event, the period preceding the event received much less rainfall (less than 100mm of rainfall over 30 days) and was much drier.

Cootamundra Flood Study Report (Reference 5) states that: “an estimate of the peak discharge was made at a point where the flow was confined, there being no flow records or gauging of the flow” and estimated the 1974 peak flow at 76 m^3/s. There are no further details on how this estimate was made.

4.10. Historic Rainfall Data

Rainfall data is recorded either daily (24-hour rainfall totals to 9:00 am) or continuously (pluviometers measuring rainfall in small increments). Daily rainfall has been recorded for over 100 years at a few locations within study area catchment. Together these records indicate the magnitude and frequency of large rainfall events that have occurred in the past.

4.10.1. Limitations of using historic rainfall data

Care must be taken when interpreting historical rainfall measurements. Rainfall records may not provide an accurate representation of past flooding due to a combination of factors including local site conditions, human error or limitations inherent to the type of recording instrument used. Examples of limitations that may impact the quality of data used for the present study are highlighted in the following:

- Rainfall gauges frequently fail to accurately record the total amount of rainfall. This can occur for a range of reasons including operator error, instrument failure, overtopping and vandalism. In particular, many gauges fail during periods of heavy rainfall and records of large events are often lost or misrepresented;
- Daily read information is usually obtained at 9:00 am in the morning. Thus if a single storm is experienced both before and after 9:00 am, then the rainfall is “split” between two days of record and a large single day total cannot be identified;
- In the past, rainfall over weekends was often erroneously accumulated and recorded as a combined Monday 9:00 am reading;
- The duration of intense rainfall required to produce overland flooding in the study area is typically of 6 hour duration, though this rainfall may be contained within a longer period of less intense rainfall. This is termed the “critical storm burst”. A short intense period of rainfall can produce flooding but if the rain starts and stops quickly, the daily rainfall total may not necessarily reflect the magnitude of the intensity and subsequent flooding. Alternatively, the rainfall may be relatively consistent throughout the day, producing a large overall total but only minor flooding as the period is much longer than the critical storm burst.
- Rainfall records can frequently have “gaps” ranging from a few days to several weeks or even years.
- Pluviometer (continuous) records provide a much greater insight into the intensity (depth vs. time) of rainfall events and have the advantage that the data can generally be analysed electronically. This data has much fewer limitations than daily read data other than the years of operation of the gauge. Pluviometers, however, can also fail during storm events due to the extreme weather conditions.

The rainfall data described in the previous sections pertains to information that was used in model calibration.

4.11. Design Flood Inputs

A range of standardised inputs are available for determining design flood behaviour from the ARR 2019 Data Hub, the following section provides an overview. A summary of the Data Hub information at the catchment centroid is presented in Appendix D.

4.11.1. Design Rainfall Data

The design rainfall intensity-frequency-duration (ARR 2019 IFD) data were obtained from the BoM online design rainfall tool for the catchment centroid and are provided in Table 17. ARR 2019 IFD data was also sourced for each sub catchment for use in the WBNM hydrologic model.

Table 17: Rainfall IFD Data at the Catchment Centre (ARR 2019)

Annual Exceedance Probability (AEP) Rainfall intensity in mm/h						
Duration	**50% #**	**20% ***	**10%**	**5%**	**2%**	**1%**
1 min	105.0	144.6	172.2	200.4	238.8	269.4
2 min	89.1	123.0	147.0	171.3	204.6	230.7
3 min	81.4	112.0	133.8	155.8	185.8	210.0
4 min	75.3	103.7	123.6	144.0	171.0	193.5
5 min	70.3	96.7	115.3	134.4	159.6	180.0
10 min	53.6	73.8	87.6	102.0	121.8	137.4
15 min	44.0	60.4	72.0	83.6	100.0	112.8
30 min	29.4	40.4	48.4	56.2	67.2	75.8
1 hour	18.7	25.8	30.8	35.9	42.8	48.4
2 hour	11.6	16.0	19.1	22.2	26.5	29.9
3 hour	8.8	12.0	14.3	16.7	19.9	22.4
6 hour	5.5	7.4	8.8	10.2	12.1	13.6
12 hour	4.1	5.6	6.6	7.6	9.1	10.2
24 hour	3.4	4.6	5.4	6.2	7.4	8.3
48 hour	2.1	2.8	3.3	3.8	4.4	5.0
72 hour	1.3	1.7	2.0	2.2	2.6	2.9
96 hour	0.9	1.2	1.4	1.6	1.9	2.1
120 hour	0.7	0.9	1.1	1.3	1.5	1.6
144 hour	0.6	0.8	0.9	1.0	1.2	1.4

Note:

 # The 50% AEP IFD does not correspond to the 2 year Average Recurrence Interval (ARI) IFD, rather it corresponds to the 1.44 ARI.

** The 20% AEP IFD does not correspond to the 5 year Average Recurrence Interval (ARI) IFD, rather it corresponds to the 4.48 ARI.*

4.11.2. Design Rainfall Losses

Methods for modelling the proportion of rainfall that is "lost" to infiltration are outlined in ARR 2019 (Reference 1). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data are 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 continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

The rural loss parameters were obtained from the ARR 2019 Data Hub and are provided in Table 18. These values were not typically used in the calibration process but are relevant for the design flood events.

ARR 2019 recommends reconciliation of design values with independent flood frequency estimates if there is a long-term stationary streamflow record at the site. If there is insufficient streamflow data (which is the case for the Berthong Road gauge), ARR 2019 recommends a combination of regional information (design rainfall losses) and at site data.

Table 18: ARR 2019 storm losses at catchment centre

Storm Initial Losses (mm)	Storm Continuing Losses (mm/hr)
27.0	4.3*

*The *Review of ARR Design Inputs for NSW* report identified that default continuing losses from ARR 2019 tended to on average over-estimate losses and therefore were not fit for purpose and should only be used where better information was not available. If default continuing losses from the ARR Data Hub are to be used these should be used with a multiplier of 0.4 applied. The applicability of this method is discussed further in Section 9.5.

As per ARR 2019 modelling methodology (Reference 1), preburst (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):

$$\text{Burst Initial Loss} = \text{Storm Initial Loss} - \text{Pre-Burst Depth}$$

The *Review of ARR Design Inputs for NSW* report determined a range of catchment specific burst losses (considering appropriate storm loss and pre-burst depth) that can be applied, termed Probability Neutral Burst Initial Loss. The values applicable to the study area catchment for a range of event frequencies and durations are provided in Table 19 below. . The burst initial loss applied to the hydrological model varies for each design storm modelled.

Table 19: ARR 2019 Probability Neutral Burst Initial Loss

Storm Duration (min)	Event (AEP) Depth (mm)					
	50%	20%	10%	5%	2%	1%
60	18.51	11.96	11.17	11.96	11.66	10.77
90	19.53	11.41	11.21	12.02	11.85	10.31
120	18.88	11.54	11.20	12.08	12.26	10.59
180	20.41	13.90	12.74	13.06	12.07	8.99
360	19.61	14.42	13.84	14.82	12.33	7.40
720	22.65	16.58	14.99	14.48	11.96	6.66
1080	24.04	18.81	17.77	17.74	14.46	9.52
1440	24.85	19.92	19.41	19.56	17.40	12.23
2160	26.63	21.72	21.43	21.87	19.89	17.05
2880	26.97	23.09	22.90	23.58	21.43	17.14
4320	26.98	23.77	24.54	25.15	23.35	20.21

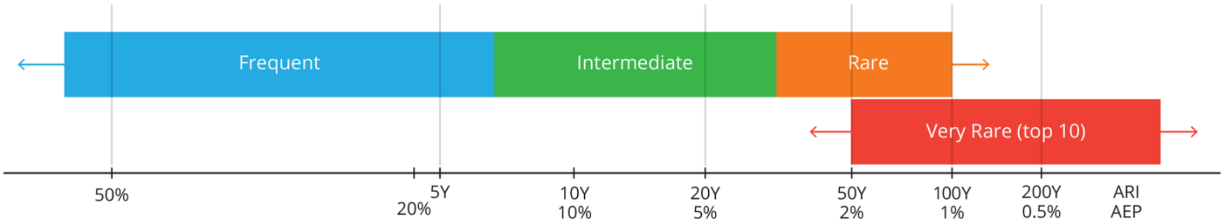
4.11.3. Design Temporal Patterns

Temporal patterns are a hydrologic tool that describe how rainfall falls over time and are often used in hydrograph estimation. Previously in ARR 1987, a single burst temporal pattern has been adopted for each rainfall event duration. However ARR 2019 (Reference 1) discusses the potential inaccuracies with adopting a single temporal pattern, and recommends an approach where an ensemble of different temporal patterns are investigated.

Temporal patterns for this study were obtained from ARR 2019 (Reference 1) and accessed from the Data Hub. There are a wide 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 recommended methodology is to consider an ensemble of design rainfall events and determine the median catchment response from this ensemble.

The ARR 2019 method divides Australia into 12 temporal pattern regions, with the study catchment falling within the Murray-Darling Basin region. ARR 2019 provides 30 patterns for each duration, which are sub-divided into three temporal pattern bins based on the frequency of the events. Diagram 2 shows the three categories of bins (frequent, intermediate and rare) and corresponding AEP groups. The “very rare” bin is in the experimental stage and was not used in this flood study.

Diagram 2: Temporal Pattern Bins



The method employed to estimate the PMP utilises a single temporal pattern (Reference 23).

4.11.4. Areal Reduction Factor Parameters

Areal Reduction Factors (ARF) account for the fact that larger catchments are less likely to experience high intensity storms across the whole catchment simultaneously. The ARF simply influences the average rainfall depth across the catchment, it does not account for variability in the spatial pattern over the catchment. The following equation and Input parameters were obtained from the Data Hub and are outlined in Table 20 below.

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

Table 20: ARF Input Parameters for the Central Region

Zone	a	b	c	d	e	f	g	h	i
Central	0.265	0.241	0.505	0.321	0.00056	0.414	-0.021	0.015	-0.00033

The ARF varies with AEP and duration and the resulting matrix of ARFs for the design storms are shown in Table 21.

Table 21: Areal Reduction Factors for the Design Storm Events

Storm Duration (min)	Event (AEP) ARF (%)					
	50%	20%	10%	5%	2%	1%
60	0.76	0.74	0.73	0.72	0.7	0.69
90	0.8	0.78	0.76	0.75	0.73	0.71
120	0.82	0.8	0.78	0.76	0.74	0.72
180	0.85	0.82	0.8	0.79	0.76	0.74
270	0.87	0.85	0.84	0.82	0.8	0.78
360	0.89	0.87	0.86	0.85	0.84	0.83
540	0.9	0.9	0.89	0.89	0.88	0.87
720	0.91	0.91	0.9	0.9	0.89	0.88
1080	0.93	0.92	0.92	0.91	0.9	0.9

5. STAKEHOLDER ENGAGEMENT

One of the central objectives of the Floodplain Risk Management Process is to actively engage with the community and stakeholders throughout the process to achieve the following key outcomes:

- Inform the community about the current study;
- Identify community concerns in regard to flooding;
- Gather information on flooding ‘hotspots’ (locations of particular flood risk) in Cootamundra; and
- Seek feedback on study outcomes via Public Exhibition (towards completion of this Study).

“Community” refers to government (both state and local departments), business, industry, and the general public. Consultation with the community is an important element of the Floodplain Risk Management process facilitating community engagement, building confidence in flood modelling tools, and leading to acceptance and ownership of the overall project.

5.1. Floodplain Risk Management Committee

The process of managing flood risk in Cootamundra is assisted by the Floodplain Risk Management Committee. The committee is made up of Councillors, Council Staff from a variety of areas across Council, NSW Government Agencies including DPIE and the NSW SES, and community representatives. The Floodplain Risk Management Committee assists Council by providing a forum for discussion of the differing viewpoints within the study area. In the Data Collection phase, the Committee assists by providing insight into historic flood events (including photos and anecdotes of observed flood behaviour), which, if appropriate, are used to shape the model calibration in the Flood Study phase.

5.2. Community Consultation

As part of the Data Collection stage, a range of community consultation activities were undertaken in Cootamundra with the following aims:

- Inform the community and promote awareness of the study and its objectives and outcomes;
- Gather information on past floods (flood marks, observed flood behaviour, photographs) for use in the calibration of flood models;
- *(Secondary objective)* Record suggestions for mitigation options that are raised – these will become useful in the subsequent Floodplain Risk Management Study and Plan.

The consultation period ran from the 24th June to the 14th August 2019, and comprised the following engagement methods:

- Newsletter and questionnaire, made available as hardcopies in the Council office;
- Online questionnaire (via SurveyMonkey);
- Drop-in Session at the Cootamundra Library on the 7th August, 3pm – 5:30pm; and
- Option for residents to provide flood photos to Council directly via USB.

The consultation activities were advertised via the following avenues:

- Article in the Cootamundra Herald (27th July, 2019);
- Posts on the Cootamundra – Gundagai Regional Council Facebook Page (23rd, 26th, 31st July, 6th and 7th August);
- Press release on the Council website (24th June 2019); and
- Council's fortnightly newsletter.

A copy of the newsletter, questionnaire and a selection of promotional articles are provided in Appendix A.

5.2.1. Drop-in Session

An informal drop-in session was held at the Cootamundra Library from 3pm – 5:30pm on Wednesday 7th August 2019. The session was attended by WMAwater staff, members of the Floodplain Risk Management Committee, and seven residents. Throughout the session, residents shared photographs taken during the 2010 and 2016 flood events in Cootamundra. They also shared several stories from these flood events, detailing any significant incidents that occurred along with flood level marks from their properties and the surrounding areas. A selection of these photographs is provided on Figure 2.

Residents also expressed their concerns over issues related to flooding in the area including the risk of people trying to cross Muttama Creek during flood events, the impact of 'new' stormwater channels and other developments along the creek, the potential for future property damage and rising insurance premiums. Several suggestions for flood mitigation measures were also voiced during this session, including the management of vegetation within Muttama Creek, construction of a basin to the north of Cootamundra between Adams Street and Temora Street, and construction of a bund or low earthen levee along McGowan Street to prevent flooding from Muttama Creek.

5.2.2. Questionnaire Results

A questionnaire was created with the aim of gathering information about specific experiences and observations of flooding in the community (Figure 12). The questionnaire was promoted via the fortnightly Council Newsletter, and hard copies of the questionnaire were available for pick up from Council and during the drop-in session. Residents were given the option to complete this survey as a hard copy from Council or online via Survey Monkey.

In total, 16 responses were received from the online survey in addition to another four hard copy responses. Most of these responses came from properties used as a residence (16) as opposed to those used for business (4). The responses highlighted that flooding in the area generally comes from the surrounding creeks and roads with most residents having experienced flooding in the front or backyard, or on roads outside the property. A summary of the survey results is provided on Figure 13 (Sheet A and B).

There were several key themes that were evident in the responses from the community. Certain spots along Muttama Creek were identified by members of the community for being particularly prone to flooding. These hotspots included the Poole Street causeway, Hovell Street causeway, as well as the creek crossings at Thompson Street and Adams Street, and Temora Street, and the affected areas of Crown Street, McGowan Street and Northcott Avenue. Residents expressed their concerns over flooding at these locations and the restriction this has on travel in and around Cootamundra during storm events, with the creek effectively separating the town into two sections.

In the September 2016 flood event, residents reported using sandbags and plastic sheeting to protect their properties, with some still having to evacuate once the water had overtopped these barriers. The concrete channel that runs from the Cootamundra Hospital alongside the nursing home and Southern Cross Care Centre was highlighted by several residents as being a major contributor to flooding that occurs in the Muttama Creek. Several ideas were presented by community members to help reduce flood risk, including the management of reeds and other vegetation in Muttama Creek, cleaning silt and debris out from stormwater drains to improve capacity and installing more stormwater drains around the area.

5.3. Public Exhibition

The Draft Flood Study was placed on an extended period of public exhibition from 25th November 2020 to 4th January 2021; this period allowed the community and other stakeholders to provide feedback on the assessment and its outcomes and for this feedback to be considered in the finalisation of the Flood Study. Community and stakeholder engagement during this period aimed to promote awareness of flood behaviour in Cootamundra and to begin a conversation with the community about strategies to mitigate flood risk. These strategies will be investigated as part of the future Floodplain Risk Management Study.

Council advertised the exhibition period through its webpage and social media platforms, in addition, a media release was issued, which contained Frequently Asked Questions and information about the study and public exhibition period. The Draft Flood Study report was available in hard copy and electronic format for viewing.

Council hosted a drop-in session in the Alby Schultz Meeting Centre on Tuesday, 1st December 2020 from 3:00pm – 6:00pm. The drop-in session provided an opportunity for residents and stakeholders to discuss the study and outcomes with WMAwater and Council staff in an informal setting. The session had six attendees.

Common themes arising from discussion at the drop-in session included:

- Understanding flood behaviour at individual properties,
- Flood mitigation strategies for individual properties and those that can be applied on a broader catchment basis,
- Understanding the broader flood behaviour including the model representation of historical events,
- Variability in flood events as a result of rainfall distribution and preceding catchment and floodplain conditions,
- Recent changes to flood behaviour due to changing catchment conditions (creek diversion), urbanisation and constraints presented by bridges and causeways,
- Impacts of vegetation on flood behaviour,
- Understanding that flood risk can be managed but is unlikely to be completely removed.

These themes relate to the broader flood behaviour and potential flood risk mitigation strategies which will be investigated further as part of the future Floodplain Risk Management Study.

In addition to attending the drop-in session, the community and other stakeholders were invited to make written submissions, no written submissions were received.

6. HYDROLOGIC MODEL SETUP

6.1. Introduction

A hydrologic model is a tool for estimating the timing and amount of runoff that flows from a catchment for a given amount of rainfall. Stream gauges (which measure water level in a stream) are a way of directly measuring this information but can be expensive to setup and maintain. Within the study catchment two streamflow gauges exist, one at Berthong Road, which has a very short period of record (commissioned in 2004) making it unsuitable for flood frequency analysis. The second at Jindalee represents less than 25% of the overall catchment and sits beyond the hydraulic model extent, limiting the ability to develop a refined rating curve for the site. In a flood study where suitable long-term gauged streamflow records are not available, using a computer-based hydrologic model is the best practice method for determining how much flow results from rainfall information (which is more widely available from rain gauges). This type of hydrologic model is referred to as a runoff-routing model.

A range of runoff-routing hydrologic models are available as described in ARR 2019 (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 sub-catchment. The generated flow hydrographs then serve as inputs at the boundaries of the hydraulic model, which allow for details about flood levels and velocities to be determined.

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. The WBNM model can be calibrated to streamflow data through adjustment of various model parameters including the stream lag factor, storage lag factor, and/or rainfall losses, where suitable streamflow records are available.

A hydrological model for the entire Muttama, Jindalee and Cootamundry Creek catchment was created and used to calculate the flows for each individual sub-catchment for inclusion in the TUFLOW hydraulic model. The parameters adopted for this study were initially based on those recommended in ARR 2019 and previous experience with modelling of similar catchments. Parameters were adjusted within reasonable limits as part of model calibration.

6.2. Sub-catchment delineation

The total catchment area covered by the WBNM model is approximately 276 km^2 consisting of 163 sub-catchments with an average sub-catchment size of 170 hectares within the broader catchment and 26 hectares within the Cootamundra urbanized area. This relatively fine-resolution sub-catchment delineation ensures that where significant overland flow paths exist in the catchment, they are accounted for and incorporated into hydraulic routing in the model. The sub-catchment delineation is shown on Figure 7.

6.3. Impervious Surface Area

Runoff from impervious surfaces (such as roads, gutters, roofs or concrete surfaces) occurs significantly faster than from pervious surfaces. This disparity results in a faster concentration of flow within the urbanized area of the catchment as well as increased peak flow in some situations. This is accounted for in the hydrologic model through an estimate of the proportion of both impervious and pervious surfaces. Previously a catchment would be split into pervious and impervious areas, with more developed areas containing a higher proportion of impervious surfaces. This also assumed that the entire impervious area contributes fully to generating runoff, neglecting consideration of depression storages and areas not connected to the drainage system. ARR 2019 identifies that an estimate of Effective Impervious Area (EIA) is more appropriate.

Further, the ARR 2019 methodology recognises that there are significantly different infiltration regimes present across the varying urban surface types and therefore recommends applying varied losses to these different urban surface types in the catchment. These surface types are:

- Effective Impervious Areas – including areas directly connected to the drainage system, such as roads, pavements and some building roofs, and other portions of a catchment area which have a similar response to impervious areas,
- Indirectly Connected Areas – areas that runoff over a pervious area before entering the drainage system such as roofs that discharge onto a lawn, both the roof and lawn are within this category,
- Pervious areas – such as parks.

The pervious and impervious areas of each sub-catchment was determined by estimating the proportion of the sub-catchment area covered by different surface types (from Google maps and aerial photography supplied by Council). The resulting distribution of surface types is summarised in Table 22 below.

Table 22: Impervious Percentage per Land Use Type

Surface Type	Percentage of Catchment
Effective Impervious Area	0.74%
Indirectly Connected Area	1.03%
Pervious Area	98.23%

6.4. Rainfall Loss

Methods for modelling the proportion of rainfall that is “lost” to infiltration are outlined in ARR 2019 (Reference 1). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data are 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 continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

Rainfall losses from a paved or impervious area are considered to consist of only an initial loss (an amount sufficient to wet the pavement and fill minor surface depressions), with the assumption that little to no ongoing infiltration occurs. Losses from grassed and vegetated areas are comprised of an initial loss and a continuing loss. The adopted losses for calibration are discussed in Section 8.3.

6.5. WBNM Parameters

WBNM requires a catchment lag parameter and a stream lag factor to be selected which describes the average travel time for runoff from the catchment surface. The lag parameter is applied to pervious surfaces and adjusted to apply to impervious surfaces by multiplication by an impervious lag factor. The WBNM parameters selected are summarised in Table 23.

Table 23: Adopted WBNM Parameters for Calibration and Design

WBNM Parameters	Value
Lag Parameter (C)	1.7
Stream Lag Factor (natural channels)	1.0
Impervious Lag Factor	0.1

The parameter values applied are generally consistent with the recommended values in the WBNM manual.

7. HYDRAULIC MODEL SETUP

7.1. Introduction

Hydraulic modelling of floods is the simulation of how floodwaters move across the terrain. A dynamic 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. Previous assessments in Cootamundra have been carried out using 1D hydraulic models. For the type of information required from a flood study, hydraulic models require 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 (Reference 4) 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 2018-03-AD-w64 (using the finite volume HPC solver); further details regarding TUFLOW software can be found in the User Manual (Reference 4).

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

7.2. DEM and Grid Resolution

The study implemented a TUFLOW model with a grid cell size of 2 m by 2 m. This resolution provides an appropriate balance between providing sufficient detail for roads and overland flow paths and workable computational run-times. The model grid was established by sampling from a triangulation of filtered ground points from the 2014 LiDAR dataset.

The LiDAR was found to be generally representative of existing conditions and creek lines within the study area (Section 4.2.2). Additional details were included to supplement the LiDAR at the Boundary Road subdivision (Stage 1) and for the open drain along the northern side of the airport. Breaklines were used to ensure that the model correctly represents these aspects.

7.3. TUFLOW Hydraulic Model Extent

The TUFLOW hydraulic model extends up to 3.8 km north of Cootamundra just upstream of the Berthong Road Muttama Creek gauge. West, the model boundary follows the north to south topographic crest located 500m west of the town. The model extends further east, following Jindalee Creek and the Olympic Highway 3km west of town. The model downstream boundary is located 2 km south of the Cootamundra Creek and Muttama Creek junction. The total area included in the 2D model covers 34 km^2 with the extents of the TUFLOW model shown on Figure 14.

7.4. Boundary Locations

The locations of the boundary conditions are shown on Figure 14.

7.4.1. Inflows

For sub-catchments within the TUFLOW model domain, local runoff hydrographs were extracted from the WBNM model (see Section 6.2). These were applied to the receiving area of the sub-catchments within the 2D domain of the hydraulic model. These inflow locations typically correspond with gutters, stormwater inlet pits, drainage reserves or open watercourses features which have typically been constructed to receive intra-lot drainage and sheet runoff flows from local upstream catchment areas.

For inflows to Muttama Creek, Jindalee Creek and Cootamundry Creek, the upstream boundary of the model was extended sufficiently far such that the influence of boundary effects was minimised in the area of interest. Total runoff hydrographs were extracted from the WBNM model at each location. Inflows location are shown on Figure 14.

7.4.2. Downstream Boundary

A HQ (height flow) boundary was utilised for Muttama Creek at the downstream end of the TUFLOW model. The outflow from this boundary is dependent on water level, which is converted to flow using a rating curve in which the topographic gradient is assumed to equal the water level gradient (i.e. uniform flow). This boundary type allows water to flow out of the model. The adopted slope (gradient) value for this HQ boundary was 0.003.

7.5. Surface Roughness

The hydraulic efficiency of the flow paths within the TUFLOW model is represented (in part) by the hydraulic roughness or friction factor formulated as Manning's 'n' values. This factor describes the net influence of bed roughness and incorporates the effects of vegetation and other features (channel sinuosity, bedform and shape) which may affect the hydraulic performance of the particular flow path.

The Manning's 'n' values adopted for the study area are shown in Table 24. These values have been adopted based on site inspection and past experience in similar floodplain environments. The spatial variation in Manning's 'n' across the model domain is shown on Figure 15.

Table 24: Manning's 'n' values adopted in TUFLOW

Surface	Manning's 'n' adopted
Urban Residential and Commercial	0.04
Light Vegetation / Grass / Field	0.05
Lightly Vegetated Channel	0.03
Roads / Pavement / Railways	0.02
Concrete-lined channel	0.02

7.6. Hydraulic Structures

7.6.1. Buildings

Buildings and other significant features likely to obstruct flow were incorporated into the model. Buildings were based on building footprints defined from aerial photography. These types of features were modelled as impermeable obstructions to flow and thus were assumed to have no flood storage capacity. While this is not necessarily realistic (as flow can enter buildings), it is an appropriate method that simulates the obstruction that buildings can impose on floodwaters and the resulting flow distribution around buildings.

Building delineation was validated in key overland flow areas by site inspection, using Google Street View photographs and aerial photography supplied by Council. The building polygons were slightly reduced when the distance between two buildings was lower than the adopted cell size (2m) to retain flowpaths between adjacent buildings.

7.6.2. Bridges and Culverts

The key model parameters for modelling of hydraulic structures such as culverts and bridges are the assumed energy losses at the structure (from turbulence, expansion/contraction of flow etc.) and blockage of the structure waterway area by the structure and debris.

Culvert and bridge dimensions were based on the information collected through data collection (Section 4.4). Schematisation of structures depended on whether they were represented in the 1D or 2D domain. Culverts were generally modelled as 1D features embedded in the 2D model, since the majority of culverts have dimensions smaller than the grid resolution. Bridge modelling was generally undertaken in the 2D domain along Muttama Creek and Cootamundry Creek and generally in the 1D domain within the Jindalee Creek area; once again due to the typical structure size in relation to the grid resolution. The loss parameters for bridges were selected in accordance with current best practice and are given in Table 25 below. For culverts, losses were adjusted based on whether they are connected to the 1D or 2D domain, up to a maximum entrance loss of K=0.5 and a maximum exit loss of K=1.0.

Table 25: Parameter Values for Hydraulic Losses at Structures

Structure	Loss Parameter K (as a factor of dynamic head $V^2/2g$)	Blockage[1]
Bridge (below deck obvert)	0.05 – 0.5 (depending on pier size)	0 to 20%
Bridge deck	0.5 - 1.0	100%
Bridge handrails (where present)	0.3 - 0.5	70%

Note (1): This blockage is due to the estimated ratio of waterway area that is obstructed by the piers at each structure, and not an allowance for potential debris blockage at these locations. Debris blockage is discussed further in Section 9.3. Values are based on inspection of survey and photographs. Appendix B provided details for individual structures.

7.6.3. Surface and Sub-Surface Drainage Network

The stormwater drainage network was modelled in TUFLOW as a 1D network dynamically linked to the 2D overland flow domain. This stormwater network includes conduits such as concrete lined channels, pipes and box culverts, and stormwater pits, including inlet pits and junction manholes. The schematisation of the stormwater network was undertaken using the pit and pipe GIS layers supplied by Council which was supplemented with tabulated data from WMAwater. Figure 14 shows the location of major drainage features and hydraulic structures included as 1D or 2D elements in the TUFLOW model.

7.6.4. Inlet Pits

Details of the 1D solution scheme for the pit and pipe network are provided in the TUFLOW user manual (Reference 1). For the modelling of inlet pits the “R” pit channel type was utilised, which requires a width and height dimension for the inlet in the vertical plane. The width dimension represents the effective inlet length exposed to the flow, and the vertical dimension reflects the depth of flow where the inlet becomes submerged, and the flow regime transitions from the weir equation to the orifice equation. For lintel inlets, the width was based on the length of the opening which was assumed to be 1.2 m for all inlet pits.

8. MODEL CALIBRATION

8.1. Objectives

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. If the modelling system can replicate flood behaviour which has occurred in the past (historical flood) then it can more confidently be used to estimate flood behaviour that will occur in the future by the estimation of design flood behaviour. Design flood behaviour can go on to be used for planning purposes, assessment of flood mitigation options, infrastructure design and emergency management.

A number of factors can prevent a comprehensive calibration of both the hydrologic and hydraulic models, these include, limited stream gauge data, limited rainfall records and particularly pluviometer records, and unknown catchment changes. Comprehensive information that provides a perfect representation of these factors is often not available and industry best practice provides guidance on how to proceed in these circumstances; this approach has been applied to this study.

The choice of calibration events for flood modelling depends on a combination of the severity of the flood event and the quality of the data available. Ideally, data is available from streamflow and rainfall gauges in addition to records of flood marks or inundation extent. There are a number of streamflow and rainfall gauges in the catchment. The majority of rainfall gauges are daily rainfall gauges, with the first pluviometer, recording sub-daily rainfall information, installed in 1975. The typical storm duration for a flood producing event within the Muttama and Jindalee Creek catchments is well below a 24 hour duration and is more likely between 3 – 9 hours, making pluviography data crucial to calibration of the modelling tools. Significant events have occurred in 1974, 1984, 2010 and 2016, with a smaller event occurring in 2012. A small number of flood marks and daily rainfall records are available for the 1974 event but there is no pluviometer information to inform the rainfall temporal pattern and duration. Anecdotal information and data from one pluviometer and stream gauge is available for the 1984 event, while anecdotal information in addition to data from three pluviometer and two stream gauges is available for the December 2010 and March 2012 events. A series of flood marks, records at three pluviometer and two stream gauges, and an indicative flood extent are available for the September 2016 flood event. The December 2010, March 2012 and September 2016 events have been used in the calibration and validation of the hydrologic and hydraulic models. Hydrologic calibration can not be undertaken for events prior to the installation of the Jindalee streamflow gauge and more realistically due to the limited catchment to the Jindalee gauge, prior to 2004 and the installation of the Berthong Road streamflow gauge.

Flood frequency analysis enables the magnitude of floods (5%, 1% AEP etc.) to be estimated based on statistical analysis of recorded floods. It can be undertaken graphically or using a probability distribution. The reliability of the flood frequency approach depends largely upon the length and quality of the observed record and accuracy of the rating curve. The observed record at the Berthong Road and Jindalee gauges present challenges to undertaking a reliable flood frequency analysis. Berthong Road is not of sufficient length to inform the statistical fit and Jindalee is located outside the hydraulic model extent, meaning that the height to flow relationship (rating curve) at the gauge cannot be confirmed. Both records can however be used to confirm hydrologic model performance for available historical events.

8.2. Rating Curve

Rating curves define a relationship of height to flow at a gauge location. Rating curves are developed from velocity measurements (gaugings) during flood events. An investigation of the latest gauging data from WaterNSW found that the highest gauging at Berthong Road gauge (gauge number 41000207) is approximately 1.4 m above gauge datum (the recorded level for the September 2016 was 2.2 m above gauge datum). This is not unexpected as the site has only a limited period of record, commissioned in 2004. At the Jindalee gauge (gauge number 410112) the highest gauging is at 0.8m above gauge datum and the recorded level for the September 2016 event was 1.3m above gauge datum. Above this level the rating curves have been extended using an extrapolation technique. The further the flow estimates are above this level the more unreliable they become. This is particularly problematic when the rating curve is extended from in-bank to overbank flow as the hydraulic behaviour and resistance to flow tends to change dramatically.

The Berthong Road gauge is within the hydraulic TUFLOW model domain, allowing a rating curve to be derived that is more representative of the out of bank flow behaviour. A new rating curve estimate was derived at the Berthong Road gauge location using the calibrated hydraulic model. The hydraulic model is able to replicate the change in behaviour between in-bank and overbank flow and therefore provides a more reliable estimate at higher flows. The curves were obtained by modelling floods of varying magnitude and obtaining the flow and peak level at the location of the gauge. The WaterNSW rating curves indicate that the flow at the gauge is much higher for a given height than the rating curves produced using the hydraulic model TUFLOW. Modelled flows, heights and velocities at the gauge section were compared against those which would be produced by the WaterNSW rating curve.

A plot of the resulting rating curve is compared to the WaterNSW rating curve and WaterNSW gaugings on Figure 16. The rating curve matches the highest gauged event (December 2010). The TUFLOW rating overestimates the flow for the low flow gaugings (approximately $3m^3/s$ and less). These gaugings are within the in bank zone. A review of the gauging site cross section in relation to the LiDAR and DEM representation showed consistency. Testing of model assumptions such as surface roughness did not improve the representation of these low flow gaugings. Given such a small flow rate it is likely that sub grid features are limiting the ability of the model to represent this behaviour, considering the overall purpose of the model to represent behaviour of more significant flood events, this aspect was not investigated further.

Calibration results at the Berthong Road gauge presented below are compared to both the TUFLOW and WaterNSW produced rating curves.

The Jindalee gauge (gauge number 410112) is beyond the hydraulic model extent and therefore the hydraulic model could not be utilised to derive a revised rating curve at the site.

8.3. Flood Frequency Analysis (Jindalee Gauge #410112)

The length of record at the Jindalee gauge (gauge number 410112) is reasonable (commencing in 1975) and despite the inability to validate the height flow relationship using the hydraulic model, small portion of the catchment and some missing years of record, its value in the calibration process cannot be discounted. A Flood Frequency Analysis (FFA) is advantageous as it does not require the assumptions made in estimating runoff from rainfall, these aspects are integrated into the recorded data. Utilising the rating curve and annual maximum series provided by WaterNSW, a FFA was undertaken at the site.

A probability distribution was fit to the annual maximum series using a Bayesian maximum likelihood approach utilising the FLIKE software developed by Kuczera. A Log Pearson III (LP3) probability distribution was adopted.

The results of the FFA are provided in Table 26.

Table 26: Flood Frequency Analysis Results and Comparison – Jindalee Gauge #410112

AEP	Peak Flow (m^3/s)		
	Jindalee Gauge FFA	WBNM Current Study	2001 FRMS (Reference 7)
50%	1	2	3
20%	4	8	5
10%	9	14	7
5%	16	19	10
2%	29	28	14
1%	42	36	19
0.5%	59	49	26

A comparison of the flows from the FFA, the previous 2001 Floodplain Risk Management Study (Reference 7) and the current investigation is also provided in Table 26. The flowrates up to the 10% AEP event are fairly comparable across the three, however at the larger events and particularly the 1% AEP, Reference 7 is shown to significantly underestimate the design flow determined via FFA by approximately 50% (42 m^3/s compared with 19m^3/s). This may be a result of the higher than default Bx factor that was adopted for the earlier studies. The design flow rate determined as part of the current study is a much closer match to the design flow determined via FFA.

An annual maximum height series was also constructed for the Berthong Road gauge (gauge number 41000207). These heights were converted to flow using the refined rating curve developed using the TUFLOW model and an attempt made to fit a probability distribution using a Bayesian maximum likelihood approach utilising the FLIKE software developed by Kuczera. This confirmed that there is not sufficient data to inform the statistical fit. ARR 2019 provides a range of methods to supplement short gauge records with regional information to improve the fit. Regional skew and standard deviation were applied at the Berthong Road gauge and did not improve the fit. A FFA at Berthong Road was therefore not considered further due to the significant uncertainty that exists in the design flow estimates due to the short record length.

A streamflow gauge also exists at Coolac (gauge number 410044), approximately 50km downstream of Cootamundra commencing in 1938. The catchment area to Coolac is 1,025 km^2, approximately 5 times greater than the catchment at Cootamundra. This gauge was considered as part of the current assessment to possibly inform suitable hydrologic parameters over the broader Muttama Creek catchment. Like Jindalee the height flow relationship could not be confirmed using the hydraulic model and the annual record was incomplete. A range of FFA scenarios were tested and the resulting 1% AEP flow ranged from 260 - 450 m^3/s. Further investigation would be required in order to utilise this gauge to inform the assessment at Cootamundra.

8.4. Hydrologic Calibration

For each flood event, different temporal patterns were tested in the hydrologic model based on available pluviometer data. Parameter values in the WBNM hydrological model were adjusted within an appropriate range until a reasonable match to the recorded flow hydrograph was produced.

The rainfall inputs for the hydrologic model were varied spatially according to the isohyets shown on Figure 8 to Figure 11. For each of the calibration events, different combinations of catchment parameters, rainfall loss parameters and temporal patterns from different gauges were tested.

8.4.1. September 2016 Event

The rainfall depths for the September 2016 event across the catchment were derived from the isohyets shown on Figure 8. The rainfall inputs for the hydrologic model were varied spatially according to these isohyets. Due to the similarities between the different available temporal patterns (see Section 4.9.3), the temporal pattern from the Jindalee pluviometer was adopted for the entire modelled catchment.

In order to best replicate the observed stream flow hydrographs (in terms of hydrograph shape, time to peak and peak discharge), the calibration focused predominantly on the initial and continuing loss values. Other parameters such as lag can assist with adjusting the timing of the modelled hydrograph, however in this case timing of the modelled hydrograph was reasonable.

For model calibration the adopted loss parameters are summarised in Table 27. These loss values are close to those recommended in ARR 2019 and are generally consistent with the parameters adopted in flood studies in similar catchment.

Table 27: Adopted Rainfall Loss Parameters for Calibration Event – September 2016

Loss Parameter	Adopted Value
Impervious Area Initial Loss	1.5 mm
Pervious Area Initial Loss	27 mm
Continuing Loss	4.3 mm/hr

Figure 17 shows the modelled and estimated flow for the September 2016 event at the Berthong Road gauge (41000207). Peak flow is overestimated by 0.5m^3/s (or 2%) (Table 28). There is however a good match to the timing and shape of the estimated hydrograph except the WBNM model overestimates the second peak and underestimates the raising limb of the flood event. Overestimation of the second peak, this may be a result of the potentially different temporal pattern experienced in the Jindalee Creek portion of the catchment as described below.

Table 28: Berthong Road Gauge – Recorded and Estimated Peak Flow, September 2016

Estimated Flow TUFLOW Rating (m^3/s)	Estimated Flow Water NSW Rating (m^3/s)	Modelled Flow (m^3/s)	Difference with TUFLOW rating (m^3/s)	% Difference with TUFLOW rating
28.7	50.1	29.2	0.5	2%

A comparison was also made at the Jindalee gauge (410112). Figure 18 shows the modelled and estimated flow for the September 2016 event at the Jindalee gauge. The WBNM model overestimates the peak flow, peaking at 7.7m^3/s in comparison to the recorded peak flow of 5.4m^3/s. The recorded peak flow is based on the WaterNSW rating curve. It is also noted that the shape and timing of the hydrograph is not replicated by the WBNM model. It is likely that the upper part of the Jindalee catchment experienced only a single burst of rainfall, that was not recorded at the Jindalee rainfall gauge. There are no other pluviometer sites which could provide this temporal information.

8.4.2. March 2012 event

The rainfall depths for the March 2012 event across the catchment were derived from the isohyets shown on Figure 9. The rainfall inputs for the hydrologic model were varied spatially according to these isohyets. The Berthong Road gauge pluviometer temporal pattern was adopted. Adopted model calibration losses are summarised in Table 29. The adopted initial loss was lower than that adopted for the September 2016 event, this may be attributed to the preceding minor events on the 29th February and 1st March.

Table 29: Adopted Rainfall Loss Parameters for Calibration Events, March 2012 event

Loss Parameter	Adopted Value
Impervious Area Initial Loss	1.5 mm
Pervious Area Initial Loss	17 mm
Continuing Loss	4.3 mm/hr

Hydrograph – Jindalee Creek at Jindalee Station, September 2016
Figure 19 shows the modelled and estimated flow for the March 2012 event at the Berthong Road gauge (41000207). There is a good match to the shape of the estimated hydrograph except that the timing of the peak occurs 1 – 2 hours earlier in the WBNM model. Modelling produces a good match to the recorded peak flow estimated with TUFLOW rating curve, with a difference of 2% as shown in Table 30.

Table 30: Berthong Road Gauge – Recorded and Estimated Peak Flow, March 2012

Estimated Flow TUFLOW Rating (m^3/s)	Estimated Flow Water NSW Rating (m^3/s)	Modelled Flow (m^3/s)	Difference with TUFLOW rating (m^3/s)	% Difference with TUFLOW rating
25.6	44.7	25.1	0.5	2%

Hydrograph – Muttama Creek at Berthong Road Station, March 2012
Figure 20 shows the modelled and estimated flow for the March 2012 event at the Jindalee gauge (410112). The WBNM model overestimates the peak flow by 4.2 m^3/s, 7.3 m^3/s (modelled) versus 3.1 m^3/s (recorded). The recorded peak flow is based on the WaterNSW rating curve. Referring to Figure 9, the upper portions of the catchment experienced lower rainfall than the lower portions. The sparse rainfall gauge network used to generate Figure 9 may be overestimating the rainfall the occurred in this portion of the catchment.

8.4.3. December 2010 event

The rainfall depths for the December 2010 event across the catchment were derived from the isohyets shown on Figure 10. The rainfall inputs for the hydrologic model were varied spatially according to these isohyets. The Berthong Road gauge pluviometer temporal pattern was adopted. Adopted model calibration losses are summarised in Table 31. Again, a lower initial loss was required in comparison to the September 2016 event. During the December 2010 significant rainfall occurred over a seven day period in the lead up to the event wetting the catchment and reducing the initial infiltration that could occur when the main burst arrived.

Table 31: Adopted Rainfall Loss Parameters for Calibration Events, December 2010 event

Loss Parameter	Adopted Value
Impervious Area Initial Loss	1.5 mm
Pervious Area Initial Loss	14 mm
Continuing Loss	4.3 mm/hr

Figure 21 shows the modelled and estimated flow for the December 2010 event at the Berthong Road gauge (41000207). The timing of the peak occurs 1 - 2 hours earlier in the WBNM model. The WBNM model captures the shape of the raising limb but doesn't reproduce the second peak in the hydrograph. It is likely that parts of the catchment experienced a slightly different temporal pattern during the storm event which was not captured at the available pluviometer sites. Modelling produces a good match to the recorded peak flow estimated with TUFLOW rating, with a difference of 2% as shown in Table 32.

Table 32: Berthong Road Gauge – Recorded and Estimated Peak Flow, December 2010

Estimated Flow TUFLOW Rating (m^3/s)	Estimated Flow Water NSW Rating (m^3/s)	Modelled Flow (m^3/s)	Difference with TUFLOW rating (m^3/s)	% Difference with TUFLOW rating
16.5	25.4	16.2	0.3	2%

Figure 22 shows the modelled and estimated flow for the December 2010 event at Jindalee gauge (410112). The WBNM model underestimates the peak flow by 11 m^3/s, 10.6 m^3/s (modelled) versus 21.7 m^3/s (recorded). The recorded peak flow is based on the WaterNSW rating curve. The general shape of the rising and falling limb are reproduced. Figure 10 shows that the higher rainfalls were experienced over the northern and western portions of the catchment, where the Jindalee gauge is located. The sparse rainfall gauge network used to generate Figure 10 may be underestimating the rainfall the occurred in this portion of the catchment.

8.4.4. March 2010 event

The rainfall depths for the March 2010 event across the catchment were derived from the isohyets shown on Figure 11. The rainfall inputs for the hydrologic model were varied spatially according to these isohyets. The Berthong Road gauge pluviometer temporal pattern was adopted. Adopted model calibration losses are summarised in Table 33.

Table 33: Adopted Rainfall Loss Parameters for Calibration Events, March 2010 event

Loss Parameter	Adopted Value
Impervious Area Initial Loss	1.5 mm
Pervious Area Initial Loss	27 mm
Continuing Loss	4.3 mm/hr

Hydrograph – Jindalee Creek at Jindalee Station, December 2010
Figure 23 shows the modelled and estimated flow for the March 2010 event at the Berthong Road gauge (41000207). The raising limb starts 30 minutes earlier in the WBNM model but the timing of the peak occurs 1 hour later. Modelling produces a good match to the recorded peak flow estimated with TUFLOW rating, with a difference of 6% as shown in Table 34.

Table 34: Berthong Road Gauge – Recorded and Estimated peak flow, March 2010

Estimated Flow TUFLOW Rating (m^3/s)	Estimated Flow Water NSW Rating (m^3/s)	Modelled Flow (m^3/s)	Difference with TUFLOW rating (m^3/s)	% Difference with TUFLOW rating
5.6	5.9	5.2	0.4	6%

The Jindalee gauge (410112) didn't record any flow for the March 2010 event. The WBNM model estimates almost null peak flow of 0.1 m^3/s, which is consistent. The recorded peak flow is based on the WaterNSW rating curve. Figure 11 shows lower rainfalls in the northern and western portions of the catchment which is also consistent.

8.5. Hydraulic Calibration

Hydraulic model calibration was undertaken using three types of data:

- Recorded water level at Berthong Road Muttama Creek gauge (41000207). (Jindalee Creek gauge is beyondthe hydraulic model extent),
- Estimated 2016 event flood extent in Cootamundra based on observations by Council, and
- Flood marks in Cootamundra estimated via photos taken during the events.

Inflows to the hydraulic model for these events were developed from the hydrologic modelling described above.

As part of the calibration process the Manning's "n" roughness values were adjusted within reasonable limits to best match the recorded flood heights along the creek system. Adopted values were selected based on an assessment of the ground cover types and vegetation density within the floodplain at the time of the event. It was found that reasonably consistent Manning's "n" values could be applied across all calibration and validation events. The majority of significant changes to the catchment that would warrant variation of the hydraulic roughness are located beyond the flood extent in the calibration and validation events. The adopted values (Refer to Table 24) were then also applied for the hydraulic modelling of the design events.

8.5.1. 2016 Configuration

Following the September 2016 event, upgrades were made to hydraulic structures within the study area:

- Cowcumbla Street causeway was raised and a box culvert (2.8 m x 1.8 m) was added under the causeway, and
- A 1.8 m x 0.8 m box culvert was added at Berthong Road.

The TUFLOW model was updated to represent the configuration at the time of the event. The above hydraulic structures were removed from the September 2016 model configuration.

8.5.2. 2010 Configuration

Following the December 2010 event and inundation across the aerodrome, modifications were made to the aerodrome drainage system:

- The bank along the fence line at the railway dam had been lowered was rebuilt up to the old level,
- The open drain along the northern side of the aerodrome was cleaned up,
- The culvert under the airport entrance road was enlarged to a 1.2 m x 0.4 m box culvert,
- The concrete lined drain in the aerodrome along the railway line was cleaned out and is now better managed,
- The drain line along the aerodrome near Hay Street was cleaned out after the event and is now better managed.

The newly added hydraulic structures described above were removed from the December 2010 TUFLOW model configuration and the drain lines described above were modelled as if they were in poor maintained condition.

8.5.3. 1974 Configuration

Following the 1974 event the Cootamundra-Lake Cargelligo railway line crossing culverts were replaced. The original box culverts (44 No. 3.15 m width x 1.0 m depth) were replaced with pipe culverts (36 No. 1.5 m diameter, 1 No. 1.6 m width x 2.4 m depth). The original culvlert sizing was used in the model to assess the 1974 event.

8.5.4. September 2016 Flood Event

8.5.4.1. Muttama Creek at Berthong Road gauge (41000207)

For the September 2016 event a reasonable match is achieved over the broader catchment. Figure 24 shows the modelled and recorded levels for the September 2016 event at the Berthong Road gauge (41000207). Similar to the flow hydrograph, there is a good match to the timing and the shape of the stage hydrograph but the model overestimated the second peak and underestimate the raising limb of the flood event.

Modelling produces a good match to the recorded peak level with a difference of 0.06 m as shown in Table 35.

Table 35: Berthong Road Gauge – Recorded and Modelled Peak Level, September 2016

Recorded Level (m AHD)	Modelled Level (m AHD)	Difference (m)
344.21	344.15	-0.06

8.5.4.2. Estimated 2016 Flood Extent

Council estimated the extent of the 2016 flood event based on observations undertaken during the event. This extent is presented on Figure 26.

The model globally reproduces the flood behaviour within Cootamundra. Upstream of the Railway, the modelled flood extends to a total width of 300 to 350 m while the observation estimated a total width of 400 to 450 m. From immediately downstream of the railway to Cutler Avenue, Muttama Creek overtopped its banks and spreads into the floodplain which can also be seen in the modelled behaviour. Temora Street is overtopped for a length of 410 m in the model compared to the 450 m estimated length.

Downstream of Adams Street, the flood extent narrows both in the observed extent and in the modelled extent. Through Cootamundra, from Adams Street to Lloyd Conkey Avenue, the Muttama Creek flood extent is limited to its channel, except at a few locations.

- Between Cutler Avenue and Crown Street, the vacant lot located on the left bank was flooded. This can also be seen in the modelled extent.
- Between Poole Street and Mackay Street, both the observed and modelled extent show that the left bank was flooded, beyond Bourke Street. Particularly, the Murray Street and Bourke Street crossroad.
- From Mackay Street to Lloyd Conkey Avenue and the Railway, the inundation extent was limited to the channel.

8.5.4.3. Flood Marks

Peak flood levels were estimated based on photographs and observations during the event. The peak flood level measured at the Berthong Road gauge was also included in the database.

Some of the flood marks in the data set are considered to be inconsistent and have been included below in the analysis for completeness, but they have been flagged as potentially inaccurate. Levels estimated from photos taken during the event may not actually represent the peak level. As such it is important to aim for general consistency across the catchment when comparing modelled results with flood marks and to not place too much emphasis on matching individual flood marks. This is particularly true for a non-surveyed set of flood marks such as the one here. Peak modelled flood depth mapping, estimated flood levels and modelled flood levels are displayed on Figure 26.

The flood marks and the corresponding modelled peak flood levels are outlined in Table 36. When taking into the account the potentially inconsistent points (points 4/5 and 6/7) and margin of error, the calibration in Cootamundra for the September 2016 is considered satisfactory.

Table 36 – Observed Peak Flood Levels on Muttama Creek, September 2016

Map ID	Location	Estimated Flood Depth (m)	Modelled flood Depth (m)	Difference (m)
1	Berthong Road Gauge	2.14	2.08	-0.06
2	West Jindalee Road Culvert	0.40	0.41	0.01
3	Adams Street / McGowan Street Crossroad	0.10	0.00	-0.10
4	Cutler Ave causeway	1.90	2.38	0.48
5	Cutler Ave causeway	2.10	2.20	0.10
6	Poole St causeway and pedestrian bridge	2.10	2.03	-0.07
7	Poole St causeway and pedestrian bridge	2.00	2.15	0.15
8	Olney Street pedestrian bridge	1.82	2.09	0.27
9	Parker Street bridge	2.50	2.57	0.07
10	Thompson St causeway	2.10	1.82	-0.28
11	Sutton Street Bridge	2.57	2.50	-0.08
12	Hovell Street Causeway	2.10	1.92	-0.18
13	Main Southern Railway Culverts	3.00	2.54	-0.46

8.5.5. December 2010 Flood Event

8.5.5.1. Muttama Creek at Berthong Road gauge (41000207)

Recorded and Modelled Stage Hydrograph, Berthong Road Station, September 2016
Figure 25 shows the modelled and recorded levels for the December 2010 event at the Berthong Road gauge (41000207). The model produces a good match to the peak as shown in Table 37. A reasonable match to timing and shape of the recorded hydrograph is achieved except that the failing limb tends to be underestimated.

Table 37: Berthong Road Gauge – Recorded and Modelled peak level, December 2010

Recorded Level (m AHD)	Modelled Level (m AHD)	Difference (m)
343.92	343.96	+0.04

8.5.5.2. Flood extent at the airport area

Figure 27 shows the modelled extent of the December 2010 event. Results are consistent with observations from Council (see Section 2.3.7). Railway dams are overtopped to the south and flood across the aerodrome. A few backyard of properties at the corner of Yass Road and Jack Masling Drive are flooded with water depth up to 0.3 m.

8.5.6. January 1974 Event

The 1974 event was a significant event across the broader region and presents value as a calibration event. However, the available data presents a number of challenges to its use as a calibration event. There are no pluviometer records to indicate the temporal pattern or duration of the event, and the few flood marks that are available have been estimated from photos and reported in the 1986 Flood Study (Reference 5). The original photos are not available and the timing of the photos during the event is not known.

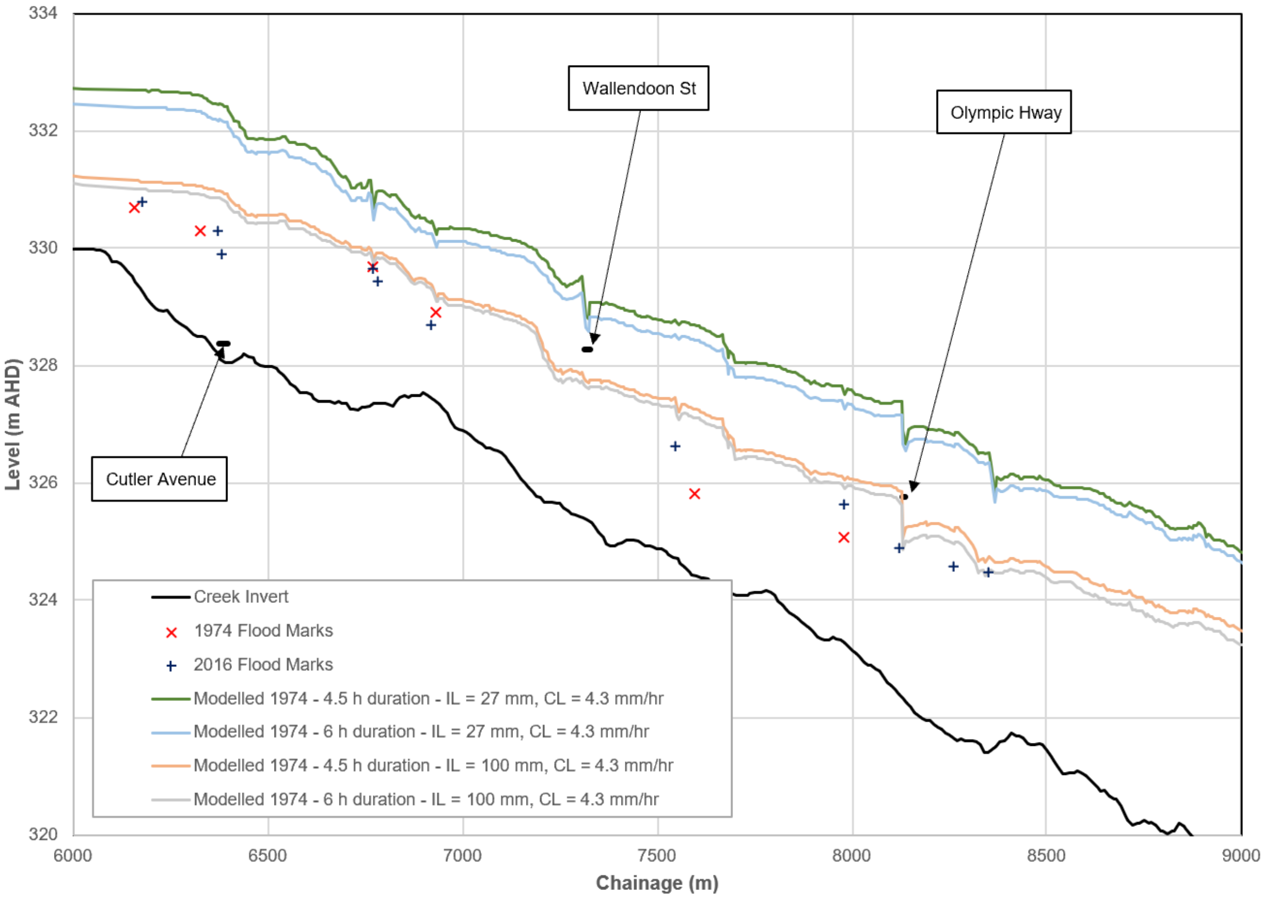
To aid the selection of appropriate model parameters an indicative assessment of the 1974 event has been made. Rainfall estimates have been derived from available daily rainfall records. The temporal pattern has been selected from the ensemble downloaded from the ARR Data Hub (Reference 1) for a range of durations, it was assumed that these would likely be representative of the type of storm that occurs at Cootamundra. Rainfall losses have been selected based on an assessment of catchment conditions and rainfall records prior to the event.

The 4.5 and 6 hour duration temporal patterns have been applied to the total recorded rainfall depth of 130mm. Initial losses of both 27mm and 100mm have been applied. Calibration of the 2016 event adopted an initial loss of 27mm, while a review of the rainfall preceding the 1974 event suggested a much drier period and justified the use of a higher initial loss (100mm). A continuing loss of 4.3mm/hr was applied as this is consistent with the other calibration and validation events and with the value provided by the ARR Data Hub.

Diagram 3 shows a comparison of peak water levels from the above scenarios with the estimated flood marks reported in the 1986 Flood Study (Reference 5). Diagram 3 shows that considering the uncertainty around the hydrologic inputs (as there is no pluviometer records for the event) and the estimated flood marks, a reasonable (although high) match is achieved upstream of Wallendoon Street, with the selection of reasonable design inputs. Downstream of Wallendoon Street the flood marks are far lower than the modelled flood behaviour; through this downstream area the 1974 flood marks also sit well below those from 2016.

The model representation of the 1974 event has significant uncertainty across a range of the inputs, including possible catchment changes, the spatial and temporal distribution of the storm event and the uncertainty regarding the flood mark estimates particularly downstream of Wallendoon Street. This uncertainty translates through to the modelled flood behaviour.

Diagram 3 Muttama Creek Long Section 1974 Event



The uncertainty associated with the available data for the 1974 event means that it cannot be used to directly inform hydrologic and hydraulic model parameters, however it is useful to confirm that broadly the hydrologic and hydraulic models can generally reproduce observed flood behaviour with reasonable assumptions in the selection of model parameters. In addition the assessment of the 1974 event has confirmed that a continuing loss of 4.3mm/hr is reasonable for the catchment.

8.5.7. Calibration Outcomes

The overall conclusion is that the hydrologic and hydraulic models have a reasonable calibration to a range of historical events and are suitable for design flood estimation. The accuracy of this process is dependent on location, the quality of survey data and the availability of calibration data; overall is estimated to be of the order of ± 0.3 m. This includes an allowance for calibration and sensitivity results and potential bias within the LiDAR.

9. DESIGN FLOOD BEHAVIOUR

Following model calibration (Section 8) the established models have been used to determine design flood behaviour in the study area catchment. The following sections outline the approach and outcomes of the assessment.

9.1. Approach

ARR 2019 guidelines for design flood modelling were adopted for this study, including the use of ARR 2019 design information for the 50%, 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 23) to estimate the probable maximum precipitation (PMP).

ARR 2019 IFD as described in Section 4.11.1, was obtained from the Bureau of Meteorology (BoM) 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.

In January 2019, the then NSW Office of Environment and Heritage released new guidance regarding the implementation of ARR 2016 (now ARR 2019) methodologies in NSW specifically: *"Incorporating 2016 Australian Rainfall and Runoff in Studies Section 3.7.1 initial and continuing losses, pre burst and burst losses in NSW"*.

The new guidance was developed in response to a study that indicated that there is significant bias in the standard ARR 2019 design event method with default ARR 2019 losses and pre-burst, available from the ARR 2019 Data Hub (described in Section 4.11.2).

It identified that default continuing losses from ARR 2019 over-estimated losses and therefore were not fit for purpose and should only be used where better information was not available. If default continuing losses from the ARR Data Hub are to be used these should only be used with a multiplier of 0.4 applied. The loss hierarchy documented in the above report lists calibration losses from the study area catchment and calibration losses from studies in adjacent catchments above use of the default continuing losses with the multiplier of 0.4. The ARR Data Hub value for rural storm continuing loss (without the 0.4 multiplier) is 4.3 mm/hr. The application of this continuing loss to all calibration and validation events shows reasonable replication of historical events.

The guidance also recommends use of ARR Data Hub probability neutral burst initial loss values. These values were applied for design storm events and are shown in Section 4.11.3.

Losses are generally in the order of 10.77 to 26.98 mm for burst initial loss, and 4.3 mm/hour for continuing loss. Probability neutral burst initial loss values are dependent on the AEP and duration of the design event. An initial loss of 1.5 mm was applied to impervious surfaces.

Temporal patterns for this study were obtained from ARR 2019. The method employed to estimate the PMP utilises a single temporal pattern (Reference 23).

Areal Reduction Factors (ARF) were applied in the WBNM model for the design storm events based on ARR 2019 and discussed in Section 4.11.4.

The flows generated by the WBNM model for the representative events for each design flood event were then used as inflows in the calibrated TUFLOW model to define the flood behaviour across the catchment. The ARR 2019 temporal patterns, the procedure for the selection of the critical pattern duration are discussed in the following sections. The resulting flood behaviour simulated in the TUFLOW model is subsequently presented, including an analysis of the results.

9.2. Critical Duration

Cootamundra is subject to flooding by two flooding mechanisms resulting from rainfall in the upper catchments of Muttama, Jindalee and Cootamundry Creeks (mainstream) and flooding as a result of local rainfall within the smaller urbanised catchments in town (local overland flow). The critical storm is the temporal pattern and duration that best represents the flood behaviour (e.g. flow, level) for a specific design magnitude. It is generally related to the catchment size, as flow takes longer to concentrate at the outlet from a larger catchment, as well as other considerations like land use, shape, stream characteristics, etc. Typically, mainstream flooding in catchments of this size is generated by longer storm durations, whereas local overland catchments are generally more responsive to shorter, more intense storms. Peak flow is often used as an indicator to determine the representative temporal pattern, however in urbanised catchments peak flow can be less representative and peak flood level is a more suitable indicator.

With ARR 2019 methodology, the critical duration is the storm duration that produces the highest mean flow or level at a point of interest (where the mean is calculated from the ensemble of ten temporal patterns for that duration. Where there are multiple locations of interest with different contributing catchment sizes, there can be multiple critical durations that need to be considered.

Once the critical duration is established, it is usually desirable to select a representative design storm temporal pattern that reproduces this behaviour for all points of interest. This representative storm can then be used for determining design flood behaviour and for future modelling to inform floodplain management decisions.

The selection of the critical duration for each of these mechanisms is discussed below.

9.2.1. Mainstream Flooding

A range of storm durations with an ensemble of ten temporal patterns per duration were run in WBNM, and the flows were analysed to determine the critical duration and representative temporal pattern at three key locations.

- Jind_Ck1 – Jindalee Creek upstream of Cootamundra airport,
- M_Coota3 – Muttama Creek in Cootamundra town,
- Coota_Ck8 – Cootamundry Creek crossing industrial zone at south Cootamundra.

The representative pattern was chosen to be the pattern which gave closest to (and slightly above) the mean ensemble critical duration flow. A box plot of 1% AEP flows for each of these locations can be seen on Figure 29 to Figure 31.

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 grey circles beyond these lines are statistical outliers. The horizontal line within the box represents the median value. The black cross is the mean value and the red triangle the selected temporal pattern.

It can be observed that for the 1% AEP event, similar median peak flows occur for a range of durations from 270 minutes up to 720 minutes. The 360 minute (6 hours) storm is critical at all of the mainstream flooding key locations (highest median flows from the ensemble of temporal patterns). Temporal pattern (TP4028) is the representative pattern at each of these locations.

This analysis was undertaken for all the design storm events, considering the key flow locations described above. The adopted representative temporal patterns and a summary of the flows can be found in Table 38.

Table 38: Representative Temporal Pattern Summary – Mainstream

Catchment ID	Ensemble Results				
	Critical Duration (mins)	Peak Flow Selected TP (m^3/s)	Temporal Pattern ID	Mean (Critical) Flow (m^3/s)	% Difference (Peak Flow minus Critical Flow)
50% AEP Event					
Jind_Ck1	720	6.3	TP4096	5.4	17%
M_Coota3	720	15.1	TP4096	14.1	7%
Coota_Ck8	720	6.1	TP4096	5.6	9%
20% AEP Event					
Jind_Ck1	720	22.4	TP4100	21.5	4%
M_Coota3	720	60.0	TP4100	57.8	4%
Coota_Ck8	720	23.5	TP4100	22.8	3%
10% AEP Event					
Jind_Ck1	540	37.7	TP4063	36.7	3%
M_Coota3	540	99.1	TP4063	98.4	1%
Coota_Ck8	540	38.5	TP4063	38.3	1%
5% AEP Event					
Jind_Ck1	360	51.7	TP3862	51.2	1%
M_Coota3	360	142.1	TP3862	139.3	2%
Coota_Ck8	360	55.4	TP3862	54.1	2%
2% AEP Event					
Jind_Ck1	360	83.2	TP4028	78.0	7%
M_Coota3	360	221.7	TP4028	211.9	5%
Coota_Ck8	360	85.6	TP4028	81.8	5%
1% AEP Event					
Jind_Ck1	360	105.3	TP4028	102.5	3%
M_Coota3	360	277.7	TP4028	275.4	1%
Coota_Ck8	360	108.1	TP4028	106.6	1%
0.5% AEP Event					
Jind_Ck1	360	126.4	TP3862	122.4	3%
M_Coota3	360	343.6	TP3862	329.2	4%
Coota_Ck8	360	134.5	TP3862	128.4	5%
0.2% AEP Event					
Jind_Ck1	360	147.9	TP4025	146.5	1%
M_Coota3	360	395.6	TP4025	394.2	0%
Coota_Ck8	360	156.6	TP4025	155.1	1%

9.2.2. Overland Flooding

The overland flow paths within town contains hydraulic structures and the routing behaviour as a result of these structure can not be well represented by the WBNM hydrologic model. Additionally, peak flood levels are usually a better indicator of flood behaviour in urban environments. Selection of the representative storm for the overland flow areas was therefore undertaken using the TUFLOW hydraulic model for the full storm ensemble. The ensemble of temporal patterns were run in the TUFLOW hydraulic model to determine the critical duration and representative temporal pattern for overland flooding.

A range of storm durations (60 min, 90min, 120 min, 180 min, 270 min, and 360 minute storms) with an ensemble of ten temporal patterns per duration were run in WBNM, and the flows were analysed to inform the selection of the representative temporal pattern at three key locations.

- W_Coota12 – Southee Circle, north-west local subcatchment,
- Coota_Ne4c – Cootamundra Town centre, east local subcatchment,
- Coota_Sth8 – Florence Street, south-east urban subcatchment.

The same durations and temporal patterns were run through the TUFLOW model to produce peak flood level result grids. The mean flood level across the ensemble for each duration was determined. An envelope of mean flood levels was produced. The duration and temporal pattern which resulted in a peak flood level slightly above the enveloped mean grid across the study was selected as the representative duration and pattern(s).

For the 1%AEP, an analysis of enveloped grids revealed that the 1 hour duration was critical in the majority of overland-flow affected areas of Cootamundra.

The adopted temporal pattern and critical duration for the largest event in each bin (See Diagram 2) was applied to the more frequent event within the same bin, for example, the adopted temporal pattern for the 1% AEP event was applied to the 2% AEP event, and that which was selected for the 5% AEP event was applied to the 10% AEP event. To ensure this approach was appropriate in this catchment, the same analysis described above was undertaken for the 2% AEP overland flow event independently, whereby the peak flood level results produced by the temporal pattern just above the mean was compared to the grid produced by the temporal pattern chosen in the 1% AEP analysis.

While the analysis revealed that temporal pattern No. 3878 would be technically the preferred selection for the 2% AEP event, the peak flood level results produced by the adopted 1% AEP temporal pattern (TP3877) were less than 0.013 m lower, indicating that applying the same temporal pattern as the 1% AEP event would not materially affect results of the 2% AEP event.

9.2.3. Probable Maximum Flood

The Probable Maximum Precipitation (PMP) is 'the greatest depth of precipitation for a given duration meteorologically possible...' (Reference 23). It is used together with spatial and temporal distributions to estimate the Probable Maximum Flood (PMF). The probable maximum precipitation (PMP) was determined using the Generalised Short Duration Method which uses a single temporal pattern (Reference 23). A range of durations from 15 minutes to 6 hours were assessed. 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 240 minute storm was the critical duration for mainstream flooding and the 60 minute storm was the critical duration for overland flooding. These durations were adopted for the PMF design flood event and results enveloped.

9.2.4. Design Flood Modelling Selected Storms

A summary of the adopted durations and temporal patterns for this study are shown in Table 39. Temporal patterns are shown on Figure 32: Adopted Durations and Temporal Patterns.

Table 39: Adopted durations and temporal patterns for design flood events

Event	Overland Flow		Mainstream Flooding	
	Duration (min)	TP#	Duration (min)	TP#
50% AEP	90	3924	720	4096
20% AEP	90	3924	720	4100
10% AEP	60	3882	540	4063
5% AEP	60	3882	360	3862
2% AEP	60	3877	360	4028
1% AEP	60	3877	360	4028
0.5% AEP	60	3877	360	3862
0.2% AEP	60	3877	360	4025
PMF	60	GSDM	240	GSDM

9.3. Blockage

There are multiple factors to be considered in assessing the potential for blockage of culverts and bridges. These considerations include:

- the type and mobility of debris that can be washed into the waterway to block the structure or inlet;
- the dimensions of the debris in comparison to the structure;
- dimensions of the structure in relation to the upstream and downstream channels;
- the presence of piers, service crossings, or other obstructions to flow on which debris can accumulate; and
- catchment land-use.

These aspects were reviewed in accordance with ARR 2019 guidance. The debris availability, debris mobility and debris transportability was deemed to be in the Low to Medium categories for the Cootamundra catchment, due to the large amount of cleared land upstream of Cootamundra. The overall debris potential was classified as Low. With this classification, no blockage was applied to culvert structures in the model.

The sensitivity of the resulting flood behaviour to the assumption has been tested in the sensitivity analyse described in Section 10.4.2.

9.4. Design Flood Behaviour Results

A summary of the design flood behaviour is provided in the following sections. These results are presented for the range of design flood events modelled from the 50% AEP to the PMF event.

Peak flood depths, levels and velocities for mainstream and overland flood events were enveloped for the purposes of design flood event mapping. Key reporting locations used in tabular presentation of results and in discussion are shown on Figure 33. Other mapping and outputs includes:

- Peak flood depth, extents and level contours on Figure 34 to Figure 42;
- Peak flood velocities on Figure 43 to Figure 51;
- Peak flood level profiles (long sections) on Figure 52 to Figure 54, reference chainage shown on Figure 33Figure 27;
- Hydraulic hazard based on the NSW Floodplain Development Manual on Figure 55 to Figure 57;
- Hydraulic hazard based on the Australian Disaster Resilience Handbook on Figure 58 to Figure 60;
- Hydraulic categories on Figure 61;
- Provisional Flood Planning Area on Figure 62.

Peak flood depth mapping has been trimmed to exclude depths less than 200mm. Depths less than this would typically not be considered flooding and result from the runoff concentration phase of the storm event.

Peak flood depth at key locations are shown below in Table 40.

These results are available in electronic GIS and tabular format. The digital data should be used in preference to the figures in this report as they provide more detail. The maps are intended to provide an overview of the results and should not be relied upon for detailed information at individual properties.

Table 40: Design Flood Depth at Key Locations

ID	Location	Peak Flood Depth (m)			
		10% AEP	5% AEP	1% AEP	PMF
1	W Jindalee Rd / Racecourse Ln	0.06	0.08	0.11	0.76
2	Cutler Avenue - Muttama Creek	1.83	1.98	2.56	5.72
3	Poole St / Bourke St	0.12	0.17	0.37	3.32
4	Mackay St / Olney St	0.00	0.00	0.14	3.41
5	Bourke St / Parker St	0.03	0.03	0.46	3.51
6	Parker St / Wallendoon St	0.01	0.02	0.41	3.57
7	French St / Horney St	0.09	0.09	0.82	4.70
8	Ursula St / Hurley St	0.00	0.00	0.42	4.29
9	Southee Circle	0.25	0.31	1.05	4.82
10	Sutton St / Hurley St	0.04	0.12	0.54	3.25
11	Hume St - Florence St	0.01	0.02	0.04	0.54
12	Gundagai Rd / Cowcumbla St	0.00	0.00	0.13	2.15
13	Binowee Rd	0.32	0.37	0.65	2.34
14	Cootamundra Airport Runway	0.02	0.02	0.05	0.39
15	Cootamundra Airport - buildings	0.10	0.14	0.29	1.03
16	Olympic Hwy / Barnes Street	0.16	0.17	0.22	0.47

In the 50% AEP event, flows are generally contained within Muttama and Cootamundry Creek downstream of Cutler Avenue. Floodwater begins to break onto the floodplain from Muttama and Jindalee Creeks upstream of Cutler Avenue. Shallow inundation resulting from overland flow is also observed downstream of Cutler Avenue through the properties between Lawrence Street and Cowcumbla Street. This behaviour echoes that which has occurred in historical flood events (described in Section 2.2) where there are distinct differences in the flood behaviour observed in the upstream and downstream portions of the study area.

In the 20% AEP, broad shallow inundation is observed including across the airport runway and parts of the floodplain upstream of Cutler Avenue. Muttama Creek overtops its bank between Cutler Avenue and Murray Street including Clarke Oval. Jindalee Creek overtops the railway dams, floods across the airport and ponds along Olympic Highway/Yass Road and the railway line. A second flow path moving from the intersection of the two railway lines at Pinkerton Road, following the irrigation channel moving to the south becomes more significant in this event. Additionally, overland flow more broadly impacts the urban areas in the south west of town, particularly Southee Circle, where depths of up to 0.3m are experienced.

For context during the September 2016 flood event a level of 2.141m was recorded at the Berthong Road gauge, during a 20% AEP a level of 2.19m is shown to occur. Noting that design flood events can produce different behaviour at different locations in comparison to historical events.

As the events increase in size greater flow breaks from Muttama Creek downstream of Cutler Avenue inundating areas adjacent to the creek. During the 1% AEP event, the inundated area downstream of the Main Southern Railway is between 500m and 1km wide.

During this event upstream of Cutler Avenue the railway is overtopped and inundation from the airport spills into Hay Street flowing towards Muttama Creek. Broad areas of inundation occur around the airport stretching across to West Jindalee Road.

Inundation extends to O'Donnell Street, Thompson Street in the east of town and to Poole Street, and Cowcumbla Street in the west of town. Depths of up to 1.2m occur in the Southee Circle area and up to 0.3m in Parker Street.

A similar pattern of flooding occurs in the 0.5% AEP and 0.2% AEP events, with floodwaters reaching 1.0 to 1.5 m at a number of properties in the western parts of town. Overland flooding along Jindalee Creek and in east extents of town remains fairly shallow (generally less than 0.1 m).

In the PMF event, there is significant flooding through Cootamundra almost exclusively due to the mainstream flooding from Muttama Creek. The broad extent of inundation is approximately 1 km to 1.5 km wide including most of Cootamundra township except properties on the western extent and on the eastern end of Sutton Street and Hovell Street. Flood depths in eastern Cootamundra are between 4 and 5 metres at Southee Circle and between 2 and 3 metres in the Cootamundra town centre in Parker Street. The railway line, Olympic highway and most of the major roads are significantly overtopped.

9.5. Comparison to Other Methods

ARR 2019 indicates that design flow estimates should be validated by comparison to alternative methods to provide confidence in the resulting design flood behaviour. A range of methods are suggested including comparison to earlier studies or studies in similar catchments, comparison to flood frequency analysis (FFA) or comparison to regional estimates. The 1% AEP flow estimates from the previous studies (Reference 5 and 7) were approximately 130m^3/s and the current estimate is 275 m^3/s at Wallendoon Street. This difference reinforces the need to compare the current estimate to other methods recommended by best practice.

The flow estimates from the previous studies were based on the rational method. ARR 2019 does not recommend the use of the rational method due in part to the considerable uncertainty with the input parameters such as C_{10}. ARR 2019 recommends the use of the Regional Flood Frequency Estimation Method (RFFE) instead of the rational method. RFFE is based on data at 853 gauged catchments across Australia and flow estimates are available from http://rffe.arr-software.org. Flow estimates are available for Wallendon Street and at the Jindalee Gauge. The estimate at Wallendoon Street has low confidence and is not consistent with surrounding catchments including that at the Jindalee gauge. The RRFE estimate for Wallendoon Street and the Jindalee gauge are 71m^3/s and 42m^3/s, respectively, for a relative catchment difference of 157km^2 compared with 14km^2. A summary of nearby catchment RFFE estimates is provided in Table 41.

Table 41: RFFE Estimates at Nearby Gauges

Site ID	Site Name	Catchment Area (km2)	Distance from Cootamundra Catchment Centroid (Km)	1% AEP Flow (m^3/s)
/	Muttama Creek at Wallendoon St bridge in Cootamundra	157	0	71.1
410112	Jindalee Creek at Jindalee	14	7	42.0
410061	Adelong Creek at Batlow Road	155	77	302.0
410107	Moutain Creek at Mountain Creek	186	84	308.4
410156	Kyeamba Creek at Book Book	145	91	358.7

The WBNM hydrologic model produces a flow of 36m^3/s at the Jindalee gauge for the 1% AEP event. This value is consistent with the RFFE estimate in comparison to the flow estimate from earlier studies (Reference 7) of 19m^3/s. This suggests that the previous estimates from earlier studies may have underestimated the catchment flow.

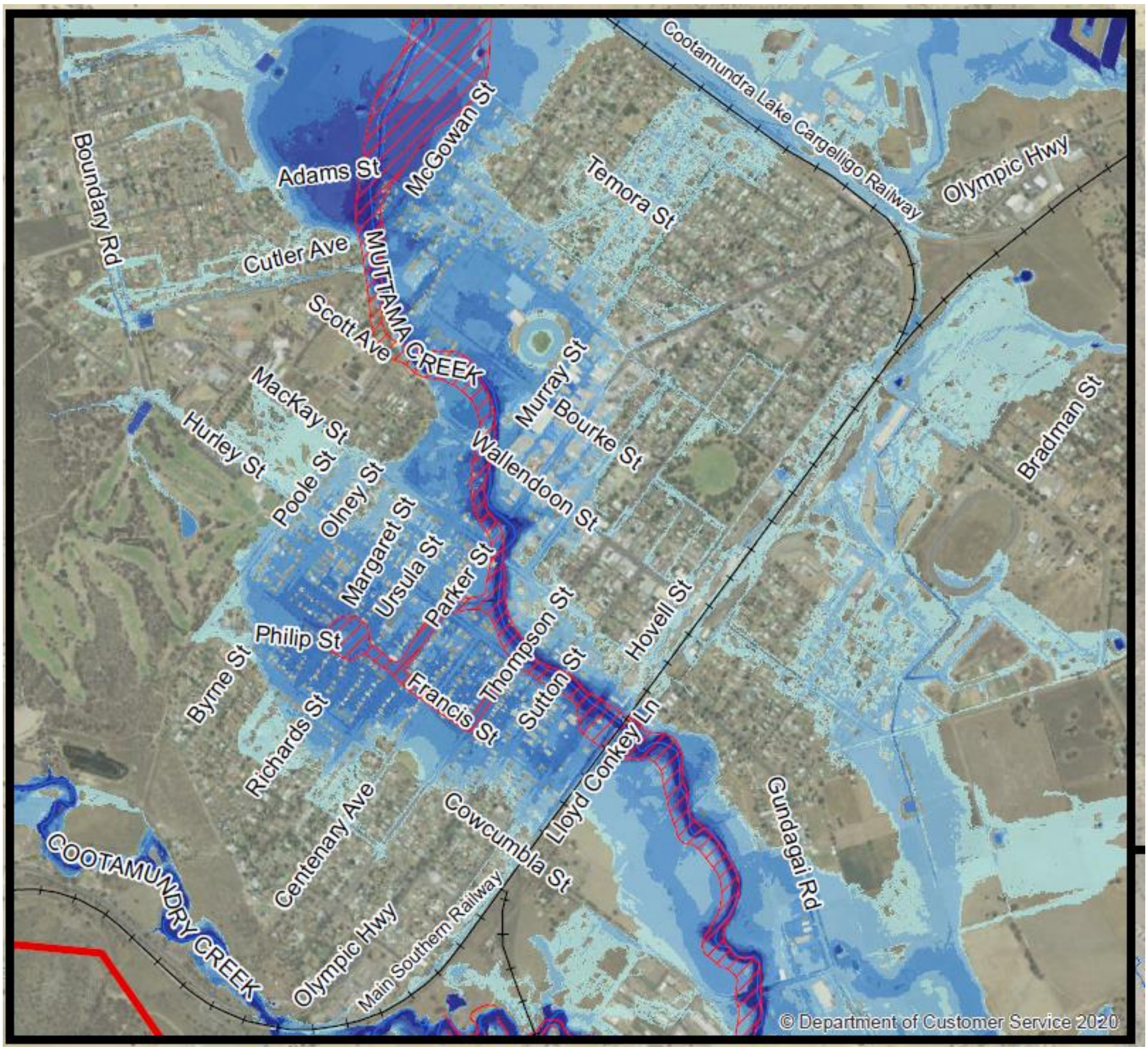
A FFA has been undertaken at the Jindalee gauge (Section 8.3) which allowed further validation of the hydrologic flows at this point in the catchment. Design flows produced with the adopted model parameters generally reconciled with the results of the FFA. For the 1% AEP event, the FFA flow was 42m^3/s (consistent with the RFFE) while the hydrologic model produces a similar flow of 36m^3/s at Jindalee. A FFA was not possible for the Berthong Road gauge and this is discussed in Section 8.3.

Considering the alignment of the results of the WBNM hydrologic model, FFA and the flow estimates from the RFFE at Jindalee; a review of RFFE flow estimates for surrounding catchments of similar size to the catchment to Wallendoon Street (157km^2) provides guidance to the relative magnitude of flow at Wallendoon Street. Table 41 shows that for catchments ranging in size from 145km^2 to 186km^2, 1% AEP flow ranges from 302 m^3/s to 358m^3/s. Aspects unique to each catchment such as shape, terrain, and landuse; impact on the relative runoff response and can account for variability in peak flow. Considering this a peak flow of around 300m^3/s would be considered reasonable at Wallendoon Street. The WBNM hydrologic model flow estimate at Wallendoon Street is 275m^3/s.

This comparison provides confidence to the adopted model parameters and resulting design flood behaviour.

The 1% AEP flood extent currently adopted by Council is based on a flow estimate of approximately 130m^3/s and has been defined using a 1D hydraulic model; which does not allow a representation of flood behaviour beyond the channel and particularly in areas subject to overland flow. A comparison of the previous flood extent with that derived from the current study is provided in Diagram 4.

Diagram 4: Comparison of 1% AEP Flood Extent



9.6. Hydraulic Hazard Categorisation

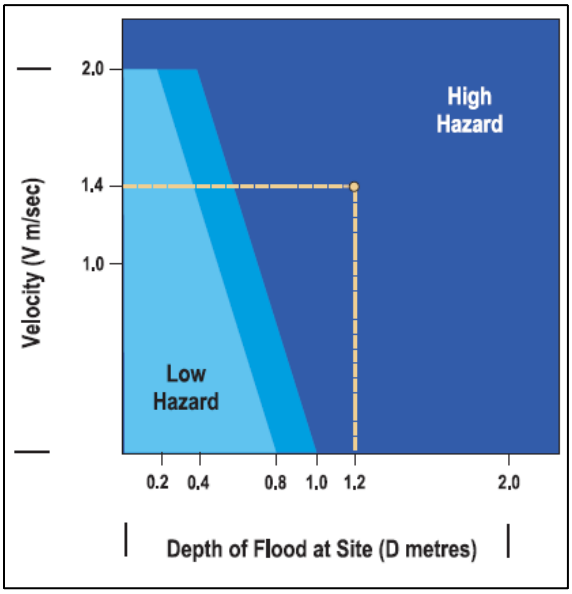
Hazard classification plays an important role in informing floodplain risk management in an area as it reflects the likely impact of flooding on development and people providing a measure of potential risk to life and property damage from flood. Hydraulic hazard is typically determined by considering 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 have been determined for the study area 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 24). Each method of hydraulic flood hazard categorisation is discussed below.

9.6.1. Floodplain Development Manual

Appendix L of the NSW Floodplain Development Manual (FDM, Reference 2) gives one method for hydraulic hazard, which is shown in Diagram 5. In this study, the transition zone was considered to be high hazard.

Diagram 5: “L2” Hydraulic Hazard Categories (FDM)



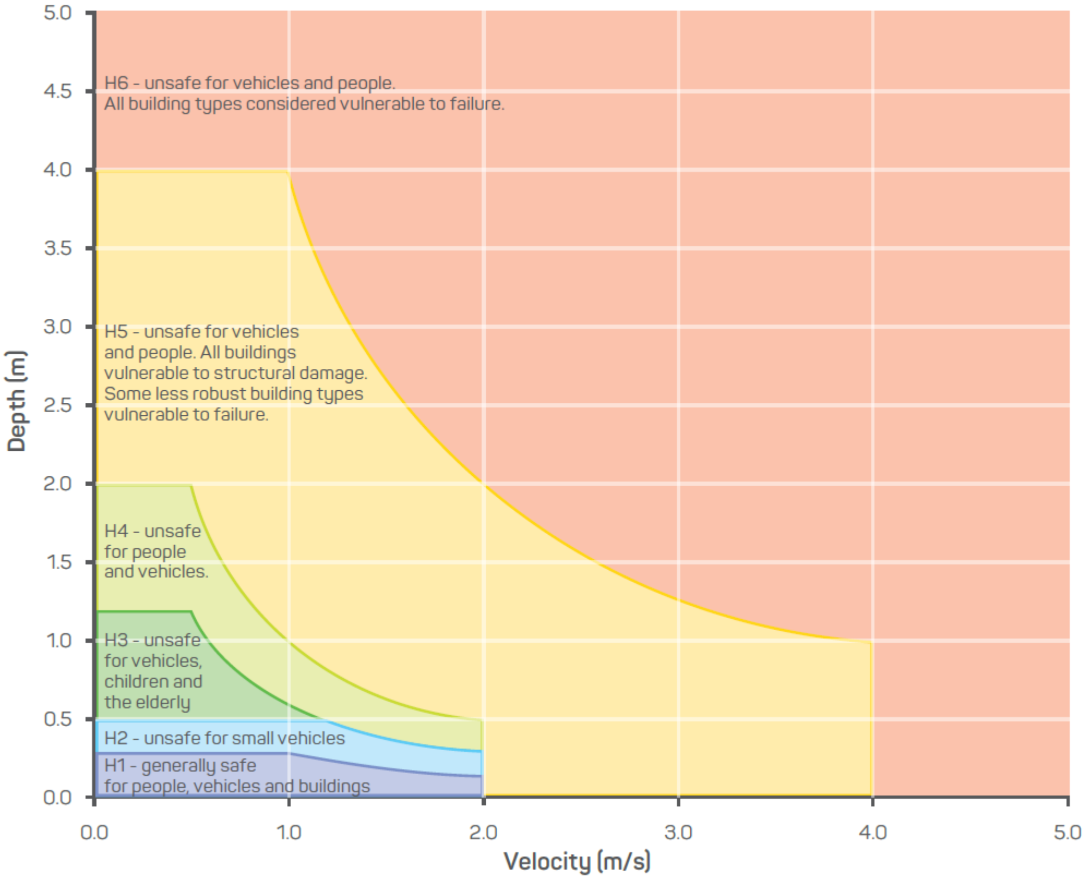
The hydraulic hazard utilising the FDM categorisation is mapped on Figure 55 to Figure 57 for the 5% AEP, 1% AEP, 0.2% AEP and PMF events. The FDM hazard categorisation has been included for applicability to existing council policy documents that may refer to this hazard classification.

The high hazard areas are primarily within the channels on Muttama Creek, Jindalee Creek and Cootamundry Creek in the 5% AEP. There are some areas of high hazard in Muttama Creek upstream of Cutler Avenue and the railway. High Hazard areas in the 1% AEP event includes parts of west Cootamundra around the Southee Circle. High hazard areas in the 0.2% AEP follow a similar pattern, with more urban flowpaths classified as high hazard areas including Parker Street in Cootamundra CBD.

9.6.2. Australian Disaster Resilience Handbook Collection

The Australian Disaster Resilience Handbook Collection deals with floods in Handbook 7 (Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia). The supporting guideline 7-3 (Reference 24) contains information relating to the categorisation of flood hazard. A summary of this categorisation is provided in Diagram 6.

Diagram 6: General flood hazard vulnerability curves (ADR)



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

- H1 – No constraints, generally safe for vehicles, people and buildings;
- H2 – Unsafe for small vehicles;
- H3 – Unsafe for all vehicles, children and the elderly;
- H4 – Unsafe for all people and all vehicles;
- H5 – Unsafe for all people and all vehicles. All building types vulnerable to structural damage. Some less robust building types vulnerable to failure. Buildings require special engineering design and construction; and
- H6 – Unsafe for all people and all vehicles. All building types considered vulnerable to failure.

The hazard maps using the Australian Disaster Resilience (ADR) classification are presented in Figure 58 to Figure 60 for the 5% AEP, 1% AEP, 0.2% AEP events.

In the 5% AEP, Jindalee Creek and Cootamundra Creek and most of Muttama Creek are in the H5 category while Muttama Creek within Cootamundra town is in the H6 category. The floodplain upstream of Cootamundra town and some areas in Cootamundra west are in category H3 while the rest of the floodplain is in category H1 and H2. In the 1% AEP event, the H5 and H6 category follows the same pattern but the H4 category is more prominent in Cootamundra town with some roads classified as H5 category (some parts of Francis Street, Hurley Street, Ursula Street and Parker Street). In the 0.2% AEP, hydraulic categories follow similar patterns. Areas classified as, H3 or greater under the ADR classification often correspond to areas of high hazard under the FDM classification method, however the ADR method provides a greater level of practical information on the relative hazard categories.

9.7. Flood Function

Hydraulic categorisation of the floodplain is used in the Floodplain Risk Management process to assist in the assessment of the suitability of future types of land use and development, and the formulation of floodplain risk management plans. Hydraulic categorisation involves mapping the floodplain to indicate which areas are most important for the conveyance of floodwaters, and the temporary storage of floodwaters. The Floodplain Development Manual (Reference 2) defines land inundated in a particular event as falling into one of the three hydraulic categories listed in Table 42. Typically, development within floodway or flood storage areas would be likely to cause water to flow into other areas redistributing the flood risk, unless the development is carefully designed to avoid these impacts.

Table 42: Hydraulic Categorisation Definitions (*Floodplain Development Manual* (Reference 2))

Category	Definition
Floodway	• Those areas where a significant volume of water flows during floods; • Often aligned with obvious natural channels; • Areas that, even if only partially blocked, would cause a significant increase in flood levels and/or a significant redistribution of flood flow, which my adversely affect other areas; and • Often, but not necessarily, areas with deeper flow or areas where higher velocities occur.
Flood Storage	• Parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood; • If the capacity of a flood storage area is substantially reduced, for example by the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased; and • Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.
Flood Fringe	• Remaining area of land affected by flooding after floodway and flood storage areas have been defined; • Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.

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 25), rely on combinations of velocity and depth criteria to define the floodway.

To define the floodway, the Howells et al. (Reference 25) methodology was applied, which differentiates the floodway from other hydraulic categories by selecting a velocity-depth product criteria that exceeds a specific threshold. These parameters were confirmed iteratively through encroachment analysis, in which all areas not defined as 'floodway' were totally excluded from the modelling domain, and the subsequent impact on flood levels examined. If the reduction in conveyance area resulted in an increase greater than 0.1 m to existing flood levels, the floodway area was increased. This approach is informed by Section L4 of the Floodplain Development Manual (Reference 2), which defines Flood Storage areas as *"those areas outside floodways which, if completely filled with solid material, would cause peak flood levels to increase anywhere by more than 0.1 m and/or would cause the peak discharge anywhere downstream to increase by more than 10%."* The resulting parameters are provided in Table 43. Following application of these criteria, the resulting floodway areas were examined to ensure continuity of flowpaths, and to remove any isolated grid cells inappropriately classified as floodway (for example as an artefact of the modelling).

Table 43: Hydraulic Category Definition Parameters

Category	Floodway Definition Parameters
Floodway	VD > 0.35 m^2/s **AND** V > 0.35 m/s; **OR** V > 1.0 m/s **AND** D > 0.3m
Flood Storage	• Areas outside floodway where D > 0.4 m
Flood Fringe	• Areas outside floodway where D < 0.4 m

The hydraulic categories have been mapped on Figure 61 for the 1% AEP event.

The hydraulic categories based on the above criteria are considered provisional and will be revisited as part of subsequent Floodplain Risk Management Study and Plan.

9.8. Interim 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 FPA. The resulting FPA was trimmed to the extent of the PMF. The preliminary FPA is shown on Figure 62. The preliminary FPA is generally more extensive than the 0.2% AEP flood event. The approach adopted to defining the FPA would be reviewed during the Floodplain Risk Management Study and Plan considering all aspects of flood risk and particularly if an alternative approach should be applied to areas defined as being subject to overland flood risk only.

10. SENSITIVITY ANALYSIS

10.1. Overview

A number of sensitivity analyses were undertaken to establish the variation in design flood behaviour that may occur if different parameter assumptions were made. These sensitivity scenarios are summarised in Table 44.

Table 44: Overview of Sensitivity Analyses

Scenario	Description
Climate Change	Sensitivity to rainfall and runoff estimates were assessed by using the 0.5% AEP and 0.2% AEP as proxies for potential changes to rainfall IFDs from climate change.
Rainfall Losses	Initial Loss and Continuing Loss was varied from those recommended from the ARR 2019 Data Hub to be consistent with those from the calibration events
Catchment Lag Factor, "C"	The catchment lag factor value was increased and decreased by 20%
Manning's "n"	The hydraulic roughness values were increased and decreased by 20%
Culvert and Bridge Blockage	Sensitivity to blockage of culverts and bridges on open channel sections was assessed for: • 50% blockage for all bridges and culverts; and • 100% blockage for all bridges and culverts.
Energy Losses	The energy loss (K parameter) at bridges was increased by 0.2
Tailwater Level	The tailwater boundary slope was increased and decreased by 50%.

The sensitivity scenario results were compared to the 1% AEP event.

10.2. 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 rainfall intensities however uncertainty remains regarding the scale of this impact and its likely impact on design rainfall for major flood producing storms.

Any increase in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment.

Projected increases to evaporation are also an important consideration because increased evaporation would lead to generally drier catchment conditions, resulting in lower runoff from rainfall. Mean annual rainfall is projected to decrease, which will also result in generally dryer catchment conditions.

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events within the catchment under warmer climate scenarios.

In light of this uncertainty, the NSW State Government's advice recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand. Specifically, it is suggested that rainfall intensity increases be considered.

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 Cootamundra catchment, these events correspond to an increase in rainfall intensity of approximately 13% for the 0.5% AEP event and 29% increase for the 0.2% AEP event (see Table 45). The peak flood depth and level results of the 1%, 0.5% and 0.2% AEP events are shown on Figure 39, Figure 40, and Figure 41, respectively. A comparison of flood levels has been provided on Figure 63 and Figure 64 with results also shown for the reporting locations for the study (see Figure 33) in Table 45.

The 0.5% AEP event flood level is approximately 0.05 to 0.20 m higher along Muttama Creek within Cootamundra town. The increase in flood level upstream Cootamundra and along Jindalee Creek is typically less than this. The largest increase in flood level is in Fisher Park where flood levels increase by up to 0.45 m. In the 0.2% AEP event, the increase in flood level is comprised between 0.20 m and 0.40 m with the largest increase occurring in Fisher Park (+ 0.62 m). The flood extents remain fairly similar between the different future climate scenarios,although downstream of the Olympic Highway an additional flowpath is created between Muttama and Cootamundry Creeks in the vicinity of Conkey Drive. This area is further inundated in the 0.2% AEP event. Between 79 and 148 additional properties are flooded overfloor during the two future climate scenarios.

Table 45: Sensitivity analysis for climate change at Key Locations

ID	Location	1% AEP Design Run Depth	0.5% AEP event	0.2% AEP event
1	W Jindalee Rd / Racecourse Ln	0.11	+0.02	+0.03
2	Cutler Avenue - Muttama Creek	2.56	+0.16	+0.28
3	Poole St / Bourke St	0.37	+0.13	+0.25
4	Mackay St / Olney St	0.14	+0.1	+0.18
5	Bourke St / Parker St	0.46	+0.14	+0.25
6	Parker St / Wallendoon St	0.41	+0.14	+0.25
7	French St / Horney St	0.82	+0.2	+0.39
8	Ursula St / Hurley St	0.42	+0.19	+0.39
9	Southee Circle	1.05	+0.19	+0.39
10	Sutton St / Hurley St	0.54	+0.12	+0.26
11	Hume St - Florance St	0.04	+0.02	+0.02
12	Gundagai Rd / Cowcumbla St	0.13	+0.05	+0.15
13	Binowee Rd	0.65	+0.08	+0.15
14	Cootamundra Airport Runway	0.05	+0.01	+0.02
15	Cootamundra Airport - buildings	0.29	+0.04	+0.07
16	Olympic Hwy / Barnes Street	0.22	+0.01	+0.02

10.3. Hydrologic Model Parameters

10.3.1. Rainfall Losses

Rainfall losses were generally adopted from the ARR 2019 Data Hub (see Section 4.11.1). As a sensitivity analysis, the calibrated rainfall initial losses for the more significant events (March 2012 and September 2016) were run for the 1% AEP event using the WBNM hydrologic model. A comparison of flows was undertaken at the key subcatchments of Jind_Ck1, M_Coota3 and Coota_Ck8, which were used to assess the critical storm patterns for the study area catchment.

The calibrated initial loss value of 17 mm (March 2012 event) instead of 27 mm was used for the sensitivity analysis. A comparison of the resulting peak flows for the initial loss sensitivity analysis at key subcatchment locations is shown in Table 46.

Table 46: Sensisitivity Analysis Results for Initial Losses for the 1% AEP event

Catchment	Adopted Data Hub Initial Losses		Sensitivity Analysis		Difference in Peak Flows	
	Critical Duration (mins)	Peak Mean Flow (m^3/s)	Critical Duration (mins)	Peak Mean Flow (m^3/s)	(m^3/s)	(%)
March 2012 event losses – IL = 17 mm						
Jind_Ck1	360	102	360	111	+8.4	+8.2%
M_Coota3	360	275	360	297	+22.0	+8.0%
Coota_Ck8	360	107	360	115	+8.7	+8.2%

On Muttama Creek (M_Coota3), the increase in peak flow is approximately 8% and the critical duration remains unchanged (360 minutes). The rising limb and peak timing is advanced by 2hour. On Jindalee Creek and Cootamundra Creek, the increase in peak flow is similar (+7%).

The ARR Data Hub with DPIE guidance recommends a continuous loss values of 1.7 mm/hr was used for the sensitivity analysis. A comparison of the resulting critical duration and peak flow for the initial loss sensitivity analysis at key subcatchment locations is shown in Table 47.

Table 47: Sensisitivity Analysis Results for Continuous Losses for the 1% AEP event

Catchment	Adopted Data Hub Initial Losses		Sensitivity Analysis		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)	(%)
ARR2019 recommended value – CL = 1.7 mm/hr						
Jind_Ck1	360	102	360	132	+29.6	+28.9
M_Coota3	360	275	360	354	+78.8	+28.6
Coota_Ck8	360	107	360	136	+29.7	+27.9

There is no change in the critical duration with the change in continuing loss. The increased continuing loss significantly increases the peak flows by 28% for Muttama Creek, Jindalee Creek and Cootamundra Creek.

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 Jind_Ck1, M_Coota3 and Coota_Ck8, which were used to assess the critical storm patterns for the study area catchment. This assessment was undertaken for the 1% AEP event.

The 2001 Floodplain Risk Management Study (Reference 7) adopted a higher than default storage delay time modifier (Bx) value. The WBNM ‘C’ parameter has a similar effect on the resulting runoff hydrograph.

An increase in catchment lag of 20% results in a reduction in catchment peak flows. A comparison of the resulting critical duration and peak flows for this sensitivity analysis at key subcatchment locations is shown in Table 48.

Table 48: Sensisitivity Analysis Results for increase in Catchment Lag for the 1% AEP event

Catchment	Adopted Data Hub Initial Losses		Sensitivity Analysis		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)	(%)
20% increase in Catchment Lag						
Jind_Ck1	360	102	360	87	-15.2	-14.9%
M_Coota3	360	275	360	235	-40.3	-14.6%
Coota_Ck8	360	107	360	91	-15.4	-14.5%

The critical duration storm remains the same (360 min). The decrease in the peak mean flows is approximately of 15%. The peak timing in Cootamundra town is delayed by 30 minutes.

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 49.

Table 49: Sensisitivity Analysis Results for decrease in Catchment Lag for the 1% AEP event

Catchment	Adopted Data Hub Initial Losses		Sensitivity Analysis		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)	(%)
20% decrease in Catchment Lag						
Jind_Ck1	360	102	360	122	19.6	+19.1%
M_Coota3	360	275	360	327	52.0	+18.9%
Coota_Ck8	360	107	360	126	19.8	+18.6%

The critical duration doesn't change for the 1% AEP event. The increase in peak flows is approximately 19% across the key subcatchments. The peak timing in Cootamundra town is increased with the peak arriving 30 minutes earlier.

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 24. A sensitivity analysis was conducted with both an increase and decrease in these values by 20%. The results can be found in the maps on Figure 65 and Figure 66, with results also shown in Table 50 for the reporting locations for the study (see Figure 33).

Table 50: Sensitivity analysis for Manning's 'n' at Key Locations

ID	Location	1% AEP Design Run Depth	-20% Manning's	+20% Manning's
1	W Jindalee Rd / Racecourse Ln	0.11	0.00	0.00
2	Cutler Avenue - Muttama Creek	2.56	-0.07	+0.07
3	Poole St / Bourke St	0.37	-0.03	+0.11
4	Mackay St / Olney St	0.14	-0.04	+0.04
5	Bourke St / Parker St	0.46	-0.04	+0.04
6	Parker St / Wallendoon St	0.41	-0.04	+0.05
7	French St / Horney St	0.82	-0.09	+0.08
8	Ursula St / Hurley St	0.42	-0.11	+0.1
9	Southee Circle	1.05	-0.09	+0.08
10	Sutton St / Hurley St	0.54	-0.03	+0.05
11	Hume St - Florance St	0.04	0.00	0.00
12	Gundagai Rd / Cowcumbla St	0.13	-0.02	+0.02
13	Binowee Rd	0.65	-0.08	+0.07
14	Cootamundra Airport Runway	0.05	-0.01	0.01
15	Cootamundra Airport - buildings	0.29	-0.04	+0.03
16	Olympic Hwy / Barnes Street	0.22	0.00	0.00

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 through the Cootamundra town. With a decrease in Manning's 'n', there is a decrease in flood levels of a similar magnitude. Overall the results were fairly insensitive to Manning's "n" assumptions.

10.4.2. Blockage

Blockage of hydraulic structures can occur with the transportation of a number of materials by flood waters. This includes vegetation, garbage bins, building materials, cars and other urban debris. However, the disparity in materials that may be mobilised within a catchment can vary greatly.

Debris availability and mobility can be influenced by factors such as channel shear stress, height of floodwaters, severity of winds, storm duration and seasonal factors relating to vegetation. The channel shear stress and height of floodwaters that influence the initial dislodgment of blockage materials are also related to the AEP of the event. Storm duration is another influencing factor, with the mobilisation of blockage materials generally increasing with increasing storm duration (Reference 1).

The potential effects of blockage include:

- decreased conveyance of flood waters through the blocked hydraulic structure or drainage system;
- variation in peak flood levels;
- variation in flood extent due to flows diverting into adjoining flow paths; and
- overtopping of hydraulic structures.

The hydraulic structures represented in the model have been tested for their sensitivity to potential debris blockage during an event. Any structure less than 7m in the diagonal has been assumed either 50% or 100% blocked and modelled for the 1% AEP event. The results of this assessment can be found on Figure 67 and Figure 68.

The structures through Main Southern Railway, Cootamundra Lake Cargelligo Railway, Sutton Street and Wallendoon Street show increasing peak flood levels by up to 0.5 m in the immediate upstream under the 50% blockage and up to 1.0 m in the 100% blockage scenario. These locations should be given consideration as part of the future Floodplain Risk Management Study and Plan. Some other less significant impacts are observed across the study area.

10.4.3. Structure energy losses

For 1d modelled structures (see Section 7.6), the entry loss coefficient and exit loss coefficient recommended values are 0.5 and 1.0 respectively. A sensitivity analysis was conducted with both an increase and decrease in these values by 20%. For 2d modelled structures, a sensitivity analysis of the loss parameter K was conducted with both an increase and decrease of 20%.

The results of this assessment can be found on Figure 69 and Figure 70. The peak flood levels are relatively insensitive to these assumptions with flood levels generally changing by +/-0.01 m. The most significant increase in flood level are in Cootamundra Creek upstream of the Olympic Highway where flood levels increase by up to 0.02 m with a loss increase of 20%. With a decrease in energy losses, there is a decrease in flood levels of a similar magnitude.

10.4.4. Tailwater Level

A HQ (height flow) boundary was utilised for Muttama Creek at the downstream end of the TUFLOW model (see Section 7.4.2). The adopted slope value for this HQ boundary was 0.003. A sensitivity analysis was conducted with both an increase and decrease in this value by 50%.
The results of this assessment can be found on Figure 71 and Figure 72.

The tailwater level assumption does not have a significant influence on peak flood levels in the area of interest. Adjusting the adopted slope impacted flood levels up to 200 m upstream of the boundary. The impact is also limited to a rural area without any residential properties.

11. ECONOMIC IMPACTS OF FLOODING

11.1. Background

The quantification of flood damages is an important part of the floodplain risk management process. It helps identify the magnitude of the flood problem, where the financial impacts of flooding will occur, 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.

A flood damages assessment has been undertaken to determine the economic costs of flooding due to the Muttama, Jindalee and Cootamundry Creeks (and overland flow contributing areas). Damages can be defined either as tangible or intangible. Tangible damages are those for which a monetary value can be easily assigned, while intangible damages are those to which a monetary value cannot easily be attributed. Damages are further categorised as being either direct or indirect. Direct damages are caused by direct contact with flood water, for example, damages to buildings and their contents. Indirect damages refer to the knock-on effects of flood events, such as loss of wages or traffic disruption. Other impacts of flooding as well as intangible damages (stress, injury, loss of life, loss of sentimental items) would be considered as part of a future Floodplain Risk Management Study.

The below assessment focuses on the direct tangible damages to properties caused by flooding in Cootamundra. It is noted that there are direct damages (e.g. to roads, bridges, other infrastructure) that are not included in the assessment as there is no clear methodology available to do so. The damages assessment forms the basis of quantifying the economic loss due to flooding, and also a non-subjective means of assessing the economic merit of flood mitigation works to be investigated as part of the Floodplain Risk Management Study, 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 damages assessment methodology is based on DPIE guidelines and is summarised below.

11.2. Assessment Methodology

The flood damages assessment methodology is presented below:

- **Establish design flood modelling results** for the 20%, 10%, 5%, 1%, 0.5%, 0.2% AEP and the PMF events;
- **Obtain floor level data (refer to Section 4.7):**
    - Floor levels for 1423 properties were estimated by site visit and LiDAR data (Refer Section 4.7);
    - In total: 1306 residential properties, and 117 commercial properties were included in the assessment.
- **Determine the peak flood depth** that would occur at each property during each design flood event;
- **Apply stage-damage curves** (derived from DPIE (formerly OEH) Guidelines, Reference 27) to relate the depth of flooding to a monetary cost in each design flood event;
- **Calculate the Average Annual Damage (AAD)**. The AAD represents the estimated tangible damages sustained every year (on average), over a long period of time.

The DPIE Guideline has been formulated using data collected following real flood events, including identification of properties flooded, the extent of flooding, depth of flooding experienced, flooding mechanism etc. One of the most thoroughly studied flood damage assessments was that undertaken at Nyngan, following the flood in 1990.

The flood damages estimates do not include the cost of restoring or maintaining public services and infrastructure. It should also be noted that damages calculations do not take into account flood damages to any basements or cellars, hence where properties have basements, damages can be under estimated.

The classification of a "habitable" floor was based on visual inspection only. As such, properties which may have created habitable spaces in under croft areas which do not mean Building Code or Council's planning requirements will still be recorded as habitable in this survey. As such, some of the above floor inundation determined below may include damages associated with illegal building structures.

Note that the results are not an indicator of individual flood risk exposure, but part of a regional assessment of flood risk. Furthermore, the purpose of the damages assessment is not to calculate the actual damage that would be incurred in a flood, but to form a basis of comparison with other flood prone communities throughout NSW, and as a baseline against which mitigation options can be assessed.

11.3. Flood Damage Assessment Results

The flood damages assessment in Cootamundra took into account damage from both mainstream flooding and overland flow mechanisms and included direct damage to both residential and non-residential (i.e. commercial and industrial) property types. The overall results are summarised in Table 51, with a breakdown provided for residential and non-residential properties provided in Table 52 and Table 53 respectively.

Chart 1 shows the cost of flooding increasing steadily as larger events occur. The rate of this is increased at the 2% AEP event. In terms of properties impacted there is also a jump observed in properties impacted over floor in the 2% AEP event. Residential damages are the most significant contributor to the overall damages in Cootamundra. The damages assessment can be used to inform selection of appropriate flood risk mitigation options as part of the future Floodplain Risk Management Study and Plan.

Damages were calculated for residential and non-residential properties separately as discussed in the following sections.

Chart 1 Total Flood Damages

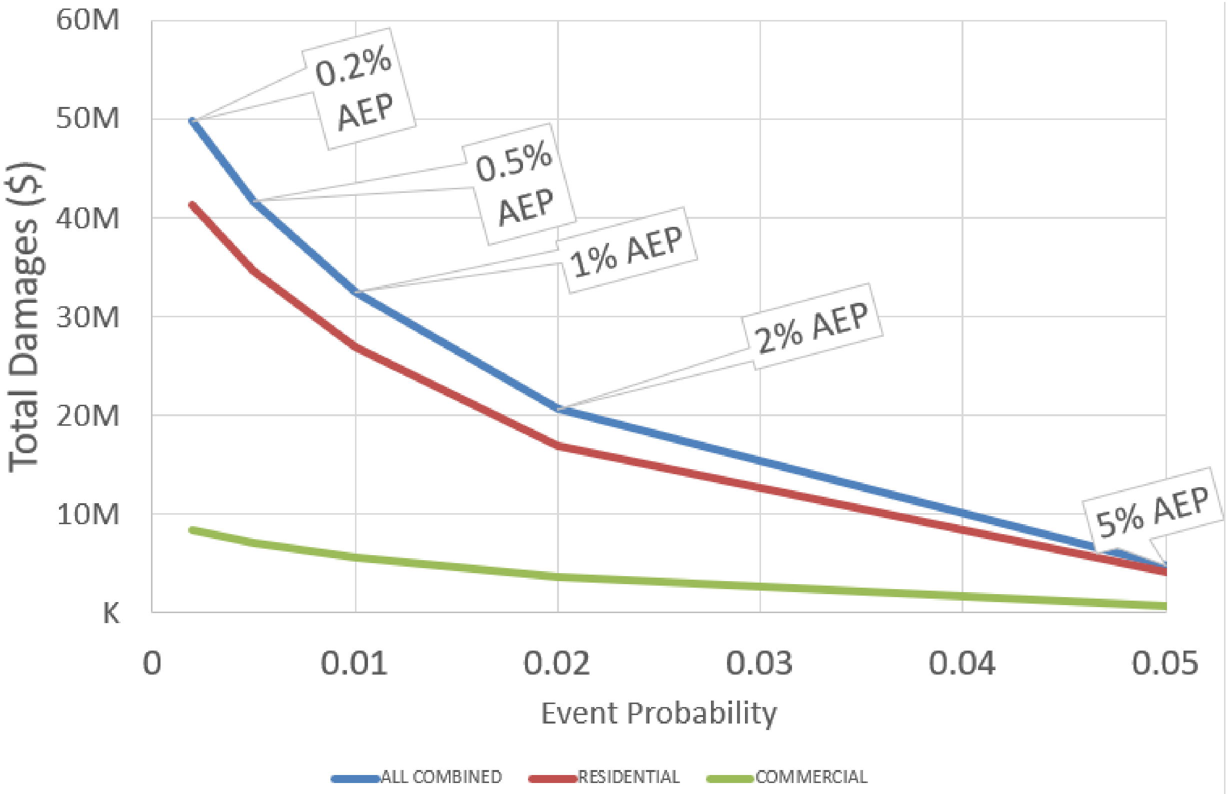


Table 51: Estimated Total Flood Damages (residential & non-residential) for Cootamundra Catchment

Event	No. of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected property
20% AEP	98	21	$1,202,500	$17,848
10% AEP	269	51	$3,025,900	$20,671
5% AEP	339	88	$4,793,900	$30,311
2% AEP	598	303	$20,610,700	$79,461
1% AEP	719	444	$32,487,500	$101,817
0.5% AEP	815	523	$41,714,200	$116,039
0.2% AEP	891	592	$49,804,200	$125,153
PMF	1774	1598	$207,680,400	$252,803
Average Annual Damages (AAD)			**$1,481,200**	**$1,893**

11.3.1. Residential properties

Table 52 provides the calculation of damages for residential properties only in the catchment. Residential property damage contributes 85% of the average annual damage in the Cootamundra study area. 88% of the total number of properties flood affected and 88% of properties inundated above floor are residential. For the 1% AEP event, residential properties account for 87% of the flood affected properties in the catchment and contribute to 83% of the total tangible damages calculated.

Table 52: Estimated Total Flood Damages (residential) for Cootamundra Catchment

Event	No. of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected property
20% AEP	87	20	$1,151,700	$13,238
10% AEP	238	44	$2,742,300	$11,522
5% AEP	301	74	$4,168,300	$13,848
2% AEP	519	254	$16,906,800	$32,576
1% AEP	623	377	$26,850,500	$43,099
0.5% AEP	710	442	$34,655,100	$48,810
0.2% AEP	773	498	$41,348,100	$53,490
PMF	1569	1401	$179,279,900	$114,264
Average Annual Damages (AAD)			**$1,257,500**	**$800**

11.3.2. Non-residential – Commercial and Industrial

The total non-residential damages for the Cootamundra study area are shown in Table 53. Whilst only 12% of the properties are non-residential, they are contributing to 15% of the AAD. This is due to a higher proportion of non-residential properties inundated in the more frequent events which generally received higher depths of inundation.

Table 53: Estimated Total Flood Damages (commercial and industrial) for Cootamundra Catchment

Event	No. of Properties Flood Affected	No. of Properties Flooded Above Floor Level	Total Tangible Flood Damages	Average Tangible Damages Per Flood Affected property
20% AEP	11	1	$50,700	$4,610
10% AEP	31	7	$283,600	$9,149
5% AEP	38	14	$625,600	$16,463
2% AEP	79	49	$3,704,000	$46,885
1% AEP	96	67	$5,636,900	$58,718
0.5% AEP	105	81	$7,059,000	$67,229
0.2% AEP	118	94	$8,456,100	$71,662
PMF	205	197	$28,400,500	$138,539
Average Annual Damages (AAD)			**$223,700**	**$1,100**

11.3.3. Annual Average Damages

Depending on its size (or severity), each flood will cause a different amount of flood damage within a flood prone area. Annual Average Damage (AAD) is the average damage per year that would occur in a nominated development situation (i.e. current catchment conditions in Cootamundra) from flooding over a very long period of time. That is, the AAD is equal to the total damage caused by all floods over a long period of time divided by the number of years in that period. Note that it is assumed that the development situation is constant over the analysis period.

The AAD in Cootamundra due to mainstream flooding and overland flow is summarised in Table 54.

Table 54 Annual Average Damages

Property Type	Annual Average Damages	% Contribution to total AAD
Residential	$ 1,257,500	85%
Commercial	$ 223,700	15%
Total	**$ 1,481,200**	**100%**

The comparison shown in Table 54 reiterates the trends shown by the total flood damages results: that the bulk of flood damages in Cootamundra are made up by residential flood damages. Flood damages to residential properties contributes approximately six times as much to Cootamundra's AAD as commercial flood damages.

12. ACKNOWLEDGEMENTS

WMAwater has prepared this document for Cootamundra Gundagai Regional Council, with technical assistance from the NSW Government through its Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Department of Planning, Industry and Environment. The assistance of the following in providing data and guidance to the study is gratefully acknowledged:

- Residents of Cootamundra;
- Cootamundra Gundagai Regional Council;
- Department of Planning, Industry and Environment;
- Bureau of Meteorology; and
- NSW State Emergency Services.

13. REFERENCES

1. Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors)
Australian Rainfall and Runoff – A Guide to Flood Estimation
Commonwealth of Australia (Geoscience Australia), 2016

Data Hub: http://data.arr-software.org/

2. **Floodplain Development Manual**
NSW Government, April 2005

3. **WBNM User Guide**
WBNM, 2012

4. **TUFLOW CLASSIC/HPC User Manual**, 2018-03-AD
BMT WBM, 2018

5. Water Resources Commission of New South Wales
Cootamundra Flood Study Report
Cootamundra Shire Council, June 1986

6. Maunsell Pty Ltd
Cootamundra Lake Flood Study
Lake Development Committee, Cootamundra, June 1997

7. Willing & Partners
Cootamundra Floodplain Management Study and Plan
Cootamundra Shire Council, June 2001

8. Cardno Willing
Jindalee Creek Levee
Cootamundra Shire Council, August 2004

9. NSW State Emergency Service
Cootamundra Local Flood Plan
Cootamundra Shire Council, June 2007

10. Brearley & Hansen
Priority Infrastructure Project: Stormwater Priority Assessment Report, Version 1.2
Cootamundra Shire Council, August 2018

11. Cardno
Survey and Design of Six Stormwater Improvement Projects, Design Report
Cootamundra Shire Council, March 2019

Queanbeyan Age, 29 April 1903
12. **The Cootamundra Flood**
Available from: http://nla.gov.au/nla.news-article31094357 (accessed 9/8/2019)

The Brisbane Courier, 29 January 1885
13. **The Fatal Railway Accident at Cootamundra**
Available from: https://trove.nla.gov.au/newspaper/article/3438609 (accessed 9/8/2019)

The McIvor Times and Rodney Advertiser, 20 February 1885
14. **Another Flood at Cootamundra**
Available from: https://trove.nla.gov.au/newspaper/article/90147613 (accessed 9/8/2019)

Wellington Times, 27 April 1903
15. **Cootamundra Flood**
Available from: https://trove.nla.gov.au/newspaper/article/137888660 (accessed 9/8/2019)

The Sydney Morning Herald, 6 December 1919
16. **Cootamundra Flood**
Available from: https://trove.nla.gov.au/newspaper/article/15866913 (accessed 9/8/2019)

The Advertiser, Adelaide, 6 December 1919
17. **Cootamundra Floods**
Available from: https://trove.nla.gov.au/newspaper/article/5647938 (accessed 9/8/2019)

The Cootamundra Herald, Friday, 11 January 1974
18. **Cootamundra and its district was today hit with the biggest series of flooding in many people's memory.**
Provided by Cootamundra Heritage Centre, 25/7/19

The Cootamundra Herald, Friday, 11 January 1974
19. **Cootamundra and its district was today hit with the biggest series of flooding in many people's memory.**
Provided by Cootamundra Heritage Centre, 25/7/19

Engineers Australia
20. **Australian Rainfall and Runoff Revision Project 15:**
Two Dimensional Modelling in Urban and Rural Floodplains
Department of Climate Change and Energy Efficiency, November 2012

Weeks, W., Witheridge, G., Rigby, E., Barthelmess, A. and O'Loughlin, G.
21. **Australian Rainfall and Runoff: Revision Project 11:**
Blockage of Hydraulic Structures (Stage 2 Report)
Engineers Australia, February 2013

22. **Floodplain Risk Management Guide**
Incorporating 2016 Australian Rainfall and Runoff in studies
State of NSW and Office of Environment and Heritage, January 2019

Bureau of Meteorology
23. **The Estimation of Probable Maximum Precipitation in Australia:**
Generalised Short-Duration Method
June, 2003

Australian Institute for Disaster Resilience
24. **Australian Disaster Resilience Guideline 7-3 Flood Hazard**
Supporting document for the implementation of Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia
Australian Government, 2017

Howells, L., McLuckie, D., Collings, G. and Lawson, N.
25. **Defining the Floodway – Can One Size Fit All?**
Floodplain Management Authorities of NSW 43rd Annual Conference, Forbes
February 2003

NSW Department of Environment and Climate Change
26. **Practical Consideration of Climate Change**
Coast and Floodplain Management, October 2007

NSW Department of Environment and Climate Change
27. **Floodplain Risk Management Guideline: Residential Flood Damages**
May 2007

Kuczera, G 28. **Bayesian Flood Frequency Analysis Software (Version 4.50)**
Department of Civil Surveying Environmental Engineering, University of Newcastle, NSW, 2001

14. GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
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.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
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).
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.
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 diagrammetic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the Aflood liable land@ concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL=s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the Astandard flood event@ in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can

increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or • water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or • major overland flow paths through developed areas outside of defined drainage reserves; and/or

- the potential to affect a number of buildings along the major flow path.

mathematical/computer models The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.

merit approach The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State=s rivers and floodplains.

The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.

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 Awater 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.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Figures

Appendix A

Appendix B

Appendix C

Appendix D