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Rous County Council

Lismore Floodplain Risk Management Study

Draft Report

29 October 2020

M76000_004

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Rev	Date	Description	Author	Reviewer	Project Mgr.	Approver
0	21/09/2020	Draft Issue for TMC & FMC Review	Kelsey Mundt/Mark Page	Mark Page/Adam Wyatt	Mark Page	Adam Wyatt
1	13/10/2020	Final Draft Issue	Kelsey Mundt	Mark Page	Mark Page	Andrew Vitale
2	29/10/2020	Final Draft Issue	Kelsey Mundt	Mark Page	Mark Page	Andrew Vitale

Signatures

DISCLAIMER

ACKNOWLEDGEMENTS

Engeny would like to acknowledge the contributions made by:

- Rous County Council for initiating and partly funding the project.
- Department of Planning, Industry and Environment (formerly known as Office of Environment and Heritage) for the funding assistance provided to Rous County Council that made this project possible.
- The Technical Management Committee for ensuring the necessary technical rigour was applied to the study.
- The Floodplain Management Committee for ensuring that the study achieved the intended floodplain management objectives.
- Mr Don Carroll from DCPM for his input to the calibrated URBS model, technical assistance and review.

EXECUTIVE SUMMARY

The Lismore Floodplain Risk Management Study (hereafter referred to as Lismore FRMS or this Study) was initiated due to the major flood event which occurred in March 2017. This event peaked at 11.59 mAHD (Lismore Rowing Club Gauge) and resulted in the CBD levee being overtopped for the first time since it was completed in 2005. The NSW Floodplain Development Manual (DPIE, 2015) also recommended that a review of floodplain management plans should occur approximately every 5 years or after a significant flood event.

This Study has included hydrologic and hydraulic analysis of historical events, design flood events, model sensitivity scenarios, and mitigation options.

The key objectives of the Lismore FRMS were:

1. To develop a detailed understanding of the flood risks using detailed and up to date models.
2. To identify and assess potential management measures to address existing, future and continuing/residual risk and guide the development of the Lismore Floodplain Risk Management Plan (Lismore FRMP).

Outcomes from the Lismore FRMS are outlined as follows.

Flood Modelling

Flood modelling has been undertaken using up to date and calibrated URBS hydrology and TUFLOW hydraulic models which were established for this Study. A joint hydrologic and hydraulic calibration of the 2017, 2013, 2012 and 1989 flood events was completed with river gauging stations on all tributaries contributing to the main Leycester Creek and Wilsons River branches utilised to inform hydrologic timing.

Comparison of TUFLOW hydraulic model flood levels with recorded levels indicated that modelled peak levels at Lismore Rowing Club gauge were within 30 mm, 70 mm, 200 mm and 220 mm, respectively for the 2017, 2013, 2012 and 1989 flood events, with the shape and timing of the modelled water-level time series matching the recorded water-level time series well. Modelled flood levels were within 150 mm of the surveyed flood levels at 47 out of 62 flood survey marks for the 2017 flood event. The TUFLOW hydraulic model was also validated using previously modelled design events by BMT in 2018 and SKM in 1993, as well as comparison to flood heights calculated from Flood Frequency Analysis at the four river gauge locations in the model extent.

The URBS and TUFLOW models were simulated for the 10%, 5%, 2%, 1%, 0.2% Annual Exceedance Probability (AEP) flood events, for all ten ensemble temporal patterns as recommended by Australian Rainfall and Runoff 2019 (ARR 2019) and for all durations from 6 hours to 72 hours. The models were also simulated for the Probable Maximum Flood (PMF) event for all durations ranging from 6 hours to 72 hours. These models have formed the basis for the hydraulic assessment of mitigation options.

A comparison of the results from this Study suggests that the flood levels are generally higher than LCC's currently adopted 1% AEP levels. For example, the currently adopted 1% AEP flood level for City Hall located at 1 Bounty Street is 12.3 mAHD, whereas this Study has predicted a 1% AEP flood level of 12.33 mAHD. Whilst this comparison shows a minor difference of 30 mm, this may not consistent across Lismore and a more detailed comparison should be undertaken including consideration of potential implications to both Council and property owners such as insurance costs and development potential to name a few.

Sensitivity analyses were undertaken for spatial variation in rainfall (two scenarios being 1% AEP rainfall in the Leycester Creek catchment with 5% AEP rainfall in the Wilsons Creek catchment, and vice versa), Manning's 'n roughness (20% increase), structure blockage (20% and 50%). The spatial rainfall variation results indicate that the flood levels throughout Lismore tend to be dominated by the magnitude of the Leycester Creek catchment inflows, where reduction in the magnitude of flow from this branch has a larger reduction in predicted flood levels in Lismore. The Manning's 'n roughness scenario produced a relatively consistent increase to flood levels of approximately 150 mm across the model extent for the 1% AEP flood event. This also indicates that the model provides a relatively accurate and stable estimate of flood levels across the model area. The 20% blockage scenario indicated that in areas upstream of key hydraulic controls, flood levels are expected to increase by approximately 30 mm for the 1% AEP flood event. This increase is relatively minor in the context of the total flood depth which is largely due to the expansive floodplain.

A climate change assessment was also undertaken to estimate the likely impact of climate change on flood conditions in Lismore based on Representative Concentration Pathway (RCP) 8.5 future climate conditions (year 2100), reflecting an increase in rainfall intensity of 19.7%. The results indicated that the estimated increase in intensity will result in flood level increases of approximately 350 - 600 mm across the flood extent.

Flood Risk Analysis

Lismore has historically experienced significant flooding, with records indicating approximately 30 historical flood events at Lismore being classified as major flood events since 1870, with the flood height exceeding 9.7 m AHD. Of these events, twelve were of a magnitude large enough to overtop the current CBD levee, with any events exceeding 9 m AHD prior to the construction of the levee (completed in 2005) causing flooding of residential and commercial areas in Lismore. Based on comparison of design event flood levels from this study and recorded gauge levels, the approximate historical event magnitude for the 1989, 2012, 2013 and 2017 events were estimated as shown below.

Location	1989	2012	2013	2017
Wilsons River at Woodlawn College - 203402	<10% AEP	<10% AEP	<10% AEP	5% AEP
Leycester Creek at Tuncester – 203443	5% AEP	<10% AEP	<10% AEP	1% AEP
Wilsons River at Lismore - 203904	10% AEP	<10% AEP	<10% AEP	5% AEP

Due to the magnitude of the 2017 event (approximately 5% AEP in Lismore) and the flood immunity of the levees (approximately 10% AEP), the 2017 flood event has been of particular interest for this study.

The design event flood behaviour for Central Lismore, North Lismore and South Lismore is well documented in *Section 5.3*. There are a number of major hydraulic controls within the floodplain which includes the South Lismore Levee, CBD Levee, Gasworks Creek floodgates, Hollingworth Creek floodgates, Bruxner Highway and railway embankments.

The 1% AEP flood hazard map is presented in Figure 5.4. The H5 and H6 flood hazard classification generally applies to the Floodway, High Risk and Flood Isolated Precincts which includes the conveyance channels as well as the Lismore CBD and parts of South Lismore and North Lismore. The H3, H4 and H5 flood hazard classification generally applies to the Medium Risk Precinct, CBD Flood Liable, East Lismore Flood Liable and South Lismore Flood Isolation areas.

A review of the existing evacuation routes for Lismore against the updated flood hazard mapping indicated that the current evacuation routes are appropriate from a perspective of selecting roads that present the lowest potential hazard whilst servicing the areas for evacuation.

Floodplain Risk Management

A range of engineering (i.e. structural mitigation/flood behaviour modification), planning (land use zoning, development control, house raising, house purchase, etc.) and emergency management (flood response, flood warning, community awareness, etc.) measures were considered to mitigate the identified risks.

The long list of options considered included:

- CBD levee raise to provide 5% AEP flood immunity.
- South Lismore levee raise to provide 5% AEP flood immunity.
- Extension of South Lismore Levee to Crown Street.
- Removal of Railway Embankment adjacent to Frank Street.
- Excavate to increase conveyance at Wilsons River bends at the Far North Coast Baseball Association fields and 387 Keen Street (note that excavation of the baseball fields was removed from the final list of options due to current land use impacts).
- Removal of Kyogle Road railway embankment and viaduct.
- Increase conveyance at key hydraulic controls at Bruxner Highway, Caniaba Road and Krauss Avenue.

Based on a qualitative review of the options listed above and in consultation with the TMC and FMC, the final list of flood modification options recommended for further consideration as part of the Lismore FRMP were as follows:

- Option 1 – CBD levee raise to provide 5% AEP flood immunity.
- Option 2 – South Lismore levee raise to provide 5% AEP flood immunity.
- Option 3 – Excavate to increase Wilsons River conveyance at 387 Keen Street.
- Option 4 – Removal of Kyogle Road railway embankment and viaduct.
- Option 5 – Increase conveyance at key hydraulic controls at Bruxner Highway, Caniaba Road and Krauss Avenue.
- Option 6 – Combined option, reflective of implementing Options 1 to 5.

All options (inclusive of the comparative base scenario) included the airport channel works completed by Lismore City Council in 2020. The Mitigated Base Case is not consistent with the modelling scenario used for the design event analysis as it included the airport channel and filling works. The six final options were simulated for the 5% AEP and 1% AEP flood events in the TUFLOW hydraulic model built for this Study. Flood impact (afflux) mapping is provided in *Appendix B*.

Outside of the implementation of the combined mitigation option, the mitigation option to raise the CBD levee was predicted to provide the greatest benefit to Lismore, with approximately 102 buildings predicted to be protected from above floor flood inundation in the 5% AEP event. This option is also predicted to provide nearly three additional hours of evacuation time for the CBD in a 1% AEP flood. The capital cost was estimated to be approximately $809,000, however adverse impacts to North Lismore and South Lismore should also be considered.

The feasibility and effectiveness of quantitatively assessed options was evaluated using a simplified cost-benefit analysis which only considers the number of buildings estimated to be protected and the associated cost to construct the mitigation measure. It is a simple estimate of the capital cost for each building that shown to be protected by the mitigation measure in a 5% AEP event. The net benefit was calculated by the difference between the number of buildings predicted to experience above floor inundation in the base case and the number of buildings predicted to experience above floor inundation in the mitigated case, noting that some previously unaffected buildings may experience above floor inundation due to the mitigation option. A more detailed cost-benefit analysis should be undertaken with consideration for more realistic flood damage cost for Lismore (if possible) and evaluation of the preferred options for a range on flood events. The outcomes are summarised below.

Table E1: Simplified Cost / Benefit Evaluation

Mitigation Measure	Preliminary Cost Estimate	Net Benefit in the 5% AEP Event[1]	Net Benefit in the 1% AEP Event[1]	5% AEP Evaluation Outcome ($/Building)
Option 1 – CBD Levee Raise	$809,000	102 Protected	53 Protected	$7,900
Option 2 – South Lismore Levee Raise	$209,000	14 Protected	11 Protected	$14,900
Option 3 – Excavation at Wilsons River Bend	$5,245,000	18 Protected	42 Protected	$291,400
Option 4 – Removal of Kyogle Road Railway Embankment	$995,000	0 Protected	8 Protected	N/A
Option 5 – Increase Conveyance at Hydraulic Controls	$8,963,000	0 Protected	20 Protected	N/A
Option 6 – Combined Option, Reflective of Options 1-5	$14,277,000	119 Protected	130 Protected	$120,000

[1] Represents the net number of buildings predicted to be protected from above floor inundation due to the mitigation option. Note that there are some buildings that were unaffected in the base case that were predicted to experience inundation above floor level in the mitigated case.

A preliminary flood damage assessment was also undertaken for the short-listed mitigation options to determine the expected reduction in flood damages following implementation of the option for the 5% and 1% AEP events only. A summary of the flood damage assessment is provided below.

Table E2: Flood Damage Assessment Outcomes

Scenario	Change to Flood Damages – 5% AEP Event	Change to Flood Damages – 1% AEP Event
Mitigation Base Case^	$455.3 M^	$732.5 M^
Option 1 – CBD Levee Raise	-$266.2 M	-$16.8 M
Option 2 – South Lismore Levee Raise	-$5.8 M	-$4.4 M
Option 3 – Excavation at Wilsons River Bend	-$12.6 M	-$16.5 M
Option 4 – Removal of Kyogle Road Railway Embankment	-$0.6 M	-$4.0 M
Option 5 – Increase Conveyance at Hydraulic Controls	$0.3 M	-$6.6 M
Option 6 – Combined Option, Reflective of Options 1-5	-$277.3 M	-$44.7 M

^Total estimated flood damage in the Mitigated Base Case, not the reduction in flood damage. The Mitigated Base Case included the airport channel and filling works.

In no particular order, based on the findings from this Study, it is recommended that:

1. The robustness of the hydrologic component of the calibration be improved by further development of rating curves for key river gauging stations. This would include calibration of previously developed TUFLOW local models for gauging stations to manually gauged events.
2. The calibration approach for future flood studies should consider integrated hydrologic and hydraulic calibration, including consideration for the greater Richmond River catchment. To improve the available data for such calibration, continued collaboration with the Bureau of Meteorology should be sought to maximise synergies between the organisations.
3. A detailed cost benefit analysis be undertaken including a comprehensive flood damage assessment utilising the updated DPIE damage curves once released. Survey of missing building floor levels should also be captured, and funding sought to undertake the survey.
4. The Lismore City Local Flood Plan be updated with flood information from this Study and a review of the total flood warning systems and flood response measures be undertaken. The review should include consideration for vulnerable members of the community (including hearing impaired persons) where evacuation assistance is required. A review of gauge locations should also be undertaken as part of the review.
5. A review and update of the Lismore LEP and DCP be undertaken with consideration for flood information provided in this Study.
6. Further investigation of the preferred mitigation measures from this Study to be undertaken as part of the Lismore FRMP development. Levee sections not previously surveyed should be captured and incorporated into the hydraulic modelling undertaken as part of the development of the Lismore FRMP.
7. Further assessment of levee modification works be undertaken including optimisation of levee heights with consideration for overtopping locations, evacuation (increasing response time), desired flood immunity for protected areas, and managing consequential flood impacts.
8. Additional flood mitigation using Nature Based Solutions (green infrastructure) be investigated as part of a separate study to inform the Lismore FRMP. RCC and LCC to seek funding for this study.

9. The list of eligible properties in the voluntary house raising and purchase schemes be reviewed based on the updated flood information from this Study and that dedicated funds be sought to continue purchasing and raising houses. The list of properties should also be updated following the development of the Lismore FRMP.
10. Additional mitigation options be investigated and modelled as part of the Lismore FRMP to reduce flows in the Wilsons River at Lismore. Options include narrowing of Leycester Creek downstream of Booerie Creek and associated downstream channel works through South Lismore, and an upstream retention structure.
11. The outcomes from this Study be used in the development of the Lismore FRMP including consideration for prioritisation and implementation of proposed measures.

ABBREVIATIONS AND ACRONYMS

1D	One-dimensional
2D	Two-dimensional
AEP	Annual Exceedance Probability
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval
ARR 2019	Australian Rainfall and Runoff (2019) guideline
RCC	Rous County Council
BoM	Bureau of Meteorology
CL	Continuing Losses
DEM	Digital Elevation Model
DFE	Defined Flood Event
DPIE	Department of Planning, Industry and Environment
EY	Exceedances per Year
FMC	Floodplain Management Committee
GSDM	Generalised Short Duration Method
GIS	Geographical Information System
GPU	Graphical Processing Unit
HPC	High-Performance Computing
IFD	Intensity Frequency Duration
LCC	Lismore City Council
LGA	Local Government Area
LiDAR	Light Detection and Ranging
mAHD	metres Australian Height Datum
OEH	Office of Environment and Heritage (now DPIE)
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
TMC	Technical Management Committee
TUFLOW	One-dimensional and two-dimensional finite volume numerical model (hydraulic modelling software).
URBS	Continuous/event rainfall runoff routing model (hydrologic modelling software).

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1 Introduction

Engeny Water Management (Engeny) was engaged by Rous County Council (RCC) to undertake the Lismore Floodplain Risk Management Study (Lismore FRMS). The Lismore FRMS was initiated due to the major flood event which occurred in March 2017. This event peaked at 11.59 mAHD (Lismore Rowing Club Gauge) and resulted in the CBD levee being overtopped for the first time since it was completed in 2005. The NSW Floodplain Development Manual (DPIE, 2015) also recommended that a review of floodplain management plans should occur approximately every 5 years or after a significant flood event.

This study builds upon previous studies and floodplain management initiatives to provide an updated understanding of the current and future flood risk to Lismore and presents potential floodplain risk management measures. It is intended that the Lismore FRMS will provide the basis for informing the preparation of a new Lismore Floodplain Risk Management Plan (Lismore FRMP).

1.1 PROJECT OBJECTIVES

The key objectives of the Lismore FRMS were to:

- Establish up to date and calibrated URBS hydrology and TUFLOW hydraulic models.
- Develop a detailed understanding of the existing flooding behaviour using the output from the updated flood modelling to define flood risk characteristics.
- Determine and evaluate potential floodplain risk management measures to address the identified flood risks with consideration for hydraulic performance and social, economic, and environmental factors.
- Develop a Floodplain Risk Management Study report that outlines the recommended management measures to be considered as part of the Lismore FRMP to address existing, future and continuing/residual risk. Specifically, the report provides updated flood risk information and identifies flood mitigation measures to reduce the likelihood and consequence of regional flooding, control future development within floodprone areas, and improve emergency planning and response to future flood events. The study also aims to further increase the community's awareness and resilience to flood risks.

1.2 STUDY AREA

Lismore is located in the Northern Rivers region of New South Wales and has a population of approximately 28,400. The township is located at the junction of Leycester Creek and Wilsons River, creating the areas of South Lismore, North Lismore and Central Lismore. The total contributing catchment to the township is approximately 1,400 sq km.

The study applies to the extent of flood prone land in the urban area of the Lismore Local Government Area, specifically the Lismore CBD, East Lismore, South Lismore and North Lismore, and is defined by the extent of the Probable Maximum Flood (PMF).

1.3 PROJECT SCOPE

The scope of works for the Lismore FRMS has been specified by RCC and the NSW Department of Planning, Industry and Environment (DPIE) (formerly Office of Environment and Heritage: OEH) and consisted of the following:

1. Refinement, update, and recalibration of the previously developed URBS model.
2. Development of a calibrated TUFLOW hydraulic model to define flood risks and assess mitigation options.
3. Floodplain risk management study including:

a) Analysis of flood behaviour including review of key hydraulic controls and flooding hot spots.
b) Flood risk assessment.
c) Identification of flood behaviour modification measures.
d) Presentation of mitigation options to the Floodplain Management Committee (FMC).
e) Hydraulic assessment of flood risk management measures.
f) Presentation of hydraulic assessment outcomes to the FMC.
g) Definition of flood risk and consequences on the community.
h) Provide information to inform future decisions on managing flood risk such as emergency response and land use planning.
i) Determination of preferred flood behaviour mitigation options in consultation with the FMC.
j) Cost estimation (high level) of preferred mitigation options.
k) Flood damages assessment for the design events and determination of flood damage reductions for preferred mitigation options.
l) Determine the benefit of preferred flood behaviour mitigation options in terms of buildings potentially protected.
m) Provide recommendations for further consideration in the development of the Lismore FRMP.

1.4 PAST STUDIES AND REPORTS

The following studies and reports provided input to this Study including background information of historical flood events at Lismore and flood management plans:

- Lismore Flood Risk Management Study – Gauge Rating Curve Review (Engeny, 2019).
  - Comprehensive review of available rating curves for river gauges located in the Lismore catchment.
- Post Event Flood Behaviour Analysis and Review of Flood Intelligence – Lismore Final Report (BMT WBM, 2018a).
  - Summary of previous joint hydrologic and hydraulic calibration for the 2017 historical flood event.
- Review of Rating Curves in the Wilsons River Catchment (BMT WBM, 2018b).
  - TUFLOW hydraulic modelling undertaken to produce possible rating curves for river gauges located upstream of Lismore.
- Lismore Floodplain Risk Management Plan (Lismore City Council, 2014).
  - Plan outlining floodplain risk management measures including implementation.
- *NSW SES (2013),* Lismore City Local Flood Plan.
  - Flood emergency plan for Lismore outlining the preparedness measures, the conduct of response operations and the coordination of recovery measures.
- Lismore Flood Study and Floodplain Management Study (Sinclair Knight Merz, 1993).
  - Comprehensive flood study of the Wilsons River catchment at Lismore, comprising hydrologic and hydraulic model builds and calibration.

1.5 FLOODPLAIN RISK MANAGEMENT APPROACH

This Study has been undertaken in accordance with the NSW Government's Floodplain Development Manual (DIPNR, 2005). The Lismore FRMS comprises Stages 1 and 2 of the Floodplain Risk Management Process which includes the following components:

- Stage 1 Flood Study – updated as part of this study.
- Stage 2 Floodplain Risk Management Study – this study.

- Stage 3 Floodplain Risk Management Plan – separate project to be delivered by LCC.

The Process as outlined in the Floodplain Development Manual is illustrated in the diagram below.

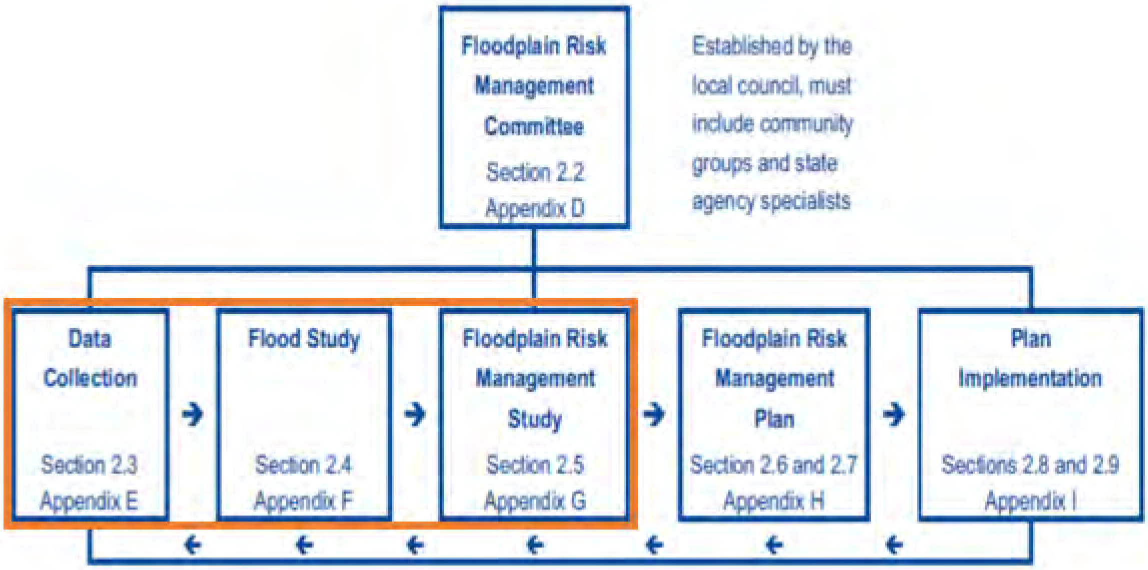


Figure 1.1: Floodplain Development Process

1.6 LIMITATIONS AND ASSUMPTIONS

The results presented in this report and in any digital data provided to RCC are inherently reliant upon the accuracy of the input data used in this study. Specific assumptions adopted in the study are outlined within the relevant sections of this report. It has been acknowledged that further review and assessment of recommended mitigation measures is required for the development of the Lismore FRMP. The assumptions for this Study are included within the relevant sections of this report.

2 Hydrologic Model Development

2.1 OVERVIEW

An URBS hydrologic model was established for the upper Lismore catchment, utilising the Split Model version of URBS, which separates catchment and channel routing in each subcatchment. The model was first calibrated to the 2017, 2013, 2012 and 1989 historical events, and later utilised for the design event modelling.

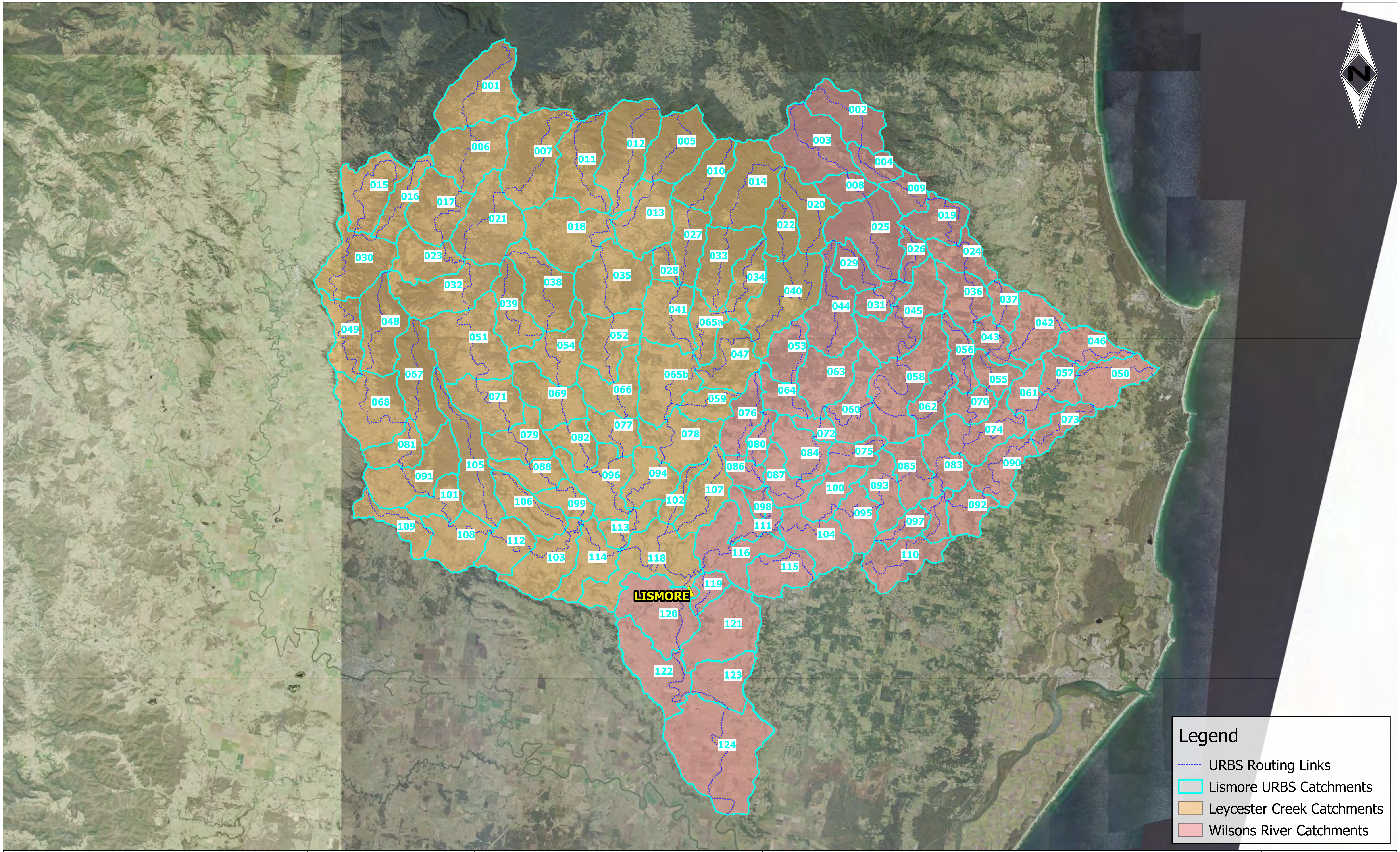
The following sections detail the Lismore URBS model establishment.

2.2 SUBCATCHMENTS AND CHANNEL REACHES

A total of 124 subcatchments were delineated for the Wilsons River catchment upstream of Lismore. The subcatchment layout for the URBS model is shown in Figure 2.1. The key reaches within the catchment are Leycester Creek, located on the western portion of the contributing catchment to Lismore, and Wilsons River, located on the eastern portion of the contributing catchment to Lismore. The confluence of Leycester Creek and Wilsons River is located within Lismore. The catchments reporting to these reaches are also indicated on Figure 2.1. The Leycester Creek and Wilsons River catchment areas upstream of the confluence are 870 km^2 (63%) and 520 km^2 (37%) respectively.

The subcatchments were defined in the URBS model by the catchment area parameter only.

Channel reach routing was based on river length (as a surrogate for channel storage). During the calibration process, localised modifications to stream routing lengths, including incorporation of on-line storages, were made to achieve a better match with observed stream gauging results.



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0 5000 10000 m

Scale in metres (1:225000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Lismore Floodplain Risk Management Study
Historical Event Calibration

Figure 2.1 - URBS Catchment Layout

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Drawn: KM
Date: 18 /9 /2020

2.3 HYDROLOGIC MODEL CALIBRATION

2.3.1 Overview

The Lismore URBS model was calibrated against rainfall and stream flow gauging data for the 2017, 2013, 2012 and 1989 historical flood events. The purpose of the calibration was to determine suitable calibration parameters to develop design hydrology for the catchment. The calibration strategy was to separate the gauging stations into three categories:

- Primary; Lismore Rowing Club.
- Secondary; Tuncester and Woodlawn College.
- Indicator; all stations upstream of the secondary stations.

The calibration process subsequently involved:

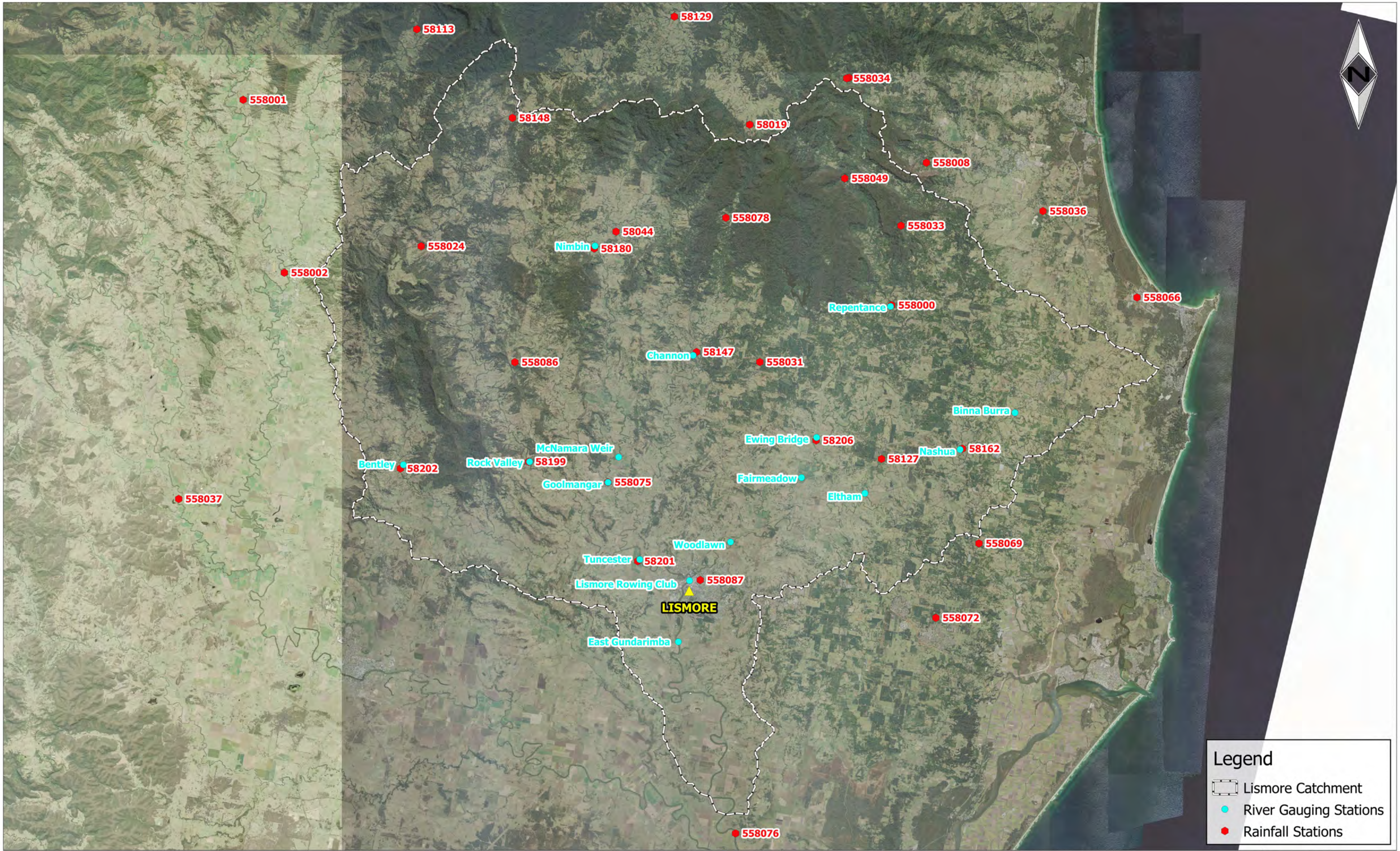
1. Achieving good timing calibration for the indicator gauges.
2. Achieving good timing and reasonable peak magnitudes calibration for the secondary gauges (Tuncester and Woodlawn College).
3. Comparative timing and peak magnitude were targeted for the Lismore Rowing Club river gauging station.

It should be noted that there was no available flood flow manual gauging for the primary and secondary gauging stations. Furthermore, these stations are likely to experience hysteresis (response lagging) and interdependency effects, rendering calibration difficult. As a result, it was necessary to generate 'calibration' rating curves for the primary and secondary stations. These curves are based on recorded peak flood levels and corresponding simulated peak flow rates. Flow gauging information for the indicator stations is poor, thus the focus for calibration was on flood peak timing.

The calibration process at the indicator stations was poor in terms of magnitude, however, timing calibration was considered satisfactory, although inline storages were required at some strategic locations. For the secondary gauges, timing calibration could only be achieved by introduction of inline storages just upstream of the gauges. Calibration of these inline storages was iterative and required storage estimation between pre-routed and post-routed station hydrographs. Calibration to the Lismore Rowing Club was considered to be good.

2.3.2 2017 Event – Rainfall Gauging Stations

A total of 30 pluviometry rainfall stations within the vicinity of the catchment upstream of Lismore were operational during the 2017 flood event. The locations of these rainfall stations are shown in Figure 2.2. Cumulative rainfall plots for stations on the Wilson River subcatchment are provided in Figure 2.3 and plots for stations on the Leycester Creek subcatchment are shown in Figure 2.4. Isohyet plotting for the total depths recorded during the 2017 flood event is provided in Figure 2.5.



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Lismore Floodplain Risk Management Study
Historical Event Calibration

Figure 2.2 - Rainfall and River Gauging Stations

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Figure 2.3: 2017 Cumulative Rainfall – Wilsons River Gauges

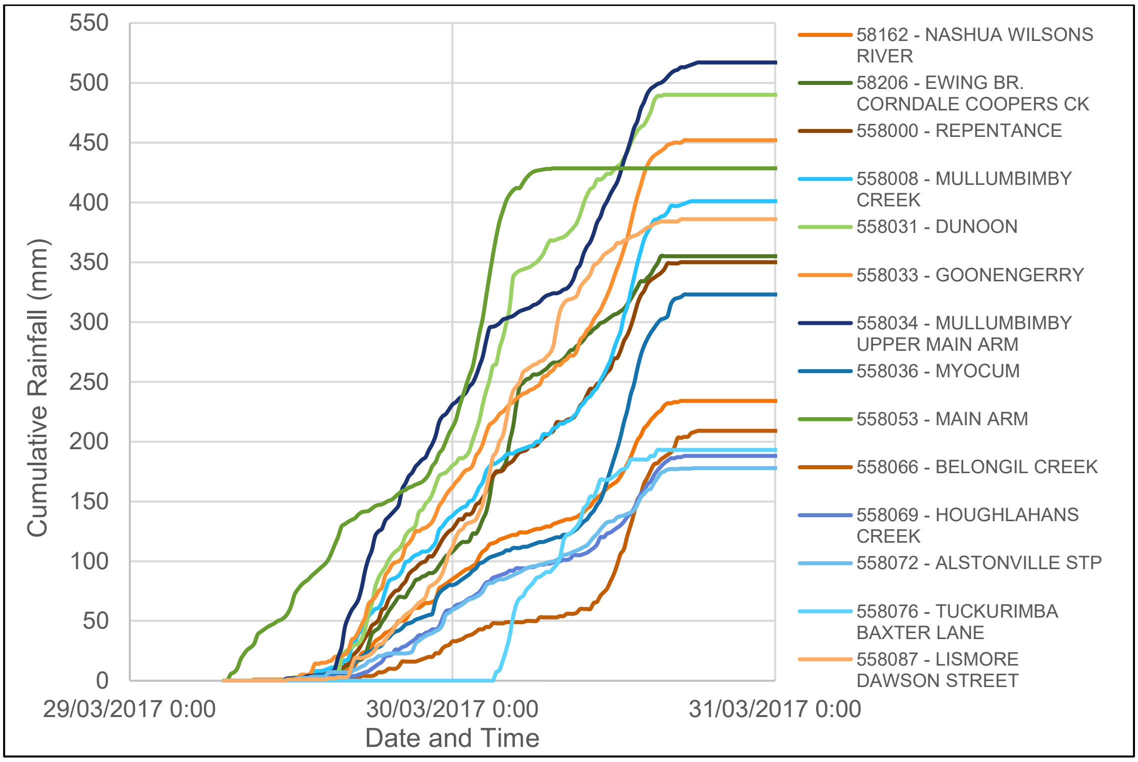
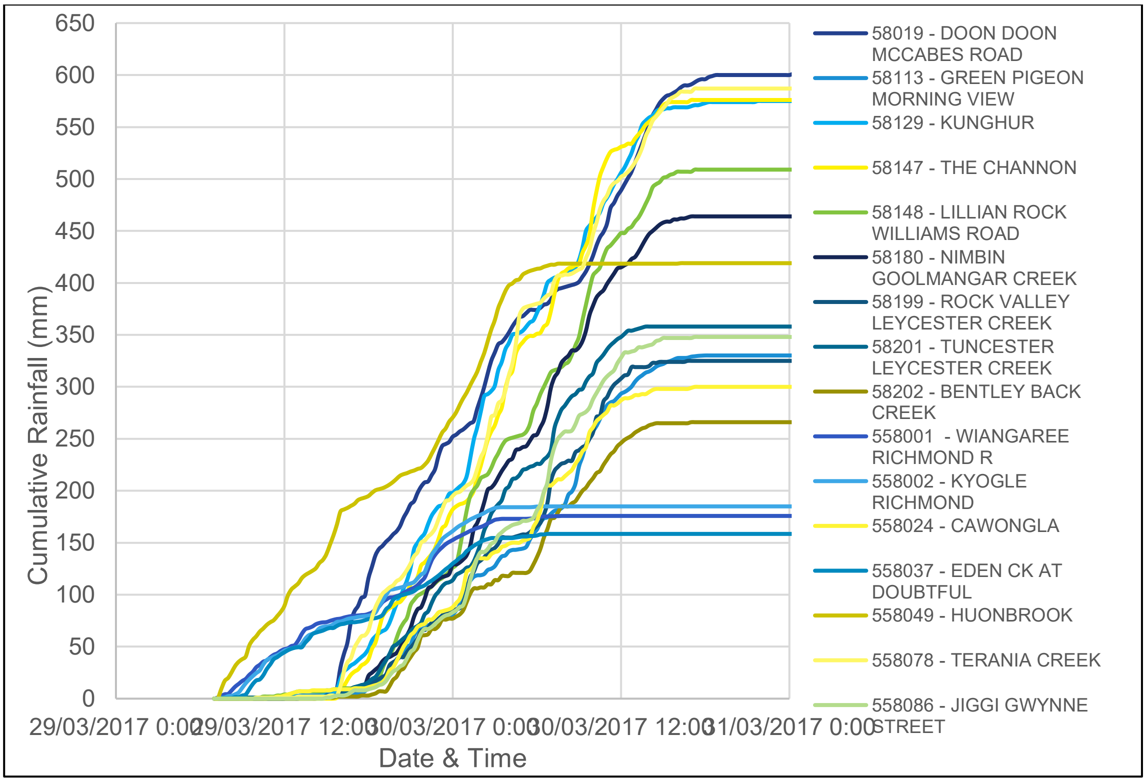
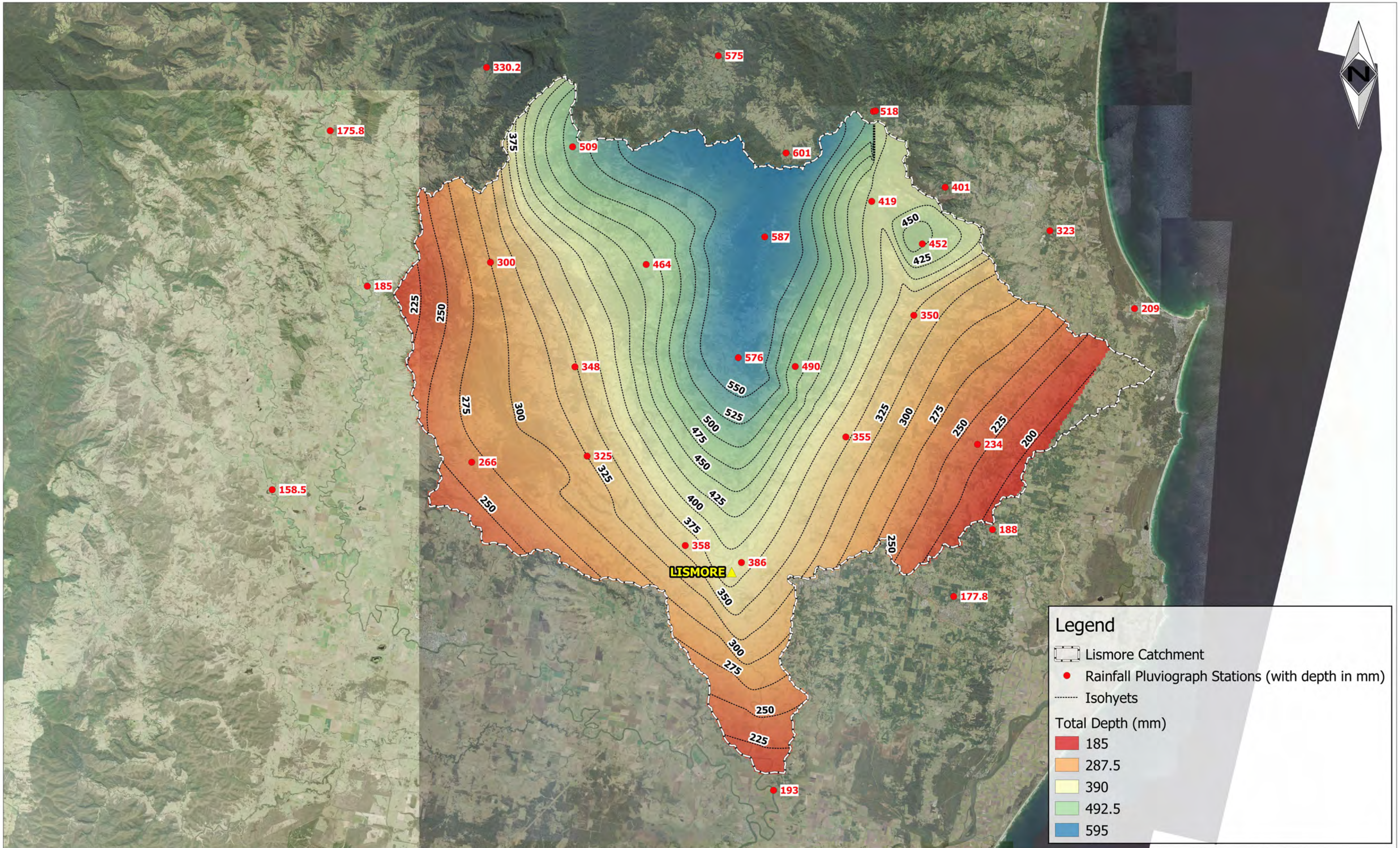


Figure 2.4: 2017 Cumulative Rainfall – Leycester Creek Gauges





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Lismore Floodplain Risk Management Study
Historical Event Calibration

Figure 2.5 - 2017 Historical Event Rainfall Isohyets

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Date: 22 /9 /2020

2.3.3 2013 Event – Rainfall Gauging Stations

A total of 20 pluviometry rainfall stations within the vicinity of the catchment upstream of Lismore were operational during the 2013 flood event. The locations of these rainfall stations are shown in Figure 2.2. Cumulative rainfall plots for stations on the Wilson River subcatchment are provided in Figure 2.6 and plots for stations on the Leycester Creek subcatchment are shown in Figure 2.7. Isohyet plotting for the total depths recorded during the 2013 flood event is provided in Figure 2.8.

Figure 2.6: 2013 Cumulative Rainfall – Wilsons River Gauges

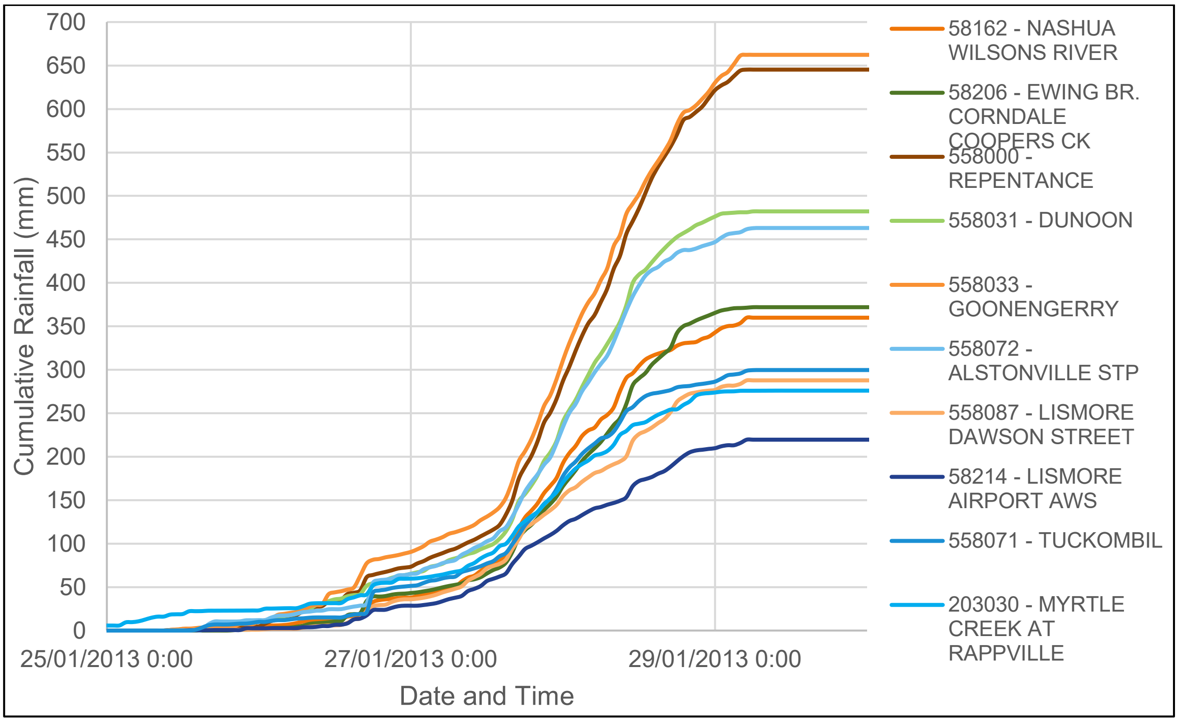
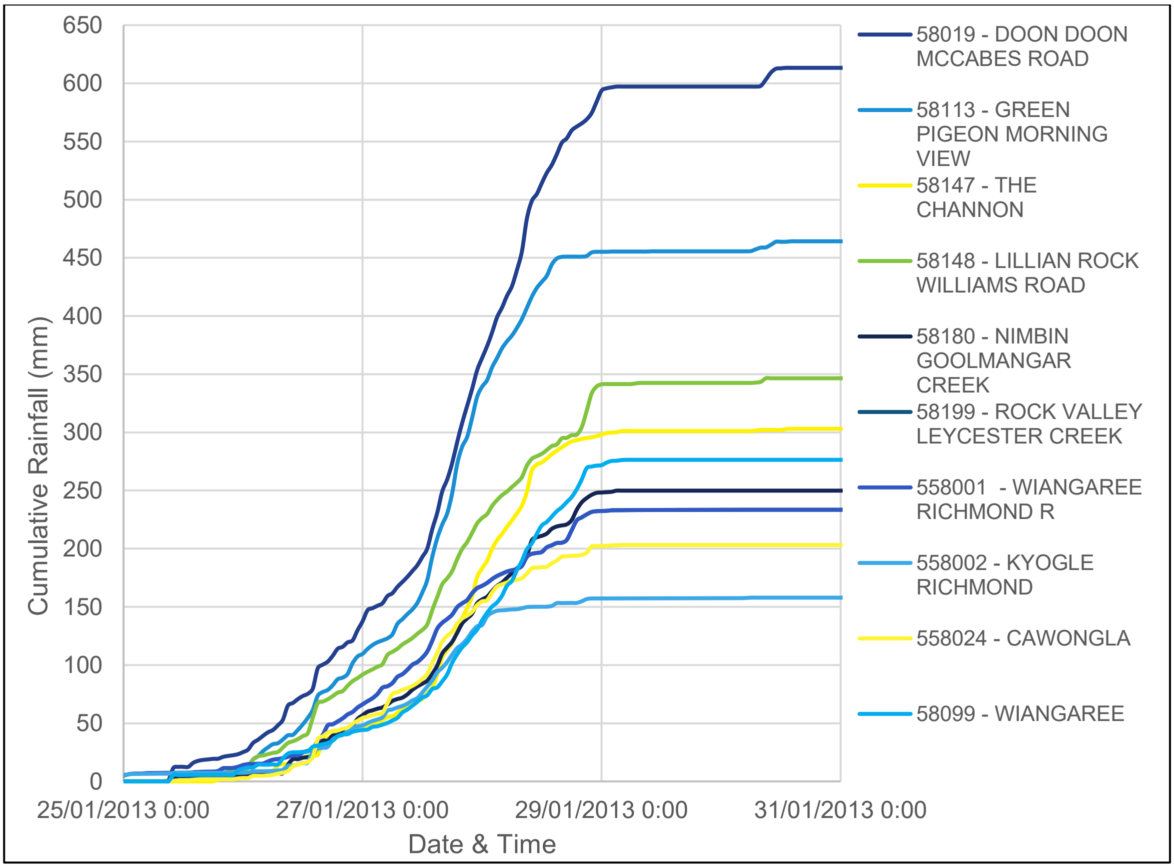
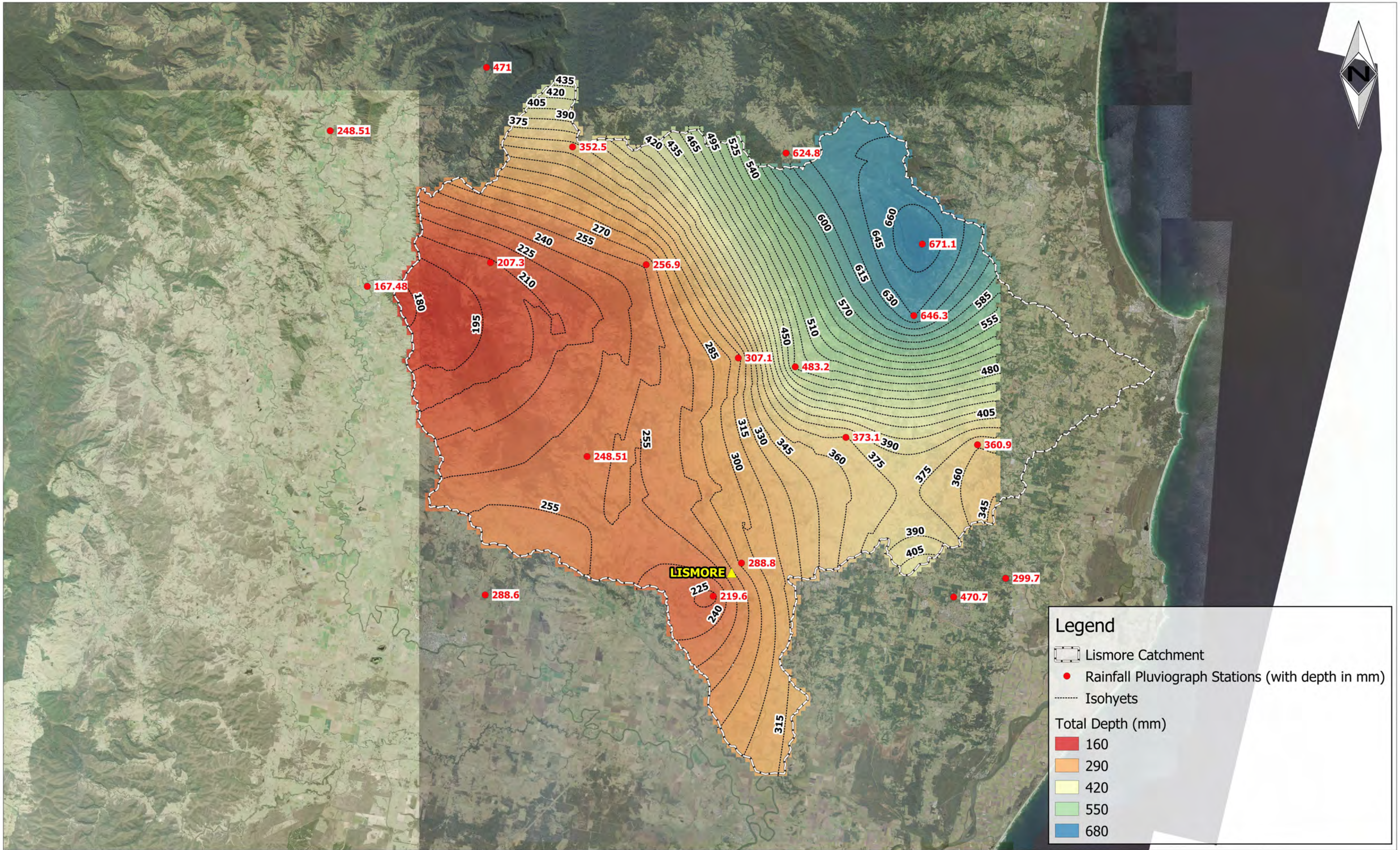


Figure 2.7: 2013 Cumulative Rainfall – Leycester Creek Gauges





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Scale in metres (1:250000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Lismore Floodplain Risk Management Study
Historical Event Calibration

Figure 2.8 - 2013 Historical Event Rainfall Isohyets

Job Number: M76000_004
Revision: 0
Drawn: KM
Date: 22 /9 /2020

2.3.4 2012 Event – Rainfall Gauging Stations

A total of 22 pluviometry rainfall stations within the vicinity of the catchment upstream of Lismore were operational during the 2012 flood event. The locations of these rainfall stations are shown in Figure 2.2. Cumulative rainfall plots for stations on the Wilson River subcatchment are provided in Figure 2.9 and plots for stations on the Leycester Creek subcatchment are shown in Figure 2.10. Isohyet plotting for the total depths recorded during the 2012 flood event is provided in Figure 2.11.

Figure 2.9: 2012 Cumulative Rainfall – Wilsons River Gauges

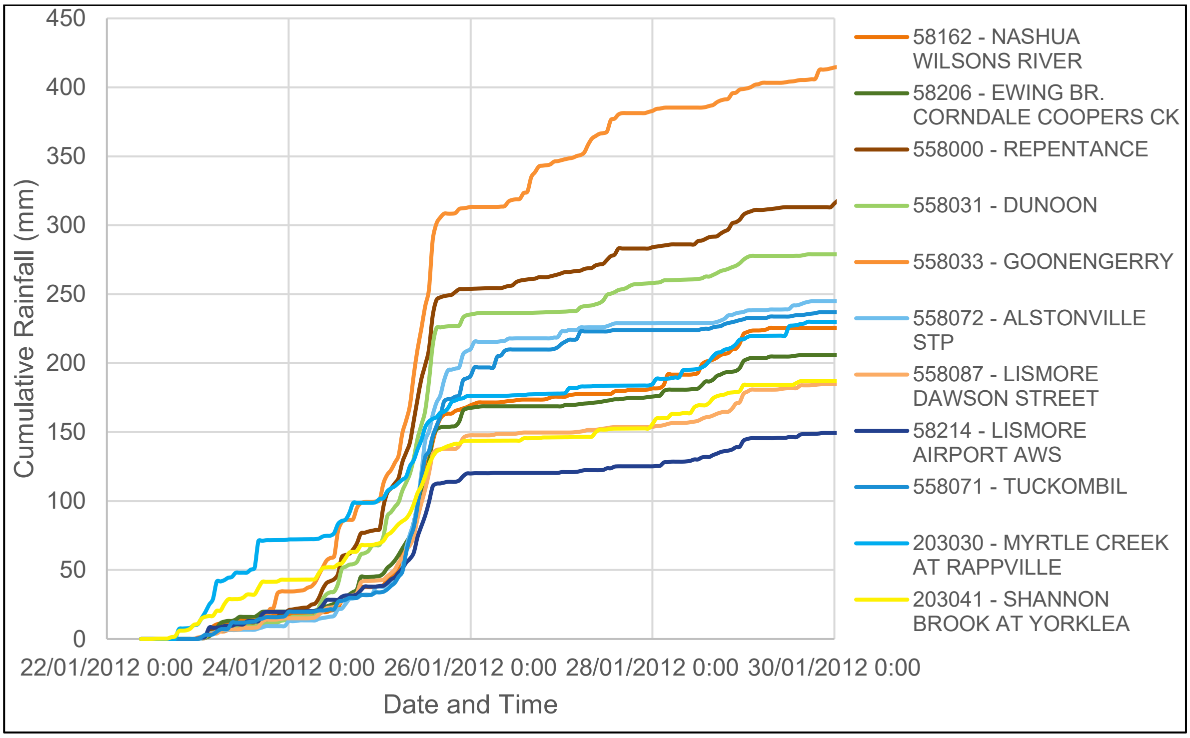
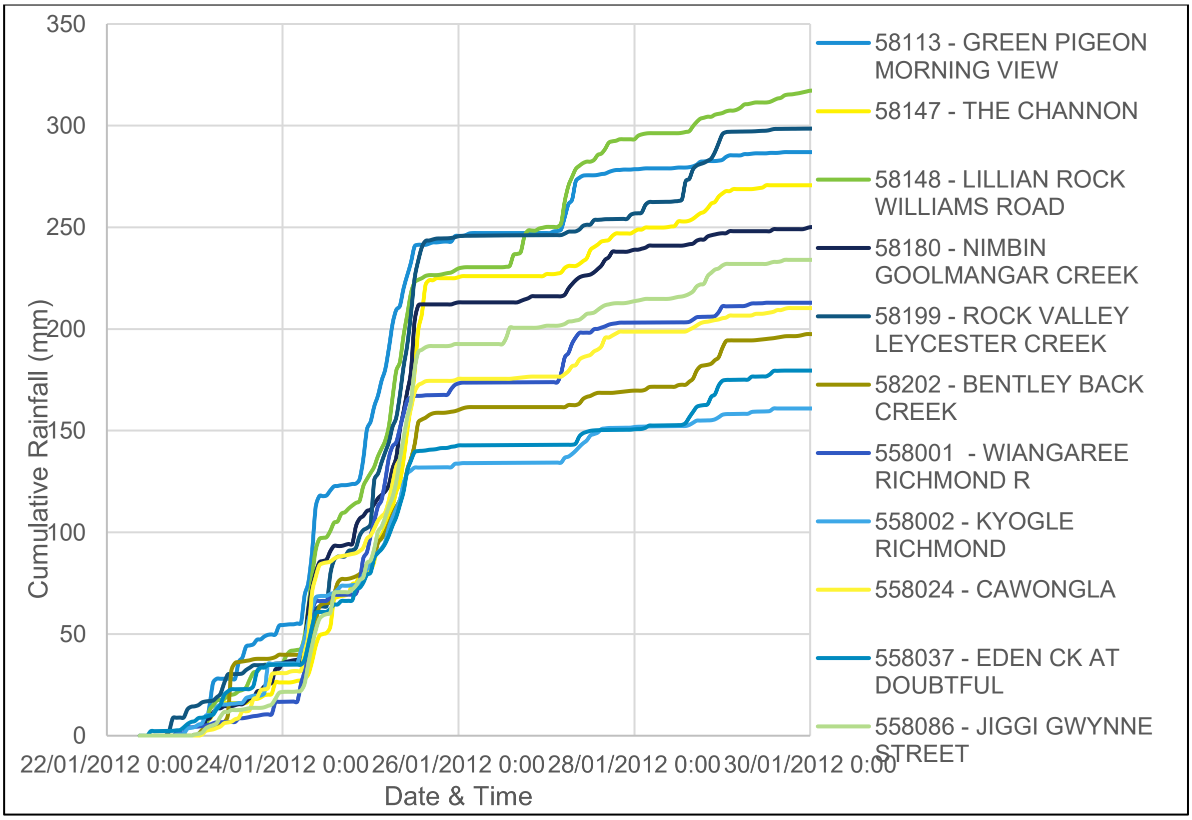
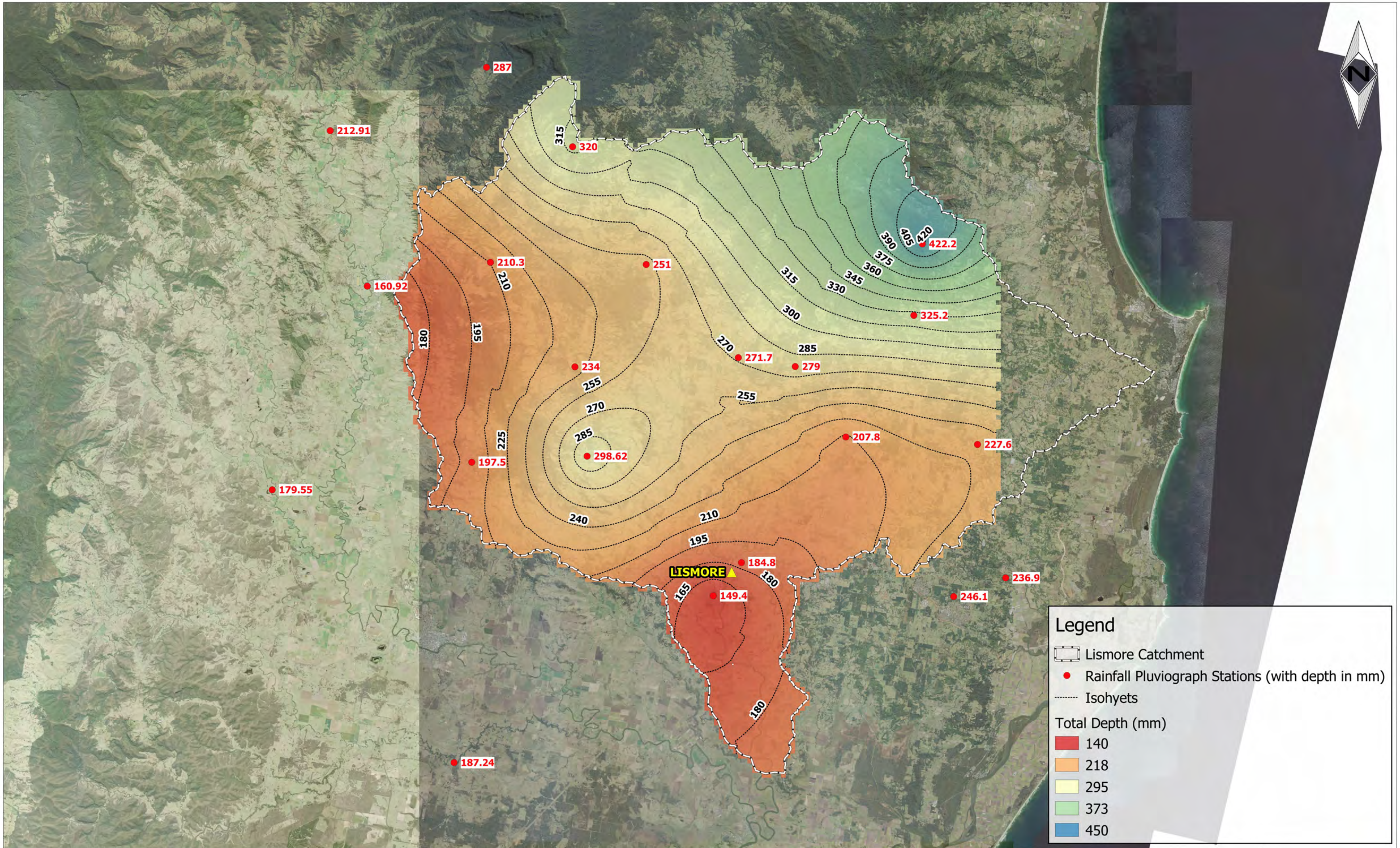


Figure 2.10: 2012 Cumulative Rainfall – Leycester Creek Gauges





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Historical Event Calibration

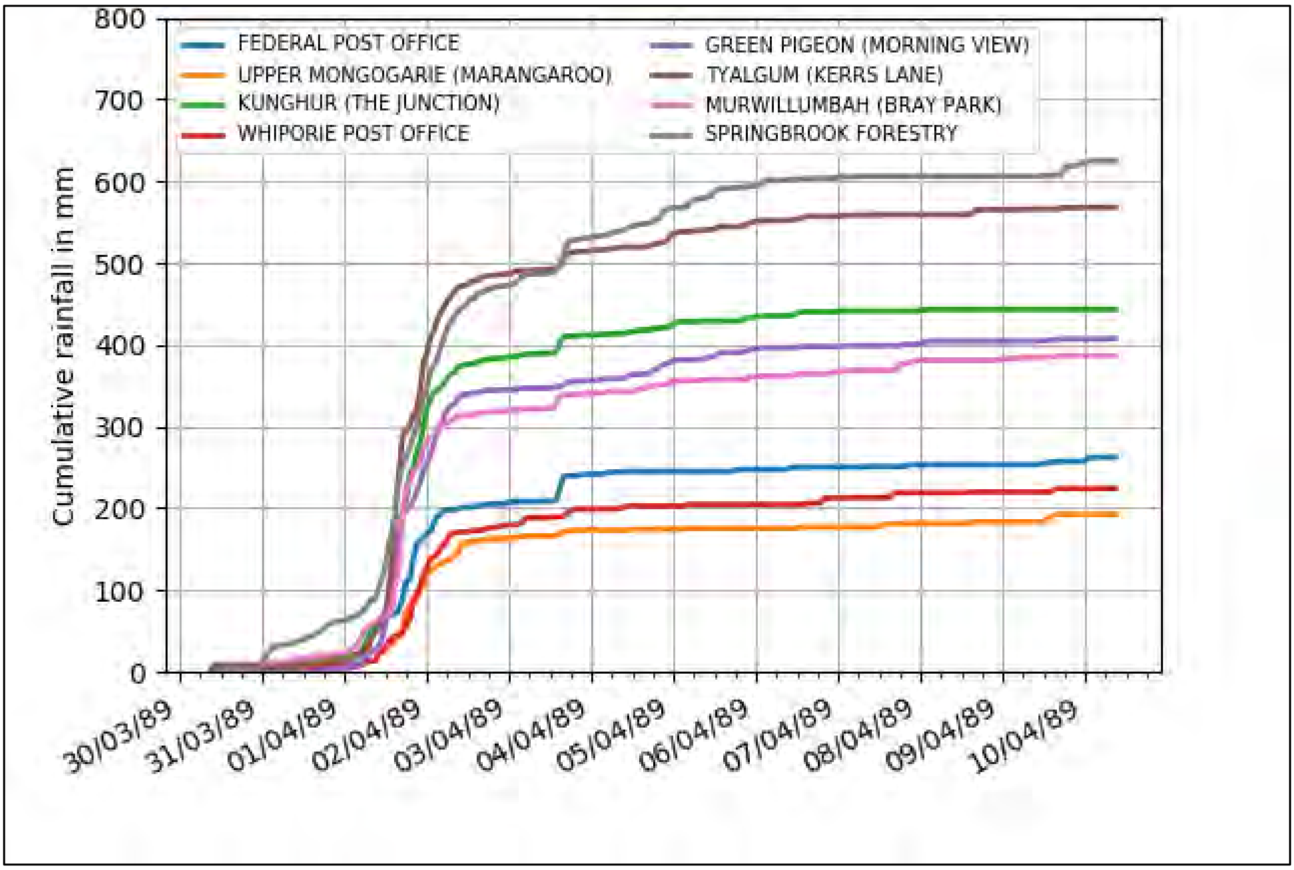
Figure 2.11 - 2012 Historical Event Rainfall Isohyets

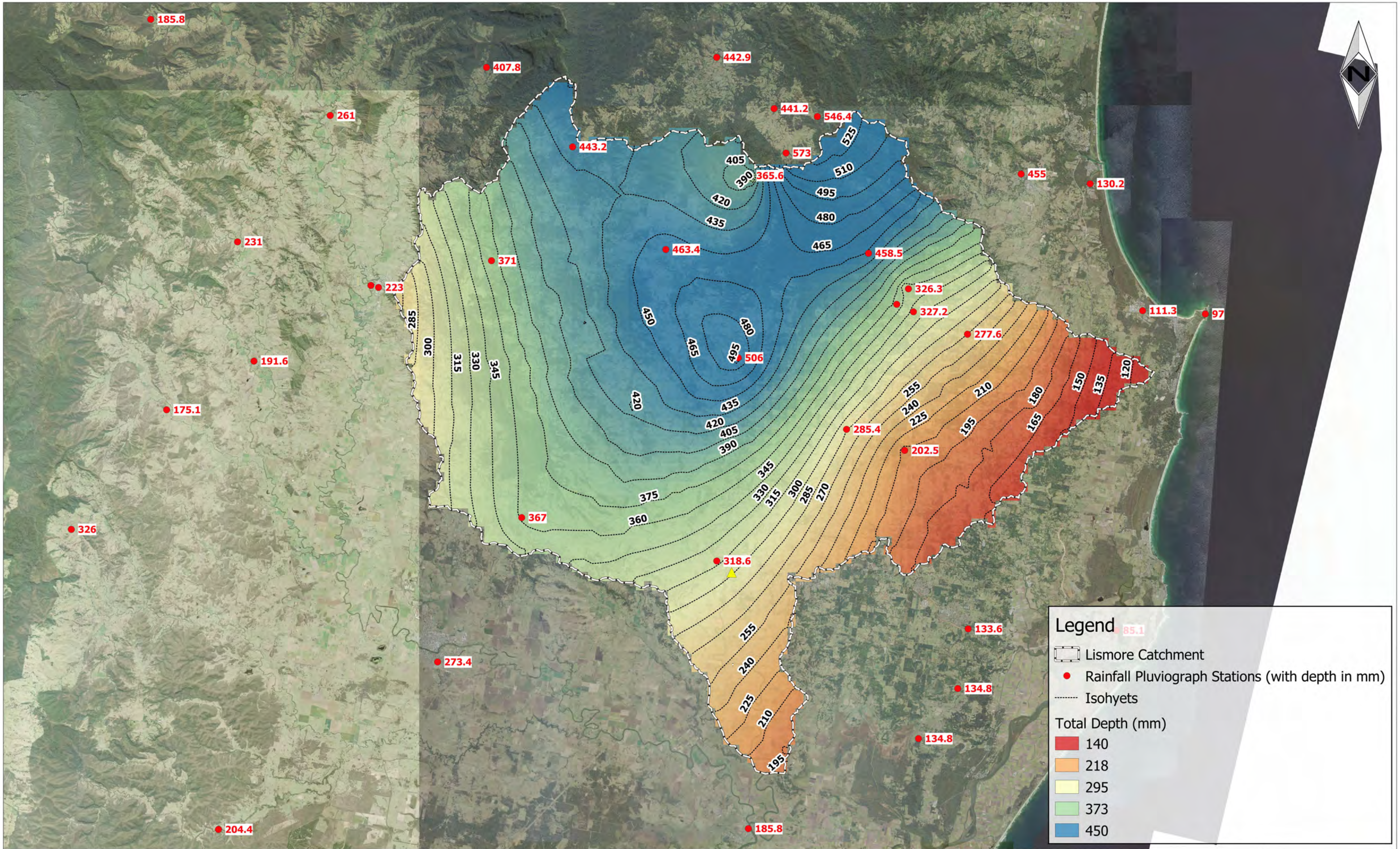
Job Number: M76000_004
Revision: 0
Drawn: SW
Date: 22 /9 /2020

2.3.5 1989 Event

A total of 8 pluviometry rainfall stations within the vicinity of the catchment upstream of Lismore were operational during the 1989 flood event. The locations of these rainfall stations are shown in Figure 2.2. Cumulative rainfall plots for all available pluviograph stations are shown on Figure 2.12. Isohyet plotting for the total depths recorded during the 1989 flood event (inclusive of daily totals) are provided in Figure 2.13.

Figure 2.12: 1989 Cumulative Rainfall





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Lismore Floodplain Risk Management Study
Historical Event Calibration

Figure 2.13 - 1989 Historical Event Rainfall Isohyets

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Date: 22 /9 /2020

2.3.6 River Gauging Stations

A total of 16 steamflow gauging stations were operational in the Lismore catchment during the historical flood events. For these gauges, various sources of rating curve information are available. Engeny has previously undertaken a review of the available rating curve information for these gauges as summarised in the memorandum titled *Lismore Flood Risk Management Study - Gauge Rating Curve Review* (Engeny, 2019), which also included the TUFLOW modelling review of ratings undertaken by BMT WBM in 2018, as outlined in the letter titled *Review of Rating Curves in the Wilsons River Catchment* (BMT WBM, 2018). A summary of the available gauges and rating curve information is provided in Table 2.1.

For the hydrologic modelling, rating curves were adopted as follows:

- Primary – hydrologic calibration curves.
- Secondary – hydrologic calibration curves.
- Indicator – utilised for timing only, rating curve largely irrelevant, selection summarised in Table 2.1.

Table 2.1: River Gauging Stations

Gauge Name and ID	Owner	Maximum & Minimum Gauged Level	Rating Curves Available	Rating Curve Adopted in URBS
Bentley – Back Creek (BoM: 058078 / MHL: 203009)	Lismore City Council	Unknown	Curve developed by BMT utilising TUFLOW BoM Rating Curve	BoM Rating Curve
Binna Burra – Byron Creek (NoW: 203012)	Water NSW	34.40 m AHD 37.52 m AHD	Water NSW Rating Curve Curve developed by BMT utilising TUFLOW	Not Used
The Channon – Terania Creek (BoM: 058147 / MHL: 203012)	Lismore City Council	Unknown	Curve developed by BMT utilising TUFLOW BoM Rating Curve	Not Used
Eltham – Wilson River (BoM: 058078 / NoW: 203012)	Water NSW	17.24 m AHD 18.74 m AHD	Water NSW Rating Curve Curve developed by BMT utilising TUFLOW BoM Rating Curve	Water NSW Rating Curve
Ewing Bridge – Coopers Creek (BoM: 058206 / NoW: 203024)	Water NSW	18.92 m AHD 20.60 m AHD	Water NSW Rating Curve Curve developed by BMT utilising TUFLOW	Not Used
Fairmeadow – Cooper Creek (NoW: 203060)	Water NSW	15.79 m AHD 16.75 m AHD	Water NSW Rating Curve Curve developed by BMT utilising TUFLOW	Water NSW Rating Curve

Gauge Name and ID	Owner	Maximum & Minimum Gauged Level	Rating Curves Available	Rating Curve Adopted in URBS
Goolmangar – Goolmangar Creek (BoM: 0558075)	Lismore City Council	Unknown	Curve developed by BMT utilising TUFLOW	Curve developed by BMT utilising TUFLOW
McNamara Weir – Goolmangar Creek (NoW: 203061)	Water NSW	16.50 m AHD 19.04 m AHD	Water NSW Rating Curve Curve developed by BMT utilising TUFLOW	Not Used
Nashua – Wilsons River (BoM: 058162 / NoW: 203902)	Lismore City Council	Unknown	Curve developed by BMT utilising TUFLOW BoM Rating Curve	Not Used
Nimbin – Goolmangar Creek (BoM: 058180 / NoW: 203901)	Lismore City Council	Unknown	Curve developed by BMT utilising TUFLOW BoM Rating Curve	Not Used
Repentance – Coopers Creek (BoM: 558000 / NoW: 203002)	Water NSW	45.99 m AHD 50.69 m AHD	Water NSW Rating Curve Curve developed by BMT utilising TUFLOW BoM Rating Curve	Not Used
Rock Valley – Leycester Creek (BoM: 058199 / NoW: 203010)	Water NSW	18.84 m AHD 25.07 m AHD	Water NSW Rating Curve Curve developed by BMT utilising TUFLOW BoM Rating Curve	Water NSW Rating curve combined with curve developed by BMT utilising TUFLOW
Tuncester – Leycester Creek (BoM 58201 / MHL: 203443)	MHL	Unknown	BoM rating curve	Hydrologic Calibration Curve
Woodlawn College – Wilsons River (BoM: 558012 / MHL: 203402)	MHL	Unknown	BoM rating curve	Hydrologic Calibration Curve
Wilsons River at Lismore (BoM: 58176 / LCC:203904)	Lismore City Council	Unknown	BoM rating curve	Hydrologic Calibration Curve

Gauge Name and ID	Owner	Maximum & Minimum Gauged Level	Rating Curves Available	Rating Curve Adopted in URBS
East Gundurimba – Wilsons River (MHL: 203427)	MHL	Unknown	-	N/A

2.4 HYDROLOGIC CALIBRATION RESULTS

2.4.1 Overview

The 2017, 2013, 2012 and 1989 historical flood events were simulated using the URBS model as follows:

- The rainfall depth assigned to each subcatchment was calculated using the 'subrain' utility within the URBS software package. The 'subrain' utility calculates an inverse distance weighted average rainfall based on the closest four (4) rainfall stations.
- The temporal pattern of rainfall was determined for each subcatchment by assigning the temporal pattern from the nearest pluviometry station (distance from pluviometry station to subcatchment centroid). The assignment of temporal pattern was undertaken using the 'subrain' utility.

2.4.2 Calibration Parameters and Results

The URBS model was calibrated by varying model parameters to achieve modelled flood hydrographs that are a close approximation to the recorded flood hydrographs at the stream gauging stations listed in Table 2.1.

The following URBS model parameters were varied for the calibration:

- Initial rainfall loss, IL.
- Continuing rainfall loss, CL.
- Channel lag parameter, α.
- Catchment lag parameter, β.
- Catchment non-linearity parameter, m.

In addition to these global parameters, localised changes to stream routing lengths including insertion of on-line storages (as described in *Section 3.1*) were made to achieve a better calibration to observed stream gauging values, particularly for the primary and secondary gauging stations.

The URBS model was simulated for a total of 37 historical flood events to ensure robustness of the hydrologic model to match historical river gauging records. Of these 37, three key calibration events were selected for joint hydrologic and hydraulic calibration. These historical events were:

- March 2017.
- January 2013.
- January 2012.
- April 1989.

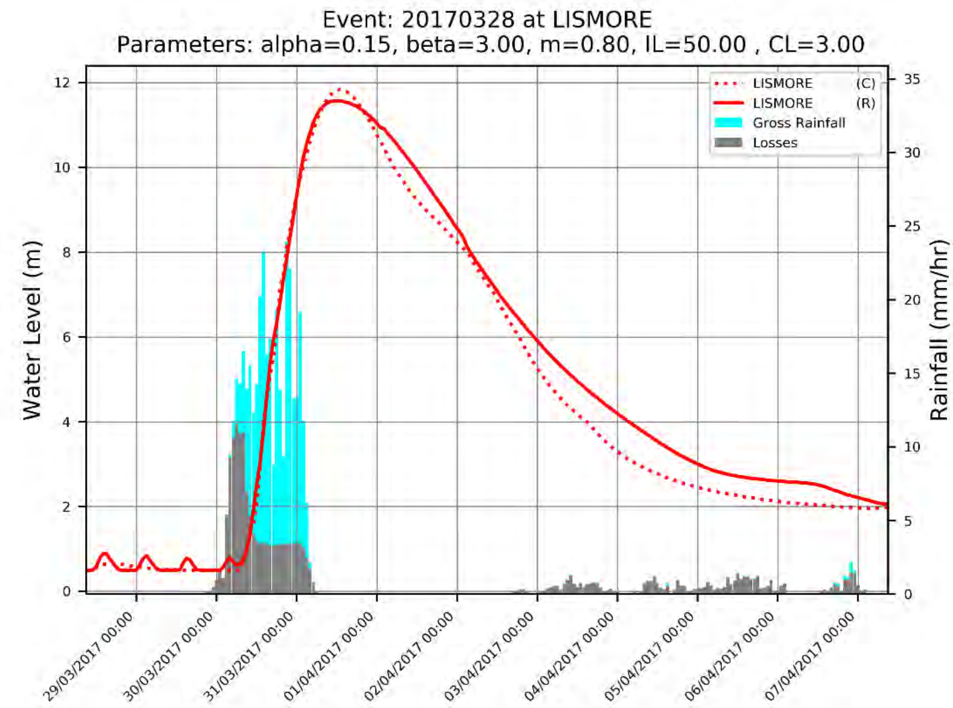
The model parameters selected for each of the historic calibration events are listed in Table 2.2.

Table 2.2: URBS Model Calibration Parameters

Parameter	2017 Event	2013 Event	2012 Event	1989 Event
Initial Loss (mm)	50	90	30	50
Continuing Loss (mm)	3	3.5	4.25	0.5
α	0.15	0.25	0.15	0.15
β	3	3	3	3
m	0.8	0.8	0.8	0.8

Level vs time outputs from URBS at the Lismore Rowing Club gauge for the four key historical events are provided in Figure 2.14, Figure 2.15, Figure 2.16 and Figure 2.17. All four events show a reasonably good replication of the recorded peak level and shape, except for 2012 which indicates a higher modelled flood peak in order to achieve a closer hydraulic calibration result.

Figure 2.14: 2017 Event URBS Level and Flow Reporting



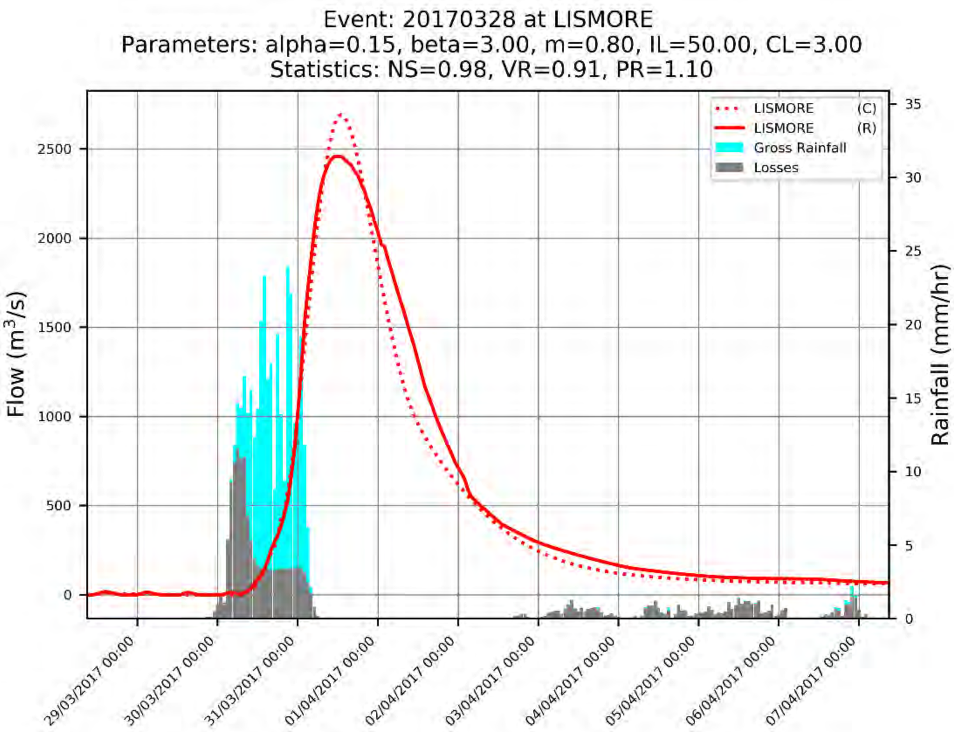
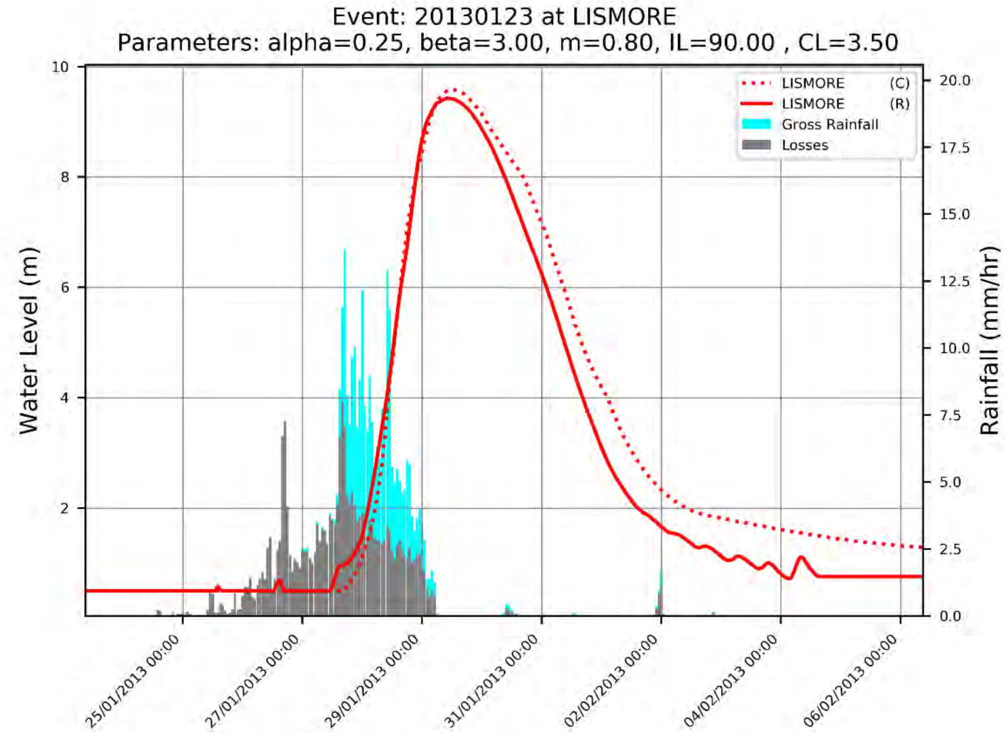


Figure 2.15: 2013 Event URBS Level and Flow Reporting



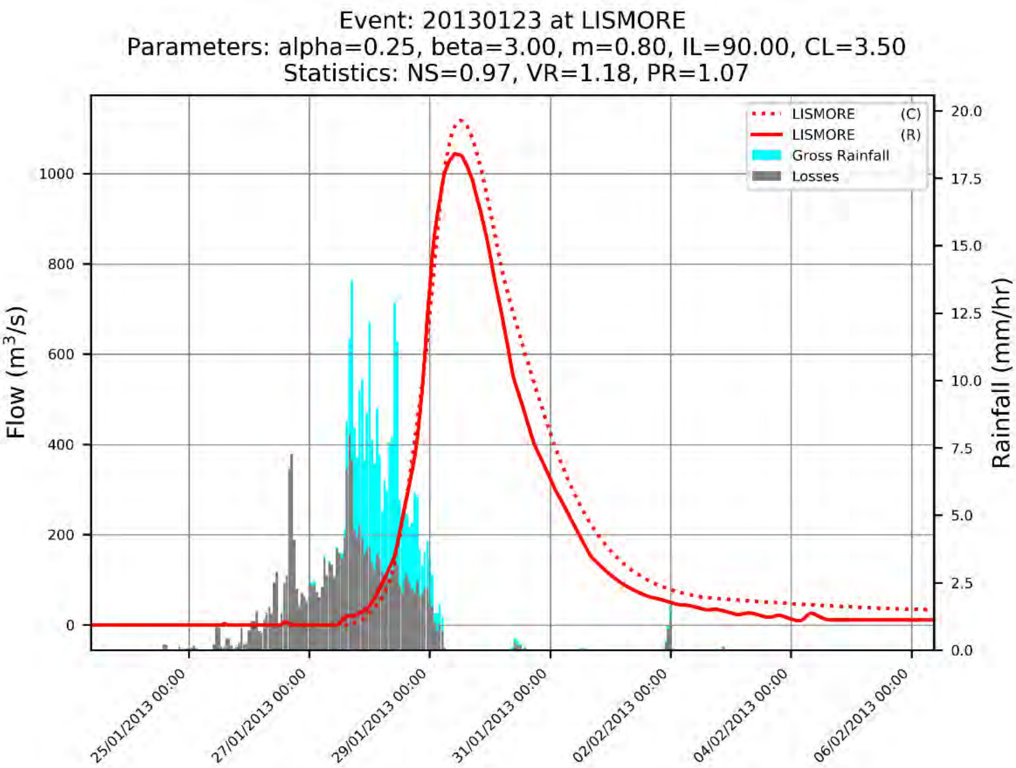
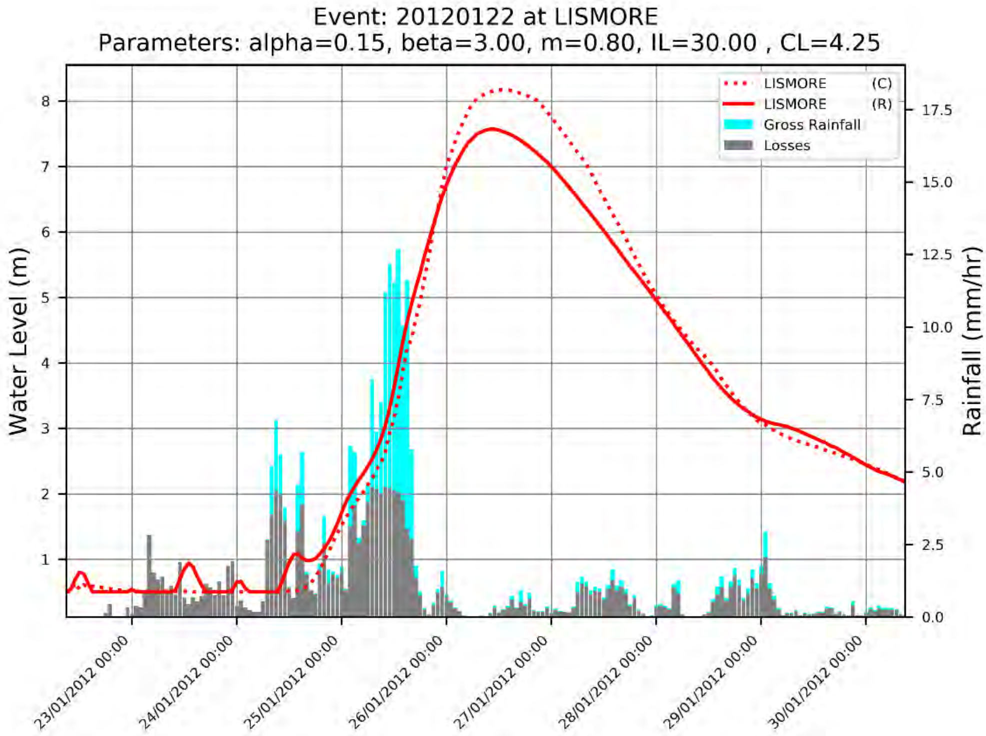


Figure 2.16: 2012 Event URBS Level and Flow Reporting



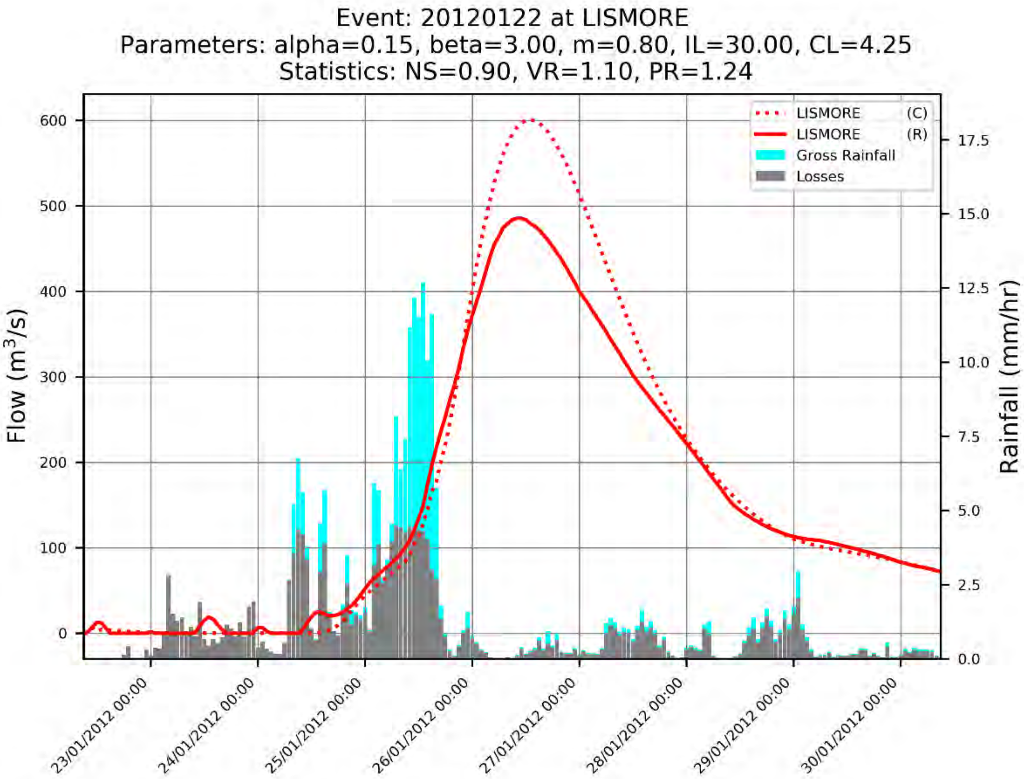
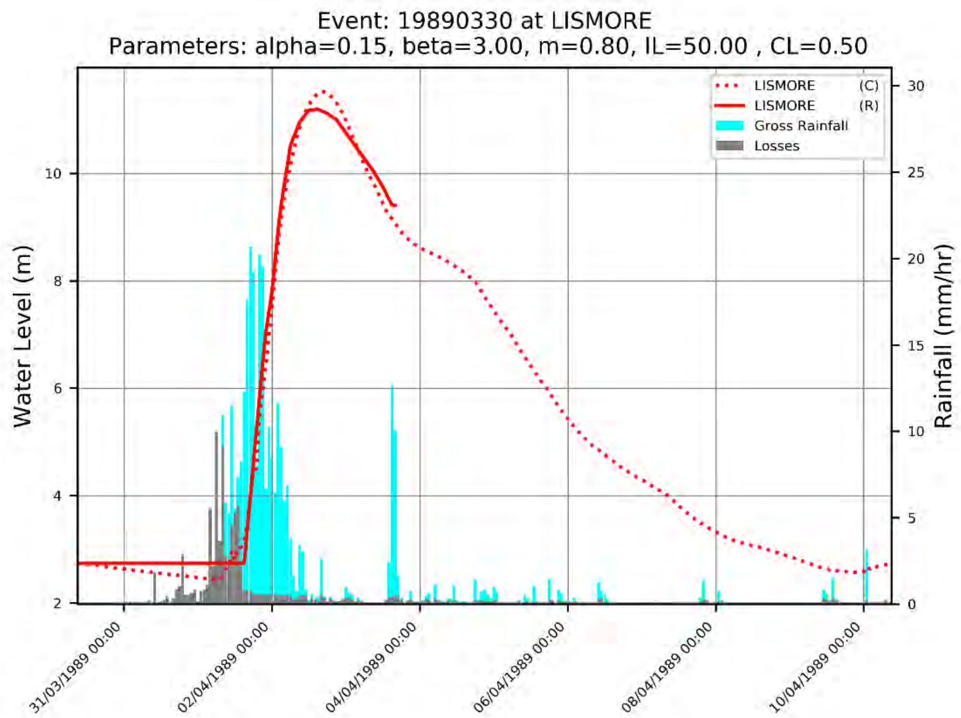
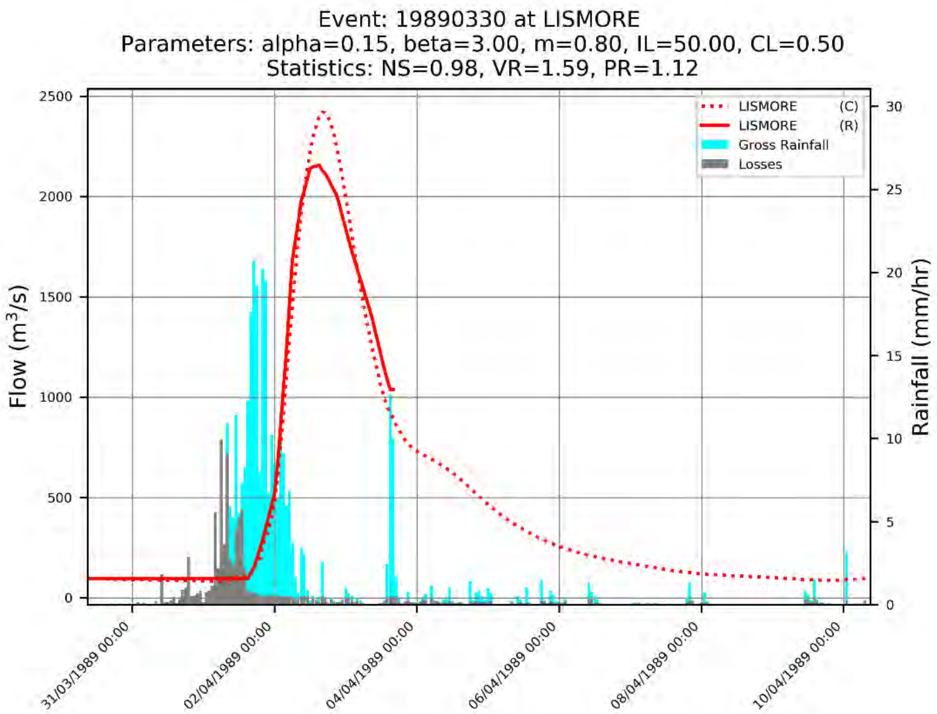


Figure 2.17: 1989 Event URBS Level and Flow Reporting





2.4.3 Hydrologic Calibration Uncertainties

There were no rating curves available for the primary or secondary gauges, rather model 'calibration' curves had to be derived. While a good relationship (monotonic) could be found for Lismore Rowing Club, establishing calibration curves for Tuncester and Woodlawn College was difficult, likely due to hysteresis effects and their inter-dependence including dependence on the Lismore Rowing Club gauge. For this reason, a hydrologic model is not suitable for the estimation of very rare and extreme floods. This estimation should properly be done by a hydraulic model whose hydrologic inputs are sufficiently upstream so that the noted dependencies no longer dominate.

Additionally, the Wilsons River system is complex where the Wilsons River arm upstream of Lismore has a wider floodplain with more storage and a relatively flat hydraulic grade line with less momentum and volume in comparison to Leycester Creek in a similar magnitude event. Leycester Creek has relatively incised channel banks which are approximately 2 m higher than the Wilsons River arm, has a steeper hydraulic grade line and flows with greater momentum than Wilsons arm. As a result of these characteristics, it is not uncommon for there to be backwater flow up the Wilsons River arm from the confluence with Leycester Creek. This is reflected in the TUFLOW model results and anecdotally. The different nature of flood behaviour in the two waterway systems and the periodic flow in an upstream direction for the Wilsons River arm make it difficult to calibrate a hydrologic model.

An iterative approach using both hydrologic and hydraulic models was used until there was reasonable agreement (similitude) between the two models at the gauging station. It is noted however that different flood magnitudes will result in different flood storage behaviours in the complex Lismore floodplain, which cannot be accurately represented within a hydrologic model. Instead, on-line storages were used, whose parametrization includes a high degree of uncertainty.

2.5 HYDROLOGIC PARAMETERISATION FOR DESIGN EVENTS

Regarding adoption of parameters in the hydrologic model for the simulation of design events, losses will generally be adopted in accordance with ARR 2019 and *Review of ARR Design Inputs for NSW* (OEH, 2019).

However, as rainfall loss data from 37 modelled events was available from the hydrologic calibration, they were also used to guide the assignment of losses to design event simulation. The median initial loss for these events was 60 mm and the median continuing loss was 2.8 mm/hr. Further adjustment of these losses (provided the resulting adjustments are within reasonable ranges and they decrease with decreasing annual exceedance probability (AEP)) was considered to ensure consistency with the flood frequency analysis.

The routing parameters adopted for the historical event calibration are typical and well within the range of recommended parameters and were considered suitable for adoption for design events. These are summarised in Table 2.3.

Table 2.3: URBS Model Parameters for Design Events

Parameter	Value
α	0.15
β	3
m	0.8

3 Hydraulic Model Development

3.1 OVERVIEW

The 2017, 2013, 2012 and 1989 historical flood events were assessed using a TUFLOW 2D hydraulic model developed specifically for this Study. This represents the most detailed hydraulic model developed to date for the Lismore floodplain.

The following sections outline the hydraulic model development.

3.2 MODEL PARAMETRISATION

3.2.1 Model Topography

The Lismore TUFLOW hydraulic model adopts a 10 m cell size. The hydraulic model is underpinned by a Digital Elevation Models (DEM), which was derived from topographic data supplied by RCC as summarised below:

- The base topography is the 2010 1m LiDAR capture.
- A series of detailed surveys were undertaken in late 2018. The following survey files were "stamped" over the LiDAR in the Lismore hydraulic model:
  - Survey of flood channel works completed in the vicinity of the Lismore Bunning's warehouse, in 3D Digital Elevation Model (DEM) format.
  - Survey of ground levels to the west of the South Lismore levee, referred to as the "flood quarry", in 3D DEM format.
  - Bathymetric survey of the Wilsons River and Leycester Creek beds, from Tuncester and Woodlawn through to 20 km south of East Gundurimba, in 3D DEM format.
  - Survey of the South Lismore levees incorporated into the model as 3D DEM format and also as breaklines.

Key levels have been incorporated into the model as breaklines from survey undertaken in late 2018. These are listed below:

- Survey of road centrelines.
- Survey of the central levee crest.

3.2.2 Structures

Structure information utilised in the Lismore TUFLOW hydraulic model is summarised below:

- Eight unidirectional 2 m diameter RCP culverts were included to allow for drainage from the CBD, as included in the BMT 2017 post-event analysis which was outlined in *Post Event Flood Behaviour Analysis and Review of Flood Intelligence – Lismore Final Report* (BMT WBM, 2018a). The model does not include the existing pumping system or overall stormwater drainage network as local flooding was not the focus of this Study and it was assumed that pumping would have little effect on peak flood levels in the CBD once the levee was breached.
- Bridge structures have been represented as 2d layered flow constrictions in the model. Many of these structures were surveyed in late 2018, and modelling parameters updated accordingly.
- Culvert structures surveyed in late 2018 were represented in the model as 1D network elements.

It is noted that the hydraulic model has been developed to analyse river and creek flood behaviour and not local catchment flooding in the CBD area that occurs before levee breaching or if the levee is not breached.

3.2.3 Hydraulic Roughness

Hydraulic roughness values have been selected for specific land use areas, which were delineated across the model extent using aerial imagery and photography. Manning's "n" roughness values utilised in the model are listed in Table 3.1.

Table 3.1: Roughness Values Adopted in the TUFLOW Model

Land Use Type	Manning's n value
Orchard/plantation	0.1
Maintained grass	0.035
Lightly vegetated creek	0.07
Pasture	0.05
Sparse vegetation	0.09
Sparse urban block	0.2
Dams, open water	0.07
Cultivated field	0.06
Creek bed	0.02
Urban block	1.0
Roads	0.025
Commercial/Industrial	1.0
Urban open space	0.05
Dense creek vegetation	0.12
Medium density vegetation	0.1
Levee crest	0.015

3.2.4 Boundary Conditions

Initially, the hydraulic model utilised total upstream inflows at the Tuncester river gauge on Leycester Creek and the Woodlawn College river gauge on the Wilsons River. However, through the joint hydrologic and hydraulic calibration process, it was determined that a more accurate match at the key calibration river gauges could be achieved by extending the model further upstream to Fairmeadow and Eltham river gauges on the Wilson River branch and the junction of Terania Creek and Goolmangar Creek and the junction of Back Creek and Leycester Creek, on the Leycester Creek branch. This extended model allows for the storage complexities associated with the Leycester Creek and Wilson River junction to be hydraulically represented, rather than relying on the hydrological representation using on-line storages in the URBS model.

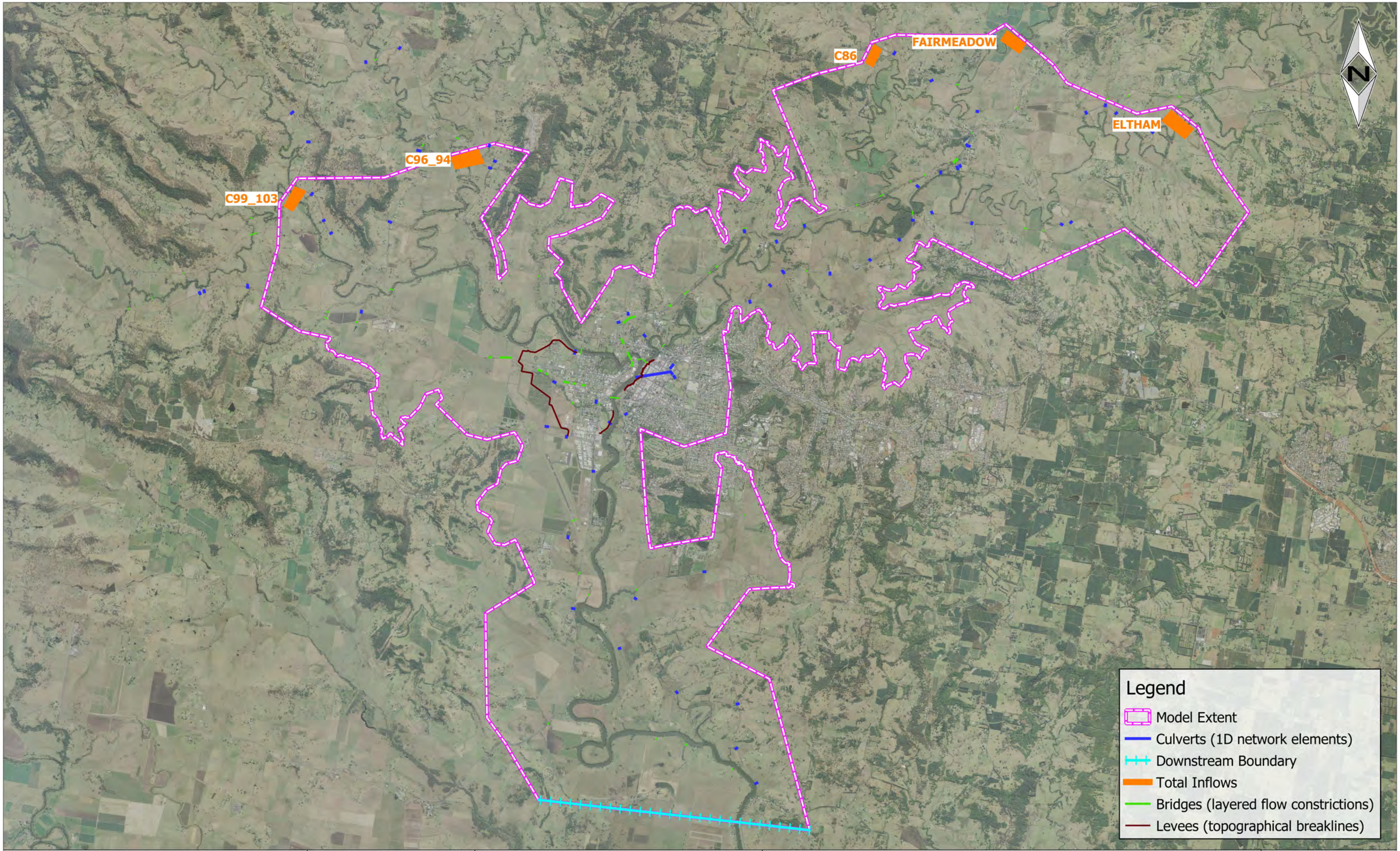
An initial assessment indicated that the extension of the hydraulic model resulted in a closer comparison to the peak recorded level at the Lismore Rowing Club river gauge for the 2017 flood event, as summarised below:

- Original model resulted in a 2017 peak flood level that was 171 mm above the recorded peak flood level.
- Extended model resulted in a 2017 peak flood level that was 30 mm above the recorded peak flood level.

As such, the final adopted boundary conditions for the hydraulic model were:

- Total flows were applied to the TUFLOW model utilising flows developed in URBS at:
  - Fairmeadow gauge location.
  - Eltham gauge location.
  - Junction Numulgi Creek and Coopers Creek (C86 on Figure 3.1).
  - Junction Terania Creek and Goolmangar Creek (C99_103 on Figure 3.1).
  - Junction Back Creek and Leycester Creek (C96_94 on Figure 3.1).
- Local flows were applied to the TUFLOW model utilising subcatchment flows developed in URBS for all catchments contributing to Leycester Creek and Wilsons River downstream of the total flow inflows outlined above. Note that local flow reporting to the CBD, or other minor tributaries, has not been captured in the model.
- A water level versus time series has been utilised as the downstream model boundary. This time series is the water level series from the East Gundurimba stream flow gauge (MHL ID 203427) for the historical calibration flood events and the design flood levels from the Richmond River Flood study model at Tucki Tucki for the design flood events.

These boundary condition locations, along with the model extent and key topographical alterations and structures are shown in Figure 3.1.



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Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
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Grid: Map Grid of Australia, Zone 56

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Figure 3.1 - TUFLOW Model Layout

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Revision: 1
Drawn: KM
Date: 12 /10 /2020

3.3 HYDRAULIC MODEL CALIBRATION

3.3.1 2017 Event Overview

The TUFLOW 2D hydraulic model was simulated using inflows generated from URBS for the 2017 historical flood event. The following sections outline the results from the hydraulic calibration.

Flood Level Comparison

A comparison of the observed and modelled stage-hydrographs at the Woodlawn College, Tuncester and Lismore Rowing Club gauging stations have been provided in Figure 3.2, Figure 3.3 and Figure 3.4. A summary of the peak level and time of peak are summarised in Table 3.2. Both the time series graphs, and absolute peak levels and timing show that the joint calibration process has resulted in a flood model that is capable of closely mimicking the 2017 historical flood event.

Both shape and peak level at the Lismore Rowing Club gauge is well replicated, with some difference observed in the rate of fall for the falling limb. The flood level peak at the Woodlawn gauge occurs later in the hydraulic model than the recorded time series, with some variance in the overall shape. However, the Woodlawn gauge malfunctioned during the 2017 event, with the recorded levels presented below being the reconstructed water level time series produced by MHL from flood debris survey and therefore some variance in modelled and recorded levels are to be expected. The shape of the Tuncester flood level time series is well represented, with the peak occurring slightly later and higher.

Figure 3.2: 2017 Flood Level Reporting at Woodlawn

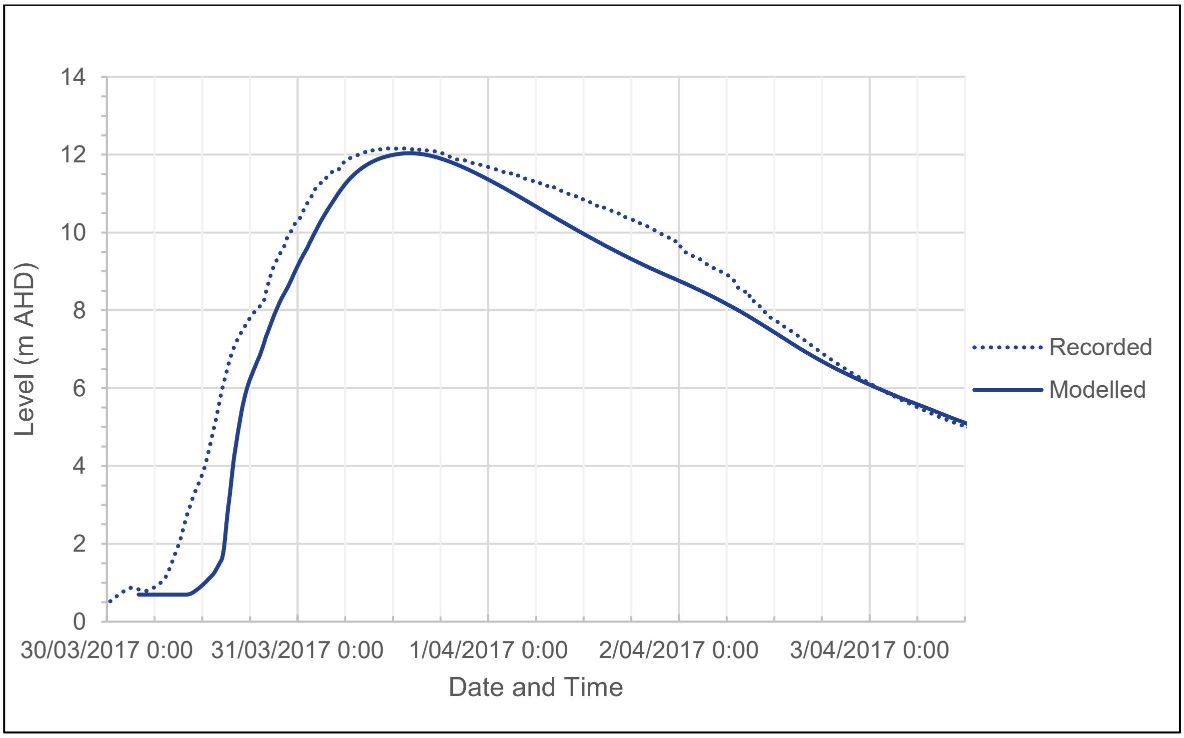


Figure 3.3: 2017 Flood Level Reporting at Tuncester

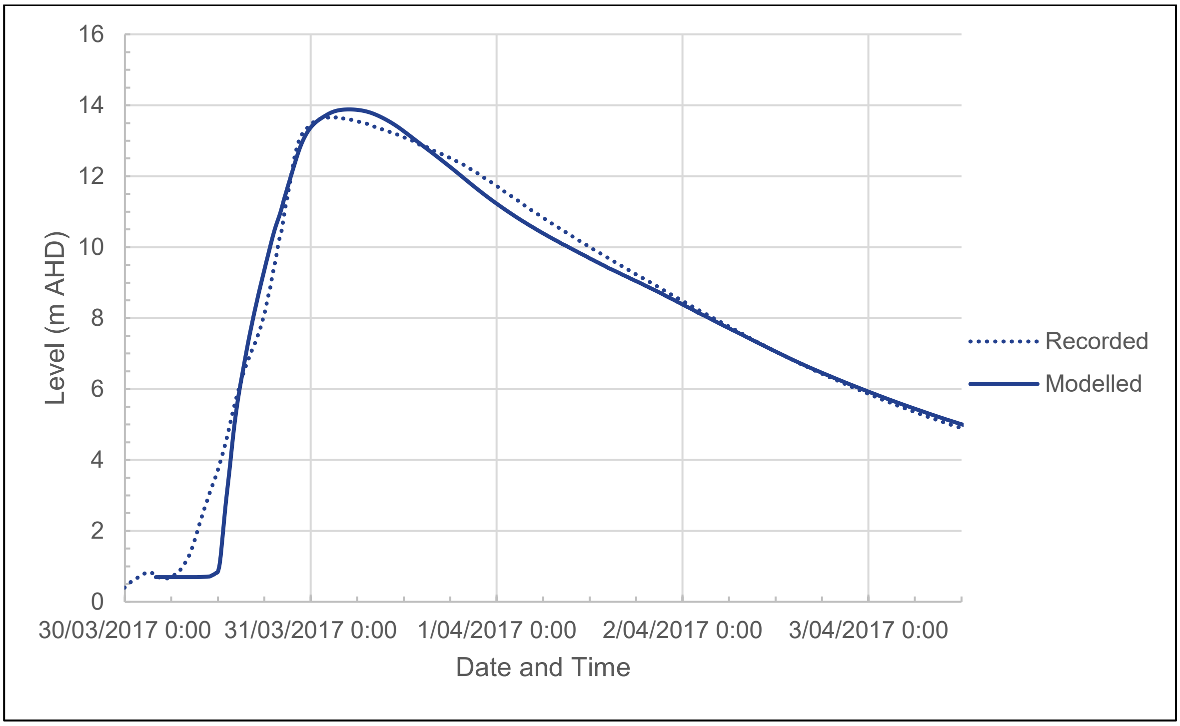


Figure 3.4: 2017 Flood Level Reporting at Lismore Rowing Club

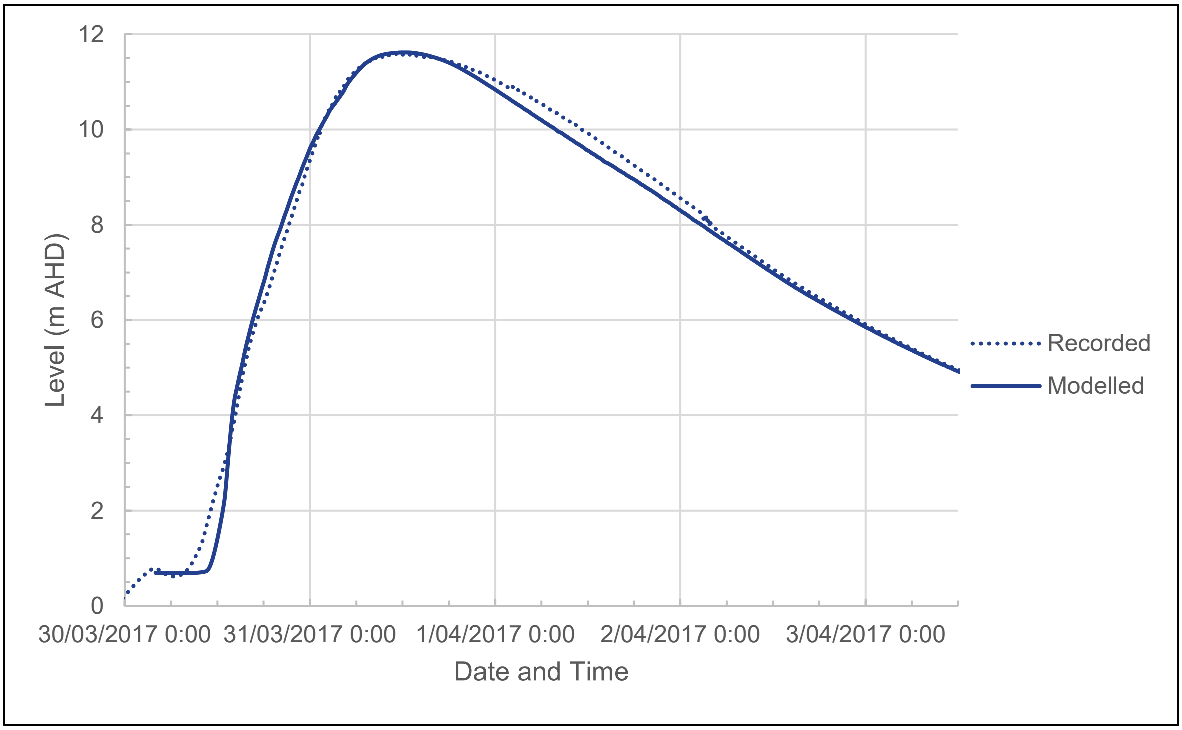


Table 3.2: TUFLOW Calibration Summary – 2017 Event

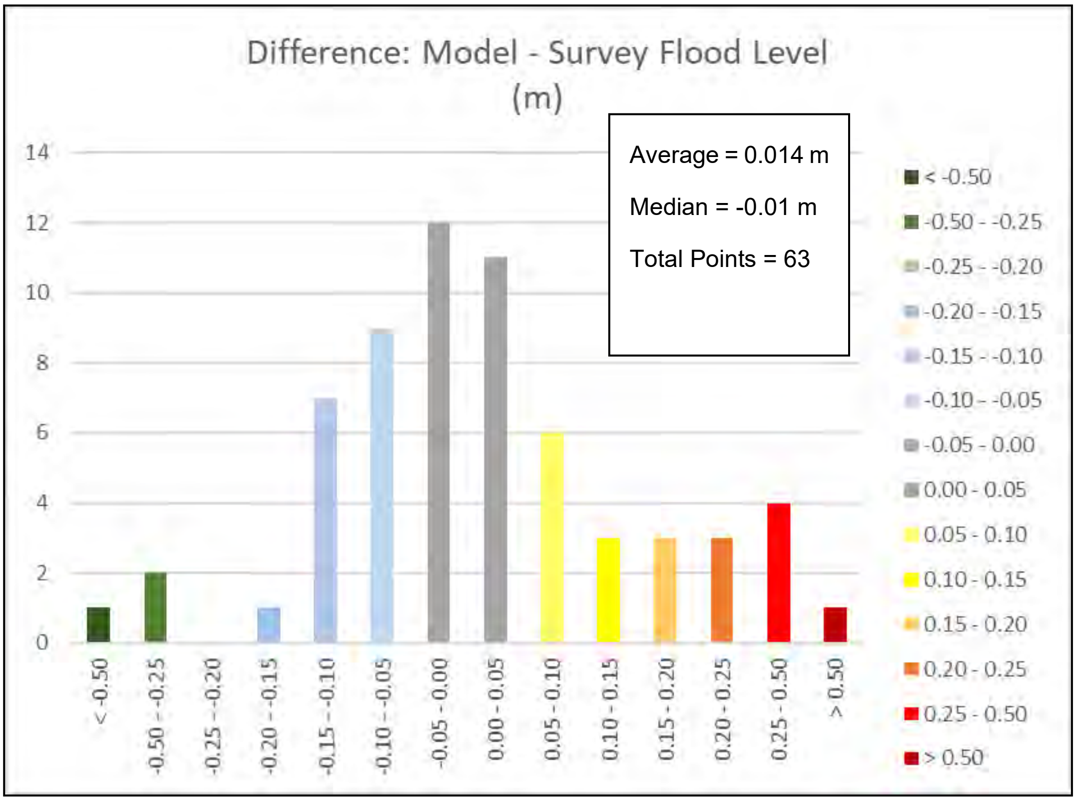
Gauging Station	Peak Level (m AHD)		Date and Time of Peak	
	Modelled	Recorded	Modelled	Recorded
Wilsons River at Woodlawn College - 203402	12.04	12.17	31/03/2017 14:00	31/03/2017 11:15
Leycester Creek at Tuncester - 203443	13.88	13.66	31/03/2017 5:00	31/03/2017 2:30
Wilsons River at Lismore - 203904	11.62	11.59	31/03/2017 12:00	31/03/2017 11:12

Rous County Council has also supplied flood level survey of the 2017 flood event. A comparison of modelled flood levels versus these survey levels has been provided in Table 3.2. In addition, an analysis has been undertaken on the variance of the modelled flood heights to the flood survey to demonstrate closeness of fit across the entire model domain. A histogram of the variance in the TUFLOW modelled levels compared to the flood survey levels is provided in Figure 3.5. The resultant spread of modelled versus recorded flood level variances are summarised below:

- 48 out of 63 points within +/- 150 mm (76%).
- 55 out of 63 points within +/- 250 mm (87%).
- 61 out of 63 points within +/- 500 mm (97%).

Given that the quality of the surveyed flood levels is unknown, these results are considered to indicate a reasonably close and acceptable calibration for the 2017 flood event.

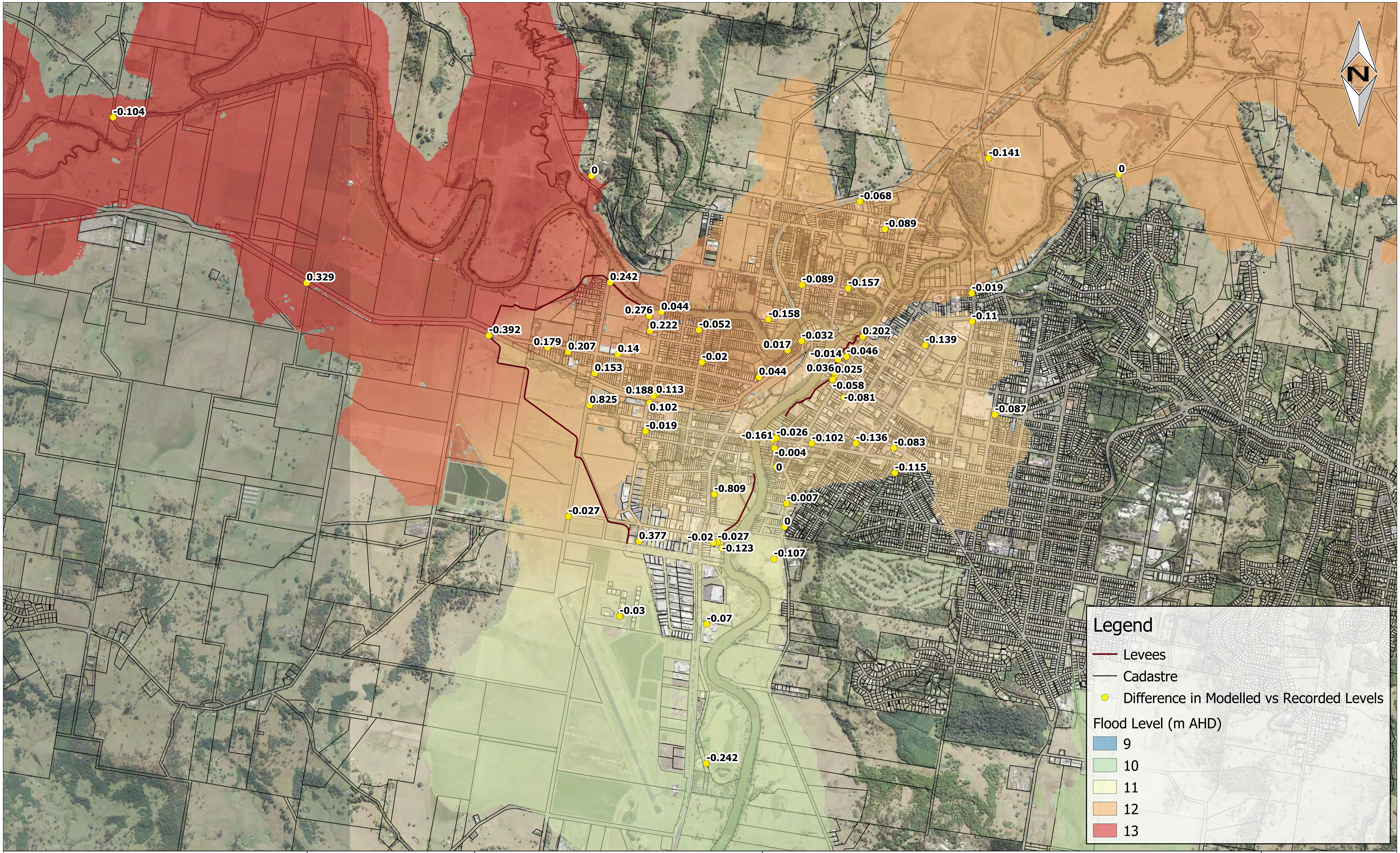
Figure 3.5: 2017 TUFLOW Level Histogram



Flood Behaviour

The modelled 2017 flood levels are presented on Figure 3.6 and key flood behaviours observed from the 2017 modelled flood event are summarised as follows:

- Overtopping of the central CBD levee was anecdotally observed to occur at 4am on 31 March 2017. Inspection of the hydraulic results shows the levee overtopping between 4 am and 5 am on 31 March 2017.
- The flood waters reached Bruxner Highway at 2 am on the 31 March 2017 in the hydraulic model.
- The flow path between the south and north of the CBD basin join at approximately 7am on March 2017 in the hydraulic model.
- Floodwaters in the hydraulic model did not overtop the levee at the Spinks Park spillway.
- Overtopping of the South Lismore levee first occurred near the bowling club.



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0 600 1,200 m

Scale in metres (1:25,000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Lismore Floodplain Risk Management Study
Historical Event Calibration

Figure 3.6 - 2017 Historical Event Flood Levels

Job Number:
M76000_004
Revision: 1
Drawn: KM
Date: 22 /9 /2020

3.3.2 2013 Event Overview

The TUFLOW 2D hydraulic model was simulated using inflows generated from URBS for the 2013 historical flood event. The following sections outline the results from the hydraulic calibration. Note that the focus of the hydrologic and hydraulic calibration was the 2017 flood event as this event has the greatest amount of available calibration data. The 2013 and 2012 (refer to *Section 3.3.3*) event calibrations were secondary to this event and were used to verify that the calibrated model parameters are suitable for events other than the 2017 flood event.

Flood Level Comparison

A comparison of modelled and observed stage-hydrographs at the Woodlawn College, Tuncester and Lismore Rowing Club gauging stations are provided in Figure 3.7, Figure 3.8 and Figure 3.9. A summary of the peak level and time of peak are summarised in Table 3.3.

Both shape and peak level at the Lismore Rowing Club gauge are well replicated, with some difference observed in the rising limb (Figure 3.9). The modelled flood level peak is slightly delayed at Woodlawn (Figure 3.7), with the shape otherwise generally well replicated. The shape at Tuncester is generally not as peaky as the recorded series, with more volume through the rising limb and a lower peak (Figure 3.8). At all gauges, the hydraulic model indicated a slow rate to recede at the tail end of the event. Given that the 2013 event is a secondary event for calibration, it is considered that the results indicate an acceptable comparison to indicate robustness of the hydrologic and hydraulic models.

Figure 3.7: 2013 Flood Level Reporting at Woodlawn

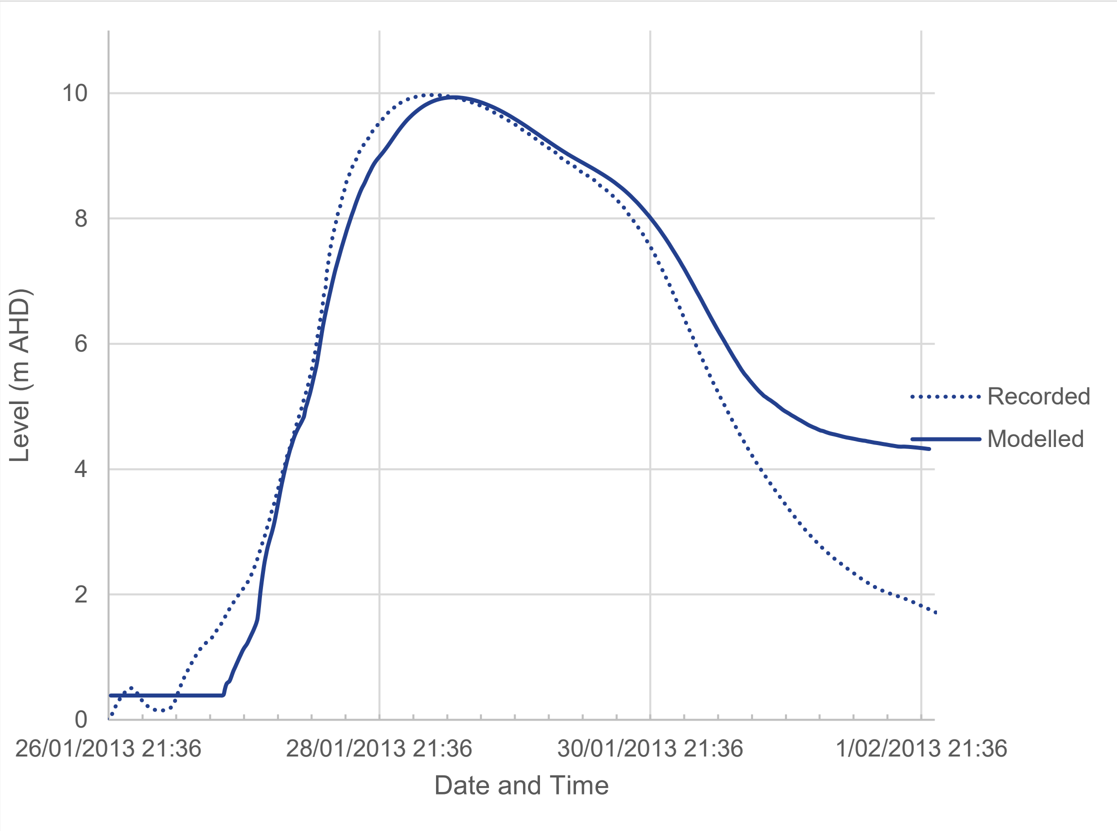


Figure 3.8: 2013 Flood Level Reporting at Tuncester

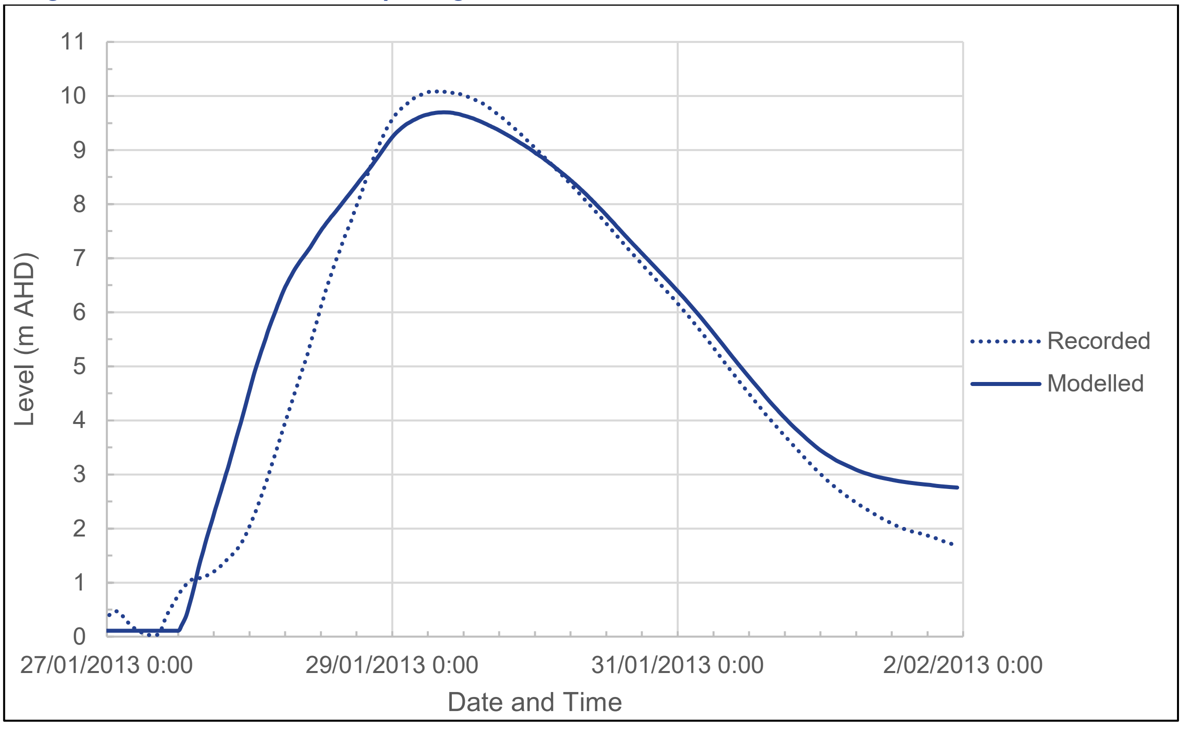


Figure 3.9: 2013 Flood Level Reporting at Lismore Rowing Club

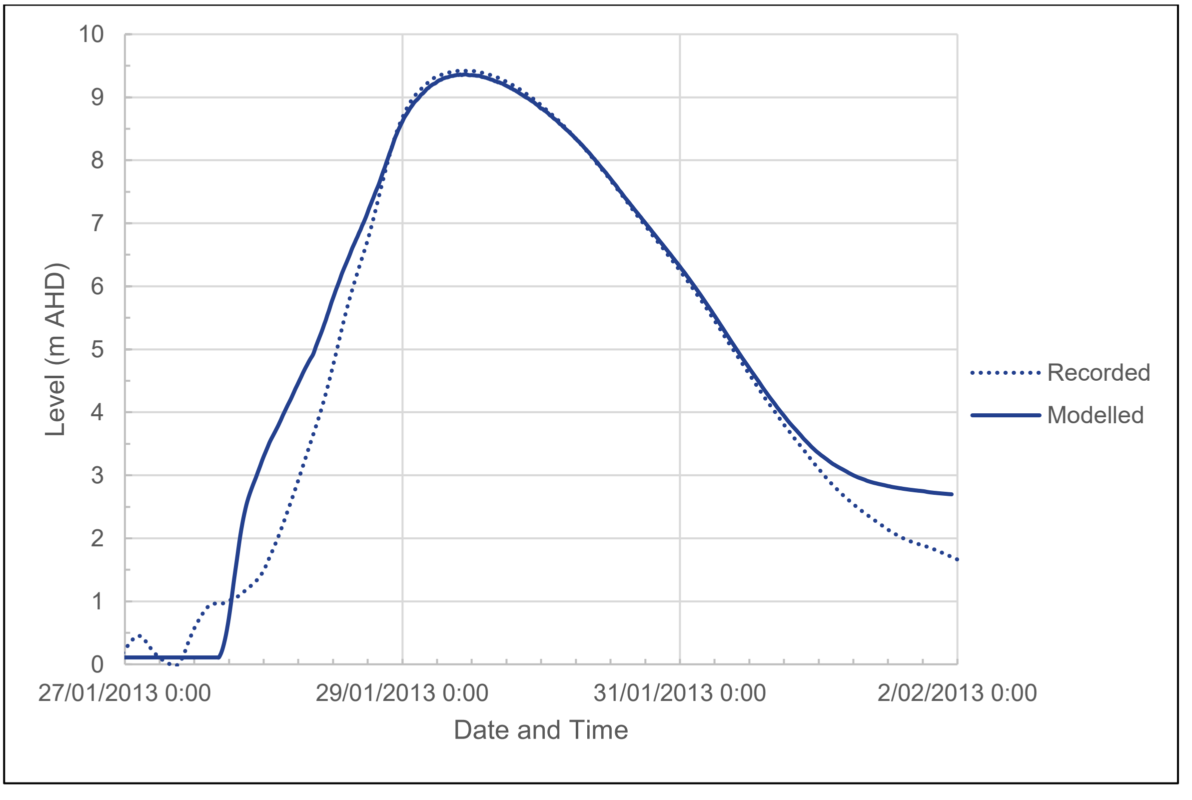
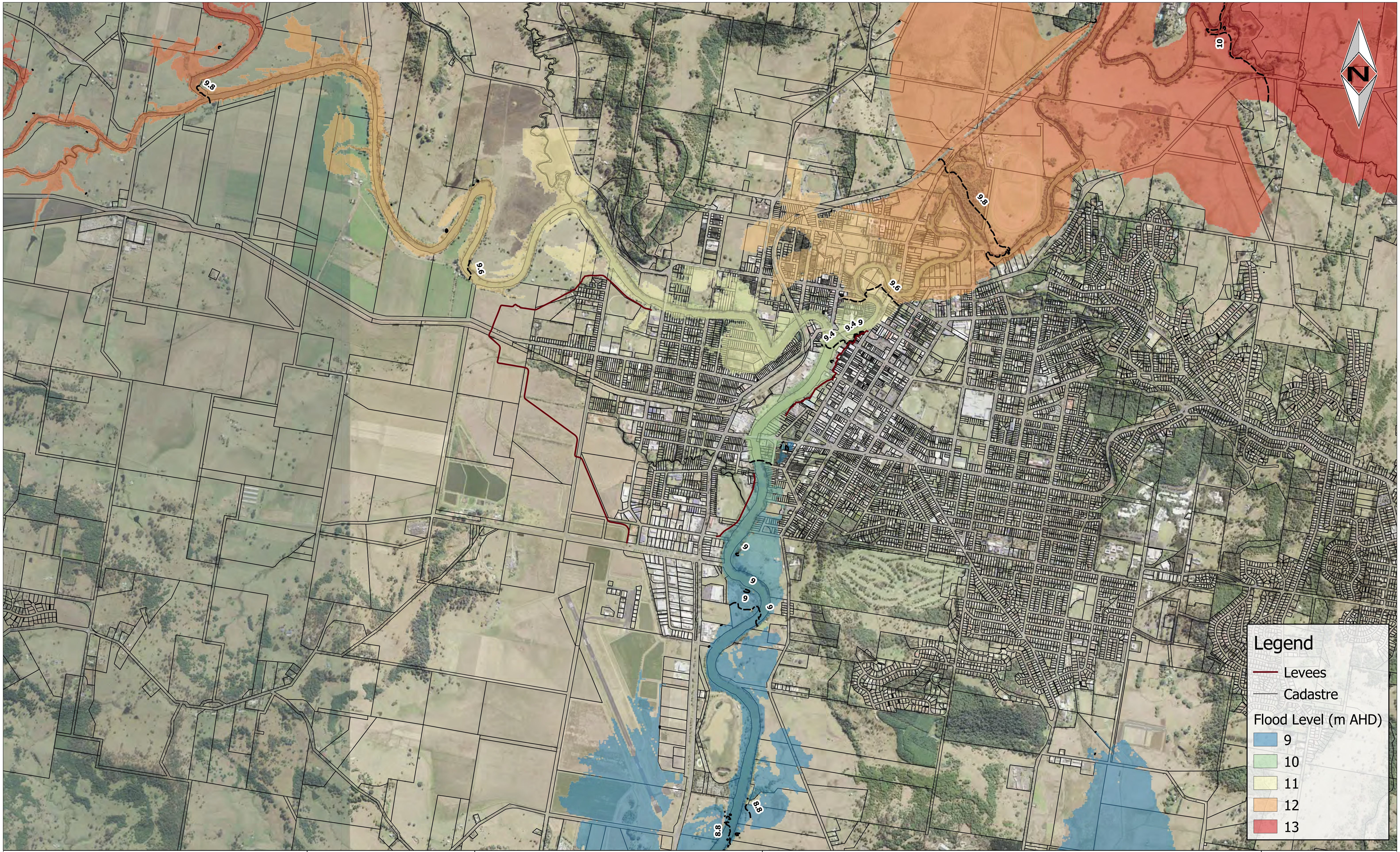


Table 3.3: TUFLOW Calibration Summary – 2013 Event

Gauging Station	Peak Level (m AHD)		Date and Time of Peak	
	Modelled	Recorded	Modelled	Recorded
Wilsons River at Woodlawn College - 203402	9.93	9.97	29/01/2013 10:45	29/01/2013 6:45
Leycester Creek at Tuncester - 203443	9.70	10.09	29/01/2013 8:45	29/01/2013 8:15
Wilsons River at Lismore - 203904	9.36	9.43	29/01/2013 11:00	29/01/2013 10:00



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0 600 1,200 m

Scale in metres (1:25,000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Lismore Floodplain Risk Management Study
Historical Event Calibration

Figure 3.10 - 2013 Historical Event Flood Levels

Job Number:
M76000_004
Revision: 0
Drawn: KM
Date: 22 /9 /2020

3.3.3 2012 Event Overview

The TUFLOW 2D hydraulic model was simulated using inflows generated from URBS for the 2012 historical flood event. The following sections outline the results from the hydraulic calibration. Note that the focus of the hydrologic and hydraulic calibration was the 2017 flood event as this event has the greatest amount of available calibration data. The 2012 and 2013 (*Section 3.3.2*) event calibrations were secondary and were used to verify that the calibrated model parameters are suitable for events other than the 2017 flood event.

Flood Level Comparison

A comparison the modelled and observed stage-hydrographs at the Woodlawn College, Tuncester and Lismore Rowing Club gauging stations have been provided in Figure 3.11, Figure 3.12 and Figure 3.13. A summary of the peak level and time of peak are summarised in Table 3.4.

Both shape and peak level at the Lismore Rowing Club gauge (refer to Figure 3.13) is well replicated, with some difference observed in the rising limb. The flood level peak is slightly lower and occurs earlier at Woodlawn (refer to Figure 3.11), with the shape otherwise generally well replicated. The peak at Tuncester (refer to Figure 3.12) is also lower and occurs earlier. Given that the 2012 event is a secondary event for calibration, the results indicate an acceptable comparison to indicate robustness of the hydrologic and hydraulic models.

Figure 3.11: 2012 Flood Level Reporting at Woodlawn

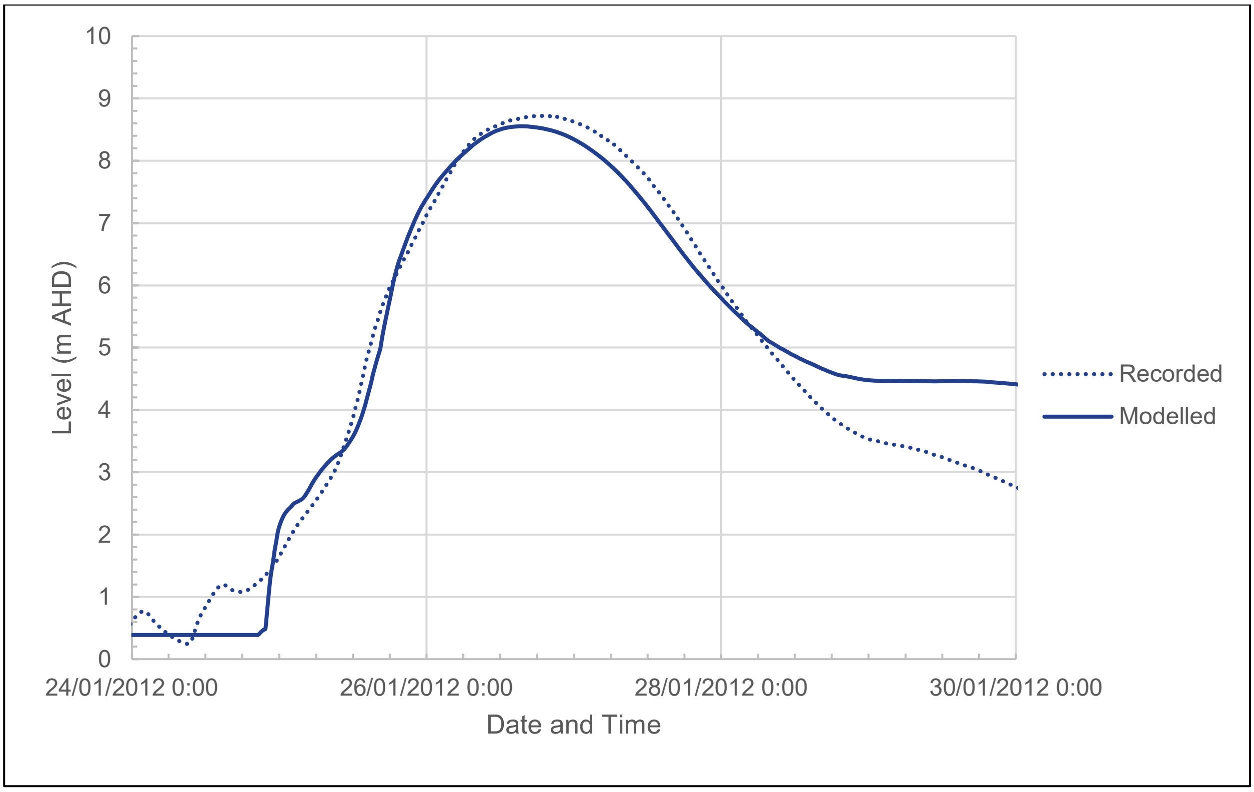

Figure 3.12: 2012 Flood Level Reporting at Tuncester

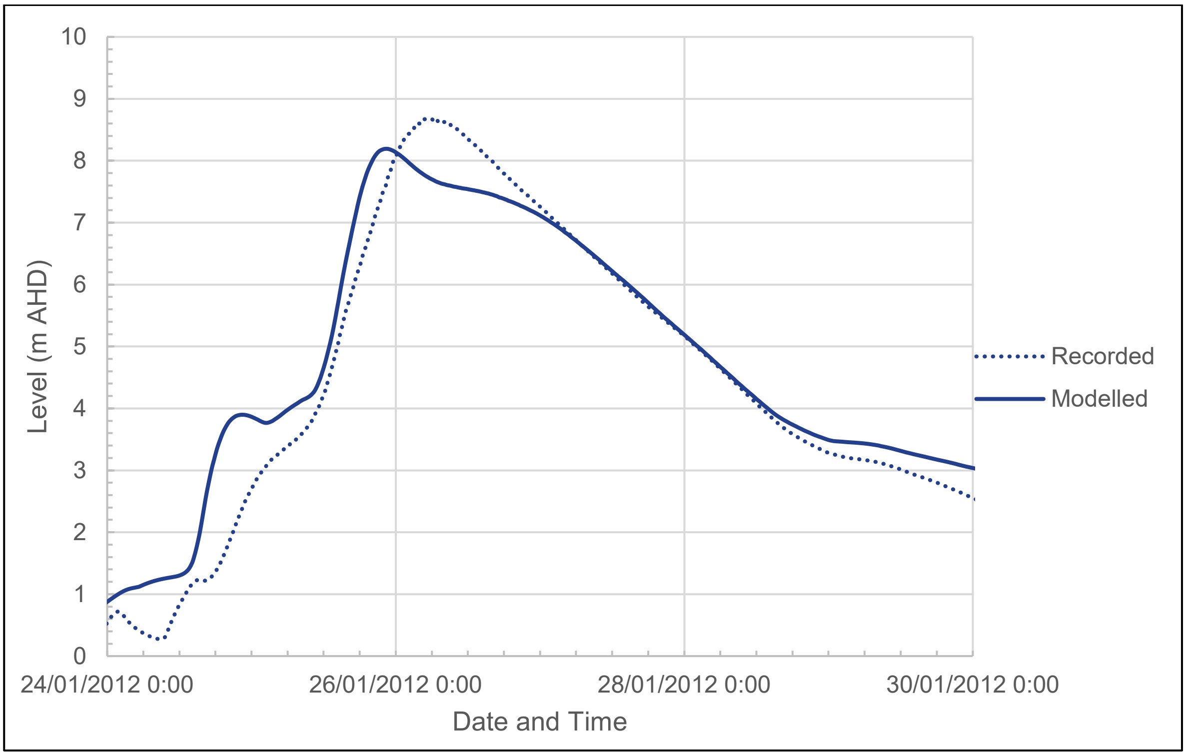

Figure 3.13: 2012 Flood Level Reporting at Lismore Rowing Club

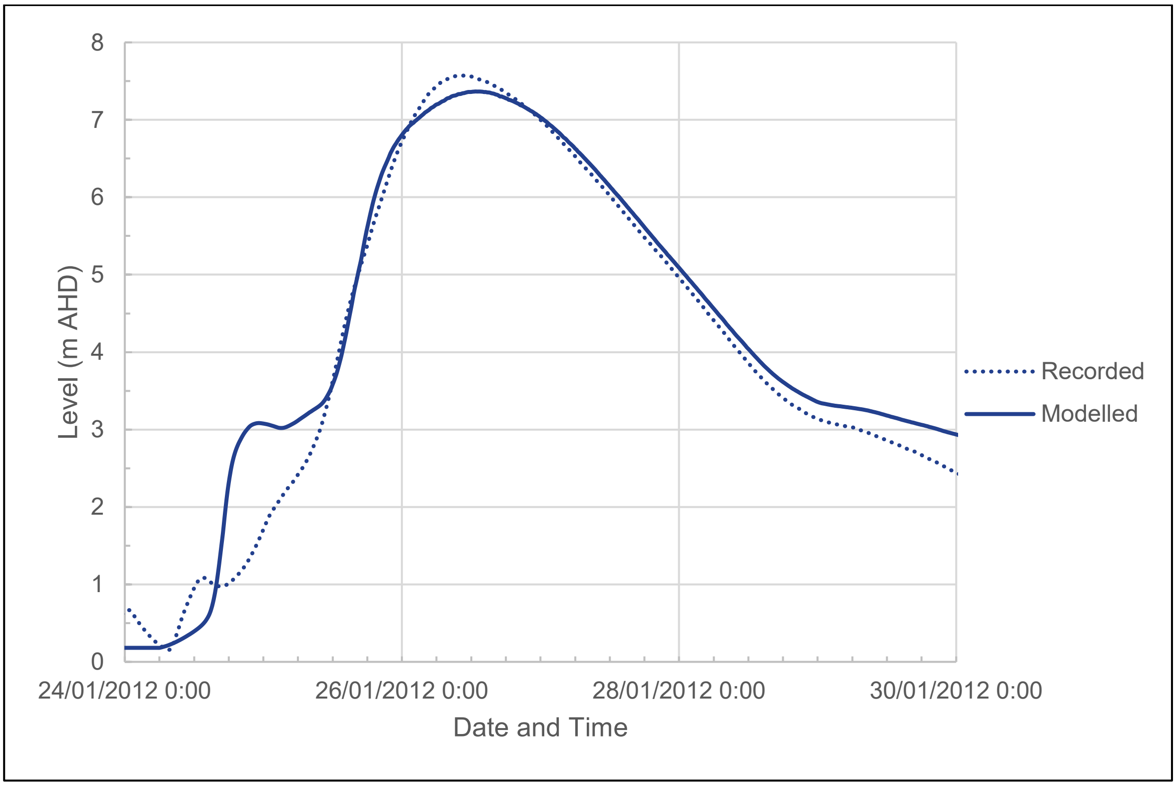

Table 3.4: TUFLOW Calibration Summary – 2012 Event

Gauging Station	Peak Level (m AHD)		Date and Time of Peak	
	Modelled	Recorded	Modelled	Recorded
Wilsons River at Woodlawn College - 203402	8.55	8.73	26/01/2012 15:15	26/01/2012 17:45
Leycester Creek at Tuncester - 203443	8.19	8.69	25/01/2012 22:30	26/01/2012 6:45
Wilsons River at Lismore - 203904	7.37	7.57	26/01/2012 13:30	26/01/2012 11:00

0 600 1,200 m

Scale in metres (1:25,000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

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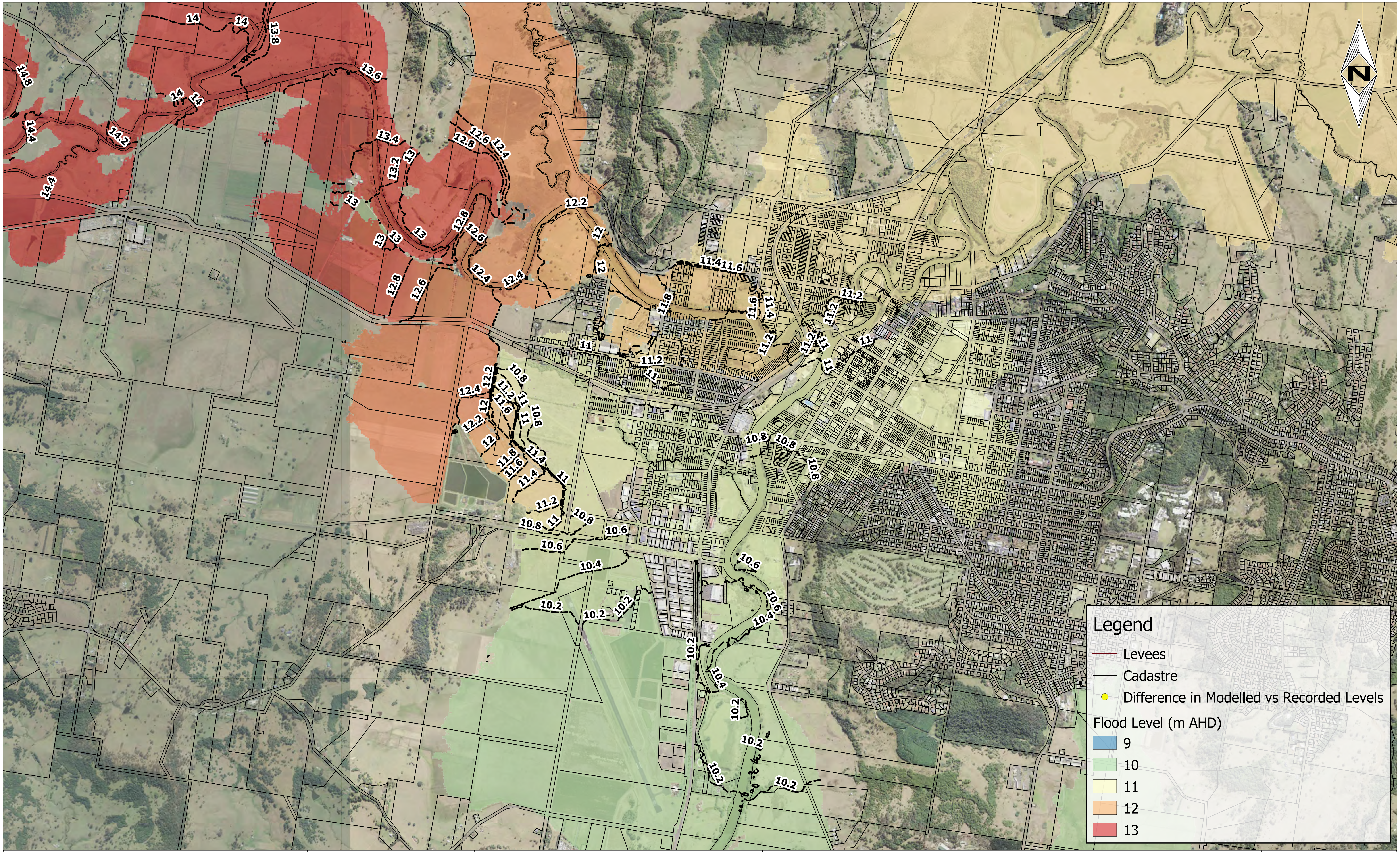
Lismore Floodplain Risk Management Study
Historical Event Calibration

Figure 3.14 - 2012 Historical Event Flood Levels

Job Number: M76000_004
Revision: 0
Drawn: KM
Date: 22 /9 /2020

3.3.4 1989 Event Overview

The TUFLOW 2D hydraulic model was simulated using inflows generated from URBS for the 1989 historical flood event. The following sections outline the results from the hydraulic calibration. Note that the focus of the hydrologic and hydraulic calibration was the 2017 flood event as this event has the greatest amount of available calibration data. The additional historical event calibrations were secondary and were used to verify that the calibrated model parameters are suitable for events other than the 2017 flood event.



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Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
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Lismore Floodplain Risk Management Study
Historical Event Calibration

Figure 3.15 - 1989 Historical Event Flood Levels

Job Number: M76000_004
Revision: 1
Drawn: SW
Date: 29 /10 /2020

3.3.5 Flood Level Comparison

A comparison of observed and modelled stage-hydrographs at the Woodlawn College, Tuncester and Lismore Rowing Club gauging stations have been provided in Figure 3.16, Figure 3.17 and Figure 3.18. A summary of the peak level and time of peak are summarised in Table 3.5.

Both shape and peak level at the Lismore Rowing Club gauge (refer to Figure 3.18) is well replicated, with the modelled water level versus time series generally sitting below the recorded series. Shape and timing are well replicated at Woodlawn (refer to Figure 3.16), with the water levels also slightly lower. The shape at Tuncester (refer to Figure 3.17) is generally not as peaky as the recorded series, with more volume through the rising limb and a lower peak. Calibration of the 1989 event posed a significant challenge, with only 8 available pluviograph stations across the Lismore catchment. Given these limitations, and the use of the 1989 event as a secondary calibration event, these results demonstrate suitable robustness of the hydrologic and hydraulic models.

Figure 3.16: 1989 Flood Level Reporting at Woodlawn

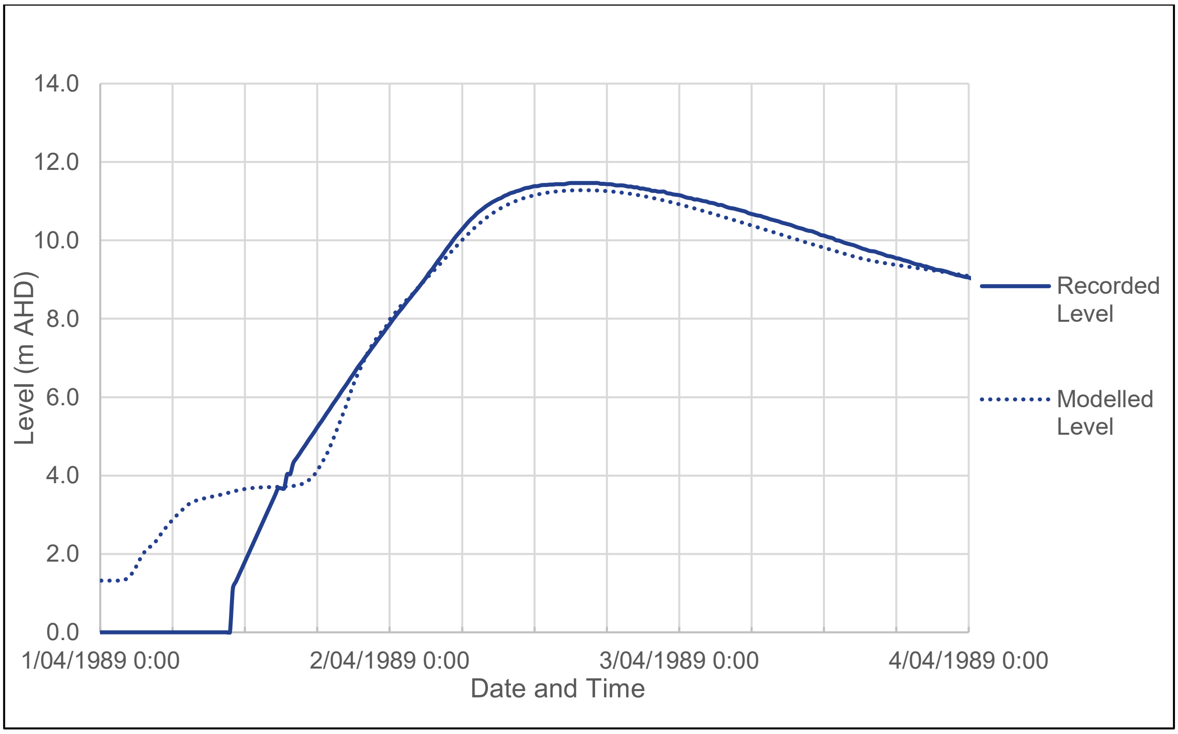


Figure 3.17: 1989 Flood Level Reporting at Tuncester

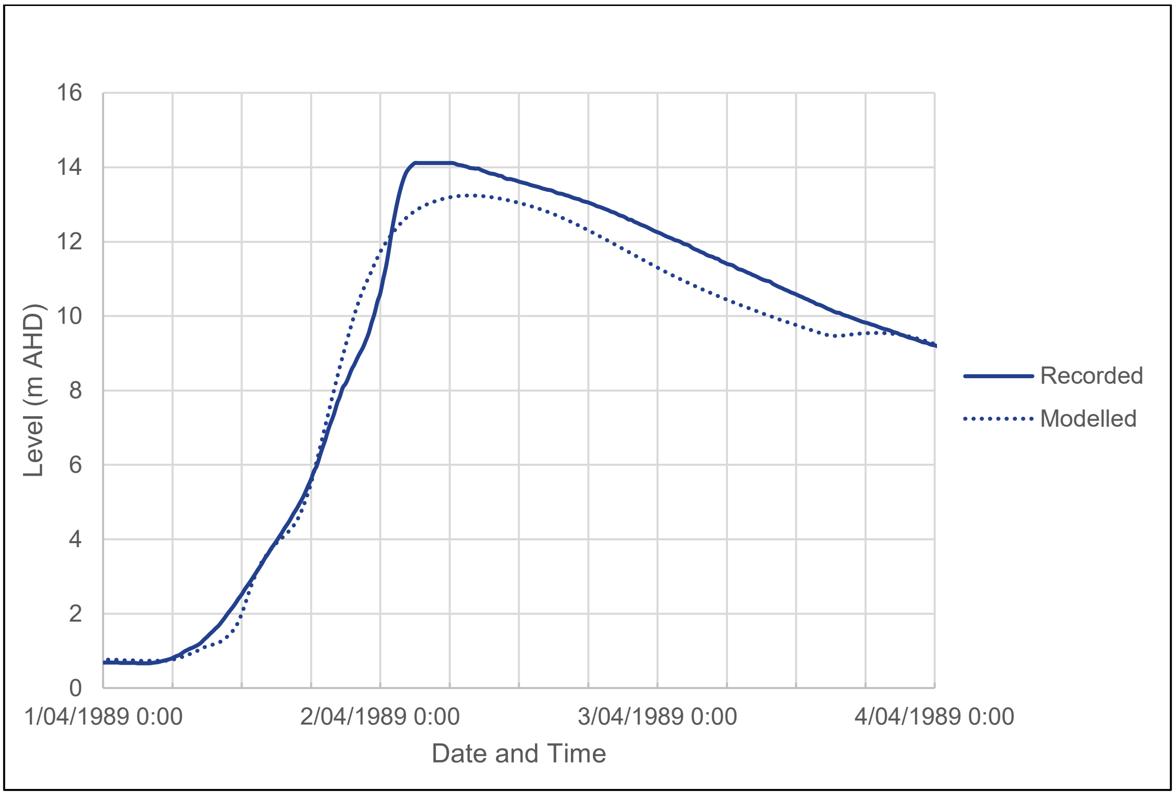


Figure 3.18: 1989 Flood Level Reporting at Lismore Rowing Club

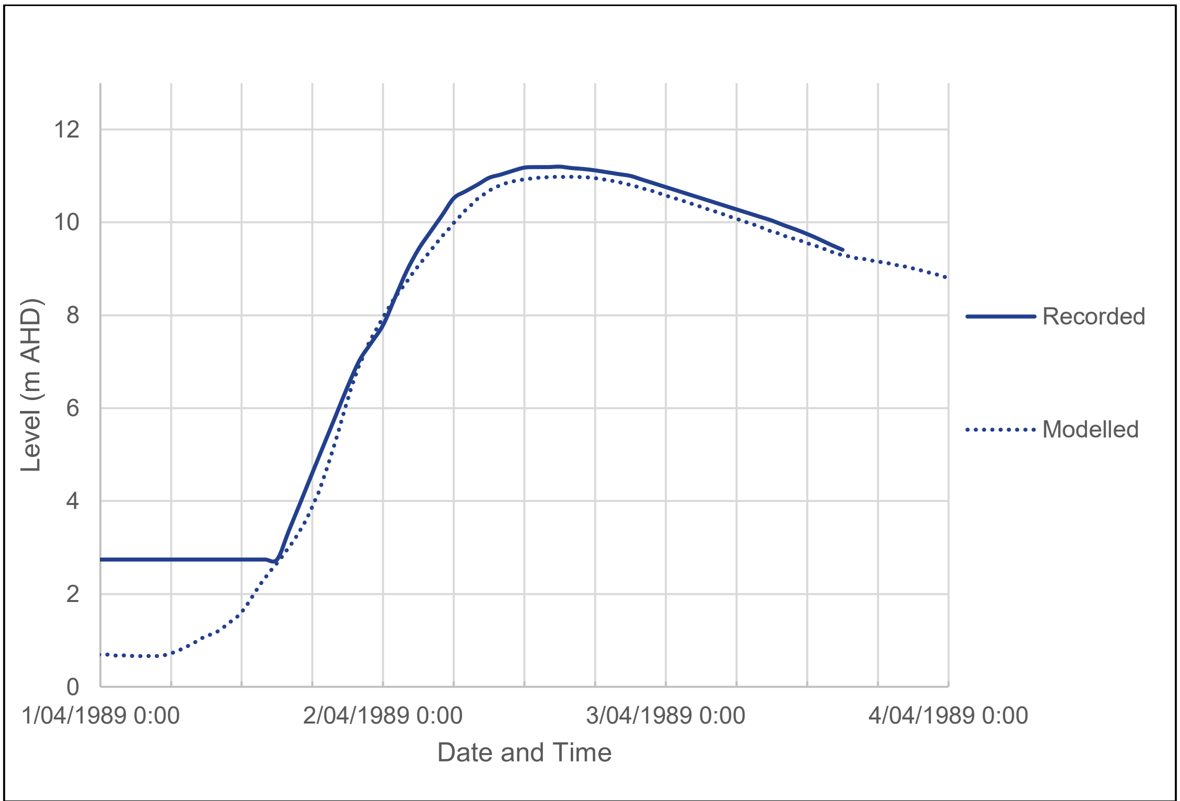


Table 3.5: TUFLOW Calibration Summary – 1989 Event

Gauging Station	Peak Level (m AHD)		Date and Time of Peak	
	Modelled	Recorded	Modelled	Recorded
Wilsons River at Woodlawn College - 203402	11.28	11.46	2/04/1989 16:00	2/04/1989 16:00
Leycester Creek at Tuncester - 203443	13.24	14.12	2/04/1989 7:30	2/04/1989 6:15
Wilsons River at Lismore - 203904	10.98	11.20	2/04/1989 15:45	2/04/1989 15:00

3.4 SENSITIVITY ON DOWNSTREAM BOUNDARY LOCATION

Following completion of the calibration, it was identified that by extending the TUFLOW hydraulic model further downstream, a Flood Frequency Analysis (FFA) could be undertaken at the East Gundurimba gauge to further validate the design event modelling. A sensitivity on the 2017 historical event was undertaken with placement of the hydraulic model's downstream boundary at Tuckurimba. The water level versus time series from the Tuckurimba stream flow gauge (ID 558076) was used to establish the downstream boundary condition.

A comparison of the recorded flood levels for the 2017 historical event at the three key reporting locations are summarised in Table 3.6, which shows that the downstream boundary location has very little impact on the modelled flood levels in Lismore.

Table 3.6: Downstream Boundary Sensitivity Assessment – 2017 Flood Event

Gauging Station	Downstream Boundary Located at East Gundurimba	Downstream Boundary Located at Tuckurimba
Wilsons River at Woodlawn College - 203402	12.06	12.01
Leycester Creek at Tuncester - 203443	13.88	13.86
Wilsons River at Lismore - 203904	11.66	11.61

Therefore, it was considered acceptable that the hydraulic model be extended further downstream for the design event modelling, with no impact on hydraulic results within Lismore. The extension of the downstream boundary has allowed for better representation of the interaction between the airport channel flow and main Wilsons River flow, including the Bruxner Highway influence.

3.5 CALIBRATION SUMMARY

Engeny has completed a joint hydrologic and hydraulic calibration of the 2017, 2013, 2012 and 1989 flood events for Lismore utilising the URBS hydrologic and TUFLOW hydraulic modelling software. A summary of the outcomes from the calibration are provided as follows:

- A joint hydrologic-hydraulic calibration was undertaken, with river gauging stations on all tributaries contributing to the main Leycester Creek and Wilsons River branches utilised to inform hydrologic timing.
- Hydrologic “calibration” rating curves were developed for the secondary and primary gauges, for which peak timing and level were targeted in the calibration. An iterative process was then undertaken between the hydrologic model and the hydraulic model to achieve suitable comparison to recorded flood levels at these primary and secondary gauges.
- Comparison of subsequent TUFLOW hydraulic model flood levels indicated that modelled peak levels at Lismore Rowing Club gauge were within 30 mm, 70 mm, 200 mm and 220 mm, respectively for the 2017, 2013, 2012 and 1989 flood events, with the shape and timing of the modelled water-level time series matching the recorded water-level time series well. Modelled flood levels were within 150 mm of the surveyed flood levels at 47 out of 62 flood survey marks for the 2017 flood event.
- A sensitivity on the downstream boundary location for the 2017 historical flood event was undertaken, with the outcomes from the assessment showing no significant difference in modelled flood levels when the downstream boundary was moved from East Gundurimba to Tuckurimba.
- To improve the robustness of the hydrologic component of the calibration, further development of rating curves for key river gauging stations should be considered. This would include calibration of previously developed TUFLOW local models for gauging stations to manually gauged events.
- Regarding the greater Richmond River catchment, the calibration approach for future flood studies should consider integrated hydrologic and hydraulic calibration. To improve the available data for such calibration, continued collaboration with the Bureau of Meteorology should be sought to maximise synergies between the agencies.

4 Design Flood Event Analysis

The hydrologic and hydraulic models as discussed in previous sections were utilised to undertake the design event analysis. The following sections outline this analysis.

4.1 DESIGN FLOOD MODELLING

4.1.1 URBS Hydrologic Modelling

Parameter Selection

The URBS model developed for the historical event calibration was used to generate hydrographs for the 10%, 5%, 1%, 0.2% AEP and probable maximum flood (PMF) events. The URBS parameters adopted for the design event analysis are consistent with those determined through the calibration process, as summarised in Table 2.3.

The design event losses adopted in the URBS model are as follows:

- Initial losses as recommended by the ARR 2019 Data Hub, with adjustment to the applied pre-burst values as calculated utilising Equation 1 of the ARR 2019 *NSW Specific Data Info* documentation. An initial loss of 0 mm was adopted for the PMF event.
- Continuing loss as recommended by the ARR 2019 Data Hub, with multiplication factor of 0.4 applied in accordance with the ARR 2019 *NSW Specific Data Info* documentation. A continuing loss of 0 mm/hr was adopted for the PMF event.

For future studies, it is recommended that 'At-site' gauge data assessment be undertaken and compared to BOM 2016 IFD's to determine whether there is significant bias.

PMF Estimate

The PMP rainfall estimates were determined using the Bureau of Meteorology guidelines for the Revision of the Generalised Tropical Storm Method for Estimating Probable Maximum Precipitation (BoM, 2003). A summary of the key PMF estimate parameters are provided in Table 4.1.

Table 4.1: PMF Parameters

Parameter	Value
Catchment Size	1400 sq km's
Topography Adjustment Factor	1.45954
Decay Amplitude Factor	0.943986
Extreme Precipitable Water	85.624077 mm
24 Hour Rainfall Intensity	1,210 mm
36 Hour Rainfall Intensity	1,430 mm
48 Hour Rainfall Intensity	1,630 mm
72 Hour Rainfall Intensity	1,990 mm

Peak Flow Estimates

The URBS model was simulated for the 10%, 5%, 2%, 1%, 0.2% AEP flood events, for all ten ensemble temporal patterns as recommended by ARR 2019 and for all durations from 6 hours to 72 hours. The URBS model was also simulated for the PMF event for all durations ranging from 6 hours to 72 hours. The critical durations were selected from the URBS analysis for simulation in the TUFLOW hydraulic model and are summarised in Table 4.2, for which all ten ARR2019 ensemble temporal patterns were simulated in the hydraulic model. Selection of the critical duration was made by comparison of the mean flow for each duration from the ensemble of ten temporal patterns. For all design events, the variance in the peak flow estimate for the envelope within the 24 hour and 48 hour duration events to the selected duration is only 10%.

Table 4.2: Selected Critical Durations

Event	Critical Duration
10% AEP	48 hours
5% AEP	48 hours
1% AEP	24 hours
0.2% AEP	36 hours
PMF	36 hours

The identified peak flows for the design events are summarised in Table 4.3.

Table 4.3: URBS Hydrologic Peak Flow Estimates

Gauge Location	10% AEP (m^3/s)	5% AEP (m^3/s)	1% AEP (m^3/s)	0.2% AEP (m^3/s)	PMF (m^3/s)
Lismore Rowing Club	2,305	2,892	4,151	5,130	15,334
Woodlawn College	929	1,140	1,655	2,125	5,271
Tuncester	1,518	1,879	2,779	3,281	10,842
East Gundurimba	2,327	2,922	4,182	5,211	15,716

Comparison of Peak Flows

A comparison of the design event peak flow estimates from the URBS hydrologic model against the available previous peak flow estimates produced by SKM in 1993 and also adopted by BMT in 2018 are provided in Table 4.4. Flow estimates at East Gundurimba, or the 0.2% AEP estimate at Lismore were not provided in the SKM or BMT documentation to enable comparison. There is significant variance between the flow estimates from the updated URBS model compared to the previous estimates. The BMT study adopted the SKM estimates and a detailed review of the SKM hydrology has not been undertaken as part of this Study, however, the different hydrologic approach and applied losses may account for some of the differences. A detailed review of the SKM hydrologic and BMT hydraulic modelling inputs is required to understand why significantly higher flows were required in the SKM and BMT studies to achieve a relatively similar flood levels to this Study. The following sections outline the hydraulic results comparison and validation which shows that the hydraulic model produces reasonable flood levels.

Table 4.4: Comparison of Peak Flows (m3/s) Against Previous Estimates

Location	10% AEP		5% AEP		1% AEP		0.2% AEP		PMF	
	Engeny 2020 Estimate	BMT/SKM Estimate)	Engeny 2020 Estimate	BMT/SKM Estimate	Engeny 2020 Estimate	BMT/SKM Estimate	Engeny 2020 Estimate	BMT/SKM Estimate	Engeny 2020 Estimate	BMT/SKM Estimate
Lismore Rowing Club	2,305	-	2,892	5,652	4,151	7,407	5,130	-	15,334	21,995
Woodlawn College	929	1,615	1,140	2,043	1,655	2,760	2,125	3,710	5,271	7,405
Tuncester	1,518	3,244	1,879	3,609	2,779	4,647	3,281	6,144	10,842	14,851

4.1.2 TUFLOW Hydraulic Modelling

The TUFLOW hydraulic model utilised for the hydrologic calibration was also used to simulate the design events. Inflows from the URBS hydrologic model as discussed in the previous sections were applied to the hydraulic model. Each flood event was simulated for the critical duration, with all ten ensemble temporal patterns simulated.

The downstream boundary applied to the model was a constant tailwater level at Tucki Tucki, taken from the Richmond River model. The applied tailwater levels were:

- 10% AEP and 5% AEP – 7.51 m AHD (from Richmond River 5% AEP event).
- 1% AEP – 8.36 m AHD (from Richmond River 1% AEP event).
- 0.2% AEP – 8.93 m AHD (from Richmond River 0.2% AEP event).
- PMF – 10.31 m AHD (from Richmond River PMF event).

Hydraulic Results

The peak flood heights (the mean of the simulated ten ensemble patterns) at key locations within the hydraulic model for the simulated design events are summarised in Table 4.5.

Table 4.5: TUFLOW Modelled Peak Flood Height

Location	10% AEP (m AHD)	5% AEP (m AHD)	1% AEP (m AHD)	0.2% AEP (m AHD)	PMF (m AHD)
Lismore Rowing Club	10.97	11.45	12.47	13.02	16.55
Woodlawn College	11.39	11.98	12.93	13.49	17.06
Tuncester	12.65	13.22	13.88	14.14	17.30
East Gundurimba	9.66	10.03	10.88	11.49	14.72

Flood height maps for the design events are provided in *Appendix A*.

4.2 HYDRAULIC MODEL VALIDATION

Two sources were utilised to validate the design event flood modelling, which were:

- Comparison to previously modelled design events by BMT in 2018 and SKM in 1993.
- Comparison to flood heights calculated from Flood Frequency Analysis (FFA) at the four river gauge locations in the model extent.

4.2.1 Flood Frequency Analysis

A FFA utilising FLIKE software was performed on the annual maximum flood level series at the Lismore Rowing Club, Tuncester, Woodlawn College and East Gundurimba river height gauges in order to provide an additional validation source for the design flood events.

The Generalised Extreme Value (GEV) probability method with Bayesian inference was adopted for the FFA, following a complete analysis comparing the results against other methodologies such as Log-Pearson 3 with various inferences. Graphs showing the FFA result, inclusive of 5% and 95% confidence limits for the Lismore, Tuncester, Woodlawn College and East Gundarimba gauges are provided in *Appendix C*.

A summary of the length of record available at each of these gauges is provided in Table 4.6.

Table 4.6: FFA Gauge Information and Methodology

Gauge ID	Length of Record
Wilsons River at Lismore (BoM: 558012 / MHL:203402)	100 years (1917 – 2017) (Note that a continuous record series is not available for this gauge, with only peak level series available)
Woodlawn College – Wilsons River (BoM: 558012 / MHL: 203402)	39 years (1980 – 2019)
Tuncester- Leycester Creek (BoM: 58201 / MHL: 203443)	39 years (1980 – 2019)
East Gundurimba (MHL: 203427)	39 years (1980 – 2019)

The calculated flood heights from the FFA for the design events are summarised in *Section 4.2.2* below.

4.2.2 Validation Results

A comparison of the modelled flood heights in TUFLOW to both the previous results from BMT in 2018, SKM in 1993 and the FFA are provided in Table 4.7 to

Table 4.11. Overall, a reasonably consistent comparison was observed across the flood events, indicating a suitable validation. There are some locations and AEPs for which flood heights were not provided in the SKM and BMT documentation for comparison.

Table 4.7: 10% AEP Flood Height Validation

Location	Engeny 2020 (m AHD)	BMT 2018 (m AHD)	FFA Estimation (m AHD)
Lismore Rowing Club	10.97	10.80	10.24
Woodlawn College	11.39	11.50	11.03
Tuncester	12.65	12.90	11.84
East Gundurimba	9.66	-	9.54

Table 4.8: 5% AEP Flood Height Validation

Location	Engeny 2020 (m AHD)	BMT 2018 (m AHD)	SKM 1993 (m AHD)	FFA Estimation (m AHD)
Lismore Rowing Club	11.45	11.30	11.31	11.02
Woodlawn College	11.98	12.00	11.85	11.72
Tuncester	13.22	13.10	13.40	13.06
East Gundurimba	10.03	-	9.83	9.98

Table 4.9: 1% AEP Flood Height Validation

Location	Engeny 2020 (m AHD)	BMT 2018 (m AHD)	SKM 1993 (m AHD)	FFA Estimation (m AHD)
Lismore Rowing Club	12.47	12.40	12.43	12.19
Woodlawn College	12.93	12.70	13.09	12.58
Tuncester	13.88	13.60	14.19	14.97
East Gundurimba	10.88	-	11.13	10.46

Table 4.10: 0.2% AEP Flood Height Validation

Location	Engeny 2020 (m AHD)	BMT 2018 (m AHD)	FFA Estimation (m AHD)
Lismore Rowing Club	13.02	13.30	12.84
Woodlawn College	13.49	13.60	12.93
Tuncester	14.14	14.00	16.10
East Gundurimba	11.49	-	10.62

Table 4.11: PMF Flood Height Validation

Location	Engeny 2020 (m AHD)	BMT 2018 (m AHD)	SKM 1993 (m AHD)
Lismore Rowing Club	16.55	15.90	15.94
Woodlawn College	17.06	16.10	17.00
Tuncester	17.30	16.30	17.50
East Gundurimba	14.72	-	15.00

4.3 SENSITIVITY ANALYSIS

4.3.1 Spatial Variation in Rainfall

Design flood events are theoretical events used for flood risk management and infrastructure design purposes. The location of Lismore at the confluence of the Wilsons River and Leycester Creek can result in various flood behaviour characteristics depending on the rainfall distribution and intensity in each catchment. The design flood events do not account for such complexities and therefore two scenarios were run to assess how sensitive the model results were to spatial variation in rainfall intensity. The spatial variation in rainfall scenarios were:

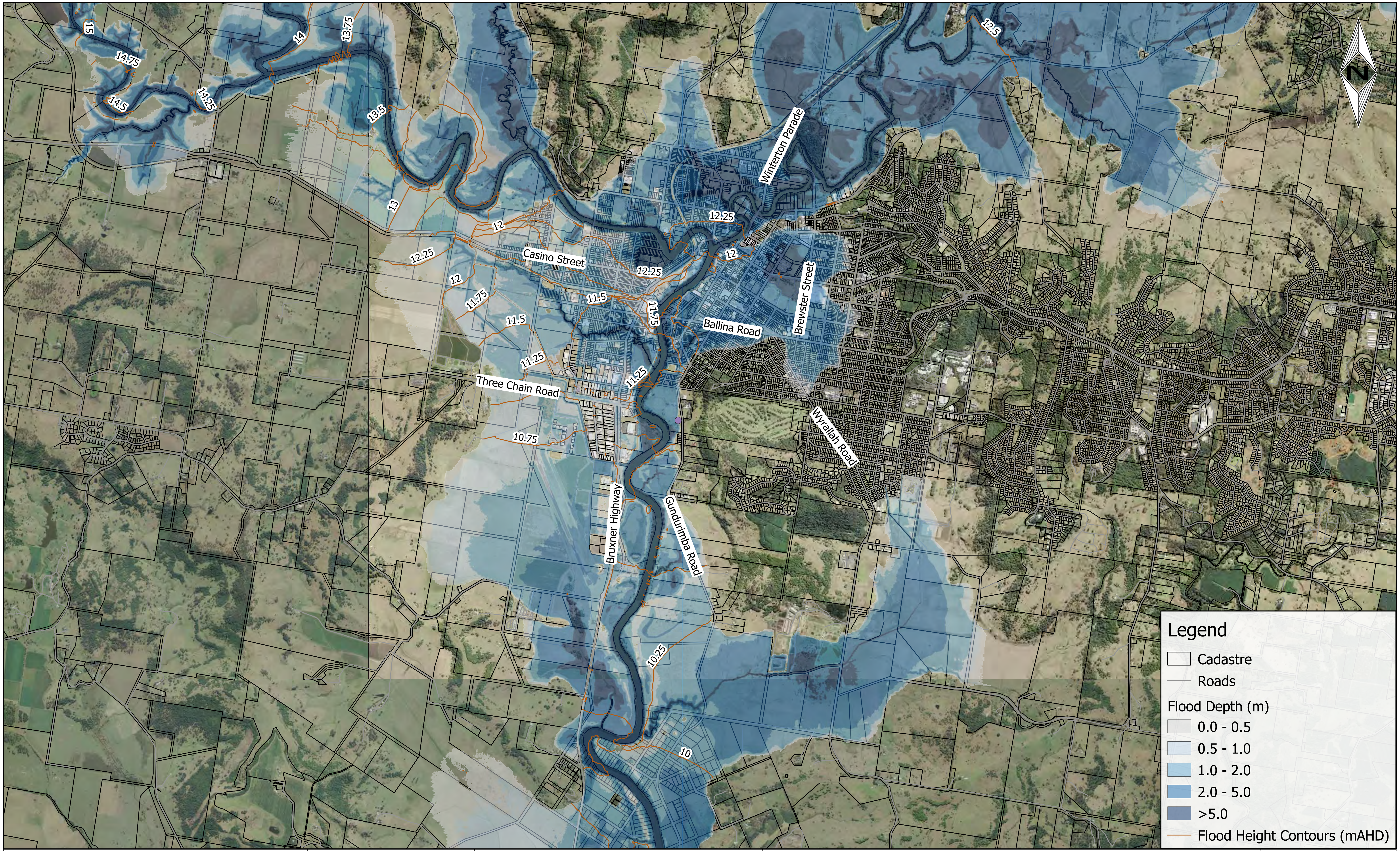
- Scenario 1: 5% AEP rainfall applied to Leycester Creek inflow locations and 1% AEP rainfall applied to Wilsons River inflow locations.
- Scenario 2: 1% AEP rainfall applied to Leycester Creek inflow locations and 5% AEP rainfall applied to Wilsons River Inflow locations.

The chosen duration for the analysis was a 24 hour flood event as it was the critical storm duration for the 1% AEP event and local inflows and tailwater conditions downstream of Lismore are dominated by the 1% AEP flood event.

Flood height mapping for both simulations are provided in Figure 4.1 and Figure 4.2. The results indicated that:

- Both scenarios result in flood levels that are lower than the design 1% AEP flood event, and higher than the 5% AEP design flood event.
- For scenario 1 (Leycester Creek inflows reduced to the 5% AEP flood event: Figure 4.1):
  - Levels in South Lismore are 400-800 mm lower than the design 1% AEP flood event and 250-400 mm higher than the 5% AEP design flood event.
  - Levels in the CBD are 550 mm lower than the design 1% AEP flood event and 250-400 mm higher than the 5% AEP design flood event.
  - Levels in North Lismore are 450-500 mm lower than the design 1% AEP flood event and 250-350 mm higher than the 5% AEP design flood event.
- For scenario 2 (Wilsons River inflows reduced to the 5% AEP flood event: Figure 4.2):
  - Levels in South Lismore are 200-350 mm lower than the design 1% AEP flood event and 400-1000 mm higher than the 5% AEP design flood event.
  - Levels in the CBD are 350 mm lower than the design 1% AEP flood event and 450-600 mm higher than the 5% AEP design flood event.
  - Levels in North Lismore are 350-400 mm lower than the design 1% AEP flood event and 450 mm higher than the 5% AEP design flood event.

These results indicate that the flood levels throughout Lismore tend to be dominated by the magnitude of the Leycester Creek catchment inflows, where reduction in the magnitude of flow from this branch has a larger reduction in predicted flood levels. The Leycester Creek and Wilsons River catchment areas upstream of the confluence are 870 km^2 (63%) and 520 km^2 (37%) respectively.



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ENGENY WATER MANAGEMENT

ROUS COUNTY COUNCIL

0 800 1600 m

Scale in metres (1:35000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Lismore Floodplain Risk Management Study

Figure 4.1 - Spatial Variation of Rainfall Analysis 1 - 5% AEP Leycester Creek Flows and 1% AEP Wilsons River Flows

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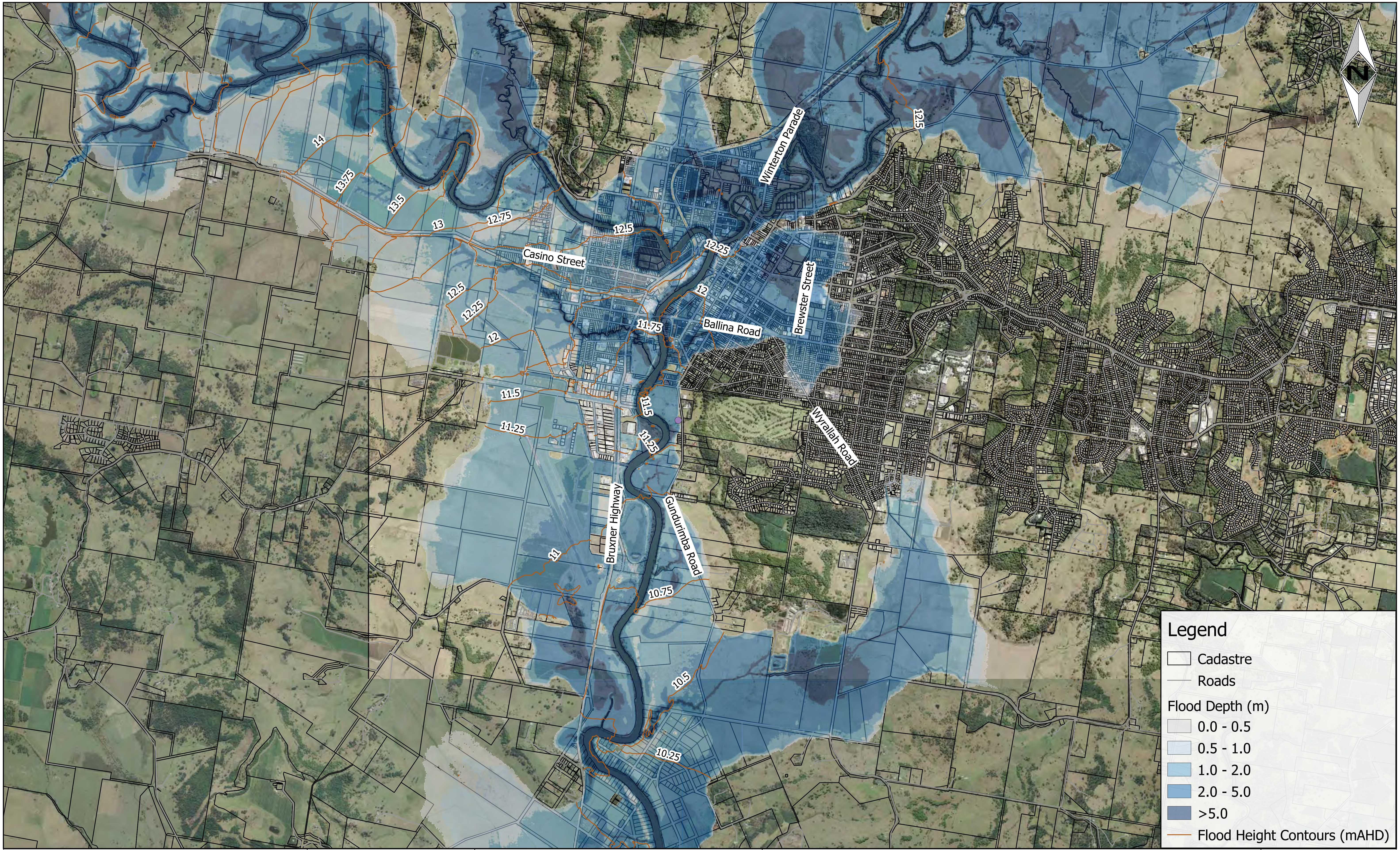

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Scale in metres (1:35000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

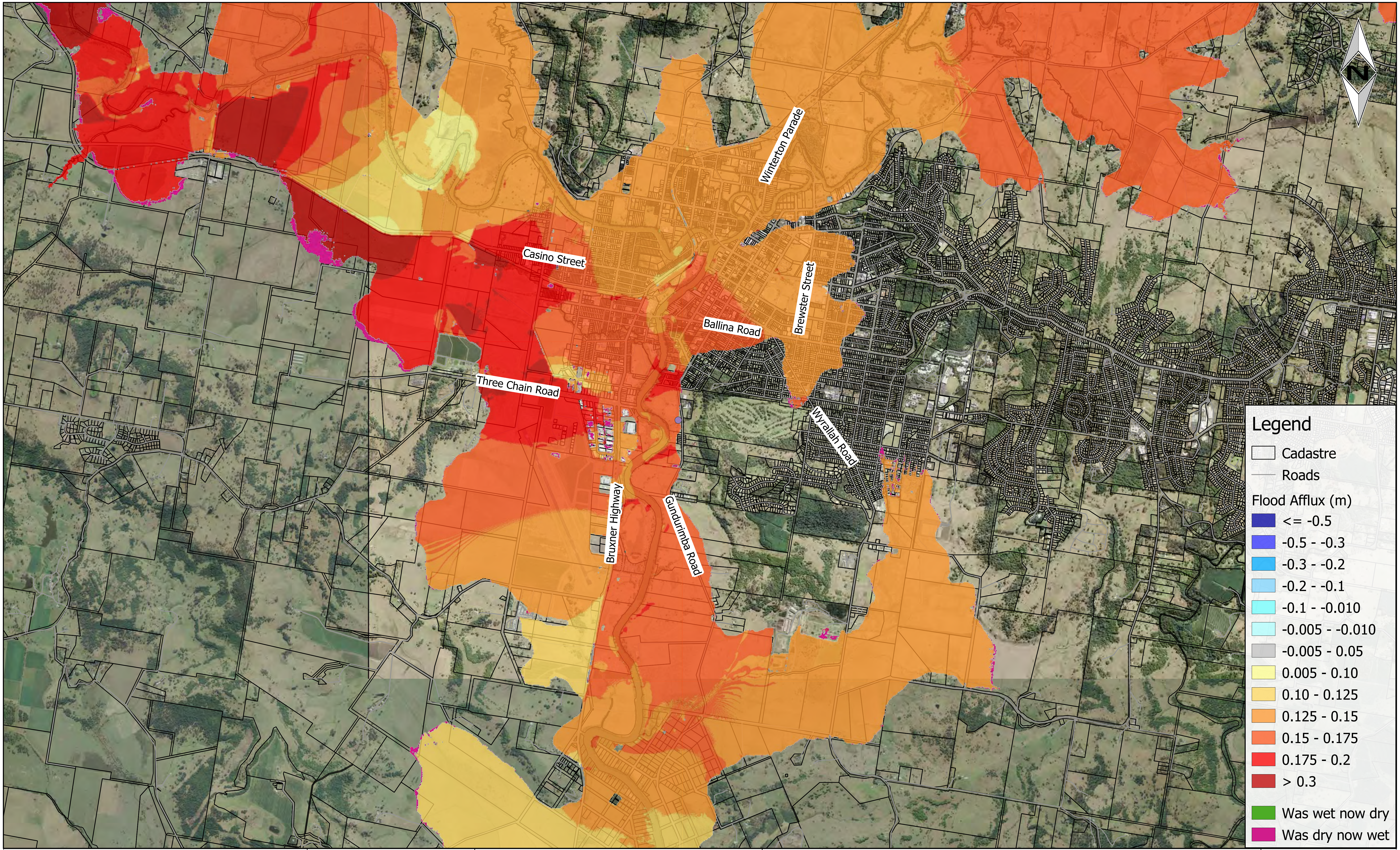
Lismore Floodplain Risk Management Study

Figure 4.2 - Spatial Variation of Rainfall Analysis 2 - 5% AEP Wilsons River Flows and 1% AEP Leycester Creek Flows

Job Number: M76000_004
Revision: 0
Drawn: SW
Date: 18 /9 /2020

4.3.2 Manning's Roughness

In order to quantify the sensitivity of the hydraulic modelling to the adopted Manning's "n" roughness values, all roughness values were increase by 20% and the model simulated for the 1% AEP flood event. Flood afflux mapping, shown as a difference between the sensitivity run and the design scenario 1% AEP flood height results, is provided in Figure 4.3. The mapping indicates that the 20% increase to the adopted model roughness results in a relatively consistent increase to flood levels of approximately 150 mm across the model extent for the 1% AEP flood event. This suggests that the model provides a relatively stable estimate of flood depths across the study area.



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Lismore Floodplain Risk Management Study

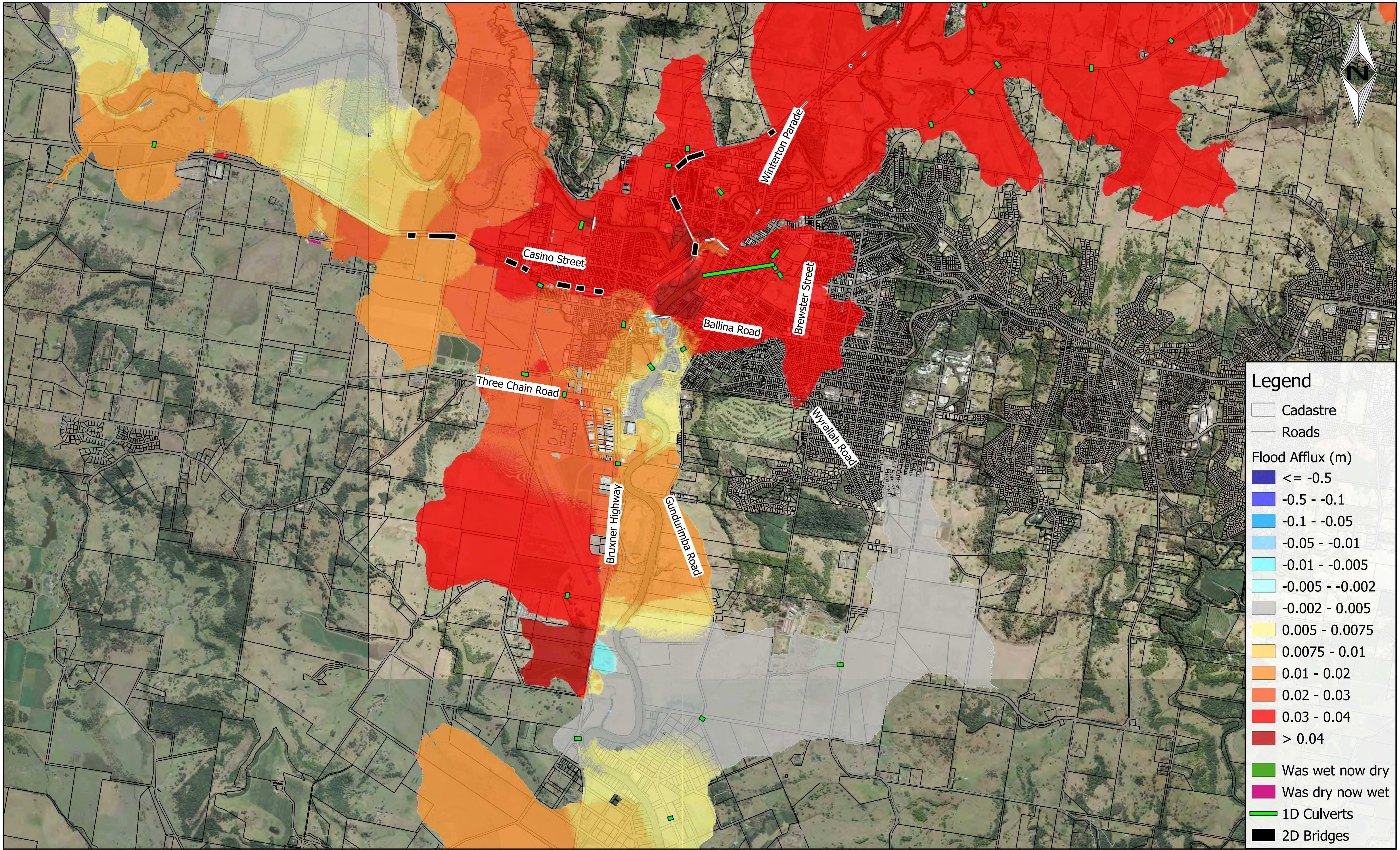
Figure 4.3 - Hydraulic Model Roughness Sensitivity 1% AEP Impact Mapping

Job Number: M76000_004
Revision: 0
Drawn: SW
Date: 18 /9 /2020

4.3.3 Structure Blockage

In order to quantify sensitivity of the hydraulic modelling to increased structure blockage, 20% and 50% blockage factors were applied to all 1D stormwater pipes and bridge structures respectively. The model was simulated for the 1% AEP flood event. Flood afflux mapping, shown as a difference between the sensitivity run and the design scenario 1% AEP flood height results, is provided in Figure 4.4. The mapping indicates that in areas upstream of key hydraulic controls, flood levels are expected to increase by approximately 30 mm for the 1% AEP flood event. There is minimal increase in the 1% AEP flood event upstream of hydraulic structures and there are unlikely to be properties that are significantly adversely affected in a large (i.e. 1% AEP) flood event if blockage of a structure occurs. The results also suggests that the hydraulic model is appropriately accounting for the modelled hydraulic structures.

It is noted that in some areas blockage of a structure for smaller flood events (less than 1% AEP) may significantly alter flood levels or behaviour, particularly upstream, and may require additional measures to reduce the blockage likelihood or modification to planning controls to allow for possible impacts.



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Scale in metres (1:35000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Lismore Floodplain Risk Management Study

Figure 4.4 - Hydraulic Model Structure Blockage Sensitivity 1% AEP Impact Mapping

Job Number: M76000_004
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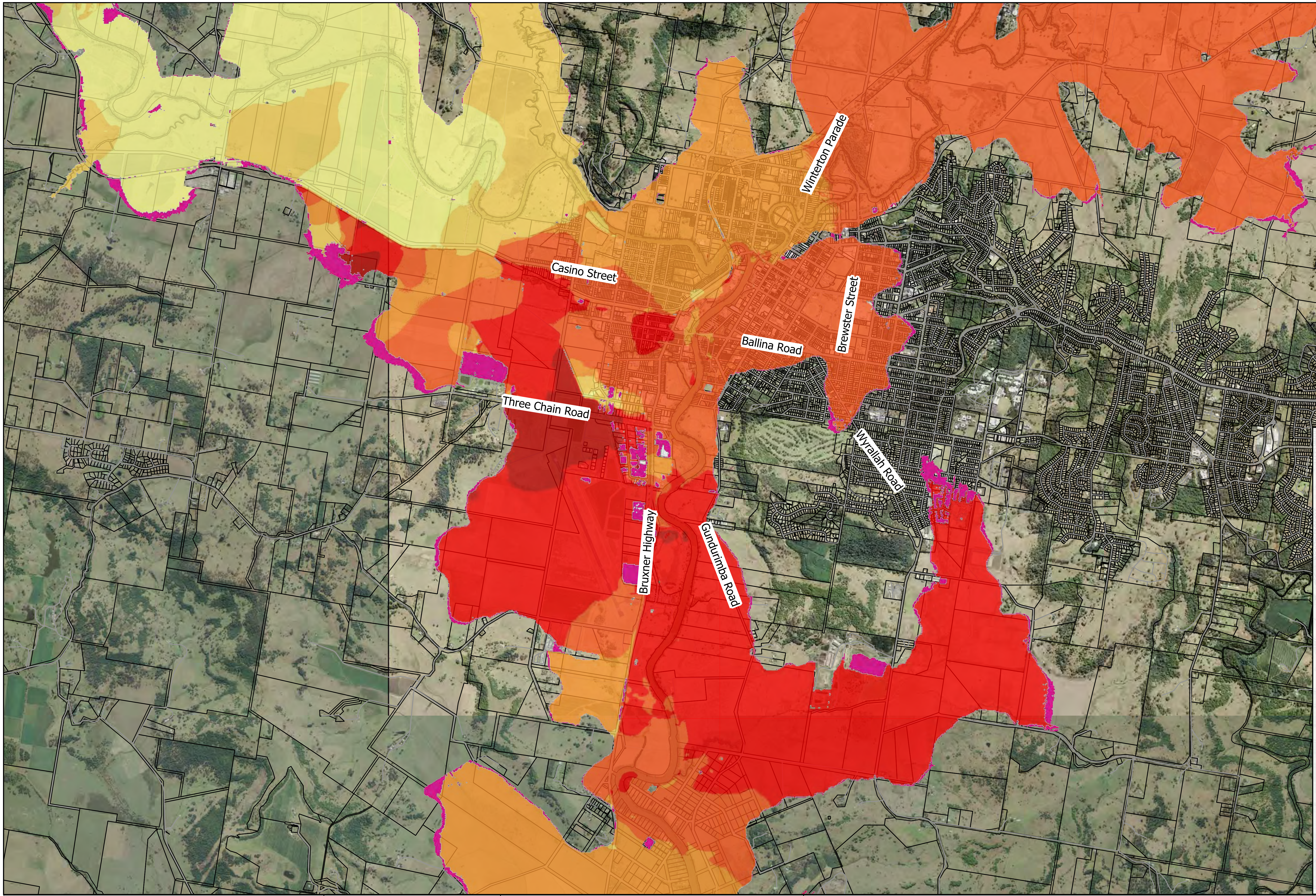
Drawn: SW
Date: 18 /9 /2020

4.4 CLIMATE CHANGE ASSESSMENT

To estimate the likely impact of climate change on flood conditions in Lismore, hydraulic model inflows were extracted from the URBS hydrologic model for Representative Concentration Pathway (RCP) 8.5 future climate conditions, reflecting an increase in rainfall intensity of 19.7% to account for a temperature increase of about 4.3˚C by 2100, as estimated using the *Climate Futures Tool* (www.climatechangeinaustralia.gov.au). The model was simulated for the 1% AEP flood event.

Flood afflux mapping, shown as a difference between the climate change scenario and the design scenario 1% AEP flood height results, is provided in Figure 4.5. The mapping indicates that the estimated increase in intensity will result in increases to flood levels of approximately 350-600mm across the flood extent. The extent of inundation was shown to be increased (indicated on flood impact map as *'was dry now wet'*), particularly within South Lismore and the fringe areas of the floodplain. This is likely to result in impacts to currently unaffected properties. In particular, impacts to multiple properties surrounding Wade Park and Nielson Park were observed due to backwater from the Wilsons River up Gundarimba Canal.



Legend

- Cadastre
- Roads

Flood Afflux (m)

- <= -0.65
- -0.65 - -0.6
- -0.6 - -0.55
- -0.55 - -0.5
- -0.5 - -0.4
- -0.4 - -0.2
- -0.2 - 0.2
- 0.2 - 0.4
- 0.4 - 0.5
- 0.5 - 0.55
- 0.55 - 0.6
- 0.6 - 0.65
- > 0.65
- Was wet now dry
- Was dry now wet

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0 800 1600 m

Scale in metres (1:35000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Lismore Floodplain Risk Management Study

Figure 4.5 - Climate Change Analysis 1% AEP Impact Mapping

Job Number: M76000_004
Revision: 0
Drawn: SW
Date: 18 /9 /2020

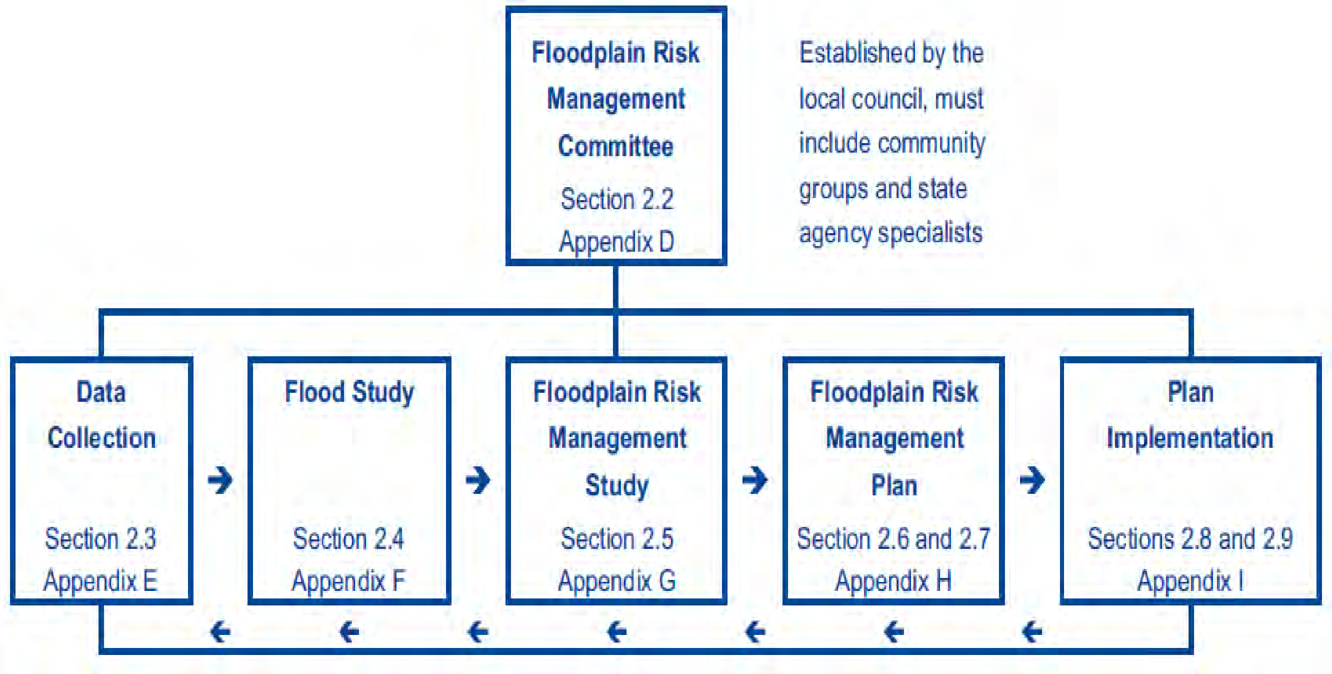
5 Floodplain Risk Analysis

5.1 OVERALL APPROACH

The Lismore FRMS has been undertaken in accordance with the NSW Government's Floodplain Development Manual (DIPNR, 2005). The project has also included a flood study update therefore comprises Stages 1 and 2 of the Floodplain Risk Management Process which includes the following components:

- Stage 1 Flood Study.
- Stage 2 Floodplain Risk Management Study.
- Stage 3 Floodplain Risk Management Plan.

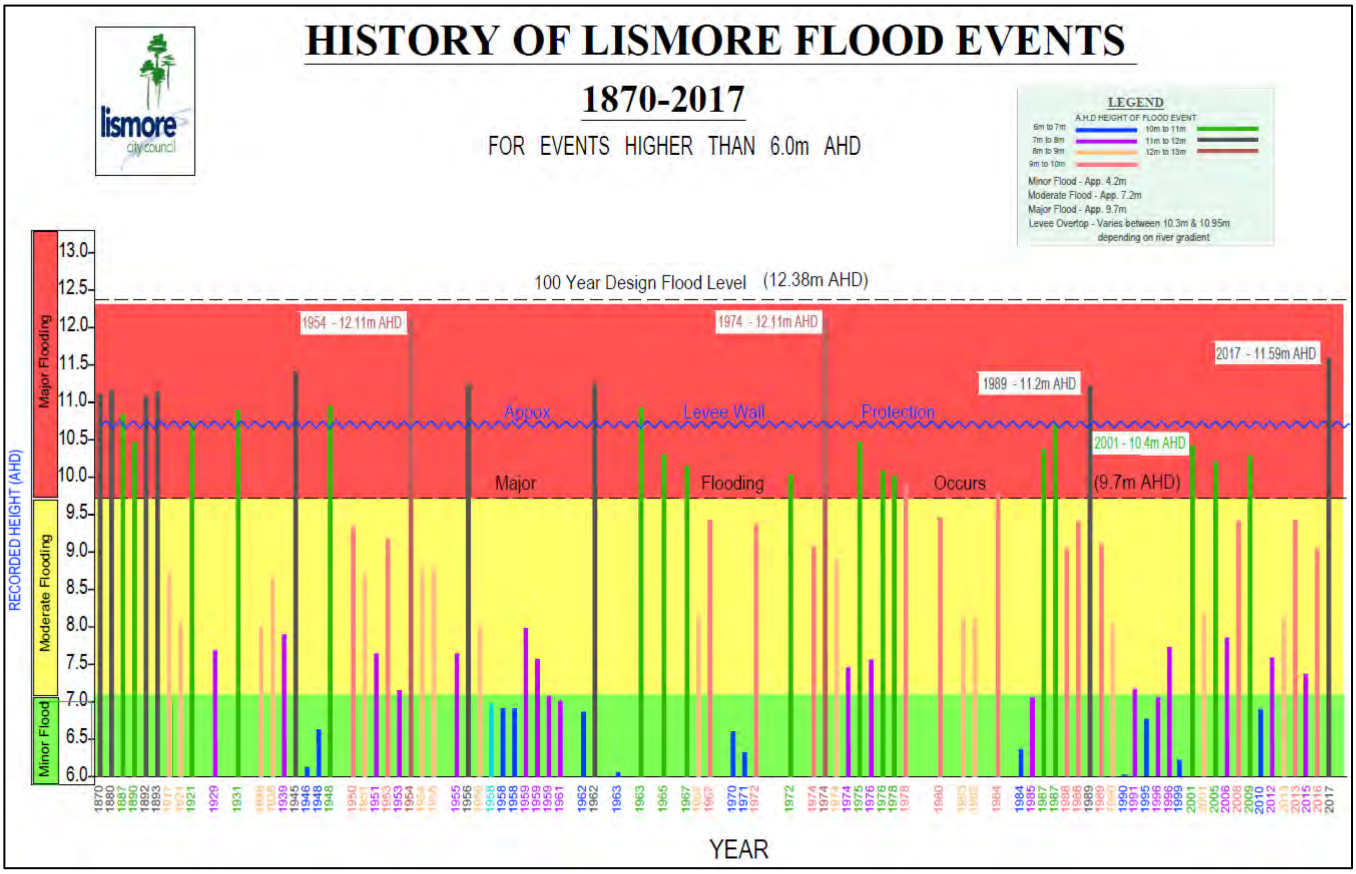
The Process as outlined in the Floodplain Development Manual is illustrated in the diagram below.



5.2 HISTORICAL FLOOD BEHAVIOUR

Lismore has historically experienced significant flooding, with records indicating that approximately 30 historical flood events at Lismore being classified as major flood events, with the flood height exceeding 9.7 m AHD. Of these events, twelve were of a magnitude large enough to overtop the current CBD levee, with any events exceeding 9 m AHD prior to the construction of the levee (completed in 2005) causing flooding of residential and commercial areas in Lismore. A graphical history of flooding events in Lismore is shown in Figure 5.1. Note that the 1% AEP level noted on this graph is from modelling completed prior to this study. The modelled 1% AEP flood level for Lismore is 12.47 m AHD. The largest floods on record are the 1954 and 1974 floods, both a result of cyclonic rains, however these floods did not reach a 1% AEP flood magnitude from this Study.

Figure 5.1: Lismore Historical Flood Event Record



Simulation of the 1989, 2012, 2013 and 2017 flood events was undertaken as part of the joint hydrologic and hydraulic calibration for this Study. *Section 3.3* outlines the calibration results from these events. Further description of the behaviour of these events, and others, are discussed in the following sections.

5.2.1 Historical Event Magnitude

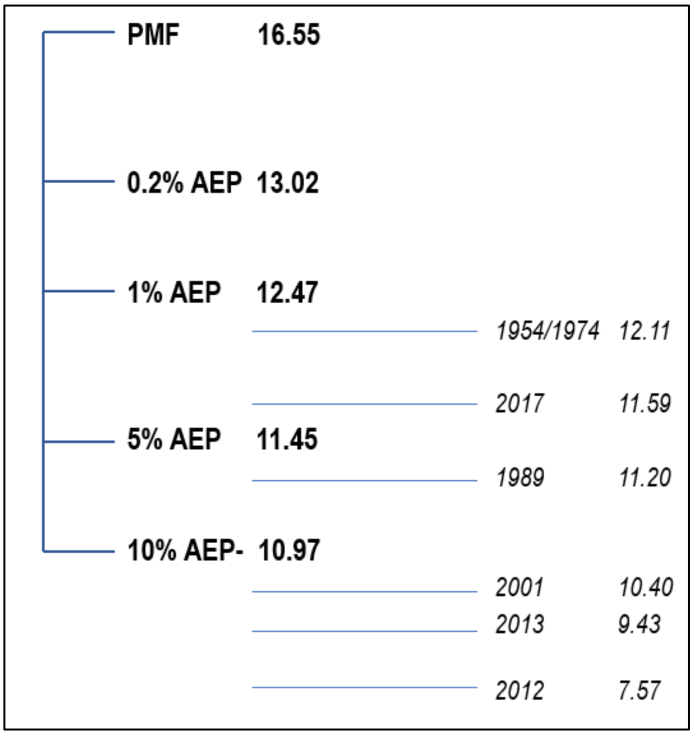
Through the calibration process and design flood modelling, the magnitude of the modelled four historical events are able to be approximated on a simulated flood height basis at three key flood gauge locations, as summarised in Table 5.1.

Graphical representation of historical events plotted against this Study's design event flood height results at the Lismore Rowing Club gauge are shown in Figure 5.2.

Table 5.1: Approximate Historical Event Flood Magnitude

Location	1989	2012	2013	2017
Wilsons River at Woodlawn College - 203402	<10% AEP	<10% AEP	<10% AEP	5% AEP
Leycester Creek at Tuncester – 203443	5% AEP	<10% AEP	<10% AEP	1% AEP
Wilsons River at Lismore - 203904	10% AEP	<10% AEP	<10% AEP	5% AEP

Figure 5.2: Historical Event Magnitude – Lismore Rowing Club Gauge



5.2.2 2017 Event Behaviour

As the most recent flood event of a magnitude to cause overtopping of the levee, the 2017 flood event behaviour is well documented. The following is a summary of the observed flood behaviour timeline for the actual event:

- 6pm 29 March – Rainfall begins in the Northern Rivers region and lasts approximately 30 hours.
- 2:55pm 30 March – Lismore gauge exceeds the minor flood threshold.
- 7:40pm 30 March – Lismore gauge exceeds moderate flood threshold.
- 12:45am 31 March – Lismore gauge exceeds major flood threshold.
- 4:00am on 31 March – CBD levee overtops at Browns Creek spillway.

5.2.3 1989 Event Behaviour

The 1989 event consisted of a significant flood on Leycester Creek and an insignificant flood on Wilsons River. During the initial stages of this event, floodwaters were observed to flow in an upstream direction on Wilsons River. Floodwaters were observed to overtop the South Lismore levee at Kyogle Road due to the railway embankment and in the vicinity of Snow Street, initially by floodwaters from the airport floodway.

5.3 DESIGN FLOOD BEHAVIOUR

5.3.1 Flooding Observations

The following sections briefly describe the flood behaviour observed across Lismore based on anecdotal information from historical events, previous studies and observations from this study's flood modelling results. Key flow paths are shown on Figure 5.3.

Central Lismore Flood Behaviour

Flooding at Lismore occurs due to flows within Leycester Creek and Wilsons River, either separately or concurrently. The influence of different flooding mechanisms is investigated in *Section 4.3.1*. In terms of elevation and floodplain characteristics, the Leycester Creek floodplain is located at a higher elevation than Wilsons River by 2-2.5 m, while the Wilsons River branch is low-lying with wider floodplains. In the instance that an event is dominated by Leycester Creek, flow direction can reverse in the Wilsons River branch as this wider floodplain storage is filled.

Much of the CBD portion of Lismore is protected from Wilsons River by the CBD levee, which has two spillway locations. These are located at Browns Creek and at Gasworks Creek. Overtopping is first observed at the Browns Creek spillway at an elevation of between 10.6-10.7 m AHD on the Rowing Club gauge, followed by flows overtopping at Gasworks Creek. Most of the CBD drains freely via Browns Creek at the beginning of an event, through culverts connected to the Wilsons River at the Browns Creek Pump Station. However, once the Wilsons River rises, the floodgates on these culverts are closed and pumps are used to drain local flood flows from central Lismore. A second pump station is also located at Gasworks Creek. For any properties outside of the levee, including those on Molesworth Street, Coleman Street and Brunswick Street, flooding of this area occurs when the Rowing Club gauge reaches 5 m AHD.

North Lismore Flood Behaviour

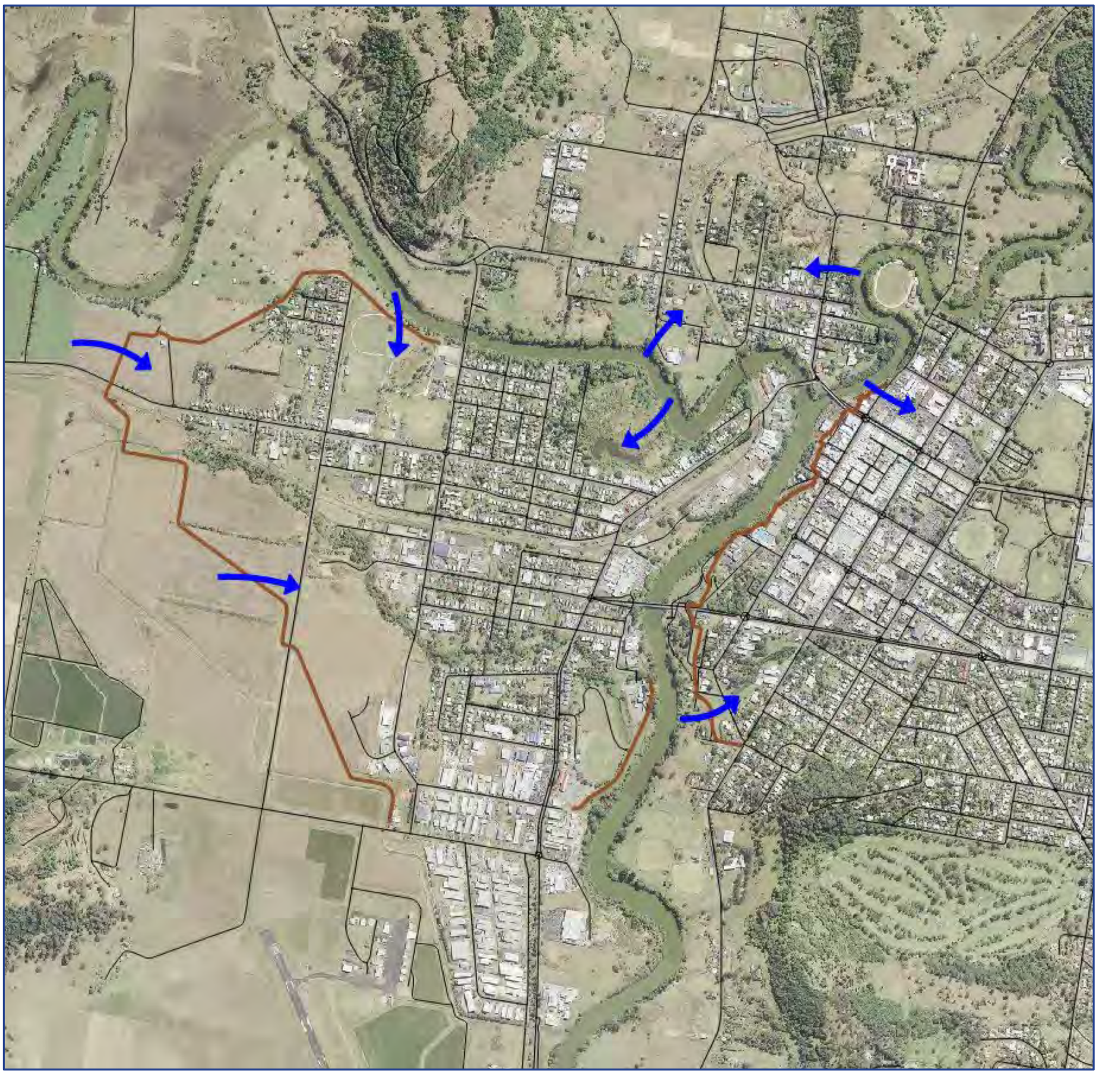
North Lismore is initially impacted by Wilsons River flooding backing up Slater Creek, inundating low-lying areas which extend from the Showground past McKenzie Park to the Wilsons River when water levels at the Rowing Club gauge exceed 4.3 m AHD. Above approximately 9.3 m AHD on the Rowing Club gauge, most roads are cut in North Lismore. Flows breakout from Leycester Creek and Wilson River across North Lismore. Floodwaters from Wilsons River first inundate North Lismore at Bridge Street and Bray Street and floodwaters from Leycester Creek breakout at Tweed Street and Bouyan Street

South Lismore Flood Behaviour

South Lismore is initially protected from flooding by the South Lismore levee, with breakout flow from Leycester Creek directed down the airport floodway. Flooding of low-lying areas in the vicinity of the Bowling Club north of Casino Street and east of Ostrom Street is observed early in the event. A flood gate on Hollingworth Creek prevents backflow from the Wilsons River, but local flows then cause flooding in South Lismore.

The first over-topping of the South Lismore levee is typically observed in the north-west corner in the vicinity of the Bowling Club. The South Lismore levee will then be overtopped at Caniaba Street if floodwaters continue to rise. It is not simple to link the overtopping of the South Lismore levee to a measured flood height at the Lismore Rowing Club. If a significant flood occurs on Leycester Creek, but not Wilsons River, the Rowing Club gauge can read as low as 7.6-8.6 m AHD when the South Lismore levee overtops. If both water courses are flooding the Rowing Club gauge can read between 10.0-10.2 m AHD when the South Lismore levee overtops. During a Wilsons River flood, the Rowing Club gauge will still read between 10.0-10.2 m AHD when the South Lismore levee overtops and South Lismore will experience back-flooding from the riverbend just west of Union Street.

Figure 5.3: Flow Path Directions



5.3.2 Design Event Flood Behaviour

A summary of the observed flood behaviour for the modelled design events in this study is provided in Table 5.2, Table 5.3 and Table 5.4. A comparison of the results from this Study suggests that the flood levels are generally higher than LCC's currently adopted 1% AEP levels. For example, the currently adopted 1% AEP flood level for City Hall located at 1 Bounty Street is 12.3 mAHD, whereas this Study has predicted a 1% AEP flood level of 12.33 mAHD. Whilst this comparison shows a minor difference of 30 mm, this may not consistent across Lismore and a more detailed comparison should be undertaken including consideration of potential implications to both Council and property owners such as insurance costs and development potential to name a few.

Table 5.2: Design Event Flood Behaviour – North Lismore

Flood Event	Flood Behaviour
10% AEP	Peak flood levels are approximately at 11.3 - 11.6 m AHD. Properties on Macaulay Street remain flood free.
5% AEP	Peak flood levels are approximately at 12 m AHD.
1% AEP	Peak flood levels are approximately at 12.8 m AHD.

Flood Event	Flood Behaviour
0.2% AEP	Peak flood levels are approximately at 13.3 m AHD.
PMF	Peak flood levels are approximately at 16.9 m AHD.

Table 5.3: Design Event Flood Behaviour – Central Lismore

Flood Event	Flood Behaviour
10% AEP	Peak flood levels are approximately at 10.3 m AHD. Isolated overtopping of the levee is observed; around the north-eastern edge and at Browns Creek spillway.
5% AEP	Peak flood levels are approximately at 11.5 m AHD. Overtopping of the CBD levee along its full length is observed.
1% AEP	Peak flood levels range from approximately at 12.1 to 12.5 m AHD. Overtopping of the CBD levee along its full length is observed.
0.2% AEP	Peak flood levels range from approximately at 12.8 to 13.0 m AHD. Overtopping of the CBD levee along its full length is observed.
PMF	Peak flood levels range from approximately at 16.3 to 16.7 m AHD. Overtopping of the CBD levee along its full length is observed.

Table 5.4: Design Event Flood Behaviour – South Lismore

Flood Event	Flood Behaviour
10% AEP	Peak flood levels range from approximately at 9 to 11.5 m AHD South Lismore levee not overtopped. Backwater up Hollingworth Creek observed, due to overtopping at Riverview Park. Some overtopping at eastern end of South Lismore levee.
5% AEP	Peak flood levels range from approximately at 11 to 12 m AHD South Lismore levee overtopped north of railway.
1% AEP	Peak flood levels range from approximately at 11.6 to 12.8 m AHD. South Lismore levee overtopped along length.
0.2% AEP	Peak flood levels range from approximately at 12 to 13.3 m AHD. South Lismore levee overtopped along length.
PMF	Peak flood levels range from approximately at 15.5 to 16.8 m AHD. South Lismore levee overtopped along length.

5.3.3 Hydraulic Controls

There are numerous hydraulic controls located throughout Lismore that have an impact on flood behaviour. A summary of each hydraulic control is provided in Table 5.5

Table 5.5: Major Hydraulic Controls

Item	Description
South Lismore Levee	The South Lismore levee directs flows around South Lismore and through the airport channel in smaller flood events. Overtopping is first observed at the Bowling Club before overtopping is observed over the full length of the levee.

Item	Description
CBD Levee	The CBD levee is a combination of concrete and earthen embankment and forms protection for the CBD from Wilsons River flooding as well as a constraint for drainage of local CBD flooding. Spillways for the levee are located at Browns Creek and Gasworks Creek. Manually operated gates are located along the levee length.
Gasworks Creek Floodgates	The Gasworks Creek culvert floodgates enable drainage from the CBD prior to flood rise in the Wilsons River. Once the Wilsons River rises the gates are closed to minimise backwater from the river through the CBD.
Hollingworth Creek Floodgates	The Hollingworth Creek floodgates enable drainage from South Lismore prior to flood rise in the Wilsons River. Once the Wilsons River rises the gates are closed to minimise backwater from the river through South Lismore.
Pump Systems	Pump systems located at Gasworks Creek and Browns Creek are utilised in a flood event to drain local flooding during a major flood event where the CBD floodgates are closed.
Airport Channel	The recent works undertaken by Lismore City Council in the airport channel increases conveyance of floodwaters and reduces flood heights through the airport channel in comparison to the pre-excavation scenario, however adverse impacts were observed due to the filling of development pads. The flood impact assessment results for the airport channel works are provided in *Appendix E*.
Bruxner Highway	In flood events not large enough to cause overtopping of the highway, the highway forms a hydraulic control, with flow controlled through key bridge and culvert structures.
Unused Railway Embankment	The unused railway embankment located near Kyogle Road, South Lismore forms a hydraulic control in minor flood events, restricting flow to South Lismore and increasing flow through Leycester Creek.

5.3.4 Flood Function and Hydraulic Categorisation

In accordance with the Lismore Floodplain Risk Management Plan (LCC, 2014) (hereafter referred to as the 2014 Plan), four main Flood Risk Precincts were identified to describe flood hazard in the Lismore floodplain. This was the result of a review undertaken by the Floodplain Management Committee (FMC) at the time which determined that the standard *NSW Floodplain Development Manual* (DIPNR, 2005) hydraulic categories did not adequately describe the hazard experienced in Lismore, particularly in the Flood Fringe category. As such, Lismore City Council undertook work, with funding assistance from DPIE (previously OEH), to categorise flood risk across the Lismore area. The Flood Risk Precincts criteria and applicability to Lismore are summarized in Table 5.6. The Flood Risk Precinct categorisation also considers flood warning times, ease of evacuation and effective flood access.

Table 5.6: Flood Risk Precincts from Lismore Floodplain Risk Management Plan (2014)

Precinct	Definition and Characteristics	Hydraulic Criteria (1% AEP Flood Event)	Applicable Areas
Floodway Precinct	Areas of the floodplain where the majority of flood discharge occurs. These areas are generally aligned with naturally defined channels. The risk to humans, animals and some structures in some floods may be extreme.	Flood Depth > 0.5 m, and Flood Velocity > 0.85 m/s, and Depth x Velocity Product > 1.0 m^2/s.	Naturally defined channels, including Wilsons River, Leycester Creek, Hollingworth Creek, Gasworks Creek and Browns Creek.
High Risk and Flood Isolated (Evacuation) Precincts	Areas in which there is: • Potential for flood waters to cause danger to personal safety and/or loss or damage to light structures such as houses. Able bodied adults could have difficulty wading to safety; and/or • Possible danger to personal safety of residents and emergency personnel due to inadequate evacuation routes and time available for evacuation. The High Risk Precinct includes those areas described by the Floodplain Development Manual as 'flood storage' areas, which are important for the temporary storage of flood	Flood Depth < 0.5 m, and Flood Velocity > 2 m/s. **OR** Flood Depth < 1.2 m, and Flood Velocity < 2 m/s, and Depth x Velocity Product 0.6 - 1.0 m^2/s. **OR** Flood Depth > 1.2 m, and Flood Velocity < 0.85 m/s.	High Risk Precincts include North Lismore and Central Basin Area. High Risk and Flood Isolated (Evacuation) Precincts include South Lismore.

Precinct	Definition and Characteristics	Hydraulic Criteria (1% AEP Flood Event)	Applicable Areas
	waters during the passage of a flood. Flood storage areas are characterised by deep water and low velocity. The loss of flood storage, for example by filling, can increase the severity of flood impacts. In Lismore, the central basin area is a flood storage area.		
Medium Risk Precinct	Applies to the areas of flood liable land within the 1% AEP flood extent, excluding the Floodway Precinct and High Risk Precincts. In these areas the risk of damage to buildings is not high and residents are able to evacuate with relative ease due to the proximity of higher ground, numerous possible evacuation routes and sufficient warning time.	Flood Depth < 1.2m, and Flood Velocity < 2 m/s, and Depth x Velocity Product < 0.6 m^2/s.	Central Lismore Area and East Lismore/Girards Hill, East Lismore south of Nielson Park.
Low Risk Precinct	Applies to the areas of flood liable land within the extent of the PMF, but outside the extent of the 1% AEP flood event. There is a low probability of an event of such magnitude inundating these areas occurring.	N/A.	All areas affected by the PMF event but not included in a previous classification.
Additional Classifications	South Lismore Flood Isolated • Area located south of Cook Street where filling has occurred to ensure buildings are flood immune in the 1% AEP event. Can become a refuge, as these areas are isolated by flooding over access roads. CBD Flood Liable • Recognises the unique nature of the CBD development as being sturdy structures and containing levels above the 1% AEP flood, although located within the Medium Risk Precinct.		

A review of the hydraulic criteria and applicable areas as presented in the 2014 Plan has been undertaken based on the flood modelling results from this study and the following recommendations should be further considered:

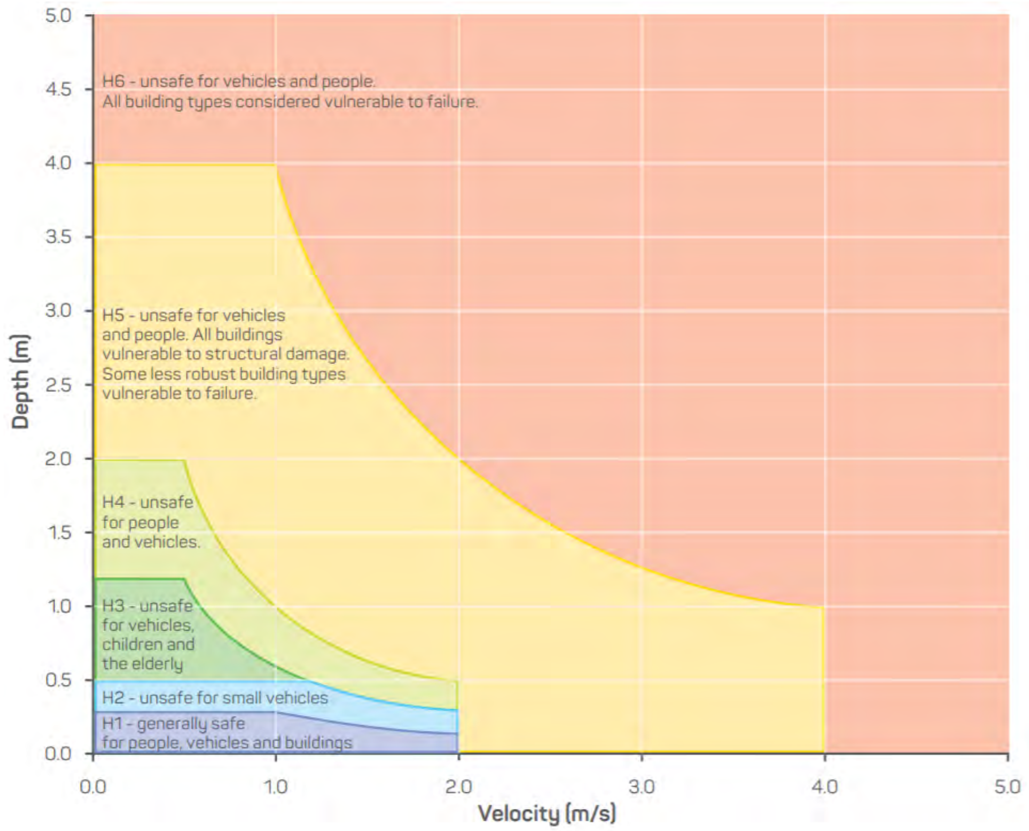
- **Floodway Precinct**: Floodway is underestimated for the Wilsons River upstream of the confluence with Leycester Creek. This is inconsistent with the Floodway represented on Leycester Creek and areas west of the flood levee through South Lismore where a broader flood conveyance corridor is represented. As such, the Floodway could be redefined to include the wider Wilsons River channel upstream of the confluence which is considered to be more closely aligned with flood hazard classification H6 (refer to Figure 5.4).
- **High Flood Risk and Flood Isolated (Evacuation) Precincts**: The defined precinct and applicable areas are considered reasonable and are relatively consistent with hydraulic results from this study. The precinct areas broadly relate to the H5 and H6 flood hazard classification. It is noted that the hydraulic hazard categories and map provided in the Lismore Development Control Plan (DCP) (Chapter 8 – Flood Prone Lands) differs from the defined flood risk precincts in the 2014 Plan and therefore it is recommended that the Lismore DCP be reviewed with consideration for the 2014 Plan and this study.
- **Minimum Risk Precinct, CBD Flood Liable, East Lismore Flood Liable and South Lismore Flood Isolation**: The defined precinct and applicable areas are considered reasonable and are relatively consistent with hydraulic results from this study. The precinct areas broadly relate to the H3, H4 and H5 flood hazard classification. The flood hazard categorisation for the area defined by the CBD Flood Liable Precinct is H5 and H6. Whilst this CBD area is completely developed, the defined extent and specific use of land within the CBD Flood Liable zone should be reviewed with consideration for the flood hazard results from this study (refer to Figure 5.4). It is noted that the hydraulic hazard categories and map provided in the Lismore Development Control Plan (DCP) (Chapter 8 – Flood Prone Lands) differs from the defined flood risk precincts in the 2014 Plan and therefore it is recommended that the Lismore DCP be reviewed with consideration for the 2014 Plan and this study. These precinct areas are broadly referred to in the Lismore DCP as Flood Fringe Area.
- **Low Risk Precinct**: The defined precinct and applicable areas are considered reasonable and are relatively consistent with hydraulic results from this study. The precinct areas broadly relate to the H1, H2 and H3 flood hazard classification. The Lismore DCP appears to be relatively consistent with the Low Risk Precinct defined in the 2014 Plan, however there are

limited development control restrictions within the Lismore DCP and therefore the need for this risk category should be reconsidered or alternatively, tighter controls should be provided in the Lismore DCP.

Overall, it is recommended that the Lismore DCP be reviewed and updated to account for the findings and recommendations from the 2014 Plan and this study.

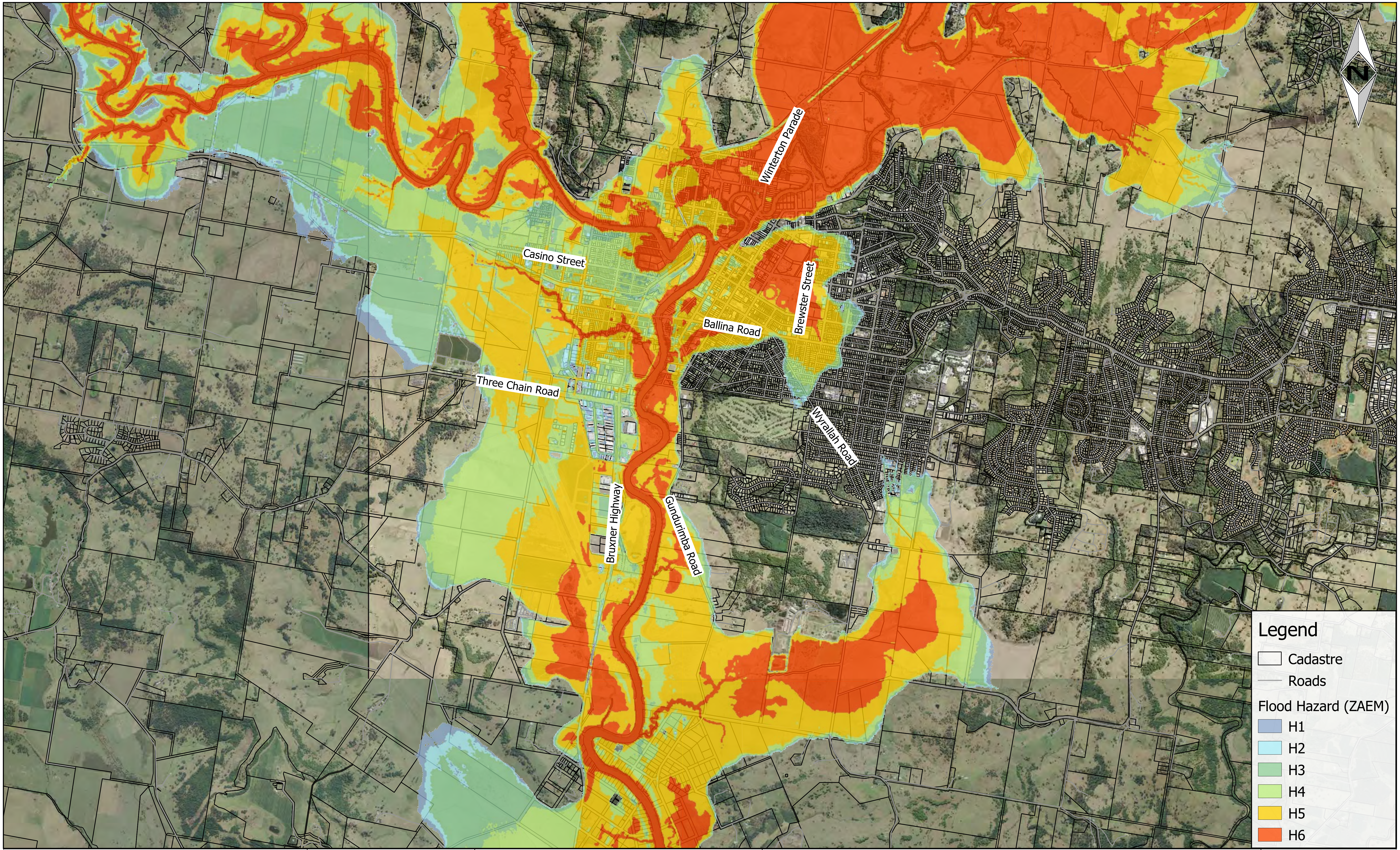
5.3.5 Flood Hazard Classification

A flood hazard map has been prepared for the 1% AEP flood event utilising the general flood hazard vulnerability curves from Australian Institute for Disaster Resilience (AIDR) Handbook 7 (2017) which is illustrated below. The flood hazard map is provided in Figure 5.4.



The flood hazard mapping indicates the following regarding expected flood hazard throughout Lismore during a 1% AEP flood event:

- The main waterways of Leycester Creek, Wilsons River, Hollingworth Creek, in addition to the Browns Creek basin area, are mapped within the H6 area.
- Areas susceptible to H5 hazard flooding, where all buildings are susceptible to damage, and some to failure, include much of the CBD, areas along Hollingworth Creek, and the majority of North Lismore.
- The remaining areas throughout Lismore which are not 1% AEP flood immune are a combination of the H3 (unsafe for vehicles, children and the elderly) and H4 (unsafe for people and vehicles) classifications.



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0 800 1600 m

Scale in metres (1:35000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Lismore Floodplain Risk Management Study

Figure 5.4 - 1% AEP Flood Hazard Mapping (ZAEM1)

Job Number: M76000_004
Revision: 0
Drawn: SW
Date: 18 /9 /2020

5.4 FLOOD IMPACTS

5.4.1 Flood Damage Assessment

Tangible flood damage estimates for Lismore were undertaken using tailored stage-damage curves developed to be representative of likely costs of damages in the Lismore City Council LGA. The following sections outline the key data utilized in the estimate, the development of the stage-damage curves and the resultant flood damage estimates.

The flood damages only take into consideration damage from creek flooding and therefore damage from local catchment flooding has not been included in the estimates. The NSW DPIE flood damage curves are currently being updated however were not released at the time of this Study. It is noted that the flood damage estimates do not represent actual flood damage costs for Lismore and are therefore indicative only.

Data

The building polygons GIS layer and floor survey were integral to the flood damage estimate. The datasets were created in 2013 by Lismore City Council following survey undertaken in the township. The following information from these datasets were utilised in the flood damage estimate:

- Floor level.
- Gate level.
- Street level.
- Building footprint area and geographic locality.

The development of the flood damage curves is discussed in the following sections.

Residential Flood Damage Curves

The residential flood damages were calculated based upon modified stage-damage curves developed by O2 Engineering for Ipswich City Council in 2011 (O2 Engineering, 2011), hereafter referred to as the Ipswich curves. These curves were developed as existing commonly used stage damage curves, such as ANUFLOOD, RAM and the NSW OEH Curves (OEH, 2007), tend to significantly under-predict flood damages, particularly at higher depths (Markar and Mirfenderesk, 2010). These existing curves are typically around 20 years old and building materials, costs and methodology has changed significantly over this time.

The Ipswich curves were developed using a range of information, including curves derived by Kellogg Brown and Root (KBR, 2011), rebuilding costs from the 2011 flooding and structural damage estimates. The Ipswich curves break residential damages into three separate categories; External Damage, Contents Damage and Structural Damage. Therefore, damages were calculated separately for each of these three categories.

The Ipswich Curves have been updated for use in the Lismore FRMP, with modifications as summarised below:

- Inflate all damage curves using the Consumer Price Index (CPI). This has been done using the ratio of CPI in June 2011 to June 2020 using information provided by the ABS (ABS, 2020).
- Assume that 80% of External Damage occurs at 0.5 m depth of above ground flooding; and assume that 80% of first storey Contents Damage occurs at 1 m depth of above floor flooding.
- Assume that there are no double storey properties within the Lismore floodplain, with high-set properties being the predominant dwelling type.
- Use of a Post Flood Inflation Factor to account for the cost of material and labour increasing due to higher demand for structural repairs. This is applied as a multiplier to structural damages. A value of 1.3 has been applied based on the values recommended in the NSW OEH (OEH, 2007) residential damage calculator.
- Use of a Regional Cost Variation Factor to account for the different construction costs in different areas. This was applied as a multiplier to structural damages. There was no specific value for Lismore and therefore a default value of 1 has been applied.

Maximum Water Surface Elevation (WSE) rasters for each modelled event were sampled using property polygons supplied by Lismore City Council. The resulting attribute table was then extracted into an Excel spreadsheet and the mean WSE within each building polygon was then assigned. These values were then used to calculate the above ground depth and above floor depth.

The flooding depths along with the stage damage curves were used to calculate the flood damage for each building for each event.

The flood damages were then amalgamated and the Annual Average Damage (AAD) and Net Present Value (NPV) calculated. The AAD represents the average cost per year of flood damages over a long time period while the NPV was calculated by projecting the AAD forward 50 years with a discount rate (4%, 7% and 11% per annum were used) to calculate the current value of flood damages.

Actual vs Potential Damages

The Ipswich curves are potential damage curves and do not take into account the behaviour of the occupants during a flood. Therefore, the Stage-damage Curves for Current Flood Risk Management Studies Memo (O2 Engineering, 2011) recommends using an Actual vs. Potential Damage multiplier. The values for this multiplier have been derived from the RAM calculations and are based on the assumptions that:

- A more experienced community will take more action to limit their external and contents damage (e.g. lifting contents on to tables, moving cars out of the floodplain).
- The more flood warning time that is available, the more action can be undertaken.

Given that there were significant floods in 2017 it was assumed that the community is experienced. Therefore, an Actual v. Potential Damage multiplier of 0.64 was applied as the warning time was 6 hours.

Commercial Damages

O2 Engineering (2011) applied the ANUFLOOD commercial damage curves, which were developed in the 1990's and acknowledged that these are likely to be an under-estimate of current commercial damages. Rather than apply the Ipswich curves with respect to Commercial and Industrial damages, the stage damage curves derived by Middlesex University for damages within the United Kingdom and presented in the Multi-Coloured Manual (MU, 2010) have been utilised as a starting point for these damages. It is likely that commercial and industrial premises in the United Kingdom are similar to those in Australia and so these have been applied, converting the 2010 UK Pound values to 2020 AUD.

The Middlesex University curves include 69 different categories of commercial and industrial operations with a stage-damage curve for each category. In assigning the different curves to identified commercial and industrial properties within the study area, the following assumptions have been made:

- Where, land use classified as "Local Centre" or "Commercial Core" within the Lismore Interactive Mapping (Lismore City Council 2020), the properties were classed as "Small Shops" with an average building footprint of 300 m^2.
- Where a land use classified as "General Industrial" or "Light Industrial" within the Lismore Interactive Mapping (Lismore City Council 2020), the properties were classed as "Medium/Large Warehouses" with an average building footprint of 500 m^2.
- With remaining impacted property boundaries with building footprints classified as "residential". Residential properties were classified into either "single storey high set (raised above 1.5 m)" or "single storey with slab (<0.5 m)".

Residential Flood Damage Estimate

The total tangible direct and indirect flood damage per AEP associated with residential buildings is summarised in Table 5.7. This estimate includes damages associated with external, contents and structural damage. The estimate is dependent on building footprint, residential structure type and depth of flooding. The event damages provided below also include an additional 15% to account for indirect damages.

Table 5.7: Lismore Residential Damage per Annual Exceedance Probability

AEP (1:x)	AEP Event Damage ($)
PMF	$648,500,000
500	$260,600,000

AEP (1:x)	AEP Event Damage ($)
100	$183,300,000
20	$106,700,000
10	$48,600,000

Commercial and Industrial Flood Damage Estimate

The total tangible direct and indirect flood damage per AEP associated with commercial buildings is summarised in Table 5.8. This estimate is largely dependent on building footprint and business type. The estimate does not include sheds located on residential property without a clear commercial use, regardless of footprint. The event damages provided below also include an additional 15% to account for indirect damages.

Table 5.8: Lismore Commercial and Industrial Damage per Annual Exceedance Probability

AEP (1:x)	AEP Event Damage ($)
PMF	$962,600,000
500	$676,000,000
100	$546,400,000
20	$339,400,000
10	$123,300,000

Total Estimated Flood Damages

Average Annual Damage (AAD) is used to account for the probabilistic nature of flood damages. It represents the theoretical tangible damage incurred on average each year if a very long period of flood records is considered. It takes into account the value of the damage in each flood and the probability of the flood. A summary of the total damages in Lismore due to flood and the contribution of each event to the AAD is summarised in Table 5.9. The estimation of average annual damages (AAD) involves calculating the area underneath the curve shown in this figure. The 5% AEP flood event contributes the largest to the AAD in Lismore, whereas the 20% AEP flood event contributes the least.

Table 5.9: Lismore Total Damage per Annual Exceedance Probability

AEP	AEP Event Damage ($)	Contribution to Average Annual Damage ($)
PMF	$1,611,100,000	$2,550,000
500	$936,600,000	$6,670,000
100	$729,700,000	$3,650,000
20	$446,000,000	$15,450,000
10	$171,900,000	$34,370,000
	TOTAL AAD	**$62,690,000**

Intangible Flood Damages

Tangible impacts are those that can be readily measured in monetary terms. They include the direct damages on goods and possessions, and indirect damages, such as loss of wages and other economic costs. These have been estimated in the sections above.

Intangible damages include direct intangible impacts such as fatalities, injuries and water borne diseases as well as the loss of pets and memorabilia and environmental damage. They also include indirect intangible damages such as emotional stress, mental health issues, illness and financial hardship. Intangible damages cannot be readily quantified in monetary terms. Nevertheless, they are real and represent a significant cost to the community and individuals.

Potential intangible damages in Lismore include:

- Potential financial hardship in flood recovery - the Australian Bureau of Statistics (ABS) 2016 census data reports that the median household income in Lismore is $1,021/week (Refer to *Employment and Income*) which is lower than the New South Wales ($1,486/week) and Australian ($1,438/week) averages. However, anecdotal information indicates that there are many households with a much lower income than the ABS data suggests.
- Economic damage – Owners and employees of these businesses may experience loss of income following a flood event as their place of work undergoes flood recovery adding to the financial hardship of flood recovery.
- As floodwaters for all flood events contain areas of extreme hazard, there is potential for fatalities and injuries in an extreme event.

5.4.2 Impacts of Flooding on the Community

The potential number of residents affected by above floor creek/river flooding in each of the flood events simulated is summarised in Table 5.10. These estimates were based upon multiplying the number of buildings affected by above floor flooding (refer to *Section 6.4.1*) by an average number of 2.3 people residing in a single dwelling as provided by the ABS 2016 census data.

Table 5.10: *Estimated Number of People in Lismore Impacted by Above Flood Flooding per Flood Event (Residential)*

	10% AEP	5% AEP	1% AEP	0.02% AEP	PMF
Number of People Potentially Impacted by Above Floor Flooding	44	782	1967	3066	4506

Key socio-economic statistics from ABS were used to develop a social profile of the Lismore community and to classify the vulnerability of the community. The latest census results (ABS, 2016) were assessed to provide a summary of the social profile of Lismore (Significant Urban Area) and highlight any vulnerability associated with the community due to this profile. It is noted that these statistics relate to Lismore as a whole and not specifically to the community located within the floodplain.

Age and Household Structure

The Lismore community was made up of 28,407 residents at the time of the 2016 census (ABS, 2016) and there were approximately 12,615 dwellings in Lismore at the time. The median age in Lismore is 41 years, which is slightly higher than the New South Wales (38) and Australian (38) averages. Table 5.11 shows the age distribution of residents in Lismore.

Table 5.11: Distribution of Ages of Residents in Lismore

Age Group (years)	Proportion (%)
0-4	5.5
5-14	12.3
15-29	19.1
30-49	24.0

Age Group (years)	Proportion (%)
50-64	20.2
65-84	15.7
85+	3.4

Vulnerable Residents

The ABS data indicates that approximately 7% of Lismore's residents require assistance due to age and/or disability. This census response was in reference to requiring assistance generally, not necessarily in reference to an emergency event. Therefore, these residents are likely to require assistance to evacuate or self-protect in a flood event due to potential mobility issues. The hearing-impaired members of the community in Lismore are also particularly vulnerable to flood risks and will require specific flood emergency response and recovery assistance. Flood awareness and community engagement programs should specifically address the needs and challenges of all vulnerable community members.

Residents that are particularly young or old could also be particularly vulnerable in a flood event due to a higher likelihood of requiring assistance to respond in a flood event. In Lismore, 25% of the population is either above 65 years of age or under 5 years of age.

Cultural and Linguistic Diversity

Approximately 83% of the residents of Lismore were born in Australia, with the next most common countries of origin being England and New Zealand. About 88% of residents are considered to speak English at home, with 6.9% of households stating that they spoke a language other than English at home.

The predominance of the English language in the Lismore community indicates that most residents will not require translation services in order to communicate with Council or emergency services in a flood event.

Internet Access

Approximately 77% of households in Lismore are reported to have internet access in the dwelling, this could be via any applicable means such as computer, phone or tablet, etc. A reasonable percentage of the population having access to the internet suggests the potential for the community to receive flood information and warnings through via the internet (i.e. BoM website, Lismore Disaster Dashboard, etc.).

Employment and Income

The median household income was reported to be around $1,021/week, which places Lismore below the New South Wales ($1,486/week) and Australian ($1,438/week) averages. Additionally, 27.5% of households were reported to have a weekly household income of less than $650. Weekly income can be a useful statistic to indicate the potential uptake of flood insurance and the ability of residents to recover financially following a flood event. The lower median household income suggests that additional resources and recovery efforts may be required.

Home Ownership and Dwelling Type

Approximately 62% of dwellings in Lismore are owned (either outright or under mortgage) by the residents, with around 34% being rented. The rental population may have limited flood experience and less access to community flood preparedness education including understanding of local warnings.

The average number of people per dwelling is reported to be 2.3 per household. The typical dwelling type in Lismore is a separate house. It is noted that there are a number of highset where illegal lower level living occurs. This should be considered with emergency management and flood damage estimation.

Social Capital

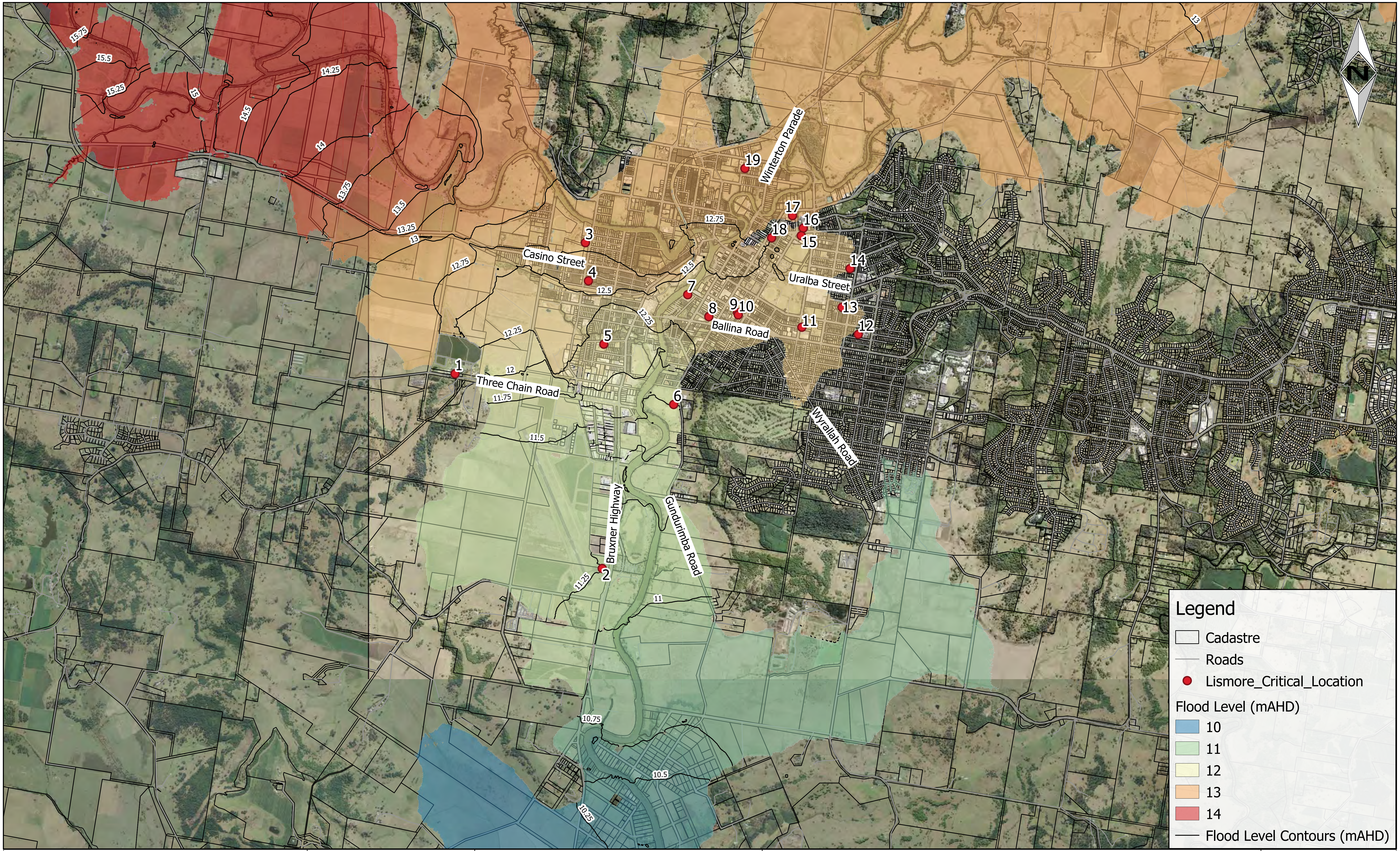
The census data stated that 21.9% of the population of Lismore reported participating in voluntary work through an organisation or group in the last 12 months, which is slightly higher than the New South Wales (18.1%) and Australian (19.0%) averages. This could indicate the community's willingness to network and assist others in a flood event, noting that some may volunteer for emergency services.

Vulnerable Land Uses and Infrastructure

The following land uses and infrastructure summarised in Table 5.12 could be considered particularly vulnerable in a flood event, classified by their locality within the 1% AEP flood extent. The locations of these land uses are shown on Figure 5.5, utilising the mapping identification number provided in Table 5.12.

Table 5.12: Vulnerable Land Uses and Infrastructure

Location	Mapping ID
South Lismore Waste Water Treatment Plant	1
Lismore Airport	2
Possums Early Education Centre	3
Lismore South Public School	4
Our Lady Help of Christians Primary School	5
Albert Park Public School	6
First Steps Early Learning Centres	7
Rainbow Region Kids	8
Living Kinder	9
Living School Lismore	10
Lismore Preschool	11
Lismore Public School	12
RSL LifeCare - Aged Care Home Lismore	13
Northern Rivers Family Day Care	14
St Joseph's Site Trinity Catholic College	15
St Carthage's Primary School	16
Trinity Catholic College Lismore	17
The Learning Cottage Early Education	18
Richmond River High School	19



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0 800 1600 m

Scale in metres (1:35000 @ A3)

Map Projection: Tranverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Lismore Floodplain Risk Management Study

Figure 5.5 - Vulnerable Land Uses and Infrastructure

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Drawn: SW
Date: 18 /9 /2020

6 Floodplain Risk Management

Managing flood risk is important to improve community resilience to flooding and limiting flood risk growth (from increased floodplain development, and changes to climate and floodplain topography). Achieving effective management involves encouraging or promoting the:

- Management of existing, future, and residual flood risk for local communities using the range of treatments available.
- Engagement with, and active participation of, the local community in managing the flood threat they face.
- Inclusion of flood risk management outcomes in policies, planning instruments and forward plans.
- Strategic planning and use of floodplains as valuable and sustainable resources capable of multiple uses of benefit to the community. These uses should be compatible with the flood function and flood hazard and aim to limit the impacts of flooding on damage to property and infrastructure, and the wellbeing, health, and safety of the floodplain community. Strategic planning should consider long-term climate, cumulative land use and demographic changes that are expected to influence risk.
- Identification, assessment, and implementation of feasible, practical, and effective options to treat intolerable risks to the existing community, considering their social, environmental, and economic benefits and costs, and their sustainability.
- Sustainable emergency management practices that consider long-term climate variation, and cumulative land-use and demographic changes.
- Management of flood risk to infrastructure and the design of new infrastructure to limit its impacts on flood behaviour; key infrastructure for emergency response and recovery needs to be fit-for-purpose when required.
- Continued aid to the community in recovering from the impacts of floods.

6.1 FLOODPLAIN RISK MANAGEMENT CATEGORIES

Flood risk management opportunities can be broadly separated into three (3) categories: property modification measures; response modification measures; and flood behaviour modification measures.

Figure 6.1 summarises potential flood risk management opportunities under each of the three categories whilst Table 6.1, Table 6.2 and Table 6.3 summarise the applicability of each opportunity in relation to property medication measures, response modification measures and flood behaviour modification measures respectively.

Figure 6.1: Summary of Potential Flood Risk Mitigation Measures (Source: AIDR, 2013)

Option type	Existing developed areas			Future development areas		
	Existing risk		Residual risk	Future risk		Residual risk
	Safety	Damage	Safety	Safety	Damage	Safety
Measures to modify property						
Zoning and development control				High	High	Low[a]
Voluntary purchase	High	High	High			
Voluntary house raising	Low	Medium	Negative[c]			
Flood proofing of buildings	Low	Low				
Access during flood events	High	Low[e]	High	High	Low[e]	High
Measures to modify response						
Community flood awareness & readiness[b,d]	Low[b]	Low[b]	Low[b]	Low[b]	Low[b]	Low[b]
Flood predictions and warnings[b]	Medium[b]	Low[b]	Medium[b]	Medium[b]	Low[b]	Medium[b]
Emergency response planning for floods[b]	Medium[b]	Low[e]	High[b]	Medium[b]	Low[e]	High[b]
Measures to modify flood behaviour						
Levees	High	High	Negative[c]	High	High	Negative[c]
Detention/retarding basins	Medium	Medium	Negative[c]	Medium	Medium	Negative[c]
Flood mitigation dams	Medium	Medium		Medium	Medium	
Bypass flow conveyance	Medium	Medium		Medium	Medium	
Channel improvements	Medium	Medium		Medium	Medium	
Enhance environment						

a. Depends upon consideration of emergency response management issues in strategic planning.

b. These options all rely on each other to be effective.

c. Measures such as house raising and levees reduce risk to property but are known to have an adverse impact on perceived risk to life because people incorrectly assume that property protection measures have eliminated flood risk.

d. There is little qualitative evidence showing community awareness and education campaigns are effective to reliably and perpetually reduce risk.

e. Have no impact on structural damage. However, in some cases, where response times and conditions allow may permit some reduction in contents damage.

Notes: Existing risk: events up to the design flood for mitigation works or the main defined flood event (DFE) for land-use planning

Residual risk: events rarer than the design flood for mitigation works or the main DFE for land-use planning.

Future risk: events up to the design flood for mitigation works or the main DFE for land-use planning.

The ratings in this table are a guide only as the effectiveness will vary dependent upon the individual situation and should be assessed accordingly.

Blank squares may be not applicable or options have nil affect.

High/medium/low relate to positive effects.

Negative relates to potential adverse impacts.

6.2 IDENTIFICATION AND OVERVIEW OF MITIGATION MEASURES

A summary of the flood mitigation options considered for Lismore as part of this Study is provided in Table 6.1. These options were classified as property modifications, response modifications or flood behaviour measures. It is noted that these options were only considered for the purpose of addressing flood risks associated with creek/riverine flooding.

Table 6.1: Consideration of Property Modification Measures

Measure	General Pros	General Cons	Applicability to Lismore	Recommendation
Zoning & Development Control	• Very effective in managing future flood risk. • Relatively low cost to LCC. • Effective planning controls may allow appropriate development in constrained areas.	• Little impact on existing flood risk. • Heavily reliant on suitable planning and development assessment.	Flood risk to future development within Lismore is managed through the Flood Planning Area Overlay in the Lismore Local Environmental Plan 2012 as well as the Lismore Development Control Plan (DCP). There is limited potential for land use intensification in Lismore, particularly South Lismore where flood evacuation is restricted. However, the hydraulic modelling outputs from the Lismore Floodplain Risk Management Study (Engeny, 2020) should be used by LCC to review and manage risks associated with future development and land use zoning.	It is recommended that development controls in the Lismore LEP 2012 and Lismore DCP are reviewed and updated to align with the latest flood risk information from this study as well as consideration for the Lismore Floodplain Risk Management Plan (2014).
Voluntary Purchase	• Completely removes population from the flood risk. • Effective in managing current and future flood risk.	• Can be a costly mitigation measure and sets a precedence for other flood affected properties. • House replacement (like for like) affordability can be an issue. • Voluntary purchase scheme can take significant time to implement.	There is currently a voluntary house purchase (VHP) scheme in place which is administered by LCC with funding assistance from the State Government. There are a number of properties vulnerable to frequent flooding in Lismore and it is understood that the scheme is restricted by the lack of available funding and also the lack of replacement housing at an affordable price. VHP is considered an essential measure to reduce the flood affected population and reduce flood damages and should be further promoted and funded. Further details on the VHP scheme are provided in Section 6.3.2.	It is recommended that LCC review the current VHP scheme and consider solutions to provide affordable housing in flood free areas. It is also recommended that the list of eligible houses be reviewed with consideration for the hydraulic results from this Study.
Voluntary House Raising	• Cost is relatively low in comparison to other structural measures. • Improves flood immunity to houses and therefore reduces flood damage.	• Only mitigates risk to population up to a certain flood level. • Generally, more effective in reducing flood damages rather than overall risk.	There is currently a voluntary house raising (VHR) scheme in place which is administered by RCC. The scheme is funded by private owners with assistance from the State Government. Properties	It is recommended that LCC review the eligibility criteria to provide greater flexibility where warranted. It is also recommended that the list of eligible

Measure	General Pros	General Cons	Applicability to Lismore	Recommendation
	• Residents can remain on property and within their home without significant change. • Can improve property value. • Can reduce insurance costs.	• Can increase residual risk due to perceived increase in safety. • Restricted to certain construction types, i.e. stumps. • Can disadvantage the elderly and disabled residents. • Does not protect property and related infrastructure (sheds, carports etc.) from flooding.	identified as suitable for the scheme are residential houses that are not constructed of masonry or slab-on-ground. VHR is considered an essential measure to reduce the likelihood and consequence of house flooding, particularly due to the funding and relocation challenges associated with the VHP scheme. Further details on the VHR scheme are provided in Section 6.3.1.	houses be reviewed with consideration for the hydraulic results from this Study.
Flood Proofing of Buildings	• Relatively low cost in comparison to other structural mitigation measures. • Improves flood resilience.	• Only effective in reducing flood damages rather than overall risk.	Flood proofing of buildings is considered to be a private matter that property owners would likely need to consider and fund privately. The Lismore LEP 2012 includes some provisions for flood compatible material.	Not recommended, however LCC could provide up to date and relevant information to assist interested property owners.
Access During Flood Events	• Allows better flood event response. • Generally, only requires works within local/state government areas. • Reduces flood risk to roads. • Potentially reduces recovery cost post-event in terms of road repair.	• Upgrading of infrastructure can be costly. • Does not directly reduce flood hazard to properties. • Can increase flood hazard and risk to existing properties as majority of properties are lower than the main access roads.	Whilst flood evacuation is critical to Lismore's response during an event and is limited for South Lismore residents, there is limited potential to provide flood free access due to the complexity and extent of the floodplain. Additionally, raising access roads in the floodplain are likely to result in increased flood risk and hazard to existing properties.	Not recommended, however the increase in evacuation time should be considered when analysing potential levee modification measures.

Table 6.2: Consideration of Response Modification Measures

Measure	General Pros	General Cons	Applicability to Lismore	Recommendation
Community Flood Awareness & Readiness	• Relatively low cost. • Encourages 'ownership' of risk in the community. • Increases flood resilience of the community.	• Does not necessarily reduce flood hazard. • Reliant on community buy-in and ownership.	Increasing community flood awareness and readiness is considered applicable to Lismore residents and is a key measure to reduce flood risk and further increase community resilience.	It is recommended that LCC continue to educate and increase community awareness through its regular business functions (i.e. development assessment, etc.) as well as develop a community awareness strategy to disseminate the latest flood information as part of the Lismore FRMP implementation.
Flood Predictions & Warnings	• Allows for activation of flood response. • Can reduce flood damage costs.	• Requires a reliable and maintained ICT system and therefore can be costly. • Reliant on accurate rainfall forecasting. • Reliant on waterway system with gauging network. • Does not necessarily reduce flood hazard.	Flood warnings and predictions are critical to Lismore's flood response. The flood predictions and warnings are issued by the Bureau of Meteorology (BoM) and the response is controlled by NSW SES in accordance with the Lismore City Local Flood Plan (NSW SES, 2013).	It is recommended that the URBS model from this Study be provided to BoM for review and consideration of use for flood prediction purposes. Additionally, it is recommended that the NSW SES in conjunction with BoM and LCC review the flood warning systems in place for Lismore.
Emergency Response for Floods	• Relatively low cost. • Can enhance community engagement.	• Does not necessarily reduce flood hazard. • Reliant on effective planning and implementation.	Flood emergency response is critical to Lismore's flood risk management. The emergency response is controlled by the NSW SES in accordance with the Lismore City Local Flood Plan (NSW SES, 2013).	It is recommended that the NSW SES in conjunction with LCC review the Lismore City Local Flood Plan in light of the updated flood modelling results from this Study and consider any lessons learnt from the 2017 event.

Table 6.3: Consideration of Flood Behaviour Modification Measures

Measure	General Pros	General Cons	Applicability to Lismore	Recommendation
Levees	• Completely mitigates flood risk up to the design level. • Could provide developable land inside the levee which would otherwise be flood prone. • Can provide protection to properties where building relocation or raising is not possible. • Temporary levees can be installed and relocated as required. • Can become a landmark which attracts tourists.	• By nature, will increase flood risk outside the levee. • Can increase residual flood risk due to perception. • There is a risk of levee overtopping or failing. This can result in significant impact to infrastructure and lives. • There can be the perception that an area is “flood free” resulting in a reduction in flood awareness and preparedness by the community that it protects. • May impact local drainage inside levee and additional infrastructure such as backflow valves and pumps often need to be incorporated into the levee design. • Earthen Levees often require a significant footprint, resulting in additional public land requirements and purchasing of easements. • Can cause adverse impacts to flood levels elsewhere. • Can cause adverse impacts to flood velocities.	Lismore currently has constructed levees in South Lismore and the CBD. Temporary levee installation for flood events is also possible in the CBD. The current levees play a vital role to protect areas up to approximately the 10% AEP event. There may be potential to optimise the current levee protection scheme and improve flood immunity.	Recommended for further assessment as part of this Study. Any potential levee improvements identified in this Study will require further review and investigation including a detailed cost benefit analysis (separate to this Study).
Detention/Retarding Basins	• Can mitigate flood risk up to the design flowrate/volume. • Generally located in upper catchments outside the urban footprint. • Land can be used for other purposes during dry periods, such as sporting fields or parks.	• Can potentially lead to negative impacts through catchment timing affects. • More suited to smaller creek systems. • Potential classification as a referable structure with associated regulatory requirements. • Potential environmental impacts associated with hydrological changes. • Can be governed by topography and geology.	It is not considered that detention or retarding basins are relevant due to the widespread extent of inundation and significant flood storage volumes that would be required to attenuate flows. Additionally, multiple basins would likely be required.	Not recommended for further assessment in this Study.
Flood Mitigation Dams	• Can mitigate flood risk up to the design flowrate/volume. • Can provided integrated flood mitigation/water supply solutions.	• Substantial ongoing operation and maintenance costs. • Potential environmental impacts due to changed flow regimes.	Given that the general dominance of Leycester Creek on Lismore flooding, a significant storage structure would be required in the Leycester Creek catchment. This option has been	Not recommended for further assessment in this Study.

Measure	General Pros	General Cons	Applicability to Lismore	Recommendation
	• Generally located in upper catchments outside the urban footprint.	• Potential classification as a referable structure with associated regulatory requirements. • Can potentially lead to negative impacts through catchment timing affects. • Governed by topography and geology.	considered and investigated in previous studies without the recommendation for implementation. The FMC recommended that this option be excluded from this Study.	
Bypass Flow Conveyance	• Can reduce flood risk up to the design standard. • Could provide developable land which would otherwise be flood prone.	• Potential environmental impacts due to changed flow regimes. • May require continual maintenance due to changing geomorphology.	A Leycester Creek diversion structure has been considered and investigated in previous studies without the recommendation for implementation. The Lismore Floodplain Management Study – Testing of Flood Mitigation Options (Stage 2) in 1994 (SKM) concluded that the option has the potential to significantly impact on the morphological regime of Leycester Creek and the erosive effects caused by the structure. The erosive effects from the 1989 flood were used to validate this conclusion. The FMC recommended that the option be excluded from this study. The removal of railway embankments at Kyogle Road and Union Street could potentially provide an alternative option, although unlikely to provide ethe same benefits as a major creek bypass.	Bypass flow conveyance not recommended for further assessment in this Study. However, the removal of railway embankment at Kyogle Road and Union Street is recommended for further assessment as part of this study.
Channel Improvements	• Can reduce flood risk due to flood level reduction. • Relatively low cost in comparison to some other structural measures.	• Likely to need approval from State Government regulatory agencies. • Can result in flood impacts beyond the area of channel improvement works (usually downstream). • Can result in environmental issues due to disturbances.	Due to the meandering characteristics of the Wilsons River in Lismore, channel excavation was considered to warrant further assessment.	Recommended for further assessment as part of this Study.
Crossing Structure Upgrades	• Crossing structure upgrades can achieve significant flood level reductions upstream of the structure. • Can provide relief to upstream flooding where the structure is a hydraulic control.	• Constrained by topography. • Constrained by land availability. • Can cause environmental and erosion problems elsewhere. • Flooding downstream is often worsened. • Generally expensive.	There are a number of road crossings on Loftville Creek that forms a hydraulic control and therefore restricts conveyance. Bruxner Highway, Caniaba Road and Krauss Avenue were identified as major hydraulic controls that could provide a flood level reduction to the	Recommended for further assessment as part of this Study.

Measure	General Pros	General Cons	Applicability to Lismore	Recommendation
	• Can improve the flood immunity of a road.	• Can result in downstream erosion issues.	areas surrounding the Lismore Airport. This option could also potentially reduce any impacts associated with other upstream works such as the removal of railway embankment at Kyogle Road and the airport channel excavation.	
Flow Attenuation using Nature Based Solutions	• Self-sustaining. • Enhanced channel stability. • Improved ecosystem function. • Water quality benefits.	• Generally suited to small and medium sized catchments only. • Lack of field-based evidence. • Limited research and evidence of flood management benefits in Australia.	Natural flood management or nature-based solutions provides an appealing solution in conjunction with traditional flood mitigation methods. Assessing the effectiveness and feasibility of this option was not considered as part of this Study, however, should be further examined, particularly given the interest from the FMC.	Should be investigated as part of a separate Study.

6.3 PROPERTY MODIFICATION MEASURES

6.3.1 Voluntary House Raising

The primary purpose of house raising is to reduce the risk of flood damage associated with severe floods in some of the more hazardous areas of the floodplain. The State Government contributes to the funding of house raising, provided a house raising program is part of Council's floodplain risk management policy.

Lismore has a Voluntary House Raising Scheme (VHRS) which is administered by RCC. The scheme was introduced as a mitigation measure to support the Lismore Levee Scheme. The Lismore Levee Scheme included the raising of some 12 dwellings located in North Lismore. Property owners whose dwellings were not protected by the levees and whose floor levels were below the 1 in 10 year recurrence (10% AEP) flood level were requested to contribute $2,500 of the actual house raising cost. The floor levels of these dwellings were raised to 0.5m above the 1% AEP flood level.

Since then, six properties have been raised and an additional four are underway or in the early stages of planning to be raised.

Eligibility and Priorities for Voluntary House Raising

The Lismore Floodplain Risk Management Plan 2014 proposed that the VHRS be extended to dwellings with floor levels below the 1% AEP flood level. The area in which voluntary house raising was to be considered was generally defined by the boundaries of the High Risk Precinct. Only residential buildings constructed on stumps were eligible.

One hundred (100) non-masonry residential properties with floor levels below the 5% AEP flood level within the nominated area were considered and prioritised using the following three criteria:

1. Floor level above ground after raising, noting that the new floor level has to be 0.5m above the 1% AEP and a maximum of 4m is permitted.
2. Current floor level above ground.
3. Depth of flooding above floor.

Funding for Voluntary House Raising

The VHRS is funded on a 2:1 basis between the State Government (2/3 share) and the property owner (1/3 share). Therefore, if the total cost of house raising, including costs associated with preparing plans, is $60,000, the State Government's share would be $40,000 and the property owner $20,000. In recent years, the State Government's available funding has reduced to the equivalent of two or three houses per year in Lismore, and rather than a confirmed funding for a town or city, there is an available pool across the state.

Recommended Action

Given the increasing budgetary pressures on local government, it is recommended that RCC and LCC write to the State and Federal Governments to request a dedicated funding pool be provided for Lismore under the VHRS. It is also recommended that the list of eligible properties be reviewed based on the updated flood information from this Study.

In addition, more flexibility in the evaluation of eligible properties should be provided, to consider local conditions which might otherwise exclude properties where raising is a viable option.

6.3.2 Voluntary Purchase

The voluntary purchase of houses from the most hazardous parts of the floodplain is regarded as a necessary part of floodplain risk management as it:

- Provides physical retreat from high flood risk areas, reducing the direct costs (damage to buildings and infrastructure) and indirect costs (trauma and ill health effects) of flooding.
- Reduces the public health and welfare costs associated with flooding.
- Removes homes from locations of highest flood risk.
- Reduces the demand for evacuation resources and risks to would be rescuers.

Lismore has one of the oldest Voluntary House Purchase Schemes (VHPS) in the State. Following the flood of 1954, LCC initiated the voluntary purchase of residential properties located in the more hazardous areas of the Lismore floodplain. Between 1954 and 1988, seventy-two (72) property settlements took place and between 1982 and 1997, approximately $1.2 million was spent on purchasing 34 houses under the VHPS. This translates to a purchase rate of just over 2 properties a year.

Initially the purchases were funded by LCC alone but since 1978, the VHPS has been funded jointly by the Federal and/or State Government and LCC. Funding is typically available on a 2:1 basis between the State Government and LCC and has typically allowed for one or two properties a year. In recent years, the State Government subsidy for the scheme has been available but LCC's ability to provide a contribution has been severely limited by budgetary constraints and competing funding priorities. This has led to unrealised expectations by landowners in affected areas and an inability to implement the scheme in an acceptable way. It is also understood that uptake of the VHPS by property owners has been restricted due to their inability to find an alternative house at an equivalent and affordable price.

A better process for determining the availability of subsidies by State Government and LCC is therefore required. As such, it is recommended that LCC work with both the State and Federal Governments to acquire additional funds or achieve an alternative funding program.

The most hazardous areas on the floodplain, defined as 'Floodway', have become the areas in which houses would be considered for voluntary purchase, which is reflected in the Lismore Development Control Plan. In addition, some consideration is given to dwellings in High Risk Precinct areas. Commercial property, industrial property and vacant land are not eligible for purchase. Vacant land was not considered as part of the VHPS however consideration could be considered to allow consolidation of lots, ensuring that new dwellings cannot be constructed.

As the CBD and South Lismore Levees do not mitigate the hazards associated with major floods and above, the Levee Scheme has not lessened the need for the VHPS.

Eligibility and Priorities for Voluntary House Purchases

Properties within the nominated areas have previously been prioritised using the following four criteria:

1. Depth of flooding above ground in a 1% AEP flood.
2. Depth of flooding above floor in a 1% AEP flood.
3. Evacuation difficulty.
4. Flood hazard category (Floodway or High Risk).

Favourable consideration may be given to properties located in areas where many properties are targeted for acquisition in order to consolidate the area.

Recommended Action

Given the increasing budgetary pressures on local government, it is recommended that LCC write to the State and Federal Governments to request additional assistance for the scheme or an alternative funding arrangement, for example, a 2:2:1 State/Federal/Council funding program. It is also recommended that the list of eligible properties be reviewed based on the updated flood information from this Study.

Additionally, it is also recommended that LCC undertake a review into affordable housing alternatives for eligible property owners which is aimed at providing affordable housing outside the floodplain.

6.3.3 Local Planning and Development Control

LCC uses the Lismore Local Environmental Plan 2012 (LEP) and Development Control Plan (DCP) to govern control on development with regards to flooding. The Lismore LEP contains land use zones, development standards and other matters such as flooding to consider when assessing potential development.

Part 6.3 of the LEP 2012 relates to the Flood planning clause which has the following objectives:

1. To minimise the flood risk to life and property associated with the use of land.
2. To allow development on land that is compatible with the land's flood hazard, considering projected changes as a result of climate change.

3. To avoid significant adverse impacts on flood behaviour and the environment.

This clause applies to -

1. The flood planning area, and,
2. Other land at or below the flood planning level.

Development consent must not be granted to development on land to which this clause applies unless the consent authority is satisfied that the development -

1. Is compatible with the flood hazard of the land, and,
2. Is not likely to significantly adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties, and,
3. Incorporates appropriate measures to manage risk to life from flood, and,
4. Is not likely to significantly adversely affect the environment or cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of riverbanks or watercourses, and,
5. Is not likely to result in unsustainable social and economic costs to the community because of flooding.

Development controls in the Lismore DCP apply to various types of development on flood prone land throughout Lismore. Flood hazard categories have been used to define the level of control required based on flood hazard mapping previously undertaken to define floodways and areas of differing flood hazard. As part of that process, various categories of flood prone land were identified for the purposes of guiding future land uses on the floodplain. A review has been undertaken of Chapter 8 (Flood Prone Lands) of the Lismore Development Control Plan applying to land where LEP 2012 applies. Overall, the Lismore DCP is considered to apply adequate controls to development within flood prone areas and has considered flood risk management controls to specific areas within Lismore and the associated land use zoning. However, it is recommended that development controls in the Lismore LEP 2012 and Lismore DCP are reviewed and updated to align with the latest flood risk information from this Study as well as consideration for the 2014 Plan and new Lismore FRMP.

6.3.4 Flood Planning Levels and Flood Planning Area

The LEP flood planning level (FPL) has been defined by the 1% AEP flood event plus 0.5 m freeboard whilst the flood planning area (FPA) is based on the PMF flood event. As a result of this study, the flood event results have been revised and therefore the FPL and FPA should be updated and adopted in a future Lismore LEP revision.

6.3.5 Land Use Zoning

Generally, the current land use zoning appears to be adequate in preventing new development within the floodplain and there is limited potential for increasing the current land use intensity. This is of importance in South Lismore, where there is restricted flood evacuation. Future land use zoning should be focused on facilitating and promoting development outside the floodplain.

6.3.6 Property Protection

Given the available flood warning time, individual properties where self-protection or damage reduction is possible, measures such as sand bagging and lifting or removing possessions should be undertaken where possible. It is recommended that LCC provide property protection advice as part of any community flood awareness campaigns.

6.4 RESPONSE MODIFICATION MEASURES

6.4.1 Flood Warning and Emergency Response

The flood emergency response for Lismore is controlled by the NSW SES in accordance with the Lismore City Flood Plan (NSW SES, 2013). The plan covers preparedness measures, the conduct of response operations and the coordination of immediate recovery measures from flooding within the Lismore City Council LGA. It covers operations for all levels of flooding within the council area.

Flood warnings are provided by the Bureau of Meteorology. It is recommended that the URBS model that has been updated, refined and calibrated as part of this study be provided to BoM for review and consideration for use. Additionally, it is recommended that the NSW SES in conjunction with BoM review the flood warning systems in place for Lismore.

Response modification measures have not been addressed as part of this study as they are expected to be reviewed separately in conjunction with the NSW State Emergency Service. However, a review of the existing evacuation routes for Lismore against the updated flood hazard mapping has been undertaken and indicates that the current routes are appropriate from a perspective of selecting roads that present the lowest potential hazard whilst servicing the areas for evacuation.

It is recommended that a review and update of the Lismore City Flood Plan be undertaken with consideration for the flood results provided in this study as well as any learnings from the 2017 event.

6.5 FLOOD MODIFICATION MEASURES

The following sections outline potential flood modification measures identified as applicable to Lismore. These options were determined based on a desktop analysis of flood modification measures previously modelled, predominantly in *Lismore Flood Study & Floodplain Management Study* (SKM, 1993), and through workshops held with the Lismore FRMS TMC and the FMC.

At the commencement of the flood modification measure identification process, a total of seven options were identified. Of these, only five were taken through to hydraulic modelling following consultation with the TMC and FMC, with an additional "ultimate case" of numerous options implemented together also considered. The long list of options considered included:

- CBD levee raise to provide 5% AEP flood immunity.
- South Lismore levee raise to provide 5% AEP flood immunity.
- Extension of South Lismore Levee to Crown Street.
- Removal of Railway Embankment adjacent to Frank Street.
- Excavate to increase conveyance at Wilsons River bends at the Far North Coast Baseball Association fields and 387 Keen Street (note that excavation of the baseball fields was removed from the final list of options due to current land use impacts).
- Removal of Kyogle Road railway embankment.
- Increase conveyance at key hydraulic controls at Bruxner Highway, Caniaba Road and Krauss Avenue.

The final list of flood modification options, as discussed in the following sections were as follows:

- Option 1 – CBD levee raise to provide 5% AEP flood immunity.
- Option 2 – South Lismore levee raise to provide 5% AEP flood immunity.
- Option 3 – Excavate to increase conveyance on Wilsons River bend at 387 Keen Street.
- Option 4 – Removal of Kyogle Road railway embankment.
- Option 5 – Increase conveyance at key hydraulic controls at Bruxner Highway, Caniaba Road and Krauss Avenue.
- Option 6 – Combined option, reflective of implementing Options 1 to 5.

6.5.1 Hydraulic Assessment

The TUFLOW hydraulic model built for the design flood event analysis was utilised, with the addition of the airport channel excavation and filling works completed by LCC in 2020. The modified base case and all mitigation options have incorporated the airport channel works. Therefore, the base case for the mitigation options assessment is not the same as the base case for the design events analysis. The influence of the airport channel works in isolation have been assessed and are presented in *Appendix E*. The results have included a reduction in flood levels throughout the channel works west of the South Lismore levee, with some impacts observed due to the filling of two pads.

The critical durations identified for the design event flood analysis (as discussed in *Section 4*) were also adopted for the hydraulic assessment of mitigation options. To reduce simulation times, the design flood event results were analysed to determine the two critical temporal patterns for each flood event for simulation. The adopted storm durations temporal patterns are summarised in Table 6.4. The list of final options was simulated for the 5% AEP and 1% AEP flood events and flood impact (afflux) mapping is provided in *Appendix B*.

Table 6.4: Selected Critical Durations for Flood Modification Measure Analysis

Flood Event	Temporal Patterns Simulated
5% AEP (48 hour)	Temporal Pattern 3 and Temporal Pattern 4
1% AEP (24 hour)	Temporal Pattern 4 and Temporal Pattern 8

Details for each of the options assessed and the associated results are provided below.

Option 1 – Raise of CBD Levee to Provide 5% AEP Immunity

This option is reflective of a raise to the existing CBD levee along the current alignment, to achieve 5% AEP immunity. The adopted levels vary down the length of the levee from approximately 12.2 m AHD at the northern end to 11.4 m AHD at the southern end. Relatively, this represents a raise of between 200 and 400 mm along the levee. This levee height should be sufficient to protect against flood events in the magnitude of the 1887 and 2017 flood events, but events larger than this such as the 1880, 1889, 1956 and 1974 flood events would be expected to overtop the levee.

Due to the scope of this Study and for modelling simplicity, there were no defined overtopping locations to control the ingress of larger events into the CBD currently represented in the model. The layout of the proposed flood modification measure is shown in Figure 6.2.

Figure 6.2: Option 1 Layout

The hydraulic modelling results from simulation of this mitigation option for Wilsons River flooding are summarised below:

- Without extending the levee, potentially through a flood gate arrangement at Molesworth Street, minor flooding is expected to still flow into the CBD along Browns Creek.
- Apart from the northern inundation, the CBD is flood free in the 5% AEP flood event. For the mitigation modelling it should be noted that local catchment inflows were applied to the river and therefore localised flooding is not represented.
- Flood levels are expected to increase throughout the remainder of the floodplain in the 5% AEP event, with 70-90 mm expected in South Lismore and 60-90 mm in North Lismore.
- No tangible impacts were observed in North and South Lismore from the model results for the 1% AEP flood event and a reduction in CBD flood levels of around 90 mm was observed in the 1% AEP event. This is not unexpected due to the loss in available flood storage within the protected areas in the 5% AEP event.

Option 2 – Raise of South Lismore Levee to provide 5% AEP Flood Immunity

This option is reflective of a raise to the existing South Lismore levee along the current alignment, to achieve 5% AEP immunity. The adopted levels vary down the length of the levee from approximately 12.6 m AHD at the northern end to 11.8 m AHD around Hollingworth Creek. Relatively, this represents a raise of between 200 and 500 mm along the levee.

The layout of the proposed flood modification measure is shown in Figure 6.3. A separate assessment was completed by Engeny on raising this levee incrementally to different heights, including the original design level; refer to *Appendix D* for the flood impact mapping prepared for this assessment.

Figure 6.3: Option 2 Layout

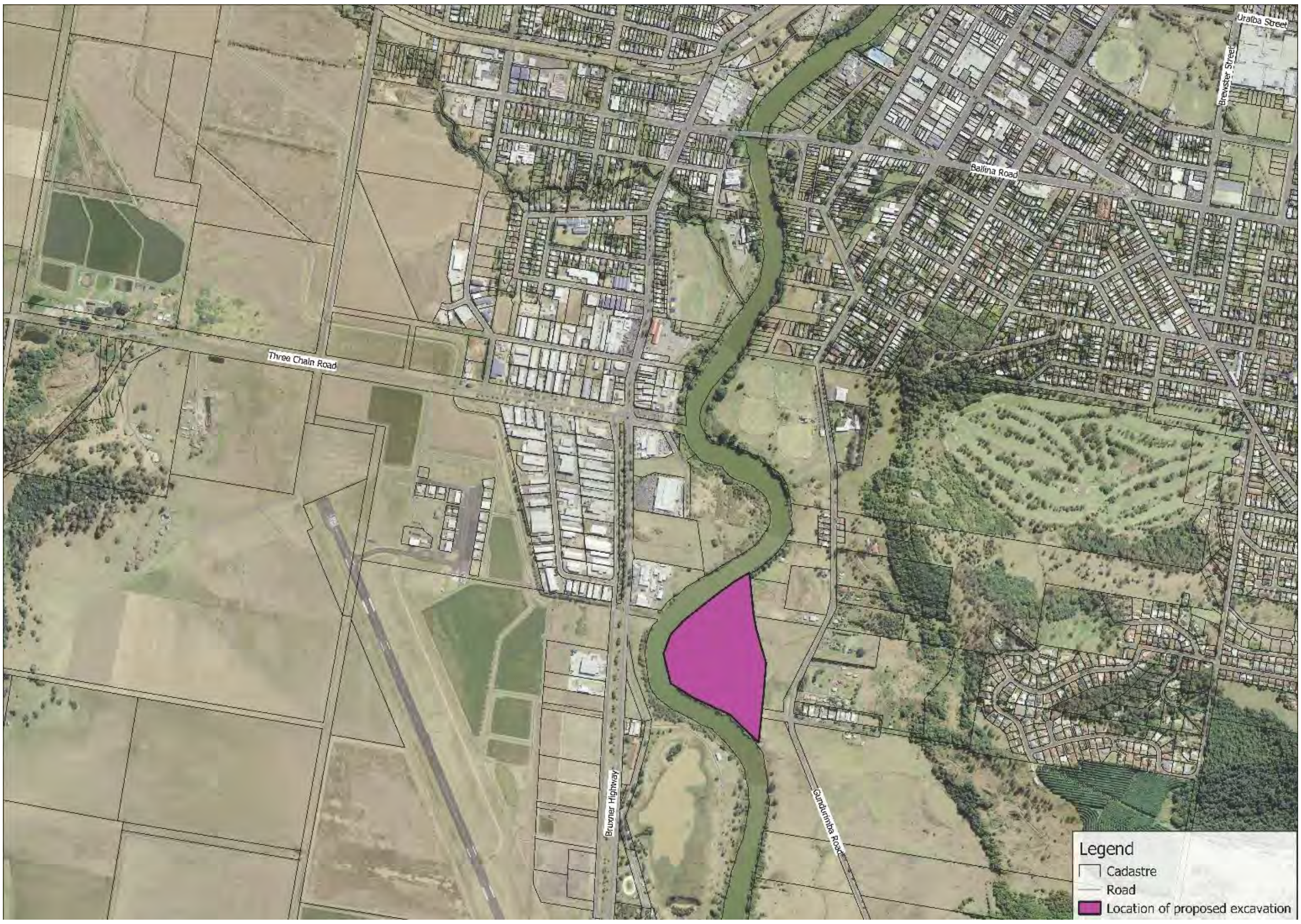
The hydraulic modelling results from simulation of this mitigation option are summarised below:

- Reductions in flood levels throughout South Lismore of between 40-400 mm were observed in the 5% AEP and 30-190 mm in the 1% AEP.
- North Lismore was predicted to experience increases in flood level of up to 15-20 mm in the 5% AEP and 1% AEP flood events.

Option 3 – Excavate of Wilsons River Bends at 387 Keen Street

This option is similar in theory to the previously completed Bunning's excavation works. The intent of the option was to increase conveyance downstream of Lismore, by reducing the constriction at the bend through excavation. Excavating the land located at 387 Keen Street which is on the eastern bank of Wilsons River by 1-3 m down to 4.9 m AHD was investigated. The layout of the flood modification measure is shown in Figure 6.4.

Figure 6.4: Option 3 Layout



The hydraulic modelling results from simulation of this mitigation option are summarised below:

- For the 5% AEP flood event, flood level reductions are expected in the CBD of 50 mm, South Lismore of 30-60 mm and North Lismore of 40 mm. Adverse impacts of up to 50 mm were observed immediately surrounding the excavation area at 387 Keen Street and south of Three Chain Road (20 mm).
- For the 1% AEP flood event, flood level reductions are expected in the CBD of 50-60 mm, South Lismore of 30-70 mm and North Lismore of 30 mm. Isolated impacts around Lismore Lake of around 30 mm were observed as well as negligible impacts of less than 10 mm west of the Bruxner Highway.

Downstream flood level impacts extend for less than 1.5 km south of the excavation area and changes to existing flood velocities are limited to within and immediately surrounding the excavation area. Based on the modelling results, downstream erosion impacts due to excavation induced velocity increases are not expected. Option 4 – Removal of Kyogle Road Railway Embankment.

This option represents removal of approximately 1,200 m of unused railway embankment along Kyogle Road and viaduct to tie into surrounding ground levels. The layout of this flood modification measure is shown in Figure 6.5.

Figure 6.5: Option 4 Layout

The hydraulic modelling results from simulation of this mitigation option are summarised below:

- Localised reductions were observed upstream of the railway embankment in the region of 15 mm in the 5% AEP event. Downstream, impacts of 20 mm were observed.
- For the 1% AEP flood event, the reduction in flood levels upstream of the railway embankment extend throughout South Lismore (15 mm), North Lismore (15 mm) and the CBD (11 mm). The downstream increases in flood levels range from 20 to 150 mm.

Option 5 – Increase Conveyance at Key Hydraulic Controls at Bruxner Highway, Caniaba Road and Krauss Avenue

This option represents upgrades to key hydraulic controls downstream of Lismore to increase conveyance through South Lismore. Generally, the option would involve widening the existing bridge or increasing the number of culverts at crossings. The three locations chosen to undertake upgrades are the bridge crossing at Bruxner Highway (approximate 40 m widening), the culvert crossing at Caniaba Road (approximate 40 m widening) and the parallel adjacent bridge crossings at Krauss Avenue and Bruxner Highway (both approximate 10 m widening). The layout of these measure is shown in Figure 6.6.

Figure 6.6: Option 5 Layout

The hydraulic modelling results from simulation of this mitigation option are summarised below:

- In the 5% AEP flood event, reductions of up to 180 mm downstream of Three Chain Road were observed. Minor localised impacts downstream of the Bruxner Highway in the order of 12 mm were also observed.
- Benefits were more widespread in the 1% AEP flood event, with reductions of 25 mm observed in South Lismore, 12 mm in North Lismore and 20 mm in the CBD. Minor localised impacts downstream of the Bruxner Highway in the order of 20 mm was also observed.

Option 6 – Combination of Options 1-5

This option reflects implementation of the five flood modification measures discussed above into a single option. The only change to the options as previously described was the removal of the excavation at the baseball fields in Option 3, leaving only the proposed excavation at 387 Keen Street. The layout of the combined measures is shown in Figure 6.7.

Figure 6.7: Option 6 Layout

The hydraulic modelling results from simulation of this mitigation option are summarised below:

- Areas negatively impacted in the 5% AEP flood event included North Lismore (70 mm), a significant portion of South Lismore (30-70 mm), Lismore airport buildings (40 mm) and the development located south of Lismore Lake (50 mm).
- Areas negatively impacted in the 1% AEP flood event generally included uninhabited areas upstream of the South Lismore levee.
- Areas where flood levels are expected to reduce in the 5% AEP flood event include South Lismore (15-400 mm) and the area west of the Bruxner Highway and south of the airport (40-110 mm). Most of the CBD is flood free in the 5% AEP flood event and there are properties along Caniaba Street downstream of the South Lismore levee that are also flood free.
- In the 1% AEP flood event, reductions in flood levels are expected throughout the floodplain, except the previously identified uninhabited areas upstream of the South Lismore Levee within the Leycester Creek floodplain.

6.5.2 Preliminary Cost Estimates

Preliminary cost estimates have been completed for the capital works associated with the shortlisted flood behaviour modification measures discussed above. It should be noted that these costings are indicative only and are utilised primarily as a means of comparing the options against each other. Key assumptions contributing to the cost estimates are summarised below:

- Rates consistent with similar works delivered in similar geographical locations as Lismore have been utilised in the estimates. A summary of the key rates is provided below:
  - Detailed concrete works - $2,500/m^{3}.
  - Topsoil strip - $4/m^{2}.

- Foundation strip - $5/m$^{2.}$
- Fill - $10/m$^{3.}$
- Topsoil and revegetation - $5/m$^{2.}$
- Excavation - $10/m$^{3.}$
- Culvert structure rates in accordance with ROCLA quotes.
- Bridge composite costs taken from Rawlinsons Construction Handbook.

- No earthworks or civil modelling has been completed to inform the quantities utilised to inform the estimates, with values conceptually estimated from indicative sections.
- An additional allowance of 50% has been included for indirects (design, project management, growth and contractor indirects) and an allowance for 30% for contingency.

A summary of the preliminary cost estimates is provided in Table 6.5.

Table 6.5: Preliminary Cost Estimates

Flood Modification Measure	Preliminary Cost Estimate
Option 1 – CBD Levee Raise[1]	$539,000
Option 2 – South Lismore Levee Raise[1]	$193,000
Option 3 – Excavation at Wilsons River Bend	$5,245,000
Option 4 – Removal of Kyogle Road Railway Embankment	$819,000
Option 5 – Increase Conveyance at Hydraulic Controls	$8,963,000
Option 6 – Combined Option, Reflective of Options 1-5	$14,277,000

[1] Material used for upgrade is consistent with existing material (i.e. concrete levee sections would be raised using concrete and similarly for earthen bunds.

6.5.3 Flood Damage Assessment and Immunity Impacts

A flood damage assessment has been undertaken for the short-listed mitigation options to determine the expected reduction in flood damages following implementation of the option. A summary of the flood damage assessment is provided in Table 6.6.

Table 6.6: Flood Damage Assessment Outcomes

Scenario	Change to Flood Damages – 5% AEP Event	Change to Flood Damages – 1% AEP Event
Base Case for Mitigation Assessment^	$455.3 M^	$732.5 M^
Option 1 – CBD Levee Raise	-$266.2 M	-$16.8 M
Option 2 – South Lismore Levee Raise	-$5.8 M	-$4.4 M
Option 3 – Excavation at Wilsons River Bends	-$12.6 M	-$16.5 M
Option 4 – Removal of Kyogle Road Railway Embankment	-$0.6 M	-$4.0 M

Scenario	Change to Flood Damages – 5% AEP Event	Change to Flood Damages – 1% AEP Event
Option 5 – Increase Conveyance at Hydraulic Controls	$0.3 M	-$6.6 M
Option 6 – Combined Option, Reflective of Options 1-5	-$277.3 M	-$44.7 M

^Total estimated flood damage in the mitigation options assessment base case scenario (including airport channel works), not reduction to flood damage.

An assessment of the net number of buildings expected to benefit following implementation of each of the options summarised above was also undertaken, and a simplified cost-benefit analysis provided (utilising cost estimates summarised in *Section 6.5.2*). The net benefit was calculated by the difference between the number of buildings predicted to experience above floor inundation in the base case and the number of buildings predicted to experience above floor inundation in the mitigated case, noting that some previously unaffected buildings may experience above floor inundation due to the mitigation option. The assessment shows that of the modelled options, Option 6 (combination of all options) is likely to provide the best improvement to flood immunity in the 5% AEP flood event, however Option 1 is the most feasible based on the simplified cost-benefit analysis.

Outside of the implementation of all options in the combined mitigation option, the mitigation option to raise the CBD levee (Option 1) would provide the greatest benefit to Lismore, with approximately 102 buildings predicted to be protected from above floor flood inundation in the 5% AEP event. This option is also predicted to provide nearly three hours of additional evacuation time for the CBD in a 1% AEP flood. The capital cost was estimated to be approximately $809,000, however adverse impacts to North Lismore and South Lismore should also be considered. The data used for the flood damage estimation, including adopted flood damage curves, are provided in *Appendix F*.

The feasibility and effectiveness of quantitatively assessed options was evaluated using a simplified cost-benefit analysis which only considers the number of buildings estimated to be protected and the associated cost to construct the mitigation measure. A more detailed cost-benefit analysis should be undertaken with consideration for more realistic flood damage costs for Lismore (if possible) and evaluation of the preferred options for a greater range on flood events. The outcomes are summarised in Table 6.7.

Table 6.7: Simplified Cost/ Benefit Evaluation

Mitigation Measure	Preliminary Cost Estimate	Total Number of Buildings Potentially Impacted[1] in the Base Case 5% AEP Event	Total Number of Buildings Potentially Impacted[2] in the Mitigated Case 5% AEP Event	Net Benefit in the 5% AEP Event[3]	Evaluation Outcome ($/Building)
Option 1 – CBD Levee Raise	$809,000	353	251	102	$7,900
Option 2 – South Lismore Levee Raise	$209,000	353	339	14	$14,900
Option 3 – Excavation at Wilsons River Bends	$5,245,000	353	335	18	$291,400
Option 4 – Removal of Kyogle Road Railway Embankment	$995,000	353	353	0	N/A

Mitigation Measure	Preliminary Cost Estimate	Total Number of Buildings Potentially Impacted[1] in the Base Case 5% AEP Event	Total Number of Buildings Potentially Impacted[2] in the Mitigated Case 5% AEP Event	Net Benefit in the 5% AEP Event[3]	Evaluation Outcome ($/Building)
Option 5 – Increase Conveyance at Hydraulic Controls	$8,963,000	353	353	0	N/A
Option 6 – Combined Option, Reflective of Options 1-5	$14,277,000	353	234	119	$120,000

[1] Represents the number of buildings predicted to experience above floor inundation in the base case.

[2] Represents the number of buildings predicted to experience above floor inundation in the mitigated case.

[3] Represents the net number of buildings predicted to be protected from above floor inundation due to the mitigation option. Note that there are some buildings that were unaffected in the base case that were predicted to experience inundation above floor level in the mitigated case.

6.5.4 Evaluation of Measures

In order to assess the overall effectiveness and impacts associated with each of the shortlisted mitigation measures, a high-level assessment criterion was developed to enable comparison of each option. A detailed cost benefit analysis was not within the scope of this Study; however, it is advised that a detailed feasibility analysis should be undertaken in the Lismore FRMP including a comprehensive flood damage assessment for all events up to the PMF to derive the reduction in average annual damage.

The key assessment criterion of each mitigation measure was to achieve the project objective through effective hydraulic performance. However, other aspects such as environmental and social impacts and economic viability were also integrated into the assessment for consideration. Table 6.8 summarizes each of the criteria used in this broad assessment.

Table 6.8: Evaluation of Measures – Flood Modification Measures

Criteria	Option 1 – CBD Levee Raise	Option 2 – South Lismore Levee Raise	Option 3 – Excavation at Bends	Option 4 – Removal of Railway Embankment	Option 5 – Increase Conveyance at Controls	Option 6 – All Combined
Flood Mitigation Performance	This option provides a tangible benefit to the CBD, but with adverse impacts experienced through the remainder of the floodplain. Approximately 102 buildings were estimated to be potentially protected from above floor flooding in the 5% AEP event.	This option provides significant benefit to properties located in South Lismore, but with adverse impacts to areas in North Lismore and areas south of Three Chain Road. Approximately 14 buildings were estimated to be potentially protected from above floor flooding in the 5% AEP event.	This option provides relief from flooding for the areas in Lismore upstream of the excavation works. Areas immediately south of the excavation are expected to experience minor impacts (i.e. 20 mm). Approximately 18 buildings were estimated to be potentially protected from above floor flooding in the 5% AEP event.	This option reduces flood levels upstream of the railway embankment location, with adverse impacts expected downstream of the railway through the airport channel to north of the Lismore Airport. No buildings were estimated to be potentially protected from above floor flooding in the 5% AEP event.	This option is expected to reduce flood levels upstream of the location of the hydraulic controls, with minimal adverse impacts expected. No buildings were estimated to be potentially protected from above floor flooding in the 5% AEP event.	Areas of expected reductions in flood levels include the CBD, South Lismore and the area between the airport and Bruxner Highway. Areas where adverse impacts to flood levels are expected include North Lismore, the airport channel and east of Bruxner Highway, downstream of Lismore Lake. Approximately 119 buildings were estimated to be potentially protected from above floor flooding in the 5% AEP event.

Criteria	Option 1 – CBD Levee Raise	Option 2 – South Lismore Levee Raise	Option 3 – Excavation at Bends	Option 4 – Removal of Railway Embankment	Option 5 – Increase Conveyance at Controls	Option 6 – All Combined
Environmental and Cultural Heritage Issues	Limited environmental impacts are expected to occur during the levee raise, due to the works being located well within the urban footprint and limited to the current levee alignment. It is unlikely that any investigations regarding potential historical or cultural significance will identify any limitations impacting upon the feasibility of the works.	Limited environmental impacts are expected to occur during the levee raise, due to the works being located along the current levee alignment. It is unlikely that any investigations regarding potential historical or cultural significance will identify any limitations impacting upon the feasibility of the works.	An environmental assessment will need to be undertaken to identify any potential impacts associated with the proposed works, predominantly due to the location of the earthworks being in close proximity to the Wilsons River. There is limited change to the flood velocity and therefore downstream erosion issues are considered unlikely. It is unlikely that any investigations regarding potential historical or cultural significance will identify any limitations impacting upon the feasibility of the works.	Consultation with relevant community groups regarding the removal of the historical railway embankment will need to be undertaken prior to implementation of the option. It is unlikely that any environmental investigations will identify any limitations impacting upon the feasibility of the works.	It is unlikely that any environmental, historical or cultural investigations will identify any limitations impacting upon the feasibility of the works.	Refer to previous option assessments. Historical, cultural and environmental investigations should be considered; however, it is highly unlikely that the investigations will identify any limitations impacting upon the feasibility of the works.
Economic Viability	Preliminary capital cost estimate is $539,000. Earthen embankments are known to settle and consolidate over time, and future maintenance to ensure consistent design elevations will be required.	Preliminary capital cost estimate is $193,000. Earthen embankments are known to settle and consolidate over time, and future maintenance to ensure consistent design elevations will be required.	Preliminary capital cost estimate is $5,245,000	Preliminary capital cost estimate is $819,000.	Preliminary capital cost estimate is $8,963,000	Preliminary capital cost estimate is $14,277,000
Social Impacts	Proposed works to be undertaken along the current levee alignment. Social impacts relate to areas in North Lismore and South Lismore which would experience adverse flood impacts. There may be some visual amenity impact of the higher levee.	As the works are proposed to be undertaken along the current levee alignment, social impacts are expected to be limited.	No social impacts are expected.	Consultation with relevant community groups regarding the removal of the historical railway embankment will need to be undertaken prior to implementation of the option.	The option is not likely to cause adverse social impacts. The increased conveyance at the hydraulic control locations are expected to improve flood immunity of the relevant roads, improving trafficability for residents.	Refer to previous option assessments.
Overall Assessment Outcome	As this option provides significant improvement to immunity in the CBD, the net benefit	Raising the South Lismore levee is feasible from a cost, environmental and social perspective.	This option does provide a net benefit to dwelling inundation, however, the capital costs	This option alone has shown to not provide a net benefit to dwelling inundation.	This option alone has shown to not provide a net benefit to dwelling inundation.	This option is considered a significant undertaking in terms of cost and

Criteria	Option 1 – CBD Levee Raise	Option 2 – South Lismore Levee Raise	Option 3 – Excavation at Bends	Option 4 – Removal of Railway Embankment	Option 5 – Increase Conveyance at Controls	Option 6 – All Combined
	to dwelling inundation that this option creates is second only to the combined option. The costs involved in the design and capital delivery of the works are considered significant, however. Mitigating impacts associated with increasing flood levels through North and South Lismore should also be considered. Further feasibility studies would be required prior to a recommendation for implementation.	Combined with the expected net benefit, this option should be further considered in combination with a flood impact reduction option such as Options 3 and 5.	associated with the works may outweigh the benefits of the option.	Consideration of this option in combination with other options such as Options 2 and 5 should be undertaken.	Consideration of this option in combination with other options such as Option 2 and 4 should be undertaken.	disturbance. However, this option provides the greatest net benefit to dwelling inundation in Lismore.

7 Conclusion & Recommendations

This Study has provided a flood behaviour and risk analysis of the Wilsons River for historical and design flood events. The different nature of flood behaviour in the two waterway systems and the periodic flow in an upstream direction for the Wilsons River arm presents challenges with hydrologic model calibration as well as managing the risk for different flood events. The Wilsons River system is complex where the Wilsons River arm upstream of Lismore has a wider floodplain with greater storage capacity and a relatively flat hydraulic grade with less momentum and volume in comparison to Leycester Creek in a similar magnitude event. Leycester Creek has relatively incised channel banks which are approximately 2 m higher than the Wilsons River arm, has a steeper hydraulic grade and flows with greater momentum than the Wilsons arm. As a result of these characteristics, it is not uncommon to observe backwater flow up the Wilsons River arm from the confluence with Leycester Creek. This is reflected both in the TUFLOW model results and anecdotally. This Study has also identified and assessed a number of flood mitigation measures, with consideration for options and outcomes from previous studies.

The conclusions from this Study were as follows:

- The jointly calibrated URBS hydrologic and TUFLOW hydraulic models are considered to provide the most up to date and accurate analysis of design and historical event flood behaviour for the Wilsons River floodplain in Lismore.
- Hydrologic “calibration” rating curves were developed for the secondary and primary gauges, for which peak timing and level were targeted in the calibration. An iterative process was then undertaken between the hydrologic model and the hydraulic model to achieve suitable comparison to recorded flood levels at these primary and secondary gauges.
- Comparison of subsequent TUFLOW hydraulic model flood levels indicated that modelled peak levels at Lismore Rowing Club gauge were within 30 mm, 70 mm, 200 mm and 220 mm, respectively for the 2017, 2013, 2012 and 1989 flood events, with the shape and timing of the modelled water-level time series matching the recorded water-level time series well.
- Nearly 80% of the modelled results were within 150 mm of the 63 flood level survey points in Lismore for the 2017 event.
- The hydraulic modelling has indicated that flood levels throughout Lismore tend to be dominated by the magnitude of the Leycester Creek catchment inflows, where reduction in the magnitude of flow from this branch has a larger reduction in predicted flood levels.
- The Lismore CBD was the highest flood hazard area and was classified as generally being H5 and H6 hazard in the 1% AEP. This means that areas within the CBD could be considered unsafe for people, vehicles and buildings.
- The major hydraulic controls within the floodplain includes the South Lismore Levee, CBD Levee, Gasworks Creek floodgates, Hollingworth Creek floodgates, Bruxner Highway and railway embankments.
- Key socio-economic statistics from ABS was used to develop a social profile of the Lismore community and to classify the vulnerability of the community. The ABS data indicated that approximately 7% of Lismore’s residents require assistance due to age and/or disability and therefore, these residents are likely to require assistance to evacuate or self-protect in a flood event due to potential mobility issues.
- A review of vulnerable land uses within the floodplain identified a number of schools and early learning centres located within high hazard areas. Adequate and effective flood warning and emergency response measures are required to ensure that early evacuation takes place.
- A review of the existing evacuation routes for Lismore against the updated flood hazard mapping indicated that the current evacuation routes are appropriate from a perspective of selecting roads that present the lowest potential hazard whilst servicing the areas for evacuation.
- The mitigation option to raise the CBD levee would provide the greatest benefit to Lismore, with approximately 102 buildings predicted to be protected from above flood inundation in the 5% AEP event. This option is also predicted to provide nearly three hours of additional evacuation time for the CBD in a 1% AEP flood. The capital cost was estimated to be approximately $809,000, however adverse impacts to North Lismore and South Lismore should also be considered.

In no particular order, based on the findings from this Study, it is recommended that:

1. The robustness of the hydrologic component of the calibration be improved by further development of rating curves for key river gauging stations. This would include calibration of previously developed TUFLOW local models for gauging stations to manually gauged events.
2. The calibration approach for future flood studies should consider integrated hydrologic and hydraulic calibration, including consideration for the greater Richmond River catchment. To improve the available data for such calibration, continued collaboration with the Bureau of Meteorology should be sought to maximise synergies between the organisations.
3. A detailed cost benefit analysis be undertaken including a comprehensive flood damage assessment utilising the updated DPIE damage curves once released. Survey of missing building floor levels should also be captured, and funding sought to undertake the survey.
4. The Lismore City Local Flood Plan be updated with flood information from this Study and a review of the total flood warning systems and flood response measures be undertaken. The review should include consideration for vulnerable members of the community (including hearing impaired persons) where evacuation assistance is required. A review of gauge locations should also be undertaken as part of the review.
5. A review and update of the Lismore LEP and DCP be undertaken with consideration for flood information provided in this Study.
6. Further investigation of the preferred mitigation measures from this Study to be undertaken as part of the Lismore FRMP development. Levee sections not previously surveyed should be captured and incorporated into the hydraulic modelling undertaken as part of the development of the Lismore FRMP.
7. Further assessment of levee modification works be undertaken including optimisation of levee heights with consideration for overtopping locations, evacuation (increasing response time), desired flood immunity for protected areas, and managing consequential flood impacts.
8. Additional flood mitigation using Nature Based Solutions (green infrastructure) be investigated as part of a separate study to inform the Lismore FRMP. RCC and LCC to seek funding for this study.
9. The list of eligible properties in the voluntary house raising and purchase schemes be reviewed based on the updated flood information from this Study and that dedicated funds be sought to continue purchasing and raising houses. The list of properties should also be updated following the development of the Lismore FRMP.
10. Additional mitigation options be investigated and modelled as part of the Lismore FRMP to reduce flows in the Wilsons River at Lismore. Options include narrowing of Leycester Creek downstream of Booerie Creek and associated downstream channel works through South Lismore, and an upstream retention structure.
11. The outcomes from this Study be used in the development of the Lismore FRMP including consideration for prioritisation and implementation of proposed measures.

8 QUALIFICATIONS

a) In preparing this document, including all relevant calculation and modelling, Engeny Water Management (Engeny) has exercised the degree of skill, care and diligence normally exercised by members of the engineering profession and has acted in accordance with accepted practices of engineering principles.

b) Engeny has used reasonable endeavours to inform itself of the parameters and requirements of the project and has taken reasonable steps to ensure that the works and document is as accurate and comprehensive as possible given the information upon which it has been based including information that may have been provided or obtained by any third party or external sources which has not been independently verified.

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g) This Body does not provide legal advice.

9 REFERENCES

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