PYRENEES SHIRE

Raglan Flood Investigation

Final Summary Report

Revision 2
July 2020

Catchment Simulation Solutions

Raglan Flood Investigation

Final Summary Report

Client	Client Representative
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Executive Summary

The Raglan Flood Investigation was commissioned by Pyrenees Shire Council with financial support from the Victorian and Australian Governments as well as technical support from Glenelg Hopkins Catchment Management Authority (GHCMA). The purpose of the Raglan Flood Investigation is to develop information fundamental to provision of effective flood controls, flood response planning and building community resilience to flooding. There was previously no flood related planning controls for Raglan and no high reliability flood information to understand the extent of flood risk. There is limited flood related information available for Raglan township or surrounding catchment area, with only one previous flood study completed within the area, the Raglan Preliminary Flood Study (2018).

The study area for the flooding investigation extends along Fiery Creek from Pitchers Lane (located about 3 kilometres upstream of Raglan) down to the Western Highway (located about 6 kilometres downstream of Raglan). It also incorporates each of the major tributaries that traverse through Raglan and drain into Fiery Creek.

A range of data was supplied by Council and the GHCMA, primarily related to topographic data, engineering plans of hydraulic features throughout the study area, flood level survey post flooding in 2010 in the area and aerial photography. Rainfall and stream gauge data was also made available. Additional survey data was collected as part of this study, including hydraulic structures cross sections of the creeklines and floor levels of existing properties.

Community consultation was carried out during three stages of the project. An initial round during the data collection phase to collect any available community flood intelligence, determine what specific flooding issues the community are concerned with and gain insight into the community's knowledge and attitudes towards flooding. An Information Brochure and Questionnaire was sent to 200 addresses, with 21 questionnaire responses were received. The next round of community consultation was carried out once the flood models had been completed to develop structural mitigation options. The final round was held during July 2020 to enable the community to provide feedback on the structural mitigation option assessment and flood warning review.

A hydrologic model of the Fiery Creek catchment and its tributaries was developed as part of the flood investigation using the RORB software. A hydraulic model was developed using TUFLOW. These models were calibrated to the January 2011 flood event based on information provided by the community from that flood event, and the September 2010 flood event. These flood level comparisons indicated that the TUFLOW model generally provided a good reproduction of surveyed floodwater levels and was appropriate to use to define design flood levels. A sensitivity analysis of several of the parameters used in the hydrologic and hydraulic model was also undertake, with the results of this sensitivity analysis indicating the parameters that had been selected were fit for purpose and appropriate to use to define design flood levels.

Modelling was undertaken to define a range of flood events, including the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF design flood events. Mapping was prepared that represented floodwater depths and levels, flood velocities, flood hazards and duration of inundation. Several different climate change simulations were completed for the 10% AEP and 1% AEP floods to gain an understanding of the potential impacts of climate change in this catchment.

Flood damage calculations were undertaken to gain an understating of the existing flood risk to the Raglan settlement. For events up to the 1% AEP design flood event there are no properties with above floor flooding and the damage estimate is comprised entirely of external damage. Between the 1% AEP and the 0.2% AEP design flood events the number of properties with above floor flooding rises from 1 to 4, and then to 19 during the PMF event. Overall, the flood damages at Raglan are relatively low, with an average annual damage (AAD) approximately $7,800 (O2 method) to $11,800 (NSW Government method).

The management of flood risk can be broadly grouped into three mechanisms – flood modification, property modification and response modifications. Property modification measures relate to planning and development controls. Response modification options relate to the emergency planning and response before, during and after a flood event. Flood modification measures aim to modify existing flood behaviour, thereby reducing the extent, depth and/or velocity of floodwater across flood liable areas and are discussed in this chapter.

The design flood mapping identified areas within and around the township of Raglan that are affected by flooding and these areas have been mapped as either Floodway Overlay (FO) or Land Subject to Inundation Overlay (LSIO). Planning Scheme Amendment documents have been prepared for the implementation of these planning overlays. The application of these overlays will assist Local Government, Catchment Management Authority and the community in carrying out more effective planning and management of flood prone land within Raglan.

Flood warning and flood intelligence information was documentation has been prepared as part of this study to assist Council and other stakeholders, such as the VIC SES prepare for and respond to flooding. This includes information of what floor levels are inundated in what magnitude flood event, information on road inundation times and durations, and the development of a “Flood / No Flood tool” that can be used to relate the fallen rainfall to potential flood impacts by looking up the depth of rainfall that has occurred over the time that has occurred since rainfall has begun.

Six (6) structural mitigation options were investigated as part of the potential flood modification management measures. Structural mitigation options were raised during Project Reference Group meetings and through Community Consultation. Each option was assessed against a range of evaluation criteria, including hydraulic impacts, change in number of buildings inundated above floor level, emergency response impacts, technical feasibility, environmental impacts, economic feasibility and community acceptance.

This assessment has determined that there are currently no feasible structural mitigation options that are considered viable to reduce the existing flood risk to Raglan settlement and surrounds. However, implementation of other mitigation options examined in this study, such as improved planning and development controls, community education and simplified flood warning (signage and gauge boards) would be of great benefit to help mitigate the existing and future flood risk in the area. These property modification and response modifications options have been assessed as more cost effective and more likely to have a broader reach in the community when compared to the six (6) structural mitigation options assessed.

The community raised the issue during community consultation that the local road drainage system is overgrown with vegetation and debris. While this would have minimal impact on the large-scale flooding examined as part of this study, smaller nuisance flooding from local runoff may be better managed if Council were to implement more regular maintenance of the local stormwater drainage system. This would need to be weighed against other competing priorities for Council resources and considered in their asset management program of all council assets.

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1 INTRODUCTION

1.1 Overview

The Raglan Flood Investigation was commissioned by Pyrenees Shire Council with financial support from the Victorian and Australian Governments as well as technical support from Glenelg Hopkins Catchment Management Authority (GHCMA). The purpose of the Raglan Flood Investigation is to develop information fundamental to provision of effective flood controls, flood response planning and building community resilience to flooding. There was previously no flood related planning controls for Raglan and no high reliability flood information to understand the extent of flood risk.

The following report provides a summary of the work undertaken to complete flood investigation. For further details on each aspect of the investigation, the following detailed reports have been provided:

- Raglan Flood Investigation - Data Review and Community Consultation
- Raglan Flood Investigation - Model Development, Calibration and Design Simulations
- Raglan Flood Investigation - Flood Damages and Structural Mitigation Options
- Raglan Flood Investigation - Flood Warning Assessment and Flood Intelligence Documentation

1.2 Catchment Description

The village of Raglan is located within the Fiery Creek catchment. Fiery Creek generally flows in a north-south direction and drains a catchment of just under 50 square kilometres to Raglan. The catchment upstream of Raglan comprises rural residential development, cleared grazing land and forested areas. In addition to Fiery Creek, there are a number of smaller unnamed tributaries that drain through Raglan and into Fiery Creek. The extents of the Fiery Creek catchment and the study area for this flood investigation are shown in **Figure 1.1.**

Raglan is home to around 230 people living primarily on rural residential lots comprising mostly low set single storey houses (Australian Bureau of Statistics, 2016). Most properties in Raglan also have other significant infrastructure such as large sheds. A public hall and school are also located within Raglan.

There is limited stormwater infrastructure within the town with no formalised stormwater drainage system. The roadway areas are most commonly drained by roadside ditches which convey runoff to dedicated cross-drainage structures (e.g., culverts).

The floodplain is traversed by a number of significant roads, including Raglan-Elmhurst Road which is the major transportation link between Raglan and Elmhurst. This particular road embankment is typically elevated around 300 mm above the adjoining floodplain elevation and forms a significant hydraulic control. The Western Highway is located about 6 kilometres south of Raglan and forms the major east-west link between Beaufort and Ararat. This roadway embankment also serves as a significant hydraulic control, being elevated by more than 3 metres above the floodplain.

The Fiery Creek channel in the vicinity of Raglan is a natural channel of variable width and depth and changing condition along its course. The creek width varies from around 6 metres upstream of Raglan to around 20 metres downstream of Raglan. Although much of the creek is well vegetated with established vegetation, other sections of the creek show notable erosion. This is particularly evident directly north of Old Beaufort Road.

The study area for the flooding investigation extends along Fiery Creek from Pitchers Lane (located about 3 kilometres upstream of Raglan) down to the Western Highway (located about 6 kilometres downstream of Raglan). It also incorporates each of the major tributaries that traverse through Raglan and drain into Fiery Creek. **Figure 1.1** represents the locality and study area.

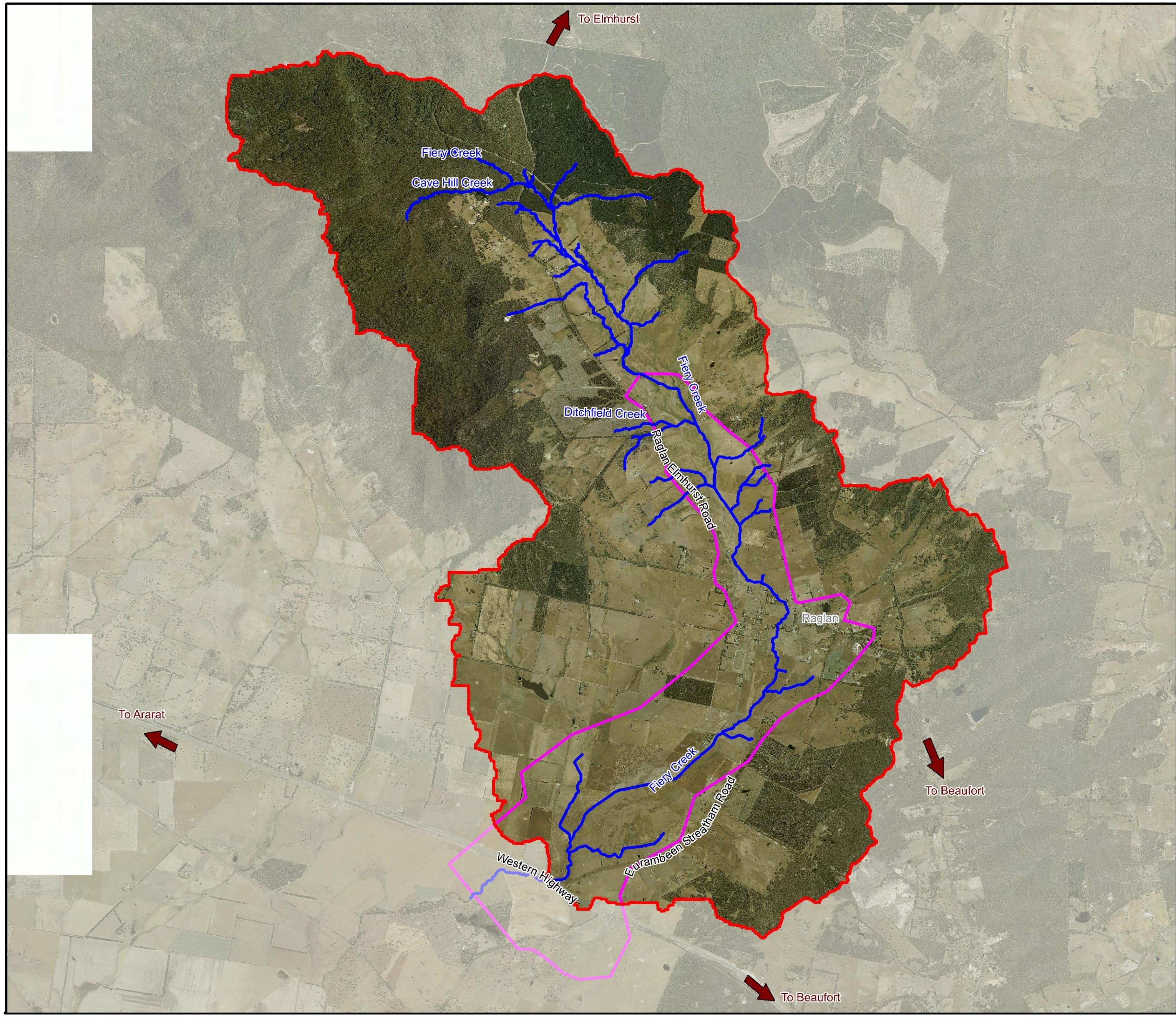

Figure 1.1
Raglan Flood Investigation
Study Area

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File Name: Raglan Flood Investigation Study Area.wor

2 Data Collection and Review

A range of data was made available to assist with the preparation of the Raglan Flood Investigation. This includes:

- Previous flood related reports
- Rainfall and stream gauge data
- Topographic and hydrographic data
- Engineering Plans
- Flood Level Survey
- Aerial Photography
- Other data provided by Council
- Survey information

A description of each dataset and a synopsis of its relevance to the investigation is summarised below.

2.1 Previous Flood Related Reports

There is limited flood related information available for Raglan township or surrounding catchment area, with only one previous flood study completed within the area, the Raglan Preliminary Flood Study (2018), undertaken by HydroSpatial and Utilis. This study was completed to gain a general understanding of the flood risk within Raglan township and to determine if a more detailed flood study of the area was warranted.

The 2018 flood study included a two-dimensional (2D) hydraulic model of Fiery Creek and its floodplain using the HEC-RAS software (version 5.03). The model was based on a 10 metre grid resolution and included bridges and culverts, as well as floodplain structures such as elevated roads and levee embankments. A RORB model (v 6.31) was developed to define the 1% Annual Exceedance Probability (AEP) design flood information based in ARR 2016 requirements. Inflows to the HEC-RAS model were extracted from the results of the RORB model and applied for Fiery Creek at the upstream extent of the model, as well as two additional inflows from sub-catchments to the east of the township.

The RORB and HEC-RAS models were used to simulate the 1% AEP design flood event in order to determine 1% AEP flows within Fiery Creek at Raglan. The model also defined flood characteristics within the Raglan such as peak flood levels, depths, velocities and flood hazard. The results indicated that flooding upstream of the main part of the Raglan township is constrained to a floodway around the Fiery Creek corridor.

The results documented in this study were found to be useful in validating the results of the hydrologic and hydraulic models developed for the current study. In addition, the details of hydraulic structures measured in the field as part of the *'Raglan Preliminary Flood Study'*

(2018) were used to define structures within the hydraulic model for this study where other relevant information was not available.

2.2 Hydrologic Data

2.2.1 Rain Gauge Data

The extent of the Fiery Creek catchment is shown in **Figure 1.1**. A number of daily read and continuous (i.e., pluviometer) rainfall gauges are located within or adjacent to the catchment. The location of each gauge is shown in **Figure 1.2**.

Continuous rainfall records are only available from 1974 onwards (Skipton Post Office and Beaufort (Sheepwash) gauges) and these gauges are located a significant distance south (i.e., 17 and 37 km respectively) of the catchment. The closest continuous gauge to the catchment, the Pyrenees (Ben Nevis) gauge, comprises continuous rainfall records extending back to 2008. As a result, it is suitable for defining the temporal variation in rainfall for the more recent floods that have occurred in the catchment.

A review of the available rainfall data was completed to identify when significant historic rainfall events have occurred and, consequently, when flooding may have been experienced in the catchment. The details of the top ten rainfall events, based on accumulated daily total rainfall depths, are summarised in **Table 1**. Note that the dates provided in **Table 1** are the dates on which the rain fell and may not necessarily coincide with when flooding was experienced.

Table 1 Significant Historic Rainfall Events

Rank	Year	Day/Month	Rainfall in 24-hour Period (mm)	Rainfall in Preceding 24-hour Period (mm)	Rainfall in Following 24-hour Period (mm)
1	1993	27 January	116	0	0
2	2011	14 January	109.4	4.8	0
3	2011	12 January	106.8	20.6	4.8
4	2010	5 September	98	0	2
5	1973	6 February	82.1	25.4	0
6	1963	15 May	84.6	0.8	6.6
7	1988	2 September	66	0	0
8	1998	13 November	65.8	19.8	1
9	1975	8 October	63	0	24
10	2016	14 September	62.4	21	12.6

NOTE: Information in the above table is based upon interrogation of long -term daily rainfall records from 89107 – Raglan gauge and 89005 – Beaufort gauge.

As shown in **Table 1**, the most significant rainfall event on record occurred in January 1993, where 116 mm of rain fell within a 24 hour period. **Table 1** also indicates that the most significant recent event occurred on 14 January 2011, where over 109 mm of rain fell within a 24-hour period. It was also preceded by over 130 mm of rainfall in the preceding 72-hour period (including the third largest rainfall event on 12 January 2011), indicating that the catchment would have been saturated prior to that event.

2.2.2 Stream Gauge Data

Figure 1.2 shows the location of stream and water level gauges located in the vicinity of the catchment. Key information for each gauge is summarised in **Table 2**.

As shown in **Figure 1.2**, there are no stream gauges located within the study area for this flood investigation. However, three of the gauges are located on tributaries of Fiery Creek in the upper reaches of catchment. Of these three gauges, only two are currently operational, including the Cave Hill Creek at Mt Cole gauge and the Long Gully at The Glut gauge.

When combined with a rating curve, the stage hydrograph at each stream gauge can be converted to a discharge hydrograph describing the time variation in discharge throughout a particular flood event. The rating curve provides a relationship between the stage at the gauge location and the corresponding stream discharge and is developed based upon manual recordings of stream discharges for a range of different water levels (the manual recordings are referred to as a "gauging"). Therefore, the reliability of the rating curve is largely dependent on the number of individual gaugings collected as well as the range of water levels over which the gaugings were collected.

Discharge hydrographs describing the time variation in discharge are available for these gauges and the data quality is specified by Central Highlands Water (CHW) as being of good quality. However, as shown in **Table 2**, these two gauges have only a relatively short length of record, only comprising about 20 years of data. A review of the available data from these gauges indicates that the largest flood during the period of record occurred on 14 January 2011.

Table 2 Available stream and water level gauges

Gauge Number	Gauge Name	Stream Name	Source*	Dataset Time Increments	Start of Records	End of Records	Located within the catchment	Located with study area?	Ratings
236231A	Cave Hill Creek at Mt Cole	Cave Hill Creek	CHW	10 minute	May 2000	Jul 2019	Yes	No	Yes
236228A	Musical Gully Creek at Musical Gully Reservoir H.G.	Musical Gully Creek	CHW	15 minute	Jun 2009	Jul 2019	No	No	None available
236230A	Long Gully Creek at The Glut	Long Gully Creek	CHW	10 minute	May 2000	Jul 2019	Yes	No	Yes – to 0.09 m^3/s
236232	Sidespring Creek at Mt Cole	Sidespring Creek	DELWP	15 minute	Nov 2007	Jul 2018	Yes	No	None available

NOTE: * CHW = Central Highlands Water, DELWP = Department of Environment Land Water and Planning

The gauges are located high within the catchment and it is our understanding that they are primarily used for rainfall harvesting and have not been gauged for flood flows. Rating information was only available for the Long Gully Creek gauge and the highest rated stage produced a flow of 0.09 m^3/s. By comparison the peak January 2011 flows are estimated at 0.9 m^3/s at the gauge, 10 times higher. Given there is no gaugings for higher stages for this location, and no gaugings for the other stations, the flows estimated by the gauges during the flood events are likely to be highly unreliable.

Review of the catchment characteristics contributing to each of the gauges shows that their sub-catchments are not representative of the total Raglan catchment, representing a very small total area that is heavily treed and much higher slopes relative to the majority of the catchment.

2.3 Topographic Data

The following topographic and hydrographic (i.e., bathymetric) datasets were provided for use in defining the variation in ground and river bed elevations across the catchment:

- 2010 Index of Stream Conditions (ISC) Light Detection and Ranging (LiDAR) survey
- 2011 Central Highlands Water (CHW) LiDAR survey

Further detailed information on each topographic dataset is provided below.

2.3.1 2010 Index of Stream Condition (ISC) LiDAR Survey

LiDAR data was collected by Fugro Spatial Solutions Pty Ltd, on behalf of Glenelg Hopkins Catchment Management Authority (CMA), as part of the Index of Stream Condition (ISC) LiDAR survey in 2010. This LiDAR dataset covers the Fiery Creek corridor within the study area and the majority of the creek corridor within the wider Fiery Creek catchment.

This LiDAR dataset has a quoted horizontal accuracy of 0.3 metres and quoted vertical accuracy of 0.2 metres. It was provided as a filtered and thinned dataset which provides ground elevations at regular spacings of 1 metre. However, since its collection, the 2010 ISC LiDAR data has been found to have a significantly high bias that suggests a systematic error in the data capture by the supplying organisation. Therefore, this data had to be validated for this flood investigation using additional ground-based survey (refer **Section 2.8**) prior to incorporation into a digital elevation model (DEM).

2.3.2 2011 Central Highlands Water (CHW) LiDAR Survey

LiDAR data was collected across the majority of the catchment in January 2011 by Central Highlands Water (CHW). The horizontal and vertical accuracy of this LiDAR dataset was not specified. It was provided as a filtered and thinned dataset which provides ground elevations at regular spacing of 2 metres.

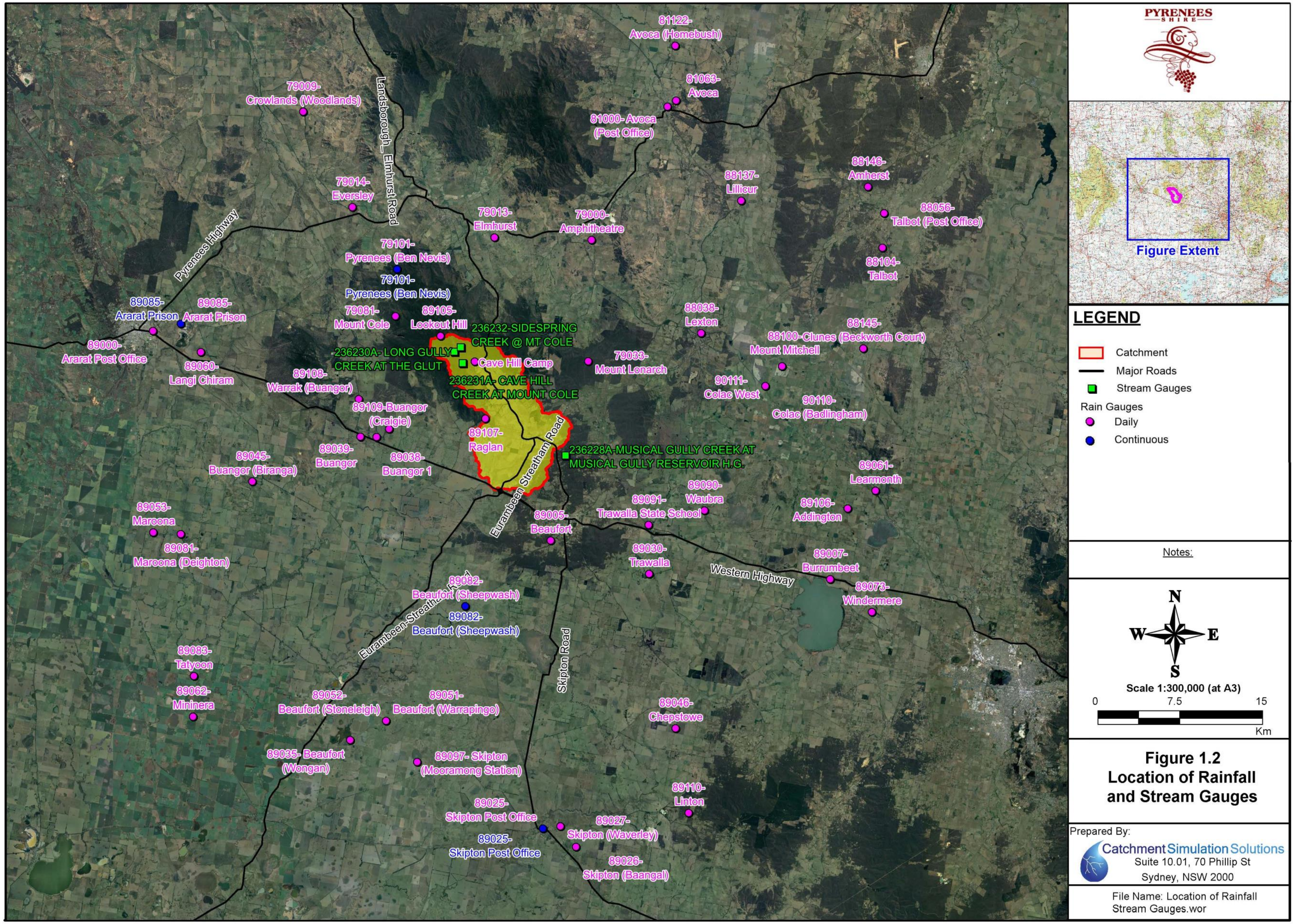


Figure 1.2
Location of Rainfall and Stream Gauges

2.3.3 Validation of the LiDAR Data

The 2011 LiDAR should generally provide a good representation of the variation in ground surface elevations across the majority of the catchment. However, LiDAR datasets can provide a less reliable representation of the terrain in areas of high vegetation density. This is associated with the laser ground strikes often being restricted by the vegetation canopy. Errors can also arise if non-ground elevation points (e.g., vegetation canopy, buildings) are not correctly removed from the raw dataset.

To quantify the ability of the LiDAR to reliably represent ground surface elevations across the floodplain, elevations defined in the LiDAR information were compared against detailed survey information collected for this investigation as described in **Section 2.8**.

Specifically, ground surface elevations from the detailed survey were compared separately for both "clear" (i.e. unvegetated and defined by surveyed elevations along road centrelines) and "vegetated" areas (defined by top of bank elevations for Fiery Creek). A summary of this comparison is provided in **Table 3**.

Table 3 Summary of LiDAR Validation

Dataset	"Vegetated" areas				"Clear" areas			
	No. of Points Compared	Minimum Difference (m)	Maximum Difference (m)	Average Difference (m)	No. of Points Compared	Minimum Difference (m)	Maximum Difference (m)	Average Difference (m)
2010 ISC LiDAR	142	1.03	-1.18	0.15	55	0.33	-0.48	0.15
2011 CHW LiDAR	134	0.92	-1.68	-0.15	57	0.14	-0.46	-0.04

Note: Difference = LiDAR elevation minus the Surveyed Elevation

Table 3 indicates that both the 2010 ISC and 2011 CHW LiDAR datasets are within ~0.5 metres of the surveyed elevations in clear areas of the floodplain. This is approximately 0.3 metres higher than the quoted vertical accuracy of for the 2010 ISC LiDAR dataset hat was quoted at 0.2 metres and is consistent with the LiDAR validation findings of other studies that have used this dataset. However, the maximum differences are significantly higher in vegetated areas, with the 2010 ISC and 2011 CHW LiDAR ground elevations varying by up to ~1.2 metres and ~1.7 metres, respectively, from surveyed elevations in areas of dense vegetation.

Overall, both the 2010 ISC and 2011 CHW are considered to provide a reasonably good representation of the terrain in areas of negligible vegetation. Whilst the LiDAR datasets do not provide a good representation of ground surface elevations at all locations along the vegetated overbank areas along the main Fiery Creek channel, surveyed elevations will be used to define the elevations within the vegetated creek channels along the top-of-bank which reliably defined the creek conveyance capacity.. The average differences between the LiDAR and ground levels is considered to be adequate for the purposes of this flood investigation considering that much of the floodplain consists of cleared pastureland (i.e., is not heavily vegetated) in the other areas.

Furthermore, the outcomes of the LiDAR validation also indicate that the 2011 CHW LiDAR has better vertical accuracy than the 2010 ISC LiDAR. Therefore, the 2011 CHW LiDAR has been used in preference of the 2010 ISC LiDAR wherever the two datasets overlap.

2.4 Engineering Plans

VicRoads provided work-as-executed plans dated October 2013 for the Fiery Creek at Western Highway bridge. These plans generally include information describing the size/dimensions of the structures including invert elevations and are sufficiently detailed for including a representation of these structures in the flood model.

2.5 Flood Level Survey

Flood level survey for Fiery Creek in the immediate vicinity of the Western Highway bridge crossing was completed by the Beveridge Williams following the September 2010 flood.

2.6 Aerial Photography

Council provided ortho-rectified aerial imagery collected in 2017. This aerial photography provides a suitable basis for preparing report figures as well as informing the computer flood model development.

2.7 Preliminary Flood Study Data

Data from the preliminary flood study undertaken by HydroSpatial and Utlis in 2018 was provided by Council. This included:

- Model Files: all setup and result files, including calculated flood overlays (FO) and land subject to Inundation Overlay (LSIO) extents;
- GIS Data: including modelled structure locations and field measurements undertaken for those structure;
- Residential Property Database: all data related to at risk properties derived from the preliminary flood study; and,
- Calculations and Notes: including rainfall analysis undertaken and photographs and notes from field inspections.

2.8 Ground Survey

Consulting surveyors, Ferguson Perry Surveying, collected additional survey information for the purposes of this flood investigation. The extent of the additional data collection included:

- six (6) hydraulic structures;
- twenty (20) cross-sections; and,
- thirty-five (35) floor levels.

Key characteristics of each bridge were collected as part of the survey (e.g., pier sizes, bridge deck elevations, details of hand rails, roadway elevations) as well as details of the creek channel directly below the bridge to ensure the conveyance capacity could be reliably defined. Key characteristics of each culvert were also collected including invert elevations, culvert dimensions, roadway elevations as well as the details of any handrails. Cross-sections of the upstream and downstream channel were also collected to ensure potential hydraulic losses associated with flow contracting into and expanding out of the culvert could be defined in the computer model.

Photographs were taken of each bridge and culvert to assist in defining Manning's "n" roughness coefficients in the computer model as well as the extent of any debris accumulation and blockage. The survey also provided information on the creek bed invert elevations, as well as the elevations of the toe of bank and top of bank at each cross-section location.

Comparisons of the surveyed cross-sections and cross-sections extracted from 2010 ISC and/or 2011 CHW LiDAR elevations (depending on where the data coverage is available) were made at three (3) locations along Fiery Creek. These comparisons confirm that the elevations from the LiDAR datasets do not reliably define the channel bed elevations due to the presence of water and/or vegetation along the creek line.

3 COMMUNITY CONSULTATION

Engaging with the community during the course of a flood investigation can significantly improve the outcomes of the study through both the value of the input of local residents and the opportunity it provides to educate the community on flood awareness.

Community Consultation activities have focussed on achieving the following outcomes from the community engagement process:

- ensure the community is appropriately informed and engaged with the flood investigation, so that their outcomes are ultimately accepted by the community;
- identify key community concerns;
- gain information from the community regarding their flooding experiences;
- gain an understanding of the flood awareness of the community; and,
- provide an opportunity for the community to suggest and provide feedback on potential flood risk management options.

Three community consultation rounds were undertaken as part of this study, with each round focused on a different aspect of the flood investigation. The rounds undertaken were:

- An initial round during the data collection phase to collect any available community flood intelligence, determine what specific flooding issues the community are concerned with and gain insight into the community's knowledge and attitudes towards flooding. This was held in Raglan Hall on the 19th of August 2019, 3 to 6 pm.
- A second round once the flood models had been completed to develop structural mitigation options. This was held in Raglan Hall on the 9th of December 2019, 3 to 6 pm.
- A third round to provide feedback on the structural mitigation option assessment and flood warning review. Due to COVID-19 travel restrictions and government health advice, this was held online via "Zoom" on the 7th of July, 2020, 4 to 6 pm.

Several community consultation devices were developed to inform the community about the study and to obtain information from the community about their past flooding experiences. Further information on each of these consultation devices is provided below.

3.1.1 Media Release

A media release was prepared and distributed to advertise each of the community consultation sessions. This release provided background information on the purpose of the investigation, how the study would be completed, and how the community could be involved in the project.

3.1.2 Community Information Brochure and Questionnaire

An Information Brochure and Questionnaire was prepared and distributed to all residents and business owners located within the Raglan study area, as well as being provided in a digital format on Council's website. The total mail out was sent to approximately 200 addresses.

The questionnaire sought information from the community regarding whether they had experienced flooding, the nature of flood behaviour, the cause and risks of flood events and whether residents could identify any historic flood marks or provide imagery. A total of 21 questionnaire responses were received.

The responses to the questionnaire indicate that:

- 62% of respondents have experienced some form of inundation or disruption as a result of flooding in the study area. This includes:
  - 6 respondents have had their front or back yard inundated;
  - 7 respondents have experienced traffic disruptions;
  - 1 respondent has had their house inundated above floor level.
- A number of respondents believe inundation in the catchment is exacerbated by:
  - Insufficient flow capacity in Fiery Creek (2 respondents)
  - Insufficient flow capacity in drains (8 respondents)
  - Blockages in the Creek or drains (6 respondents)
  - Overland flow obstructions (e.g. roads, buildings) (4 respondents)
- Several respondents noted that their primary flooding concern is associated with blocked or unmaintained drains.

Four respondents provided photos of the 14 January 2011 flood at various times throughout that day. Discussion with residents suggested that the peak of the event occurred early in the morning (approximately 5 AM) and therefore these photos were not representative of the peak. The photographs that were provided by the community generally show shallow depths of water across front and back yards as well as local roads.

A number of respondents were impacted by the flood events that occurred in January 2011 and September 2016, with only one respondent stating they were impacted by the September 2010 flood event.

4 Hydrological Model Development

A hydrologic model of the Fiery Creek catchment and its tributaries was developed as part of the flood investigation using the RORB software. RORB is developed by Monash University in conjunction with Hydrology and Risk Consulting and has been used extensively across Victoria for the purpose of defining flood behaviour (Laurenson et al, 2010).

The Fiery Creek catchment was delineated using the available elevation data outlined in **Section 2**. The overall catchment draining to Raglan (at the Raglan-Elmhurst Road) is 47 square kilometres while the overall catchment draining to the Western Highway crossing is approximately 93 square kilometres.

The Fiery Creek catchment was subdivided into 115 subcatchments based on the alignment of major streams, topographic divides and the location of key infrastructure such as culvert crossings. The subcatchments were delineated with the assistance of the CatchmentSIM software using a 5 metre Digital Elevation Model (DEM). The CatchmentSIM subcatchments were subsequently refined by hand to provide the final subcatchment layout that is presented in **Figure 2.1**. An attempt was made to keep the individual subcatchment sizes relatively consistent. However, some deviation from this goal was necessary to account for the significant differences in contributing subcatchment areas of Fiery Creek versus the small tributaries draining through the village.

Key hydrologic properties including area and impervious proportion were calculated automatically for each subcatchment using CatchmentSIM in conjunction with land use information delineated from recent aerial imagery. Buildings and roads were assumed to be 100% impervious while the residual catchment areas were assumed to be 2% impervious to account for isolated concrete surrounding rural properties, rock outcrops etc.

The RORB software also requires specification of a “Kc” and “m” parameter. The “m” parameter is a measure of the non-linearity of the catchment. “Kc” is an empirical coefficient that is specific to the catchment and stream network and is intended to reflect the storage afforded by the catchment.

A value of 0.8 for the “m” parameter is most commonly used (Laurenson et al, 2010). “Kc” can be estimated using a variety of regional equations. Some of the “Kc” and “m” estimation methods and the associated values are summarised in **Table 4**.

Table 4 RORB parameter values for the Fiery Creek catchment

Method		m	Kc
1	Default RORB	0.8	21.20
2	Victoria data (Morris, 1982) - Eq 7.6.14 ARR2019	0.75	19.88
3	Vic MAR>800 mm - Eq 7.6.15 ARR2019	0.8	19.77
4	Victoria data (Pearse et al, 2002) (D_{av} = 10.54km)	0.8	13.18
5	Aust wide Dyer (1994) (Pearse et al 2002)	0.8	12.02
6	Vic MAR<800 mm - Eq 7.6.16 ARR2019	0.8	9.33
	Adopted	**0.8**	**9.33**

When selecting an appropriate "Kc" value for the current study, a preference was placed on adopting a "Kc" value recommended in '*Australian Rainfall and Runoff: A Guide to Flood Estimation'* (ARR2019) (Geoscience Australia, 2019) (the ARR2019 methods are highlighted in blue in **Table 4**). The mean annual rainfall in the vicinity of Raglan is approximately 700 mm, which rules out method (3). This narrowed down the "Kc" value to either method (2) or method (5) in **Table 4. "**Kc" values of 19.88 (with "m" = 0.75) and 9.33 (with "m" = 0.8) were both trialled as part of the calibration discussed in **Section 6**.

The "Kc" value of 9.33 was ultimately adopted as it was found to provide the best overall calibration outcomes when combined with the rainfall losses recommended as part of ARR2019. However, to gain an understanding of the potential impacts associated with adopting the "Kc" and "m" values estimated using methods (2) and (3) additional sensitivity simulations were completed.

During a typical rainfall event, not all of the rain falling on a catchment is converted to runoff. Some of the rainfall may be intercepted and stored by vegetation, some may be stored in small depressions and some may infiltrate into the underlying soils.

To account for rainfall "losses" of this nature, the hydrologic model incorporates a rainfall loss model. For this flood investigation, the "Initial-Continuing" loss model was adopted, which is recommended in ARR2019. This loss model assumes that a specified amount of rainfall is lost during the initial saturation/wetting of the catchment (referred to as the "Initial Loss"). Further losses are applied at a constant rate to simulate infiltration/interception once the catchment is saturated (referred to as the "Continuing Loss Rate"). The initial and continuing losses are deducted from the total rainfall over the catchment, leaving the residual rainfall to be distributed across the catchment as runoff.

The following losses were adopted for all calibration simulations based on information downloaded from the ARR2019 Data Hub. The location was taken as the centroid of the Fiery Creek catchment upstream of Raglan:

- Initial Loss = 25mm
- Continuing Loss Rate = 4.6 mm/hour

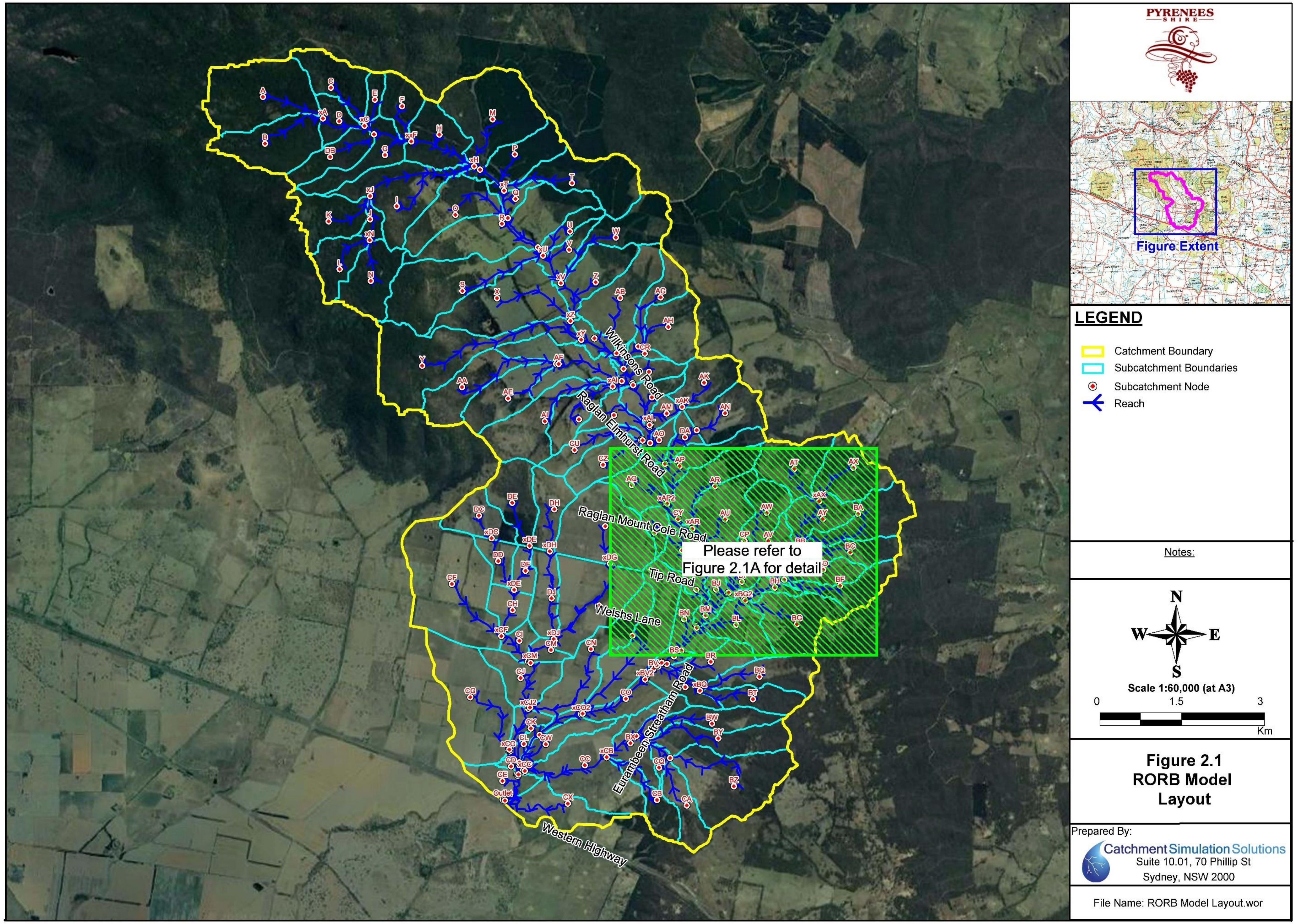


Figure 2.1
RORB Model Layout

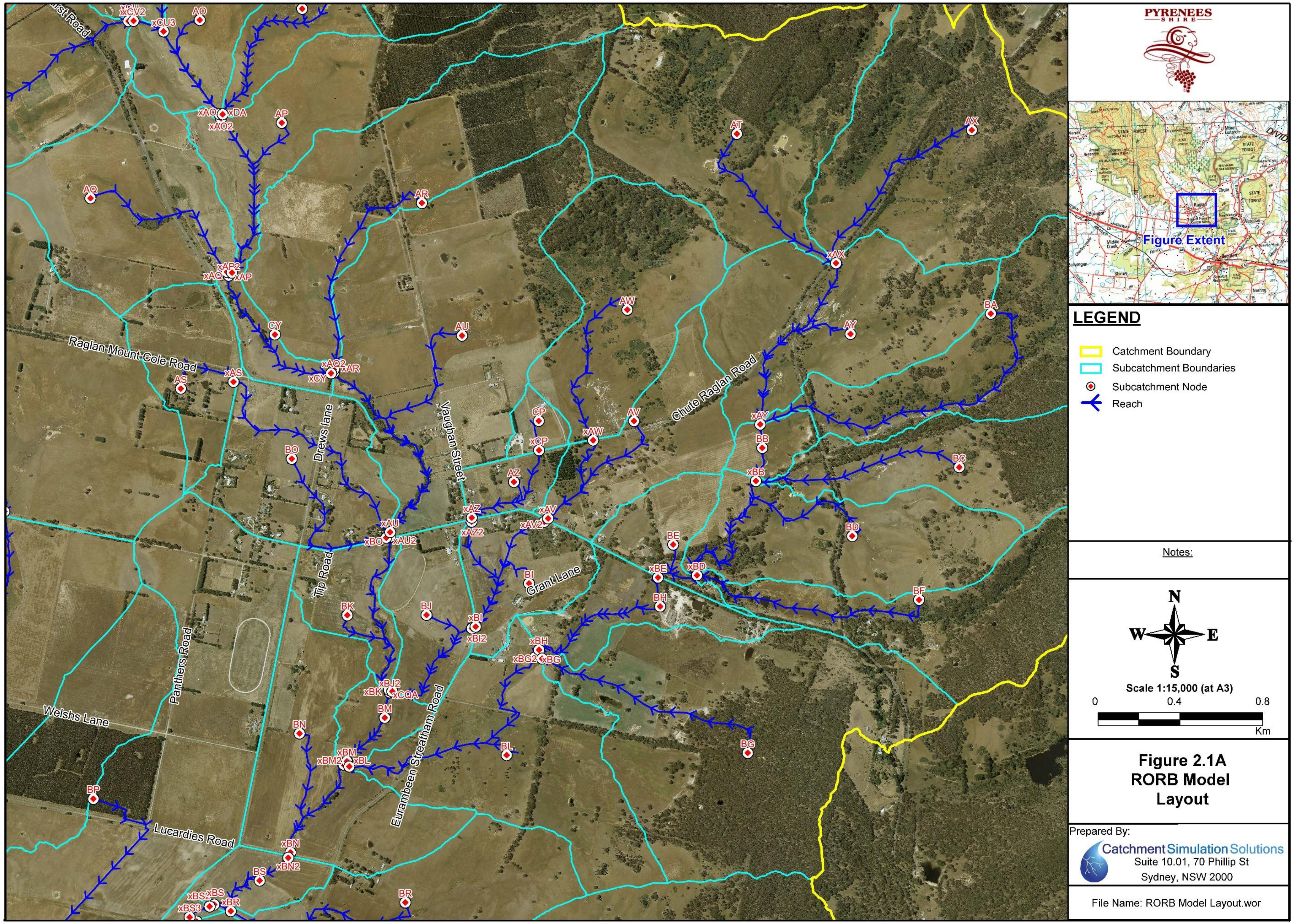


Figure 2.1A RORB Model Layout

5 HYDRAULIC MODEL DEVELOPMENT

Hydraulic computer models are commonly used to simulate flood behaviour through a particular area of interest. They are developed so they include a description of the topography, drainage infrastructure (e.g., bridges, culverts) as well as the resistance to flow afforded by the different materials (e.g., grass, buildings) across the flood investigation area. The hydraulic computer model can then be used to simulate the passage of floodwaters throughout the flood investigation area and predict flood characteristics such as peak flood levels, depths and flow velocities.

The TUFLOW software was used to develop a hydraulic computer model of the Fiery Creek catchment in the vicinity of Raglan. TUFLOW is a fully dynamic, 1D/2D finite difference model that is used extensively across Australia to assist in defining flood behaviour (BMT WBM, 2018). The model was developed using TUFLOW version 2018-03-AE (i.e., the most recent release at the time the flood investigation was prepared).

The TUFLOW software uses a grid to define the spatial variation in topography and hydraulic properties (e.g., Manning's "n" roughness) across the model area. Accordingly, the choice of grid size can have a significant impact on the performance of the model. In general, a smaller grid size will provide a more detailed and reliable representation of flood behaviour relative to a larger grid size. However, a smaller grid size will take longer to perform all of the necessary hydraulic calculations. Therefore, it is typically necessary to select a grid size that makes an appropriate compromise between the level of detail provided by the model and the associated computational time required. A grid size of 2 metres was ultimately adopted and was considered to provide a reasonable compromise between reliability and simulation time for this study area.

Elevations were assigned to the grid cells within the TUFLOW model based on the Digital Elevation Model derived primarily from the Central Highlands Water (CHW) 2011 LiDAR dataset which provides the most reliable topographic dataset for the flood investigation area. However, the CHW LiDAR did not extend across the full TUFLOW model area. Therefore, it was supplemented with the 2010 Index of Stream Condition (ISC) LiDAR dataset as well as Shuttle Radar Topography Mission (SRTM) data, where necessary.

The TUFLOW software uses land use information to define Manning's "n" values for each grid cell in the model. Manning's "n" is an empirically derived coefficient that is used to define the resistance to flow (i.e., roughness) afforded by different material types and land uses. It is one of the key input parameters used in the development of the TUFLOW model.

Land use information was delineated by hand based on recent aerial imagery of the catchment. The "n" values listed in **Table 5** were ultimately found to provide reliable calibration results, which are summarised in **Section 6**.

It is noted that the Manning's "n" values are not known with certainty. As a result, a sensitivity assessment was completed to confirm what uncertainty in the Manning's"n" values may have on the results produced by the TUFLOW model.

Table 5 Manning's 'n' Roughness Values

Land Use	Manning's "n"
Long grass/pastures	0.050
Short grass	0.035
Low density trees	0.060
Medium density trees	0.080
High density trees	0.100
Creek with low vegetation	0.035
Creek with medium vegetation	0.050
Creek with dense vegetation	0.080
Dams	0.030
Buildings	1.000
Paved roads	0.020
Dirt roads	0.030

Culverts and bridges can have a significant influence on flood behaviour, particularly if they become blocked during the course of the flood. Therefore, all major bridges and culverts within the TUFLOW model area were represented within the TUFLOW model as hydraulic structures.

During a typical flood, sediment, vegetation and urban debris (e.g., litter, fences, bins) from the catchment can become mobilised leading to blockage of downstream culverts and bridges. Consequently, bridges and culverts will typically not operate at full efficiency during most floods. This can increase the severity of flooding across areas located adjacent to these structures.

In recognition of this, blockage factors were calculated for all bridges and culverts. The blockage factors were calculated based on blockage guidelines contained in ARR2019.

Guardrails above bridges and culverts in the study area were assumed to provide 50% blockage and concrete barriers were assumed to afford complete blockage.

As discussed, a RORB hydrologic model was developed and was used to simulate the transformation of rainfall into runoff and generate discharge hydrographs at discrete locations across the full extent of the Fiery Creek catchment. However, the TUFLOW model extends across only a part of the overall Fiery Creek catchment. Therefore, the total flows from the upstream sections of the Fiery Creek catchment as well as flows from the local subcatchments in the vicinity of Raglan must be accounted for. Accordingly, 'total' inflow hydrographs (i.e., hydrographs describing the total upstream contributing flow) were used to define the primary design inflows from Fiery Creek into the upstream end of the TUFLOW model. In addition, 'local' discharge hydrographs (representing flows from the local subcatchments only) were also extracted from the RORB model results and were used to represent local inflows for each of the major tributaries in the vicinity of Raglan.

Hydraulic computer models also require the adoption of a suitable downstream boundary condition in order to reliably define flood behaviour throughout the area of interest. The downstream boundary condition for the TUFLOW model was defined using a “normal depth” calculation downstream of the Western Highway bridge. That is, the downstream stage was defined based on the stream geometry and slope as well as the total discharge at the downstream model boundary. A slope of 0.003 was adopted based on survey information for Fiery Creek near the Western Highway bridge.

The downstream boundary of the hydraulic model was located downstream of the Western Highway embankment. As the Western Highway embankment and bridge is located upstream of the model boundary, it is considered that the highway will have a greater influence on flood behaviour across the lower parts of the catchment. Furthermore, the downstream model boundary is located more than 6km downstream of Raglan. Therefore, any uncertainty associated with the downstream boundary condition should not impact on flood behaviour across the main areas of interest in and around Raglan itself.

However, to confirm the extent of any changes in TUFLOW model results associated with uncertainty in the adopted downstream boundary, a sensitivity assessment was completed of the downstream boundary conditions and is discussed in **Section 6.3.**

6 Model Calibration

Computer flood models are approximations of a very complex process and are generally developed using parameters that are not known with a high degree of certainty and/or are subject to natural variability. This includes catchment roughness as well as blockage of hydraulic structures. Accordingly, the model should be calibrated using rainfall, flow and flood mark information from historic floods to ensure the adopted model parameters are producing reliable estimates of flood behaviour.

Unfortunately, the only stream gauges are located in the headwaters of the catchment and do not have a sufficient quantity and quality of rating information to enable reliable flow estimates to be derived for significant rainfall events. Therefore, it is not possible to complete a full calibration of the hydrologic model developed for this flood investigation.

However, descriptions of flood behaviour around Raglan were provided by the community as part of the community consultation for a number of historic floods. These included descriptions of floodwater depths as well as photographs of past floods. Therefore, it was possible to undertake a "pseudo" calibration of the of the computer models by routing recorded rainfall from the nearby rain gauges through the hydrologic model. The flows from the hydrologic model can then be routed through the hydraulic model and simulated floodwater depths and extents can be validated against floodwater depths and flood photographs provided by the community.

The January 2011 flood was the most commonly reported flood event by the community. Accordingly, this flood was selected as the primary calibration event.

A limited amount of flood information was also provided by the community for a flood that occurred in September 2010. Therefore, the 2010 flood was also simulated, however, a greater priority was placed on the replicating the more abundant historic information provided for the 2011 event.

6.1 January 2011 Event Calibration

The TUFLOW model was used to simulate the 2011 flood for no blockage and design blockage conditions. In general, it was found that there were minimal differences between the "no blockage" and "design blockage" flood model results in areas where flood photographs were provided. However, the design blockage factor results were considered to provide a more realistic "real world" blockage scenario so were selected in preference to the no blockage simulation results for reporting purposes.

Floodwater depths were also estimated at discrete locations throughout the study area based on interpretation of photographs of the 2011 flood that were provided by the community.

The simulated and observed water depths are summarised in **Table 6.** It should be noted that the observed water depths are based on interpretation of information presented in photographs and can be considered approximate only. Furthermore, the flood photographs were not necessarily captured at the peak of the flood. On average, the simulated peak depths are 0.11 metres greater than what is estimated from the photo. This is to be expected given the photos were not taken during the peak of the flood.

Table 6 Comparison between simulated and observed water depths for the 2011 flood

Location	Observed Water Depth (metres)	Simulated Water Depth (metres)	Difference (m)
On road in front of 189 Drews Lane	0.30	0.44	+ 0.14
Southern yard of 189 Drews Lane	0.10	0.30	+ 0.20
On east side of Drews Lane (~30m south of 189 Drews Lane)	0.40	0.48	+ 0.08
On Drews Lane on east side of 272 Raglan-Elmhurst Road	0.20	0.46	+ 0.26
On road in between 154 Drews Lane and 159 Drews Lane	0.20	0.29	+ 0.09
Southern yard of 154 Drews Lane	0.05	0.22	+ 0.17
Driveway of 154 Drews Lane	0.05	0.19	+ 0.14
In front of 154 Drews Lane dwelling	0.05	0.20	+ 0.15
On road in between 4 Tip Road and 15 Tip Road	0.05	0.21	+ 0.16
On road in front of 238 Raglan-Elmhurst Road	0.05	0.06	+ 0.01
Near pit located at the side of driveway for 238 Raglan-Elmhurst Road	0.30	0.43	+ 0.13
On road in front of 224 Raglan-Elmhurst Road	0.05	0.06	+ 0.01
At the northwest corner of 4 Codrington Street (Raglan Public Hall)	0.05	0.07	+ 0.02
55 Drews Lane	0.15	0.18	+ 0.03
		Absolute Average	0.11

As shown in **Table 6**, the simulated floodwater depths are close to but most commonly exceed the depths that were estimated from the flood photos. This is associated with the simulated depths reflecting the water depth at the peak of the flood, whereas most of the photographs provided by the community were taken from 9am up to 2pm on the 14th January (i.e., 4 to 8 hours after the peak). Therefore, to provide a more meaningful comparison, simulated flood extents were extracted from the TUFLOW model at roughly the same time that the photographs were taken.

The simulated inundation extents compare favourably with the flood photographs. More specifically, “wet” and “dry” areas shown in the photos are typically consistent with modelling results. A perfect correlation between simulated and actual flood depths experienced isn’t always achieved, and this is generally associated with uncertainties of the time during the flood the photographs were taken. However, overall, it is considered that the outcomes of the calibration show that the TUFLOW model is providing a realistic reproduction of observed flood behaviour for the 2011 flood.

6.2 September 2010 Event Calibration

The TUFLOW model was used to simulate the 2010 flood for no blockage and design blockage conditions. Four flood marks were surveyed following the 2010 event based on debris marks in the vicinity of the Western Highway bridge (refer **Plate 1**). The flood level comparison is summarised **Table 7**.

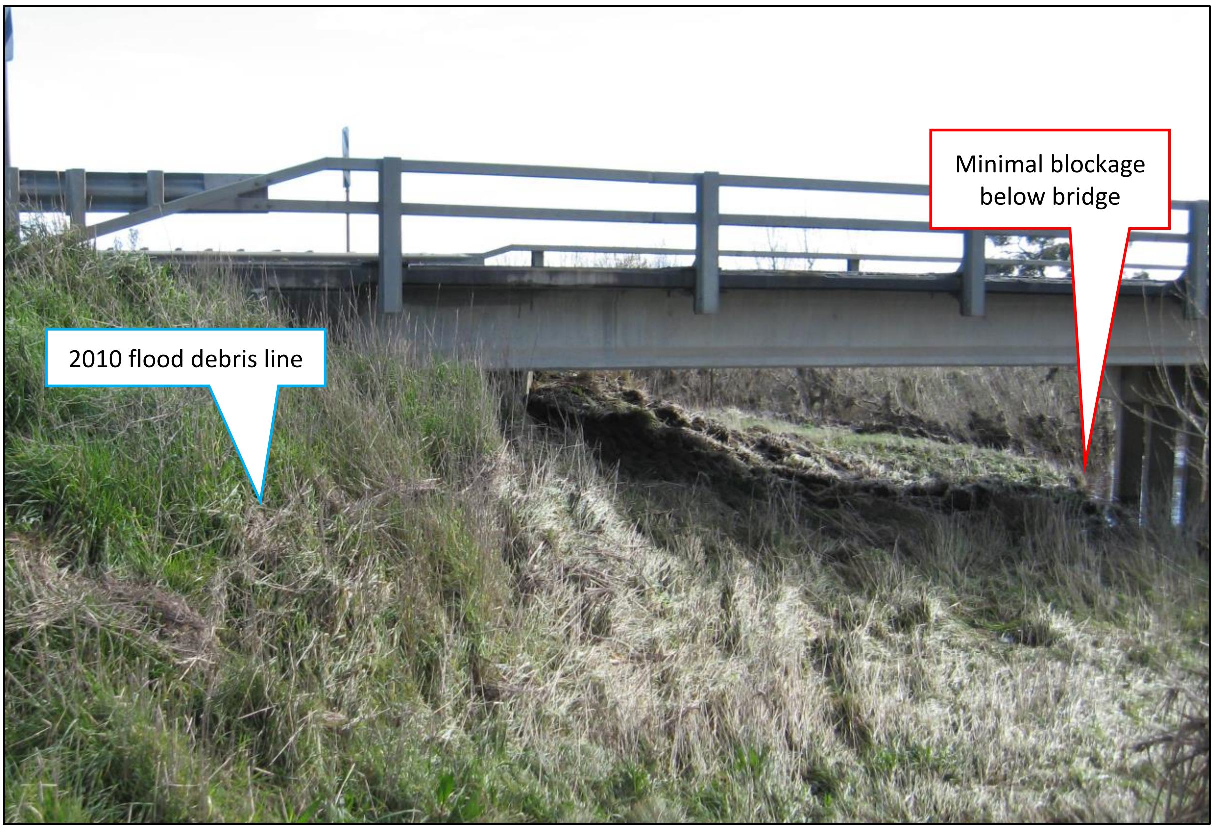


Plate 1 - Photograph of part section of the Western Highway bridge that was taken following the 2010 flood showing minimal debris/blockage

Table 7 Comparison between simulated water levels and surveyed flood marks for the 2010 flood

Location	Surveyed Flood Mark Elevation (mAHD)	Simulated Water Level (mAHD)	Difference (m)
10m downstream of Western Highway	357.32	357.34	+ 0.02
Immediately downstream of Western Highway	357.40	357.38	- 0.02
Immediately upstream of Western Highway #1	358.02	357.96	- 0.06
Immediately upstream of Western Highway #2	357.99	357.98	- 0.01

The flood level comparison provided in **Table 7** shows that the TUFLOW model generally provides a good reproduction of surveyed floodwater levels. In all cases, the TUFLOW model produces peak levels that are within 0.1 metres (and in most cases within 0.05 metres) of the surveyed food mark levels.

The 2010 flood was not identified by the community as a significant event. This likely indicates that most water was contained to the Fiery Creek channel and there were minimal breakouts/overland flow paths during this event. A review of the simulated floodwater depth information presented in **Chapter 7** tends to confirm this with most water being contained in close proximity to the main watercourses.

Overall, it is considered that the TUFLOW model is providing a good reproduction of reported flood levels for the 2010 event.

6.3 Sensitivity Analysis

Computer flood models require the adoption of several parameters that are not necessarily known with a high degree of certainty or are subject to variability. Each of these parameters can impact on the results generated by the flood model.

As discussed in this chapter, the RORB and TUFLOW models were jointly calibrated against observed flood information for two historic events. In general, this information confirmed that the models were providing realistic descriptions of flood behaviour in the vicinity of Raglan for these historic floods.

Nevertheless, it is important to understand how any uncertainties and variability in model input parameters may impact on the results produced by the model. Therefore, a sensitivity analysis was undertaken in both the hydrologic and hydraulic model to establish the sensitivity of the results generated by the computer model to changes in model input parameter values. Parameters that were analysed during the sensitivity analysis are outlined in **Table 8.**

Table 8 Parameters analysed during sensitivity analysis

Parameter	Existing Value	Change in value	Result)
Continuing Loss Rate	4.6mm/hr	+ 1mm/hr – 1mm/hr	Very slightly sensitive to changes in rainfall losses
Kc Parameter	9.33	19.88 (based on ARR2019 alternate methods)	Higher Kc value lead to sub-standard calibration outcome
Model Grid Size	2 metre	1 metre	Insensitive – slight changes only in creek channel
Manning's 'n'	various	+20% -20%	Insensitive in overbank areas, slightly sensitive in in-bank areas
Downstream Boundary Condition	0.003	0.0015 0.006	Insensitive

It was found during the sensitivity analysis that the model was sensitive to some parameters and not sensitive to other. This is often the outcome with a sensitivity analysis and the changes observed were in line with how the flood model is expected to behave. The outcomes of sensitivity analysis simulations demonstrated that adopting alternate modelling parameters will not improve the outcomes of the calibration simulations i.e. changes to parameters made the calibration worse.

7 Design Flood Events

Design floods are hypothetical floods that are commonly used for planning and floodplain management investigations. Design floods are based on statistical analysis of rainfall and flood records and are typically defined by their probability of exceedance. This is often expressed as an Annual Exceedance Probability (AEP).

The AEP of a flood flow or level or depth at a particular location is the probability that the flood flow or level or depth will be equalled or exceeded in any one year. For example, a 1% AEP flood is the best estimate of a flood that has a 1% chance of being equalled or exceeded in any one year.

Design floods can also be expressed by their Average Recurrence Interval (ARI). For example, the 1% AEP flood can also be expressed as a 1 in 100 year ARI flood. That is, the 1% AEP flood will be equalled or exceeded, on average, once in a 100 years.

It should be noted that there is no guarantee that a 1% AEP flood will occur once in a 100-year period. It may occur more than once, or at no time at all in the 100-year period. This is because design floods are based upon a long-term statistical average. Therefore, it is prudent to understand that the occurrence of recent large floods does not preclude the potential for another large flood to occur in the near future.

Design floods are typically estimated by applying design rainfall to the hydrologic model and using the hydraulic model to route the rainfall excess across the catchment to determine design flood level, depth and velocity estimates.

7.1 Hydrology

Design hydrology was defined as part of the flood investigation using ARR2019. The following sections describe each of the hydrologic inputs that were derived based upon ARR2019 as well as the outputs.

7.1.1 Rainfall

As prescribed in ARR2019, point design rainfall depths were downloaded from the Bureau of Meteorology's IFD webpage. The design rainfall intensities were extracted at the centroid of the Fiery Creek catchment draining to Raglan (latitude: -37.337, longitude: 143.319).

As part of the flood investigation it was also necessary to define flood characteristics for the Probable Maximum Flood (PMF). The PMF is considered to be the largest flood that could conceivably occur across a particular area. The PMF is estimated by routing the Probable Maximum Precipitation (PMP) through hydrologic model. The PMP is defined as the greatest depth of rainfall that is meteorologically possible at a specific location.

PMP depths were derived for a range of storm durations up to and including the 3-hour event based on procedures set out in the Bureau of Meteorology's *'Generalised Short Duration Method'* (GSDM) (Bureau of Meteorology, 2003).

7.1.2 Areal Reduction Factors

The design rainfall depths available from the Bureau of Meteorology's IFD webpage are only applicable for catchment areas of up to 1 square kilometre. Therefore, ARR2019 includes areal reduction factors that recognise that there is unlikely to be a uniformly high rainfall intensity across all sections of large catchments.

The primary input variable to calculate the areal reduction factor is the contributing catchment area. One of the main difficulties in applying the areal reductions factors for a study area such as the one in this study is the fact that the contributing catchment areas vary considerably across the study area. For example, the Fiery Creek catchment draining to Raglan comprises a catchment area of over 46 km^2. However, the smaller subcatchments draining through parts of Raglan into Fiery Creek generally comprise areas of less than 1 km^2.

Therefore, two sets of areal reductions factors were applied to the point rainfall depths as part of the design storm simulations:

- Fiery Creek catchment: Area reduction factor calculated based upon area of 46.3 km^2; and,
- Other smaller subcatchments draining through Raglan: No areal reduction factors applied.

7.1.3 Rainfall Losses

The ARR2019 initial rainfall losses are calculated by subtracting median pre-burst rainfall losses from the overall storm loss for the area. This aim is to recognise that the most intense "downpour" is frequently preceded by rainfall that would serve to "wet" the catchment, thereby reducing the potential for rainfall during the main "burst" to infiltrate into the underlying soils (i.e., the median pre-burst rainfall depth is intended to reflect the "lead up" rainfall).

The overall storm loss data (25 mm) and pre-burst rainfall data for the study area was sourced from the ARR2019 data hub. The storm initial loss is subsequently adjusted by subtracting the median pre-burst rainfall depth (which varies based on storm duration and AEP) from the adjusted storm loss. For example, the "burst" initial loss for the 1% AEP, 120-minute storm would be calculated as:

- Burst initial loss = storm initial loss – median pre-burst rainfall depth

  Burst initial loss = 25mm – 1.6mm

  Burst initial loss = 23.4mm

No pre-burst rainfall losses are provided on the ARR2019 data hub for storm durations less than 1 hour. Therefore, it was assumed that the pre-burst rainfall losses for the 1 hour storm also applied for storm durations less than 1 hour. The resulting "burst" initial rainfall losses for the study area vary between 22.8 mm and 25 mm. No pre-burst rainfall information is available for events rarer than the 1% AEP storm. Therefore, the 1% AEP burst losses were also used for the 0.5% AEP, 0.2% AEP and PMP design flood events.

The ARR2019 data hub continuing loss rate of 4.6 mm/hour was applied to the RORB model without any alteration (as per ARR2019 recommendations).

7.1.4 Temporal Patterns

Application of ARR2019 requires application of 10 different temporal patterns to describe the temporal (i.e., time varying) distribution of rainfall during for each AEP and for each storm duration. This is intended to reflect that no two rainfall events are the same, thereby creating a greater range of more realistic design storms.

ARR2019 groups the temporal patterns into “frequent”, “intermediate” and “rare” groupings, which were applied to each design storm as follows:

- Frequent temporal patterns: 20% AEP
- Intermediate temporal patterns: 10% AEP and 5% AEP
- Rare temporal patterns: 2% AEP, 1% AEP, 0.5% AEP and 0.2% AEP

For the PMP, a single temporal pattern was adopted for each PMP storm simulation in line with the approach recommended in the *‘Generalised Short Duration Method’* (GSDM) (Bureau of Meteorology, 2003).

7.1.5 Results

The RORB model was subsequently used to simulate rainfall runoff processes for the complete suite of design storms with the assistance of the Storm Injector software. The design 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP storms were simulated using the RORB model. The PMF was also simulated.

A suite of ten temporal patterns were used to represent the temporal variation in rainfall for each design flood frequency up to and including the 0.2% AEP for each storm duration. The average peak discharge was calculated for each AEP and storm duration. The storm duration that produced the highest average discharge was selected as the critical storm duration for a particular location.

It was then necessary to select a representative temporal pattern for the critical storm durations. The temporal pattern that generated the peak discharge immediately above the average discharge was selected as the most representative temporal pattern for each subcatchment.

The results of this analysis indicate that the critical duration for the Fiery Creek catchment draining to Raglan is most commonly between 9 and 12 hours while the critical duration of the smaller subcatchments draining through Raglan typically fall between 2 and 3 hours.

Results Verification

To confirm the reliability of the design discharge estimates, the adopted peak 1% AEP discharge for Fiery Creek at Raglan-Elmhurst Road were verified against peak 1% AEP discharge estimates produced using the Regional Flood Frequency Estimation (RFFE) model. The RFFE is a simplified regional approach for estimating design discharges based upon the coordinates of the catchment centroid, coordinates of the catchment outlet and catchment area. The comparison is presented in **Table 9**.

Table 9 Verification of Peak 1% AEP Discharge for Fiery Creek at Raglan-Elmhurst Road

Location	Peak 1% AEP Discharge (m^3/s)			
	Current Study	RFFE		
		Lower Confidence Limit (5%)	Expected Quantile	Upper Confidence Limit (95%)
Fiery Creek @ Raglan-Elmhurst Rd	70.5	8.07	24.6	76.0

This comparison presented in **Table 9** shows that the peak 1% AEP discharge produced as part of the current study is well above the best RFFE 1% AEP discharge estimate but within the 95% upper confidence bound. It is noted that the RFFE can be less reliable in catchments with dams, where significant clearing has occurred or where drainage modification activities have occurred. There is evidence of each of these activities having occurred within the Fiery Creek catchment which reduces the reliability of the RFFE method. Nevertheless, the comparison indicates that the estimates produced as part of the current study are within the expected confidence limits of the RFFE. When this is combined with the calibration outcomes, it indicates that RORB model developed as part of the study is generating reasonable estimates of flood behaviour in the vicinity or Raglan.

7.2 Hydraulics

7.2.1 Boundary Conditions

Inflows

As previously discussed, the RORB hydrologic model was used to simulate the transformation of rainfall into runoff and generate discharge hydrographs throughout the catchment. The discharge hydrographs generated by the RORB model were used to define upstream (i.e., inflow) boundary conditions for the TUFLOW model.

However, as noted above, a large number of storms are considered as part of each hydrologic analysis. This can potentially result in dozens for critical durations and temporal patterns. Although the RORB model runs in a matter of seconds and can run a large number of storms in a relatively short amount of time, the hydraulic model takes several hours to run a single storm. Therefore, it was not considered feasible to run all unique combinations of storm durations and temporal patterns through the hydraulic model in a timely manner.

Therefore, the assessment of critical durations and temporal patterns was restricted to a selection of "focus" locations. The focus locations included:

- Fiery Creek at Raglan-Elmhurst Road;
- Unnamed watercourse at Raglan-Elmhurst Road (west of Raglan Recreation Reserve); and
- Unnamed watercourse at Raglan-Elmhurst Road (west of Codrington Street intersection)

The temporal patterns and storm durations that were ultimately selected for each AEP for application to the TUFLOW model are summarised in **Table 10**.

Table 10 Adopted temporal patterns and storm durations for hydraulic analysis

Design Storm	Storm Durations and Temporal Pattern ID							
	1 hour	1.5 hours	2 hours	3 hours	4.5 hours	6 hours	9 hours	12 hours
20% AEP			6057		6126		6186	6217
10% AEP			5989			6138	6172	6198
5% AEP		6015				6136	6178	6205
2% AEP		5997		6065			6167	5991
1% AEP	5969			6066			6167	5991
0.5% AEP	5914			6066			6168	5991
0.2% AEP	5942		6036				5998	5991

7.2.2 Hydraulic Structure Blockage

Culvert and Bridge Blockage

'Base' blockage factors for each bridge and culvert in the study area were estimated based upon recommendations in Chapter 6 of Book 6 of ARR2019. This document also recommends adjusting the 'base' blockage factors up or down depending on the severity of the event (i.e., higher blockage factors during larger floods and lower blockage factors during smaller floods). A summary of the blockage scenarios that were adopted for each design flood is summarised below:

- Low Blockage Scenario –20% AEP and 10% AEP events
- Medium Blockage Scenario – 5%, 2%, 1% and 0.5% AEP events
- High Blockage Scenario – 0.2% AEP and PMF events

7.3 Results

The results from each simulation for each design flood were interrogated and combined to form a "design flood envelope" for each design flood. It is this "design flood envelope", comprising the worst-case depths, velocities and levels at each TUFLOW cell that forms the basis for the results documented in the following sections.

Results were extracted from the final design flood envelopes and were used to prepare a range of flood mapping for the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF events. This includes:

- Floodwater Depths and Levels
- Floodwater Velocities:
- Floodwater Hazard (velocity depth product)

Duration of inundation maps were also prepared for each design flood to illustrate the amount of time different areas would be subject to inundation. The duration of inundation maps were prepared based upon two different depth cut-offs:

- 0 mm depth cut off - reflects the total amount of inundation time from when an area first becomes "wet" until it is no longer subjects to any inundation.
- 300mm depth cut off - reflects the total amount of inundation time from when an area is first subject to at least 300 mm of water until the water depths drop below 300mm. This depth approximates when vehicular access could likely be cut/resumed.

The duration of inundation maps show that some lower lying sections of floodplain are predicted to be inundated for periods exceeding 20 hours during most of the design floods. However, in the immediate vicinity of roadways and houses, the inundation durations are most commonly less than 10 hours.

It should be noted that when reviewing the maps, the inundation times are based on the critical design floods. That is, the storm duration that produced the highest peak flood levels around Raglan. However, no two floods are exactly the same and the duration of inundation is strongly correlated to the length of rainfall. Therefore, there is potential for extended periods of rainfall (i.e., longer than the critical duration for the catchment) to inundate the area for longer periods. Similarly, shorter rainfall "bursts" may inundate the area for shorter periods. Therefore, the inundation times should be taken as indicative rather than precise.

7.4 Climate Change Scenarios

Climate change refers to a significant and lasting change in weather patterns arising from both natural and human induced processes. The most recent Intergovernmental Panel on Climate Change (IPCC, 2019) report states that climate change is expected to have adverse impacts on sea levels and rainfall intensities in the future.

Although there is considerable uncertainty associated with the impact that climate change may have on rainfall, it was considered important to provide an assessment of the potential impact that climate change may have on the current flood risk across the study area. ARR2019 recommends assessment of two representative concentration pathways (RCP) which reflects current best estimates of likely upper and lower bounds of potential rainfall intensity increases. These are:

- Representative Concentration Pathway scenario 4.5 (RCP4.5): greenhouse gas emissions are reduced in the future; and,
- Representative Concentration Pathway scenario 8.5 (RCP8.5): greenhouse gas emissions increase in the future.

The current interim climate change factors documented on the Australian Rainfall and Runoff Data Hub for the Fiery Creek catchment are presented in **Plate 2.** This information indicates that under RCP 4.5 conditions, rainfall intensities could increase by 5.4% by 2050 and by 7.6% by 2090. Under RCP 8.5 conditions, rainfall intensities could increase by 7.3% by 2050 and by 16.3% by 2090

Interim Climate Change Factors			
	RCP 4.5	RCP6	**RCP 8.5**
2030	**0.648 (3.2%)**	0.687 (3.4%)	**0.811 (4.0%)**
2040	**0.878 (4.4%)**	0.827 (4.1%)	**1.084 (5.4%)**
2050	**1.081 (5.4%)**	1.013 (5.1%)	**1.446 (7.3%)**
2060	**1.251 (6.3%)**	1.229 (6.2%)	**1.862 (9.5%)**
2070	**1.381 (7.0%)**	1.460 (7.4%)	**2.298 (11.9%)**
2080	**1.465 (7.4%)**	1.691 (8.6%)	**2.719 (14.2%)**
2090	**1.496 (7.6%)**	1.906 (9.7%)	**3.090 (16.3%)**

Plate 2 - Interim climate change factors for the Fiery Creek catchment (Geoscience Australia, 2019)

Several different climate change simulations were completed for the 10% AEP and 1% AEP floods to gain an understanding of the potential impacts of climate change in this catchment. This included the following RCPs and planning horizons

- RCP 4.5 for 2050 and 2090 horizons; and
- RCP 8.5 for 2050 and 2090 horizons

The rainfall intensity increases were applied to the existing 10% AEP and 1% AEP design rainfall depths. The peak discharge comparison indicates that increases in rainfall will increase peak discharges at all locations in the vicinity of Raglan. The peak 1% AEP discharges are predicted to increase by between 10% (under RCP 4.5 2050 conditions) up to 50% (under RCP 8.5 2090 conditions). Peak 10% AEP discharges are predicted to increase by between 14% (under RCP 4.5 2050 conditions) to more than 80% (under RCP 8.5 2090 conditions). Accordingly, existing peak design discharges are likely to increase considerably across some areas of Raglan as a result of rainfall intensity increases.

The revised discharge hydrographs were then applied to the TUFLOW model and the TUFLOW model was used to re-simulate the 10% AEP and 1% AEP design flood with the rainfall intensity increases.

The peak climate change flood level results were reviewed, and this determined that peak 10% AEP flood levels/depths in the vicinity of Raglan will typically increase by between 0.1 metres (under RCP 4.5 2050 conditions) and 0.5 metres (under RCP 8.5 2090 conditions). However, most water level increases are contained to the Fiery Creek channel only.

During the 1% AEP flood, the peak flood level and depth increases are more modest but extend across a larger area. More specifically, peak 1% AEP levels are predicted to increase by between 0.05 metres (under RCP 4.5 2050 conditions) and 0.3 metres (under RCP 8.5 2090 conditions) with the flood level increases being most significant in the immediate vicinity of the Fiery Creek channel. The flood level increases are predicted to extend across a number of properties, particularly near Drews Lane (although the level increases in this area generally do not exceed 0.1 metres).

Overall, the outcomes of the climate change simulations show that increases in rainfall associated with climate change have the potential to increase the severity of flooding across Raglan.

7.5 Design Flood Mapping

As noted in **Section 7.3**, flood mapping for the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF design flood events. The 1% AEP design flood event is the primary design event that is used for planning and development purposes, with planning scheme amendment documents prepared as part of this study based on the 1% AEP design flood event and discussed further in **Section 8.** The peak floodwater depths and levels have been included below, with the study area broken up into three (3) areas – northern (**Figure J5.1**), middle (**Figure J5.2**) and southern (**Figure J5.3**) .

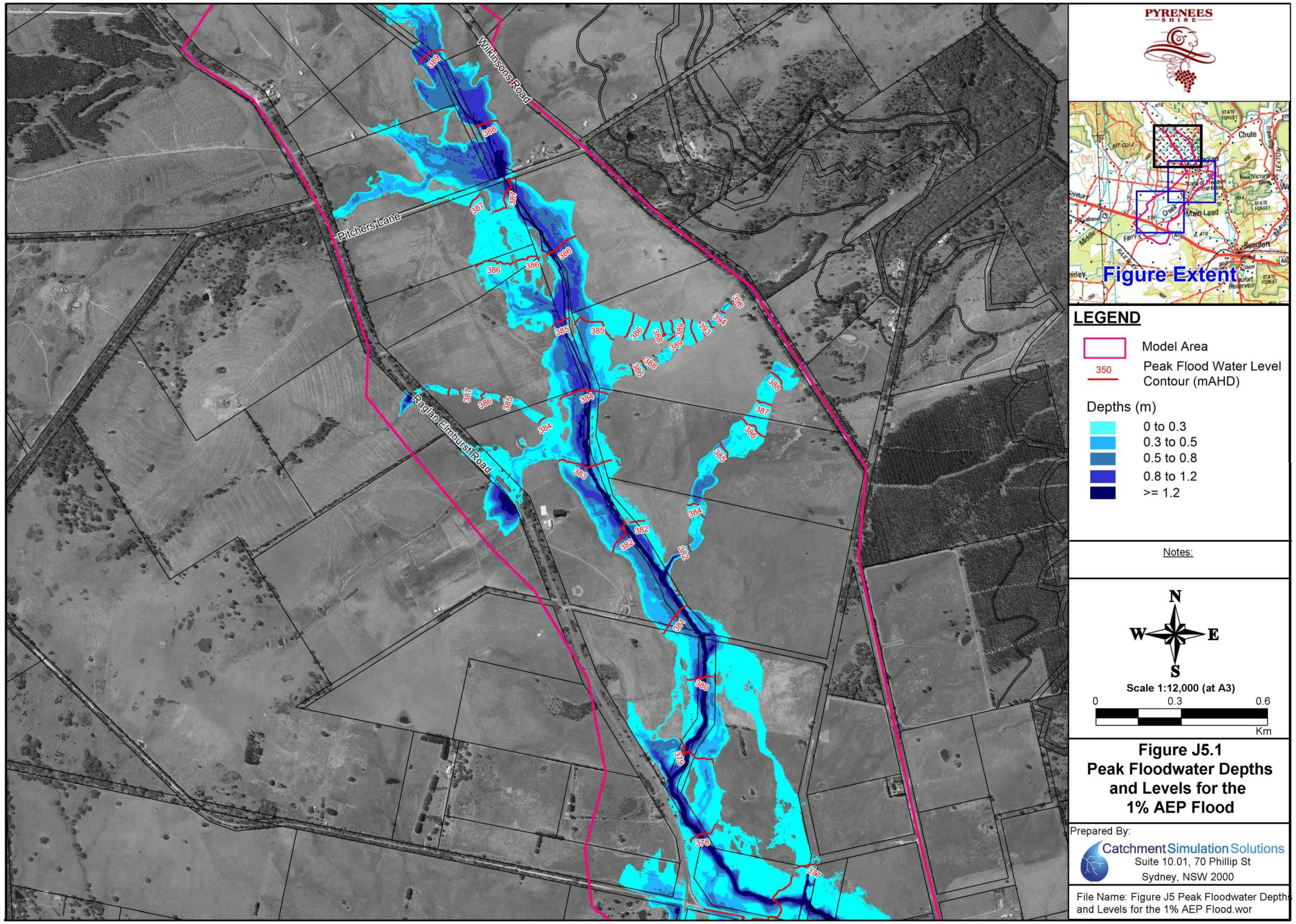


Figure J5.1 Peak Floodwater Depths and Levels for the 1% AEP Flood

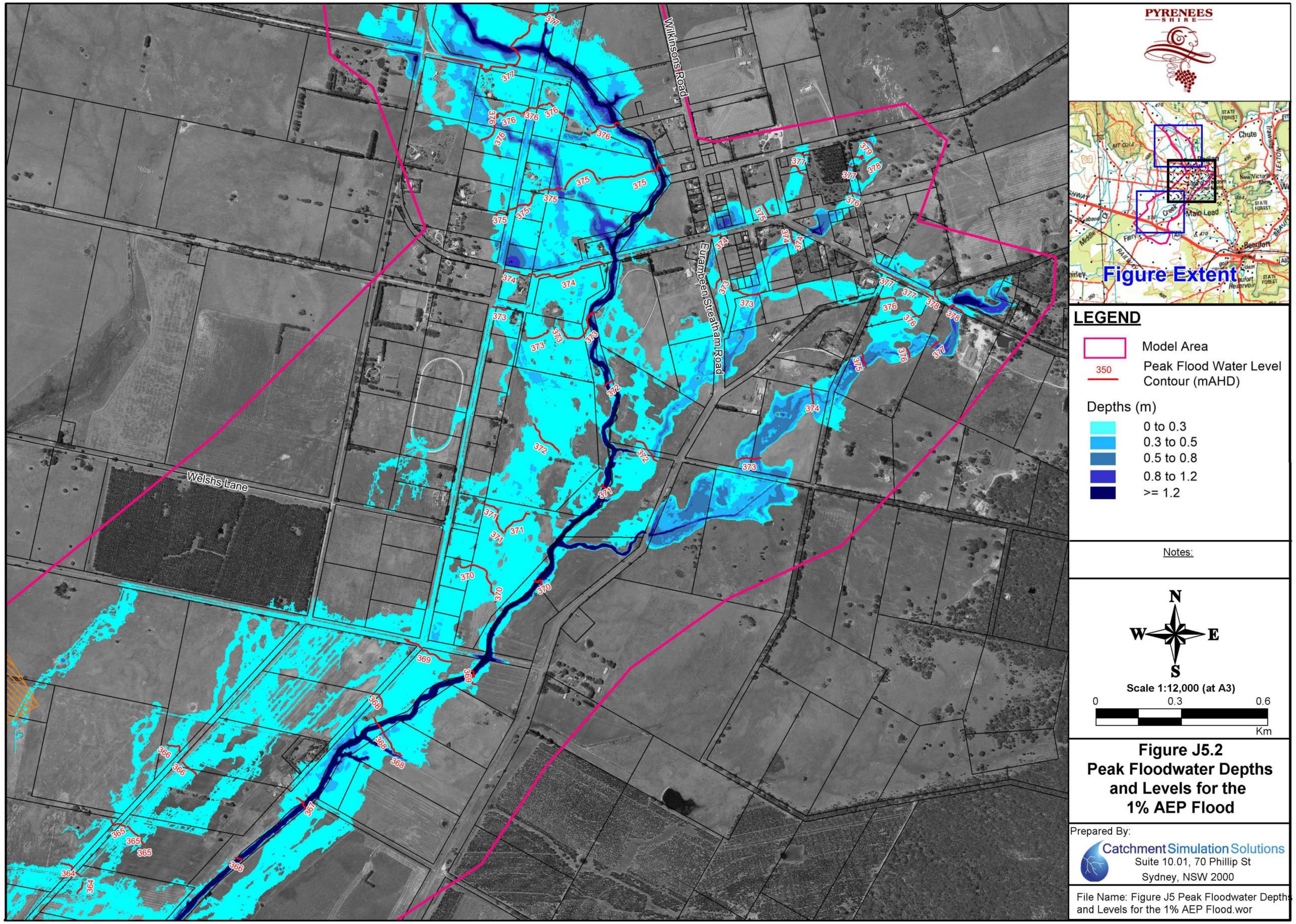


Figure J5.2
Peak Floodwater Depths and Levels for the 1% AEP Flood

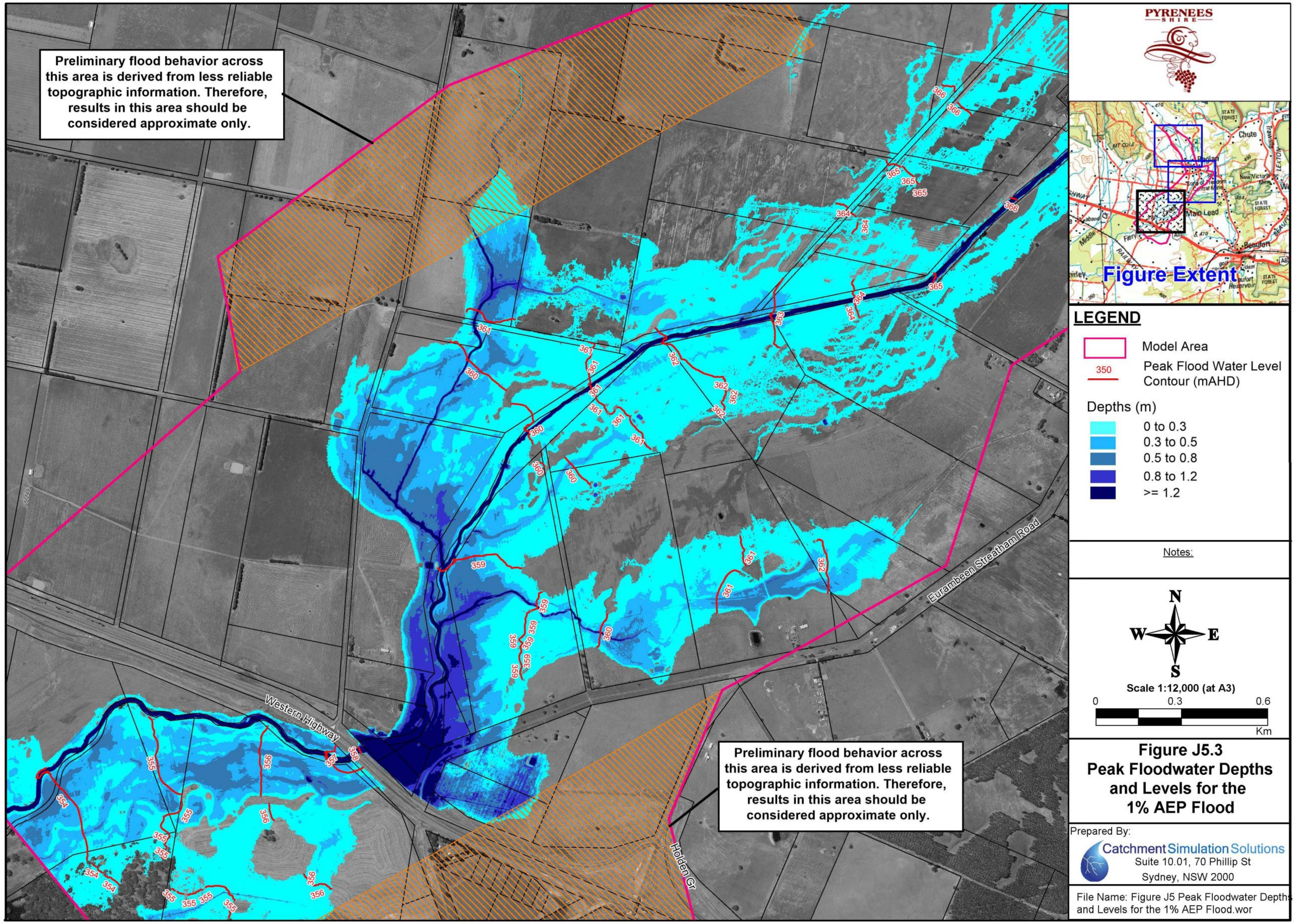


Figure J5.3
Peak Floodwater Depths and Levels for the 1% AEP Flood

8 FLOOD PLANNING CONTROLS

There are currently no flood information or flood extents reflected in the Pyrenees Planning Scheme's overlays for Raglan. Therefore, Council and developers have limited readily accessible information that can be used to guide future development in an appropriate manner with respect to flood risk.

The Raglan flood Investigation includes high quality and detail flood behaviour information that can be included in flood planning overlays. Therefore planning scheme amendment documents have been prepared for Council in order to facilitate the inclusion of new flood overlays within Raglan.

The study identified areas within and around the township of Raglan that are affected by flooding and these areas have been mapped as either Floodway Overlay (FO) or Land Subject to Inundation Overlay (LSIO).

- The FO identifies waterways, major flood paths and drainage depressions and has been applied to areas recognised as having the greatest risk and frequency of being affected by mainstream flooding, especially areas that convey active flood flows or store floodwater to hazardous depths; and

- The LSIO identifies land in flood storage or flood fringe areas affected by the 1 in 100 year flood event and has generally been applied to areas affected by mainstream flooding that have a lower risk of flooding and are outside of the FO boundaries. In addition, the LSIO may apply to areas that are known to flood but where there is no available information on flood depths, velocities or level of hazard.

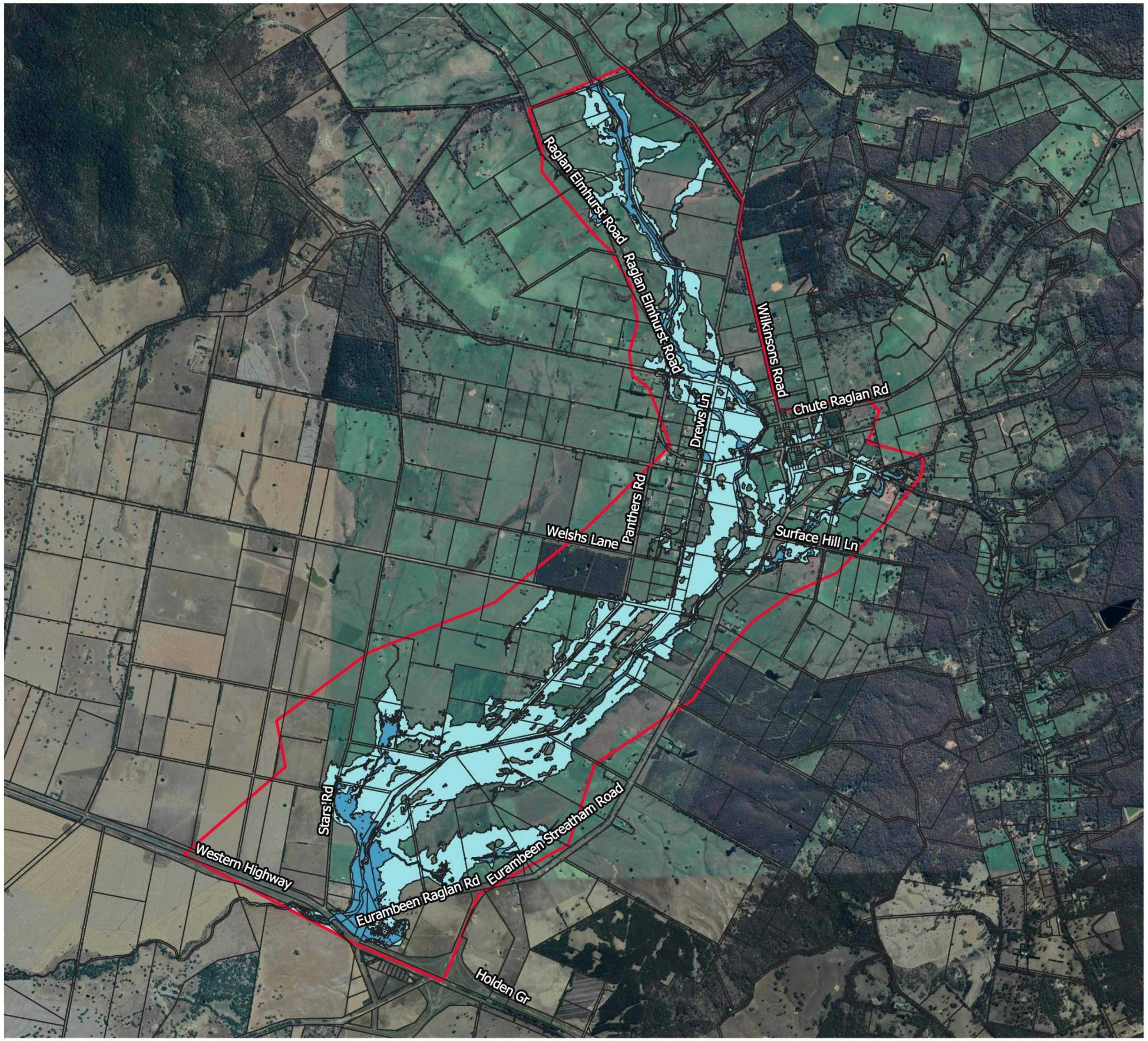
The FO is delineated from the LSIO where areas of flooding occur equal to or greater than 0.5m flood depth or with a depth velocity product equal to or greater than $0.4m^2/s$.

These flood planning overlays will trigger planning permits for development, works and subdivision on land affected by flooding. The schedules to these overlays specify a number of exemptions to the permit trigger for specific types of buildings and works. The exemptions contained within these schedules are considered appropriate for the form of flooding identified within Raglan.

The application of these overlays will assist Local Government, Catchment Management Authority and the community in carrying out more effective planning and management of flood prone land within Raglan.

The controls associated with each overlay are proposed to mirror those outlined in the Beaufort Local Flood Development Plan. While the development types are typically more rural through Raglan settlement and surrounding areas than Beaufort, flood mechanisms are similar and localised development controls within the LGA would add additional unwarranted complexity for Council and Developers to deal with.

The recommended flood overlay map for Raglan is presented below. The area covered in this flood overlay map extend from Pitchers Lane in the north to the Western Highway to the south.



Legend

- Project Study Area
- Floodway Overlay
- Land Subject to Inundation Overlay

0 0.5 1 1.5 2 km

N

Horizontal Datum: GDA 1994 / MGA Zone 55
Vertical Datum: m AHD

RAGLAN FLOOD INVESTIGATION
FLOOD OVERLAY MAP

FIGURE 1
RAGLAN FLOOD OVERLAY MAP

9 Flood Damages Assessment

The damage costs associated with inundation can be broken down into a number of categories, as shown in **Error! Reference source not found.** However, broadly speaking, damage costs fall under two major categories;

- tangible damages;
- and intangible damages.

Tangible damages are those which can be quantified in monetary terms (e.g., cost to replace household items damaged by floodwaters). Intangible damages cannot be as readily quantified in monetary terms and include items such as inconvenience and emotional stress.

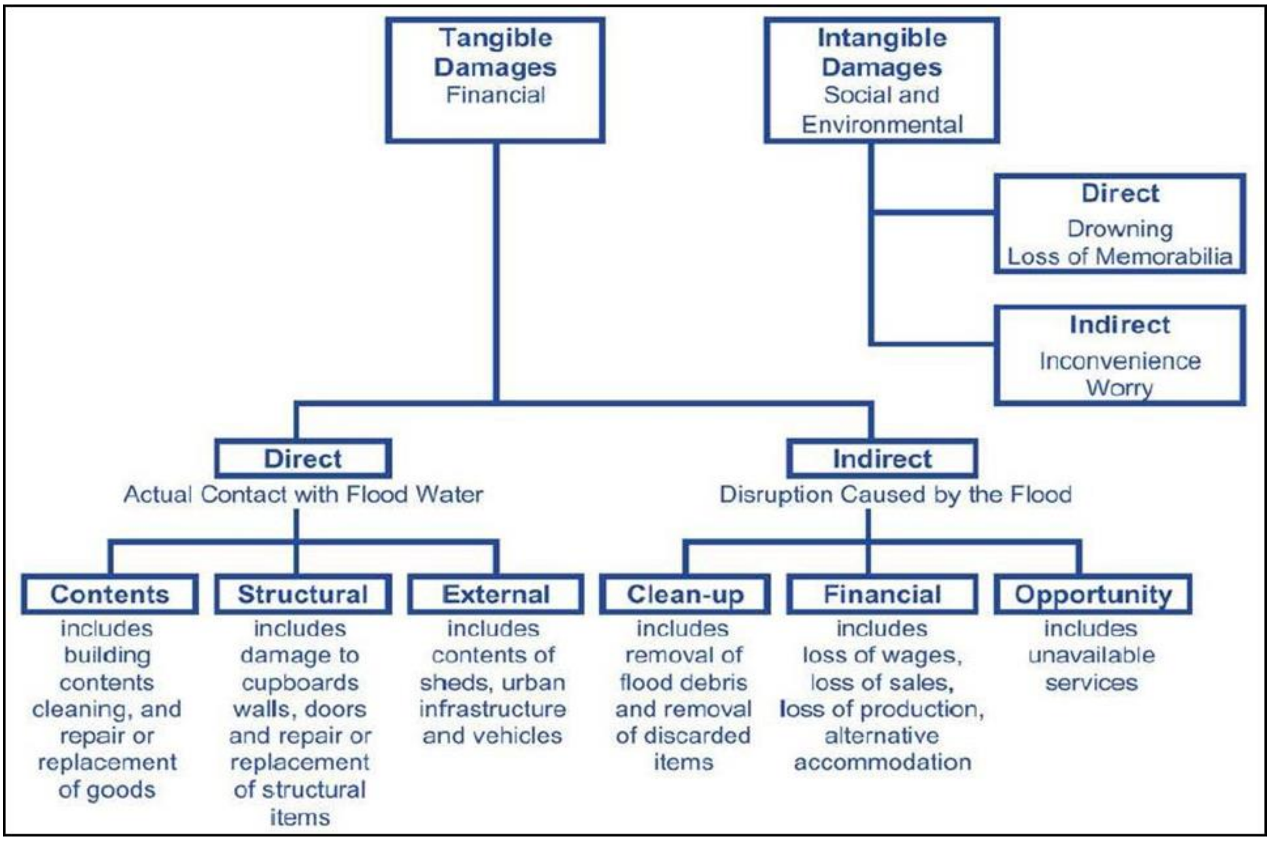


Plate 3 - Flood Damage Categories (NSW Government, 2005)

Tangible damages can be further broken down into direct and indirect damage costs. Direct costs are associated with floodwater coming into direct contact with buildings and contents. Indirect flood damage costs are costs incurred outside of the specific flood event. This can include clean-up costs, loss of trade (for commercial/industrial properties) and/or alternate accommodation costs while clean-up/repairs are undertaken.

Direct tangible flood damages are typically calculated using stage-damage tables that assign a dollar value to the damage based on the depth of flooding above the ground or floor level. There are several different studies that have determined methodologies for deriving flood damage curves. In this study we have utilised the O2 (2012) and the NSW Governments (2007) stage-damage curves.

Indirect damages are difficult to quantify and therefore typically applied as a percentage of the direct tangible damages. This is typically between 15% (based on ANUFLOOD, 1992) and 30% (based on the RAM method, NRE, 2000). In this study we have adopted 15% for the indirect tangible damages as it is recommended in the O2 methodology and is most commonly used when applying the NSW Governments flood damage estimate methodology.

Due to the difficulty associated with assigning monetary values to intangible damages, only tangible damages were calculated as part of this study and included in the economic assessment, however some discussion of intangible flood damages is included.

The floor level for each property was represented using a single point. This point was positioned in a location considered to be most representative of the flood level in the vicinity of property (usually at the front of the building or the side upstream of the building)

Building floor areas were calculated for each building using GIS building polygons. The building floor area serves as one of the residential damage curve inputs. A typical representative building floor area of 150 m^2 was adopted for the study area and was used as input to develop the residential damage curves.

For each simulated flood event, the maximum water surface elevation of the computational cells that are in contact with the building is assigned as the flood level for that property. The flooded properties are then further categorised as:

- Below Floor Flooded: This is where there is some flooding against the building but it has not exceeded the floor level, typically a small amount of flood damage is incurred as out buildings such as sheds and garages as well as gardens may be affected. This is also referred to as Above Ground Flooding.
- Above Floor Flooded: The flood level exceeds the floor level of the building and it is assumed that water has entered the building and has begun to damage the buildings structure as well as contents.

For events up to the 1% AEP design flood event there are no properties with above floor flooding and the damage estimate is comprised entirely of external damage. Between the 1% AEP and the 0.2% AEP design flood events the number of properties with above floor flooding rises from 1 to 4, and then to 19 during the PMF event.

In reality, the cost of flooding fluctuates from next to nothing most years when only minor flooding is experienced, to large values in years with big floods. Therefore, to get an estimate of the overall flood damages across a longer period, damages are often expressed as average annual damages (AAD). AAD is essentially the cost of flooding each year, on average over a very long period of time. Overall, the flood damages at Raglan are relatively low, with an average annual damage (AAD) approximately $7,800 (O2 method) to $11,800 (NSW Government method).

Another way to express flood damages is using the Net Present Value (NPV) of damages. This is calculated by adding the AAD for a specified period of time (typically 50 years) while discounting damages in future years (i.e. damage that occurs in 50 years' time has less value today in today's dollar values). For Raglan, using a standard 7% discount rate, the NPV of damages ranges between $106,800 and $162,200.

The NPV figure is important as the cost of structural options is assessed against the reduction in the NPV of flood damages induced by the option to determine its financial feasibility.

Table 11 Summary of base case flood damages

Event (AEP %)	Number of Below Floor Flooded	Number of Above Floor Flooded	Total Damages ($) (OEH)	Total Damages ($) (O2)
20	1	0	13,754	5,890
10	2	0	27,507	11,238
5	3	0	29,159	13,385
2	7	0	99,120	61,892
1	9	1	184,545	91,464
0.5	14	3	307,398	123,655
0.2	15	4	386,715	160,087
PMF	23	19	1,446,390	792,631

10 Flood Mitigation Options

A number of existing properties in the settlement of Raglan are exposed to flood risk. This risk may be due to flood waters entering the property directly or due to access issues caused by floodwaters inundating roads.

The management of flood risk can be broadly grouped into three mechanisms – flood modification, property modification and response modifications. Property modification measures relate to planning and development controls and were discussed in **Section 8**. Response modification options that relate to the emergency planning and response before, during and after a flood event and are discussed in **Section 11**. Flood modification measures aim to modify existing flood behaviour, thereby reducing the extent, depth and/or velocity of floodwater across flood liable areas and are discussed in this chapter.

In order to mitigate the flood risk at Raglan and surrounds, six (6) structural mitigation options were investigated as part of the potential flood modification management measures. Structural mitigation options were raised during Project Reference Group meetings and through Community Consultation. A Community consultation session was held on the 9th of December 2019 at the Raglan Community Hall between 3pm and 6pm to discuss specific mitigation options. Three residents attended and provided a range of feedback.

The following options were suggested at the reference group meetings and community consultation:

1. Raise Old Beaufort Road which can act as a levee to prevent the breakout via Drews Lane
2. Raise Raglan-Eurambeen Rd to above the 1% AEP design flood level
3. Raise Raglan-Elmhurst Road through the main section of town
4. Expand the Raglan-Elmhurst Road bridge over Fiery Creek
5. Investigate a drainage solution along Raglan-Elmhurst Road between Codrington Street and Vaughan Street
6. Improve flow conveyance through regular clearing of the creek and drains

The modelled options are presented in **Plate 4Error! Reference source not found.** and described further following.

Each flood risk management option will generally be a compromise as it is unlikely that an option will provide only benefits (e.g., there may be an adverse environmental impact or significant costs associated with the implementation of the option). In general, if the advantages associated with implementing the option outweigh the disadvantages, it will afford a net positive outcome and may be considered viable for future implementation. Therefore, each option was evaluated against a range of criteria to provide an initial appraisal of the potential feasibility of each option.

Each flood and property modification option was evaluated against the following criteria, where sufficient information was available:

- Hydraulic impacts
- Emergency responses impacts
- Change in number of buildings inundated above floor level
- Technical feasibility
- Environmental impacts
- Economic feasibility
- Community acceptance

Further details on each of these evaluation criteria is presented below. The scoring system that was used to rank each option against these criteria is also provided in **Table 12**.

Table 12 Adopted Evaluation Criteria and Scoring System for Assessment of Flood Risk Management Options

Criteria	**Ranking/Score**				
	- -	**-**	**-N-**	**+**	**++**
Hydraulic Impacts	Significant increases in levels (>0.1m) / extents	Minor increases in levels (<0.1m) / extents	Negligible changes in levels / extents	Minor decreases in levels (<0.1m) / extents	Significant decreases in levels (>0.1m) / extents
Change in number of buildings inundated above floor level	Significant increase in number of buildings impacted by above floor flooding	Small increase in number of buildings impacted by above floor flooding	No Change in number of buildings impacted by above floor flooding	Small decrease in number of buildings impacted by above floor flooding	Significant decrease in number of buildings impacted by above floor flooding
Emergency Response Impacts	Significant adverse impact on emergency response	Small adverse impact on emergency response	Negligible impact on emergency response	Small improvement to emergency response	Significant improvement to emergency response
Technical Feasibility	Significant technical challenges	Moderate technical challenges	Minor technical challenges	Negligible technical challenges	No technical challenges
Environmental Impacts	Significant negative environmental impact	Small negative environmental impact	Negligible environmental impacts	Small opportunity for environmental enhancement	Significant opportunity for environmental enhancement
Economic Feasibility	BCR <0.5 and / or high capital / ongoing costs	0.5 < BCR < 0.8	0.8 < BCR < 1.0	1.0 < BCR < 1.2	BCR > 1.2 and / or low capital / ongoing costs
Community Acceptance	Majority of community opposed	Some opposed	Neutral	Some community support	Majority of community support

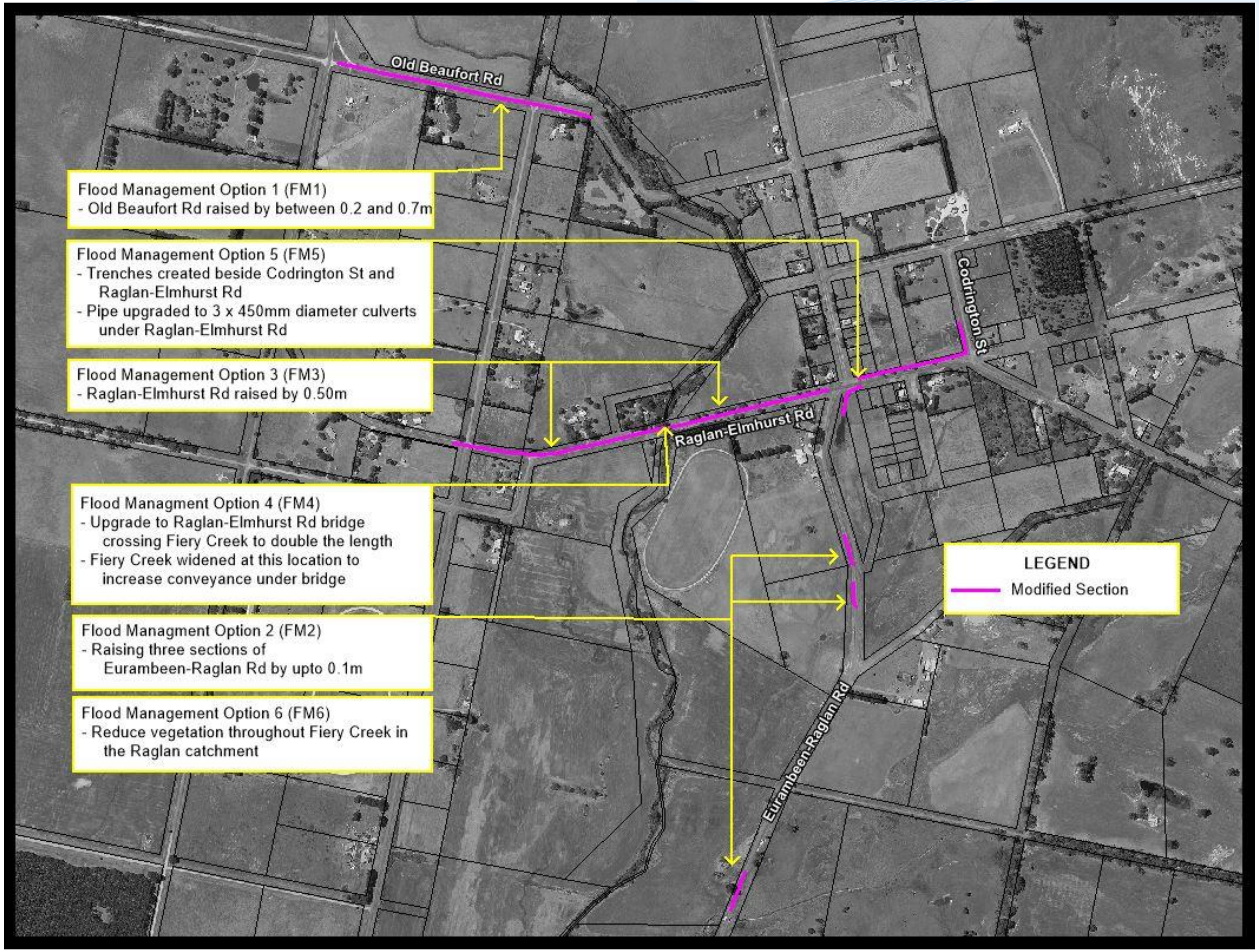


Plate 4 - Modelled Structural Mitigation Options

10.1 Structural Options Assessment

10.1.1 FM1 Raising Old Beaufort Road

Assessment of raising Old Beaufort Road for the impact on flood extents for the 1% AEP is shown in **Plate 5**. The option has a significant re-distributive effect, effectively blocking a large amount of the flow down Drews Lane and the western side of the Fiery Creek while increase flood levels and extents on the Eastern side. The impacted area is largely undeveloped and so there are no adverse impacts on existing infrastructure or residential dwellings. On the western side, one property is no longer flooded above floor in the 1% AEP design flood event and two properties no longer flooded in the 0.5 and 0.2% AEP design flood events.

This option would have significant capital costs and the benefits are largely limited to those two properties in extreme flood events. The overall BCR is 0.09 which indicates that the option is not financially viable. Also worth noting is that the affected landholders to the east would need to be heavily consulted as this would potentially have a significant impact on the development potential of their land.

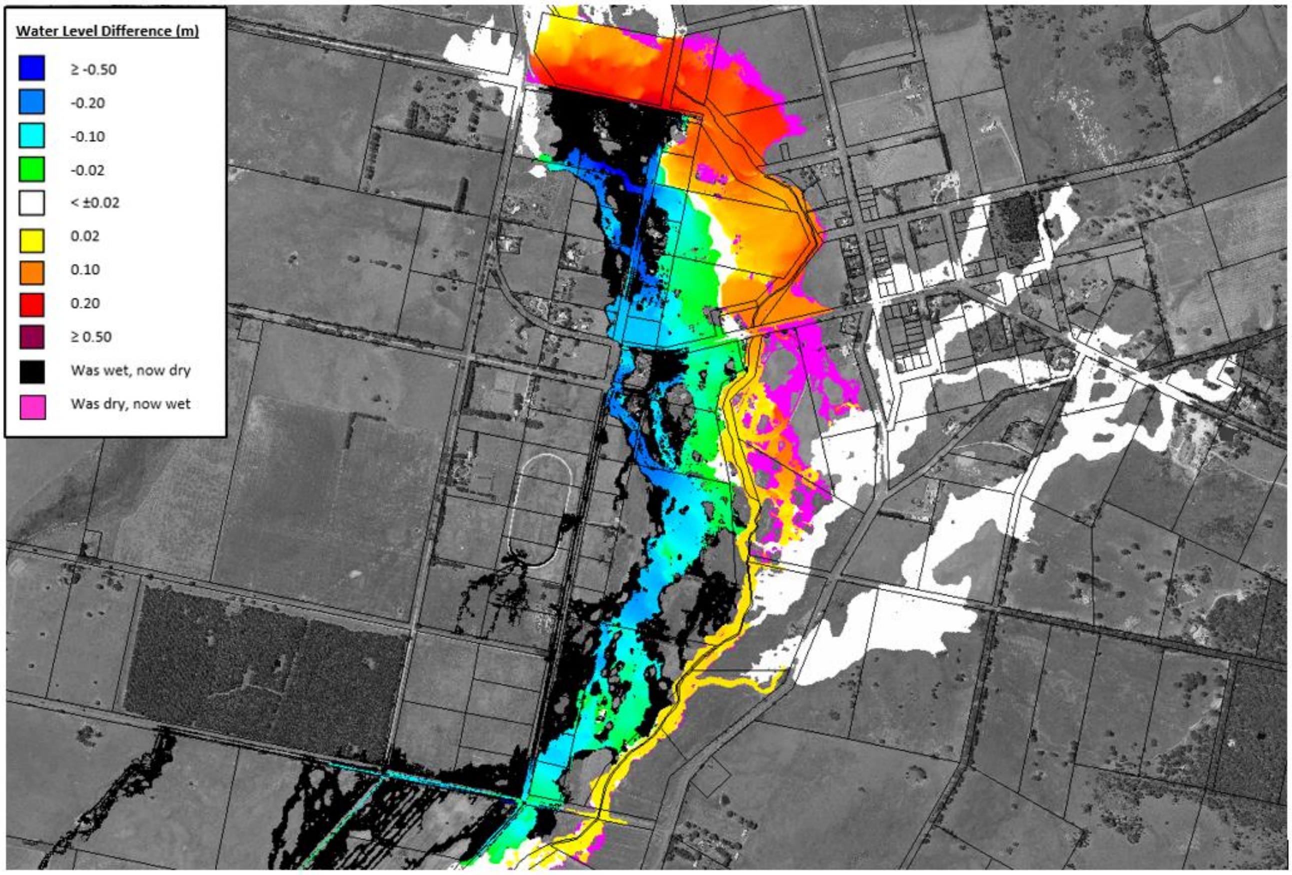


Plate 5 - 1% AEP change in flood levels due to raising Old Beaufort Road

10.1.2 FM2 Raising Eurambeen - Raglan Road

The assessment summary of the raising Eurambeen – Raglan for the impact on flood extents for the 1% AEP is shown in **Plate 6**. Overall the option has very limited impact on flooding, reducing the inundated area downstream of where the road has been raised and slightly increasing levels upstream.

No properties are affected (either positive or negative) in this option and therefore there is no financial benefit from the project when the change in flood damages are assessed. The main benefit is associated with the improved road access during large floods where properties may be cut off from Beaufort or Ballarat. While this option does improve that access which would be of benefit to the emergency services during a flood event, many properties will still be isolated internally within Raglan, particularly those on the western side of the Fiery Creek.

Given that the road is only cut in relatively large and infrequent events (> 2% AEP), flood duration is relatively short (likely to be inundated for less than a few hours) and there are other internal flood access constraints. There is likely to be little benefit gained from this option.

Plate 6 - 1% AEP change in flood levels due to raising Eurambeen - Raglan Road

10.1.3 FM3 Raising Raglan-Elmhurst Road at Fiery Ck Crossing

Assessment of raising Raglan-Elmhurst Road is presented in **Plate 7** for the impact on flood extents for the 1% AEP design flood event. The aim of raising the road is to prevent water over-topping the bridge or roadway up to the 1% AEP design flood level, however this causes significant ponding behind the raised road embankment that inundates additional properties. While there is a reduction in flood levels and extents on the western side of Fiery Creek downstream of the road, the flood affectation of residential buildings does not change.

While the option would increase the connectivity between the eastern and western parts of Raglan during a flood, the town itself would likely be cut off from the surrounding area. There are limited services within the town that would need to be accessed during a flood and therefore limited benefit to improving the eastern and western connectivity during flood events. This option would be of limited benefit to emergency services as roads in to and out of town would still be cut off during flood events.

Overall, the option causes an increase in flood damages within the study area and would have very significant capital costs. Therefore, the options is considered unviable and is not recommended for implementation.

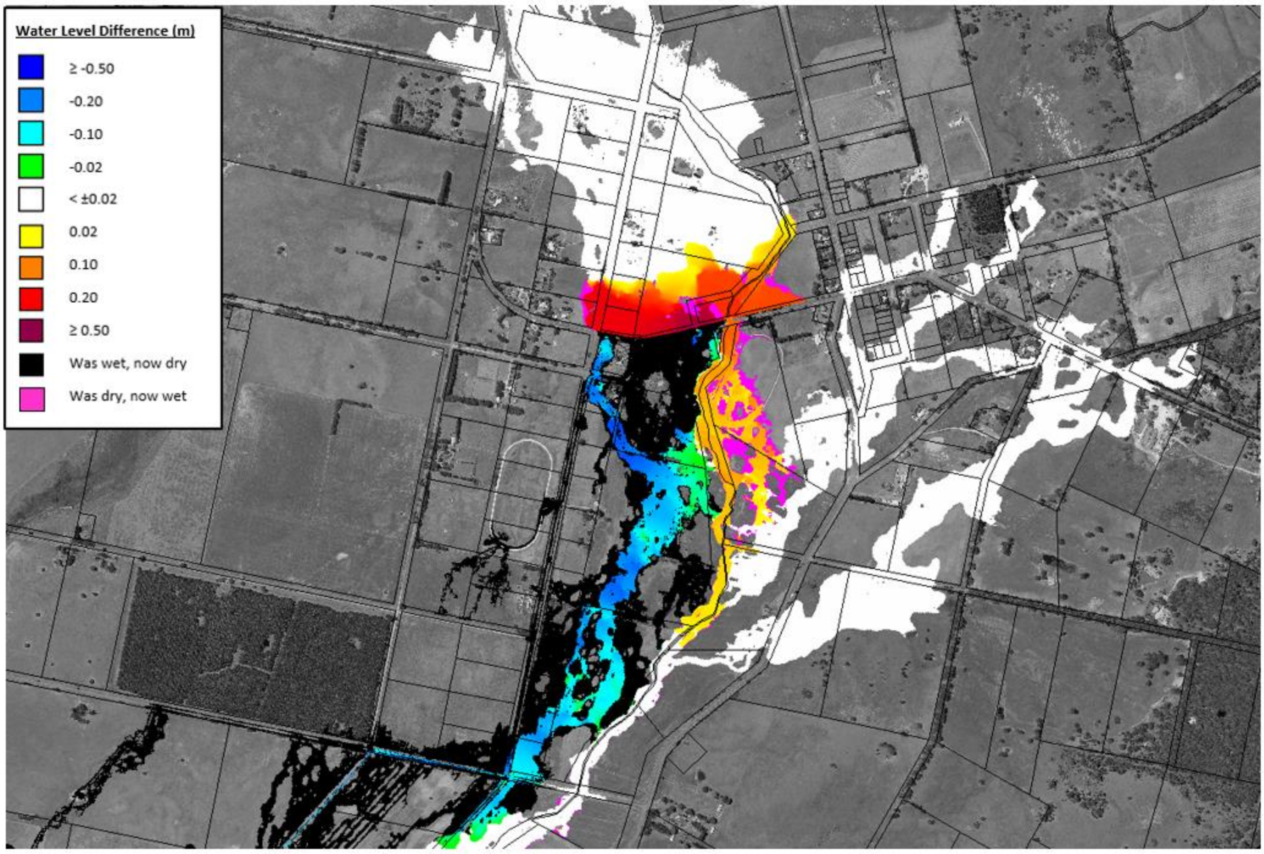


Plate 7 - 1% AEP change in flood levels due to raising Raglan - Elmhurst Road

10.1.4 FM4 Widening Fiery Creek Crossing at Raglan-Elmhurst Road

The assessment of widening the Fiery Creek crossing at Raglan-Elmhurst Road is presented in **Plate 8** for the impact on flood extents in the 1% AEP design flood event. The effect of the option is to reduce the flood levels immediately upstream of the bridge and along the creek corridor for approximately 500 metres with only very minor increases downstream.

While having a net benefit in reducing flood levels during the 1% AEP design flood event, the option has no impact on the number of buildings impacted by flooding and therefore has an effective Benefit-Cost-Ration (BCR) of zero. In addition, the option would require significant earthworks in and around the Fiery Creek channel and may have environmental impacts.

While there is a clear (but limited) benefit to this option with little to no flood impacts, the option is the most expensive option considered as part of this study and is financially unviable, even if it was incorporated into a bridge replacement scheme.

Plate 8 - 1% AEP change in flood levels due to widening the Fiery Creek crossing at Raglan - Elmhurst Road

10.1.5 FM5 Improving Drainage along Codrington and Vaughan Street

The assessment summary for the improving drainage along Codrington and Vaughan Streets is presented in **Plate 9** for the impact on flood extents in the 1% AEP design flood event

This option was considered as it was widely expected that new development that had occurred in Raglan would be heavily impacted by flooding. However, these properties are largely unaffected until floods greater than the 1% AEP design flood event, indicating the option will have very limited benefits when comparing flood damage before and after the works. The channel, currently designed to contain the 1% AEP flow, would need to be significantly greater to provide a reduction in flood levels, with the size achievable in the area unlikely. Therefore, the potential to protect against floods larger than the 1% AEP design flood event would be unfeasible. Such works would also afford those properties which receive an improvement in their flood hazard a level of protection that is generally not considered in floodplain management (i.e. greater than the 1% AEP design flood event).

The option also has a negative impact on properties downstream, by reducing flood storage and increasing conveyance across Raglan – Elmhurst Road. While these properties are currently undeveloped, the owners would need to be consulted as it may impact their ability to develop their land in the future.

The community has expressed some desire for improved drainage through Raglan, however this would need to be a much wider ranging drainage plan so as not to adversely impact some properties to the benefit to others. The overall Net Present Value (NPV) of the Raglan flood damages is approximately $100,000 – $150,000 and this small section of drainage improvement costs approximately $40,000. Therefore, a drainage improvement scheme across the whole Raglan settlement area would likely cost many times more than the total NPV of flood damages, while not actually eliminating most of the flood damage, as the flood risk is sourced from Fiery Creek rather than local drainage. Therefore, any drainage improvements would need to be justified from a nuisance flooding and stormwater infrastructure planning perspective rather than from a mainstream flood perspective.

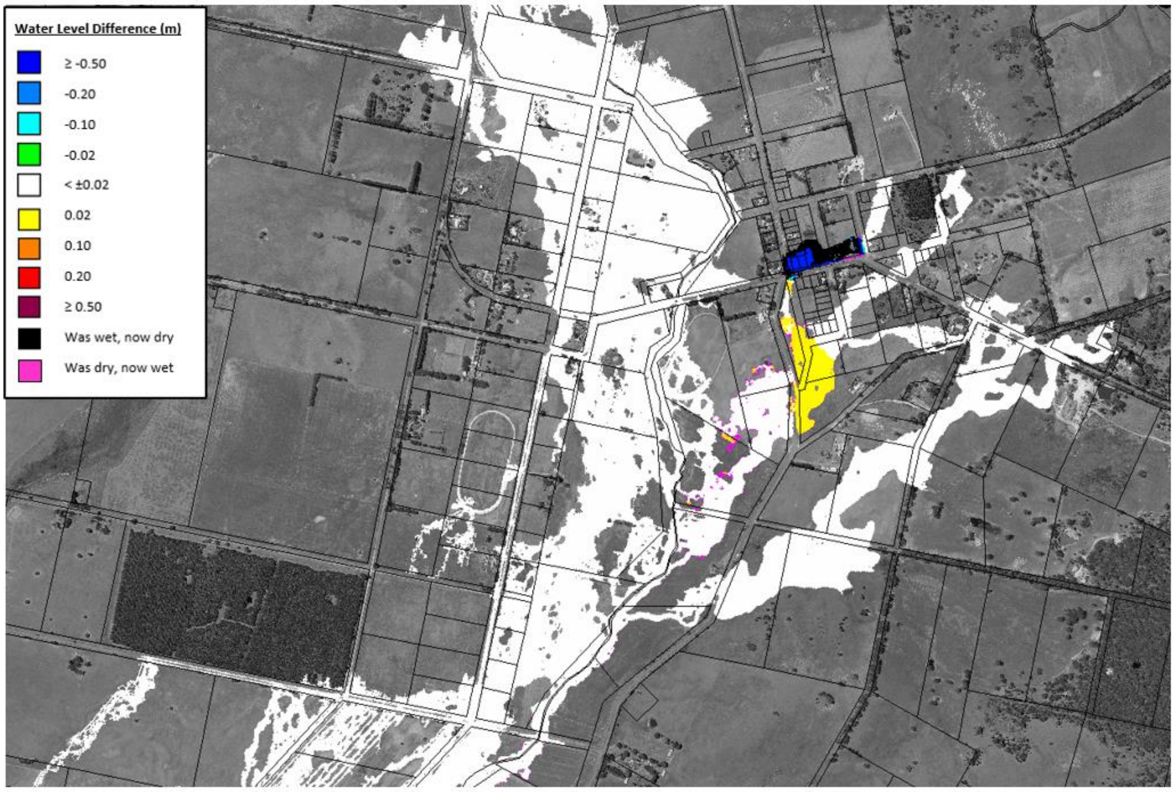


Plate 9 - 1% AEP change in flood levels due Codrington and Vaughan Streets Drainage Option

10.1.6 FM6 Channel Clearing

The assessment provided by the channel clearing option is presented on **Plate 10** for the 1% AEP design flood event. This option leads to relatively minor decreases in flood levels (0.02 – 0.1 m in the 1% AEP design flood event) across large sections of Raglan settlement, however only one building goes from being inundated above floor to not inundated above floor in the 0.5% and 0.2% AEP design flood events.

The option has been costed at $630,000 and reduces the NPV of flood damages by $13,200. This indicates a very significant cost for minimal financial benefit. Similarly, the option would have significant environmental approval hurdles as it would require a large amount of vegetation and wildlife habitat removal which may make the project unfeasible from that perspective. This option would have no impact on emergency services response during a flood event.

A potential alternative to this option would be to establish a culvert clearing and table-drain clearing program. This could be undertaken as part of the regular Council roadside maintenance works and included in Councils asset management program.

While channel clearing is shown to have fairly minimal benefit for larger floods perspective (studied here), it may improve nuisance flooding that occurs during more frequent storms and therefore improve community sentiment towards this nuisance flooding.

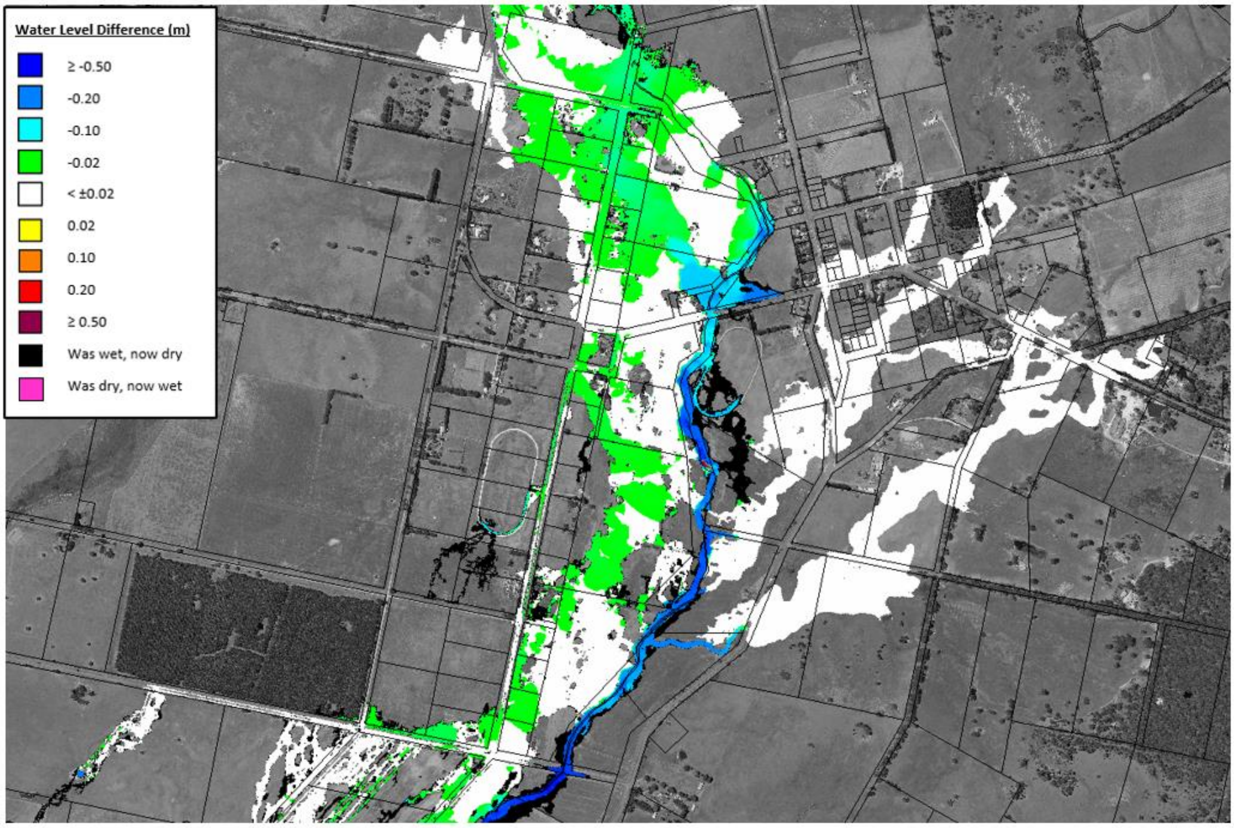


Plate 10 1% AEP change in flood levels due to channel clearing

10.1.7 Structural Option Summary

Six (6) structural mitigation options were raised through the Project Reference Group meetings and community consultation. These were analysed by implementing the proposed option in the TUFLOW model and then re-running the range of design flood events.

For each option, the resulting differences in flood levels against the existing case were analysed. A benefit-cost ratio (BCR) was calculated by comparing the reduction in NPV of flood damages to the calculated cost of constructing each option. Additional analysis was undertaken regarding other key aspects of each option, such as the impact on emergency response, technical feasibility, environmental impacts and community acceptance.

Table 13 provides a summary of the analysis of each of these structural mitigation options. Two of the options resulted in an overall negative score, two options resulted in a neutral score and two options (raise Raglan – Eurambeen Road and Codrington – Vaughan Street drainage) resulted in a slightly positive score. Generally, options that have a strong overall positive value would be recommended for further analysis or implementation. Note that no weighting has been applied to the different evaluation criteria.

A critical factor that is perhaps lost in this analysis is that each option has a significant initial capital, and in some cases significant ongoing, costs with very little reduction in overall flood damages. This is primarily due to:

- There are not many at risk properties within Raglan that suffer extensive damage as a result of flooding over their floor levels

- Above floor flooding only occurs in rare events at or above the 1% AEP design flood event
- Development throughout the study area is generally at a very low density and therefore mitigation measures that have specific localised effects will only benefit a few properties

The flood investigation has assessed the flood risk at Raglan to existing developments as relatively low. A range of structural mitigation options were assessed to help manage the existing flood risk, with flood risk to future development to be managed through planning and development controls assessed through earlier stages of the project. This assessment has determined that there are currently no feasible structural mitigation options that are considered viable to reduce the existing flood risk to Raglan settlement and surrounds.

However, other mitigation options that are examined in this study, such as improved planning and development controls, community education and simplified flood warning (signage and gauge boards) must be implemented to help mitigate the existing and future flood risk in the area. These property modification and response modifications options have been assessed as more cost effective and more likely to have a broader reach in the community when compared to the six (6) structural mitigation options assessed.

The community raised the issue during community consultation that the local road drainage system is overgrown with vegetation and debris. While this would have minimal impact on the large-scale flooding examined as part of this study, smaller nuisance flooding from local runoff may be better managed if Council were to implement more regular maintenance of the local stormwater drainage system. This would need to be weighed against other competing priorities for Council resources and considered in their asset management program of all council assets.

Table 13 Summary of Structural Mitigation Measure Assessments

Potential Measures	Evaluation Criteria / Score							
	Change in Flood Levels / Extents	Inundated Buildings	Emergency Response	Technical Feasibility	Environmental Impacts	Economic Feasibility	Community Acceptance	Overall Score
Raise Old Beaufort Rd	0	1	0	1	0	-2	0	0
Raise Raglan-Eurambeen Rd	0	0	2	1	0	-2	0	1
Raise Raglan – Elmhurst Rd	-1	-2	1	0	0	-2	0	-4
Widen Fiery Ck crossing at Raglan – Elmhurst Rd	1	0	0	-1	-1	-2	0	-3
Upgrade Drainage	1	0	0	1	0	-2	1	1
Channel Clearing	1	1	0	0	-2	-2	2	0

11 Flood Warning Assessment

The purpose of a flood warning is to provide advice on impending flooding so people can take action to minimise its negative impacts. An effective flood warning system requires integration of a number of components (Australian Government, 2009):

- monitoring of rainfall and river flows that may lead to flooding;
- prediction of flood severity and the time of onset of particular levels of flooding;
- interpretation of the prediction to determine the likely flood impacts on the community;
- construction of warning messages describing what is happening and will happen, the expected impact and what actions should be taken;
- dissemination of warning messages;
- response to the warnings by the agencies involved and community members; and,
- review of the warning system after flood events.

Where effective flood warnings are provided, risk to life and property can be significantly reduced. Studies have shown that flood warning systems generally have high benefit-cost ratios if sufficient warning time is provided and if the population at risk is aware of the threat and prepared to respond appropriately.

The Bureau of Meteorology issues a number of products that provide warning of floods, including Severe Weather Warnings for torrential rain and/or flash flooding, and Flood Watches that typically provide 24 to 48 hours' notice that flooding is possible based upon current catchment conditions and forecast rainfall.

The opportunity to enhance the flood warning system was considered for each of the phases of the total flood warning system. The Bureau of Meteorology's new Flash Flood Advisory Resource (FLARE) was used as a resource for this analysis. Flash flooding is defined in FLARE as flooding that occurs within 6 hours of the rainfall commencing. In Raglan, this is certainly the case, although for Fiery Creek the peak of the flood occurs around 7 - 9 hours, i.e. flooding starts in less than 6 hours, but does not peak till afterwards. The small overland flow tributaries through the Raglan settlement peak within an hour of rainfall occurring for their critical duration.

The FLARE resources include a method of assessing risk and determining the appropriate level of warning system. Risk is a function of Likelihood (how often a significant flood occurs) and the consequence (what are the impacts of the flood).

FLARE does not specifically state what a "significant" flash flood is, however in the case of Raglan there is no above floor flooding in events smaller than the 1% AEP, therefore this event was adopted which leads to a "Likelihood" of Unlikely (Every 50 – 100 years) to Rare (> 100 years).

In terms of consequences, FLARE divides impacts into Social, Environmental and Economic and outlines consequences across four categories; negligible, low, medium and high. Assessment of the consequences has been undertaken from analysis of the flood study results and the 2012 event, which approached a 1% AEP design flood event. The results are presented in **Table 14**, the highest adopted rating is used for the overall assessment which is "Low".

Table 14 FLARE Consequence Assessment

Assessment Category	Adopted Rating	Consequences for that Rating
Social	Low	Minimal danger to life. Isolated and temporary cases of reduced services within the community Repairable damage to objects of cultural significance Impacts within emotional and psychological capacity of the community
Environment	Low	Isolated cases of environmental damage One off Recovery efforts required
Economic	Low	Disruptions at business level leading to isolated cases of loss of employment Isolated cases of short to mid-term failure of infrastructure and service delivery. Repairs undertaken in 1 week to 1 month Localised inconvenience Isolated repairable damage to residential or commercial properties

Combining the Unlikely likelihood, with a Low consequence. The FLARE methodology assigns a risk rating of "Very Low" for Raglan. The recommended minimum components for a flood warning system for a "very low" risk area is largely met with the standard BoM products that are issued and do not list any site-specific requirements.

While this is the minimum recommended components, the responsible agencies may choose to adopt a more advanced system. For example, if the risk rating were increased to "Low" then the minimum requirements would include additional aspects such as rainfall triggers for action, specific messages and communication methods linked to those triggers which would then lead to more precautionary actions taken by the local community, which could then be enhanced through a simple local public awareness and education program.

Some of these more advanced elements that would be components of a "Low" rated system have been investigated as part of this study.

11.1 Potential Flood Gauge Sites

11.1.1 Water Level Gauges

Gauges are best located upstream of the main area of interest, to provide warning time as the flood travels between the gauge location and the area of interest. Gauges are most often placed on public property, to allow for ease of access for maintenance, and at a stable section of the water course, such as at a bridge or culvert.

Placing a gauge is a trade off between the warning time available (the further upstream the better), versus how representative the location is of the flooding behaviour. This can be approximated by comparing the catchment area at the gauge site to the catchment area at the area of interest.

The timing and catchment area values at the selected gauge sites are presented in **Table 15**. The E1 road has a significant lead time, however it only represents a small proportion of the catchment. Pitchers Lane offers a small amount of warning time and represents the majority of the catchment, while Old Beaufort Road offers minimal warning time but is effectively the whole catchment.

Given the high spatial variability of rainfall, and the lack of detailed information about the distribution of rainfall in the Fiery Creek catchment, using the E1 Road as a site for a flood gauge would potentially lead to significant under or over-estimation of the flooding, as flows at this location may not be representative of the overall catchment. At Pitchers Lane, it could be reasonably expected that flow here would be representative of the flooding that would be experienced in Raglan, however the warning time is minimal (not a lot of flood preparation can be effectively undertaken in 30 minutes). Similar constraints exist if a gauge were to be located along the Old Beaufort Road.

Table 15 Key statistics for potential gauge sites

Location	Approximate Travel Time to Raglan-Elmhurst Road	Percentage of the catchment area at Raglan-Elmhurst Road
E1 Road	2 hours	32%
Pitchers Lane	30 minutes	72%
Old Beaufort Road	5 - 10 minutes	Greater than 95%

11.1.2 Rainfall Gauges

There is currently a daily read rainfall gauge within the Fiery Creek study area. However, given the critical duration for the creek is significantly short, it is likely that the rain will have fallen and the flood will have occurred between the daily readings that generally occur at 9am. Therefore, for use in flood warning, pluviography gauges are required which record real time rainfall.

The Ben Nevis gauge is located just to the north west of the study area and has been used in the model calibration for disaggregation of daily rainfall data. This was relatively successful as the calibration of the model proved it to be valid against historic flood events, however it is likely that there will be some flood events that are not effectively captured by gauges outside of the catchment.

It is expected that the majority of runoff producing rainfall occurs in the steeper parts of the catchment that ring the edge of the Fiery Creek catchment, therefore any new gauge would best be placed either in or near to these areas. There is likely no "best" location to locate a gauge in any catchment, as rainfall is often highly spatially variable, and experiments have shown that gauges placed only a few hundred metres apart can produce significantly different rainfall depths.

There are a number of other requirements around siting new rainfall gauges, such as being sited twice the height away from the nearest trees. These requirements are documented in the BoM observation specification (2013). Other considerations need to be made regarding access for maintenance and repair and potential for vandalism. Desktop analysis of the upper catchment shows that appropriate sites would be:

- Richards Campground, although it may be difficult to appropriately site the gauge with the existing surrounding tree cover
- The Cave Hill Creek site, although this is private property and permission and access would need to be negotiated with the landowner

In terms of warning time, it is unlikely that any rain gauge will produce sufficient warning time for the flash flood tributaries through town. However for Fiery Creek, it is possible that a warning produced by fallen rainfall itself would provide some time for residents to prepare for flooding. The Flood – No Flood tool presented in **Section 12.2** can be used to relate the fallen rainfall depths over different durations to the design flood extents.

For the modelled 9 hour critical duration 1% AEP design flood event, the peak of the flood occurs approximately 9 hours after the onset of rain. Therefore, if rainfall is trending along one of the flood lines in the Flood / No Flood tool for several hours, then this could be used to predict flooding with a few hours warning. For example, at 5 hours after the onset of rainfall if the depths show a significant flood occurring on the Flood / No Flood tool, then it can be assumed that in 3 – 4 hours that flooding will occur in and around Raglan, and residents can be warned accordingly.

11.2 Community Education

Based on learnings from recent disasters, the focus of community disaster education has now turned from a concentration on raising awareness and preparedness to building community resilience through learning. Simply disseminating information to the community does not necessarily trigger changed attitudes and behaviours. Flood education programs are most effective when they:

- Are participatory i.e. not consisting only of top-down provision of information but where the community has input to the development, implementation and evaluation of education activities;
- Involve a range of learning styles including experiential learning (e.g. field trips, flood commemorations), information provision (e.g. via pamphlets, DVDs, the media),

collaborative group learning (e.g. scenario role plays with community groups) and community discourse (e.g. forums, post-event de-briefs);

- Are aligned with structural and other non-structural methods used in floodplain risk management and with emergency management measures such as operations and planning; and
- Are ongoing programs rather than one-off, unintegrated 'campaigns', with activities varied for the learner.

It is difficult to accurately assess the benefits of a community flood education program but the consensus is that the benefits far outweigh the costs. Nevertheless, sponsors must appreciate that ongoing funding is required to sustain gains that have been made.

The high level of detail available from the Raglan Flood Investigation also makes it possible to prepare customised flood information flyers, fridge magnets etc for individual properties.

Community education needs to come prior to any flood and needs to be an integral part of any flood warning system. For example, if the residents receive an SMS or door-knock from emergency services, but do not know how to interpret the message, then they may inadvertently put themselves at greater danger.

11.3 Options for Raglan

The following response modification options have been suggested for Council to consider:

- Flood depth indicators could be installed at the Raglan – Elmhurst Road crossing. The depth indicators show the depth of water across the roadway, thereby helping to inform the community about whether the roadway may be safe to cross in a vehicle. However, without any accompanying information to describe the potential dangers associated with crossing flooded roads, the potential success of flood depth indicators can be limited. Furthermore, emergency services advocate not driving through any floodwater regardless of depth as the integrity of the road surface beneath the water cannot be guaranteed. Therefore, there is potential for installation of depth indicators to increase the number of vehicles driving through water which may increase the flood risk.

  Therefore, if this option is pursued it should be supplemented with appropriate signage not to drive through floodwaters and/or other education material

- Rain Gauge: a real time rain gauge (pluviograph) would be useful to provide some advanced warning to emergency responders and Council and would provide local situational awareness during an event. These systems can be set up to provide automated alerts through SMS or through online social media platforms based on pre-programmed trigger levels. While three non-specification gauges could be purchased for the price of one specification gauge (and therefore being more representative) there is limited potential locations for gauging sites and there is a high risk of the three gauges failing. Therefore, if the recommendation to install a rain gauge is adopted then it is recommended that a BoM specification gauge is installed.

A key consideration for any gauge system is the requirement for on-going maintenance, this is often completed annually and would include checking the calibration of the system and battery and other component replacement. Period checks between annual maintenance can be completed following rainfall by comparing the gauge depth to other nearby gauges. Gauge providers typically also offer maintenance contracts.

- Pyrenees Shire Council is completing the Upper Avoca Creek, Upper Mt Emu Creek and Raglan Flood Investigations concurrently. It has also completed the Beaufort Flood Study and preliminary flood investigations for Lexton and Waubra. It now has significant information covering the major flood affected centres in the shire. Therefore, it is recommended that Pyrenees develop an integrated, ongoing flood community education programme that covers all these areas.

12 Flood Intelligence

A range of flood intelligence documentation has been prepared as part of this study to assist Council and other stakeholders, such as the VIC SES prepare for and respond to flooding.

12.1 Flood Intelligence Card

A flood intelligence card (FIC) has been prepared for the Raglan – Elmhurst Road crossing of Fiery Creek as this is the recommended location for any potential future gauge.

Flood intelligence cards essentially outline the flood impacts expected for a range of different water levels at a gauging site. These impacts are expressed in terms of access (i.e. when roads are inundated and cut) and residential flooding. Other key features such as the bridge deck level are also added to make the reported flood levels relatable to easily observable features.

Currently there is no gauge at Raglan and therefore the flood intelligence card is not useful unless gauge boards are installed and related to the FIC by reducing the depth to Australian Height Datum (AHD). The bridge level could be used as a rudimentary datum in the meantime.

For access, the roads have been broken down into the depth of inundation across the road, particularly;

- High hazard flood waters
- Greater than 0.3 m depth, which is unlikely to be trafficable to most vehicles and should not be encouraged by any vehicles
- 0.1 to 0.3 m depth, which is potentially trafficable to most vehicles but should not be encouraged
- Less than 0.1 m, which is likely to be trafficable to most vehicles, but should not be encouraged

12.2 Flood / No Flood Tool

A Flood / No Flood tool has been developed for Raglan using the Intensity-Frequency-Duration curves. This tool can be used to relate the fallen rainfall to potential flood impacts by looking up the depth of rainfall that has occurred over the time that has occurred since rainfall has begun.

This method is fairly approximate and will be conservative in all durations except for the critical duration. For example, while 130 mm over 30 hours and 45 mm over 1 hour are both

1% AEP rainfalls, these are both likely to produce smaller flood extents than the critical duration for Fiery Creek (around 9 – 12 hours).

In some instances where the appears to be a storm burst within a longer duration of rainfall, then the time since the storm burst has occurred also needs to be measured. For example, rain may be falling at a non-flood intensity for 12 hours, but then a much more intense storm may occur within that period of rain for a few hours. The time from rainfall beginning for that storm should be read from when the intensity increases, not including the initial 12 hours, while the overall duration of rainfall should also be continuously checked.

An example of the Flood/No-Flood tool is presented in **Plate 11.**

12.3 Above floor flooding for Residential Properties

A map has been produced showing the locations of residential properties that have above floor flooding, with each property colour coded based on the design flood event their floor levels first become inundated. During emergency management and evacuation planning, this information can be used to identify the priority properties for evacuation. During a flood event, this information can be related to the Flood / No Flood tool to determine the potential for above floor flooding. The information presented in this figure should also be communicated to the owners of each of the properties as part of the community flood education campaigns

12.4 Road Inundation Timing and Duration

There are a number of roadways within the Raglan study area which may be required for evacuation or emergency services access during floods. It is important to understand the impacts of flooding on these roads so that appropriate emergency response planning can occur.

An assessment of the location where roadways are first predicted to be overtopped was completed as part of this study as well as the duration that they are overtopped for each event. The roadway overtopping locations are shown as yellow dots in Appendix A for the 10% and 1% AEPs as well as the PMF.

It must be noted that where a culvert goes under a roadway, the peak floodwater depth and level figure indicates the water that is travelling through the culvert under the roadway, not the water that is travelling across the road crest exclusively. Those locations where the roadway does become inundated and is overtopped during the 1% AEP design flood event are included in the following figure**.**

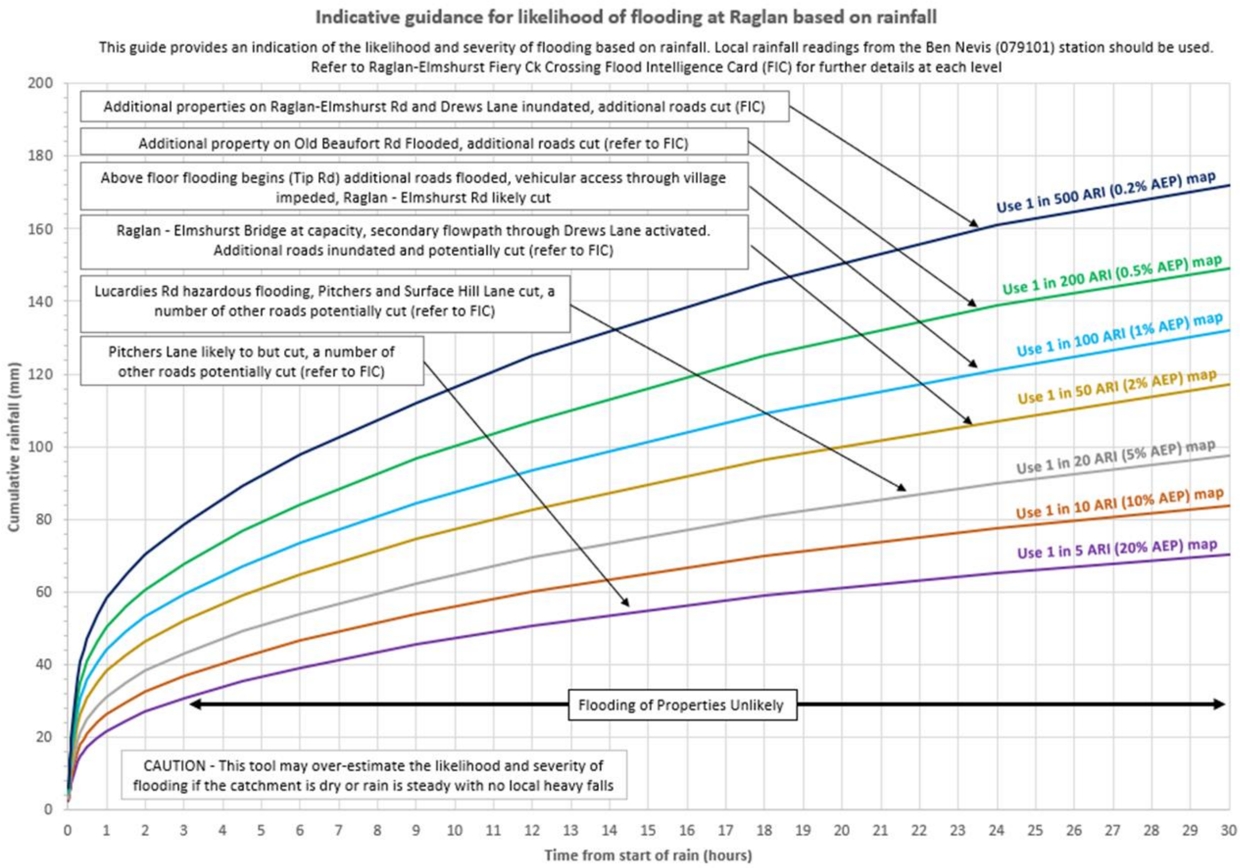
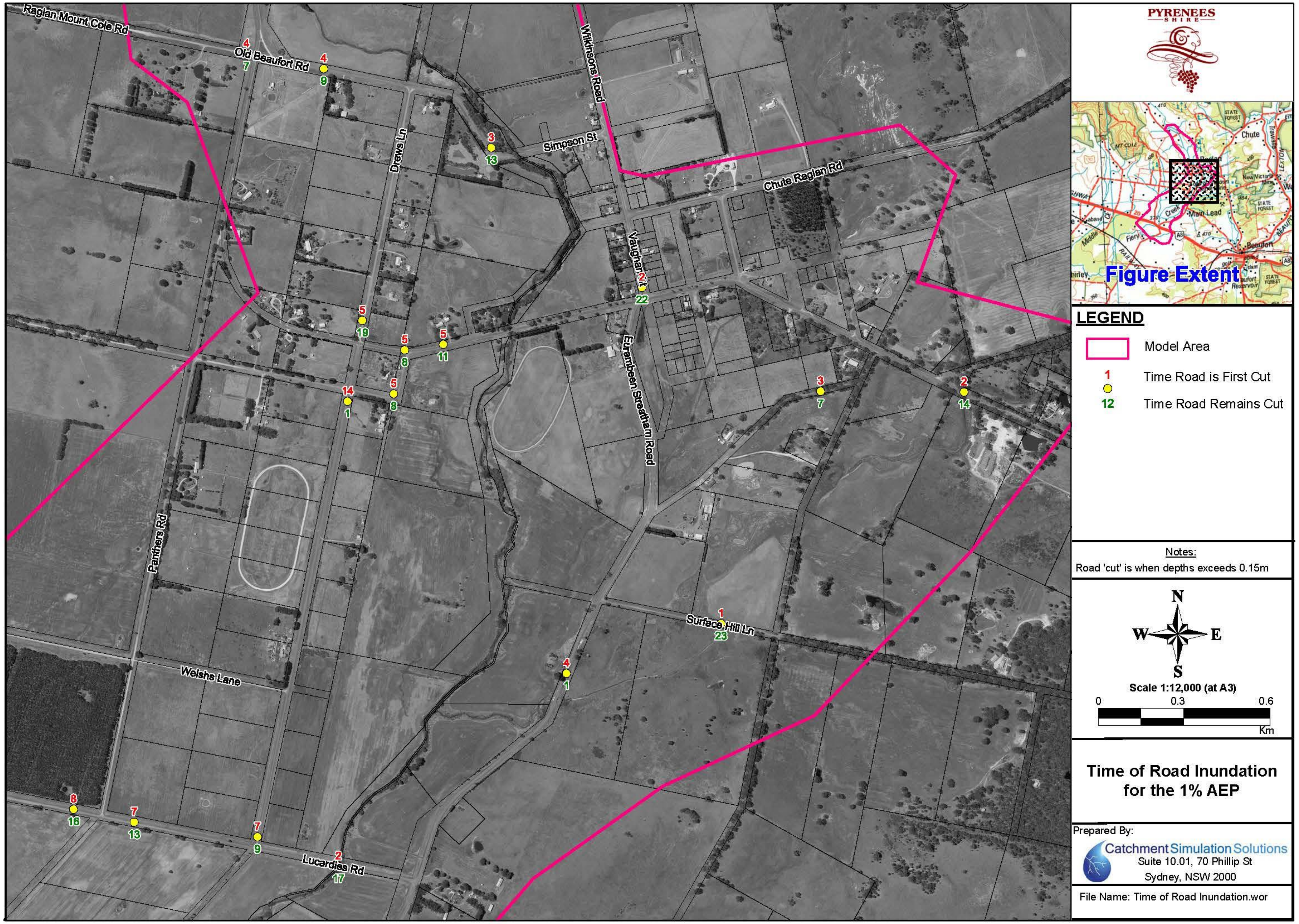


Plate 11 Flood / No Flood Tool as example of Flood Intelligence Documentation


Raglan Mount Cole Rd
Old Beaufort Rd
Wilkinsons Road
Simpson St
Drews Ln
Chute Raglan Rd
Vaughan St
Eurambeen Streatham Road
Panthers Rd
Welshs Lane
Surface Hill Ln
Lucardies Rd
PYRENEES SHIRE
Figure Extent
LEGEND
Model Area
1 Time Road is First Cut
12 Time Road Remains Cut
Notes:
Road 'cut' is when depths exceeds 0.15m
N
W
E
S
Scale 1:12,000 (at A3)
0
0.3
0.6
Km
Time of Road Inundation for the 1% AEP
Prepared By:
Catchment Simulation Solutions
Suite 10.01, 70 Phillip St
Sydney, NSW 2000
File Name: Time of Road Inundation.wor

13 SUMMARY

The Raglan Flood Investigation was commissioned by Pyrenees Shire Council with financial support from the Victorian and Australian Governments as well as technical support from Glenelg Hopkins Catchment Management Authority (GHCMA). The purpose of the Raglan Flood Investigation is to develop information fundamental to provision of effective flood controls, flood response planning and building community resilience to flooding.

The study area for the flooding investigation extends along Fiery Creek from Pitchers Lane (located about 3 kilometres upstream of Raglan) down to the Western Highway (located about 6 kilometres downstream of Raglan). It also incorporates each of the major tributaries that traverse through Raglan and drain into Fiery Creek.

A hydrologic and hydraulic model were developed based on the information provided by Council, the GHCMA and survey undertaken as part of this study. Modelling was undertaken to define a range of flood events, including the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF design flood events. Mapping was prepared that represented floodwater depths and levels, flood velocities, flood hazards and duration of inundation. Sensitivity analyses of model parameters, as well as for potential impacts associated with climate change, were carried out. Calibration of the hydrologic and hydraulic models to the January 2011 and September 2010 event indicate the model and parameters that had been selected were fit for purpose and appropriate to use to define design flood levels.

Flood damage calculations were undertaken to gain an understating of the existing flood risk to the Raglan settlement. For events up to the 1% AEP design flood event there are no properties with above floor flooding and the damage estimate is comprised entirely of external damage. The number of properties impacted by above floor flooding in the 0.2% AEP design flood event rises to 4, and then to 19 during the PMF event. The an average annual damage (AAD) at Raglan are estimated as $7,800 (O2 method) to $11,800 (NSW Government method), which are considered low.

Flood modification, property modification and response modifications options were investigated to help manage the flood risk in and around Raglan.

Flood Planning Controls were developed that included the mapping of Floodway Overlay (FO) or Land Subject to Inundation Overlay (LSIO) in and around Raglan. Planning Scheme Amendment documents have been prepared for the implementation of these planning overlays which will assist Local Government, Catchment Management Authority and the community in carrying out more effective planning and management of flood prone land in the study area.

As part of the response modification options, Flood warning and flood intelligence information was documentation has been prepared. This includes information of what floor levels are inundated in what magnitude flood event, information on road inundation times and durations, and the development of a “Flood / No Flood tool” that can be used to relate the fallen rainfall to potential flood impacts and determining appropriate emergency management actions accordingly.

Six (6) structural mitigation options were investigated as part of the potential flood modification management measures. Structural mitigation options were raised during Project Reference Group meetings and through Community Consultation. Each option was assessed against a range of evaluation criteria, including hydraulic impacts, change in number of buildings inundated above floor level, emergency response impacts, technical feasibility, environmental impacts, economic feasibility and community acceptance. This assessment has determined that there are currently no feasible structural mitigation options that are considered viable to reduce the existing flood risk to Raglan settlement and surrounds based on the reduction to flood damage.

However, other property modification and response modifications options that are examined in this study, including improved planning and development controls, community education and simplified flood warning systems must be implemented to help mitigate the existing and future flood risk in the area. These options have been assessed as more cost effective and more likely to have a broader reach in the community when compared to the six (6) structural mitigation options assessed.

Community consultation was carried out during three stages of the project. The first round of community consultation was during the data collection phase to collect any available community flood intelligence, determine what specific flooding issues the community are concerned with and gain insight into the community’s knowledge and attitudes towards flooding. The next round of community consultation was carried out once the flood models had been completed to develop structural mitigation options. The final round was carried out during the final stages of the project to enable the community to provide feedback on the structural mitigation option assessment and flood warning review.

Overall, the flood assessment has determined that there is some flood risk to the settlement of Raglan and surrounding area. With the implementation of the recommended property modification and response modification options included in this study, it is considered that this flood risk could be appropriately managed for existing ad future developments. Information associated with the mapping of the Floodway Overlay (FO) or Land Subject to Inundation Overlay (LSIO) should be implemented as soon as possible to ensure these flood risks are acknowledged thorough councils statutory .documents.

14 REFERENCES

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