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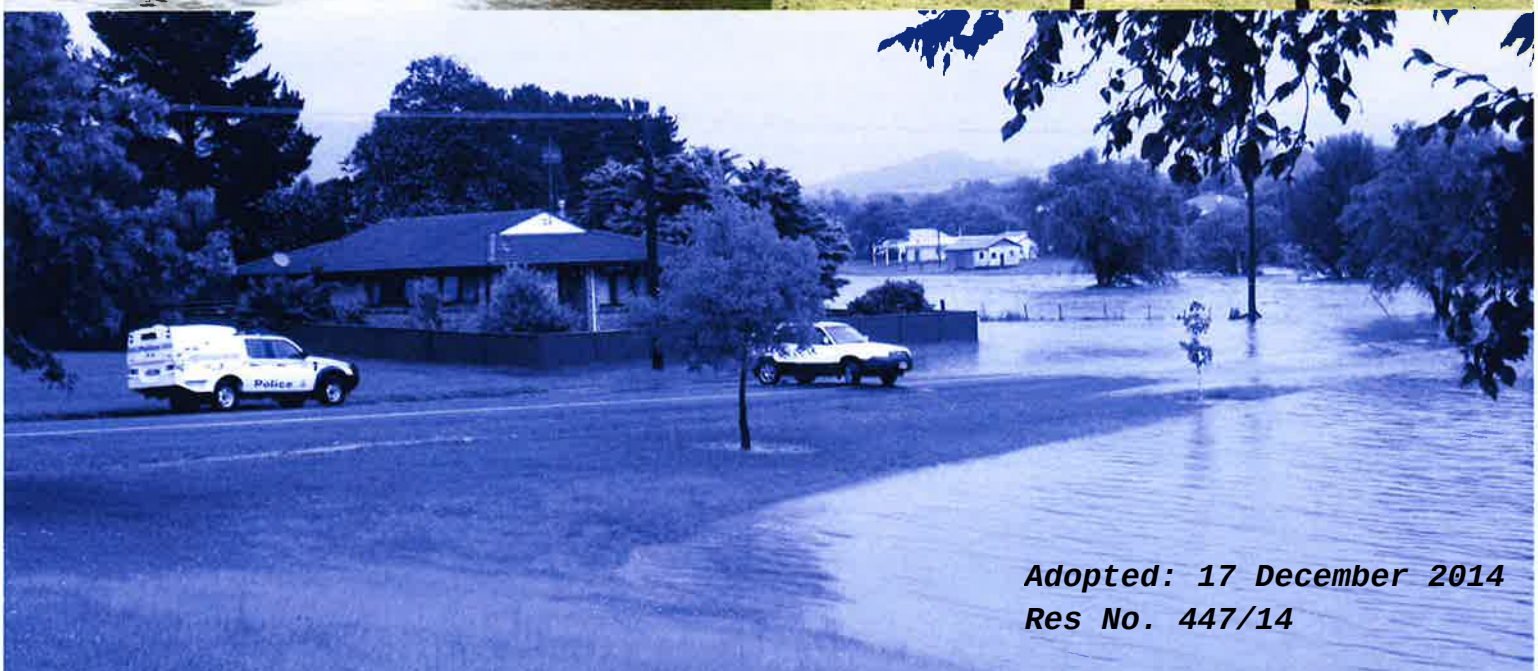
TENTERFIELD FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

TENTERFIELD SHIRE COUNCIL

CAS-13770-WVRW | Draft Report | 16 October 2014



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Tenterfield Floodplain Risk Management Study and Plan

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Document history and status

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0	20/08/14	DRAFT for Review and Comment	FS	SA	21/08/2014
1	08/10/14	DRAFT FRMP for Review and Comment	FS	SA	08/10/2014
2	16/10/14	FINAL FRMP	FS	SA	16/10/14

Contents

Glossary

Afflux	Rise in flood level as a result of an obstruction to flow.
ALS	Aerial laser survey.
Annual Exceedance Probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 cubic metres per second has an AEP of five per cent, it means that there is a five per cent chance (i.e. a 1 in 20 chance) of a peak discharge of 500 cubic metres per second (or larger) occurring in any one year (see also average recurrence interval).
AR&R	Australian Rainfall and Runoff
Australian Height Datum (AHD)	National survey datum corresponding about to mean sea level.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrence of a flood as big as (or larger than) the selected event. For example, floods with a discharge as great as (or greater than) the 20 year ARI design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. (see also annual exceedance probability)
Average Annual Damage (AAD)	Average annual damage is the average flood damage per year that would occur over a long period of time.
BoM	Bureau of Meteorology
catchment	The catchment at a particular point is the area of land that drains to that point.
DEM	Digital Elevation Model
design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100 year ARI or one per cent AEP flood).
discharge	The rate of flow of water measured in terms of volume over time (i.e. the amount of water moving past a point). Discharge and flow are interchangeable.
DPI	NSW Department of Planning and Infrastructure
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for,

	respond to and recover from flooding. In NSW, the State Emergency Service (SES) is the principal agency involved in emergency management during floods.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high river or creek flows, which may overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
flood behaviour	The pattern / characteristics / nature of a flood.
flood damage	The financial and social costs of flooding.
flood depth	The height or elevation of floodwaters above ground level.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals
flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage.
flood hazard	The potential risk to life and limb and potential damage to property resulting from flooding. The degree of flood hazard varies with circumstances across the full range of floods.
flood impact	The increase (or in some cases decrease) in flood levels or flood depths as a result of the project.
flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as "stage".
floodplain	Land adjacent to a river or creek that is periodically inundated due to floods. The floodplain includes all land that is susceptible to inundation by the probable maximum flood (PMF) event.
floodplain management	The co-ordinated management of activities that occur on the floodplain.
floodplain management measures	A range of techniques that are aimed at reducing the impact of flooding. This can involve reduction of: flood damages, disruption and psychological trauma.
floodplain management scheme	A floodplain management scheme comprises a combination of floodplain management measures. In general, one scheme is selected by the floodplain management committee and is incorporated into the plan.

Flood Planning Levels (FPL)	Flood planning levels selected for planning purposes are derived from a combination of the adopted flood level plus freeboard, as determined in floodplain management studies and incorporated in floodplain risk management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of landuse and for different flood plans. The concept of FPLs supersedes the "standard flood event". As FPLs do not necessarily extend to the limits of flood prone land, floodplain risk management plans may apply to flood prone land beyond that defined by the FPLs.
flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Management Plans should encompass all flood prone land (i.e. the entire floodplain)
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate damages during a flood.
Floodplain Risk Management Study (FRMS)	These studies are carried out in accordance with the Floodplain Development Manual (NSW Government, 2005) and assess options for minimising the danger to life and property during floods. These options aim to achieve an equitable balance between environmental, social, economic, financial and engineering considerations. The outcome of a Floodplain Risk Management Study is a Floodplain Risk Management Plan.
Floodplain Risk Management Plan (FRMP)	A document outlining a range of actions aimed at improving floodplain management. The plan is the principal means of managing the risks associated with the use of the floodplain. A floodplain risk management plan needs to be developed in accordance with the principles and guidelines contained in the NSW Floodplain Development Manual. The plan will usually contain both written and diagrammatic information describing how particular areas of the floodplain are to be used and managed to achieve defined objectives.
flood storage areas	The areas in a floodplain important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway	Floodways are those parts of a floodplain where significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are area that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
freeboard	A factor of safety usually expressed as a height above the adopted flood level thus determining the flood planning level. Freeboard tends to

	compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
historical flood	A flood that has actually occurred.
hydraulics	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrograph	A graph showing how a river or creek's discharge changes with time.
hydrology	The term given to the study of the rainfall-runoff process in catchments.
Local Environment Plan (LEP)	A Local Environment Plan is a plan prepared in accordance with the Environmental Planning and Assessment Act, 1979, that defines zones, permissible uses within those zones and specifies development standards and other special matters for consideration with regard to the use of development of land.
mAHD	Metres above Australian Height Datum (see Australian Height Datum).
modification measures	Measures that modify the flood, the property or the response to flooding.
OEH	NSW Office of Environment and Heritage was formed in April 2011.
peak flood level, depth, flow or velocity	The maximum flood level, depth, flow or velocity that occurs during a flood event at any given point.
Probable Maximum Flood (PMF)	An extreme flood deemed to be the maximum flood likely to occur.
probability	A statistical measure of the likely frequency or occurrence of flooding.
risk	Risk is measured in terms of consequences and likelihood. In the context of floodplain management, it is the likelihood and consequences arising from the interaction of floods, communities and the environment.
risk management	The process of identifying, analysing, evaluating, treating, monitoring and communicating risks.
runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
SES	State Emergency Services of New South Wales
Section 149 Certificates	Certificates issued under Section 149 of the NSW Environmental Planning and Assessments Act. It is compulsory to attached Section 149 certificates to contracts for sale of land.

velocity	The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, i.e. the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.
VxD	Velocity multiplied by depth of water. This variable is an indicator of flood intensity and has units of m^2/s

Executive Summary

Introduction

This Floodplain Risk Management Study and Plan (FRMSP) for the Tenterfield township has been commissioned by Tenterfield Shire Council (Council) with financial assistance from the Office of Environment and Heritage (OEH). The study has been prepared by Jacobs Group Australia (Jacobs) with assistance from the Floodplain Risk Management Advisory Committee (FRMC) and Prospect Environmental Pty Ltd.

The FRMSP was developed using modelling results and data obtained through the Tenterfield Flood Study completed by DHI in 2013. The study area includes the Tenterfield township only.

Framework for Floodplain Risk Management

Floodplain risk management in NSW is the responsibility of local Councils with support from the State Government and should be undertaken in accordance with the NSW Floodplain Development Manual (NSW DIP, 2005), herein referred to as the Manual. The Manual specifies that a Floodplain Risk Management Study must include the following aspects:

- Flood behaviour, danger and damage
- The community costs of flooding
- Future land use
- A comprehensive range of flood risk management measures
- The environmental needs of the river and floodplain areas
- Environmental and cultural impacts of management measures

The Manual states that the study should identify and quantify all relevant issues. This should inform a Floodplain Risk Management Plan that outlines a strategy for future flood risk management.

The Tenterfield FRMS assesses flood risk in Tenterfield; assigns hazard categories specific to the nature of flooding in the town; assesses flood damages and investigates potential mitigation measures. The Tenterfield Floodplain Risk Management Plan (FRMP), Section 9 of this report, outlines a strategy for future floodplain risk management in Tenterfield.

Data Review

As part of the FRMS the flood study was reviewed to determine if the study was an appropriate basis for the assessment of flood risks. The Model Adequacy Review noted a number of issues which were discussed with Council and the OEH. In particular, additional work was undertaken as part of the FRMS to confirm the peak flow estimates and critical storm duration. Whilst some issues were identified with the study assessment of these parameters it was noted that the above issues need to be considered in the context of the flood risk within Tenterfield. As all of the design events more frequent than a 1% AEP are largely contained within the creek, revising the hydrology for the more frequent events was considered unlikely to significantly change the resulting flood risk to Tenterfield. As such, the review identified the opportunity to utilise the existing flood modelling results to address flood risk without the need to revisit the entire flood study.

Flood Hazard Assessment

An assessment of flood hazard in Tenterfield was undertaken in accordance with the Manual. A number of factors for consideration in determining flood hazard criteria are listed in the Manual. These factors were classified as having a high, moderate or low impact on flood hazard in Tenterfield based on the modelling

results and an understanding of historical flood behaviour in Tenterfield. Figure 1-1 shows the outcome of this assessment.

High	Moderate	Low
• Depth and velocity of floodwaters • Rate of rise of the floodwaters • Effective warning time	• Size of the flood • Evacuation problems • Flood readiness	• Duration of flooding • Flood access • Types of development

Figure 1-1 Classification of factors influencing flood risk in Tenterfield

Based on consideration of these factors and a review of relevant literature, the following flood hazard categories were derived for Tenterfield. The criteria are believed to incorporate an appropriate level of conservatism given the nature of flooding in Tenterfield.

Table 1-1 Proposed flood hazard categories for Tenterfield

Category	Definition
High	Within the 10% AEP extent or preliminary flood hazard is high or medium in 1 % AEP event
Medium	Within the 1 % AEP extent or preliminary flood hazard is medium or high in 0.05 % AEP event
Low	Within the 0.05 % AEP event
Very Low	Within the PMF extent

An assessment of buildings and infrastructure within each hazard category was undertaken for Tenterfield. The results are shown in Table 1-2. In general Tenterfield is fortunate to have the majority of existing properties and structures located outside of the high and medium hazard zones with commercial and heritage infrastructure located in these areas generally associated with parkland and storage facilities.

Table 1-2 Buildings within defined hazard categories

Hazard	No Buildings within Hazard Category		
	Residential	Commercial	Heritage & Emergency Services *
High	0	3	5
Medium	2	3	0
Low	19	21	7
Very Low	85	17	9
Total	**105**	**42**	**21**

Risk to People

The risk to people from flooding in Tenterfield is considered low for the following reasons:

- High and medium flood hazard zones are largely confined to areas of parkland.
- The majority of existing property is located outside the high and medium hazard zones with residential property located within the medium hazard zone very close to the low hazard zone.
- The flood behaviour does not materially change with the increasing size of the flood event.
- Access to flooded properties and evacuation access is very good with the flood extent confined to within 300 m of the creek and higher ground within 200 m of most flooded properties.

- No material differences in demographics that increase community vulnerability to a flood event
- Community knowledge of flooding (a large number of long-term residents & a recent flood history with the January 2011 flood event) means that people respond appropriately to flooding.
- Low probability of events occurring that result in significant flooding
- Very few sensitive areas located inside the Probable Maximum Flood (PMF) extent
- The economic consequences of flooding are relatively low when compared to other floodplains in Australia. Therefore, the local economy is likely to recover relatively quickly following flood damages.

Risk to Property

Damages assessments were undertaken for residential and commercial properties, community infrastructure and road infrastructure. Modelling results were considered along with damages curves relating water depth to damage at a property based on the ground and flood levels at that property. The following damages curves were used in this assessment (all data converted to 2014 AUD):

- Residential damages curves developed by OEH (2007) and available on the OEH website
- Commercial damages curves outlined in the ANU Flood Guidelines (1992)
- Community infrastructure damages curve developed by Jacobs (2014) based on an anecdotal understanding of the flood-prone community infrastructure in Tenterfield and likely repair costs
- Road damages as per the 2002 NRM Guidelines

The number of properties and roads subject to flood damages in each modelled design event is outlined in Table 1-3.

Table 1-3 Properties and roads affected by flooding in modelled events

Flood Event	Residential Properties Flooded	Non-Residential Properties Flooded	Road Closures
10% AEP	0 (0)	1	9
5% AEP	0 (0)	3	11
2% AEP	1 (0)	3	11
1% AEP	3 (3)	3	14
2011 event^	13 (12)	11	18
0.05%	24 (23)	19	19
PMF	105 (105)	42	37

*Brackets indicate number of properties flooded above floor level

^The AEP of the January 2011 event was estimated at 0.14% for the purposes of this assessment

Figure 1-2 shows the flood damages calculated for Tenterfield. It is noted that the total Average Annual Damage (AAD) calculated for Tenterfield of $23, 400 is very low when compared to other floodplains in Australia. This indicates that the existing risk to property from flooding is low.

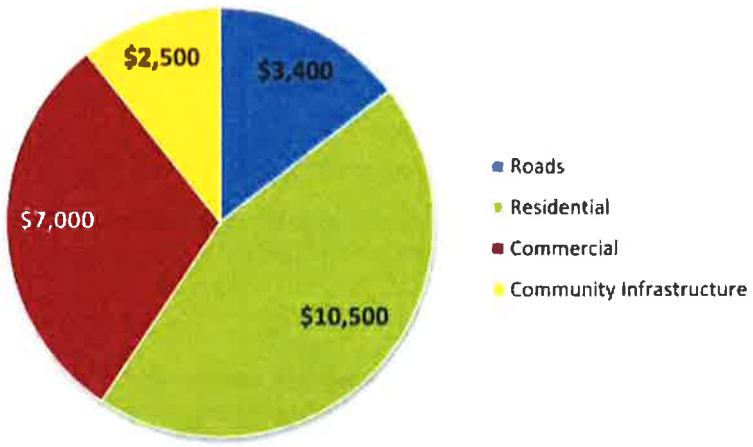

Figure 1-2 Distribution of Average Annual flood damages in Tenterfield

Risk Management Measures

Floodplain risk management options were considered for Tenterfield based on the recommendations of the NSW Floodplain Development Manual. These included property modification measures, disaster response measures and flood modification measures.

The nature of flooding in Tenterfield, potential for risk to people and estimated flood damages were considered along with socio economic factors and feedback received during stakeholder consultation. The investigation outlined a number of measures that could be implemented in Tenterfield, as well as discussing reasons for other options being considered inappropriate.

The following floodplain risk management measures are recommended for Tenterfield:

- Review of planning zones based on the proposed flood hazard categories
- Support for Council to improve access to flood hazard information for Council and the community.
- Programs to increase community awareness and readiness
- Improved flood prediction and warning systems
- Consideration of disaster response tools such as pre-prepared flood maps
- Further consideration of local road upgrades to reduce the risk of the eastern and western sides of Tenterfield becoming separated

The following floodplain risk management measures were not recommended for Tenterfield:

- Changes to the definition of Flood Planning Levels
- Changes to development controls
- Major structural works

Floodplain Risk Management Plan

The FRMP provides a framework to implement the recommendations of the FRMS to address flood risk in Tenterfield over the next five to ten years. **Table 1-4** provides a summary of the recommended options that form the basis of this plan.

The prioritisation of measures has been based on consideration of the cost of the measure and its effectiveness as a control to provide the greatest value for money for Council.

Table 1-4 Summary of Flood Risk Management Measures

Measure	Property Modification Measures	Response Modification Measures	Flood Modification Measures
Description	Modifying existing properties to address existing, future or continuing flood risk	Modifying the response of the population at risk to enable them to better cope with a flood event.	Modifying the behaviour of the flood to remove or reduce the extent, severity or frequency of flooding.
Recommended Measures			
Priority	P1 a) Development control based on flood hazard P2 a) Flood Information on 149 Planning Certificates.	R1 a) Investigations into new BoM ALERT Stations R2 a) Pre-cooked flood maps based on design events: R3 a) Flood education to improve community readiness: R3 b) Flood totems	None
Secondary	P1 b) Future land use planning based on flood hazard P3 a) Support for owner driven modifications of at risk properties:	R1 b) Upgrades current flood Siren to Include Voice Warnings: R2 b) Pre-cooked flood maps linked to gauge data	F1 Improvements to road safety:

Given the relatively low flood damages in Tenterfield the costs of major capital works are not justified. However, it is important that the threat to life associated with the potentially high flood hazard on existing road crossings is further mitigated through improvements to flood warning and community awareness and readiness. Therefore, the proposed measures have focused on low cost activities which can largely be completed through Council's existing resources and capital funding of improvements to the flood warning system.

The total estimated capital costs of implementing the plan is estimated at $218,000 with maintenance costs of between $3 ,000 and $7,000 p.a., This maintenance cost assumes an on-going cost associated with maintaining gauges, community flood awareness campaigns and flood readiness. The majority of this cost is driven by updates to the flood warning system and is scheduled to occur within the first five years of the plan.

As part of the NSW Governments Floodplain Management Program, financial assistance is provided to Councils for the implementation of floodplain management measures. At present funds are provided on a 2:1 (State: Council) basis. It is recommended that Council seek funding to assist in the capital costs of improvements to the current flood warning system.

The success of this FRMP will require commitment by organisations involved to dedicate appropriate time and resources to achieve the objectives and timeframes within the Plan. It is recommended that this is supported through ongoing regular communication between the relevant parties.

The FRMP provides a framework for the implementation of floodplain risk reduction measures. The FRMP is considered a live document and requires regular monitoring and review to ensure its effectiveness and ultimately the success of the plan in addressing existing, future and continuing flood risks.

About this report

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This document has been prepared with financial assistance from the NSW Government through the Office of Environment and Heritage. This document does not necessarily represent the options of the NSW Government or the Office of Environment and Heritage.

The sole purpose of this report and the associated services performed by is to assess flood risk in Tenterfield and potential mitigation options in accordance with the scope of services set out in the contract between Jacobs and the Tenterfield Shire Council. That scope of services, as described in this report, was developed with the Tenterfield Shire Council and Office of Environment and Heritage.

The data derived the data in this report was sourced from Tenterfield Shire Council (if any) and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. This report has been prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted for use of any part of this report in any other context.

This document forms the draft Flood Risk Management Study and Plan for Tenterfield. The report has not been endorsed by Council and is provided to provide an opportunity for community and stakeholder consultation and feedback. This draft will be updated to incorporate comments from the community and Council more broadly before being finalised and submitted to Council for endorsement.

FLOODPLAIN RISK MANAGEMENT STUDY

1. Introduction

1.1 Background and Purpose

Floodplains are low-lying areas of land adjacent to waterways that are subject to inundation by floodwater. The Commonwealth and State Government enforce legislation to control the risks to people and properties located in the floodplain. The State Government requires that Local Governments prepare a Floodplain Risk Management Study and Plan in accordance with the NSW Government's Flood Prone Land Policy and the Floodplain Development Manual (then NSW DIP, 2005), herein referred to as the Manual. To assist, the State Government supports and assists Local Government in compliance with the relevant legislation to manage risk and liability by providing funding and technical support.

The Tenterfield Floodplain Risk Management Study (FRMS) provides the basis of the management of existing and future flood risks for the township of Tenterfield. The Tenterfield FRMS seeks to quantify the level of flood risk in the study area, identify management options and provide recommendations on how to manage and, where possible, reduce flood risk.

Tenterfield is fortunate to have an existing flood risk profile considerably less than many other floodplains in NSW and Australia. This FRMS has been developed to provide a study that meets the requirements of the NSW Government's Flood Prone Lands Policy and the Manual, and is commensurate with the existing and future flood risk to the community.

1.2 Locality

Tenterfield, in northern NSW, is located approximated 150 km west of Ballina and 770 km north of Sydney at the junction of the New England and Bruxner Highways. It has a population of approximately 3100 and the main industries are cattle breeding and wool production.

Tenterfield sits in a valley on the western slopes of the Great Dividing Range and Tenterfield Creek runs from south to north through the town. Within the town, Tenterfield Creek is surrounded by parkland, playgrounds and walking tracks. The location of the creek relative to the town is illustrated in **Figure 1-2**.

Tenterfield Creek Dam is situated approximately 2 km upstream of the town. As the dam owner, Tenterfield Shire Council (Council) is responsible for ensuring the safety of the Tenterfield Creek Dam and is currently undertaking the Tenterfield Creek Dam Safety Upgrade Options Study (NSW Public Works, April 2014). It is noted that the safety assessment of Tenterfield Creek Dam is a separate study being undertaken by Council and that the Tenterfield FRMS does not aim to consider flood risk associated with dam failure events.

Tenterfield Creek is crossed by a number of roads that connect east and west Tenterfield. At present, the Creek is also crossed by the New England Highway, which serves as a major interstate freight route and is part of the National Land Transport Network. However, the Australian Government has committed funding to identify a heavy vehicle bypass route for Tenterfield. The preliminary route options report suggests that the preferred option for the bypass route may avoid crossings of Tenterfield Creek (GHD, 2014).

Tenterfield is one of Australia's oldest towns, known as the "Birthplace of our Nation", where Sir Henry Parkes delivered his famous Federation Speech at the Tenterfield School of Arts in 1889, which ultimately lead to Federation in 1901 (Tenterfield Tourism, 2014). This history is an important component of the town's character and there are a number of buildings and streetscapes of historical significance. These include the showgrounds, areas of parkland and a number of buildings. A total of 87 heritage listed locations are identified in Tenterfield. Of these, 21 are within or partly within the floodplain.

The study area for the Tenterfield FRMS includes only the township of Tenterfield. The study area extends from Tenterfield Dam to just downstream of Rouse Street as illustrated in **Figure 1-2**. The study area has been defined to focus on areas of existing and potential future development.

It is noted that the flood modelling undertaken by DHI in 2013 extends approximately 8.5 km downstream of Tenterfield to the confluence with Washpool Creek. However, a review of the flood modelling in this area indicates that flood levels may potentially be underestimated, as hydrology for the local catchments in this reach was not included in the DHI modelling. Therefore, while flood risk mapping has been undertaken for this area, it is considered indicative only as flow behaviour in this area may be influenced by local inflows and downstream tributaries.

1.3 Flood History

The largest recorded flood in Tenterfield was in January 2011. The January 2011 was a rare event with fast flowing floodwaters that inundated roads and resulted in significant damage to a number of road crossings and bridges, particularly at Molesworth Bridge. Council infrastructure including park facilities and a pump station were also damaged. A number of properties reported flooding within their property and three residences reported over floor flooding. The event did result in flooding of a number of commercial properties including the Bowling Club Motor Inn, where at least one motel unit adjacent to the bowling greens was reportedly inundated above floor level (DHI, 2013).

The general, Tenterfield community was most significantly impacted by road flooding that cut access between east and west Tenterfield for a period of around three hours. This resulted in social impacts for people returning home from work and deliveries of meals on wheels. It also resulted in a potential impact on emergency services, with the hospital and ambulance being located on opposite sides of the town. Fortunately, there were no incidents requiring ambulance transport of persons to the hospital. While the town being split resulted in an impact to the community, this occurred over a relatively short timeframe and, as such, did not result in long term social or economic impacts.

Smaller floods also occurred in Tenterfield in 2001, 1999 and 1976, with the 1976 flood being the largest of the three.

Council commissioned the Tenterfield Creek Flood Study in 2001. This study included data collection and community consultation; a hydrologic investigation; and one-dimensional hydraulic modelling of the Tenterfield Creek floodplain using the modelling package MIKE 11. This study was completed in 2006.

Following the large flood event in 2011 that caused significant damage, post flood data collection was undertaken. The flood data collected for Tenterfield was extensive and informed the Tenterfield Flood Study, which was completed in 2013. The Tenterfield Flood Study included linked one-and two-dimensional hydraulic modelling, along with detailed flood mapping for a range of historical and design flood events. The model was calibrated to the 2011 flood event. Hydraulic categories and preliminary flood hazard categories (as per the Manual) were mapped.

The 2011 flood event was an example of rare flooding in Tenterfield, where roads were cut by fast-flowing floodwaters and a number of Council facilities, business and properties were inundated. This recent event highlights the need for adequate flood management in Tenterfield.

The Tenterfield FRMS was developed with reference to the Tenterfield Flood Study.

1.4 Floodplain Risk Management in NSW

Figure 1-1 outlines the Floodplain Risk Management Process as outlined in the Manual. This project covers the FRMS and Floodplain Risk Management Plan (FRMP).

The purpose of a FRMS is to identify, assess and compare various floodplain risk management options and provide recommendations for the management of existing, future and continuing flood risk. The FRMS should provide an overview of the impact of the recommendations of the study on the flood behaviour and the community.

The FRMP provides inputs to the strategic and statutory planning roles of Council and additional detail on the management of flood prone land. The FRMP has been developed following feedback from the community and key stakeholders on the findings and recommendations of the FRMS.

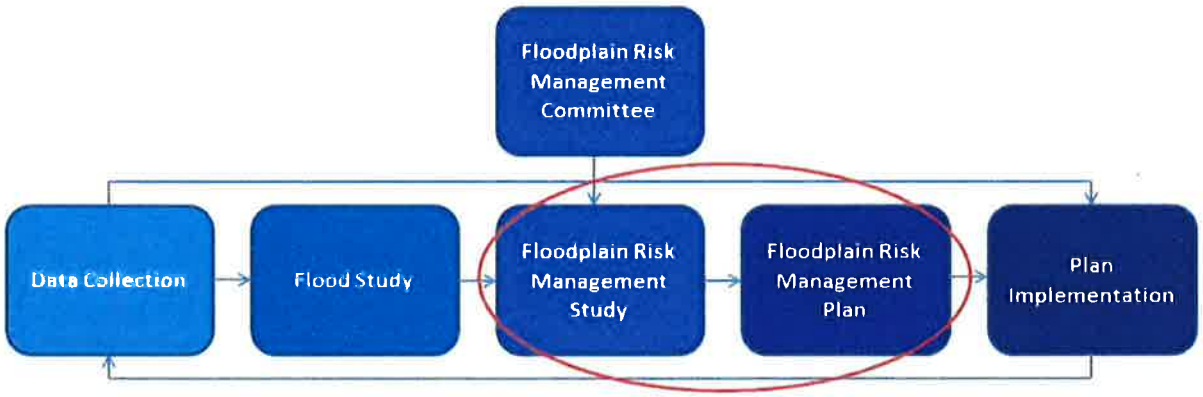

Figure 1-1 Floodplain Risk Management Process

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Scale: 1:10,000

Datum: MGA56
Coordinate System: MGA Zone 56

Figure 1-2

Tenterfield Study Area

Project: Tenterfield Floodplain Risk Management Study

2. Data Review

2.1 Tenterfield Flood Study Summary

The first Flood Study for Tenterfield Creek was completed by DHI in 2006. The study involved the development of a one-dimensional model of Tenterfield Creek. The model was calibrated to the February 2001 flood event.

In 2012, following the January 2011 flood event, Tenterfield Shire Council commissioned DHI to update the Tenterfield Flood Study and upgrade the existing one dimensional flood model to a two dimensional flood model. This Flood Study was completed in 2013 and forms the basis of the Tenterfield FRMS. Copies of the results of the flood modelling undertaken by DHI are provided in **Appendix A.**

2.1.1 Historical Flooding – Calibration and Verification

Modelling was undertaken as part of the 2013 Tenterfield Flood Study for the 2011 event (calibrated) and the 2001 event (validated). The Tenterfield Flood Study used a joint calibration process to calibrate the hydrologic and hydraulic models. The joint calibration process requires the user to adjust the model parameters in both the hydrologic and hydraulic model in an iterative manner until the model gives a result that provides a reasonable fit to the observed flood levels. This approach is considered appropriate as there was insufficient streamflow gauging within the catchment to support independent calibration of the hydrologic model.

The comparison of modelled and recorded flows presented in the report demonstrates that the model provided an accurate prediction of the peak levels and is, therefore, considered appropriate. While the calibration is considered appropriate, it is noted in the Flood Study conclusions that the hydrologic model accuracy is limited by data scarcity. In particular, the report notes limitations around the availability of sub-daily rainfall data within the catchment and recommends that installing an additional rainfall gauge close to the town is considered further. This is discussed in **Section 7.5** of this report.

The 2001 event was relatively small, with the modelled levels being lower than those of the 10% AEP design event. According to the modelling results, no buildings were inundated in this event, but some local roads were flooded including Naas Street, Logan Street, Manners Street, Link Street and Molesworth Street. Velocities modelled in the creek were in the order of 1 – 2 m/s.

The 2011 event was significantly larger than the modelled 1% AEP. The model results show that 13 residential and 11 non-residential buildings would have been flooded during this event. The results also show road inundation in 18 locations, with the western side of Tenterfield being cut off from the eastern side. The velocities modelled were generally in the order of 2 – 3 m/s in the creek through the town. However, in the upper reaches of the creek (south of the town), the modelled velocities exceeded 5 m/s in some locations. Rouse Street, Petre Street and Molesworth Street were also shown to be cut by floodwaters with velocities exceeding 4 m/s.

Copies of the results of the historical flood modelling undertaken by DHI are provided in **Appendix A.**

2.1.2 Design Flood Events

The following flood events were modelled as part of the Tenterfield Flood Study: 10%, 5%, 2%, 1% Annual Exceedance Probability (AEP)'s and Probable Maximum Flood (PMF) event. The design events were based on data from Australian Rainfall and Runoff (AR&R) (Institute of Engineers Australia, 2001) with the exception of the PMF event, which was determined using the Bureau of Meteorology's (BoM)'s Generalised Short Duration Method (BoM, 2003).

Tenterfield is on the boarder of the Zone 1 and Zone 2 areas for design storm temporal patterns. The flood study reports that sensitivity assessment was undertaken as part of the 2006 flood study and that the model was not sensitive to the temporal pattern assumption. Given this, the Zone 2 temporal pattern was adopted. The sensitivity of the model to the Zone 1 and Zone 2 temporal patterns is discussed further in **Section 2.2.**

The critical duration for the PMF event was determined to be 2 hours, with the critical duration of all other events being 48 hours. This is considered to be unusually long for the size of the catchment, but is reported by DHI to be due to the attenuation of Tenterfield Dam. The critical duration is discussed further in **Section 2.2**.

The design event modelling indicates that the majority of design events with a frequency greater than 1% AEP are largely contained within the creek and parkland areas. Furthermore, modelling of the PMF event indicates that the extent of flooding is relatively narrow, extending less than 300 m from the creek bed with no major break-outs or changes in flood behaviour. This is an important observation for floodplain risk management, and is discussed further in **Section 3.2.1**.

The main bridges over Tenterfield Creek (e.g. Douglas St, Manners St, High St, Molesworth St, Naas St) connecting the eastern and western sides of the town are shown to be overtopped in a 10% AEP event. The flood immunity of the New England Highway/Rouse Street is between 10% and 2% AEP.

Copies of the results of the design flood modelling undertaken by DHI are provided in **Appendix A**.

2.1.3 Sensitivity

Two sensitivity assessments were undertaken as part of the Flood Study. These assessments investigated the sensitivity of the model to changes in Manning's n hydraulic roughness and peak flows. The results indicated that the model was moderately sensitive to these changes, with 20% increase in hydraulic roughness and peak flow resulting in a 150 mm and 200 mm increase in flood levels respectively for the 1% AEP flood event. However, these increases did not result in a notable change in the flood extent or behaviour. This indicates that the implications of the potential uncertainty in the modelling are not likely to materially change the approach to flood risk management.

The Tenterfield Flood Study notes that the model sensitivity to culvert blockages was not part of the scope of the Flood Study. However, DHI recommended an analysis of the sensitivity to culvert and bridge blockages reporting that "*flood behaviour is strongly controlled by the presence of numerous road crossings and bridges in the town*". A sensitivity assessment to culvert and bridge blockage was undertaken as part of the Tenterfield FRMS and is presented in **Section 3.2.1**.

2.2 Model Adequacy Review

As part of the Tenterfield FRMS, the flood modelling undertaken for the Tenterfield Flood Study (DHI 2013) was reviewed. The purpose of the review was to confirm that the flood modelling provides an appropriate basis for defining floodplain risk and developing risk reduction measures.

The model review identified a number of issues, which were discussed with Council and the Office of Environment and Heritage (OEH). The majority of these issues were resolved or determined not to have a material impact on the elements relevant to the Tenterfield FRMS. However, the review highlighted two issues that had the potential to have significant implications for the FRMS. These were:

1) **The design flood hydrology**: The modelling appears to underestimate peak flows through the town of Tenterfield for the respective AEP when compared to regional flood estimates based on the Australian Rainfall and Runoff Update Project 5.
2) **Flood warning**: The 48 hour critical duration, does not appear to reflect observations of historical floods and appears inconsistent with the catchment size and 2 hour critical duration for the PMF. The 48 hour design storm temporal pattern was reviewed and found to have an intense 6 hour burst embedded within the pattern that effectively resulted in a 6 hour rainfall event within the 48 hours. This burst exceeded that of the 6 hour design storm.

The review recommended a further review of the design flood hydrology and validation against other regional methods. The review also recommended that the filtering of the design storm temporal patterns should be undertaken to remove the embedded burst and that the critical duration be reassessed on this basis.

The review was discussed with the OEH and Council on the 11th of February 2014. OEH recommended an additional scope of work be undertaken to further examine the above issues and support decision making for the progression of the FRMS. This included:

- Understanding the sensitivity of the hydrologic modelling to the Zone 1 temporal patterns (Tenterfield is on the boarder of Zone 1 and Zone 2) and to filtering. This was to be undertaken for durations of 2, 4, 6, 12 and 48 hours for the 1% and 10% AEP.
- Estimate critical duration from above and select 3 storm durations (closest to estimated critical duration) for each AEP to assess in the hydraulic model.
- Plot profile of above hydraulic model simulations against the January 2011 flood event.

A copy of the full discussion paper outlining the review as well as commentary from the OEH and DHI is provided in **Appendix B**.

From the review and analysis, the following conclusions were drawn:

- The design event temporal patterns for Tenterfield should be filtered as the current AR&R design storms have a burst imbedded in the 48 hour storm of greater intensity than the 6 hour storm.
- The impact of filtering is that the critical design event storm duration should be 6 (Zone 2) to 12 hours (Zone 1).
- The filtered Zone 1 temporal pattern results in the largest water surface levels through town with an increase in flood levels of up to 250 mm over the results presented in the Flood Study for the 1 % AEP.
- The increased flood levels do not substantially change the extent of flooding or the flood behaviour from that presented in the flood study.
- A review of historical gauged streamflow data for the area surrounding Tenterfield indicates the regional design flow estimates from Project 5 typically over estimate peak flows for the region. Flood frequency analysis of these streamflow gauges indicated the 5th percentile estimates from Project 5 are more closely aligned to the observed flows. As such, the peak flow estimates from the Flood Study are considered appropriate.
- The January 2011 event was significantly larger than a 1% AEP design flood event. The 2011 levels are in the order of 1 m higher through the majority of the town.

The review concluded that the potential inaccuracy or uncertainty in the flood study does not result in significant consequences for the definition of flood risk in Tenterfield. In particular, the costs (time and money) to revise the Flood Study to account for this difference would outweigh the benefits.

At the time of assessment, the model adequacy review recommended the FRMS consider the above in the definition of the Flood Planning Levels (FPLs) for Tenterfield. This review was undertaken following consideration of the flood hazard and is discussed further in **Section 7.1**

It was therefore considered appropriate that the Flood Study be adopted with the above notations and those of the Model Adequacy Review (4th of November 2014). It was considered appropriate that the FRMS progress on the basis of the previous modelling and that the uncertainty be accommodated through the FRMS until sufficient data becomes available to support revision of the Flood Study.

2.3 Planning and Development

Tenterfield's current land use planning was reviewed as part of this FRMS and discussed with Council planning officers. At present, all of Tenterfield town is zoned as Village, meaning it is appropriate for future development subject to the conditions of the Tenterfield Local Environment Plan 2013 (LEP). Under Clause 6.2 of the LEP, the development must satisfy a number of conditions related to the development of flood prone land. Generally these conditions seek to minimise flood risk to the development and changes to existing flood risk as a result of the development up to the FPL. The FPL is currently defined as the 100 year ARI[1] (1% AEP) flood level plus

[1] The NSW Floodplain Development Manual refers to the chance of a flood of a given or larger size occurring in any one year as an Annual Exceedance Probability (AEP). This probability is usually expressed as a percentage to illustrate that **there is a chance that the event may occur in any given year**. While the 100 year Annual Recurrence Interval (ARI) has the same statistical probability of occurrence the industry has

0.5 m freeboard. Discussions with Council planning officers indicate that the current development pressures in Tenterfield are minor and there is no shortage of available land for development. This provides Council with an opportunity to set up appropriate future flood risk mitigation measures in the form of development control and zoning.

A copy of Clause 6.2 of the LEP is provided in **Appendix C**.

2.4 Survey of January 2011 Flood Levels

Following the 2011 event in Tenterfield, a large amount of data was collected by DHI on behalf of the State Emergency Service (SES). This data was used to inform the Flood Study and calibration of the modelled January 2011 flood event. A summary of the questionnaire sent to residents is provided in **Section 5.2**

2.5 Tenterfield Bypass

The New England Highway which serves as a major interstate freight route and is part of the National Land Transport Network runs through the centre of Tenterfield with two crossings of Tenterfield Creek. The Australian Government has committed to funding to identify a heavy vehicle bypass route for Tenterfield. The preliminary route options report was reviewed as part of this FRMS to identify if the bypass may improve the connectivity of east and west Tenterfield during a flood event.

The preliminary route options report outlines a number of different route options. However, the preferred route corridors are likely to bypass Tenterfield to the west of the current New England Highway avoiding a major crossing of Tenterfield Creek.(GHD, 2014) This suggests that the preferred option for the bypass is unlikely to improve the towns connectivity during a flood event.

2.6 Tenterfield Dam Break

The assessment of flood impacts associated with Tenterfield Creek Dam is outside the scope of this FRMS. However, mapping of the dam break modelling undertaken as part of the dam safety upgrade works (NSW Department of Public Works, 2014) was compared to the Flood Study mapping developed by DHI. The comparison suggested that the location of high hazard flood waters was not materially different. Therefore while the Tenterfield Creek Dam break scenario was not considered in this study many of the floodplain risk management measures proposed in this assessment will also assist in reducing flood risks under a dam break scenario.

moved away from the ARI terminology as recurrence interval incorrectly implied that the probability of occurrence of an event was related to the time since the last event. With the 2010 updates to Australian Rainfall and Runoff, the AEP terminology is now considered the industry standard. Therefore, where documentation refers to a 100 year ARI this should be taken to be the same as the 1% AEP.

3. Flood Hazard Assessment

3.1 Preliminary Flood Hazard

Risk can broadly be defined as the likelihood of a hazard occurring and the consequences of that hazard.

The preliminary flood hazard for Tenterfield was defined by the Tenterfield Flood Study completed by DHI in 2013. The preliminary flood hazard is a function of the physical properties of the flood being depth and velocity as defined by the Manual and illustrated in **Figure 3-1**.

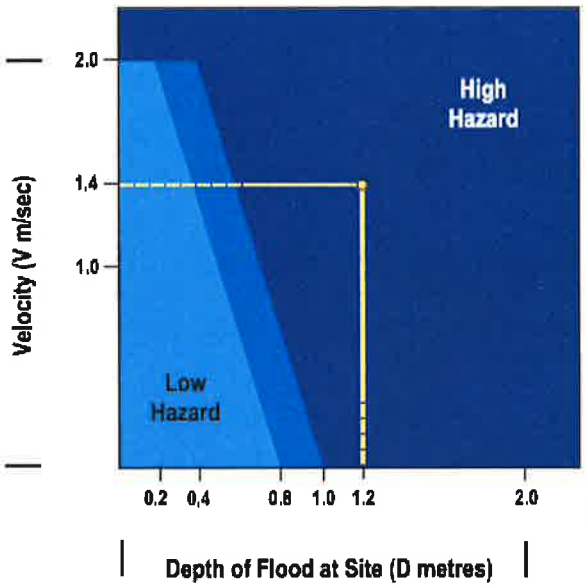


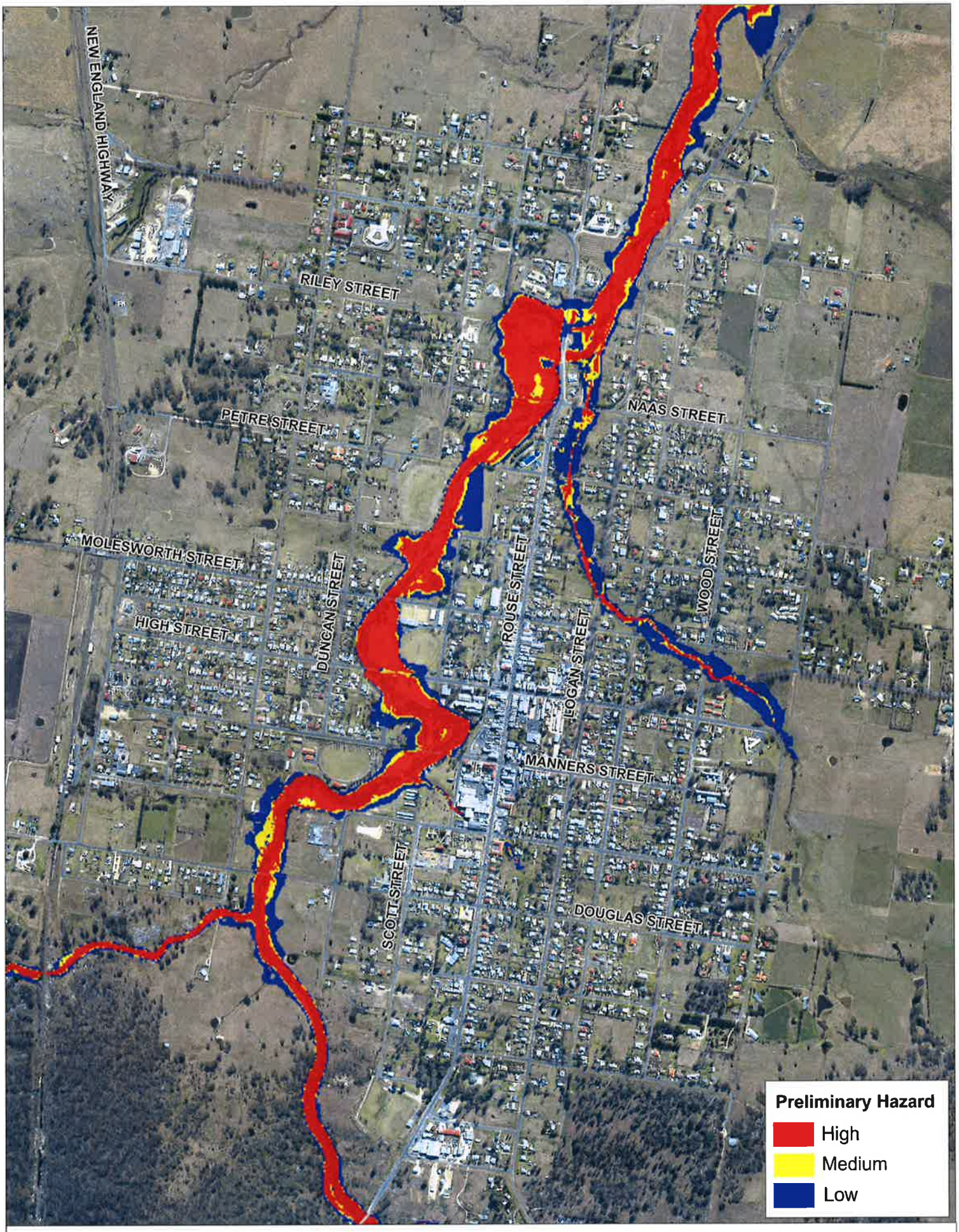
Figure 3-1 Preliminary Flood Hazard

The preliminary flood hazard calculated for the 1% AEP and PMF events are illustrated in **Figure 3-2** and **Figure 3-4**.

To develop flood hazard categories specifically for Tenterfield, the preliminary flood hazard was considered along with a range of other factors. These flood hazard categories are based on the flood behaviour during a range of flood events and resulted in the assignment of hazard ratings that are not specific to a particular flood event. For example, an area that is expected to regularly experience potentially dangerous flooding would be a 'high' hazard area. However, this same dangerous flooding may be a 'moderate' hazard area if it was only expected to occur in extreme circumstances.

As part of this study, one additional design flood event (in addition to the events considered in the Tenterfield Flood Study) was assessed to aid in the development of the hazard categories. Through discussions with Council, it was decided that the most appropriate design event to model was the 0.05% AEP event. This event gives an indication of the upper limit of the flooding that the town could reasonably expect to experience within a lifetime.

The preliminary flood hazard for this 0.05% AEP flood event is provided in **Figure 3-3** with full results in **Appendix D**. It is noted that the flood behaviour for the 0.05% AEP is very similar to that observed in the 1% and PMF flood events. No new areas of inundation or flood break outs were observed.



JACOBS

N

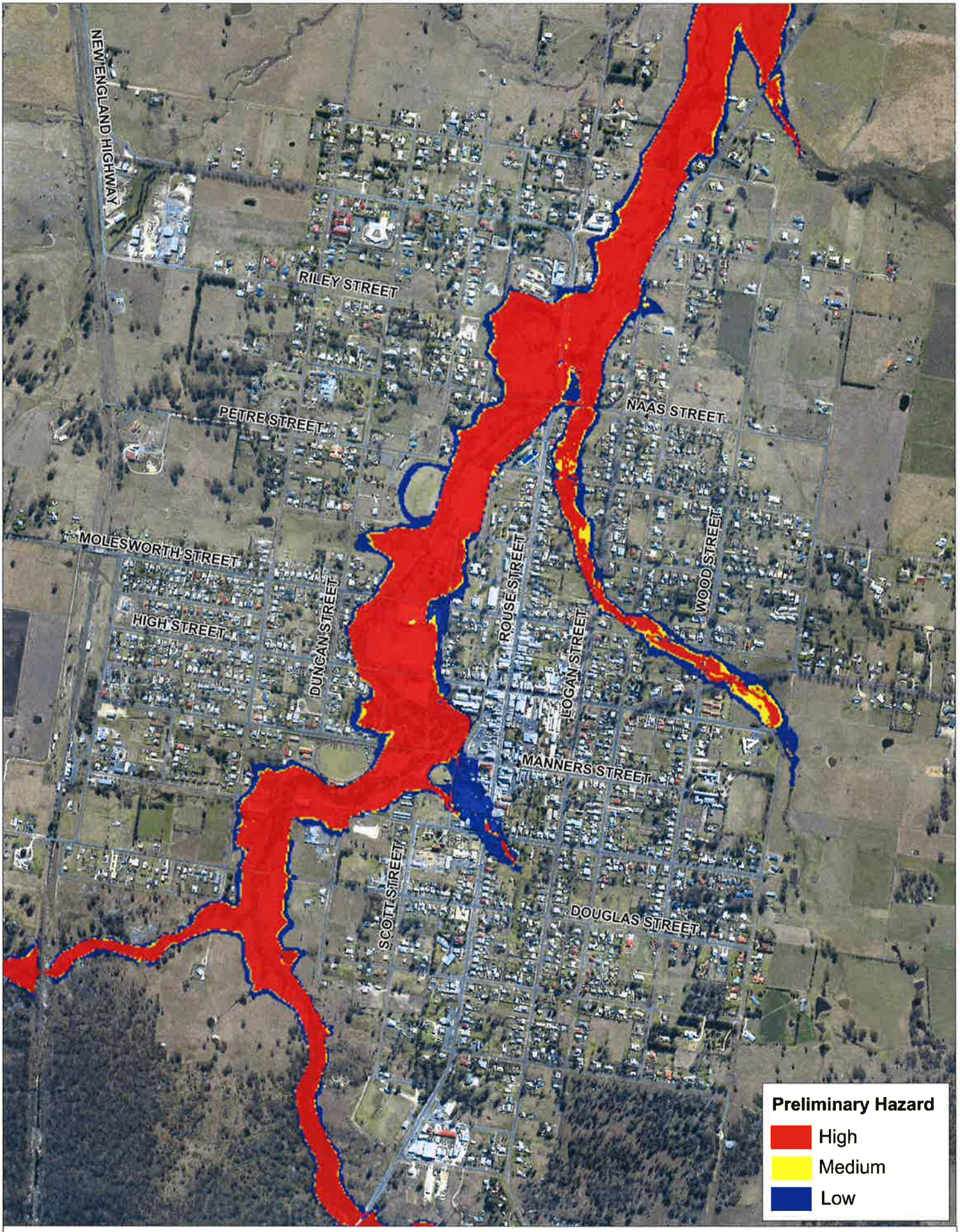
Scale: 1:10,000

Datum: MGA56
Coordinate System: MGA Zone 56

Figure 3-2

Preliminary Flood Hazard, 1% AEP Event

Project: Tenterfield Floodplain Risk Management Study



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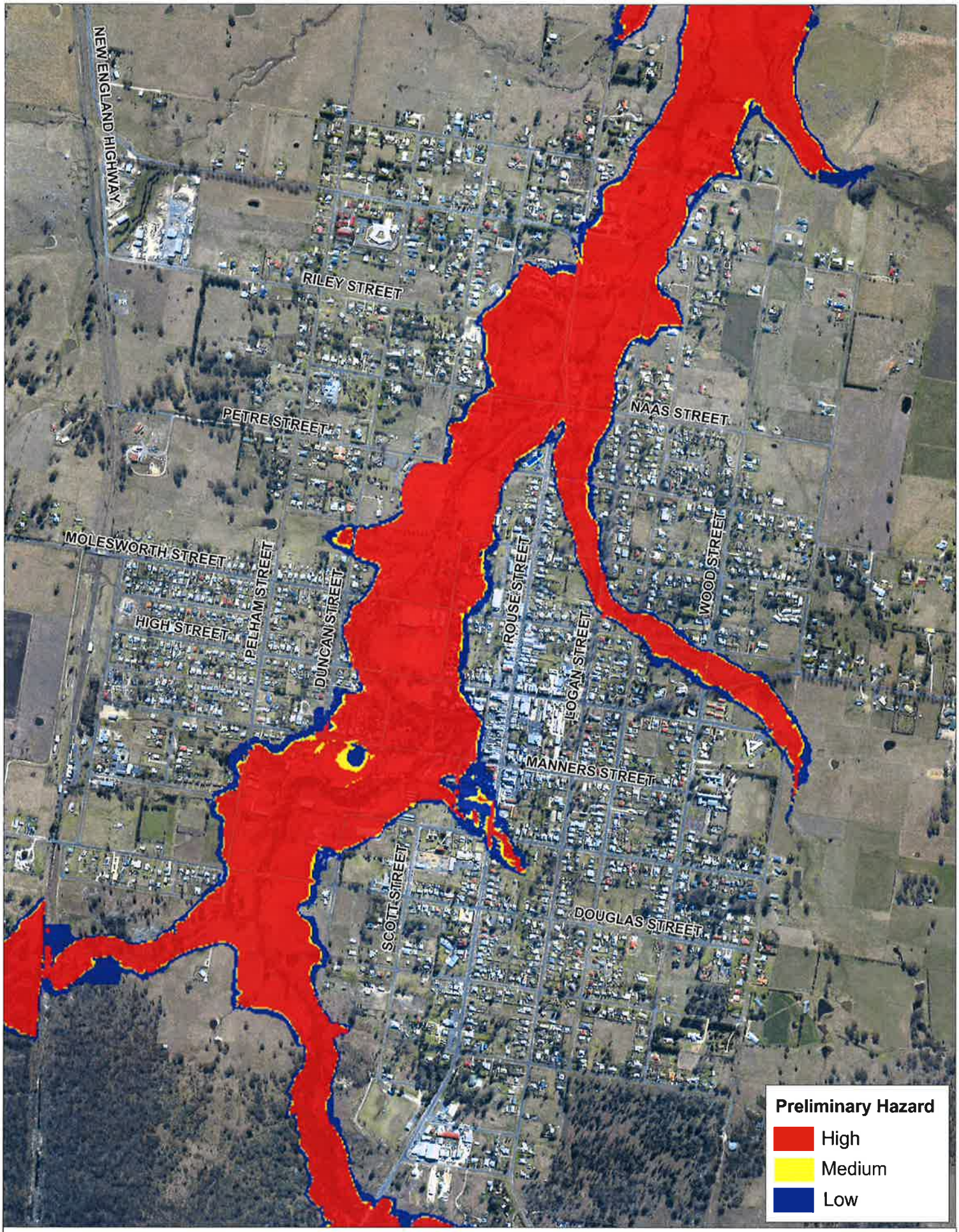
Scale: 1:10,000

Datum: MGA56
Coordinate System: MGA Zone 56

Figure 3-3

Preliminary Flood Hazard, 0.05% AEP Event

Project: Tenterfield Floodplain Risk Management Study



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Scale: 1:10,000

Datum: MGA56
Coordinate System: MGA Zone 56

Figure 3-4

Preliminary Flood Hazard, PMF Event

Project: Tenterfield Floodplain Risk Management Study

3.2 Factors Influencing Flood Hazard in Tenterfield

A number of factors are listed in the Manual for consideration in refining preliminary flood hazard to flood hazard. The factors influencing existing flood hazard in Tenterfield and their relative severity is presented in **Table 3-1** and discussed in the following sections.

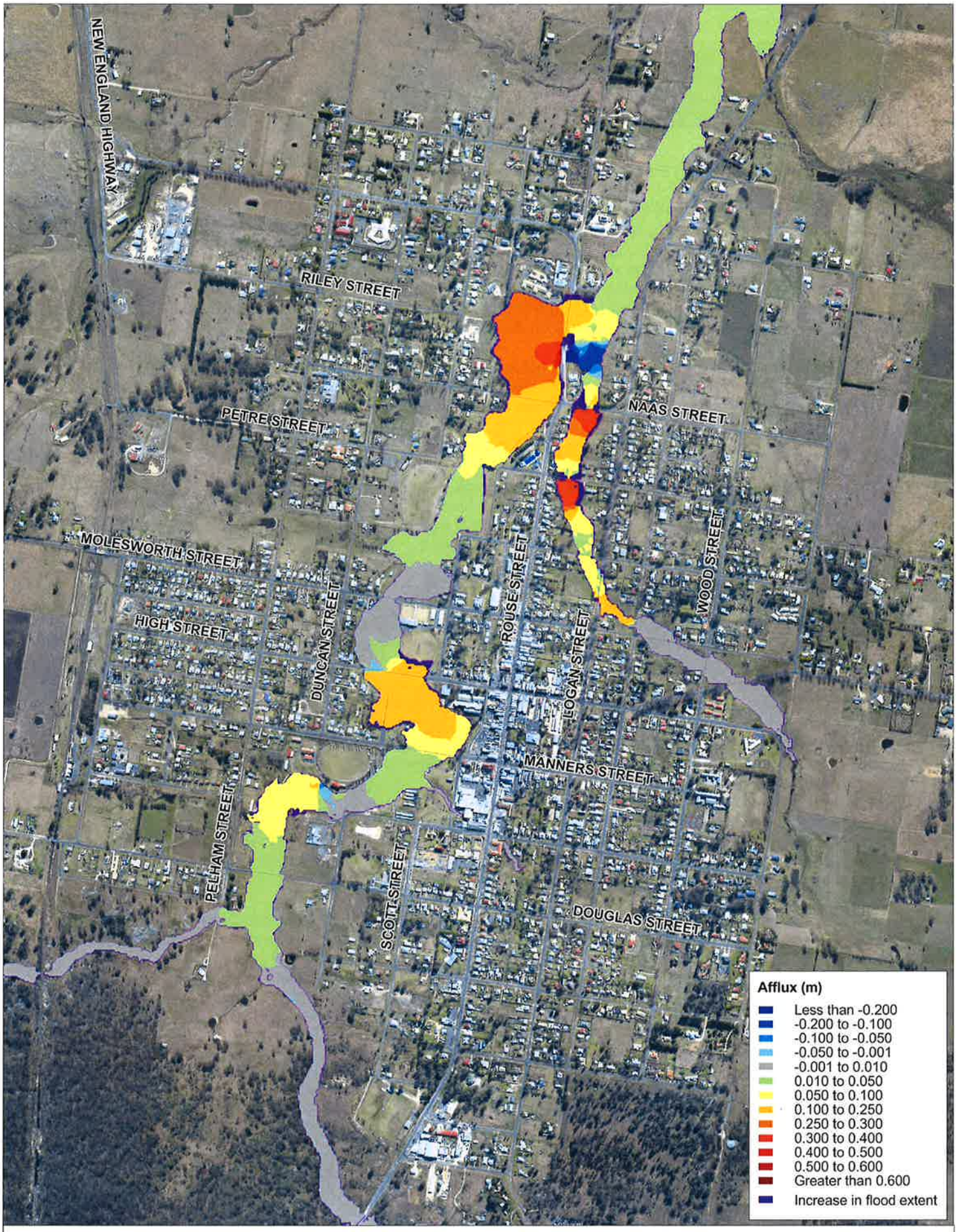
Table 3-1 Factors Influencing Existing Flood Hazard in Tenterfield

Hazard	Description	Relevance to Tenterfield?
Size of flood	Is the location subject to flooding during relatively small flood events or only large events? How does the size of the flood affect flood behaviour in this location?	Moderate
Effective warning time	The effective warning time is less than the total warning time because of the time taken to alert residents and for residents to respond.	High
Flood readiness	Situations in which the community is prepared to respond promptly and efficiently can reduce the consequences of the flood hazard.	Moderate
Rate of rise of floodwaters	Situations in which floodwaters rise rapidly can be more dangerous and damaging than situations in which flood waters rise slowly.	High
Depth and velocity of floodwaters	These parameters are related to preliminary flood hazard. The ability for residents to safely drive or walk through floodwaters is dependent on depth and velocity. The damage to infrastructure and movement of debris are also dependent on these factors.	High
Duration of flooding	Longer duration floods can cause more problems with isolation and resource shortages.	Low
Evacuation problems	Any factors hindering evacuation can influence flood hazard. These factors could be related to flood behaviour, infrastructure, capacity of evacuation routes, mobility issues and/or communications.	Moderate
Effective flood access	Available access routes for affected residents to escape and emergency services to assist should be considered in determining flood hazard.	Low
Type of development	A number of factors relating to the type of development can increase flood hazard. For example, hazardous industries on the floodplain increase flood hazard because dangerous spills could result. Isolated development and development over watercourses can also impact flood hazard, as well as the existence of special evacuation needs.	Low

3.2.1 Depth and Velocity of Floodwaters – High Influence

The depth and velocity of floodwaters in flood events is considered to be one of the main factors that influences flood hazard in Tenterfield. This is because the risk of harm to residents and damage to structures increases significantly with both depth and velocity of floodwaters. The results of the 2013 modelling were used to consider flood velocities and depths in the flood hazard categorisation. **Figure 3-2** and **Figure 3-4** illustrates the 1% AEP and PMF flood hazard from the DHI 2013 study.

In addition, the potential impact of blockages of drainage structures such as culverts and bridges on flood levels and velocities has been considered. A sensitivity analysis was undertaken to assess the impact of blockages on flood depths and velocities. The sensitivity analysis included a 50% blockage of key bridges at Rouse Street, Naas Street East, Naas Street West, Logan Street, High Street and the Showground Footbridge for the 1% AEP flood event. Tenterfield Creek was found to be only moderately sensitive to blockages, with relatively minor increases in the predicted flood level of 0.2m. These results are presented in **Figure 3-5**.



JACOBS

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Scale: 1:10,000

Datum: MGA56
Coordinate System: MGA Zone 56

Figure 3-5

Sensitivity to Blockages, 1% AEP Event

Project: Tenterfield Floodplain Risk Management Study

3.2.2 Effective Warning Time – High Influence

In some locations, flood hazard may be reduced if the warning time would allow residents to evacuate before a flood event. The 2013 modelling predicted that Tenterfield may experience long duration flooding (critical duration in the order of 48 to 72 hours). However, a review of this modelling found that the critical duration of flooding in Tenterfield is likely to be shorter (in the order of six hours). This six hour warning time is also consistent with that experienced in the January 2011 flood. Therefore, it is considered appropriate to assume that warning time before a flood event may be short. This means that the flood hazard calculated in consideration of other factors will not be reduced due to effective warning time.

Tenterfield Creek Dam is located immediately upstream of the township. In the event of a dam failure, the effective warning time would be very short. Consideration of dam break modelling results is outside the scope of this assessment. However, it is recommended that this should be undertaken in the future.

3.2.3 Rate of Rise of Floodwaters – High Influence

The rate of rise of floodwaters is likely to be relatively quick in Tenterfield due to the short flood durations expected (around six hours) and the relatively small catchment size. This has been considered in defining the flood hazard categories. It is recognised that the potentially fast rate of rise necessitates more conservative criteria than would be applied in a very large catchment where the rate of rise would be slower.

3.2.4 Size of Flood – Moderate Influence

The flood extents and modelled flood behaviour for events of different return periods (AEPs) are important in analysing flood hazard in Tenterfield. The results of the 2013 modelling were used to consider flood extent in the flood hazard categorisation. The size of the flood is particularly important where there is a change in the flood behaviour and therefore flood risk for different sized floods. i.e. a new breakout from the creek. **Figure 3-2** through to **Figure 3-4** provides the preliminary flood risk for a number of different sized events.

In Tenterfield flood flows are largely restricted to the area immediately adjacent to Tenterfield Creek. No significant floodplain flows or flow breakouts were observed. However, it is noted that in all AEPs the majority of the flood extent is high hazard floodwaters.

The 10 % AEP event (which has a 10 % chance of occurring in any given year) provides an indication of an event that is likely to occur. Most residents will experience several floods of this magnitude within a lifetime. While this flood is largely contained within the creek there are properties on the eastern side of town that would experience high hazard floodwaters in this event.

The 1% AEP flood event plus 0.5 m freeboard is typically adopted for defining FPLs and is currently the basis of the FPL in Tenterfield. This event would represent a flood that residents may experience in a lifetime, but is a rare event. This event is still largely contained in Tenterfield Creek. However, in 2011 (estimated as between a 0.2% and 0.1% AEP) an event rarer than the 1% AEP event the creek breaks its banks, inundating property and overtopping roads. The 2011 event provides an example of the continuing risk that Tenterfield is exposed to beyond that mitigated by the definition of FPLs at the 1% AEP level plus 0.5 m freeboard, a risk that needs to be considered in the FRMP.

The 0.05 % AEP modelling results would be considered as indicative of a very rare flood that most residents are unlikely to experience, but still a feasible event that should be considered in disaster planning.

The PMF flood modelling results from the 2013 modelling have been taken as an upper bound of the possible flood extent. It is not considered that general development needs to be limited by the PMF flood extent, but it may be appropriate to limit emergency services to building outside of this area.

3.2.5 Evacuation Problems – Moderate Influence

Because the number of residences that may be flooded in Tenterfield is relatively small (approximately 100 houses in a PMF event), it is unlikely that the number of people requiring assistance will be particularly high.

The distance to dry ground is less than 200 m for all residences flooded in a PMF event. A review of the 2011 census data indicates that there are no demographic factors in Tenterfield that would cause more evacuation problems than would be experienced in other towns (i.e. access to a car, disabilities, and low adult to child ratios). Therefore, evacuation problems are not expected to increase flood hazard significantly in Tenterfield.

However, it is noted that there is significant flooding over roads that cross Tenterfield Creek. This high hazard floodwater presents a significant risk to people in the event that they attempt to cross these roads during a flood event.

It should be noted that the Tenterfield Police Station is within the PMF flood extent determined through the 2013 modelling. However, it is not within the 1 % AEP or 0.05% AEP flood extent.

3.2.6 Flood Readiness – Moderate Influence

As no information to the contrary has been provided, it is assumed that Tenterfield residents have an average level of awareness around flooding. Therefore, a high degree of flood readiness has not been assumed to reduce flood hazard.

It is noted that flood readiness increases immediately after a flood event, such as that in 2011, but decreases in the time after the event. It will be important for the community to maintain their current level of flood readiness to minimise their exposure to the flood risk.

3.2.7 Duration of Flooding – Low Influence

Long flood durations can result in increased flood hazard due to isolation, which can induce stress, place high demands on services and hinder access to medical services. Due to the relatively small catchment size, it is not expected that Tenterfield would experience long duration flooding. In addition, the flood maps do not indicate that isolation is likely as areas are not cut off from exit routes. Therefore, it is considered that the flood hazard categories do not need to consider the impacts of long duration flooding in Tenterfield.

3.2.8 Effective Flood Access – Low Influence

Flood hazard increases in areas where access and evacuation are hindered by flooding of roads and railways. The 2013 modelling has shown that flooding in Tenterfield does not prevent residents from exiting the town, even in very large events, and there are a number of roads that residents can take to travel from flooded to dry areas. Therefore, it is not expected that access issues will impact flood hazard.

3.2.9 Type of Development – Low Influence

No hazardous developments have been identified as being within the PMF flood extent in Tenterfield. Therefore it is considered that the flood hazard does not need to be increased due to the type of development.

3.3 Summary of Key Factors Influencing Flood Hazard Tenterfield

Table 3-2 provides a summary of the key components of flood hazard that may influence flooding in Tenterfield. The high influence factors of velocity, depth, rate of rise and flood warning time should be considered in the flood hazard categorisation and selection of appropriate options.

Table 3-2 Classification of Factors influencing flood risk at Tenterfield

High	Moderate	Low
• Depth and velocity of floodwaters • Rate of rise of the floodwaters • Effective warning time	• Size of the flood • Evacuation problems • Flood readiness	• Duration of flooding • Flood access • Types of development

3.4 Hazard Categorisation

3.4.1 Literature Summary

A review of a number of previous studies, papers and publications was undertaken to determine what the current industry standard is for development of hazard classifications. A brief summary of these documents has been outlined below.

3.4.1.1 Project 10 - Australian Rainfall and Runoff (AR&R, 2010)

The aim of Project 10 was to provide guidance on pedestrian safety and stability in floods (AR&R Project 10, 2010). The outcome of the Project 10 is shown in Table 3-3 below:

Table 3-3 Australian Rainfall and Runoff hazard ratings

<table>
<tr><th>DV (m^2s^{-1})</th><th>Infants, small children (H.M ≤ 25) and frail/older persons</th><th>Children (H.M = 25 to 50)</th><th>Adults (H.M > 50)</th></tr>
<tr><td>0</td><td>Safe</td><td>Safe</td><td>Safe</td></tr>
<tr><td>0 – 0.4</td><td rowspan="5">Extreme Hazard; Dangerous to all</td><td>Low Hazard[1]</td><td rowspan="2">Low Hazard[1]</td></tr>
<tr><td>0.4 – 0.6</td><td>Significant Hazard; Dangerous to most</td></tr>
<tr><td>0.6 – 0.8</td><td rowspan="3">Extreme Hazard; Dangerous to all</td><td>Moderate Hazard; Dangerous to some[2]</td></tr>
<tr><td>0.8 – 1.2</td><td>Significant Hazard; Dangerous to most[3]</td></tr>
<tr><td>> 1.2</td><td>Extreme Hazard; Dangerous to all</td></tr>
</table>

The definitions of hazard ratings are given as:

- **Low hazard** - stability uncompromised for persons within laboratory testing program at these flows to a maximum depth of 0.5 m for children and 1.2 m for adults and maximum velocity of 3m/s at shallow depths
- **Moderate Hazard; Dangerous to some** - working limit for trained safety workers or experienced and well equipped persons
- **Significant Hazard; Dangerous to most** – upper limit of stability observed during most investigations.

3.4.1.2 Newcastle Flood Planning – Stage 1: Concept Planning (BMT WBM 2009)

This document proposes five (5) flood hazard categories which are a function of velocity and depth. Categories H1 and H2 are considered a low risk to life and property and H3, H4 and H5 are considered a high risk to life and property. **Table 3-4** below defines the hazard categories.

Table 3-4 Hazard ratings for Newcastle flood planning

	H1	H2	H3	H4	H5
Category Description	No significant life risk. Property risk only to items which come in direct contact with floodwaters such as building contents	Low life risk, Able bodied adults can walk safely. Cars can float and precautions must be followed to keep them out of floodwaters	Able bodied adults cannot safely walk. Only large vehicles (trucks) can safely travel.	Major life risk. Light frame buildings (e.g. Houses) can fail structurally.	Extreme life risk. Majority of buildings could fail.
Hydraulic Threshold	V < 0.5m/s; Depth < 0.3m	V < 2m/s; D < 0.8m; V*D < (3.2-4*D)	V < 2m/s; D<2.5m; V*D < 1m2/s	V < 2.5m/s; D < 2.5m/s; V*D < 2.5m2/s	Remainder

3.4.1.3 Managing the Floodplain a Guide to Best Practice in Flood Risk Management in Australia (Disaster Management Australia, 2013)

This disaster management Australia guideline forms the most recent national guideline on Emergency Management in Australia. The guideline outlines four categories low, medium, high and extreme. This guideline also considers the safe wading depths for adults and children, evacuation problems, and warning time. However, warning time is generally only considered relative to the time required to evacuate. i.e. for a Medium Hazard evacuation routes are open 1.5 times as long as evacuation times.

Low:

- No significant evacuation problems
- Children and elderly people could wade to safety with little difficulty
- Flood depths and velocities along evacuation routes are low
- Evacuation is possible by sedan or small vehicle
- Ample time for flood forecasting and flood warning.
- Evacuation routes remain trafficable for at least twice as long as the evacuation time.

Medium:

- Fit adults can wade to safety; children and elderly may have difficulty
- Maximum flood depth and velocities are higher
- Sedan type evacuations possible in early stages, after which four-wheel drive are required.
- Evacuation routes are open 1.5 times as long as evacuation times

High:

- Fit adults have difficulty in wading to safety
- Maximum flood depths (<1m) and velocities (<1.5m/s)
- Evacuation by four wheel drive and trucks only in early stages of flood
- Boats and helicopters may be needed for evacuation
- Evacuation routes remain trafficable only up to max evacuation time.

Extreme:

- Boats and helicopters needed for evacuation
- Wading not an option because of rate of rise, depth and velocity of floodwaters
- Maximum flood depths are over 1m and velocities greater than 1.5m/s.

3.4.1.4 Summary of Literature Review

Table 3-5 provides a summary of the flood hazard criteria from the literature review. The literature review indicates that the definition of flood hazard is strongly linked to the stability of adults, children and vehicles. The review also suggests that the definition of flood hazard is generally more conservative than that of the NSW Manual's preliminary flood hazard where a low flood hazard could be defined by depths of less than 0.4 m, velocities of up to 2 m/s and velocity depth products in the order of 0.7m^3/s.

Table 3-5 Summary of Flood Hazard Criteria – Literature Review

Flood Hazard Category	Project 10 (AR&R, 2013)	Newcastle Flood Planning: Stage 1	Emergency Management Handbook (2013)
Low	Stability uncompromised for persons to max depth of 0.5m for children and 1.2m for adults and max velocity of 3m/s at shallow depths. V*D product of 0 m^2/s to 0.4 m^2/s children and 0.6 m^2/s for adults	H1 = V*D < 0.15 m^2/s V < 0.5m/s; Depth < 0.3m No significant life risk. Property risk only to items which come in direct contact with floodwaters such as building contents	Depth < 0.3m Velocity < 0.4m/s Ample time for flood forecasting and flood warning. Evacuation routes remain trafficable for at least twice as long as the evacuation time.
Medium	Working limit for trained safety workers of experienced and well equipped persons. V*D 0.6 m^2/s to 0.8 m^2/s	H2 V< 3.2 - (4*D) V <2m/s; D<0.8m; V*D < (3.2 m^2/s - 4*D) Low life risk, Able bodied adults can walk safely. Cars can float and precautions must be followed to keep them out of floodwaters	Depth < 0.6m Velocity < 0.8m/s Velocity Depth <0.25 m^2/s Evacuation routes are open 1.5 times as long as evacuation times
High	Upper limit of stability observed during most investigations. V*D of 0.8 m^2/s to 1.2 m^2/s	H3 (VD<1 m^2/s) V < 2m/s; D < 2.5m; VD < 1 m2/s Able bodied adults cannot safely walk. Only large vehicles (trucks) can safely travel.	Depth < 1.2m Velocity < 1.5m/s Velocity Depth < 0.7 m^2/s Evacuation routes remain trafficable only up to max evacuation time.
Extreme	Dangerous to all – V*D >1.2 m^2/s	H4 (VD<2.5 m^2/s) & H5 (VD>2.5 m^2/s) V<2m/s; D<2.5m; V*D<2.5 m^2/s and above Major life risk. Light frame buildings (e.g. Houses) can fail structurally. Extreme life risk. & Majority of buildings could fail. Major life risk. Light frame buildings (e.g. Houses) can fail structurally. Extreme life risk. & Majority of buildings could fail.	Depth >1.2m Velocity >1.5m/s Velocity Depth >0.7 m^2/s

3.4.2 Hazard Categories for Tenterfield

In consideration of the flood behaviour in Tenterfield and the accepted literature on flood hazard, the categories outlined in **Table 3-6** have been derived. These categories are based on modelled flood extents in Tenterfield and the depth and velocity of floodwaters (preliminary flood hazard) with consideration of the rate of rise. The rate of rise will be different for every event, but it is recognised that the short duration flooding expected in Tenterfield (around six hours critical duration based on catchment size) will mean that the criteria should be more conservative than would be appropriate for an area with longer warning times.

Table 3-6 Proposed flood hazard categories for Tenterfield

Category	Definition	Development
High	Within the 10% AEP extent or preliminary flood hazard is high or medium in 1 % AEP event	Prohibited use
Medium	Within the 1 % AEP extent or preliminary flood hazard is medium or high in 0.05 % AEP event	No sensitive developments. Developments must be 0.5 m above the 1% AEP flood level.
Low	Within the 0.05 % AEP event	No emergency services. Developments must be 0.5 m above the 1% AEP flood level.
Very Low	Within the PMF extent	Consider whether emergency services should be located in this zone.

A flood hazard classification of 'High' is considered appropriate for locations that are flooded regularly (within the 10 % AEP extent) or experience high or medium preliminary hazard in the 1 % AEP event. A preliminary hazard of medium has been selected as a threshold in consideration of the short warning times and the indication in literature (AR&R Project 10) that medium hazard areas can be significantly more hazardous to children and the elderly. It is recommended that development other than parks and fields be prohibited in these areas.

A flood hazard classification of 'Medium' is considered appropriate for locations that are flooded in the 1% AEP event or that experience high or medium preliminary flood hazard in a 0.05 % AEP event. These areas are relatively unlikely to experience flooding that would be dangerous to able bodied children or adults, but sensitive developments such as childcare facilities and retirement homes should be prohibited. All buildings should be constructed with floor levels 0.5 m above the Flood Planning Level in these areas.

Any further areas likely to be flooded in a 0.05 % AEP event were assigned a Hazard Category of 'Low'. These areas may experience flooding, but it is unlikely that it will be dangerous. It is recommended that emergency services be located outside of these areas. All buildings should be constructed with floor levels 0.5 m above the Flood Planning Level in these areas.

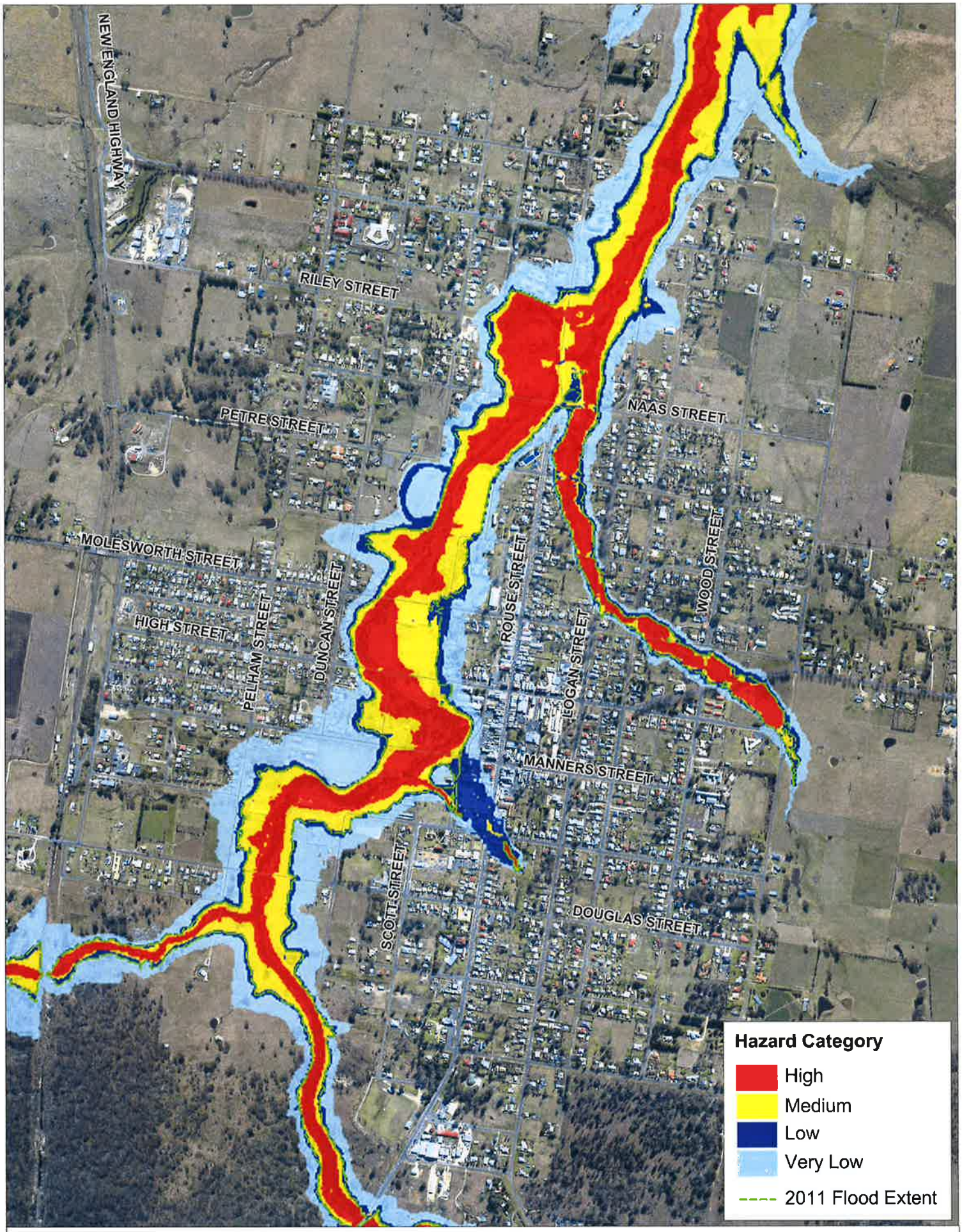
Consideration should be given to developing emergency services facilities outside of the PMF extent. The area within the PMF extent but outside the 0.05 % AEP extent has been classified as 'Very Low' hazard.

It is noted that these categories are relatively conservative. For example, an area with medium flood hazard in the 1% AEP event is given a rating of 'High' for flood hazard. This is considered appropriate in consideration of the short warning times and fast rates of rise likely to be experienced in Tenterfield.

In addition, during design flood events up to the 1 % AEP and the modelled 2011 event, floodwater remains relatively contained within Tenterfield Creek with only a small number of existing properties being affected. Therefore, it is not expected that the proposed flood hazard categories will unduly limit development in Tenterfield. It is noted that January 2011 flood event is approximately 1 m higher than the 1% AEP flood level and approximately 300 mm below the 0.05 % AEP flood event.

Table 3-7 outlines the number of properties within each hazard zone based on the categories discussed. Residential, commercial and emergency services buildings were located based on aerial imagery and prior knowledge of the town. Heritage properties were defined based on the spatial dataset provided by Council. Most of the flood-prone heritage areas are parklands with buildings such as rotundas and other Council infrastructure. However, there are also heritage areas encompassing buildings such as Tenterfield High School; residences on Manners Street, Molesworth Street and Martin Street; Tenterfield Courthouse and Tenterfield Police Station.

The flood hazard categories are mapped in **Figure 3-6**.



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Datum: MGA56
Coordinate System: MGA Zone 56

Figure 3-6

Proposed Hazard Categories

Project: Tenterfield Floodplain Risk Management Study

Table 3-7 Properties within defined hazard categories

Hazard	No of Properties Inundated		
	Residential	Commercial	Heritage & Emergency Services *
High	0	3	5
Medium	2	3	0
Low	19	21	7
Very Low	85	17	9
Total	105	42	21

*Note that heritage properties are excluded from the residential and commercial calculations to avoid double counting of heritage properties which also contain residential or commercial buildings

3.4.3 Floodway, Flood Storage and Flood Fringe

The Manual states that "*to achieve effective and responsible floodplain risk management. It is necessary to divide the floodplain into areas that directly reflect, first the impact of development activity on flood behaviour and second the impact of flooding on development and people. The division of flood prone land into these two bases is referred to as hydraulic categories and hazard categories.*"

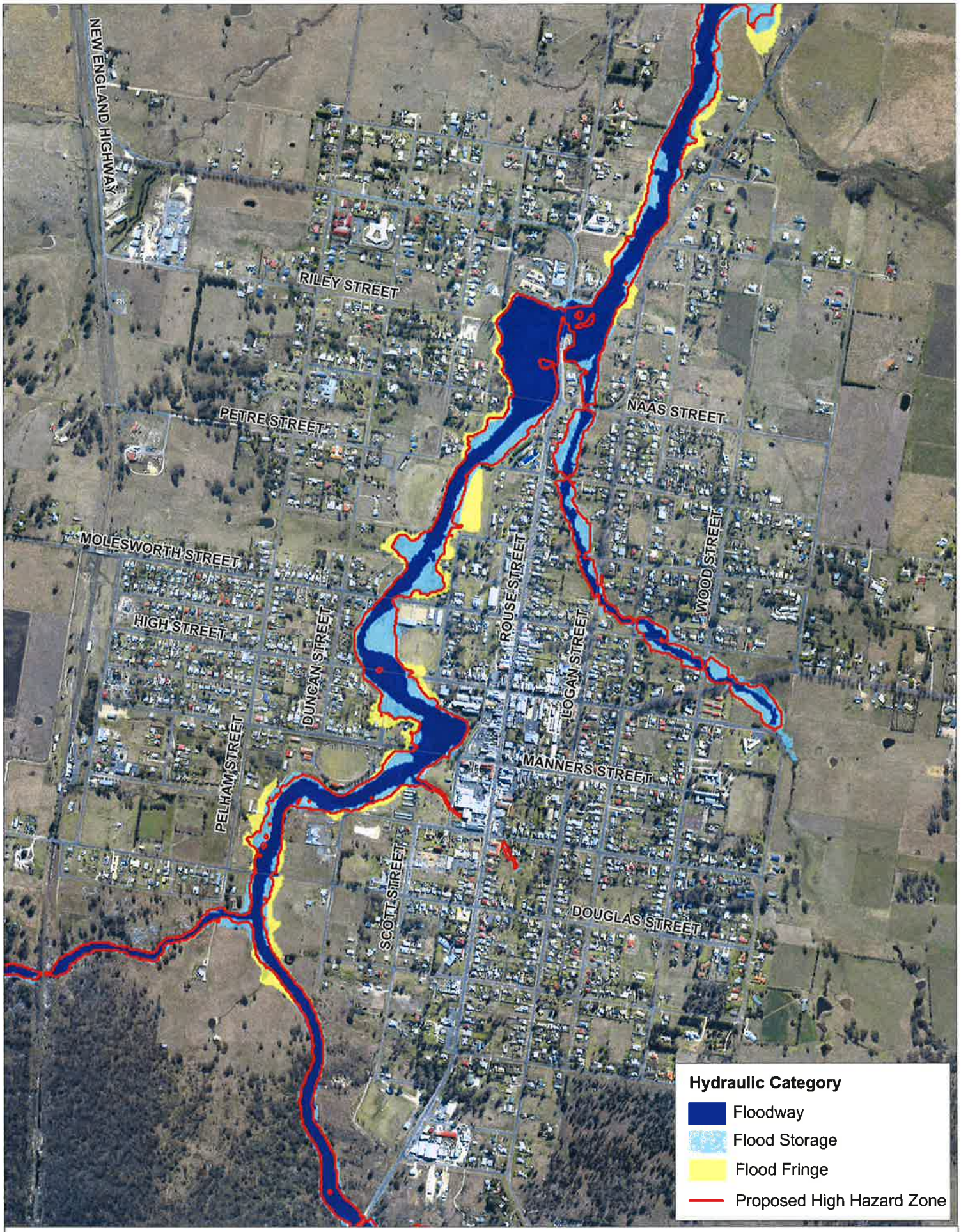
There are three hydraulic categories defined by the Manual being:

- Floodway – areas that are important for the conveyance of floodwaters, typically these pass a significant volume of water that even if partially blocked would result in significant impacts to flood behaviour.
- Flood Storage – areas that are important for temporary storage of floodwaters during an event. If the capacity of the floodwaters is substantially reduced the peak flood level and or discharge downstream may increase.
- Flood Fringe – the remaining areas of land affected by flooding. Development within this area would not have a significant impact on flood behaviour or levels.

The above hydraulic categories were defined by DHI as part of the 2013 flood study. The categories were determined through and iterative process of modelling fill within the low hazard areas whilst restricting flood level increases to 0.1 m and downstream discharge increases to 10%. This method is considered appropriate for informing floodplain management of future development. The hydraulic categories for the 1% AEP flood are presented in **Figure 3-7**.

The Manual also classifies the hydraulic categories as low or high hazard, allowing for a potential 6 categories. Low hazard is based on the ability of adults to wade to safety and vehicle access via a truck. Based on the preliminary flood hazard classification for Tenterfield it is recommended that the areas of Floodway and Flood Storage are classified as high hazard and Flood Fringe as low hazard.

It is noted that the hydraulic categories are not intended to be used for assessing individual development but to support future land use planning and for broader consideration in this Tenterfield FRMS.



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Datum: MGA56
Coordinate System: MGA Zone 56

Figure 3-7

Hydraulic Categories, 1% AEP Event

Project: Tenterfield Floodplain Risk Management Study

3.4.4 Climate Change

Climate change may affect rainfall intensity as warmer atmosphere can hold more water vapour, and hence produce heavier precipitation. Also, changing the temperature patterns across the globe means that the wind patterns (the circulation) will change with potential to impact on rainfall temporal patterns and intensity. To accurately estimate the potential impacts of climate change on rainfall intensity in a particular locality climate change forecast modelling would need to be undertaken.

In lieu of any climate change modelling, the degree to which climate change may impact on rainfall can be approximated by the theoretical maximum amount in water held in the atmosphere per degree of temperature (8%). This approach has been adopted in a number of studies in Australia and New Zealand and was considered appropriate as an indicative assessment for this purpose.

Annual mean and summer temperature increases were obtained from the Climate Change in Australia website (CSIRO, 2007) where climate change projections based on the 4th IPCC Assessment Report modelling were used. Figures from this website indicated that the temperature in this region may increase between 1°C (10th percentile estimation) and 3°C (90th percentile) by 2050, refer to **Figure 3-8**. Therefore, increases in rainfall intensity over this same period may be in the order of 8% to 24%. This assessment is supported by the CSIRO's projections for average rainfall which are predicted to increase by up to 20 to 30% over the same period and are presented in **Figure 3-8**.

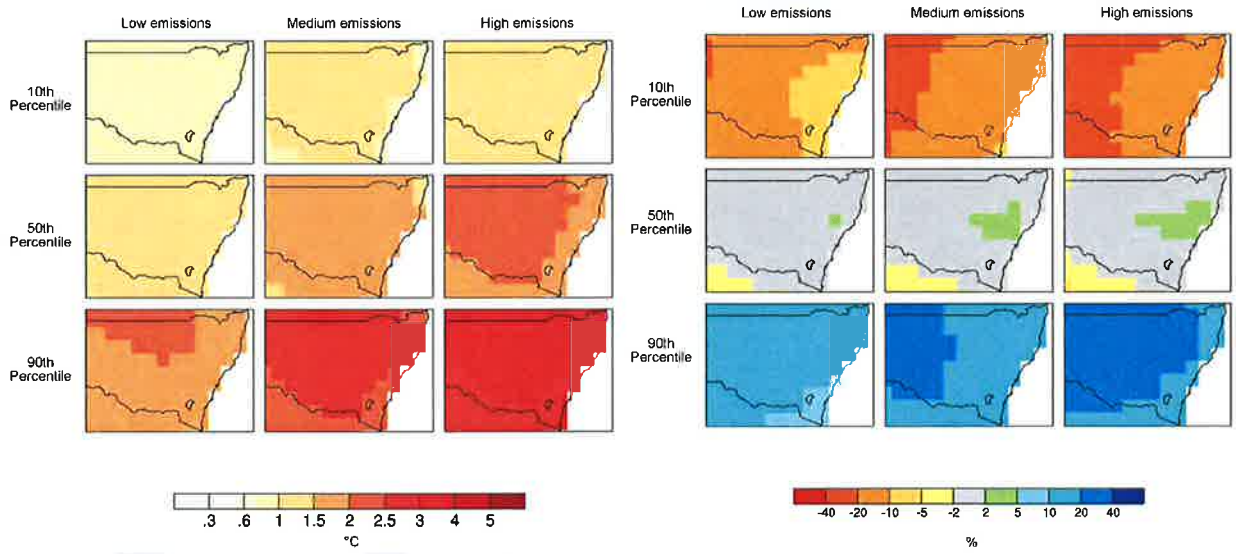

Figure 3-8 NSW Temperature (left) and Rainfall (right) Climate Change Projections – Summer 2050 (CSIRO, 2007)

Modelling of climate change was outside the scope of this study. However, while climate change was not assessed by the 2013 DHI Flood Study a sensitivity analysis was undertaken on the peak flows. The analysis investigated the sensitivity of increasing peak flows. Given that peak flows are influenced by rainfall, this assessment was considered an acceptable proxy for the assessment of climate change impacts. The analysis found that increasing the peak flow for the 1% AEP by 20% resulted in only minimal increases in flood levels in the order of 150 mm. This is illustrated in **Figure 3-9**. It is therefore expected that the future climate risk is unlikely to significantly change the flood risk for Tenterfield.

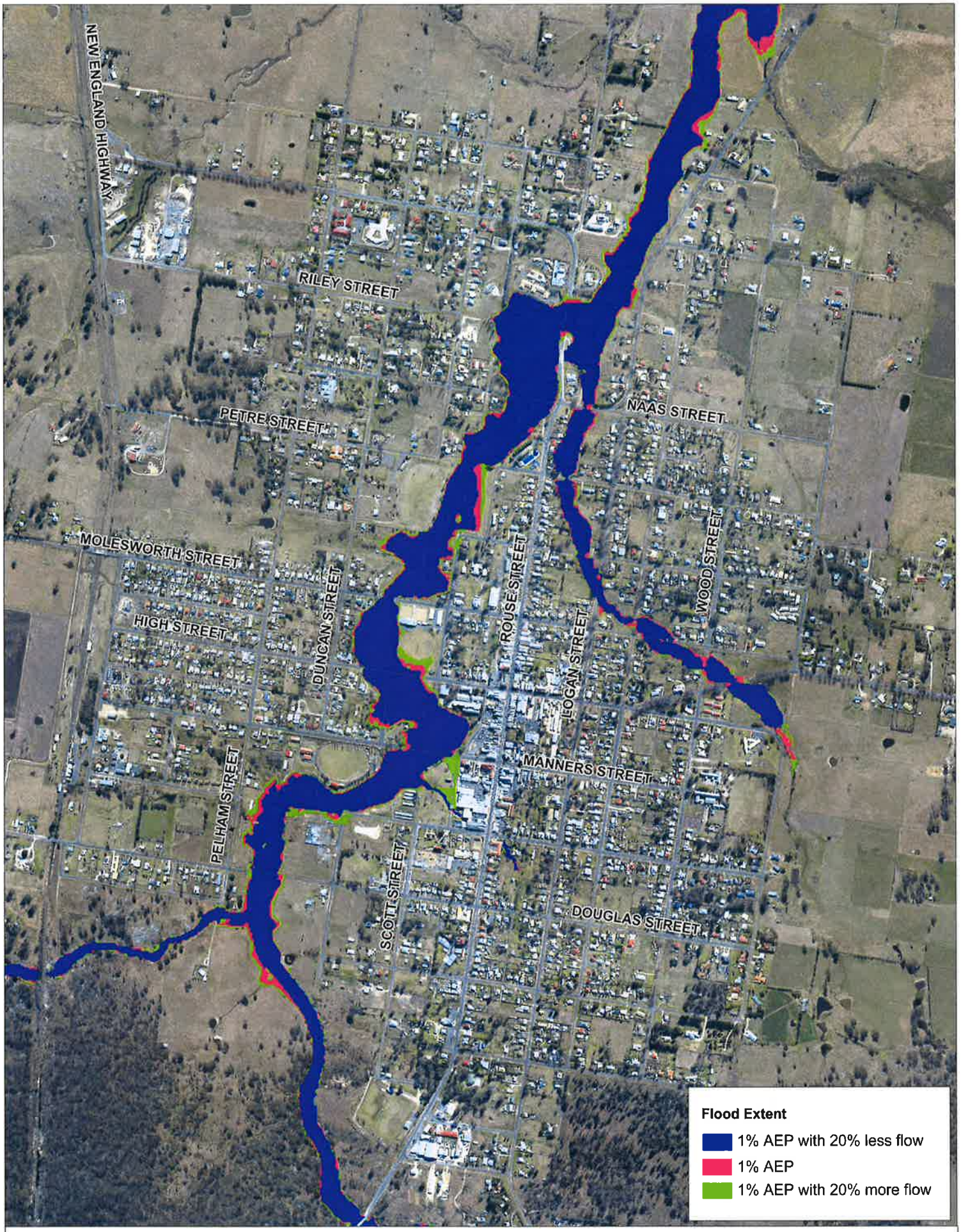

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Figure 3-9

Model Sensitivity to Flow, 1% AEP Event

Project: Tenterfield Floodplain Risk Management Study

4. Flood Risk Assessment

4.1 What is Flood Risk Assessment

Flood risk is defined by the Manual as "*the potential danger to personal safety and potential damage to property resulting from flooding*" (OEH 2005). The flood risk is separated into three types, these are defined as:

- **Existing flood risk**: the risk a community is exposed to as a result of its location on the floodplain.
- **Future flood risk**: the risk a community may be exposed to as a result of new development on the floodplain.
- **Continuing flood risk**: the risk a community is exposed to after floodplain risk management measures have been implemented.

A FRMS must address all three types of flood risk.

4.2 Existing Flood Risk to People

The safety of people is considered the most important element of a FRMS. In general the existing flood risk for Tenterfield is considered low due to the low probability of an event occurring that would result in significant inundation of property and that high hazard floodwaters are relatively well confined to existing areas of parkland.

Up until the January 2011 floods, flood deaths in Australia were predominately related to car usage. A study undertaken in 2010 of all 73 reported flood deaths in Australia (1997 to 2008) found the following:

- 50% of deaths related to car usage
- 25% attributable to *"inappropriate or high-risk behaviour during floods"*
- 16% associated with attempts to swim / wade across flooded waterways
- 9% unknown
- ***None were in house at time of flood***

Tragically, this statistic changed in January 2011, with over 70% the people that lost their lives in the Lockyer Valley located in their home (SKM, 2012). The findings of the Lockyer Valley Floodplain Risk Management Plan indicated that the three factors that contributed to this were: significant velocity depth products flash flooding (warning time was less than 2 hours) and a significant change in flood behaviour with rare and extreme flood events. (SKM, 2012)

Tenterfield experiences two of the key factors experienced by the Lockyer Valley in that: the area has a significant physical flood hazard in the speed and depth of flood waters; and relatively little warning time. Due to this the 0.05% AEP was selected to inform the flood risk categorisation for Tenterfield. This categorisation is more conservative than typically adopted, however is considered appropriate given the minimal warning time for the town.

Importantly for Tenterfield, the third and critical factor that exists in the Lockyer Valley is not present in Tenterfield. In Tenterfield the creek profile is such that there is no significant change in flood behaviour with increased flows. That is the risk profile increases gradually with increasing flood size. This is illustrated in **Figure 4-1** where the depth of flooding above floor for existing properties is generally less than 0.2 m for the 0.05% AEP.

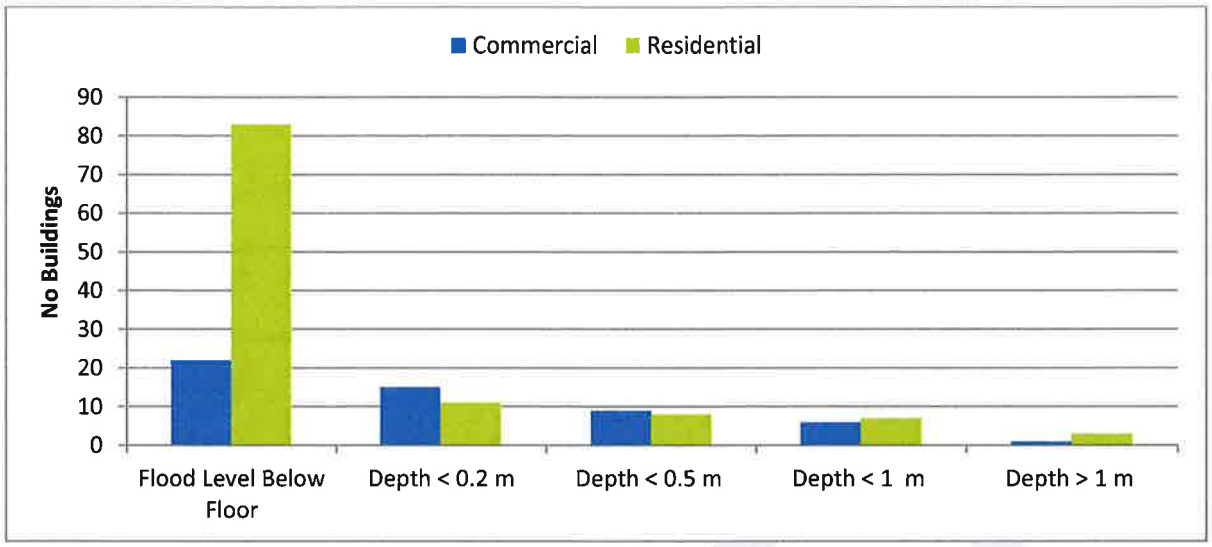


Figure 4-1 Above floor flood depths for the 0.05% AEP Flood event

There are only two options to manage the risks of flooding on people; these being safety in place or evacuation to higher ground. Fortunately for Tenterfield the relatively narrow flood corridor means that the community can easily evacuate to higher ground on both sides of the floodplain. Typically, access to flood free high ground would be within 100 to 200 m of most residences.

It is therefore considered that the largest threat to the safety of people from flooding in Tenterfield remains the threat to people attempting to drive on flooded roads or wade through floodwaters. As such it is recommended that a key element of flood risk reduction measures in Tenterfield must be to maintain and where possible improve existing controls that prevent people attempting to cross flooded roads.

4.2.1 Community Vulnerability

A number of demographic factors are considered to determine the vulnerability of a community to flooding. These generally include the following:

- **Dwelling tenure** – renters are sometimes assumed to have less knowledge of the area due to a transient lifestyle and can therefore be more vulnerable than homeowners.
- **Age** – people over the age of 65 are often assumed to be more vulnerable to flooding than others due to the physical forces of the floodwater and ability to wade to safety.
- **Culturally and Linguistically Diverse (CALD) communities** – in some cases, people in CALD communities are assumed to be more vulnerable to flooding due to difficulties communicating with authorities or receiving warnings in English.
- **Vehicles** – people who do not have access to a vehicle may find it more difficult to evacuate during flood events. However, it is noted that this is unlikely to be a significant factor in Tenterfield with short distances to high ground evacuation on foot is practical.
- **Income** – low income earners (household income of less than $600 per week) are often assumed to be more vulnerable to flood risk than others because they may have less ability to recover quickly from the consequences of flooding.

The 2011 census considered all of these aspects. A comparison between the relevant demographic statistics for Tenterfield, New South Wales and Australia is shown in **Table 4-1**.

Table 4-1 Demographic statistics relevant to vulnerability to flooding

Category	Tenterfield	New South Wales	Australia
Properties rented	23.4 %	30.1 %	29.6 %
People aged > 65	21.0 %	14.7 %	14.0 %
Language/s other than English spoken at home	7.8 %	27.5 %	23.2 %
Dwellings with no vehicle	7.9 %	10.4 %	8.6 %
Households income < $600/week	43.7 %	24.2 %	23.7 %

While Tenterfield was found to be significantly above the state and national averages for two vulnerability factors (age over 65 and household income less than $600 per week), it was below the state and national averages for the other three factors. Overall, it is believed that Tenterfield's flood vulnerability is likely to be reasonably close to the average for communities in New South Wales.

4.3 Existing Flood Risk to Property

The main objective of the flood damages assessment is to establish the 'baseline' socio-economic costs of flooding which can then be used to help quantify the potential benefits of various mitigation measures. Flood damages comprise of both tangible (financial) and intangible (social and environmental). Furthermore, tangible damages comprise of both direct and indirect costs. The components of flood damage are illustrated in **Figure 4-2**.

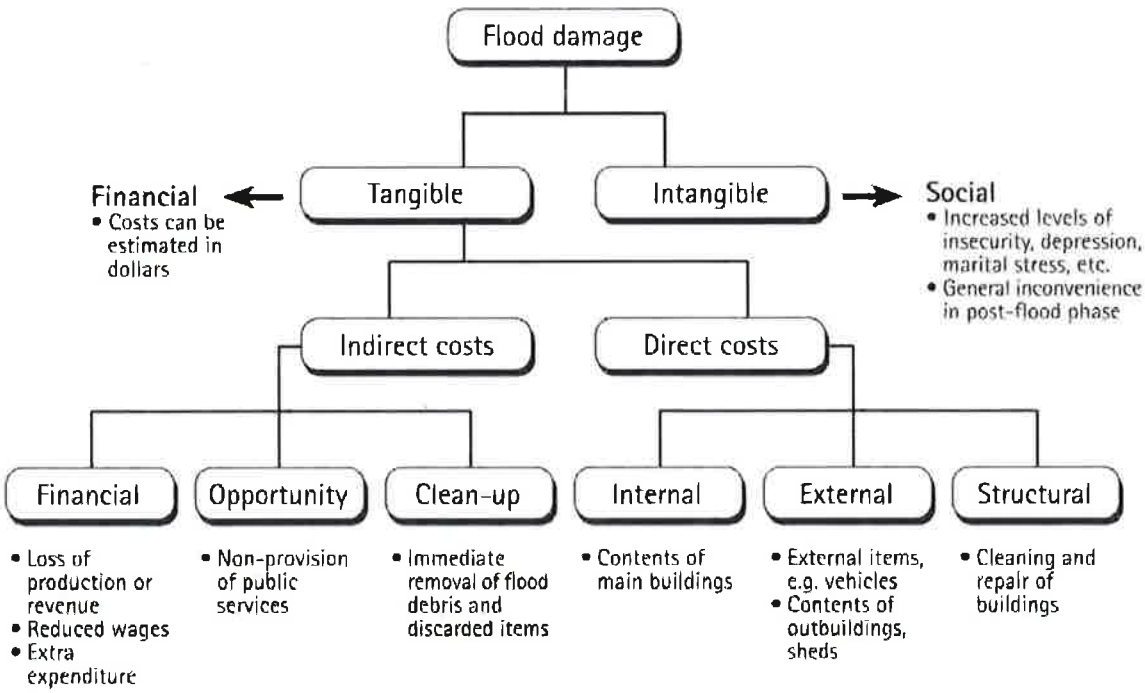


Figure 4-2 Components of Flood Damage (DNRM, 2002)

The tangible flood damages for Tenterfield have been estimated for residential properties using the stage damages curves sourced from the then Department of Environment and Climate Change 2007. These stage damages curves include an estimation of direct and indirect flood damages. Commercial and infrastructure damages were estimated from the Commercial Damage Curves produced by the then QLD Department of Natural Resources and Mines (DNRM) which were adapted from those developed for ANUFLOOD. These

curves have been adopted for a number of other flood studies in NSW and were approved by OEH for use in this FRMS. The indirect damages associated with commercial damages are often high and have been estimated at 55% of the direct damages as recommended by DNRM. This was also the approach adopted in the Tweed Floodplain Risk Management Study (OEH, *personal communication*. 2014).

It is noted that the flood damages for Tenterfield are relatively minor when compared to other floodplains in NSW. This observation will be important in the consideration of appropriate flood mitigation options, which are typically based on a cost benefit assessment with the tangible flood damages as the key component.

4.3.1 Properties Affected by Flooding

Relatively few properties are affected by flooding in Tenterfield except in rare events. **Table 4-2** outlines the number of commercial and residential properties subjected to damages during modelled flood events. Note that residential properties can be subject to flood damages (see **Section 4.3.2**) without inundation of the floor level according to the calculation method used. The number of houses inundated above floor level is shown in brackets. The number of road sections submerged by floodwaters is also included.

Table 4-2 Properties and roads affected by flooding in modelled events

Flood Event	Residential Properties Flooded	Non-Residential Properties Flooded	Road closures
10% AEP	0 (0)	1	9
5% AEP	0 (0)	3	11
2% AEP	1 (0)	3	11
1% AEP	3 (3)	3	14
2011 event^	13 (12)	11	18
0.05%	24 (23)	19	19
PMF	105 (105)	42	37

*Brackets indicate number of properties flooded above floor level

^ The AEP of the January 2011 event was estimated at 0.14% for the purposes of this assessment

4.3.2 Damages to Residential Properties

Tangible flood damages to residential properties were calculated in accordance with the method outlined by the Department of Environment and Heritage. Flood-prone residences in Tenterfield were identified using GIS software and the floor level height above ground was estimated using publically available street view imagery. The digital elevation model and flood modelling results could then be used to estimate the depth of flooding above ground and above flood level for each property in each modelled flood event. The damages curve as provided by the Department of Environment and Heritage (see **Appendix E**) was used to estimate the costs associated with flooding at each property.

Table 4-3 shows the results of the flood damages assessment of residential properties.

Table 4-3 Residential damages

Flood Event	Average Damages per Flooded Property ($)	Total Tangible Damages ($)
10% AEP	0	0
5% AEP	0	0
2% AEP	28,000	28,000
1% AEP	61,400	184,200
2011 event*	73,900	960,400
0.05%	73,300^	1,759,500
PMF	92,800	9,745,600

Flood Event	Average Damages per Flooded Property ($)	Total Tangible Damages ($)
Average Annual Damages	**$10,500**	

* The AEP of the January 2011 event was estimated at 0.14% for the purposes of this assessment

^average damages per property decrease from the 2011 event as more properties are flooded with a lower average damage.

4.3.3 Damages to Non-Residential Properties

The non-residential properties in Tenterfield were assessed in two categories: commercial properties and community infrastructure. Two public toilets, a playground, the police station, the fire station and a bore were classified as community infrastructure. All other properties were classified as commercial infrastructure.

Direct flood damages to commercial properties and community infrastructure were calculated using the stage damages curves outlined in the 1992 ANUFlood Guidelines converted to 2014 Australian dollars. However, some structures were identified that would be expected to have lower flood damages than represented by the curves. Therefore, an additional value class was created for the playground and public toilets. The direct damages were multiplied by 1.55 to account for indirect damages as per the DNRM Guidelines to give tangible damages. For more information, see **Appendix E**.

Table 4-4 shows the tangible flood damages calculated for commercial properties.

Table 4-4 Commercial damages

Flood Event	Average Damages per Flooded Property ($)	Total Tangible Damages ($)
10% AEP	0	0
5% AEP	12,000	12,000
2% AEP	30,000	30,000
1% AEP	55,700	55,700
2011 event*	65,500	524,100
0.05%	91,700	1,375,700
PMF	228,100	7,755,300
Average Annual Damages	**$7,000**	

* The AEP of the January 2011 event was estimated at 0.14% for the purposes of this assessment

Table 4-5 outlines the tangible flood damages calculated for community infrastructure. The damages were dominated by the bore on High Street near the cricket ground, which is flooded in a 5% AEP event and costs approximately $20 000 to repair following inundation. The flood damages are provided for community infrastructure excluding the bore along with the total flood damages (including bore).

Table 4-5 Community infrastructure damages

Flood Event	Damages Excluding Bore ($)	Total Tangible Damages ($)
10% AEP	700	700
5% AEP	1,000	32,000
2% AEP	1,200	32,200
1% AEP	1,300	32,300
2011 event*	3,000	34,000
0.05%	30,300	61,300
PMF	212,700	243,700
Average Annual Damage	**$200**	**$2,500**

* The AEP of the January 2011 event was estimated at 0.14% for the purposes of this assessment

4.3.4 Damages to the Transport Network

Several local roads in Tenterfield are prone to inundation and in large events the western side of the town can become cut-off from the eastern side. Damages to roads were calculated based on the cost per kilometre of inundated road provided in the 2002 NRM Guidelines. Roads are classified as either major or minor, with major roads having higher flood damages. The values provided in the NRM Guidelines were annualised to 2014 Australian dollars.

Indirect damages to roads were not considered in this assessment. **Table 4-6** shows the direct damages calculated for roads in Tenterfield.

Table 4-6 Road damages

Flood Event	Direct Damages (S)
10% AEP	19,700
5% AEP	30,600
2% AEP	35,300
1% AEP	43,100
2011 event*	99,900
0.05%	104,800
PMF	298,500
Average Annual Damage	**$3,400**

* The AEP of the January 2011 event was estimated at 0.14% for the purposes of this assessment

4.3.5 Summary of Flood Damages

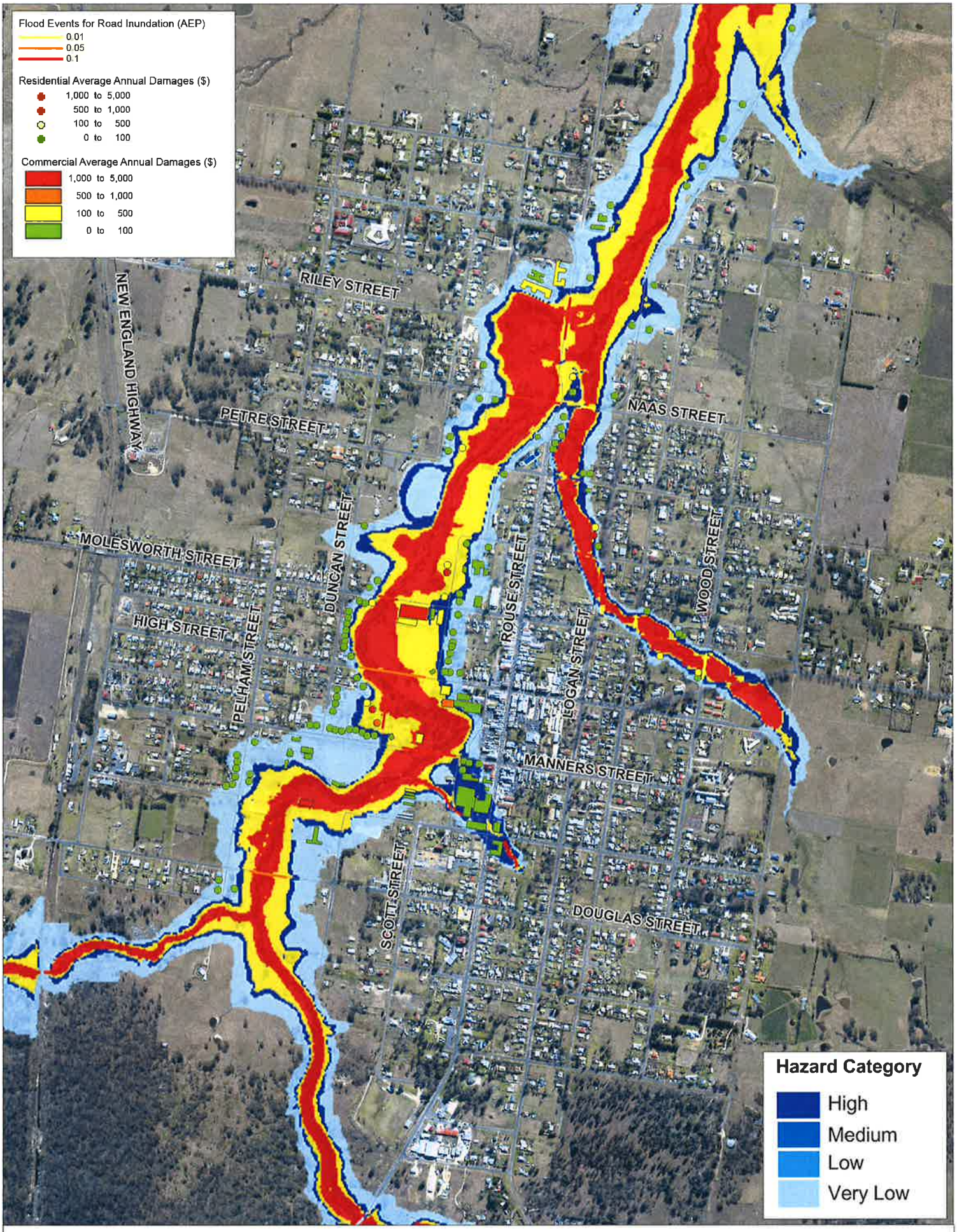
The total tangible Average Annual Damages resulting from flooding in Tenterfield were calculated to be approximately AU$23 400. These calculations did not include intangible damages or indirect damages for roads. **Table 4-7** presents the flood damage results for Tenterfield. **Figure 4-4** illustrates the breakdown of flood damages related to different types of infrastructure and indicates that the flood damages are dominated by residential damages. **Figure 4-5** outlines the change in flood damages and inundated properties with flood events of decreasing likelihood.

Table 4-7 Summary of total flood damages for Tenterfield

Flood Event	Residential Damages ($)	Commercial Damages ($)	Community Infrastructure Damages ($)	Road Damages ($)	Total Damages ($)
10% AEP	0	0	700	19,700	20,500
5% AEP	0	120,00	32,000	30,600	74,600
2% AEP	28,000	30,000	32,200	35,300	125,000
1% AEP	184,000	557,00	32,300	43,100	315,000
2011 event	960,000	524,000	34,000	99,900	1,620,000
0.05% AEP	176,0000	1,380,000	61,300	104,800	3,300,000
PMF	9,750,000	7,760,000	2,44,000	298,500	18,000,000
Average Annual Damages	**$10,500**	**$7,000**	**$2,500**	**$3,400**	**$23,400**

* The AEP of the January 2011 event was estimated at 0.14% for the purposes of this assessment

The flood damages relative to the hazard categorisation is illustrated in **Figure 4-3**.



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Coordinate System: MGA Zone 56

Figure 4-3

Proposed Hazard Categories and Estimated Flood Damages

Project: Tenterfield Floodplain Risk Management Study

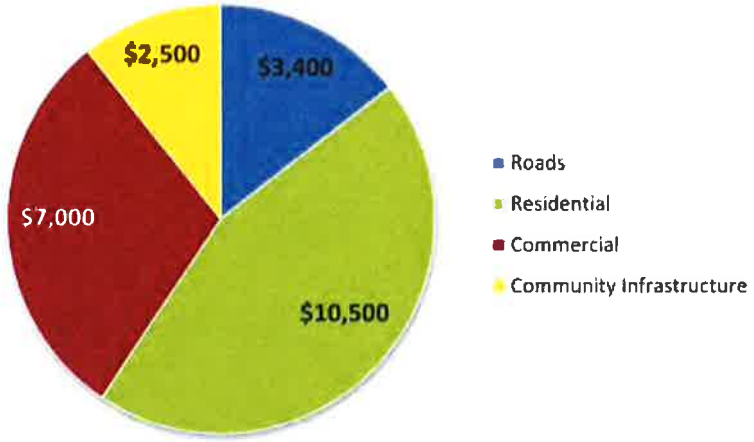


Figure 4-4 Distribution of flood damages in Tenterfield (AAD)

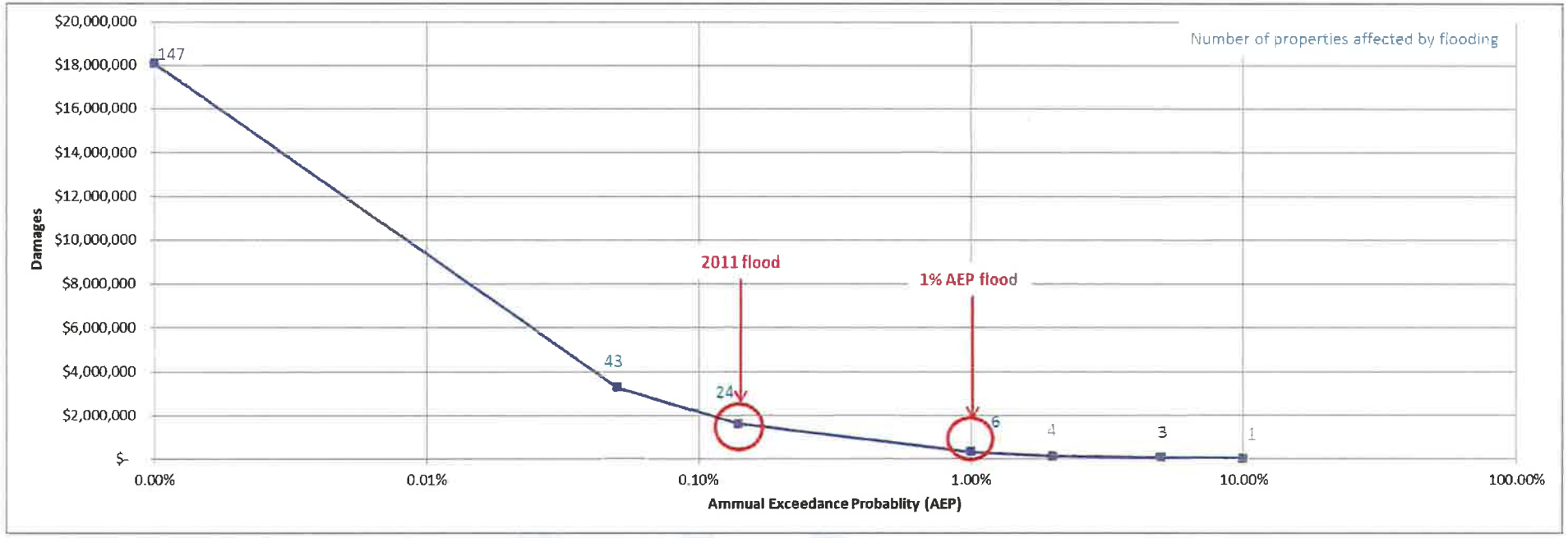


Figure 4-5 Summary of flood damages in Tenterfield

It is noted that the flood damages for Tenterfield are low when compared to other floodplains in NSW. This is illustrated in **Figure 4-6**. This observation will be important in the consideration of appropriate flood mitigation options, which are typically based on a cost benefit assessment for which the tangible flood damages are the key component. Therefore, the assessment of appropriate flood mitigation options for Tenterfield has relied on input from the Floodplain Risk Management Committee (FRMC) and community to aid in the estimate of other costs and benefits not captured in this damages assessment. This is discussed in **Section 7**.

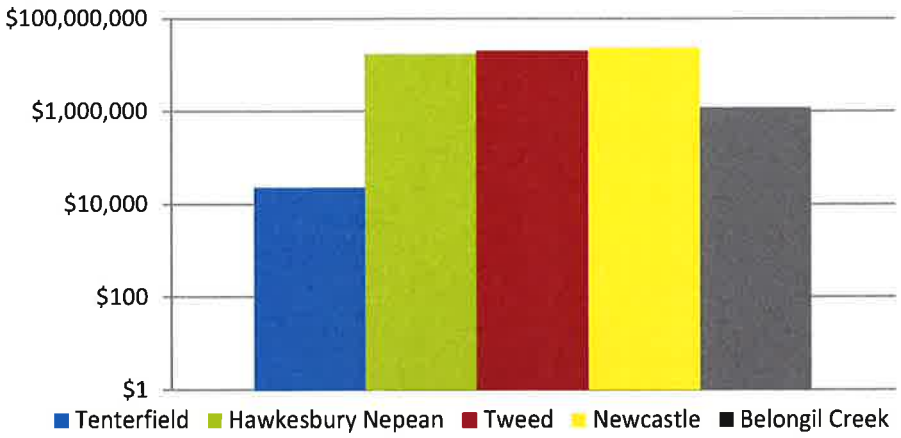


Figure 4-6 Comparison of Flood Damages Relative to Other Floodplains in NSW

4.4 Future Flood Risk

The future flood risk refers to the risk associated with future changes to the floodplain. The assessment of future flood risk in Tenterfield should consider the implications of both the potential change in flood behaviour due to increased rainfall intensity and/ or frequency due to climate change and the potential for development of the floodplain.

As discussed in **Section 3.4.4** climate change is not expected to result in significant changes to flood behaviour and hazard in the medium term horizon (2050).

Tenterfield's current land use planning was reviewed as part of this FRMS and discussed with Council's planning officers. At present all of Tenterfield town is zoned as Village meaning it is appropriate for future development subject to the conditions of the Tenterfield Local Environment Plan 2013 (LEP). Discussions with Council's planning officers indicate that the current development pressures in Tenterfield are minor and there is no shortage of available land for development.

As part of the study a very high level assessment of the potential for future flood risk due to development was undertaken. This assessment does not represent a real development scenario but was undertaken to provide an indication of the likely upper bound of potential future flood damages associated with development. The assessment applied a conservative assumption of locating a residential property in the centre of all vacant blocks within the extent of flood prone land. Flood damages were then reassessed assuming that all of these residential blocks were developed to the current FPL (1% AEP with 0.5 m freeboard). The assessment indicated that AAD could increase from $23,800 to $80,000. While this is a factor of four increase on the existing damages it is orders of magnitude lower than the existing and future flood damages for other floodplains in Australia. This assessment is considered highly conservative due to the lack of development pressures in Tenterfield and the availability of suitable land outside the PMF, actual future flood damages are likely to be much less than this estimate.

The current land use planning controls that apply to existing and future flood risk are discussed in **Section 4.5.1**. The consideration for changes to existing planning guidelines is discussed further in **Section 7.1**

4.5 Assessment of Existing Floodplain Risk Management Controls

At present Flooding in Tenterfield Creek is managed through the following controls:

- Land use Planning
- Flood Prediction and Warning
- Disaster Management and Response
- Tenterfield Creek Dam

With the exception of the Tenterfield Creek Dam the effectiveness of these existing controls were reviewed as part of this study. The review of operation of Tenterfield Creek Dam was outside the scope of this assessment. Tenterfield Creek Dam is currently being reviewed by Council with assistance from the NSW Department of Public Works and Council is currently considering options to upgrade the dam to improve dam safety.

4.5.1 Planning Guidelines

Tenterfield's current land use planning was reviewed as part of this Flood Risk Management Study and discussed with Council's planning officers. At present all of Tenterfield town is zoned as Village meaning it is appropriate for future development subject to the conditions of the Tenterfield Local Environment Plan 2013 (LEP). A copy of Clause 6.2 of the LEP is provided in **Appendix C**.

Under Clause 6.2 of the LEP the development must satisfy a number of conditions related to the development of flood prone land. The objectives of the clause are:

a) to minimise the flood risk to life and property associated with the use of land,
b) to allow development on land that is compatible with the land's flood hazard, taking into account projected changes as a result of climate change,
c) to avoid significant adverse impacts on flood behaviour and the environment.

Clause 6.2 of the LEP applies to land below the current FPL defined as the 100 year ARI[2] (1% AEP) flood level plus 0.5 m freeboard. That is Council may only restrict residential development on land at or below the FPL. However, a review of the flood hazard categories for Tenterfield indicates that this would capture the entire high hazard zone and the majority of the medium hazard zone. In addition to this the LEP allows Council to apply additional restrictions to development to manage the risks within this area. In particular the LEP states that:

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

a) is compatible with the flood hazard of the land, and
b) is not likely to significantly adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties, and
c) incorporates appropriate measures to manage risk to life from flood, and
d) is not likely to significantly adversely affect the environment or cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses, and
e) is not likely to result in unsustainable social and economic costs to the community as a consequence of flooding.

As part of the Flood Study undertaken by DHI the impact of filling of the floodplain within the 1% AEP was assessed using the flood model. The analysis indicated areas that if filled would result in adverse impacts to flood levels and velocities. This area was reviewed against the flood hazard categories defined in this Flood Risk Management Study. The review found that these areas overlap with the areas of high flood hazard. Therefore it is considered that under the requirements of the current LEP and FPL it is unlikely that any additional development would be permitted to occur in high hazard areas under the current planning controls.

[2] The NSW floodplain development manual refers to the chance of a flood of a given or larger size occurring in any one year as an Annual Exceedance Probability (AEP). This probability is usually expressed as a percentage to illustrate that **there is a chance that the event may occur in any given year**. While the 100 year Annual Recurrence Interval (ARI) has the same statistical probability of occurrence the industry has moved away from the ARI terminology as recurrence interval incorrectly implied that the probability of occurrence of an event was related to the time since the last event. With the 2010 updates to Australian Rainfall and Runoff, the AEP terminology is now considered the industry standard. Therefore, where documentation refers to a 100 year ARI this should be taken to be the same as the 1% AEP.

In January 2007 the NSW Department of Planning released a guideline documenting changes to the environmental planning and assessment regulation 2000 and section 117 Direction on flood prone land. The guideline confirms that unless there are exceptional circumstances councils should adopt the 1% AEP flood as the basis of the FPL for residential development.

However, the guideline does allow for controls to apply to critical infrastructure and for consideration to be given to evacuation routes for vulnerable developments in areas above the 1% AEP flood. The guideline also reports that "*Section 733 of the Local Government Act 1993 (the LG Act) protects councils from liability if they have followed the requirements of the Manual. The Minister has notified that the Guideline should be considered in conjunction with the Manual under section 733(4) and (5) of that Act.*"

It is noted that while Council's LEP provides the legislative context to manage development in accordance with flood risk Council does not have access to GIS data to enable council to easily provide information to developers and the community and to use in the assessment of development applications. Providing this information to Council is a recommendation of this study and further details are presented in **Section 7.2.**

4.5.2 Flood Warning

In January 2011 Council and emergency services monitored the potential flood event through rainfall and water level gauges at Tenterfield Creek Dam. These gauges were used to assist Council in responding to the flood event. In addition to these gauges Council also has a flood warning system that was installed for Dam Safety.

In 2000 Council received funding for the design and installation of a real time flood forecasting and warning system to assist in managing the flood risks associated with the Tenterfield Creek Dam. The system was installed in 2000 complete with:

- Rainfall Gauging Stations (2 in total)
- Water Level Gauging Stations (2 Creek, 1 Dam)
- Electronic Warning Stations (3 in total, 1 also with water level sensing equipment)
- 2 Base Stations (Council Chambers/ Works Depot)
- SCADA software application (configured Master/Slave) – 2 licences
- Repeater Station (Mount McKenzie)
- Annunciator panel (located at the SES HQ)
- Hydrological forecast model

As part of this study; an inspection of the existing monitoring and warning system network was undertaken on July 29, 2014 followed by discussions with representatives from Council. The purpose of the site visit was to ascertain the opportunities for the system to be retrofitted or upgraded to also assist in flood warning for non-dam break scenarios. One of the inspectors managed the design and installation of the flood warning system in 2000 and detailed to Council there understanding of the original intent and purpose of the system.

The current flood warning system was designed to manage dam safety risks. The risks associated with this are outside the scope of this study. However, it is recommended that Council discuss matters relating to the operation of the Flood Warning System with the NSW Dam Safety Committee.

It was also noted during the site visit that the warning sirens associated with the system were not activated during the January 2011 flood event past event. Discussions with council indicated that the current warning sirens were not considered to be particularly effective. The opportunity to improve the effectiveness of the sirens by including a voice message stating the purpose of the warning was discussed with Council and was considered to provide a more effective option. This is discussed further in the assessment of management options in **Section 7.5.1.3**.

4.5.3 Disaster Planning and Response

Despite the January 2011 flood event being the largest event in recent memory, the disaster response was well coordinated and effective. Council and emergency services are well aware of the potential for Tenterfield Creek to split the town as most roads are cut in an event with a frequency greater than 10%. Emergency services respond to this by locating service operations on both sides of the town.

In January 2011, Council were also proactive in closing roads to minimise risks associated with flooded roads. The majority of the areas cut off by flooding have good access during a flood event and can be quickly accessed for road closure purposes. Since January 2011, Boom gates have been fitted to Manners Street and Old Ballandean Road (outside of study area) and will be used to halt the flow of traffic if required.

However, as the January 2011 event was the largest event on record there was some uncertainty with the location and number of properties at risk. This is discussed further in **Section 5** which summarises discussions with key stakeholders. This is also discussed in the recommended measures in **Section 7.3**.

It is also noted that the FRMC identified that providing accurate information to the community during a flood event would be a key issue in the future with a number of rumours circulating in January 2011. In addition to this the FRMC indicated that members' of the public were unsure how to respond after the flood event and more information should be made available to assist in flood recovery.

4.6 Continuing Flood Risk

Continuing flood risk refers to the risk that remains after floodplain risk management measures have been put in place. Typically this risk refers to rare and extreme flood events larger than land use or flood planning controls. As the existing flood damages for Tenterfield are low and the 1% AEP flood is largely contained within parkland the management of continuing flood risk in Tenterfield is a key issue for future floodplain risk management.

5. Community and Stakeholder Consultation

Community and stakeholder consultation is an important component of a Floodplain Risk Management Study and Plan. Whilst the community consultation requirements of the Manual are not explicit they identify the need to base consultation on the specific requirements of the locality. This section outlines the community and stakeholder engagement activities undertaken as part of the Tenterfield FRMS.

5.1 Community and Stakeholder Consultation Program

The primary stakeholder and community consultation activity was engagement with Council, OEH and Community representatives through the FRMC. At the time of writing the committee had met four times with one further meeting scheduled prior to the conclusion of the Study.

The following consultation activities were also undertaken to support the study.

- Review of the questionnaires from the 2011 flood data collection undertaken by DHI on behalf of the SES. This review was used to determine the flood awareness and flood related concerns that residents in the study area possess. The review of this questionnaire is discussed further in **Section 5.2**.
- Consultation with the key stakeholders was undertaken via direct consultation through telephone interviews. The key issues identified through this process are discussed further in **Section 5.3**.
- Preparation of information for three media releases to allow Council to publicise the study via the Council website and/or Council page in the local newspaper. At the time of writing two of these releases had been issued to the community. Council had also issued the flyer advertising the public exhibition of the FRMS to residents along Tenterfield Creek with a letterbox drop to 200 residencies.
- Public exhibitions. A public exhibition of both the draft FRMS and FRMP was undertaken. The public exhibition included a four to six week period over which the community and key stakeholders could view the drafts of the respective studies at Council offices and provide comments to the study team and FRMC. The exhibition periods were supported by a display outlining the key findings and recommendations of the studies. The display was located in Council's administration office at Rouse Street. The FRMS public exhibition was supported by a half day community open session whereby the study consultants were present to discuss the study and key findings. Key issues raised by the community during this period are presented in Section 5.4.
- Establishment of a study email address to facilitate community enquires. This incudes and opportunity for community members to leave their details so that a representative of study team can contact them to discuss their particular queries or concern.

5.2 SES Survey – 2011 Flood Event

The SES conducted a survey following the large flood in 2011 and the results have been made available for this study. For privacy reasons commentary that may identify an individual respondent is not provided. However the following general observations are made from this survey:

- Of the 37 people who responded to the survey, 22 said that they had experienced flooding before.
- Most of the respondents (and all of the respondents from Tenterfield) said that the 2011 flood was the largest flood they had experienced.
- 13 respondents noted the length of the flooding at their property as 12 hours or less, while 12 stated that they experienced flooding over a period of more than 12 hours (sometimes several days).
- Nearly all of the respondents classified flooding on their properties as being riverine or creek flooding.
- Access issues were reported in Tenterfield including inundation of main roads.
- Many residents noted that the access issues were minor, with local roads being cut for 2 – 3 hours.
- None of the respondents in Tenterfield reported any above floor flooding.

The SES has since notified Jacobs that further surveys were undertaken in which three residences reported above floor flooding. While these additional survey responses were not available for this study, photographs and evidence provided by the SES have been reviewed.

5.3 Discussions with Key Stakeholders

As part of the Tenterfield FRMS, the following key stakeholders were consulted:

- Tenterfield Shire Council Engineers and Planners (Council)
- Floodplain Risk Management Committee (FRMC)
- Fire and Rescue New South Wales (NSW)
- The local State Emergency Service (SES)
- Tenterfield Hospital
- Tenterfield Police
- The Bureau of Meteorology (BoM)
- The Rural Fire Service
- The Catchment Management Authority (CMA)

5.3.1 Input from Tenterfield Shire Council

Tenterfield Shire Council represents a key stakeholder in the FRMS as Council will be responsible for the implementation and funding of any floodplain mitigation measures. A number of discussions were held with Council officers from the planning and engineering departments.

At present Council do not have GIS access to the results of the flood study to assist in assessment of developments and provision of flood information to the community. Council identified that access to these GIS layers as well as those produced by the flood risk study would assist in application of the current LEP. Council also identified the potential to include this information in web mapping which is currently being investigated by Council.

5.3.2 Input from Floodplain Risk Management Committee

The FRMC is the key stakeholder in the FRMS with representatives from Council, the community and local business'. Key issues identified by the committee at the commencement of the project included:

- The uncertainty associated with the Flood Study due to the lack of data for calibration particularly rainfall. The committee suggested that the opportunity to install another rainfall gauge and or improve flood warning should be investigated.
- The flood study recommended that blockage of bridges be considered as flood behaviour was strongly influenced by blockage, need to understand if this will impact on management options.
- Climate change is of concern with one day rainfall totals predicted to increase.
- Provide community with confidence and information on any potential purchase or relocation of houses at high flood risk.
- Provision of clear flood information during an event.
- Investigate opportunities to provide connectivity of the town during a flood event. In January 2011:
  - The SES was isolated for a couple of hours
  - Fire and Rescue personnel are aware of when roads are cut and the need to locate crews on either side of the creek.
  - The hospital is on the western side of town and the ambulance on the eastern side.
  - Meals on Wheels couldn't cross the town to deliver meals.

- Information on flood recovery is also important as in January 2011 not many people knew what to do after the event.
- The community will seek information on the Dam break. The study should consider if options may also assist in managing risks from dam break scenarios.
- The community will be interested in flood warning downstream of Tenterfield township. The study should identify where measures recommended for Tenterfield will also benefit downstream areas.
- All elements of the total solution need to be in a plan to achieve funding requirements.
- The consideration of adoption of a higher FPL based on the January 2011 flood event.

Recommendations and concerns from the FRMC regarding the preliminary options assessment is discussed further in **Section 6.2**.

5.3.3 Input from Fire and Rescue NSW

Fire and Rescue NSW play an important role in emergency response for the town of Tenterfield. Prior the 2011 flood event, Fire and Rescue NSW were provided with information about expected flooding that could isolate the eastern side of the town from the western. This allowed them to ensure that they had sufficient equipment to aid rescue efforts on both sides of the creek. Emergency management information is supplied to Fire and Rescue NSW by Council and the SES.

Fire and Rescue NSW indicated that information on which buildings are likely to be inundated first would aid future rescue efforts. This would be useful for prioritising where assistance would be likely to be required first and which residents should be evacuated first.

5.3.4 Input from the Local SES

The local SES is involved in both information distribution and on-the-ground rescue efforts during emergencies in Tenterfield. As such, input from the SES will be an important part of the Tenterfield Flood Risk Management Study and Plan.

The SES supplied a number of reference documents to the study team including:

- SES requirements for the Floodplain Risk Management Process (DECC, 2007)
- Flood Emergency Response Planning Classification Of Communities Guideline (DECC, 2007)
- Key Floodplain Risk Management Issues for the NSW SES
- Australian Fire and Emergency Service Authority Council (AFAC) Guideline on Emergency Planning and Response to Protect Life in Flash Flood Event (AFAC, 2013)

In addition to this the SES has undertaken a number of local investigations for the Tenterfield region including the survey of the 2011 Flood Event, described in **Section 5.2** and the development of Volume 1 of the Tenterfield Shire Flood Emergency Sub Plan (SES, 2013). The Tenterfield Shire Flood Emergency Sub Plan is a sub plan of the Tenterfield Shire Council Local Emergency Management Plan and was prepared following the 2011 flood event to cover the preparedness measures, conduct of response operations and coordination of immediate recovery measures from flooding within the Tenterfield Shire Council Area. This area includes an area broader than the focus of this Tenterfield Creek Floodplain Risk Management Study.

It is noted that at the time of writing the SES is in the process of developing volume 2 of the Tenterfield Shire Flood Emergency Sub Plan. It is envisaged that the outcomes from this study will provide additional flood intelligence information that will provide a resource for the SES and may be inserted into the Volume 2 of the Tenterfield Shire Flood Emergency Sub Plan. Furthermore it is anticipated that recommendations from this study regarding upgrades to the flood warning system and Tenterfield specific public education will also assist in improving the preparedness of the community and emergency services.

The SES has expressed interest in future engagement with the FRMC. It is envisaged that further consultation with the SES will be undertaken as part of the development of the FRMP and that Council will work with the SES during the implementation phase of the FRMP.

5.3.5 Input from Tenterfield Hospital

Tenterfield Hospital was contacted in regard to the role of the ambulance service during emergencies in Tenterfield. During the 2011 flood event, there were no medical emergencies requiring assistance from the ambulance service. However, it was recognised that there was potential need for emergency medical services and plans were put in place.

The representative from Tenterfield Hospital noted that the communication between emergency services at the time of the 2011 flood was very good. The hospital was first informed about the impending flood by the SES and they maintained regular contact throughout the event.

The hospital and the ambulance depot are on opposite sides of Tenterfield Creek and were isolated from each other in 2011. This was not perceived to pose a significant problem because plans were in place to manage the issue. However, it was noted that if the roads were cut for longer (i.e. for 48 hours or more), the hospital would likely experience staffing issues.

Local emergency services have been meeting monthly to discuss disaster response in Tenterfield. This process was in place before the 2011 flood event.

5.3.6 Input from Tenterfield Police

The Tenterfield Police were involved in rescue efforts during the 2011 flood event, both within Tenterfield and in areas outside the town. Leading up to and during the flood, the main source of information for the police was the SES.

In 2011, floodwaters came close to inundating a police house next to the station, but the station itself was not at risk of flooding. If the station were to flood in a rare event, police officers could evacuate and those on duty could continue working from their cars. However, at the end of a shift, there could be resourcing issues if officers were not able to reach the police station.

The main issue identified by the representative of Tenterfield Police was the flooding of roads, especially near the corner of Rouse Street and Naas Street (New England Highway). This important route was reported to have been flooded for about one hour in 2011. Inundation of roads could potentially result in people being unable to reach the hospital in emergency medical situations.

5.3.7 Input from the Bureau of Meteorology

A key consideration of this study is the potential to upgrade the flood warning system in Tenterfield. This could involve installing new rainfall and streamflow gauges in the catchment. This would be undertaken through the Bureau of Meteorology. As such, it was necessary to find out what the potential for installing new gauges in this area is likely to be and what processes would be required.

The Bureau of Meteorology provided information regarding the approximate costs for installation of new gauges and the opportunity to seek capital funding through Floodplain Management Grants. It is envisaged that further consultation will be undertaken with the Bureau of Meteorology as part of the implementation of the FRMP.

5.3.8 Input from the Rural Fire Service

The Rural Fire Service is not directly responsible for rescue efforts in the town of Tenterfield, but it is recognised that they may sometimes be called upon to assist with rescue. Providing assistance in other ways, such as ferrying equipment for the SES, is part of their role.

In 2011, they were well prepared for the flood and had equipment on both sides of the creek in preparation for the expected road cuts. It is estimated that the floodwaters came to within 1.2 metres or four feet (vertically) of inundating the Fire Control Centre. There are plans in place for managing inundation of the Fire Control Centre, including relocating to the Fire and Rescue NSW building.

If the Fire Control Centre were inundated, it is believed that the disruption to emergency response efforts would be minimal. The Rural Fire Service has the ability to relocate quickly to the Fire and Rescue building and the Fire Control Centre would withstand inundation. Some electronics would need to be replaced following inundation.

During the 2011 flood, power was cut to the Fire Control Centre. This was managed through the use of a back-up generator. There was also an incident where a Rural Fire Service vehicle was compromised by a large ditch that had been washed out at the approach to the bridge on Molesworth Street. The representative from the Rural Fire Service did not feel that there were any particular gaps in available information that compromised the response to the 2011 flood.

5.3.9 Input from the Catchment Management Authority (CMA)

The CMA was identified as a key contact for obtaining information relating to the environmental consequences of flooding in Tenterfield Creek.

Following the 2011 flooding the CMA commissioned an assessment of the Flood Resilience in the Border Rivers-Gwydir catchment including Tenterfield Creek. The focus of the study was to review the effectiveness of the flood recovery works which included in-stream bank control, replanting, re-establishment of fences and off stream watering point, reconstruction of wildlife corridors and the restoration of in-stream habitat. However, the focus of the study was on reaches of Tenterfield Creek downstream of this study area, approximately 30km downstream of the Tenterfield Town. Therefore the study did not provide any specific commentary relevant to this FRMS area.

In general, the study CMA study found that the flood recovery works provided a significant benefit to the social recovery of individuals; and, where targeted erosion control works were undertaken, significant environmental benefits. The study also identified that in some areas works which improved recovery for farm business owners may not necessarily have resulted in ecosystem recovery such as the removal of woody debris which provide important habitat. However, it is believed that this conflict would have been lessened in the area relevant to this FRMS as the land use within the creek corridor is parkland. As such the driver for removal of debris is to provide for public safety and access. Therefore it is possible that following future flood events Council may leave smaller debris within the creek corridor for both visual amenity and ecosystem repair.

5.4 Feedback from the Community

A public exhibition of the draft FRMS occurred at Council offices between the 29th of August and 3rd of October. The public exhibition was supported by a half day community open session where the study consultants were available to discuss the study and key findings. The half day open session and public exhibition were advertised by Council through Council's website; an advertisement in the local paper and through a letter box drop to over 200 properties adjacent to Tenterfield Creek.

The half day open session was attended by ten (10) people, attendees included five (5) members of the public, three (3) Councillors the SES' regional controller and one business representative. The following provides a summary of the key issues raised by the attendees:

- There is a new power supply connection for Millrace, aged care which is believed to be below the flood level in January 2011 and for the event prior (It is assumed that this prior event is the 2001 event). Millrace has a back-up generator but has noted that the power supply connection being flood prone is of concern to the safe operation of the facility.
- The community noted that size of January 2011 event believed to be due to location of rainfall, which was different to previous rainfall events.

- The community raised concerns over changes to the vegetation in the creek and the sensitivity of the modelling to this. The sensitivity of the modelling was explained as not particularly significant based on the analysis undertaken by DHI as part of the Tenterfield Flood Study.
- The community raised concerns over effectiveness of current sirens. In particular, they were concerned that the community didn't know how to appropriately respond and new residents or tourists wouldn't know how to respond. The recommendation to eventually move to a voice activated siren was seen as a positive by the community.
- The community was also seeking general information on the accuracy of the modelling (particularly for the January 2011 event), changes to the dam, potential changes to areas of developable land and the potential for road raising.

In general the community was supportive of the measures proposed in particular the provision of flood information including the January 2011 flood event levels. The community was particularly supportive of visual indicators of historical flood information such as flood totem's and any improvements to the flood warning system.

While outside the scope of this study the following issues were also raised by the community and are noted here for further consideration by Council.

- There were concerns raised about flooding downstream of Tenterfield. In particular, the community noted significant velocity and scour. As the flooding downstream of Tenterfield is outside the scope of this FRMS, the community indicated that there was a need for separate investigation for this area.
- A question was raised regarding local drainage and potential for changes to runoff from further development. While this is outside the scope of this study it was noted as not likely to be a key issue given the relatively minor development pressure in Tenterfield.

No additional information or concerns were received from the community through the FRMS' email address or mail box.

6. Potential Options for Improving Floodplain Risk Management

The Manual acknowledges three different categories of floodplain risk management measures. These include:

- Property Response Measures:
- Response Modification Measures:
- Flood Modification Measures:

Flood modification measures are those that mechanically change the way floodwaters flow. Conversely, property and response measures do not change how floods occur but are focused on how human activities can react. Examples of measures for each category are provided in **Table 6-1**.

The initial assessment of floodplain risk management options involved a high level assessment of each measure against the flood risks specific to Tenterfield. This assessment is provided in **Table 6-2** through to **Table 6-4**.

Table 6-1 Typical Floodplain Risk Management Measures (adapted from the NSW Floodplain Development Manual, 2005)

Measure	Property Modification Measures	Response Modification Measures	Flood Modification Measures
Description	Modifying existing properties to address existing, future or continuing flood risk	Modifying the response of the population at risk to enable them to better cope with a flood event.	Modifying the behaviour of the flood to remove or reduce the extent, severity or frequency of flooding.
Examples	• Zoning • Voluntary Purchase • Voluntary House Raising • Building and Development Controls • Flood Proofing Buildings • Flood Access	• Community Awareness • Community Readiness • Flood Prediction and Warning • Local Flood Plan • Evacuation Arrangements • Recovery Plans	• Flood Control Dams • Retarding Basins • Levees • Bypass Floodway's • Channel Improvements • Flood Gates

6.1 Community suggestions

As outlined in **Section 5.4** in general the community was supportive of the measures proposed in particular the provision of flood information including the January 2011 flood event levels. The community was particularly supportive of visual indicators of historical flood information such as flood totem's and any improvements to the flood warning system.

6.2 Stakeholder suggestions

The FRMC was consulted regarding the preliminary options assessment at a FRMC meeting in July 2014. The following provides a summary of the key points of raised by the committee and the floodplain risk management options that were identified for further assessment.

- **Flood Planning Level** – The committee raised concerns that the current FPL is based on the 1% AEP plus 0.5 m freeboard which is below the January 2011 flood levels. Several members of the committee suggested that the FPL should be based on the January 2011 flood levels as this was the largest event on record and as a real event provided a reliable record of flooding. This view was not unanimous amongst the FRMC with other committee members indicating that Tenterfield should remain consistent with other floodplains and state practices. There was discussion amongst the FRMC regarding the benefits and

implications of this option and it was agreed that a separate discussion paper would be issued outlining these constraints. The discussion paper was reviewed by the committee and a vote undertaken which confirmed the decision to maintain the FPL based on a 1% AEP plus 0.5 m freeboard.

- **Flood Warning** – The FRMC identified that improved flood warning was a key concern for the community and warranted further investigation. The FRMC committee identified that it was necessary to review the current flood warning system which was not believed to be operating effectively.
- **Improvement to Flood Immunity of Road Crossings** – The preliminary options assessment undertaken by the study consultant suggested that the opportunity to improve flood immunity at road crossings and improve the connectivity of the town in a flood event would not be justified based purely on the flood damages assessment. Furthermore, improving the flood immunity may worsen existing flooding upstream of the crossing. The FRMC discussed the other benefits associated with improving flood immunity not captured in the damages assessment. While it was agreed that improving road flood immunity would be of benefit to the town the relatively short duration of road closure (2-3 hours) was considered to limit the social and economic impacts of the road closures. However, it was agreed that raising of one of the roads to a 1% AEP flood immunity be considered to provide an indication of the relative costs and benefits of this option.

The FRMC also raised concerns regarding the flooding warning, road crossing and flood risk further downstream of Tenterfield. While the assessment of flood risks in this area is outside of the scope of this assessment it was agreed that the potential benefits for downstream areas from measures proposed in this study, such as flood warning be noted as a potential benefit.

6.3 Options Recommended for Further Investigation

The initial options assessment resulted in recommendations for further investigation of the following:

- Consideration of the adoption of a FPL based on January 2011
- Provision of GIS based flood risk information to Council's planning department to support the assessment of future development against the LEP and apply appropriate development controls where required.
- Flood education to improve community readiness
- Improvements to the flood warning system
- Support for the disaster management team
- Consideration for the opportunity to improve flood immunity for a road crossing of Tenterfield Creek.

The benefits and constraints of these options are discussed further in **Section 7**.

It is noted that, while local levees and retarding basins were noted as potentially providing an appropriate tool to manage future flood risks, no immediate need for these mitigation measures was identified due to the lack of development pressures in the Tenterfield Creek catchment. These elements were therefore not considered further as part of this study.

Table 6-2 through to **Table 6-4** list the flood mitigation measures considered and rate their relevance for implementation in Tenterfield. The relevance ratings are defined as follows:

- High – likely to be relevant to flood risk in Tenterfield and related flood management measures could assist in flood risk management
- Medium – not likely to be highly relevant to flood risk management in Tenterfield, but some related flood management measures could prove beneficial
- Low – not likely to be relevant to Tenterfield. Related flood risk management measures are unlikely to be worthwhile

Table 6-2 Property Modification Measures

Mitigation Option	Description	Relevance to Flood Management in Tenterfield	
Zoning	Limiting or restricting development based on flood risk.	High	Development should be limited or restricted in areas that are subject to problem flooding. This is an important measure for managing ***Future Flood Risk***. At present Council's planning department has limited information regarding flood hazard and risk. It is proposed to support Council in this through provision of spatially referenced information which can support the DA assessment process.
Development controls	In areas where development is permitted, regulations are put in place to minimise the risk of flood damages.	High	Developments in flood-prone areas need to consider measures for minimising the effects of flooding. This is an important measure for managing ***Future Flood Risk***. This would also be supported by provision of information to Council's planning department.
Aspects dealt with in individual Development Applications (DA)'s	DA's are assessed on a case by case basis to check that the proposed layout, floor levels and works comply with the intent of the planning scheme.	High	Developments should consider and comply with the intent of the planning scheme in relation to flooding. This is an important measure for managing ***Future Flood Risk***. This would also be supported by provision of information to Council's planning department.
Voluntary purchase	For houses affected by high hazard flooding, voluntary purchase may sometimes be more economical than other mitigation measures.	Low	For events up to the 0.05% AEP event no existing houses are located in high hazard flood waters, therefore the physical risk to houses and the need for purchase is considered unnecessary and unlikely to be justified in a flood damages, cost benefit assessment.
Voluntary house raising	Houses that are already on stumps can often be raised for a reasonable cost (in the order of $40k) to reduce potential flood damages.	Low	While many houses in Tenterfield are on stumps and could potentially be raised, the relatively low flood damages mean that this is unlikely to be justified in terms of cost benefit.
Flood proofing of buildings	Buildings are designed and constructed with appropriate materials such that flood damage is minimised should inundation occur.	Med	A number of Council buildings, such as showground and park facilities, are subject to flooding. The costs associated with repairing these structures after flooding could be reduced through measures such as ensuring that all electronics are 0.5 m above the 2011 flood level and suitable materials are used in construction. However, this may be provided through flood education to enable the community to take steps to minimise their own damages.

Mitigation Option	Description	Relevance to Flood Management in Tenterfield	
Flood access	Planning needs to ensure that flood access/escape routes are available for residences and critical facilities.	Low	The nature of flooding in Tenterfield is not conducive to flood access issues as with the exception of two locations floodwater breaks out of the creek without causing isolated 'islands' and there are a number of different routes that allow escape from the PMF flood extent.

Table 6-3 Disaster Response Measures (Disaster Response Measures are considered measures that address *Existing, Continuing and Future Flood Risk.*)

Mitigation Option	Description	Relevance to Flood Management in Tenterfield	
Flood education	Ensuring that the community is fully aware that floods can interfere with activities in the floodplain.	High	While there are no residences in high hazard areas in Tenterfield, community awareness is important to minimise the risk of unsafe behaviour on the floodplain. Residents are unlikely to be physically harmed by flooding in Tenterfield unless they try to swim, drive or wade in floodwaters. Appropriate education will ensure that residents are aware of the dangers associated with these activities.
Flood information leaflets	Leaflets containing information specific to each area are distributed to the community.	Med	Flood information leaflets could provide a useful means of educating the community, to encourage the community to avoid floodwaters.
Community readiness	Community readiness is closely linked to awareness. It is conducive to an efficient, appropriate response to flooding.	High	The short duration flooding expected in Tenterfield means that minimal warning time is likely to be available for flood events. Measures such as storing valuables above floor level and being ready to evacuate quickly could reduce flood damages in Tenterfield. Strategies for evacuating vulnerable people (for example, residents of the retirement home) should be in place.
Flood prediction and warning	A combination of information supplied by BOM and local information from the SES is used to warn residents of an impending flood.	High	The short duration flooding expected in Tenterfield means that minimal warning time is likely to be available for flood events. Efficient warning systems could have a significant impact in reducing the flood damages experienced in a large event. This will be particularly important for vulnerable locations that are subject to flooding such as the retirement home.

Mitigation Option	Description	Relevance to Flood Management in Tenterfield	
Local flood plans	The SES and the Local Emergency Management Committee are responsible for the development and implementation of a plan for areas with significant flood problems. The plan outlines procedures to be followed before, during and after a flood.	Med	The level of flood hazard in Tenterfield is not considered to necessitate a local flood plan. However, it could be useful in managing large flood events.
Recovery planning	A procedure for clean-up after the flood that outlines Council's responsibilities and those of individuals. It may include post-event counselling or meetings that allow the community to share experiences. Procedures for collecting information that could help deal with subsequent events should be included.	Med	Recovery planning is considered to be valuable for all communities that could be flood-affected. However, Tenterfield's level of flood risk is not considered to necessitate extensive action in this area.

Table 6-4 Flood Modification Measures

Mitigation Option	Description	Relevance to Flood Management in Tenterfield	
Flood mitigation dams	Reduce downstream discharges by storing some of the floodwater temporarily.	Low	The level of flood hazard in Tenterfield is not considered to justify the construction of major structural mitigation measures. Additionally, only very large events cause problem flooding in Tenterfield. Flood mitigation dams are more useful in locations where smaller flows cause significant flooding... It is also acknowledged that any dam flood mitigation works would be more appropriately invested in improving the dam safety of Tenterfield Dam and it is understood this is currently being investigated by the state.
Retarding basins	A retarding basin behaves similarly to a flood mitigation dam, but generally on a much smaller scale. They are typically used as a means of controlling peak discharge from newly urbanised areas.	Med	Any significant urbanisation of rural land in Tenterfield should consider the need for flood detention using a retarding basin to prevent increased flooding in immediately surrounding areas. This measure may therefore provide an appropriate tool for managing ***Future Flood Risk***.

Mitigation Option	Description	Relevance to Flood Management in Tenterfield	
Levees	A levee is often the most economically viable option of mitigating flood risk in a particular location. However, it is important to consider that they can fail due to poor design, construction or maintenance. Additionally, unless they are designed for the PMF event, levees can overtop. The failure of a levee can result in more hazardous flooding than would have occurred under existing conditions. They can also increase flood levels in locations outside the protected area.	Med	Any small levees could be considered to protect highly vulnerable, flood-prone locations such as the retirement home. However, appropriate design and the potential impacts on nearby properties would need to be considered. This item is identified for further discussion with the FRMC. It is considered that this item may provide an opportunity to manage ***Existing Flood Risk*** for sensitive existing development.
Bypass floodways	Provide an alternative route for floodwaters to redirect them away from areas under threat of flooding. Flood levels downstream are reduced, but environmental problems and worsening of flooding in other locations can limit the practicality of this option.	Low	No suitable location for redirecting floodwaters in Tenterfield has been identified. Additionally, the level of flood hazard in Tenterfield is not believed to justify large structural mitigation measures.
Channel Improvements	Provide increased conveyance through channel widening or improvements.	Low	This option may result in significant impacts on existing amenity and or vegetation within the creek. Any clearance of the creek would require significant channel works and approvals. In addition to this it is considered likely that increasing conveyance will result in significant increases to downstream flows and water levels.
Bridge Modification	A key issue highlighted by the FRMC was the connection of the east and west parts of the town. In particular the need for safe access during a flood event.	Med	Bridge modification is likely to be an expensive option that would require further justification given the relatively low flood damages in Tenterfield and the relatively short flood duration. However, this option may provide additional indirect benefits to the community that are not captured in the damages assessment and may provide an alternative safe access point minimising risks during large events.

7. Recommendations for Floodplain Risk Management Strategy

7.1 Flood Planning Levels

One of the most important measures under consideration is the adoption of a revised Flood Planning Levels (FPL) definition for Tenterfield.

FPLs are defined based on a flood of a given probability and a freeboard requirement or an historic flood. The current FPL for residential development in Tenterfield is defined by the 1% Annual Exceedance Probability (AEP) flood event with 0.5 m freeboard. A 1% AEP flood has a 1% chance of occurring in any given year.

FPLs are referenced by Council when assessing proposed development on the floodplain. In general, any new development will need to have a floor level above the FPL applicable to that type of development unless specifically exempt.

In January 2011, Tenterfield experienced the largest flood event in recent memory with flood levels approximately 1 m greater than the predicted 1% AEP levels. The hazard associated with this floodwater was significant in places with deep high velocity flows through the creek causing significant damage to parkland, bridges and road crossings. Fortunately, few properties were inundated above floor level and as a result the associated direct tangible damages were relatively minor.

There is significant uncertainty associated with an estimation of the probability of occurrence for an event of similar magnitude to January 2011. The estimated AEP of the January 2011 event ranges from 0.2% to 0.05%. The uncertainty in the estimate is influenced by a lack of recorded flow or water level data within the catchment and the region.

During consultation with the FRMC, it was agreed that the selection of the January 2011 event as the basis of the FPLs should be explored as part of the Floodplain Risk Management Study.

7.1.1 Purpose of Flood Planning Levels

FPLs should be considered when assessing development applications to assist in managing future flood risk. In general, new developments will be required to have a floor level above the FPL unless specifically exempt. FPLs are also used as design levels for flood mitigation works, although structural flood mitigation works can nominate a design level that provides a different level of immunity to the FPL.

In most cases, FPLs will vary for different types of development. For example, it may be appropriate to assign more stringent guidelines to residential development than commercial development. One reason for this is that it may be difficult to warn residents about floods that occur at night while people are sleeping. Therefore, a flood at night may be more dangerous than the same flood during the day. At night, most people are expected to be in residential dwellings rather than on commercial properties.

FPLs are not intended to eliminate flood risk entirely and it is generally impractical to define FPLs based on the largest possible flood event. Therefore, FPLs for a Local Government Area need to be defined based on the local flood behaviour and the level of risk that is considered acceptable. In locations where flooding in large events is likely to be dangerous and result in very large damages, a FPL based on the 1% AEP flood plus 0.5 m freeboard may give an unacceptable level of continuing risk to people and property. However, in other locations where the consequences of large floods are expected to be less severe, these criteria may be acceptable for defining FPLs.

Table 7-1, taken from the NSW Floodplain Development Manual (Office of Environment and Heritage (OEH) 2005), outlines the chance of experiencing selected design flood events over a lifetime. This highlights that, although the probability of a given flood may seem low based on the AEP, long-term residents and developments with a relatively long design life are likely to experience large events at some point.

Table 7-1 Probabilities of experiencing a given size flood once or more in a lifetime (OEH 2005)

Size of Flood (Chance of occurrence in any year) ARI/(AEP)	Probability of Experiencing the Given Flood in a Period of 70 Years	
	At least once (%)	At least twice (%)
1 in 10 (10%)	99.9	99.3
1 in 20 (5%)	97.0	86.4
1 in 50 (2%)	75.3	40.8
1 in 100 (1%)	50.3	15.6
1 in 200 (0.5%)	29.5	4.9

As outlined in **Section 4** the existing flood risk for Tenterfield is considered low.

The NSW Government requires that FPLs are set through consideration of a full range of flood risks.

7.1.2 Precedence for Deviating from the 1 % AEP

Precedence for deviating from the 1% AEP plus freeboard was discussed with OEH. At the time of writing, only Wollongong had considered adoption of an FPL that deviated from the 1% AEP event plus freeboard. The basis of this consideration was that the type of flooding was flash flooding with very short warning times. The Wollongong example is one of few variations to the standard FPL definition in NSW.

Australia wide, there are few examples of local councils, with approval from the State Government, adopting flood planning levels higher than the 1% AEP flood level plus freeboard. The two localities discussed as examples in this section are the Lockyer Valley (QLD) and the Gold Coast (QLD). In these cases, there was significant justification for adopting a level higher than the 1% AEP flood plus freeboard.

7.1.2.1 Flood Planning Levels in the Lockyer Valley

In January 2011, the Lockyer Valley experienced a large flood that resulted in 19 deaths, a significant number in an area with a population of just 37 000. Four bridges were destroyed, sewerage systems were inoperable for days, roads were significantly damaged and the state and local government was absorbed with managing the event (SKM 2012). The Flood Risk Management Study, prepared by SKM in 2012, recommended changes to the Defined Flood Event (DFE)[3] based on the consequences of the 2011 event, the modelled flood hazard and the uncertainty in the calculated rainfall intensities.

It is also important to note that Lockyer Creek is perched, meaning that the water level in the creek can be higher than the surrounding land. This means that flood damages and hazard can increase significantly if the creek breaks its banks, which is possible to occur in rare flood events. The flood breakout can also isolate properties causing islands surrounded by high hazard flood waters. Due to the much higher consequences of rare flood events compared with the 1% AEP event, it was considered necessary to contemplate larger events in planning.

Based on the findings of the study, it was recommended that the DFE for the upper Lockyer Creek floodplain (upstream of and including Grantham) be based on the modelled 2011 flood event. This was due to the uncertainty in design flood estimates, short warning time, hazardous flooding and actual deaths resulting from the 2011 flood in this area, which justified a higher DFE than the conventional 1% AEP DFE.

The decision to adopt a DFE with a probability rarer than the 1% AEP was made after extensive community consultation and was adopted by Council resolution. A freeboard of 0.3 m was applied to the DFE.

[3] The defined flood event (DFE) is Queensland's equivalent to a FPL.

A DFE based on the 1% AEP event with freeboard was maintained in the lower Lockyer Creek floodplain (downstream of and including Gatton) in accordance with convention. In this area, a higher DFE was not considered justified because of the lower flood hazard and longer warning time.

7.1.2.2 Flood Planning Levels at the Gold Coast

The wall of the Hinze Dam, located in the Gold Coast Hinterland, was raised for a third time in 2012. This was undertaken to increase the City of Gold Coast's water supply and reduce flood risk (FMA 2014). Due to the raising of the dam wall, the 1% AEP flood level was recalculated as being lower than it had previously been. Therefore, Council had the option of reducing the DFE to reflect the new 1% AEP flood level estimate plus freeboard (as per convention) or maintain the original, higher DFE.

A flood risk study titled "Hinze Dam Stage III Post Mitigation Flood Policy" was undertaken for the Gold Coast. Based on this report, the Council unanimously decided to maintain the original DFE. This was in consideration of projected growth over the next 50 years, which would result in the loss of most of the mitigation benefits gained from the dam upgrade if the DFE was reduced. In addition, it was identified that the Nerang Floodplain is subject to a 'spill effect' during large floods, where the creek banks break resulting in much more damaging flooding than would be experienced in the 1% AEP event. Around 50% of flood damages on the Nerang Floodplain occur at about the existing 1% AEP flood line (FMA 2014).

In the case of the Gold Coast, it was deemed appropriate to adopt a DFE higher than the mitigated 1% AEP level plus freeboard due to the local flood behaviour and the potential for losing the benefits of the flood mitigation works due to new developments being constructed at lower levels.

7.1.3 Factors Influencing Selection of Flood Planning Levels

7.1.3.1 Flood Behaviour

The local flood behaviour needs to be considered to determine whether FPLs based on a particular flood event will result in an acceptable level of continuing risk. Localities subject to highly hazardous or damaging flooding may need to consider adopting rarer flood events to define the FPLs when compared with localities that are not likely to be subject to flooding with such severe consequences.

The difference between the extents of inundation for floods of varying magnitude also needs to be considered. For example, if a 1% AEP flood results in relatively little inundation of properties, but a 0.5% AEP flood results in the waterway breaking its banks and causing extensive flooding, it may be appropriate to select an event larger than a 1% AEP flood plus freeboard for defining FPLs.

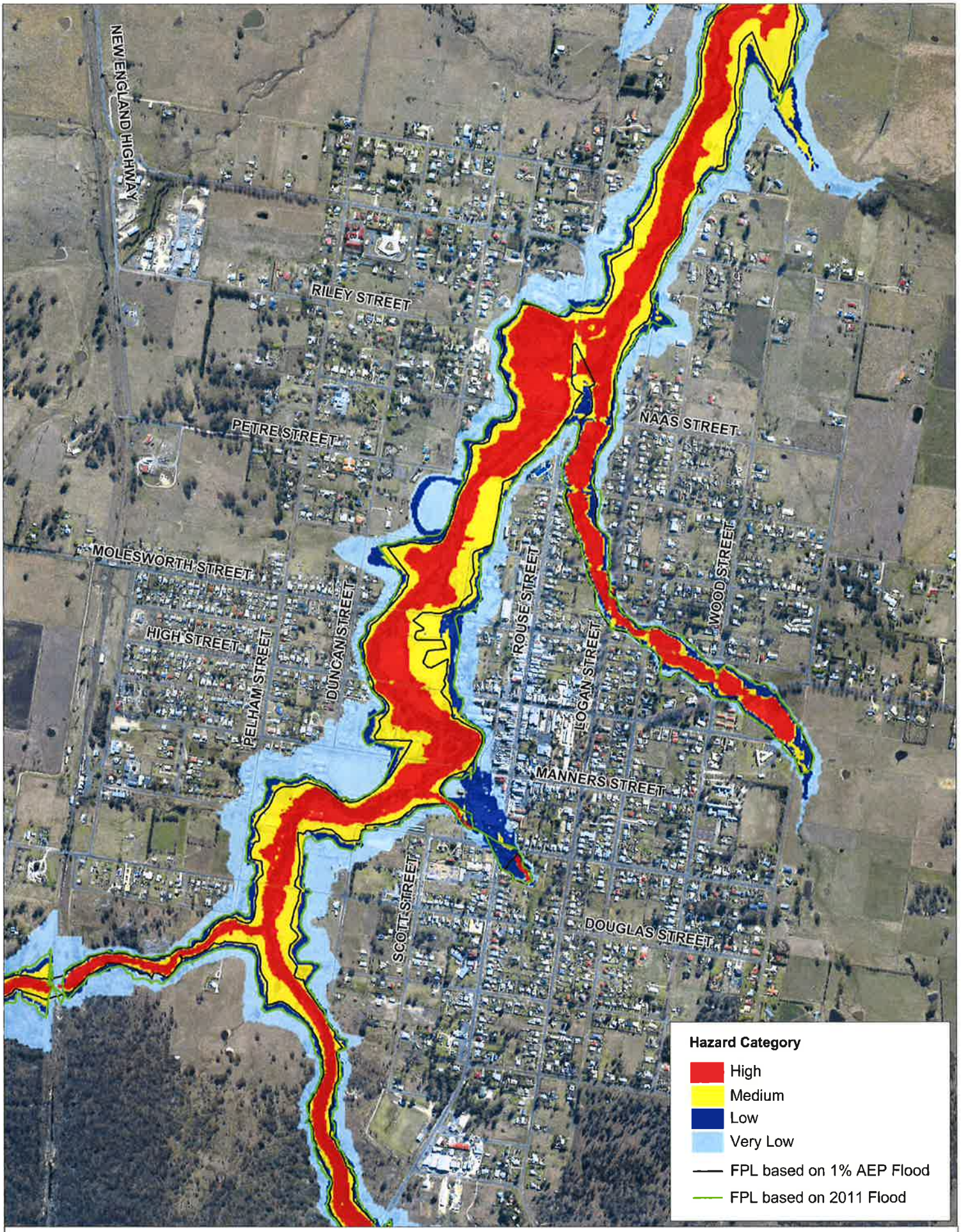
The Manual requires the definition of flood hazard categories to be based on the flood behaviour during a range of flood events. This results in the assignment of hazard ratings that are not specific to a particular flood event. The flood hazard categories proposed for Tenterfield include consideration of the flood hazards associated with a 0.05% AEP event. The 0.05% AEP event has been considered due to the relatively short warning times for Tenterfield. While the probability of the January 2011 event is not accurately defined, it is estimated as being between a 1% and 0.05% AEP event.

In Tenterfield, high hazard flood areas are mostly confined within 100 m of the creek banks. Some roads, but no existing properties, are located in the high flood hazard category. There is also only a limited amount of undeveloped land located in this category, with considerable vacant land located outside this category. On this basis it is considered that the level of flood hazard expected in Tenterfield does not support the selection of a rarer flood event than the 1% AEP plus 0.5 m freeboard for defining FPLs.

In comparison with many floodplains, the increase in flood extent with increased flood size is relatively small in Tenterfield. This is due to the relatively steep floodplain. The 1% AEP flood extent (without freeboard) downstream of Douglas Street and upstream of Drummond Street (based on the modelling undertaken in 2013) is 44 ha, while the 0.05% AEP extent is 71 ha. This is a relatively small increase in flood extent given the much lower probability of a 0.05% AEP flood event. It is noted that the January 2011 flood event is considered to have a probability more frequent than a 0.05% AEP but rarer than a 1% AEP flood event.

Figure 7-1 illustrates the hazard categories defined as part of this study along with approximate extents of the FPL defined by the 1% AEP plus 0.5 m freeboard and an FPL defined by the 2011 flood plus 0.5 m freeboard. Both flood extents cover practically all of the high hazard area. However, some medium hazard areas are not covered by the FPL as defined by the 1% AEP flood level plus freeboard. If based on the 2011 flood, the FPL would include almost all of the medium flood hazard area but would also encompass some low and very low hazard areas.

This highlights an issue with the current FPL defined by the 1% AEP flood level plus freeboard, as Council's LEP triggers development controls only in areas below the FPL, which would exclude some medium hazard areas. However, the FPL defined by the 2011 flood may unduly limit development, as it would capture areas of low and very low hazard, particularly in the commercial district surrounding Rouse Street. This is discussed further below.



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Scale: 1:10,000

Datum: MGA56
Coordinate System: MGA Zone 56

Figure 7-1

Proposed Flood Hazard Categories with FPLs

Project: Tenterfield Floodplain Risk Management Study

7.1.3.2 Risk to Life

Risk to life issues need to be considered with reference to the full range of flood events that could occur on a floodplain. Adopted FPLs need to ensure that risk to life issues are appropriately managed, with consideration of the consequences of events larger than the event used to define the FPL. Risk to life will increase during events greater than the FPL because:

- Buildings become flooded above floor level
- Flood mitigation works may become ineffective (for example, a levee may overtop)
- Hazardous flooding may occur where there is no hazardous flooding in the event used to define the FPL
- Access issues and isolation may put people at risk

The risk to life generally increases with the size of the flood in all flood-prone locations. This is true for Tenterfield because larger floods result in more flooded roads and larger areas of deep and/or fast-flowing flooding that could pose a threat to residents' safety. The width of the high preliminary flood hazard area approximately doubles between the 1% AEP and 2011 modelled flood events and the flood levels increase by about 1 m. In the largest conceivable flood (the PMF), the high preliminary flood hazard area is approximately double that of the 2011 flood event. This flood risk to life would remain in both FPL options. However, even in the PMF, most residences have easy access to safe high ground, reducing the risks to personal safety.

In Tenterfield, there is no unexpected increase in risk to life with increase in flood size, as may be seen in areas with perched creek banks where flood damage increases dramatically when the banks overtop (such as in the upper Lockyer Valley).

In Tenterfield, the overall risk to the population from flooding is not considered particularly high. Isolation is not expected to increase risk to life because there are continuously-rising roads leading out of the floodplain and most high hazard areas are within 100 m of the creek banks. The main risk to life is likely to be related to hazardous flooding on roads. Therefore, educating the community on the dangers of attempting to drive or wade through floodwaters and warning systems are likely to be more effective measures for addressing risk to life than raising FPLs.

7.1.3.3 Land Values and Social Equity

When defining FPLs, it is necessary to consider the implications on land values and existing developments. Owners of properties that would have been readily developable under a particular FPL definition may be unfairly impacted if the definition changes significantly, making it more difficult for them to develop and decreasing the value of their land. Therefore, the FPL should not be increased more than is justifiable based on risk to people and property.

The impact on existing development would be an issue in Tenterfield if the FPL for residential properties was raised from the 1% AEP flood level plus freeboard to the 2011 flood level plus freeboard. It is estimated that 19 existing residences would fall within the FPL extent based on the 2011flood, whereas only 12 are thought to fall within the current FPL extent. This means that seven properties that were previously outside the FPL extent would now be subject to development control. All 19 properties would be affected by the higher FPL if the owner planned to redevelop or alter the site.

There are seven existing residential properties that fall between the January 2011 and 1% AEP FPL's. Of these, four are located in areas categorised as medium hazard, with all of the four properties located within close proximity to the low and medium hazard boundary. Therefore it is expected that the flood hazard in this area is likely to be at the lower end of the medium zone.

Eleven existing commercial properties are located between the current 1% AEP plus freeboard FPL and that which would be defined by the January 2011 event plus freeboard. However, only one commercial property, the motel, is located outside the current FPL and within an area of medium hazard. This property experienced minor flooding in January 2011 but did not experience any risks to personal safety.

The physical magnitude of the change in FPL would be large, with 2011 flood levels being over a metre higher than the modelled 1% AEP flood levels. This means that, if a resident wanted to rebuild or extend a house, modifications would have to comply with a FPL over a metre higher than the FPL considered in the original design.

A change in FPL could lead to a decrease in property value for both developed and undeveloped lots with ground levels below the new FPL. This would be due to the increased difficulty (costs) of developing to the new FPL.

Tenterfield is one of Australia's oldest towns. Maintaining streetscapes that are in keeping with the towns historic character is important and should also be considered in any proposed change to the FPL.

7.1.3.4 Future Development

The impact of a change in the FPL definition on future development is also a factor for consideration. As is the case for existing developments, future developments in the floodplain could be significantly impacted by the change. If the 2011 flood rather than the 1% AEP flood were to be used in defining FPLs (assuming the same freeboard requirements), future developments would be have to be designed in accordance with a FPL over a metre higher than the current FPL.

Adopting the 2011 flood as a basis for the FPL may reduce the future flood damages for Tenterfield. A high level estimate of the potential change in flood damages by such a change was undertaken. This estimate assumed that the remaining vacant blocks within the PMF extent were developed into residential areas with a floor level 0.5 m above the 1% AEP (current FPL). While this development resulted in an increase in the potential Average Annual Damages, it remains very low when compared to most floodplains in NSW.

Several undeveloped lots in Tenterfield would be affected by the change, leading to a decrease in property values as discussed in Section 7.1.3.3. However, in terms of the overall potential for future development in Tenterfield, a change in FPL is unlikely to cause major limitations. This is because the town has a large quantity of developable land available outside of flood-prone areas.

The equity of the proposed change to the FPL needs to be considered, while the change would benefit future development this comes at a cost to a number of existing properties. Given the lack of development pressures in Tenterfield, the potential cost to existing properties is considered to outweigh the potential benefit to future development and potential reduction in future flood damages.

The adoption of a higher FPL would not significantly alter the continuing flood risk.

7.1.3.5 Uncertainty

It is important to consider the uncertainty in modelled flood results when defining FPLs. If there is confidence around the flood levels defined for the floodplain, it may be more justifiable to incorporate less conservatism in the approach. The modelling undertaken for the Tenterfield Flood Study is believed to be fit for purpose, but it is recognised that the approach used in defining the hydrology has resulted in a degree of uncertainty in the design flood model results.

As part of the review of the flood modelling undertaken by DHI a number of gauges from surrounding catchments were reviewed. A statistical analysis of an adjacent gauge on Broadwater Creek at Barkers suggests that the uncertainty window for the 1% AEP event is -30% and + 45%. This indicates that the peak flows may actually be 45% higher than predicted or 30% lower. Based on the results of the sensitivity analysis undertaken as part of the flood study it is likely that the variation in flood levels associated with this uncertainty would be accommodated within the 0.5 m freeboard.

The uncertainty associated with design flood estimates at Tenterfield is unlikely to be decreased until additional rainfall or streamflow data becomes available. Typically an additional 10 years of data would be required to

provide additional confidence to flood frequency estimates from the region's rainfall or streamflow record. This time period is likely to coincide with the typical review period for the current flood study and 1% AEP flood estimates. During this time the flood risk associated with uncertainty will need to be managed through measures set out in the Floodplain Risk Management Plan.

It is noted that uncertainty is typically addressed through incorporation of a freeboard. In NSW, this freeboard is 0.5 m. As can be seen in Section 7.1.3.1 the 0.5 m freeboard on the 1% AEP encompasses all of the high flood hazard category and most of the medium category. However, a 0.5 m freeboard on the January 2011 flood event results in a flood extent that extends into areas of low or very low flood hazard and is therefore considered unnecessarily conservative. Adoption of a FPL based on a historical event without a freeboard is not recommended as it does not allow for any potential differences in future flood events due to rainfall and or localised impacts such as blockages.

7.1.3.6 Planning Guidelines

The current planning guidelines are presented in **Section 4.5.1**. The review of the current planning guidelines indicates that the current FPL applied with the flood hazard and non-worsening controls in the current LEP would restrict development within all high hazard areas and the majority of moderate flood hazard areas.

7.1.4 Recommended Approach

Based on the assessments discussed in this report, it is recommended that the current FPL based on the 1% AEP flood level plus 0.5 m freeboard be maintained in Tenterfield.

The recommendation is primarily based on the fact that the existing FPL and LEP currently provides substantial mitigation of the flood risk in Tenterfield. The characteristics of the flood hazard and the relatively low risk to life, particularly for flood events rarer than the 1% AEP event does not support moving away from the current FPL.

As shown in **Figure 7-1**, the current FPL encompasses practically all of the areas classified as high flood hazard in this study. While some medium hazard areas are not captured, it is considered that development in these areas is unlikely to result in undue risk to life or property. It should be noted that the majority of existing properties located in medium hazard areas are on the fringe of the medium and low hazard zone. There is very little precedence in Australia for deviating from the 1% AEP plus freeboard definition of FPL's. In the instances where this has occurred it has been driven by strongly the risk to life and or significant development pressures on the floodplain (resulting in a significant increase in flood risk and damages). These drivers are not present in Tenterfield and the situation is not expected to change over the medium term.

It is recommended that appropriate development controls be applied to areas with the current FPL to prevent risk to the community due to development in areas of high flood hazard.

7.1.4.1 Managing Continuing Risk

Unless the FPL is selected based on the PMF levels, effectively limiting all development on the floodplain, there will always be continuing risk. If the decision is made to keep the FPL at the current level, it will be important to consider that both new and existing developments in the floodplain could be affected by flood events greater than the modelled 1% AEP event. This means that, if an event the size of the 2011 flood were to occur again, new properties built in accordance with the FPL could be inundated. It is therefore recommended that Council consider management options for continuing flood risk. However, continuing risk will need to be managed even if the 2011 flood levels were used to define the FPL.

Continuing risk and flood hazard associated with rare flood events can be managed in a number of ways without changes to the FPL. The potential management measures recommended for Tenterfield will be discussed in detail in the Floodplain Risk Management Study and Plan. They are likely to include increased community awareness and readiness measures that can help residents respond appropriately to minimise risk to life during floods. Community awareness will be the key measure to reduce risks to life in a flood event with the most significant flood hazard likely to be due to flooded roads. It is also important that the community

understands that flooding can exceed the FPL (whether defined using the 2011 flood or 1% AEP) and know how to respond accordingly.

Provision of flood information is an important tool for increasing community awareness. The Floodplain Risk Management Study and Plan is expected to identify the inclusion of January 2011 flood information in Council's database and on section 149 planning certificates. This will allow the community to make an informed choice regarding their own flood risk for future developments and inform new residents of the risks when they purchase an existing property. This option would allow the community to select their own level of risk when they purchase, build or make improvements to a property. This is discussed further in **Section 7.2**.

Emergency response is an important measure for increasing community resilience to flooding. Optimising the flood warning system in Tenterfield is an option to be assessed in detail in the Floodplain Risk Management Study and Plan. Pre-prepared flood maps and related information for the emergency services can also assist with disaster response and management.

In summary, in the absence of sufficient justification to raise the FPL, it is recommended that the current FPL defined by the modelled 1% AEP event plus 0.5 m freeboard be maintained. It is recognised that there is continuing flood risk that should be managed through other measures however when considering the flood affected area of Tenterfield adopting a FPL based on the 2011 flood will not significantly alter the continuing flood risk.

7.2 Zoning and Development Control

The Manual strongly recommends appropriate land use control measures to limit the rate of growth of future flood damage. It involves the division of flood-prone land into appropriate land use zones to limit development that is considered inappropriate based on local flooding conditions. However, it is important to avoid unjustifiably restricting development simply because land is flood-prone. It is also important to consider the impact of rezoning on existing developments.

It is recommended that Tenterfield use the hazard categories produced in this study to define zones for development as per **Section 3.4.2** and **Section 3.4.3** and presented again in **Table 7-2**.

In order for development to occur in the high hazard zone the proponent would need to demonstrate that the development can appropriately manage the risks associated with flooding (LEP Clause 6.2 3a). It is considered unlikely that a development could demonstrate that the risks can be appropriately managed in this zone particularly given the lack of warning time in the Tenterfield Creek catchment. Furthermore the development would need to satisfy the remaining requirements of Clause 6.2 part 3, which would be difficult given the modelling undertaken in the flood study suggests that filling in these areas would have a significant impact on adjacent flood levels and velocities.

Table 7-2 Proposed flood hazard categories for Tenterfield

Category	Definition	Development
High	Within the 10% AEP extent or preliminary flood hazard is high or medium in 1 % AEP event	Development not recommended
Medium	Within the 1 % AEP extent or preliminary flood hazard is medium or high in 0.05 % AEP event	No sensitive developments. Developments must be above the FPL.
Low	Within the 0.05 % AEP event	No emergency services. Developments must be above the FPL.
Very Low	Within the PMF extent	Consider whether emergency services should be located in this zone.

Development in the medium hazard zone may occur but under the LEP Clause 6.2 3a this development would also need to demonstrate the development is compatible with the hazard of the land. This could be achieved

through flood free access for evacuation and or structural design and of the building such that it can withstand the likely flood forces. In particular, sensitive development such as child care centres and aged care facilities would need to provide appropriate controls for their occupants to manage the risks to life from the flood event. Such controls may include:

- Access to the site during floods
- Earthworks in the floodplain
- Freeboard
- Impact of development on flood behaviour
- Structural soundness when flooded
- Building materials
- Impacts of fencing

Given the availability of flood free land in Tenterfield and that the costs associated with providing controls to manage flood risk would decrease as flood risk decreases; it is considered that this policy would result in the majority of future development occurring outside of high and medium flood risk areas.

It is expected that Tenterfield can appropriately manage the future development with the current village zoning under the current provisions of the LEP. However, it is recommended that Council consider the options to revise the village zoning with consideration for the proposed hazard categories, as part of any future updates to the planning scheme. This will limit the future flood hazard associated with new development.

The flood hazard zones developed for this FRMS will be provided to Council in GIS format to apply to future development applications. Therefore the cost of implementing this measure is considered minimal as it is largely serviced via Council's existing processes. Time will need to be invested by Council staff to understand the application of this data.

The Tenterfield Creek floodplain is dominated by conveyance rather than storage. Therefore, the areas where development will need to be limited to avoid impacts on flooding are likely to be relatively small. This is illustrated in **Figure 3-7** where the area of flood storage and flood fringe is considered likely to have undue impacts on existing development. However, it will still be important to assess the impacts of development on flood behaviour on a case by case basis.

An option that should be considered is including information on predicted flooding at properties on 149 Planning Certificates in the *Additional Comments* field. This would allow residents to better understand the flood risk at their property. Three example statements that could be included on the 149 Planning Certificates for flood-prone houses are:

"Ground or building levels are below the Flood Planning Level defined by the 1% AEP flood level plus 0.5 m freeboard, which is (insert flood level) at this property. Development will need to be undertaken in accordance with Flood Planning Levels."

"Ground or building levels are above 1% AEP flood level of (insert flood level) and above the Flood Planning Level but below the 2011 flood event level of (insert flood level). Consideration should be given to potential flood risk when developing on this property."

"Ground or building was not inundated in the 2011 flood event but is within the defined Probably Maximum Flood extent. This property could be subject to flood risk in extreme flood events."

7.3 Disaster Response Measures

The risks to personal safety may be reduced for existing and future residents for floods of all magnitudes by the enhancement of existing disaster response measures. Given the relative abundance of flood refuges in Tenterfield any steps that can be taken to pre-prepare the community and make use of the effective warning time will enable the community to take action reducing their flood damages. For example, DNRM estimate that

by increasing community awareness and the effective warning time the AAD may reduce to 80%, providing an AAD for Tenterfield of $18,720. However, based on the relatively short warning time for Tenterfield Creek floods the potential for disaster response measures to drastically reduce flood damages is limited. Furthermore the reduction in AAD of $6,000 is unlikely to on its own justify a significant investment in disaster response improvements.

However, the Intangible benefits associated with a reduced risk to life from a personal awareness of flood waters (such as avoiding flooded roads) will also provide benefits to the community. The analysis below has been undertaken with consideration for this and measures recommended for the short and medium term on this basis.

It is also proposed to use the tools developed as part of this study to improve the flood emergency planning for the study area. Flood maps based on flood model simulations could be incorporated into the detailed flood intelligence section of the Tenterfield Shire Flood Emergency Sub Plan and used to better inform flood emergency plans, especially in regard to the most vulnerable properties to inform evacuations and disaster management support. The mapping is provided digitally as well as a hard copy booklet that would be distributed to all emergency management services. An example of the detail of the mapping is provided in Figure 7-2 below.

Figure 7-2 Example of pre-cooked flood maps

Ideally these maps are linked to flood gauge records so that a flood extent for an estimated gauged water level could be referenced in a real flood event. While the pre-cooked maps will never exactly replicate a real flood event they serve as an appropriate estimate and minimise the need for real time modelling which is impractical in a flash flood environment.

These maps could also be created for a dam break scenario provided the flood extents associated with the dam break modelling can be made available.

Improved flood emergency planning could lead to more efficient evacuations, leaving more time for other flood emergency activities.

The costs for this measure would be a function of the number of maps required. However, as a guide, a set of maps based only on design event mapping would cost approximately $6,000, with mapping linked to gauged data at approximately $15,000. As Tenterfield has recently experienced and effectively managed a rare flood event there is no immediate driver for this option. However, this measure is recommended as part of Council's

medium to long term planning to ensure the knowledge of flooded and vulnerable properties is maintained and available for potentially rarer flood events.

As an additional tool for disaster response, it is recommended that Council give consideration to installing additional boom gates at flood-prone road crossings. However, it should be noted that this may lead to a risk that flooded roads without gates or where the gates have not yet been closed are presumed safe for vehicles. It will be important to assess whether the potential benefits of installing boom gates outweigh this risk. Installing boom gates does not negate the need for community education measures, particularly in Tenterfield where hazardous road flooding presents the greatest flood risk to residents.

7.4 Community Awareness and Readiness

Because Tenterfield experienced a large flood in 2011, it is likely that the community awareness is relatively high. However, as the time since a significant flood event increases, it is likely that the community awareness will decrease. In order to maintain an acceptable level of awareness, many Councils run targeted programs to increase understanding of flood risk in the community.

Flood awareness campaigns may include:

- Advertisements placed in public areas
- Flood totems
- Clear identification of evacuation routes and refuges (signage)
- Web-based information, in particular development of an SES FloodSafe brochure for Tenterfield highlighting the specific risks to the Tenterfield township.
- Individual awareness tools such as flood property reports and flood flag maps. This may also be provided as information of 149 Planning Certificates issued with the purchase or modification of a property.

Due to the short warning times that are expected for large flood events in Tenterfield, community awareness is considered important. In particular, the risk of hazardous flooding of roads and public areas should be managed through educating the public on the dangers of driving or wading through floodwaters. This could be achieved through advertisements and web-based information. Reminders prior to the wet season through Council's newsletter, website and paper advertisements serve a low cost investment in maintaining community awareness.

Flood totems are an inexpensive tool that can be useful tool for reminding communities of the risk of flooding and preserving flood knowledge. This is considered to be a viable option for Tenterfield because there are several Council-owned areas close to the creek where a flood totem could be installed at a reasonable distance from private property. Four potential locations were identified as providing suitable locations for a flood totem. These are illustrated on **Figure 7-3**.

Flood totems are a relatively low cost floodplain risk management measure and are in the order of $10,000 per Totem. The installation of flood totems is recommended for Tenterfield to preserve flood knowledge of the January 2011 event and remind the community that events larger than this event can occur. However, given that the 2011 flood event was less than 5 years ago installation of flood totems need not be undertaken as a priority action and may be installed over the next 5 year planning horizon. However, community feedback on flood totems during the public exhibition of this document was very positive and this feedback should be considered during development of the schedule of implementation. **Figure 7-4** provides an example of a basic telegraph pole used as a flood totem. Flood totems may also be commissioned as a component of a public sculpture.

Figure 7-3 Example locations for flood totems in Tenterfield

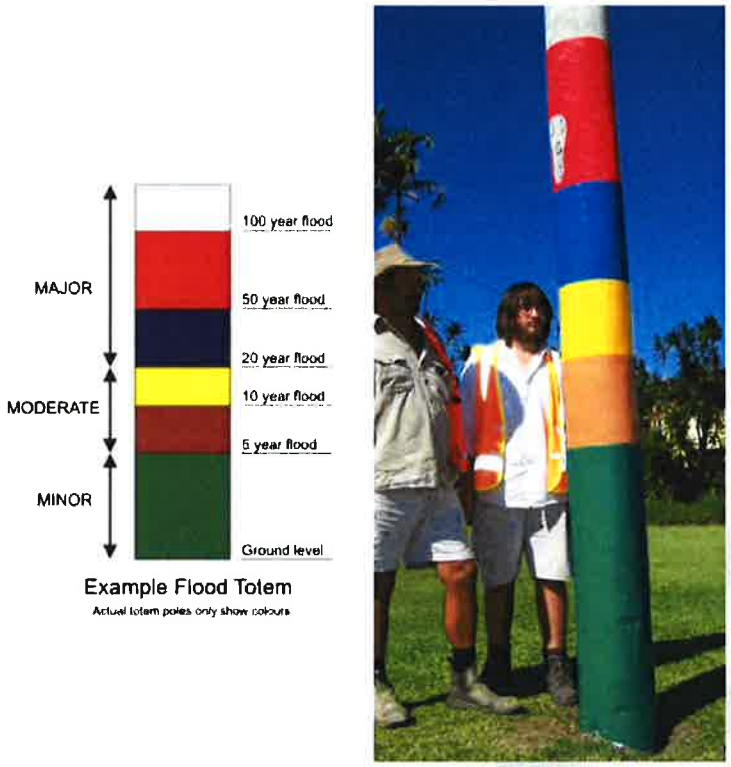


Figure 7-4 Example Flood Totems

Isolation of dry areas during floods has not been found to cause significant issues in Tenterfield and a large number of routes are available to escape flooded areas. Therefore, signage of evacuation routes may not be appropriate. However, the current disaster response procedures to close flooded roads through the manual or boom gate functions should continue.

Few properties in Tenterfield are affected by flooding in events up to and including the 1% AEP event. Therefore, individual flood property reports and flood flag maps would only be useful for a small number of properties and this measure is not likely to be cost effective. However, to manage the future flood risks it is recommended that this information is provided to the community through 149 Planning Certificates and to the emergency services through pre-cooked databases and mapping. This is discussed further in **Section 7.2** and **Section 7.3** respectively.

7.5 Flood Prediction and Warning

The Office of Water (within the Department of Primary Industries) operates a monitoring site on Tenterfield Creek at Clifton. There have been suggestions from the community following the 2011 flood event that installing a gauge further upstream (either at the Whalen Creek junction or at the crossing of the New England Highway) could assist in flood warning. It is thought that this could be particularly useful for residents of Mingoola, where there is a junction between Severn River, Mole River, Tenterfield Creek and Pikes Creek. Additional gauge information could potentially assist in determining whether flood peaks from multiple waterways are likely to coincide, resulting in a larger event.

A site visit was undertaken by a member of the study team who specialises in flood warning systems to assess the opportunity to use the existing flood warning system developed for the dam for non-dam break scenarios and to benefit downstream towns. The review indicated that the operating rules associated with the current system can be altered such that an additional constraint can be added to address non-dam break scenarios. However, altering the operating rules alone would achieve little. To increase the effectiveness of the warning system (non-dam break situations) would most likely require additional gauges in the Groombridges and Curry's Gap Catchment. This is due to the fact that Tenterfield Creek makes up only a proportion of the total catchment area to Tenterfield Town.

As part of the review the requirements to reinstate the current warning gauge system to its original design requirements was assessed. The cost estimate associated with reinstating this system is estimated at $25,000.
Improvements to the Flood Warning System – Non Dam Break Scenarios

The original system (as installed in 2000) included a flood forecast model developed by Hydro Tasmania Consulting (now Entura), however this model has long been discarded. Council therefore has two options to improve the flood warning system for non-dam break scenarios

- Option 1 – Council managed system based on retrofitting or upgrading the existing system; and
- Option 2 – Council to approach BoM regarding further investment in BoM managed systems in the catchment.
- Option 3 – General improvements to the flood warning system.

It is also recommended that Council consider alternative communication options such as sending flood warnings via SMS. However, it is thought that this option should be considered at a later stage after the flood prediction system has been improved.

It may also be beneficial to consider installing a tilt pan zoom camera at Curry's Gap Road to assist with flood warning. This would be the responsibility of Council to maintain and use for flood warning information (whereas flood gauges would be operated by BoM), meaning that Council would take on more responsibility for flood warning.

7.5.1.1 Option 1 – retrofit or upgrade the existing system

Additional gauges could be added to the system, to provide a system that covers both dam break and non-dam break flooding. However, to provide any additional warning time the system would require a flash flood model capable of running in real time and able to link to the SCADA. A new rain gauge would be required in the upper Groombridges Creek Catchment and the Douglas Street Gauge (refer to **Figure 7-5**) upgraded to include velocity monitoring. Additional software would be required to store the data, schedule the running of the model and to output the results to the SCADA. Calibration of the model would be required as would verification of rating curves. The Douglas Street Gauge code would also need to be modified.

Figure 7-5 Douglas Street Warning Gauge

If this option were to be selected a hydrologic and hydraulic model would need to be built and calibrated. The existing two dimensional hydraulic modelling undertaken by DHI would not be a suitable model for this purpose as the model simulation time of 24 hours would not support the rapid response required. The existing one dimensional model developed by DHI in 2001 may provide a suitable model for this purpose but would need to be revised for this purpose. Council would also need to have staff capable of running simulations in an emergency situation.

The costs associated with this option are estimated at $150,000. This option is not recommended as the costs of this option are significant relative to the potential benefits / likely reduction in flood damages in town. Furthermore, it is likely to be impractical to run a flood forecasting model within Council during a flash flood event. The outcomes of the modelling are also considered unlikely to change Council and the community's response to a disaster event. Real time modelling of flood events for flood warning is considered more appropriate for floodplains with a 12 to 48 hour warning time.

7.5.1.2 Option 2 – Council to approach BoM regarding further investment in BoM managed systems in the catchment.

As flood warning is the responsibility of the BoM not Council (Dam break warning is the responsibility of Council) it is best that the BoM be consulted regarding the inclusion of any new gauging stations (and even the data from the existing system) into the BoM Flood ALERT system.

These gauges may assist not only in improved flood warning but also in the collection of rainfall and flow data for future calibration and verification of the flood study.

While the costs of installation of new gauges would need to be discussed with BoM typical costs of ALERT stations are:

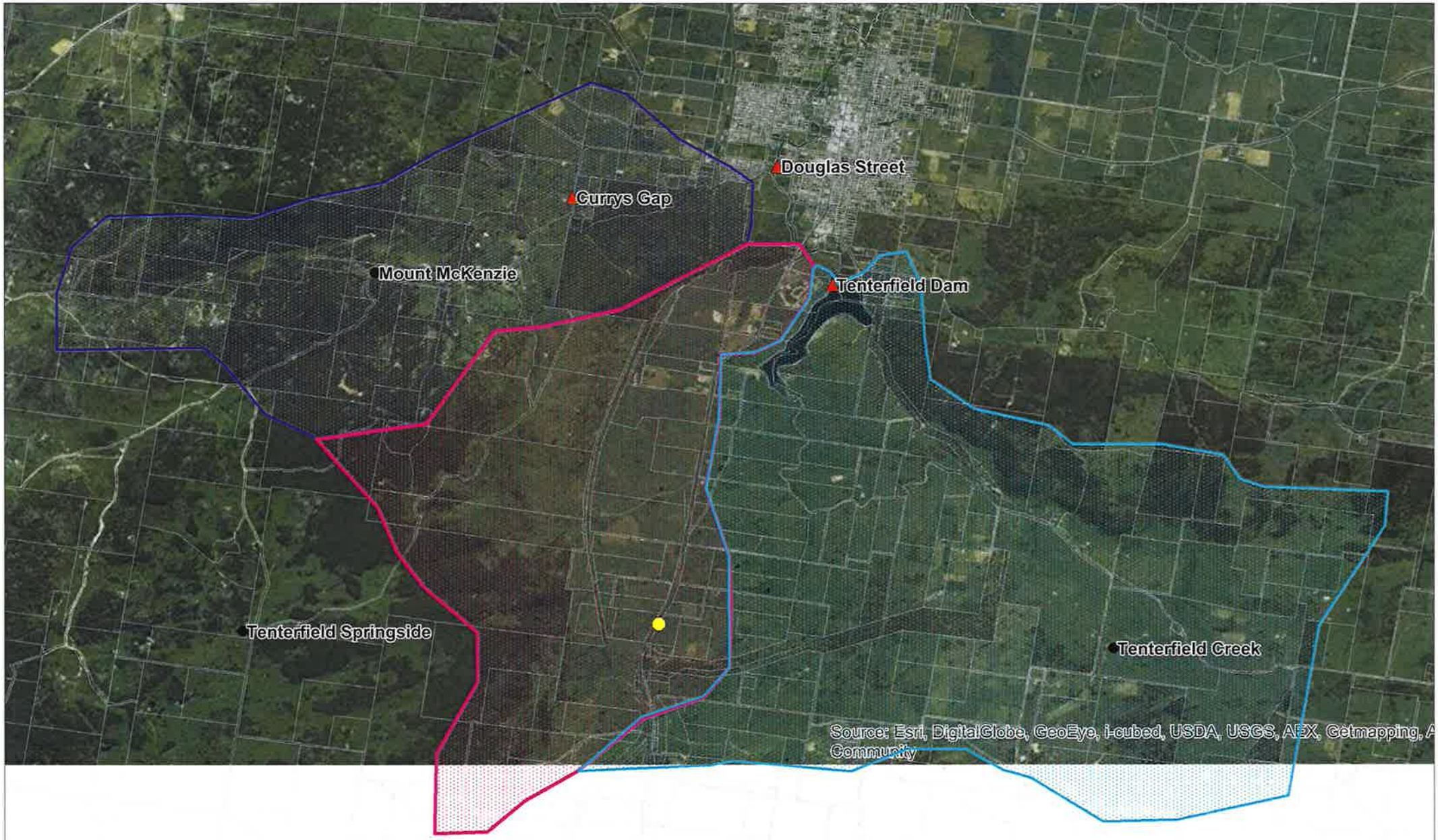
- ALERT Rainfall Station to BoM specifications: $20,000

- ALERT Water Level Gauging Station to BoM specifications: $38,000-$45,000 depending on the site
- ALERT Repeater Station: $22,000

It is recommended that Council discuss the opportunity to improve flood warning through additional BoM gauges with BoM as part of the Tenterfield FRMP. **Figure 7-6** illustrates the location of the existing gauges and highlights the data gap in the Groombridges and Curry's gap catchments. The Groombridges and Currey's catchments are of similar magnitude to the Tenterfield Dam catchment. However due to the siltation of the existing Currey's gap gauge data is only captured at the downstream flow gauging station at Douglas Street. As the Douglas Street gauge is owned and operated by Council it is not set up for non-dam break flow gauging and is not part of the BoM ALERT system. In addition to this an additional rainfall gauge within the Groombridges catchment may also assist with flood warning and calibration of future flood events. Review of the rainfall radar from the 2011 flood event (refer **Appendix B**) indicates that the most intense rainfall may have fallen within this catchment and may explain the challenges associated with calibration of the January 2011 flood event.

It is noted that the system can be upgraded to provide warning for the broader catchment and agricultural land downstream of the township, however as the system uses one repeater station located at Mount McKenzie there is a limitation as to how far the radio signals can travel. An alternative to this would be to add stations using NextG or Satellite communications.

According to Council, the closest centre requiring enhanced flood warning is Mingoola. Council provided copies of correspondence between the Mingoola Progress Association and The Federal Minister (2012) which included details of discussions with the NSW Office of Water and the BoM. The Progress Association is requesting that new water level gauging stations be installed on Mole and Tenterfield Creeks and rain gauges in the catchment. Assessment of flood warning for Mingoola is outside the scope of this assessment. While any improvements to flood warning for Tenterfield will improve predictions at Mingoola, Mingoola is located a significant distance downstream of Tenterfield and as such it is noted that there may be more appropriate locations for flood warning and gauging downstream of Tenterfield.



JACOBS

N

Scale: 1: 80,000

Datum: MGA56

Coordinate System: MGA Zone 56

LEGEND

- Currys Creek Catchment
- Groombridges Creek Catchment
- Tenterfield Creek Catchment
- Existing Water Level Gauge
- Existing Rainfall Gauge
- Potential New Rainfall Gauge

Figure 7-6

Existing Rainfall and Level Gauges

Project: Tenterfield Floodplain Risk Management Study

7.5.1.3 Option 3 – General Improvements to the Flood Warning and Broadcasting System

The following budget estimates are also provided for general improvements to the flood warning system.

The existing flood warnings could be upgraded with warning tone and pre-recorded voice messages which would provide an immediate improvement in the effectiveness of the warning system. Pre-recorded voice messages are now used in modern warning systems such as those installed at Grantham QLD, Mundubbera QLD and soon to be installed at Killarney and Leyburn QLD.

The voice messages are used to advise of system testing and to inform the public as to the reason for the warning followed by an instruction. Typical examples include:

"*This is a test of the Tenterfield Flood Warning System, I repeat, this is only a test*".

"*This is a Tenterfield Shire Council flood warning announcement, avoid low lying areas, move to higher ground now, I repeat avoid low lying areas, move to higher ground now!*"

It would be possible to upgrade the existing system to achieve this. However this is not recommended as:

- The existing stations are too close together
- The amplifiers and speakers are not specifically designed for voice messages
- The voice messages must be properly engineered by a warning system manufacturer to suit the warning equipment being used

An alternative to this would be to decommission Federation Park, Shirley Street and Douglas Street sirens and install a modern version. Just one system would be required at Shirley Street that would cover all of Tenterfield. This is illustrated in **Figure 7-7**. The existing telemetry equipment at Shirley Park would be also be upgraded and the SCADA would have a new siren control page.

The cost estimates for decommissioning of the current sirens and installation of a modern version is approximately $75,000. At present this option would only assist in managing flood risks associated with a dam break scenario as the current flood warning system that activates the siren is not set up for non-dam break scenarios. In the event that the flood warning system was improved for non-dam break scenarios this would also assist with non-dam break flood warning.

While this is a significant investment relative to the flood damages it is considered to provide the most effective means of quickly distributing flood alerts to the community, thereby minimising risks to life. As the assessment of mitigation options for dam break is outside the scope of this study this option is not a recommendation of this study. However, it is recommended that Council consider this option in the context of the broader dam safety upgrade activities currently being undertaken.

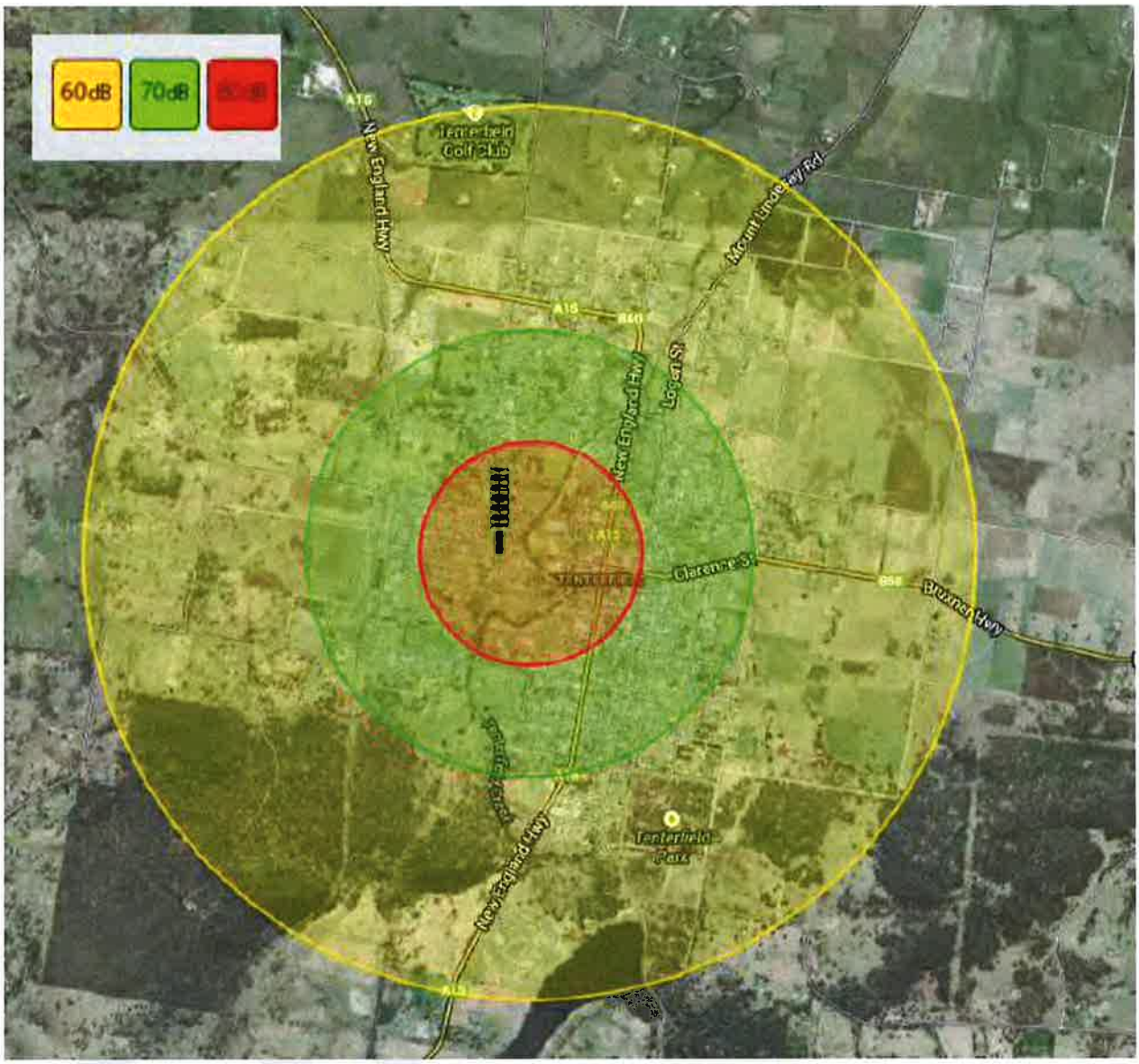


Figure 7-7 Potential Location of a New Electronic Siren Equip with pre-recorded messages.

Remote Pan Tilt Zoom Cameras could be installed at key hotspots to provide real time viewing. The systems aid in disaster management through increased situational awareness. The cameras can also provide a historical pictorial record of the events as they take place. The cost associate with these systems is approximately $25,000 per installation. While these cameras systems provide a great tool for disaster management, they have not been recommended as a priority measure for Tenterfield as Council already has good physical access to most hotspots.

7.6 Flood Modification Response Measures

7.6.1 Road and Bridge Upgrades

Due to the magnitude of flood damage costs associated with infrastructure in Tenterfield, it is considered that large structural measures will probably not provide sufficient benefit to justify their cost. However, many roads in Tenterfield are subject to flooding and there may be value in considering local road upgrades.

It is important to note that raising a road crossing to increase its flood immunity will generally result in more blockage of the waterway in a large event that overtops the road. This means that, while conveyance will increase in smaller flood events that pass underneath the raised bridge deck, it will decrease in larger floods, potentially resulting in upstream flood impacts. The potential additional blockage of a waterway area is illustrated in **Figure 7-8.** Therefore, it is not recommended that crossings are raised in close proximity to flood-prone buildings.

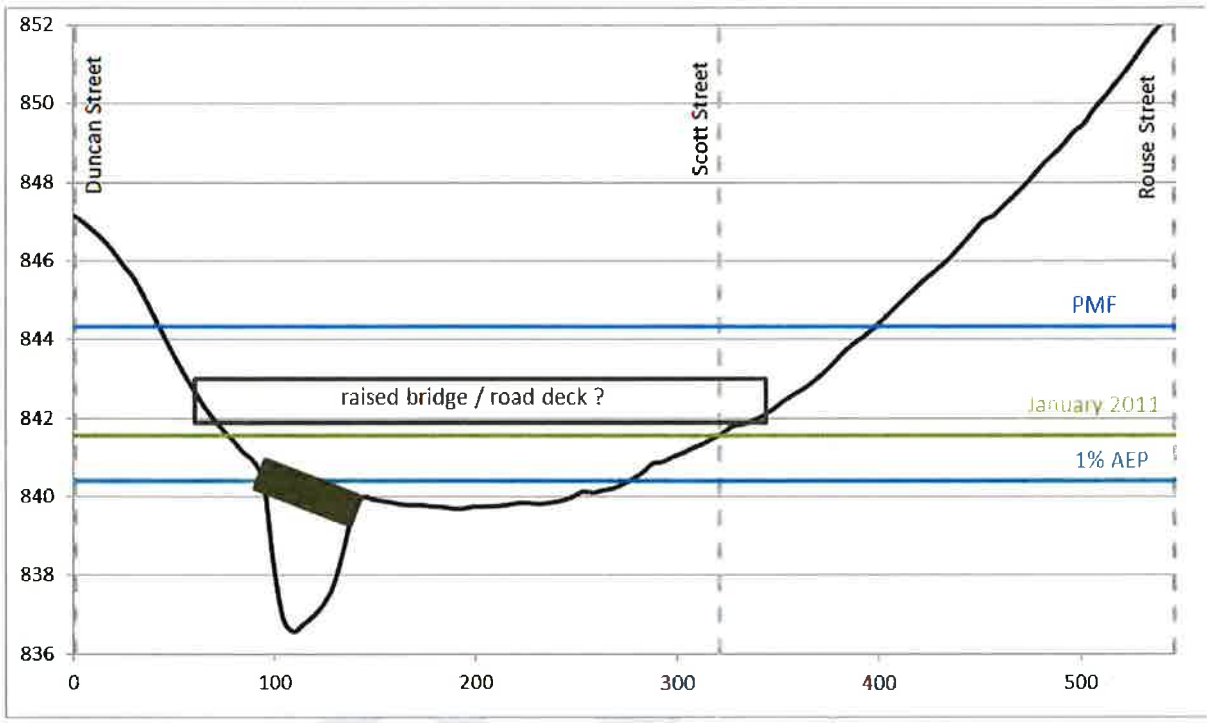


Figure 7-8 Example of a road upgrade to achieve increased flood immunity at High Street

For this study, one road upgrade option was assessed in order to give an indication of the potential benefits that similar measures are likely to have in Tenterfield. The location for the modelled upgrade was the crossing on High Street, selected because there are limited dwellings immediately upstream that are likely to be affected by the potential increase in water surface levels.

A simulation was undertaken to assess the feasibility of raising the road to have 1% AEP flood immunity. This was run for a 1% AEP flood event. The bridge deck and road either side of the bridge were raised so that the 1% AEP flood would not overtop the road or reach the bridge deck. This resulted in flood impacts upstream, with increases in flood levels of up to 60 mm at residential properties. The extent of the impact is illustrated in **Figure 7-9.**

The cost of raising the road and upgrading the bridge structure to achieve a 1% AEP flood immunity would be significant in the order of $2,000,000. This cost investment would not be justified on the basis of the flood damages in Tenterfield. Therefore this option is not recommended as a key floodplain risk management reduction measure.

While targeted road upgrades are unlikely to be justified in terms of cost, it may be appropriate for Council to select priority crossings for re-establishing access following a flood event. Future road investments may take this into consideration. In the short term, it will help to ensure that the most important road crossings are prioritised for re-opening following flooding. An emergency response strategy for inspecting priority bridges after flood events could assist in minimising closure time due to flooding.