Muswellbrook FRMS&P

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EXECUTIVE SUMMARY

Introduction

Muswellbrook and Denman are located in the Upper Hunter Region of New South Wales approximately 110 km north west of Newcastle. Muswellbrook is situated at the confluence of the Hunter River and Muscle Creek, while Denman is located on the western edge of the Hunter River Floodplain. Flooding in the study area can occur from a range of flood mechanisms including the: Hunter River; Muscle Creek; and the local Denman catchment.

Muswellbrook Shire Council (Council) is responsible for flood risk management and local land use planning within the Local Government Area (LGA). Council has commissioned Royal HaskoningDHV (RHDHV) to produce the Muswellbrook Floodplain Risk Management Study and Plan (FRMS&P) on behalf of Council and The NSW Office of Environment and Heritage (OEH). The project has been conducted under the state assisted Floodplain Management Program and received state financial support.

The primary purpose of the FRMS&P is to reduce risk to life and property by identifying, assessing and comparing various risk management options whilst considering opportunities for environmental enhancement as part of the mitigation works (NSW State Government, 2005).

The FRMS&P included provision for a Flood Study for Muscle Creek and an Overland Flow study for Denman as well as a Flood Study Revision for the Hunter River (Muswellbrook to Denman). The Flood Study Revision included model re-calibration and validation as well as updating the model to use the latest Australian Rainfall and Runoff (ARR) 2016 guidelines and techniques.

History of Flooding in Muswellbrook and Denman

It is generally agreed that the largest flood to have been experienced in Muswellbrook and Denman occurred in 1870 (estimated discharge 5900 m^3/s). The largest flood to have been formally recorded occurred in February 1955 (recorded discharge 5013 m^3/s). The event had an estimated Average Recurrence Interval (ARI) of 500 years. Large areas within the urban centres of Muswellbrook and Denman were inundated during the event.

Glenbawn Dam, located in the upper catchment of the Hunter River some 20 kilometres northeast of Muswellbrook, was under construction during the 1955 flood event. However, the dam was not in full operation until 1958. The dam has a catchment area of approximately 1290 square kilometres (31% of the Hunter catchment at Muswellbrook and 28% of it at Denman) and an approximate storage volume of 750 gigalitres of which 120 gigalitres is dedicated to flood storage. The dam has significantly reduced the flood risk characteristics along the Hunter River downstream. Despite the presence of the dam, further significant flood events occurred in Muswellbrook and Denman in February 1971, January 1976, August 1998, November 2000 and June 2007; although it should be noted that the inundation that occurred during the June 2007 flood event was primarily the result of flooding from Muscle Creek, which feeds into the Hunter River at Muswellbrook. The 1971 event is estimated to be a 50-100 yr ARI magnitude while the other Hunter River events were of the order of 20-50 yr ARI. The June 2007 rainfall on Muscle Creek was estimated to be an approximate 50 yr ARI event.

Muswellbrook is now protected by a 1.16 km levee that was constructed in 1992 and provides significant flood relief for events up to the 500yr ARI. It should be noted that while the levee protects Muswellbrook from upstream flooding, tailwater flooding in events greater than the 10 yr ARI still results in floodwaters backing up from the end of the Scott / Brook Street.

The Denman Levee is approximately 2.4km long and was constructed in 1988 and protects Denman from flooding for events up to the 500yr ARI, provided the Crinoline Road temporary flood barrier is used for events larger than the 100yr ARI.

Community Consultation

Community consultation was undertaken to inform the community about the development of the Floodplain Risk Management Study, its likely outcomes as well as improving the community's awareness and readiness for flooding. The consultation process provided an opportunity to collect information on the community's flood experience, their concerns on flooding issues and to collect feedback and ideas on potential floodplain management measures and other related issues. The key elements of the consultation program involved:

- Consultation with the Floodplain Management Committee through meetings, presentations and workshops;
- Distribution of questionnaires and information brochures;
- Community information sessions; and
- Public exhibition of the Draft Floodplain Risk Management Study and Plan.

Flooding Behaviour

Flood behaviour for the study area was quantified during the FRMS&P in three studies including:

- Flood Study for Muscle Creek (RHDHV, 2017c)
- Overland Flow study for Denman (RHDHV, 2017b)
- Flood Study Revision for the Hunter River - Muswellbrook to Denman (RHDHV, 2017a)

Flood extents from each individual flood mechanism were combined to produce a single envelope of design flood extents which represented the magnitude of flooding for a given frequency (i.e. annual exceedance probability (AEP) or average recurrence interval (ARI)) as discussed in **Section 4.1**

The Hunter River catchment area upstream of Muswellbrook is approximately 3,370 km^2 while at Denman the total catchment area is approximately 4,510 km^2. The Goulburn River flows into the Hunter River just downstream of Denman adding an additional 7,800 km^2 catchment inflow at this location.

The property inundation assessment (refer **Section 4.2**) indicates that while no properties are impacted (by above floor flooding) in the 10% AEP (10yr ARI), some 20 properties are flooded in the 5% AEP (20yr ARI), 175 properties are flooded in the 1% AEP (100yr ARI) and 659 properties are estimated to be flooded in the PMF. Due to the large size of the catchment, longer 24-48 hour rainfall events are required to cause significant flooding in the study area from the Hunter River catchment.

Muscle Creek drains 92 km^2 of catchment upstream of Muswellbrook bringing flows centrally through the township of Muswellbrook before joining the Hunter River. It should be noted that flooding in as little as the 5% AEP (20yr ARI) event can inundate the only two roads connecting the northern and southern parts of Muswellbrook creating a potential issue for emergency services.

The property inundation assessment (refer **Section 4.2**) indicates that while no properties are impacted (by above floor flooding) in the 10% AEP (10yr ARI), some 17 properties are flooded in the 5% AEP (20yr ARI), 38 properties are flooded in the 1% AEP (100yr ARI) and 168 properties are estimated to be flooded in the PMF. Due to the moderate size of the catchment, while longer (36 hour) rainfall events are required to cause critical flood levels, shorter duration events 2-12 hours may also produce flash flooding during intense rain events.

The township of Denman receives runoff from a local catchment area that extends from the Denman Levee to a ridge line that is located approximately 2 km to the west of the township. The Northern Catchment has a total area of 3.3 km^2 and drains to the east through two discrete channels that do not enter the existing residential areas. The Southern Catchment has a total area of approximately 7.2 km^2 and drains through a number of discrete channels and overland flow paths towards the township of Denman. The 2 hour duration event was identified as producing the highest peak flows and flood levels within the majority of the study area.

The property inundation assessment (refer **Section 4.2**) indicates that while no properties are impacted (by above floor flooding) in the 10% AEP (10yr ARI), 3 properties are flooded in the 2% AEP (50yr ARI), 7 properties are flooded in the 1% AEP (100yr ARI) and 412 properties are estimated to be flooded in the PMF, though most of these are due to the Hunter River overtopping the Levee and not the local catchment flood mechanism.

Property Inundation Assessment

A summary of the location and frequency of above floor property inundation in the study area is presented in **Section 4.2.2**. The assessment shows that:

- In an extreme flood (i.e. the PMF), 1239 properties in the study area are inundated above floor level. Of these properties, 659 (53% of properties) are on the Hunter River floodplain, 412 (33% of properties) are in the township of Denman, and 168 affected by local flooding from the Muscle Creek catchment.
- Similarly, in the rare, 0.2% AEP (500-year ARI) event, 360 properties are inundated above floor level. Of these properties, 274 (77% of properties) are on the Hunter River floodplain, 15 (3% of properties) are in the township of Denman and 71 properties are affected by local flooding from the Muscle Creek catchment.
- During the 1% AEP (100-year ARI) event, 220 properties are inundated above floor level. Of these properties, 175 (80% of properties) are on the Hunter River floodplain, 38 (19% of properties) are affected by local flooding from the Muscle Creek catchment with only 7 properties) affected in the township of Denman.
- During the 5% AEP (20-year ARI) event, 37 properties are inundated above floor level. Of these properties, 20 (58% of properties) are on the Hunter River floodplain with the remainder affected by local flooding from Muscle Creek. No properties are flooded above floor level in the township of Denman.
- During the 10% AEP (10-year ARI) event, no properties are inundated above floor level.

Flood Damages Assessment

The Average Annual Damage (AAD) is the main comparative factor that is derived from the flood damages assessment with which to evaluate the effectiveness of proposed mitigation options. The AAD represents the estimated direct tangible damages sustained every year on average over a given 'long' period of time and is determined using the full range of flood events previously considered in the FRMS. A summary of flood damages (AAD Contribution) and property inundation is presented in **Section 4.2.3** and shows:

- In the 1% AEP (100-year ARI) event, it is estimated that $20.8 Million of tangible flood damages would occur in the study area. The majority (i.e. 79%, $16.9 Million) of these damages are attributed to main stream flooding on the Hunter River floodplain. During a 1% AEP event, flood damages from Muscle Creek are estimated to be $3.0 Million, and for the township of Denman approximately $1.6 Million.
- In the 1% AEP (100-year ARI) event, residential properties make up 93% (i.e. $20.0 Million) and non-residential (i.e. either commercial or industrial) properties estimated to incur an estimated $1.5 Million worth of flood damages.
- With the exception of the PMF event, the majority (greater than 75%) of flood damages occur in the Hunter River floodplain area with the Muscle Creek area accounting for most of the remainder and the Denman area accounting for typically less than 10% of the damaged properties. During the PMF event, however, the number of properties with above floor flooding in the Denman area increases substantially accounting for 35% of the total.
- Residential properties account for between 89% and 96% of the flood damage costs for events greater than the 10% AEP. For the 10% AEP, flood damage costs are entirely related to residential properties.

Planning and Development Controls

Council's existing and proposed DCP provides general provisions relating to all the floodplains and specific provisions relating to individual floodplains which are subject to a Floodplain Management Plan. Some minor revisions to the proposed DCP are recommended based on the adopted FRMS&P for Muswellbrook and the associated flood risk mapping derived in this study. In particular the DCP should be updated to be consistent with recent NSW DoP guidance as discussed in **Section 5.2**.

Floodplain Management Options Considered

Measures which can be employed to mitigate flooding and reduce flood damages can be separated into three broad categories including: **flood**, **property** and **response** modification measures. The following mitigation options were considered applicable/suitable for reducing flood risk in the study area, and were therefore the subject of a detailed assessment (including flood damages and cost/benefit analysis) as part of this FRMS in **Section 6.4**.

Flood modification measures

HRS1 - Backwater Levee Option – Section 6.4.1

HRS2 - Sydney Street Option – Section 6.4.2

HRS3 - Channel Vegetation Removal – Section 6.4.3

MC1 - Enhance creek bank adjacent to golf course – Section 6.4.4

MC2 - Golf course flood bund – Section 6.4.5

MC3 - Channel vegetation management – Section 6.4.6

D1 - Blockage / maintenance policy to unblock 2 Virginia St (Denman) culverts – Section 6.4.7

D2 - Upgrade to Virginia St (Denman) culvert (north) - Section 6.4.8

Property modification measures

P1 - Voluntary House Raising and Voluntary Purchase (properties below 1% AEP) - Section 6.4.9

P2 - Voluntary House Raising and Voluntary Purchase (properties below 2% AEP) - Section 6.4.10

P3 - Voluntary House Raising and Voluntary Purchase (properties below 5% AEP) - Section 6.4.11

Response modification measures

FW1 - Flood Warning System - The development of a flood warning system for Muscle Creek is presented in detail in Section 7.

Recommended Floodplain Risk Management Options

An analysis of mitigation options for the Hunter River HRS1 (Muswellbrook Backwater Levee) HRS2 (Sydney Street Levee) shows that they result in a significant reduction in flood damages (between $1.45 and $2.66 Million). However, due to the high cost of implementing such measures, all benefit/cost (B/C) ratios are significantly below unity (one) and hence would not be considered for implementation on an a solely economic basis and have been given a low priority in the floodplain risk management plan (FRMP). HRS3 (Channel Vegetation Removal) is not recommended in the FRMP as the environmental damage resulting from this option means that it is unlikely to be approved by the land management authority.

Both of the structural mitigation options for the Muscle Creek MC1 (Enhance creek bank adjacent to golf course) or MC2 (Golf Course flood bund) are able to significantly reduce flood risk in Muswellbrook. Both benefit/cost (B/C) ratios are significantly above unity (one) and hence should be considered for implementation on an economic basis and have been given a medium-high priority in the floodplain risk management plan (FRMP). While option MC2 costs slightly more than MC1, ($1.1 Million vs $0.84 Million), MC2 provides greater reduction in flood damages ($1.93 Million vs $1.83 Million). However, while the B/C ratio of MC1 is slightly higher than MC2 (2.18 vs 1.76), because MC2 is able to provide flood storage, it provides a greater degree of protection in more extreme events and despite the additional cost is considered to be the favourable option in terms of reducing flood risk. MC3 (additional Muscle Creek vegetation management) does not adequately reduce flood risk and is not recommended in the FRMP.

If MC1 or MC2 are not likely to be implemented within a 2 to 5 year timeframe, then a flood warning system (FW1) is strongly recommended to reduce risk to life from rapidly rising floodwaters that sweep through residential areas of Muswellbrook to the south of Muscle Creek and can isolate the southern side of town as frequently as the 5% AEP flood event.

Options D1 (Blockage / maintenance policy to unblock 2 Virginia Street culverts) and D2 (Upgrade to Virginia Street culvert (north)) investigated two options to reduce flood risk and damages in Denman. Due to the low cost of D1 and ability to protect 2 properties from above floor flooding and 2 properties from under floor flooding in the 1% AEP event it has been given a medium to high priority in the FRMP. The low B/C associated with D2 means it has not been recommended in the FRMP.

Mitigation option P3 (VHR of 12 properties and VP of 6) produces a B/C ratio 0.84 and should be considered to reduce flood risk in the study area. Further analysis is recommended to identify which of the VHR/VP properties are in a high risk area and should be prioritised.

Draft Muswellbrook and Denman Floodplain Risk Management Plan

The following table forms an action list of the draft Muswellbrook to Denman Floodplain Risk Management Plan (the Plan). The objective of the Plan is to recommend a range of property, response and flood modification measures to mitigate the existing and future flood affectation in the study area.

The Plan (as detailed in **Section 8**) should be regarded as a dynamic instrument requiring review and modification over time. The catalyst for change could include new flood events and experiences, legislative change, alterations in the availability of funding or changes to the area's planning strategies. In any event, a thorough review every five years is warranted to ensure the ongoing relevance of the Plan.

Mitigation Measures Recommended for Implementation

Measure*	Description	Estimated Capital Costs and (Ongoing Costs)	Responsibility and Funding	Priority / Time frame
MC1[1] or **MC2**[1]	**Muscle Creek** Enhance creek bank adjacent to golf course Golf course flood bund	$840,000 $1,100,000	Council and OEH	**Medium - High** 2-5 years[1]
FW1[1]	Flood warning system for Muscle Creek	$50,000 to $100,000 ($5000/yr)	Council and OEH	**Medium - High** 2-3 years[1]
EM1	Emergency Management Planning (develop a Local Flood Plan)	SES and Council staff time of ~$10,000	SES	**High** <1 years
P3[3]	Consider VP and/or VHR for significant risk properties currently experience above floor flooding in the 5% AEP flood event	The VHR of 12 properties and VP of 6 properties is estimated to cost $2.40 Mil. Further analysis is recommended to identify which of the VHR/VP properties are in a high risk area and should be prioritised	VP – Council and OEH VHR - Property owner and OEH	**Low-Medium** <2 years
P4	Update the LEP	Council staff time of $5,000-10,000	Council	**High** <1 years
D1	Blockage / maintenance policy to unblock 2 Virginia St (Denman) culverts	$50,000 over 50 years	Council	**Medium - High** <1 years
EM2	Community Flood Education	Council / SES staff time ~$10,000	Council / SES.	**Medium** 2-5 years
HRS1	Muswellbrook Backwater Levee	$2.25 Million	Council and OEH	**Low** 2-10 years[2]
HRS2	Sydney Street Levee	$3.5 Million	Council and OEH	**Low** 2-10 years[2]

Notes: * details of the mitigation measures are provided in **Table 6-21** and **Section 6.4**

VP = Voluntary Purchase, VHR = Voluntary House Raising

1) If MC1 or MC2 are not likely to be implemented within a 2 to 5 year timeframe, then a flood warning system is recommended to reduce risk to life from rapidly rising floodwaters that sweep through residential areas of Muswellbrook to the south of Muscle Creek and can isolate the southern side of town as frequently as the 5% AEP flood event.

2) Due to the high cost and low B/C ratio of these options they would require long term planning and it may be difficult to obtain funding from OEH until higher priority flood risks in NSW have been dealt with.

3) A desktop study into the prioritisation of all at risk properties suitable for VP or VHR should be conducted.

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Abbreviations and Glossary of Terms

Abbreviations	
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AR&R87	Australian Rainfall and Runoff (1987)
AR&R16	Australian Rainfall and Runoff (2016) Major Update
DEM	Digital Elevation Model (a technique to define ground surface elevation data on a grid)
DoP	NSW Department of Planning
FLC	Form Loss Co-efficient (i.e. structure hydraulic loss parameter)
IEAust	Institution of Engineers Australia
IFD	Intensity Frequency Distribution
FRMS&P	Floodplain Risk Management Study and Plan
LiDAR/ALS	Light Detection and Ranging (method used to collect ground surface elevation data using an aircraft)
MHL	Manly Hydraulic Laboratory
OEH	NSW Office of Environment and Heritage
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RCBC	Reinforced Concrete Box Culvert
RCP	Reinforced Concrete Pipe
RHDHV	Royal HaskoningDHV
1D	One-dimensional (i.e. a flood model based on cross-section, pipe or structure information only)
2D	Two-dimensional (i.e. a flood model which is based on a full description of the ground terrain and is not restricted to cross-section data only)

Glossary of Terms	
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 m3/s has an AEP of 5%, it means that there is a 5% chance (i.e. a 1 in 20 chance) of a peak discharge of 500 m3/s (or larger) occurring in any one year. (see also average recurrence interval)
Australian Height Datum (AHD)	National survey datum corresponding approximately 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 20yr 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)

Catchment	The catchment at a particular point is the area of land that drains to that point.
Design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100yr ARI or 1% AEP flood).
Development	Existing or proposed works that may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving. For example meters per second (m/S)
Flood	Relatively high river or creek flows, which 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 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 level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as “stage”.
Flood liable land	See flood prone land
Flood plain	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.
Flood plain management	The co-ordinated management of activities that occur on the floodplain
Flood plain risk management plan	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 Management Manual. The plan usually contains both written and diagrammatic information describing how particular areas of the floodplain are to be used and managed to achieve defined objectives
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 Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
Flood source	The source of the floodwaters.
Flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
Floodway	A flow path (sometimes artificial) that carries significant volumes of floodwaters during a flood.
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.
Geomorphology	The study of the origin, characteristics and development of land forms

Gauging (tidal and flood)	Measurement of flows and water levels during tides or flood events.
Historical flood	A flood that has actually occurred
Hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems
Hydrodynamic	Pertaining to the movement of water
Hydrograph	A graph showing how a river or creek's discharge changes with time.
Hydrographic survey	Survey of the bed levels of a waterway.
Hydrologic	Pertaining to rainfall-runoff processes in catchments
Hydrology	The term given to the study of the rainfall-runoff process in catchments.
Isohyet	Equal rainfall contour
Morphological	Pertaining to geomorphology
Peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
Pluviometer	A rainfall gauge capable of continuously measuring rainfall intensity
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.
Riparian	The interface between land and waterway. Literally means "along the river margins"
Runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
Stage	See flood level
Stage hydrograph	A graph of water level over time
Sub-critical	Refers to flow in a channel that is relatively slow and deep
Topography	The shape of the surface features of land
TUFLOW	A hydraulic model that is used to simulate flood events.
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.
Water level	See flood level

PART A – FLOODPLAIN RISK MANAGEMENT STUDY

1 Introduction

Muswellbrook Shire Council (Council) is responsible for flood risk management and local land use planning within the Local Government Area (LGA). Council has commissioned Royal HaskoningDHV (RHDHV) to produce the Muswellbrook Floodplain Risk Management Study and Plan (FRMS&P) on behalf of Council and The NSW Office of Environment and Heritage (OEH). The project has been conducted under the state assisted Floodplain Management Program and received state financial support.

1.1 Study Objectives

The primary purpose of the FRMS&P is to reduce risk to life and property by identifying, assessing and comparing various risk management options whilst considering opportunities for environmental enhancement as part of the mitigation works (NSW State Government, 2005). This study assessed a suite of flood risk management measures and their associated tangible and intangible costs and determined a range of options for inclusion in the Floodplain Risk Management Plan and potential future implementation.

1.1.1 Flood Studies and Flood Study Revisions

The FRMS&P included provision for a Flood Study for Muscle Creek and an Overland Flow study for Denman as well as a Flood Study Revision for the Hunter River (Muswellbrook to Denman). The Flood Study Revision included model re-calibration and validation as well as updating the model to use the latest ARR 2016 guidelines and techniques.

The Flood Study for Muscle Creek and an Overland Flow study for Denman reports were delivered to Council in January 2017, while the Flood Study Revision report for the Hunter River (Muswellbrook to Denman) was delivered to Council in October 2017.

The flood studies required the development of flood models that could define the existing flood risk in Muswellbrook and Denman and evaluate potential mitigation options assessed as part of the Floodplain Risk Management Study.

1.1.2 Desktop Assessment of Muswellbrook and Denman Levees

Part of the FRMS scope was to undertake a desk top study of available information on the Muswellbrook and Denman Levee Systems. The key objectives of the reviews were to:

- Review a visual inspection report that was prepared by NSW Department of Public Works in 2016.
- Review levee design drawings and survey information that has been provided by Council.
- Apply the hydraulic model that has been developed as part of the FRMS to assess freeboard, likely overflow locations and identify portions of the levee that are exposed to elevated flow velocities.
- Make recommendations as required.

Reports detailing the assessment were delivered to Council in November 2016.

1.1.3 Floodplain Risk Management Study Objectives

The aim of a Floodplain Risk Management Study is to assess a range of flood mitigation strategies to alleviate flood risk in an LGA, in accordance with the NSW Government's Flood Prone Land Policy. The objectives of this study include:

- Reduce the flood hazard and risk to people and property in the existing community and to ensure future development is controlled in a manner consistent with the flood hazard and risk (taking into account the potential impacts of climate change).
- Reduce private and public losses due to flooding.
- Protect and where possible enhance the floodplain environment.
- Be consistent with the objectives of relevant State guidelines and policies, in particular, the Government's Flood Prone Land and State Rivers and Estuaries Policies and satisfy the objectives and requirements of the Environmental Planning Assessment Act, 1979.

1.1.4 Floodplain Risk Management Draft Plan Objectives

The Floodplain Risk Management Draft Plan presents a range of flood mitigation recommendations to address the existing flood liability of an LGA. The objectives of the plan are outlined below:

- Ensure that the draft floodplain risk management plan is fully integrated with Council's existing corporate, business and strategic plans, existing and proposed planning proposals, meets Council's obligations under the Local Government Act, 1993 and has the support of the local community.
- Ensure actions arising out of the draft plan are sustainable in social, environmental, ecological and economic terms.
- Ensure that the draft floodplain risk management plan is fully integrated with the local Emergency Management Plan (Flood Plan) and other relevant catchment management plans.
- Establish a program for implementation and suggest a mechanism for the funding of the plan, which should include priorities, staging, funding, responsibilities, constraints and monitoring.

1.2 The Study Area

Muswellbrook and Denman are located in Upper Hunter Region of New South Wales approximately 110 km north west of Newcastle. Muswellbrook is situated at the confluence of the Hunter River and Muscle Creek, while Denman is located on the western edge of the Hunter River Floodplain as presented in **Figure 1-1.** Muswellbrook has a population of 12,072, while 1789 people reside in Denman. The study area covers approximately a 60km reach of the Hunter River from 8km above Muswellbrook to 26km downstream of the confluence with the Goulburn River.

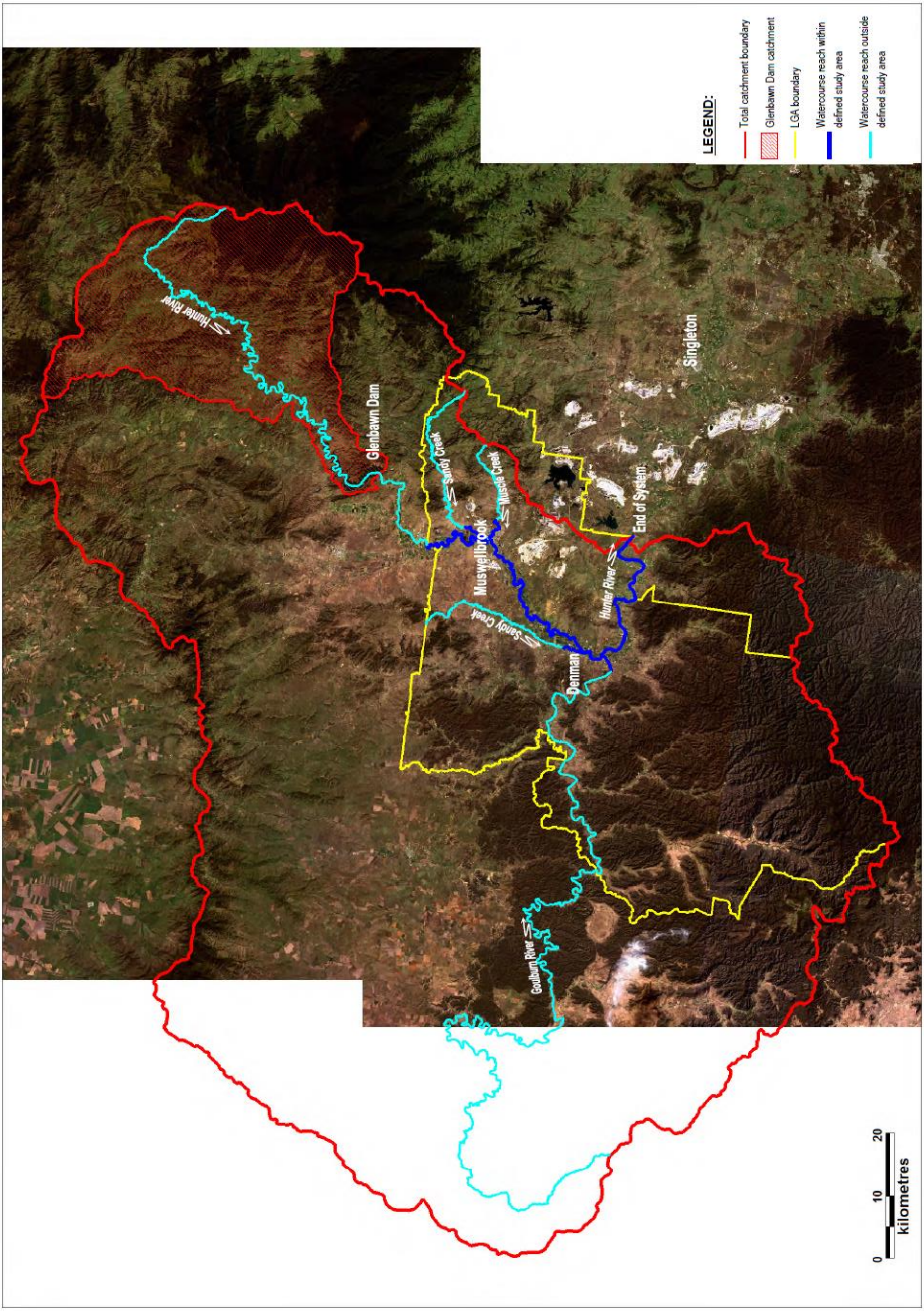

Figure 1-1: Location of Study Area

Source: WorleyParsons (2014)

1.3 The Need for Floodplain Management in Muswellbrook and Denman

Flooding in the study area can occur from a range of flood mechanisms including:

- the Hunter River;
- Muscle Creek;
- The local Denman catchment.

Details of these flood mechanisms are provided in **Section 2.1**. The local Denman catchment provides a source of regular “nuisance type” flooding due to overland flow paths and partially blocked culverts. In terms of risk to life, Muscle Creek provides the greatest source of flood risk due to the hazardous flow conditions that can rapidly occur between Bell and Wilder Streets (refer **Section 7**). Muscle Creek flooding in as little as the 5% AEP (20yr ARI) event can inundate the only two roads connecting the northern and southern parts of Muswellbrook creating a potential issue for emergency services.

Effective floodplain risk management identifies which properties or areas in the study area are at highest risk and will determine and prioritise appropriate mitigation measures to reduce the risk. Flooding considerations are also an important constraint to the location and nature of future development in the study area. By determining the detailed flooding characteristics of the study area including the full extent of floodplain inundation for a range of design event magnitudes, the flood study outcomes provided further detail for future development planning in the catchment.

Council has commissioned this study with the desire to approach local floodplain management in a considered and systematic manner. This study comprises the final stages of that systematic approach, as outlined in the Floodplain Development Manual (NSW Government, 2005). The approach will allow for more informed planning decisions within the floodplains of Muswellbrook Shire Council.

1.4 The Floodplain Management Process

The NSW State Government’s Flood Policy provides a framework to support the sustainable use of floodplains. The Policy is specifically structured to support development of mitigation measures to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas. Policy and practice are defined in the Government’s Floodplain Development Manual (2005).

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils with their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through the following sequential stages:

1. Establish Floodplain Risk Management Committee (or Working Group) - Conducts a vital oversight role for the floodplain risk management process, acting as a focus and forum for discussion of key issues in formulating the management plan.

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

3. Floodplain Risk Management Study - Evaluates management options for the floodplain in respect of both existing and proposed development.

4. Floodplain Risk Management Plan - Involves formal adoption by Council of a plan of management for the floodplain.

5. Implementation of the Plan - Construction of flood mitigation works to protect existing development, and use of flood risk management measures (such as development controls) to ensure new development is compatible with the flood hazard.

The Muscle Creek Flood Study (RHDHV, 2017b), Denman Overland Flow Study (RHDHV, 2017c and Hunter River (Muswellbrook to Denman) Flood Study Revision (RHDHV, 2017a) define the existing flood behaviour and establishes the basis for future floodplain management activities.

The Muswellbrook Floodplain Risk Management Study and Plan (this document) constitutes the third and fourth stages of the management process. It has been prepared for Muswellbrook Shire Council to provide the basis for future management of flood liable land within the catchment.

1.5 About This Report

This report documents the Study's objectives, results and recommendations.

Section 1 introduces the study.

Section 2 provides background information including a catchment description, history of flooding and previous investigations.

Section 3 outlines the community consultation program undertaken.

Section 4 describes the flooding behaviour in the study area including a property inundation and damages assessment.

Section 5 presents a review of existing planning provisions.

Section 6 provides an assessment of relevant floodplain management measures.

Section 7 considers the requirement of a flood warning system for Muscle Creek.

Section 8 presents the recommended measures and an implementation plan.

1.6 Design Event Terminology (AEP & ARI Explanation)

Design flood events are hypothetical floods used for floodplain risk management. They are based on having a probability of occurrence specified either as:

- Annual Exceedance Probability (AEP) expressed as a percentage; or
- Average Recurrence Interval (ARI) expressed in years.

The relationship between AEP and ARI is presented in **Table 1-1** with further descriptions of typical design event terminology provided in **Figure 1-2**.

Table 1-1: Design Event Terminology (AEP & ARI Explanation)

Annual Exceedance Probability AEP (%)	Average Recurrence Interval (ARI, 1 in X years)	Comment
Probable Maximum Flood (PMF)		A hypothetical flood or combination of floods which represent an extreme scenario.
0.2%	**500 yr**	A hypothetical flood or combination of floods likely to occur on average once every 500 years or with a 0.2% probability of occurring in any given year
0.5%	**200 yr**	As for the 0.2% AEP flood but with a 0.5% probability or 200 year return period.
1%	**100 yr**	As for the 0.2% AEP flood but with a 1% probability or 100 year return period.
2%	**50 yr**	As for the 0.2% AEP flood but with a 2% probability or 50 year return period.
5%	**20 yr**	As for the 0.2% AEP flood but with a 5% probability or 20 year return period.
20%	**5 yr**	As for the 0.2% AEP flood but with a 20% probability or approximately a 5 year return period.

Although the probability of a flood of a given size occurring remains the same from year to year (unless the flood regime is altered or new data lead to a revision of statistical estimates), the chance of such a flood occurring at least once in any continuous period increases as the length of time increases. **Table 1-2** shows the probability of experiencing various-sized floods at least once or twice in a lifetime. Over an 80 year timeframe/lifetime there is a 7.7% change of experiencing a 1 in 1000 ARI (0.1% AEP) event. This puts the likelihood of such a severe and very rare event into some perspective. The probability of experiencing a second 1 in 1000 ARI (0.1% AEP) magnitude event in an 80 year period is only 0.3%.

Table 1-2: Probability of experiencing a given-sized flood one or more times in 80 years

Source: Managing the floodplain: a guide to best practice in flood risk management in Australia (AEMI (2013))

Annual exceedance probability (%)	Approximate Average recurrence interval (years)	Probability of experiencing a given-sized flood in an 80-year period	
		At least once (%)	At least twice (%)
20	5	100	100
10	10	99.9	99.8
5	20	98.4	91.4
2	50	80.1	47.7
1	100	55.3	19.1
0.5	200	33.0	6.11
0.2	500	14.8	1.14
0.1	1,000	7.69	0.30
0.01	10,000	0.80	0.003

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
Very Frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
Frequent	0.69	50	2	1.44
	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	20
	0.02	2	50	50
	0.01	1	100	100
Very Rare	0.005	0.5	200	200
	0.002	0.2	500	500
	0.001	0.1	1000	1000
	0.0005	0.05	2000	2000
Extreme	0.0002	0.02	5000	5000
			↓	
			PMP/ PMPDF	

Figure 1-2: Australian Rainfall and Runoff (2016) Preferred Terminology

2 Background Information

2.1 Catchment Description and Flood Mechanisms

Muswellbrook is located in the Upper Hunter Valley 110 km north west of Newcastle and 230 km north-west of Sydney. The township is centrally located in the Hunter Valley with the Great Dividing Range to the west, Liverpool Range to the north and Mount Royal Range to the east. Muswellbrook is situated at the confluence of the Hunter River and Muscle Creek, while Denman is located on the western edge of the Hunter River Floodplain as presented in **Figure 1-1**

Details of the catchments and flood mechanisms that have been investigated as part of this FRMS are detailed in **Table 2-1** and described below.

It should be noted that the Possum Gully Catchment which is a partly urbanised 1.5 km^2 catchment in Muswellbrook was excluded from assessment in this FRMS because it was adequately assessed in the Possum Gully Catchment Stormwater Drainage Studies (SMEC, 2015a & b) (refer Section 2.4.4).

Table 2-1: Details of Study Area Catchments

Source	Catchment Size
Hunter River (above Muswellbrook)	3,370 km^2
Hunter River (above Denman))	4,510 km^2
Muscle Creek	92 km^2
Denman Local Catchment	10.5 km^2
Goulburn River	7,800 km^2

2.1.1 Hunter River Flood Mechanism

The Hunter River enters Muswellbrook Shire by passing through its northern border just south of the township of Aberdeen (*refer* **Figure 1-1**). From there, the river meanders some 20 kilometres to the south and through Muswellbrook. At Muswellbrook the river turns markedly to the southwest and flows a further 32 kilometres before reaching the township of Denman.

The river finds its confluence with the Goulburn River approximately 5 kilometres downstream of Denman. From there, the river changes direction once again and flows for some 31 kilometres to the southeast where it exits the Muswellbrook Shire as it flows beside the Golden Highway just south of Plashett Reservoir.

The catchment of the river upstream of Aberdeen covers an area of approximately 3,090 square kilometres. A number of tributaries flow into the river between Aberdeen and Denman. Most notable of these are Middle Brook and Dart Brook, which both have their headwaters around 40 kilometres north of Aberdeen. However, the two streams unite and flow around the outskirts of Aberdeen before entering the Hunter River just south of the township itself. The combined area of the sub-catchments that feed the river between Aberdeen and Denman totals 1,440 square kilometres. As such, the total area upstream of Denman is approximately 4,510 square kilometres.

Similarly, the catchment area upstream of Muswellbrook is approximately 3,370 square kilometres. The catchment area of the Goulburn River upstream of its confluence with the Hunter River is approximately 7,800 square kilometres. Several smaller sub-catchments flow into the

Hunter River between Denman and the eastern border of the LGA resulting in a total catchment area feeding the Hunter River upstream of this point totalling over 13,000 square kilometres. Details of the Hunter and Goulburn River sub-catchments are presented in **Figure 2-1.**

Flooding has long been an issue along the Hunter River, most famously in February 1955, when Muswellbrook and Denman both sustained considerable damages during an event that has long been considered one of the worst natural disasters in Australian history. Other serious flooding events occurred in 1971, 1976 and more recently in June 2007.

The property inundation assessment (refer Section 4.2) indicates that while no properties are impacted (by above floor flooding) in the 10% AEP (10yr ARI), some 20 properties are flooded in the 5% AEP (20yr ARI), 175 properties are flooded in the 1% AEP (100yr ARI) and 659 properties could be flooded in the PMF.

Due to the large size of the catchment, longer 24-48 hour rainfall events are required to cause significant flooding in the study area from the Hunter River catchment.

2.1.2 Muscle Creek Flood Mechanism

Muscle Creek drains 92 km^2 of catchment upstream of Muswellbrook as presented in **Figure 2-2**. The upper and middle portions of the catchment comprise moderately steep forested terrain. The lower portion of the catchment is predominately forested but includes areas of mining and agricultural land uses as well as some urban areas. The critical duration of the catchment is 36 hours.

Muscle Creek flows centrally through the township of Muswellbrook before joining the Hunter River. There are three bridge crossings across the creek on Bell Street, Wilkinson Avenue and Bridge Street, though it should be noted that Wilkinson Avenue only provides access to the sporting facilities on the North side of the creek but does not provide a link to the northern part of Muswellbrook. It is important to note that flooding in as little as the 5% AEP (20yr ARI) event can inundate the only two roads connecting the northern and southern parts of Muswellbrook creating a potential issue for emergency services.

A substantial flood event occurred in Muscle Creek in June 2007. A review of available rainfall data was undertaken by Umwelt who estimated the event to be similar to a 2% AEP event (Umwelt, 2009). It is understood that substantial out of channel flooding occurred within the Muswellbrook Golf Course and that some flood waters spilt over Bell Street and flowed through residential areas located between Bell Street and Wilder Street before re-entering the channel (Umwelt, 2009).

The property inundation assessment (refer Section 4.2) indicates that while no properties are impacted (by above floor flooding) in the 10% AEP (10yr ARI), some 17 properties are flooded in the 5% AEP (20yr ARI), 38 properties are flooded in the 1% AEP (100yr ARI) and 168 properties could be flooded in the PMF.

Due to the moderate size of the catchment, while longer (36 hour) rainfall events are required to cause critical flood levels, shorter duration events 2-12 hours may also produce flash flooding during intense rain events. The potential for rapid flows to develop through urban areas mean that unless flood mitigation measures (refer Section 6.4.4 & 6.4.5) are implemented in a reasonable timeframe, a flood warning system (refer Section 7) is recommended.

2.1.3 Denman Local Catchment Flood Mechanism

The township of Denman receives runoff from a local catchment area that extends from the Denman Levee to a ridge line that is located approximately 2km to the west of the township. The western portion of this catchment area comprises steep vegetated terrain with grades in excess of 30% in some areas. There is a subtle ridge line that commences in the northern portion of Denman and extends to the west, dividing the overall catchment into two catchments as presented in **Figure 2-3**.

The Northern Catchment has a total area of 3.3 km^2 and drains to the east through two discrete channels that do not enter the existing residential areas. The Southern Catchment has a total area of approximately 7.2 km^2 and drains through a number of discrete channels and overland flow paths towards the township of Denman. Drainage in the central portion of the catchment has been highly modified through the establishment of dams, drains and re-contouring of the land. The 2 hour duration event was identified as producing the highest peak flows and flood levels within the majority of the study area.

The property inundation assessment (refer Section 4.2) indicates that while no properties are impacted (by above floor flooding) in the 10% AEP (10yr ARI), 3 properties are flooded in the 2% AEP (50yr ARI), 7 properties are flooded in the 1% AEP (100yr ARI) and 412 properties could be flooded in the PMF, though most of these are due to the Hunter River overtopping the Levee and not the local catchment flood mechanism.

Due to the small size of the catchment, this flood mechanism typically only produces “nuisance” type flash flooding which may be exacerbated by blocked or undersized drainage infrastructure.

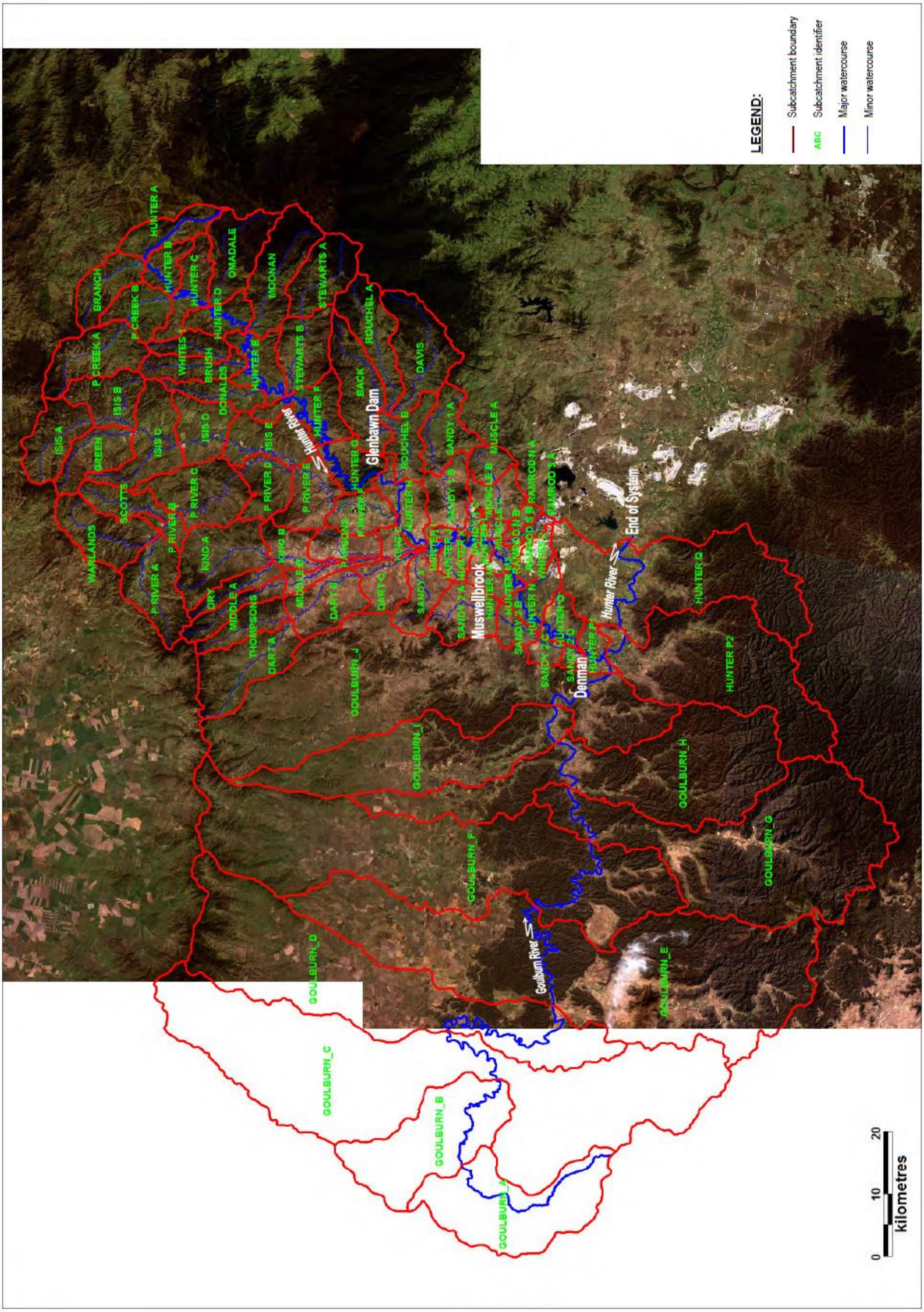

Figure 2-1: Hunter River Catchment and Hydrologic Model Sub-Catchemnts

Source: WorleyParsons (2014)

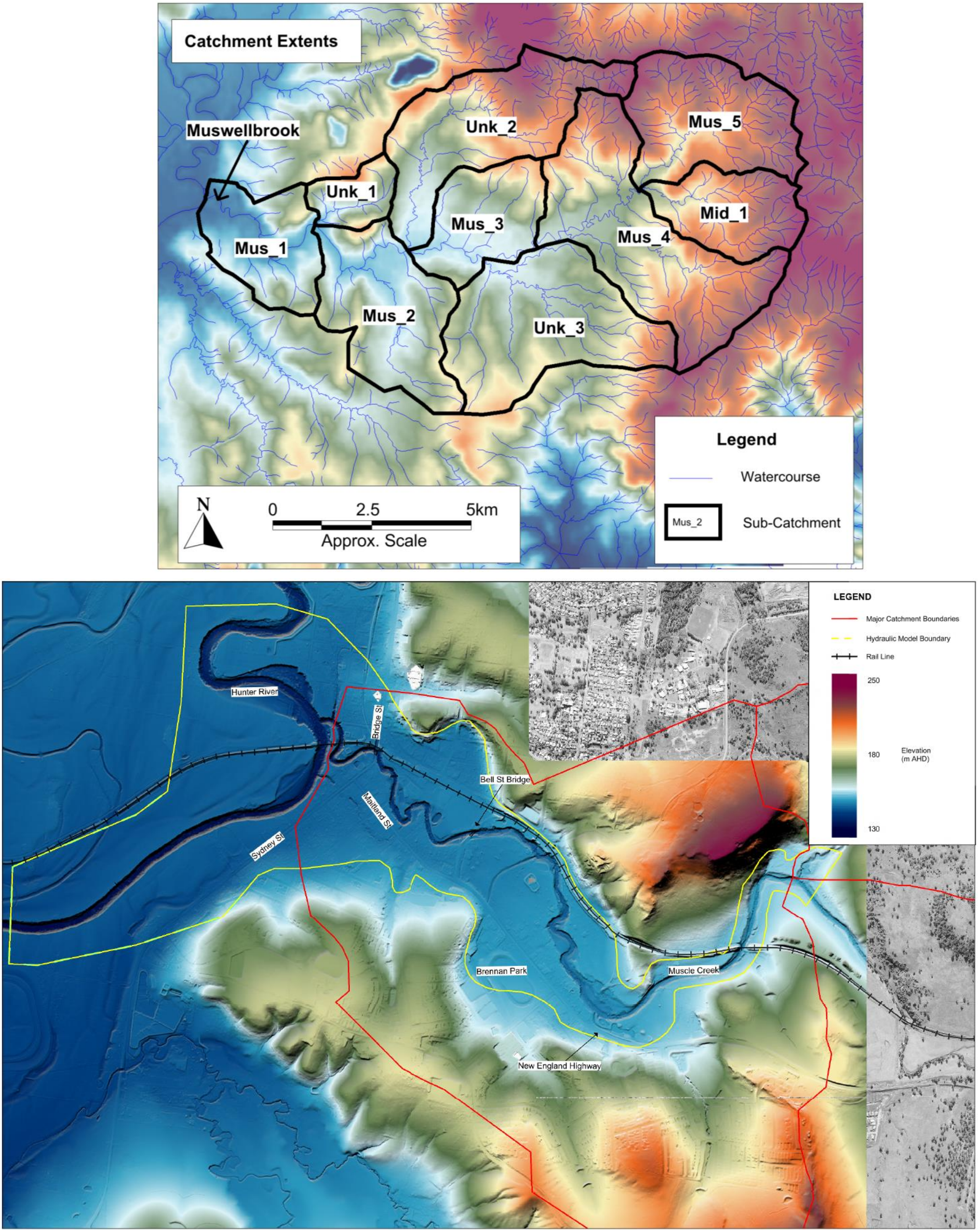

Figure 2-2: Muscle Creek Catchment and Model Extent

Source: Royal HaskoningDHV (2017b)

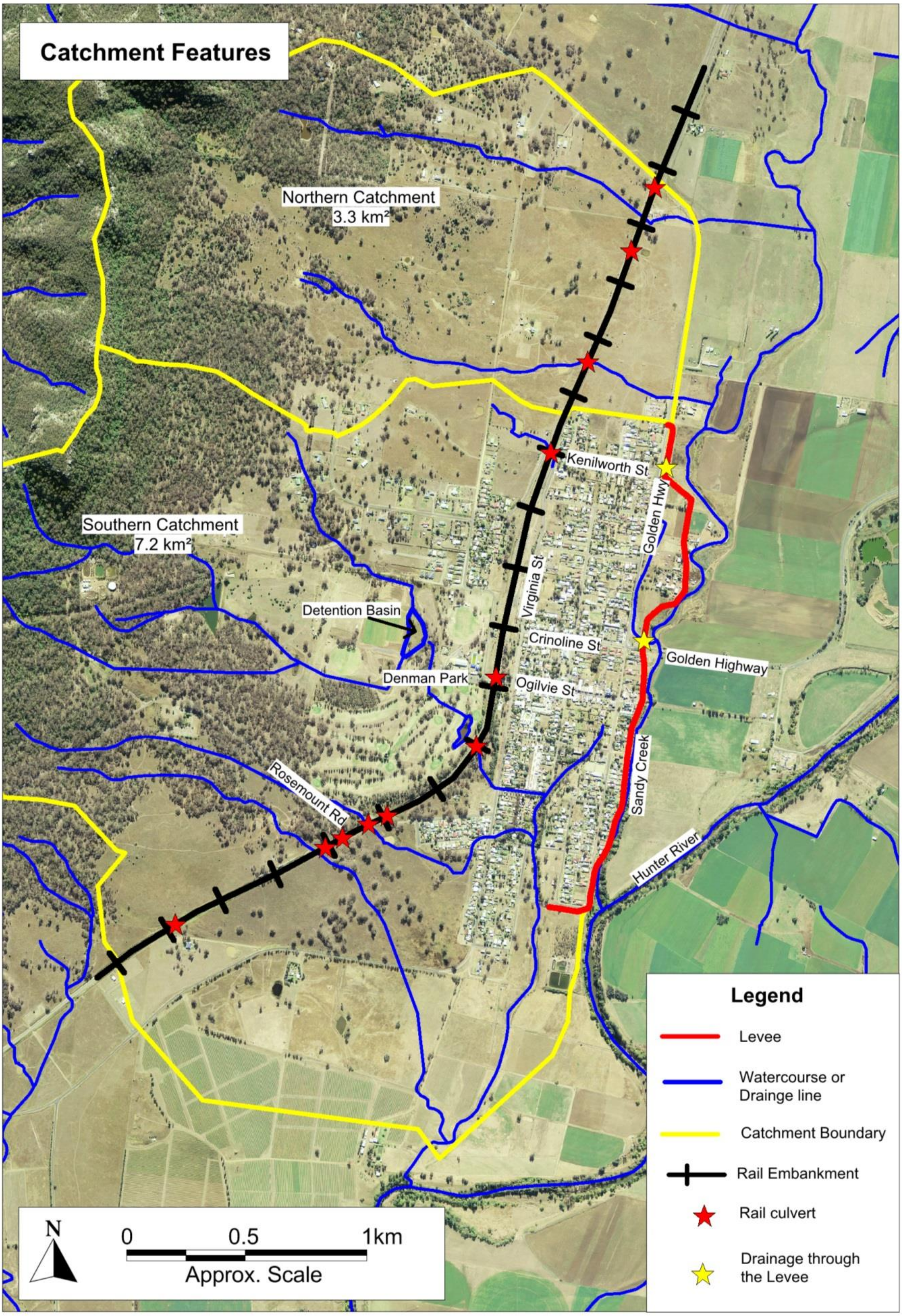

Figure 2-3: Denman Local Catchments

Source: Royal HaskoningDHV (2017c)

2.2 History of Flooding

European settlement commenced in the study area in approximately 1826. It is generally agreed that the largest flood to have been experienced in Muswellbrook and Denman since this time occurred in 1870 (estimated discharge 5900 m^3/s). The largest flood to have been formally recorded occurred in February 1955. The 1955 flood occurred as a result of heavy rainfall across the catchment over several days and resulted in what is often regarded as one of the worst natural disasters in recent Australian history. The event had an estimated Average Recurrence Interval (ARI) of 100 years (Muswellbrook Flood Study, WRC 1986). Large areas within the urban centres of Muswellbrook and Denman were inundated during the event.

Glenbawn Dam, located in the upper catchment of the Hunter River some 20 kilometres northeast of Muswellbrook, was under construction during the 1955 flood event. However, the dam was not in operation until 1958. The dam has an upstream catchment of approximately 1290 square kilometres (31% of the Hunter catchment at Muswellbrook and 28% of it at Denman) and an approximate storage volume of 750 gigalitres of which 120 gigalitres is dedicated to flood storage. The dam has significantly reduced the flood risk characteristics along the Hunter River downstream. Despite the presence of the dam, further significant flood events occurred in Muswellbrook and Denman in February 1971, January 1976, August 1998, November 2000 and June 2007; although it should be noted that the inundation that occurred during the June 2007 flood event was primarily the result of flooding from Muscle Creek, which feeds into the Hunter River at Muswellbrook. **Table 2-2** provides a list of the major floods and the estimated peak heights and discharges at Muswellbrook (Kayuga Road Bridge) and peak flood levels at Denman. WRC (1986) also reports significant floods in 1864, 1867, 1870 and 1893. Cameron McNamara (1988) reports that the 1870 flood was the highest on record being approximately 0.1m higher than the 1955 flood.

Table 2-2: Summary of Historic Floods at Muswellbrook and Denman

Source: Worley Parson (2014)

Year	Peak Gauge Depth (m)	Peak Gauge WL Muswellbrook (mAHD) [3]	Peak Gauge WL Denman (mAHD) [4]	Discharge Muswellbrook (m^3/s)	Approx. ARI[1] (yr)
1955	11.55	147.8	110.3	5013	> 500yr
1971	10.91	147.2	109.9	3207	~50-100
1976	10.29	146.5	109.7	2104	~20-50
1992	10.32	146.5	109.6	2144	~20-50
1998	9.66	146.3	109.9	1502[2]	~20-50
2000	9.98	146.6	109.7	1598[2]	~20-50
2007	5.48	142.1	107.3	256	Rainfall for Muscle Creek ~50 year ARI

*[1] Approx. ARI is based on Revised Flood Study Design Discharge Estimates.
*[2] Flow using rating data provided in Revised Flood Study (RHDHV, 2017a).
*[3] Muswellbrook Gauge zero is 136.244 m AHD
*[4] Denman Gauge zero is 101.997 m AHD

Denman's highest recorded flood, in 1955, reached 8.29 metres on the local gauge. Other floods peaked above 8.0 metres in 1807, 1821 and 1870. The height at which water breaks out of the channel at Denman (7.25 metres) has been exceeded on 20 occasions since 1806.

2.3 Existing Flood Mitigation Structures

A number of existing flood mitigation measures that influence flooding in the study area are described in the below Section.

2.3.1 Glenbawn Dam

Glenbawn Dam, located in the upper catchment of the Hunter River, some 20 kilometres northeast of Muswellbrook, was under construction during the 1955 flood event. However, the dam was not in operation until 1958. The dam has an upstream catchment of approximately 1290 square kilometres (31% of the Hunter catchment at Muswellbrook and 28% of it at Denman) and an approximate storage volume of 750 gigalitres of which 120 gigalitres is dedicated to flood storage. The dam has significantly reduced the flood risk characteristics along the Hunter River downstream.

Glenbawn Dam is located on the Hunter River, approximately 35 km upstream of Muswellbrook. The dam's catchment accounts for approximately 31% of the Hunter River Catchment upstream of Muswellbrook. Construction of the dam commenced in late 1947 and was completed in late 1957. According to the Aberdeen Flood Study (WMAwater, 2013), the dam wall was only partially constructed during 1955 and the 1955 flood event passed through the dam relatively un-attenuated. Glenbawn Dam was constructed with a dam wall height of 78 m, a storage capacity of 300,000 ML and a flood mitigation capacity of 133,000 ML.

An upgrade of Glenbawn Dam was undertaken in 1986 / 1987. The upgrade comprised raising the dam wall height to 100 m and reconfiguring the outlet controls. The upgrades increased the dam's storage capacity to 750,000 ML. However, the flood mitigation capacity was reduced from 133,000 ML to 120,000ML. The Muswellbrook Flood Study (1986) references a study by Hayes (1982) which found that the flood storage capacities of 133,000 ML and 120,000 ML would "effectively have the same mitigating effect".

The adequacy of the flood mitigation function of this dam has not been reviewed as part of the FRMS&P. However, the Aberdeen Flood Study (WMAwater, 2013) concluded that no outflow from the dam's spillway is expected for the 0.2% AEP and lower magnitude flood events. The influence of the dam on flood flows is presented in **Figure 2-4**. The figure presents the flood frequency analysis for Muswellbrook before and after the dam was constructed. For a given AEP/ARI design event, the dam appears to reduce peak flows by ~500m^3/s for the 20% AEP (i.e. 20yr ARI) and ~1500m^3/s for the 1% AEP (i.e. 100yr ARI). In terms of reduced magnitude a previous 1% AEP (i.e. 100yr ARI) event without Glenbawn Dam would now have a ~3% AEP (i.e. ~30yr ARI).

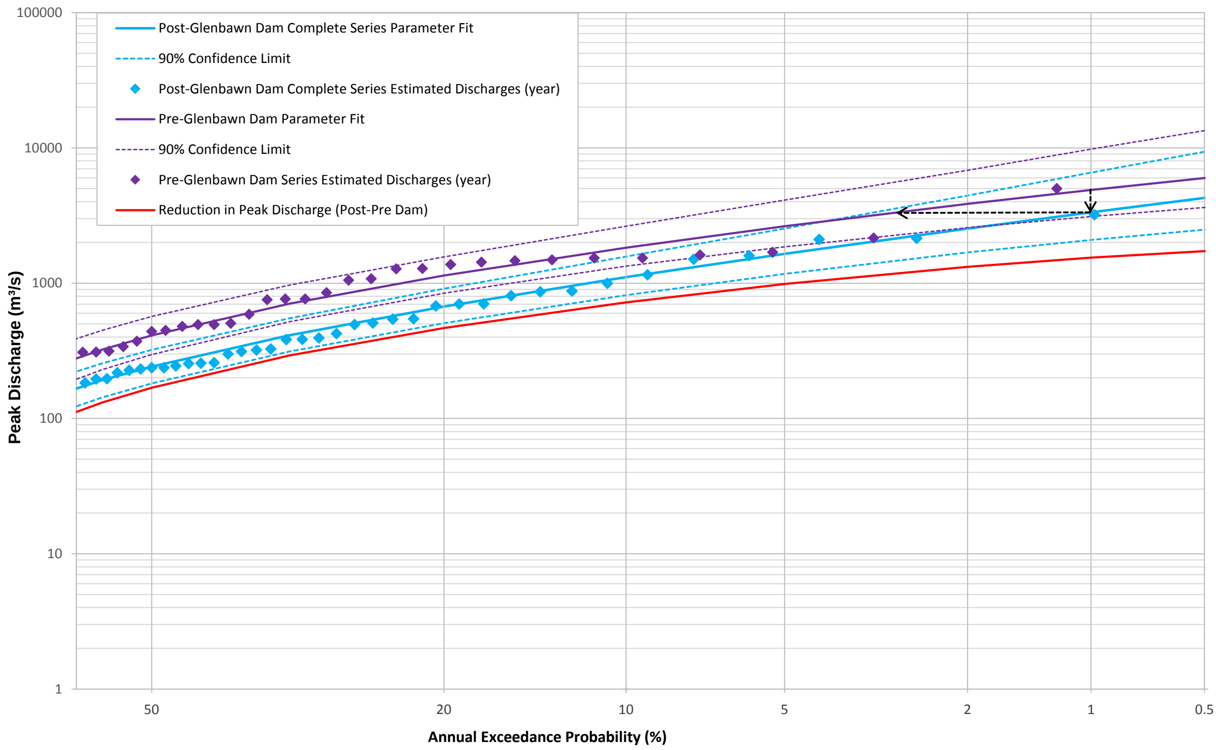

Figure 2-4: Pre and Post Glenbawn Dam Flood Frequency Analysis

Source: Royal HaskoningDHV (2017a)

2.3.2 Muswellbrook Levee

The Muswellbrook Levee is a relatively short levee system offering "flood relief" for residents situated on the north-western corner where the town is in close proximity to the Hunter River. The total levee length is approximately 1.16 km. The average height of the levee is approximately 3.5 m with the maximum height of approx. 4.8 m in the vicinity of Ford Street.

The Muswellbrook Levee was constructed in 1992 and was the result of a Flood Study, Social Economic and Ecological Effects Study and a Floodplain Management Study carried out in the late 1980s. Construction was undertaken by Council with the authority from the then Department of Water resources under the Hunter Valley Flood Mitigation Act (1956) which gave the then Department of Water Resources the power to construct the levee. The Act has since been replaced by the Water Management Act 2000. The levee was constructed following the detail design and confirmation of funding under the Federal Water Resources Assistance Program where funding was contributed by the Federal Government, State Government and Council.

The Muswellbrook Levee Management Plan reported that the levee was constructed with a 1.0 m freeboard over the 1 in 100 AEP design flood level over its entire length, i.e. design crest level at approx. RL 146.80 m AHD. The levee freeboard was assessed in RHDHV (2016b) (a desktop study commissioned as part of this FRMS) using the WorleyParsons (2014) flood study model. The assessment found that the 1% AEP freeboard ranged from 0.1 to 1.9m. However, it is important to note that the RHDHV (2017a) revised flood study produces 1% AEP flood levels that are between 0.3 and 0.7m lower than the 2014 flood study. This means that the 1% AEP freeboard is likely to be close to the original 1m, design freeboard.

The plan reported that the levee has not been designed to fully enclose the area west of the railway line. During major flooding from approx. the 1 in 7.14 ARI (14% AEP) flood event and greater, floodwater would back up from the end of the Scott / Brook Street, i.e. southern region of the levee, inundating properties progressively up to the northern regions on the dry side of the levee. This explains the notions of “flood relief” and “flood severity reduction” reported in association with this levee. Due to this, it would appear that while the Muswellbrook Levee technically only caters for the 1 in 7.14 ARI flood event, it offers significant flood reduction for larger events. The changes in 1% AEP flood levels due to the Muswellbrook levee were assessed in RHDHV (2016b). **Figure 2-5** shows that the levee reduced flood levels by between 0.7 and 1.3 m. The influence of backwater flooding is also apparent in the figure. Green areas show where flooding has been completely eliminated while the blue areas show the reduction in flood levels in locations impacted by backwater flooding. Extension of the levee to prevent backwater flooding is assessed in **Section 6.4.1** of this report.

A desktop study of available information regarding the Muswellbrook Levee was undertaken as part of the FRMS&P and is presented in a separate memo (RHDHV, 2016b) provided to Council in November 2016. The memo provides a number of recommendations to reduce the risk of the structure being compromised during a flood event.

2.3.3 Denman Levee

The Denman Levee is approximately 2.4km long commencing immediately to the east of the Golden Highway just north of Denman and traverses the Hunter River flood plains, crossing the Golden Highway just east of the Crinoline Street / Palace Street Intersection. The Levee then proceeds in a southerly direction east of the houses in Palace Street. It terminates at the Denman Sewerage Treatment Works. The average height of the Levee is approximately 2.5m with the maximum height being approximately 4.0m near the commercial centre of town.

The changes in 1% AEP flood levels due to the Denman levee were assessed in RHDHV (2016a). **Figure 2-6** shows that the levee reduced flood levels by between 2.1 and 1.3 m. The influence of backwater flooding is also apparent in the figure. Green areas show where flooding has been completely eliminated while the blue areas show the reduction in flood levels in locations impacted by backwater flooding.

The Levee is designed with a 1.0m freeboard over the 1% AEP flood level over its entire length except where it crosses the Golden Highway near the intersection of Palace Street / Crinoline Street. At this point (the breakout) the Levee is constructed at the 1% AEP Level with no freeboard for the width of the road.

The levee freeboard was assessed in RHDHV (2016a) (a desktop study commissioned as part of this FRMS) using the WorleyParsons (2014) flood study model. The assessment found that the 1% AEP freeboard ranged from 0.1 to 0.8m. However, it is important to note that the RHDHV (2017a) revised flood study produces 1% AEP flood levels that are between 0.3 and 0.7m lower than the 2014 flood study. This means that 1% AEP freeboard is likely to be close to the original 1m, 1% AEP design freeboard. The revised flood study also indicates that the Crinoline (Golden Highway) low point (ground level = 108.85 m AHD) would not be inundated in the 1% AEP (flood level = 108.80 m AHD).

The construction of the Levee Bank for Denman was proposed following extensive flooding in February 1971. At the Council’s request, the Department of Water Resources designed a levee which would protect vulnerable areas of the town from damaging floods. The Levee was completed in August 1988 and commissioned on 27 October 1988. The Levee was installed to protect the town from overbank flooding from the Hunter River and close off the breakout into the town from Sandy Creek. A Manual for the Operation and Maintenance of the Levee was provided by the Dept of Water Resources.

Cardno (2011) reports that a significant risk identified in the 2009 Management Plan related to the operation of the valves that shut off pipes that drain local internal stormwater. These valves are manually operated and are highly geared so that closing them off takes a considerable amount of time. When a flood of significance is forecast at Denman, the present system relies on a suitably trained operator to arrive at the floodgates in a timely manner and manually close off a valve at Crinoline St (1500Ø pipe) and 2 valves at Kenilworth St (750Ø pipes). The 375Ø drainage pipe at Macauley Street is fitted with a flap valve. A recommendation of (Cardno, 2011) was the installation of elastomeric in-line check valves to supplement the manual valves, however, it is believed that this action is yet to be implemented.

The Golden Highway also passes over the levee at Crinoline Street. The levee has been lowered at this point by approximately 1m to allow a reasonable vertical grading of the road as it passes over the levee. This provides a potential area for breaching of floodwaters and requires filling during floods to prevent the inundation of floodwater from the Hunter River. It is understood that Council acted on the recommendation of Cardno (2011) and purchased a temporary flood gate to be installed at Crinoline Street when a large flood is imminent.

A desktop study of available information regarding the Denman Levee was undertaken as part of the FRMS&P and is presented in a separate memo (RHDHV, 2016a) provided to Council in November 2016. The memo provides a number of recommendations to reduce the risk of the structure being compromised during a flood event.

2.3.4 Diversion Channels

WRC (1986) reports on the construction of two pilot channels in the late 1970's near Muswellbrook including:

- The Kayuga Bridge Diversion Channel which was constructed in 1978 to protect the approaches to Kayuga Bridge. It is understood this channel is generally referred to as Rosebrook Creek and runs parallel to Wybong Road for some distance before re-joining the Hunter River Channel near the Race Course.
- Koolbury Pilot Channel (near Lyndema Park) was constructed in 1976 to protect potential erosion undermining New England Highway. It is understood that this pilot channel is now the main channel of the Hunter River with a remnant Oxbow lake remaining where the old river channel was.

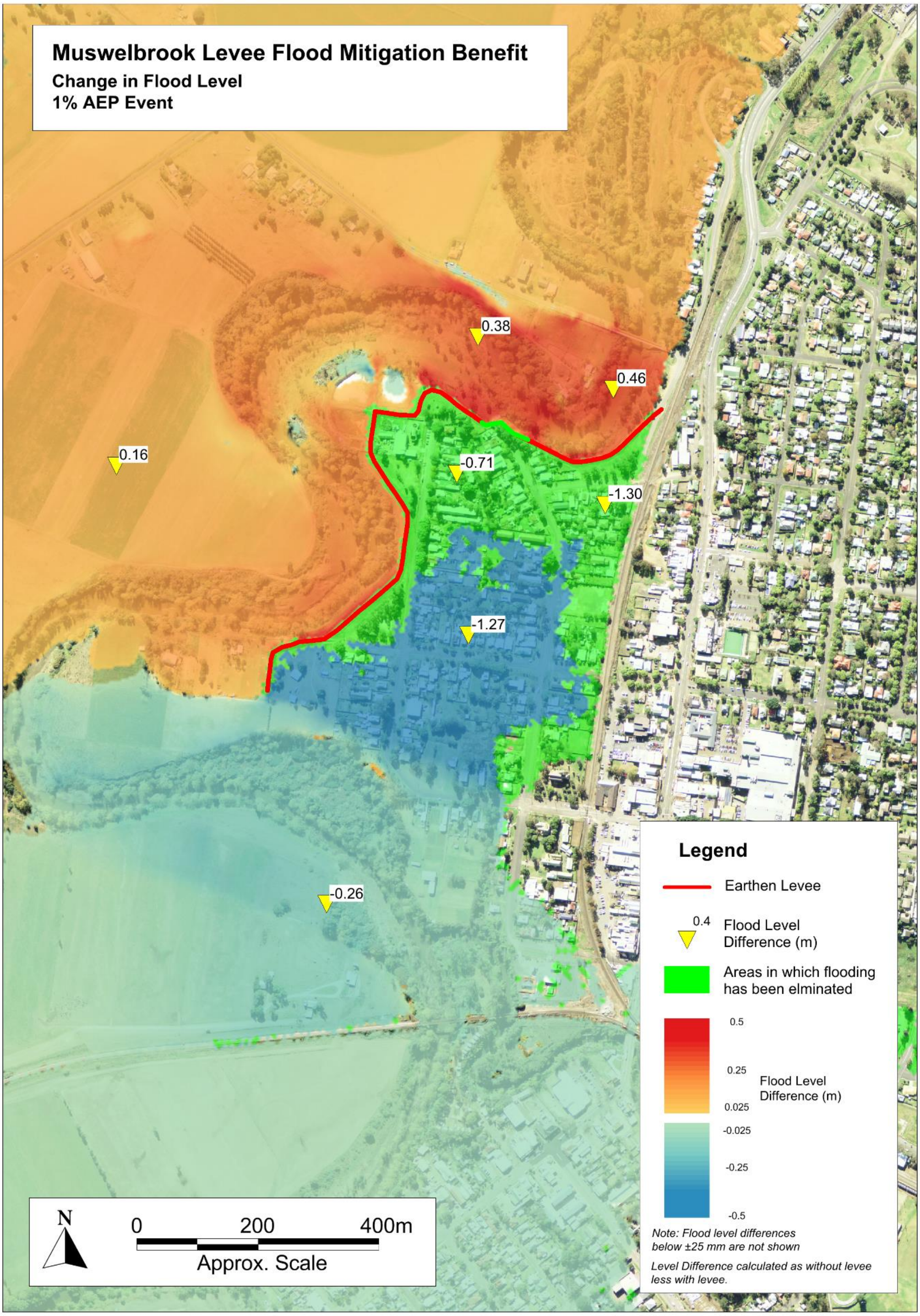

Figure 2-5: Muswellbrook Levee 1% AEP Flood Level Differences

Source: RHDHV (2016b) – Using WorleyParsons (2014) Flood Model

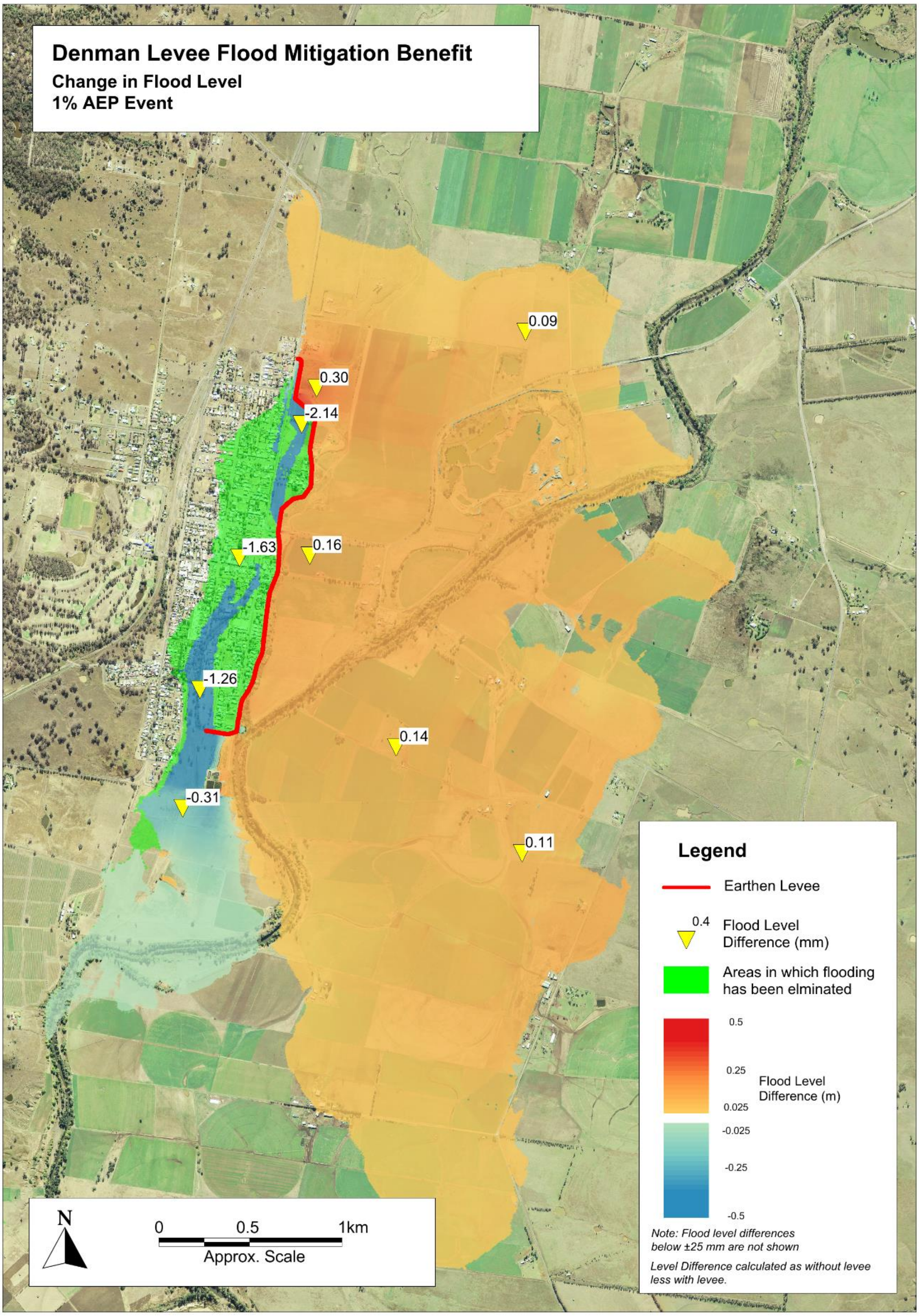

Figure 2-6: Denman Levee 1% AEP Flood Level Differences

Source: RHDHV (2016a) – Using WorleyParsons (2014) Flood Model

2.4 Previous Studies

A number of previous studies have been undertaken to investigate flooding in the study area. A summary of key studies is presented below.

2.4.1 *Hunter River Flood Study - Muswellbrook to Denman (Worley Parsons, 2014)*

The Hunter River Flood Study (Muswellbrook to Denman) was produced by Worley Parsons in 2014 as part of the NSW Government's Floodplain Management Program. The study is informed by an integrated hydrologic and hydraulic model of the Upper Hunter River Floodplain Catchment. The model encompasses the entire extent of the Hunter River Floodplain that is located within the Muswellbrook Council Local Government Area (LGA). The upstream portion of the model (from the upstream LGA boundary to the Goulburn River) was developed in TUFLOW as a two-dimensional (2D) hydraulic model, while the lower portion of the model (from the Goulburn River to the downstream LGA boundary) was developed in TUFLOW as a one-dimensional (1D) hydraulic model dynamically linked to the upstream 2D model.

Surface elevations within the hydraulic model are informed by Light Detection and Ranging (LiDAR) data that was acquired by State Water in 2010. The integrated hydrologic and hydraulic models were calibrated using available information from flood events that occurred in 1998, 2000 and 2007. The study did not attempt to use available information from the 1955 or 1971 events or the extensive Muswellbrook Stream Gauge record to verify the model results.

The hydrologic and hydraulic models developed as part of this study were provided to RHDHV for use in the FRMS. RHDHV have modified some aspects of the models. All modifications are noted in Section 4 of RHDHV (2017a).

2.4.2 *Muswellbrook and Denman Flood Studies (WRC, 1986)*

The Muswellbrook Flood Study and Denman Flood Study reports were prepared by the Water Resources Commission in 1986. Further details of the studies are provided in RHDHV (2017a). They provided an assessment of flooding that was used to inform the design of the Muswellbrook and Denman levees. The flood information is largely superseded by Worley Parson (2014) flood study and this study.

2.4.3 *Muswellbrook Shire Council - Floodplain Management Study (Cameron McNamara, 1988)*

This report identified a range of mitigation options aimed at reducing flood risk on residential properties in the Muswellbrook Shire. The key outcome was recommendation of the Muswellbrook Levee. The Denman Levee had already received approval so was not further investigated in the study. A diversion channel including upgrade of rail crossings was also investigated and found to reduce flooding for 29 houses.

The report also produced hazard maps that are still used in the current DCP.

2.4.4 *Possum Gully Catchment Stormwater Drainage Study (SMEC, 2015a & b)*

In 2015, SMEC was engaged by Council to undertake a stormwater drainage study for the Possum Gully Catchment which is a partly urbanised 1.5 km^2 catchment in Muswellbrook. The SMEC (2105a) study used an XP-RAFTS hydrologic model and a TUFLOW hydraulic model to investigate six (6) mitigation options including:

- **Mitigation Option 1**: Stormwater detention basin upstream of George Street;

• **Mitigation Option 2**: Culvert upgrades under Doyle Street roundabout, Carl Street, culverts immediately downstream of Carl Street crossing and Sowerby Street;
• **Mitigation Option 3**: Channel improvements between Queen Street and Sowerby Street;
• **Mitigation Option 4**: Augmentation of Queen Street Basin;
• **Mitigation Option 5**: Formalising channel/channel improvements between Carl Street and Sowerby Street; and
• **Mitigation Option 6**: Combination of Mitigation Option 1 and Mitigation Option 5.

Council then selected Mitigation Option 1, 5 and 6 to carry out a benefit-cost assessment as reported in SMEC (2015b). The final report also includes a concept design of the preferred Mitigation Option 5.

The modelling reported in SMEC (2015a) indicates a peak 1% AEP discharge from Possum Creek Gully of 13.3 m^3/s for current catchment conditions and 19.5 m^3/s for fully developed catchment conditions.

2.4.5 Lower Muscle Creek Flood Study (Umwelt, 2009)

In 2009, Council commissioned Umwelt to prepare a flood study of the Lower Muscle Creek Floodplain. The study is titled Flood Assessment of Bell Street, Muswellbrook (Umwelt, 2009). The study included:

- A review of a substantial flood that occurred in June 2007.
- The development of a hydrologic model of the Muscle Creek Catchment using the XP-Storm software package.

Development of a two-dimensional model of the lower Muscle Creek Floodplain using the RMA-2 software package. It is noted that the RMA-2 model was informed by photogrammetry survey data which is considered to be less reliable that the LiDAR data that was available to inform the updated study outlined in Section 2.5 (RHDHV, 2017b).

The hydrologic and hydraulic models were applied to assess the June 2007 and 1% AEP design events.

The study also assessed the following potential mitigation measures:

1. Widening of the Muscle Creek Channel.
2. Removing debris and vegetation from the creek channel and overbank areas.
3. Widening an overflow path between the golf course and the Muscle Creek Channel.
4. Restricting the entry of backflows into the Thompson Street drain.
5. Building a levee on the edge (adjacent to Bell Street) of the golf course

The study concluded that building a levee on the edge of the golf course would be the most practical and effective means of mitigating flooding downstream of Bell Street. The study recommended that a 0.8 m to 1.8 m high levee with a crest level of 147.8 m AHD would prevent the 1% AEP event from overtopping Bell Street. This option is further assessed in Sections 6.4.4 and 6.4.5 of this report.

2.5 Associated Studies and Study Outputs

A number of associated studies have been undertaken as part of the development of this FRMS&P. They include:

Muswellbrook and Denman Levee System: Desktop Study (16 November 2016)

Desktop Studies of Muswellbrook Levee and Denman Levee are reported in memo's RHDHV (2016a) and (2016b). The objectives of the desktop studies were to:

- Review a visual inspection report that was prepared by NSW Department of Public Works in 2016.
- Review levee design drawings and survey information that has been provided by Council.
- Apply the hydraulic model that has been developed as part of the FRMS to assess freeboard, likely overflow locations and identify portions of the levee that are exposed to elevated flow velocities.
- Make recommendations as required.

More information regarding the levees is presented in Sections 2.3.2 and 2.3.3.

The memos provide a number of recommendations to reduce the risk of the structure being compromised during a flood event.

Model and Data Review Note (21 March 2016)

Reviewed the TUFLOW model developed as part of the Muswellbrook Flood Study Model (WorleyParsons, 2014). The review found that the model was suitable for assessing mainstream flooding from the Hunter River, though a separate model of Muscle Creek should be developed to improve an understanding of the Muscle Creek flood mechanism. The review also recommended the development of a local catchment model for Denman to improve the understanding of the impact of this flood mechanism.

Flood Study Model Calibration Review and Results Verification (21 March 2016)

This memo presented a review of discrepancies between the outflows from the Aberdeen Flood Study Model (WMA, 2013) and the inflows applied to the Muswellbrook Flood Study Model (Worley Parsons, 2014). The review found some issues with the design hydrology adopted in Worley Parsons (2014) and recommended adopting the Aberdeen Flood Study Model (WMA, 2013) hydrology and that all design events would need to be re-run.

Summary of Flood Study Model Modifications (17 October 2016)

This memo discussed the influence of adopting the Aberdeen Flood Study Model (WMA, 2013) hydrology on design flood conditions in Muswellbrook. An outcome of the study (after consultation with Council, OEH and WaterNSW (who confirmed rating gauge updates)) was that a re-calibration of the hydrologic and hydraulic model should be considered.

Model recalibration and revisions (10 March 2017)

This presentation provided information on the model update and re-calibration findings. Of particular note was the influence of changes to the rating tables on hydrological calibration and also the influence of channel and floodplain vegetation changes on model roughness and predicted flood levels.

Model Revisions Report - 19 October 2017

The Flood Study Revision (RHDHV, 2017a) was required to produce an up-to-date flood study to provide appropriate information regarding flood risk to form the basis of the FMRS&P. The study included model re-calibration and validation of the models initially developed in the WorleyParsons (2014) flood study as well as updating the hydrology to use the latest ARR 2016 guidelines and techniques. The following scope for the model revision process was established by RHDHV in consultation with OEH and Council:

- Review and analyse recent changes to stream gauge rating curves.
- Modify the Hunter River hydraulic model to more reliably represent the current floodplain characteristics.
- Recalibration of the Hunter River hydrologic and hydraulic models using data from flood events that occurred in 1998 and 2000.
- Undertake flood frequency analysis using data from the Muswellbrook stream gauge.
- Apply the outcomes from the model calibration and verification process and the Australian Rainfall and Runoff 2016 methods to establish revised design event conditions for a full range of Annual Exceedance Probability (AEP) flood events.
- Verify the revised design model outcomes using available data from the 1955 and 1971 events.

The changes in estimates of design discharge and also changes in flood levels are discussed in Sections 4.1.2 and 4.1.3. The results from this flood study revision were combined with estimates of peak flood levels from the Muscle Creek and Denman local catchment to provide an overall assessment of flood risk for Muswellbrook and Denman (refer Section 4.1).

Muscle Creek Flood Study and Denman Overland Flow Flood Study - 30 January 2017

The Flood Studies for Muscle Creek (RHDHV, 2017b) and an Overland Flow study for Denman (RHDHV, 2017c) reports were delivered to Council in January 2017. The flood studies required the development of flood models that could define the existing flood risk in Muswellbrook (from the Muscle Creek mechanism (refer Section 2.1.2)) and Denman (from the Local Catchment (including drainage and overland flow flood mechanisms (refer Section 2.1.3)) and evaluate potential mitigation options assessed as part of the Floodplain Risk Management Study. The results from these two flood studies were combined with estimates of peak flood levels from the Hunter River flood mechanism to provide an overall assessment of flood risk for Muswellbrook and Denman (refer Section 4.1).

2.6 Floor Level Survey

Floor level survey was commissioned by Council and performed by MM HYNDES BAILEY & Co surveyors for all properties that may be flooded in the study area. Survey included some 900 urban properties (in Muswellbrook and Denman) and some 95 properties in rural areas. The survey was delivered in October 2016 and was used in the inundation and damages assessment (as presented in Section 4.2).

3 Community Consultation

Community consultation is a fundamental element of the floodplain risk management process as it facilitates community engagement and ultimately aids the endorsement of the overall project.

A range of consultation and communication methods have been utilised including:

- A media release on the Council Website at the start of the project (https://muswellbrook.nsw.gov.au/index.php/2015-05-29-01-29-46/2398-your-comments-on-living-near-the-hunter-river-floodplain-are-invited);
- An information brochure and questionnaire was delivered to all residents and businesses in the study area informing them of the study and requesting any information on previous flood events. The survey was available online at https://www.surveymonkey.com/r/NJSQS3Z
- Regular presentations of study progress at floodplain committee meetings;

3.1 Local Resident Survey Responses

As part of the FRMS, a Local Resident Survey was mailed to 888 properties that were identified as being potentially on flood prone land. A study brochure was also provided with the Local Resident Survey.

The key objectives of the community survey were to gauge the understanding of flood risk held by the community and to give local residents an opportunity to put forward key concerns and questions and provide information that could be used in the study.

88 responses were received and have been reviewed by RHDHV. The responses are summarised as follows:

- **Flood Insurance**: 75% of respondents advised that they have flood insurance. Cost and self- assessment of minimal flood risk were the key reasons provided by respondents who do not have flood insurance cover.
- **Awareness of Flood Risk:** 79% of respondents advised that they were aware that their property may be subject to flooding. Many respondents also indicated that they were aware of local flood levels from the 1955 and 1971 events.
- **Experience of Flooding**: Respondents experience of flooding has been divided into the following categories:
  - 12% have experienced flood waters entering their house or business.
  - 21% have experienced flood waters entering their property, but not their house or business.
  - 20% have experienced flooding of local roads, but not their property.
  - 47% have never experienced flooding.

  Many responses included comments that they or a local neighbour had knowledge of local flood levels from the 1971 and 1955 events. This suggests that knowledge of flood risk is well held amongst the community despite the last major flood occurring in 1971, 45 years ago.

- **Knowledge of Local Flood Plan**: 85% of respondents advised that they have no or limited knowledge of the Local Flood Plan.
- **Key Concerns / Questions**: The following key concerns / questions were raised by respondents:
  - Flood warning, specifically:
    a) How reliable is the flood warning system?
    b) How much warning will be provided?
    c) How will warnings be communicated to residents?
  - Evacuation process, specifically:
    d) What areas need to be evacuated?
    e) Will assistance be available to help elderly residents and others in need?
    f) Concern about the availability of medications and medical assistance.
  - Risk to life and pets.
  - Potential for property damage, including furniture and personal items.
  - Flood clean-up costs and post flood recovery hardship.
  - Levee systems in Muswellbrook and Denman are untested.
  - Risk of sewerage discharging to floodwaters.
  - Potential for bank erosion along Muscle Creek to damage properties.
  - Muscle Creek rehabilitation is only localised.
  - Movement of stock, pumps and machinery from rural properties.
  - Looting during evacuation periods.
  - Unnecessary traffic (sightseers).

A number of photographs and videos of flooding in Muscle Creek (2007 event) were provided.

3.2 Public Exhibition of the Draft Muswellbrook and Denman FRMS&P

Public exhibition of the Draft Muswellbrook to Denman FRMS&P report was undertaken to gain the support of the local community. The report was made available digitally with links from Councils website. A hard copy was also displayed at the Council Offices for a period of four weeks for the public's comments. The public exhibition period was from 14/11/2018 to 12/11/2018.

Council did not receive any comment regarding Draft Muswellbrook to Denman FRMS&P report so no further community consultation was deemed necessary.

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4 Existing Flood Behaviour, Property Inundation and Damages

4.1 Existing Flood Behaviour

Flood behaviour in the study area was quantified for three different flood mechanisms (refer Section 2.1) during the project as reported in:

- Hunter River Flood Study (Muswellbrook to Denman) Model Revision Report (RHDHV, 2017a)
- Muscle Creek Flood Study (RHDHV, 2017b)
- Denman (Local Catchment) Overland Flow Study (RHDHV, 2017c).

Flood extents from each individual flood mechanism were combined to produce a single design flood extent which represents the magnitude of flooding for a given frequency (i.e. annual exceedance probability (AEP) or average recurrence interval (ARI)). Peak flood depths and levels for Muswellbrook and Denman for the 1% AEP (100yr ARI) design flood event are presented in **Figure 4-1** and **Figure 4-2.** The figures include a line showing the location of which flood mechanism produces the highest peak flood level. A full series of flood maps for a range of design events is provided in the Appendix A (as described below).

A discussion of changes to design flood levels presented in the FRMS&P compared to the WorleyParsons (2014) Flood Study is provided in Section 4.1.2.

Design flood extents for three events including the: 20% AEP (5yr ARI), 1% AEP (100yr ARI) and Probable Maximum Flood (PMF) are presented in **Figure 4-5, Figure 4-6** and **Figure 4-7**.

The Map Compendium (Appendix A) presents maps of:

- Peak flood depths and contours of flood levels for the 5% AEP (20yr ARI), 1% AEP (100yr ARI), 0.2% AEP (500yr ARI), and probable maximum flood (PMF)
- Peak flood velocities for the 5% AEP (20yr ARI), 1% AEP (100yr ARI), 0.2% AEP (500yr ARI), and probable maximum flood (PMF)
- Peak flood hazard for the 1% AEP (100yr ARI).
- Hydraulic classification for the 1% AEP (100yr ARI) and PMF.

4.1.1 Hunter River Design Flood Levels

Peak flood levels for a range of design events are presented in **Table 4-1**.

Table 4-1: Hunter River Design Flood Levels (ARR2016)

Location	Elev (mAHD)	50% AEP 2yr ARI	20% AEP 5yr ARI	10% AEP 10yr ARI	5% AEP 20yr ARI	2% AEP 50yr ARI	1% AEP 100yr ARI	0.5% AEP 200yr ARI	0.5% AEP 500yr ARI	PMF Event
Kayuga Road Bridge, Muswellbrook	137.43	141.36	144.89	146.50	147.38	148.06	**148.32**	148.51	148.76	150.82
Muswellbrook Greyhound Track	132.31	137.38	141.51	143.22	143.73	143.95	**144.04**	144.12	144.25	146.88
Bengalla Link Road Bridge	129.77	133.40	136.56	137.74	138.32	138.88	**139.11**	139.29	139.52	142.84
Craigend	114.88	120.44	124.44	125.64	126.08	126.31	**126.39**	126.47	126.59	129.42
Kenilworth Street, Denman (Floodplain)	104.38	-99.00	106.37	107.80	108.63	109.46	**109.77**	110.01	110.30	112.51
Sandy Creek Confluence, Denman	99.17	102.86	105.88	106.71	107.04	107.49	**107.64**	107.76	107.92	110.81
Goulburn River Confluence	94.80	96.27	98.31	99.39	100.55	102.43	**103.16**	103.67	104.20	109.67
Golden Highway (Bowmans Crossing)	73.57	74.91	77.20	78.64	80.03	82.27	**83.20**	83.92	84.72	92.08

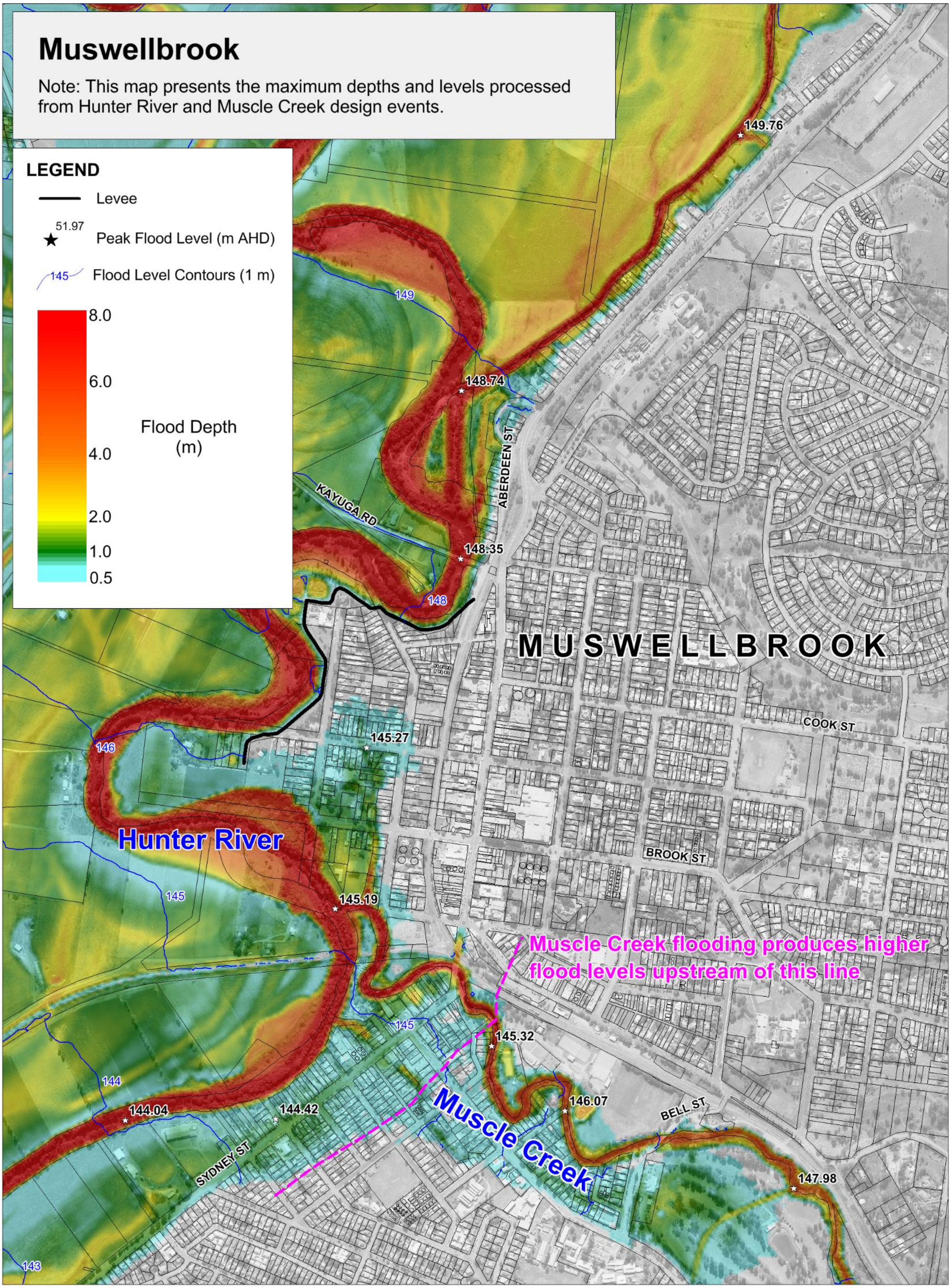

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FIGURE 4-1

Critical Flood Depths and Mechanisms in the Muswellbrook Area (1% AEP)

NORTH

0 125 250m
Approx. Scale

SCALE 1:10,000 PAGE SIZE A4

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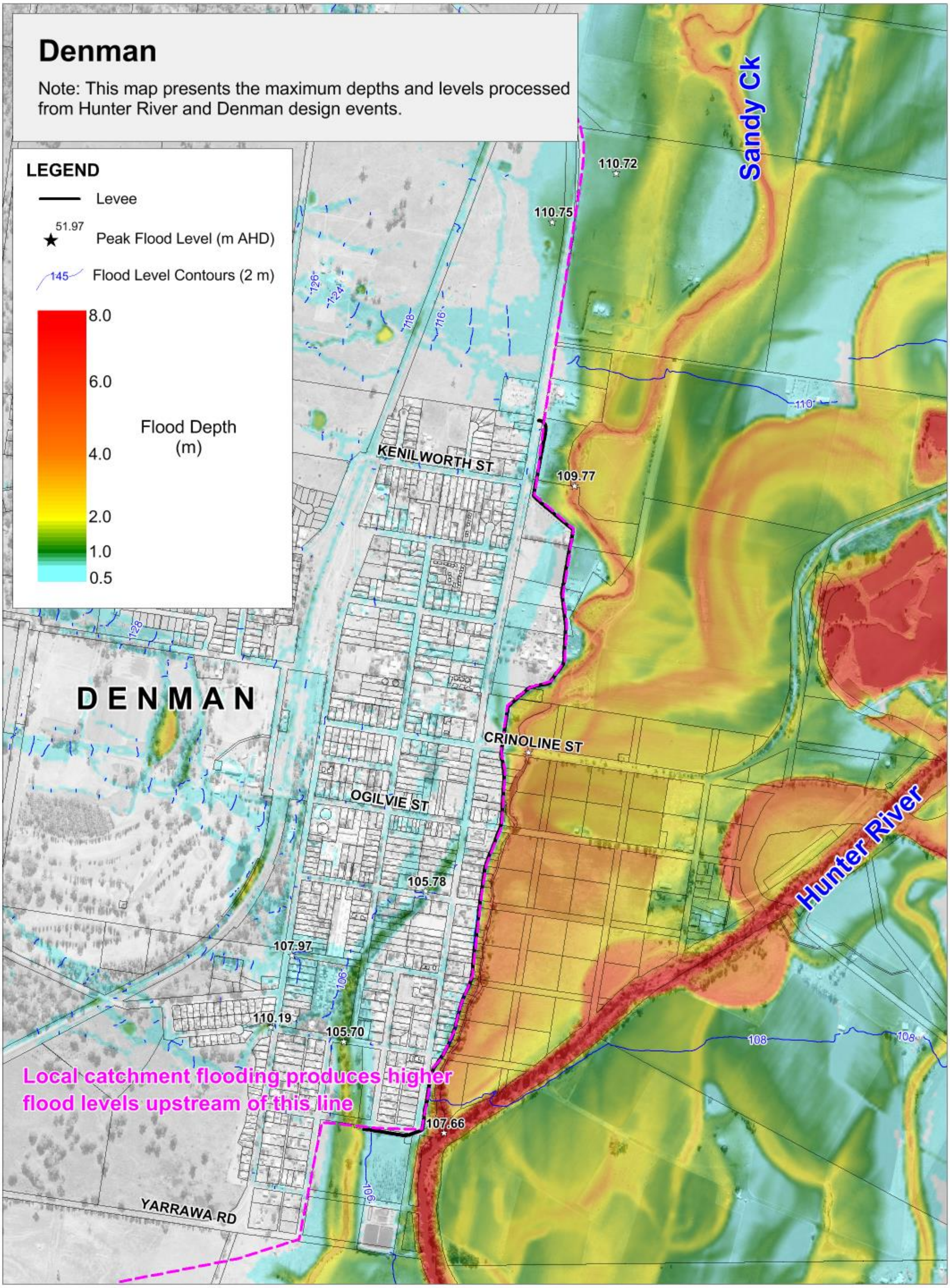

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FIGURE 4-2

Critical Flood Depths and Mechanisms in the Denman Area (1% AEP)

NORTH

0 125 250m Approx. Scale

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4.1.2 Changes in Hunter River Design Flood Levels

A comparison of the 1% AEP (100yr ARI) design levels to those produced in the previous Worley Parsons (2014) flood study are provided in **Table 4-2**.

Flood level difference maps have been prepared to show the changes in peak Flood Study (Worley Parsons, 2014) design flood levels due to the various model changes that are documented in RHDHV (2017a). **Figure 4-3** and **Figure 4-4** present flood level difference maps for the Muswellbrook and Denman area respectively.

With reference to **Figure 4-3** and **Figure 4-4**, the various model changes that are documented in RHDHV (2017a) resulted in 1% AEP flood level reductions ranging from 90 to 360 mm. Reductions in the flood affected areas of Muswellbrook are typically in the 90 to 340 mm range. Flood level reductions adjacent to the Muswellbrook Levee are in the 230 to 270 mm range, while moderately higher (140 to 350 mm) reductions are predicted adjacent to the Denman Levee. A grid calculation of the entire Hunter River between Muswellbrook and Denman (i.e. excluding the downstream area influence by the Goulburn River inflows) gave an average reduction in flood depths for the 1% AEP of 0.2 m.

The reduction in flood levels is due to the significant reduction in the assumed peak flows (see **Section 4.1.3**), partially offset by higher channel roughness assumptions (as discussed in RHDHV (2017a)). An even larger difference in water levels occurs downstream of the Goulburn River influence. The adoption of ARR2016 has resulted in design flow estimates nearly halving and as this section is modelled in 1D only, there has been no corresponding adjustment to roughness so estimates of flood levels in the 1D portion of the model should be used with caution.

Table 4-2: Comparison of 1% AEP Design Flood Levels

Location	Elev (mAHD)	1% AEP FS (2014)	1% AEP FRMS (2017)	Difference (m)
Kayuga Road Bridge, Muswellbrook	137.43	148.64	148.32	-0.32
Muswellbrook Greyhound Track	132.31	144.08	144.04	-0.04
Bengalla Link Road Bridge	129.77	139.34	139.11	-0.23
Craigend	114.88	126.45	126.39	-0.06
Kenilworth Street, Denman (Floodplain)	104.38	110.13	109.77	-0.36
Sandy Creek Confluence, Denman	99.17	107.84	107.64	-0.20
Goulburn River Confluence	94.80	104.46	103.16	-1.30*
Golden Highway (Bowmans Crossing)	73.57	85.36	83.20	-2.16*

Note* - Large changes in Goulburn River hydrology due to adoption of ARR2016 methodology.

4.1.3 Adopted Hunter River Hydrology

A comparison of adopted hydrologic inflows to the comprehensive flood frequency analysis (FFA) of flow gauge data at Muswellbrook (RHDHV, 2017a) are presented in **Table 4-3**. The data shows that the adopted hydrologic inflows are within 2 to 10% of those derived from a comprehensive flood frequency analysis (FFA) of flow gauge data at Muswellbrook for all events up to the 1% AEP. The close agreement between the FFA and the design hydrologic estimate using ARR2016 adopted in this study allow a good degree of certainty to be associated with the estimates of flood levels calculated in this study.

Hydrologic inflows presented in RHDHV (2017a) are also compared to the hydrologic inflows estimated in WorleyParsons (2014) is presented in **Table 4-3.** In general the adopted hydrologic flow used in this study are typically 30% lower than those calculated in Worley Parsons (2014). The adoption of ARR2016 procedures and in particular updated IFD data is responsible for the majority of the differences in design hydrology as discussed in RHDHV (2017a).

Table 4-3: Flood Frequency Analysis & Design Flow Comparison at the Muswellbrook Gauge

Event (AEP)	FFA Flow (m^3/s)	Adopted Hydrologic Model Flows (m^3/s)	Previous Flood Study[2] Hydrologic Model Flows (m^3/s)
0.2 EY	**680**	**640***	**1125***
10%	**1137**	**1080**	**2430**
5%	**1714**	**1650**	**3107**
2%	**2682**	**2900**	**3973**
1%	**3583**	**3510**	**4857**
0.5%	**4643**	**4070**	**5800**
0.2%	**6308**	**4860**	**7199**

*Note: 0.2 EY has a slightly different probability of occurrence to the 20% AEP, equivalent to 18.13% AEP

[2] Note: From Table 6.2 Worley Parsons (2014). Also flows are from upstream of Muswellbrook Gauge so are slightly lower than if a comparison at the actual gauge was available.

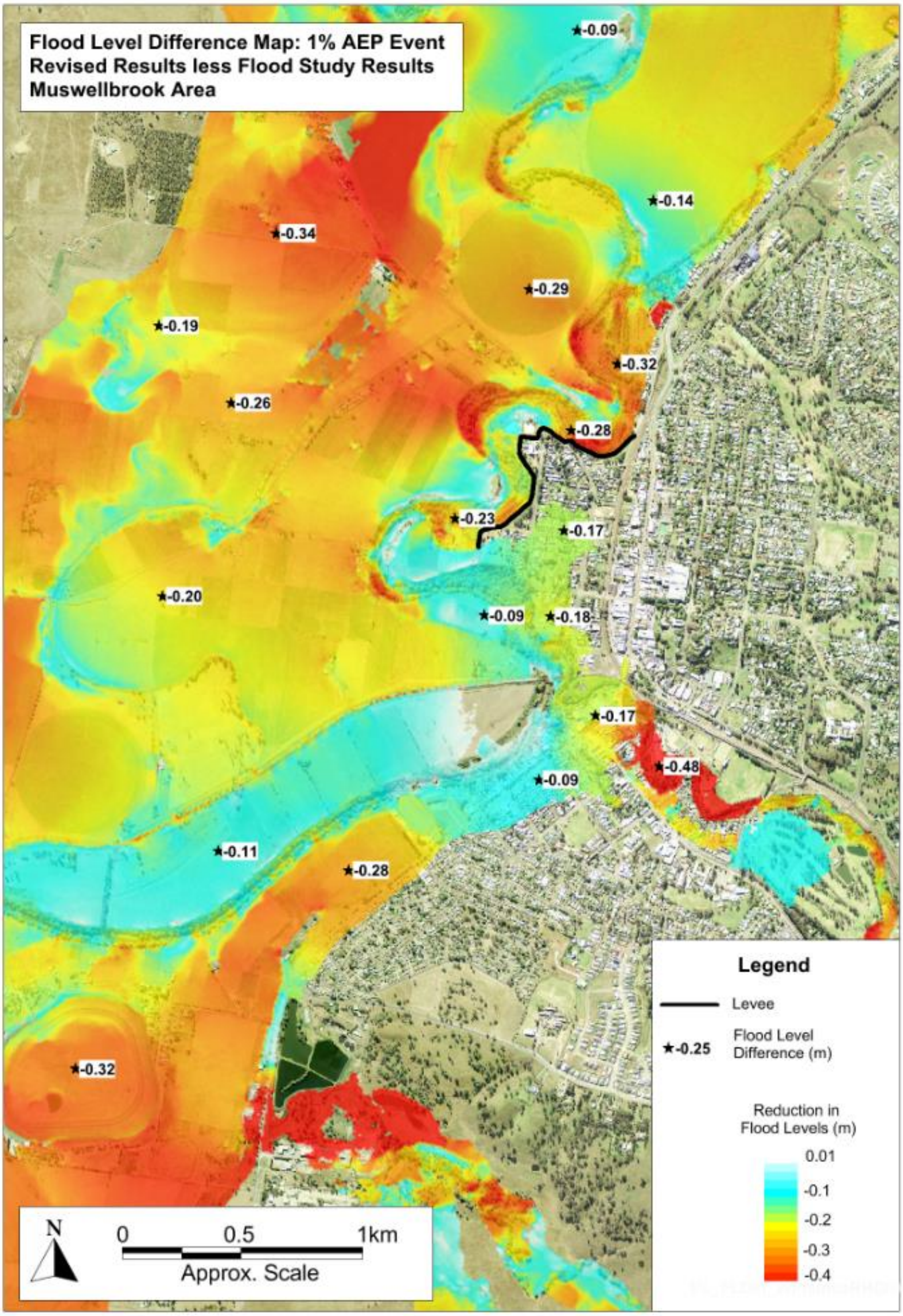

Figure 4-3: Changes to 1% AEP Levels: Muswellbrook Area

Note: a negative number represents a reduction in flood levels for the current study compared to the 2014 Flood Study.

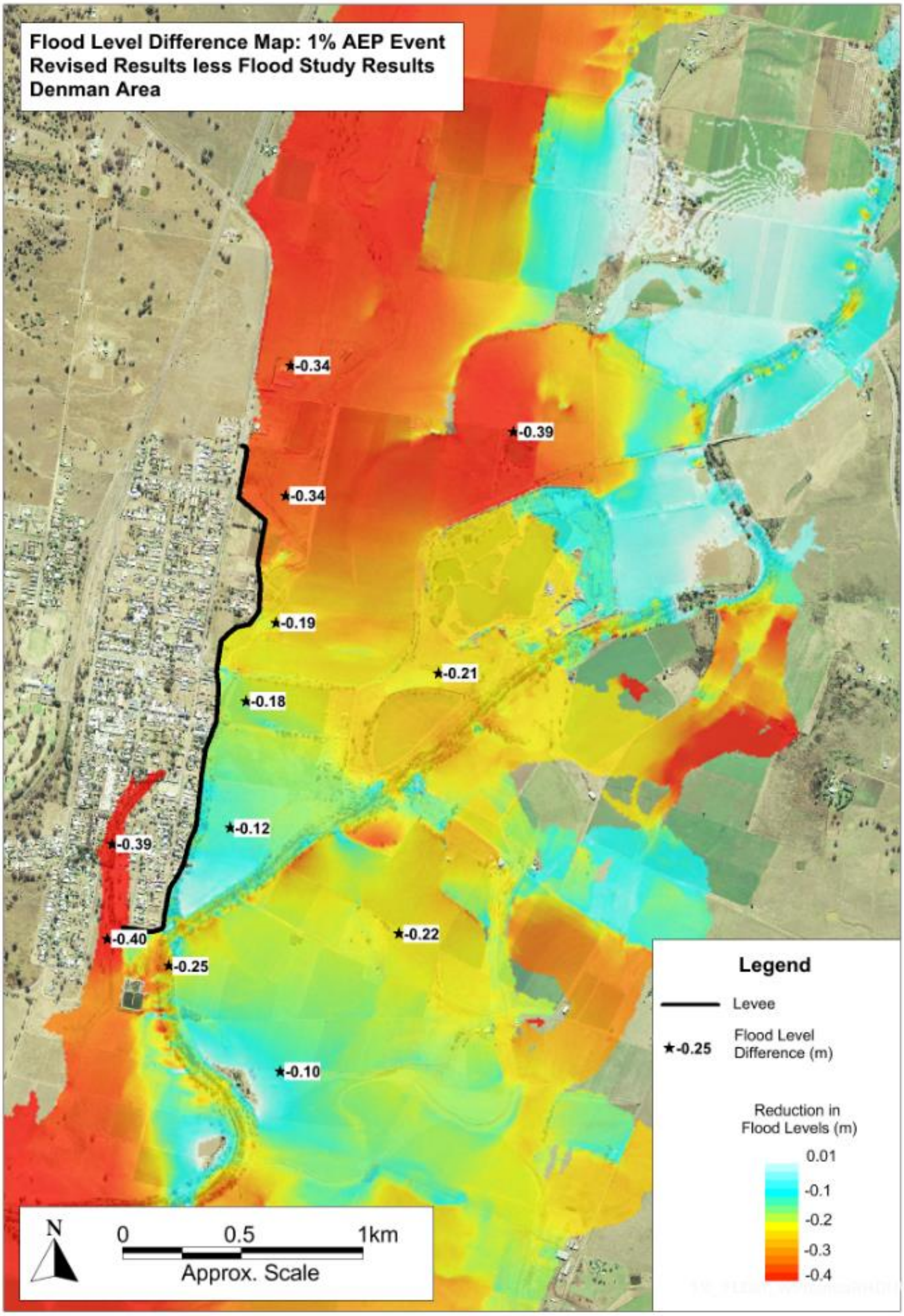

Figure 4-4: Changes to 1% AEP Levels: Denman Area

Note: a negative number represents a reduction in flood levels for the current study compared to the 2014 Flood Study.

4.2 Property Inundation and Flood Damages Assessment

A flood damage assessment has been undertaken to identify flood affected property, to quantify the extent of damages in economic terms for existing flood conditions (see below) and to enable the assessment of the relative merit of potential flood mitigation options by means of benefit-cost analysis (as detailed in **Section 6**). The general process for undertaking a flood damages assessment incorporates:

- Identifying properties subject to flooding
- Determining depth of inundation above floor level for a range of design event magnitudes
- Defining appropriate stage-damage relationships for various property types/uses
- Estimating potential flood damage for each property, and
- Calculating the total flood damage for a range of design flood events.

4.2.1 Property Database

A property database was established containing information regarding flood liable properties. The database contains the required information to carry out the flood damages assessment including:

Location Data: The locations of flood affected properties were determined by examining Council cadastre information and detailed aerial photography. Using GIS software, property data could be efficiently extracted into the property database. A total of 1255 properties were identified as occurring within the PMF extents. It should be noted that the database represents the catchment conditions circa September 2016 when the survey was undertaken. As such it excludes any properties that have been constructed or demolished since that time.

Land Use: For the purposes of the flood damage assessment, property was considered as either residential or non-residential (i.e. commercial or industrial). Commercial and industrial buildings (e.g. Libraries, Community Halls, Denman Multi-Purpose Service and other businesses etc.) properties have been identified from the property survey. Public infrastructure and utility assets (i.e. pumping stations, electricity sub-stations, etc.) were excluded from the damages assessment.

Ground and Floor Level Data: A floor level survey of property within the PMF flood extent was undertaken by Council surveyors. The survey provided building floor level, geographic coordinates, building classification (i.e. residential, commercial or industrial), approximate year constructed, number of stories, construction type (i.e. brick or weatherboard), foundation type (slab on ground or piers) and photographic record to identify property type. Ground level data was based on the LiDAR based DEM.

The distribution of surveyed properties within the study area with reference to the PMF flood extent is shown in **Figure 4-5, Figure 4-6** and **Figure 4-7**.

Flood Level Data: The design flood levels across the catchment were adopted from the Hunter River Flood Study (Muswellbrook to Denman) Model Revisions Report (Royal HaskoningDHV, 2017). The flood modelling results were used to generate a continuous flood profile across the floodplain. Flood levels calculated from the TUFLOW model were queried from TUFLOW's GIS output at each property reference point, creating a property specific flood level. The resultant flood level was used to calculate the depth of flooding above the property floor level or ground level for each design flood event. The depth of flooding was used to calculate a property specific flood damage estimate using the damage curves previously adopted by WorleyParsons (2014) for the Hunter River Flood Study (Muswellbrook to Denman).

4.2.2 Property Inundation Assessment

A summary of the location and frequency of above floor property inundation in the Muswellbrook to Denman study area is presented in **Figure 4-5** and **Table 4-4**. The assessment shows that:

- In an extreme flood (i.e. the PMF), 1239 properties in the study area are inundated above floor level. Of these properties, 659 (53% of properties) are on the Hunter River floodplain, 412 (33% of properties) are in the township of Denman, and 168 affected by local flooding from the Muscle Creek catchment.
- Similarly, in the rare, 0.2% AEP (500-year ARI) event, 360 properties are inundated above floor level. Of these properties, 274 (77% of properties) are on the Hunter River floodplain, 15 (3% of properties) are in the township of Denman and 71 properties are affected by local flooding from the Muscle Creek catchment.
- During the 1% AEP (100-year ARI) event, 220 properties are inundated above floor level. Of these properties, 175 (80% of properties) are on the Hunter River floodplain, 38 (19% of properties) are affected by local flooding from the Muscle Creek catchment with only 7 properties) affected in the township of Denman.
- During the 5% AEP (20-year ARI) event, 37 properties are inundated above floor level. Of these properties, 20 (58% of properties) are on the Hunter River floodplain with the remainder affected by local flooding from Muscle Creek. No properties are flooded above floor level in the township of Denman.
- During the 10% AEP (10-year ARI) event, no properties are inundated above floor level.
- During all design flood events, residential properties make up 80-90% of the above floor inundated properties with non-residential (commercial and industrial buildings) making up the remainder.

Table 4-4: Summary of Above Floor Property Inundation by Flood Mechanism and Property Type

AEP / ARI	Study Area (i.e. Total)	Hunter River	Muscle Creek	Denman	Residential	Non-Residential
PMF	1239	659	168	412	1113	126
0.2% / 500yr	360	274	71	15	315	45
0.5% / 200yr	283	225	49	9	251	32
1% / 100yr	220	175	38	7	192	28
2% / 50yr	150	123	24	3	133	17
5% / 20yr	37	20	17	0	30	7
10% / 10yr	0	0	0	0	0	0

For the range of design flood events above, a further 9 (for the 10% AEP event) to 1253 (for the PMF event) properties may experience below floor flooding. A summary of the number of properties that experience underfloor (or near house) flooding is presented in **Table 4-7**.

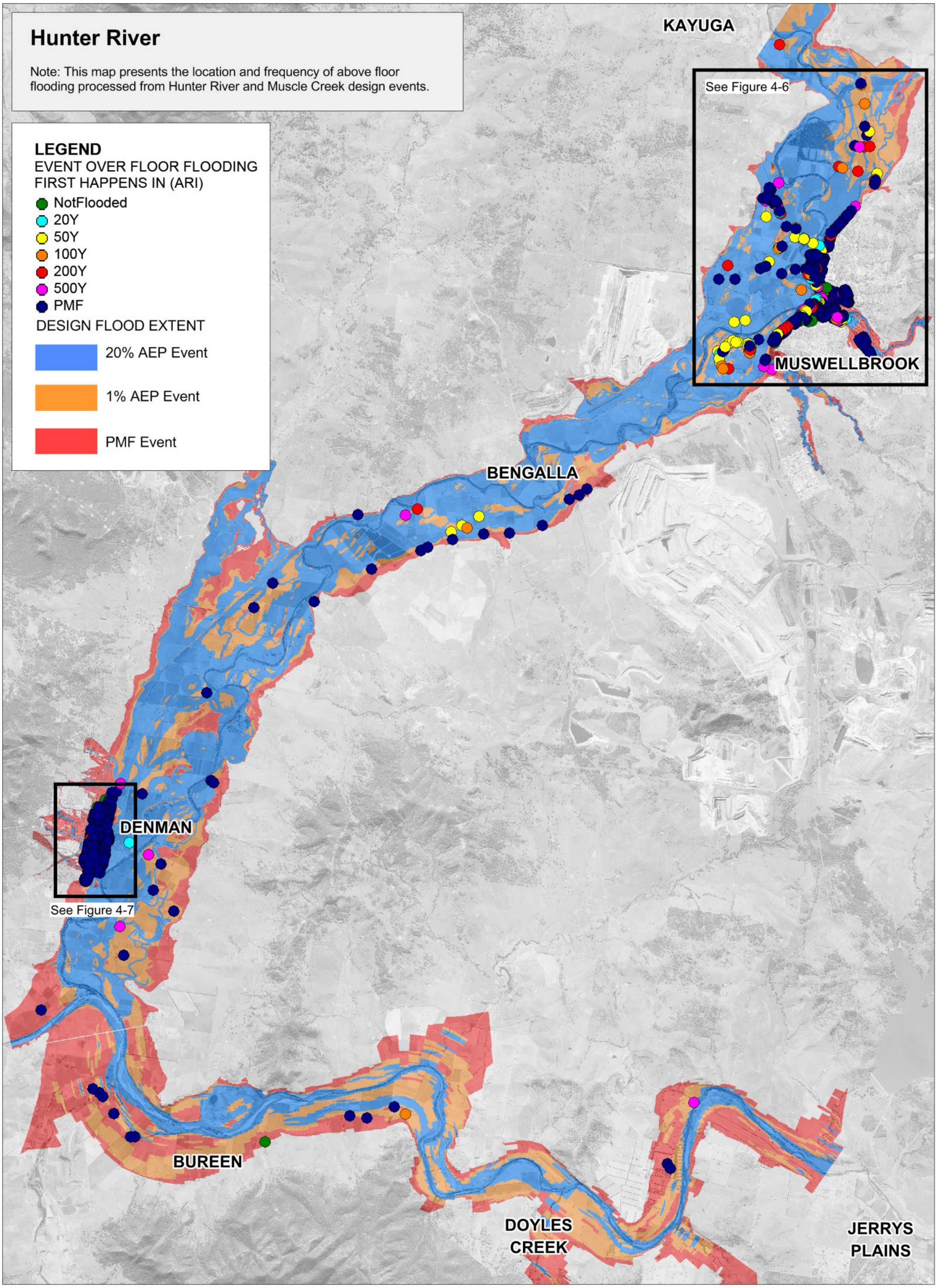

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FIGURE 4-5

LOCATION AND FREQUENCY OF ABOVE FLOOR FLOODING IN THE STUDY AREA

SCALE 1:130,000 PAGE SIZE A4

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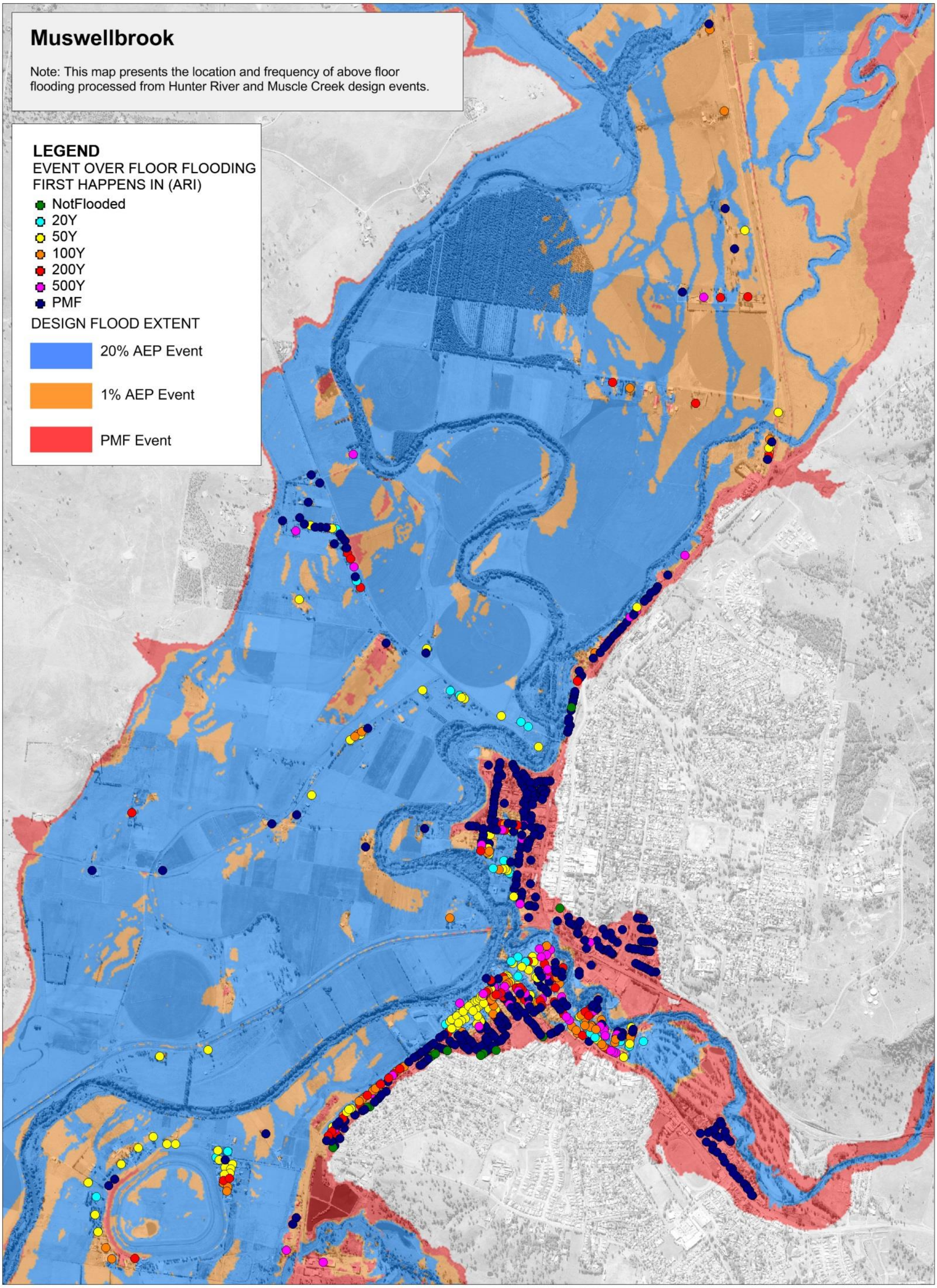

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FIGURE 4-6 LOCATION AND FREQUENCY OF ABOVE FLOOR FLOODING IN MUSWELLBROOK

NORTH

0 250 500m
Approx. Scale

SCALE 1:30,000 PAGE SIZE A4

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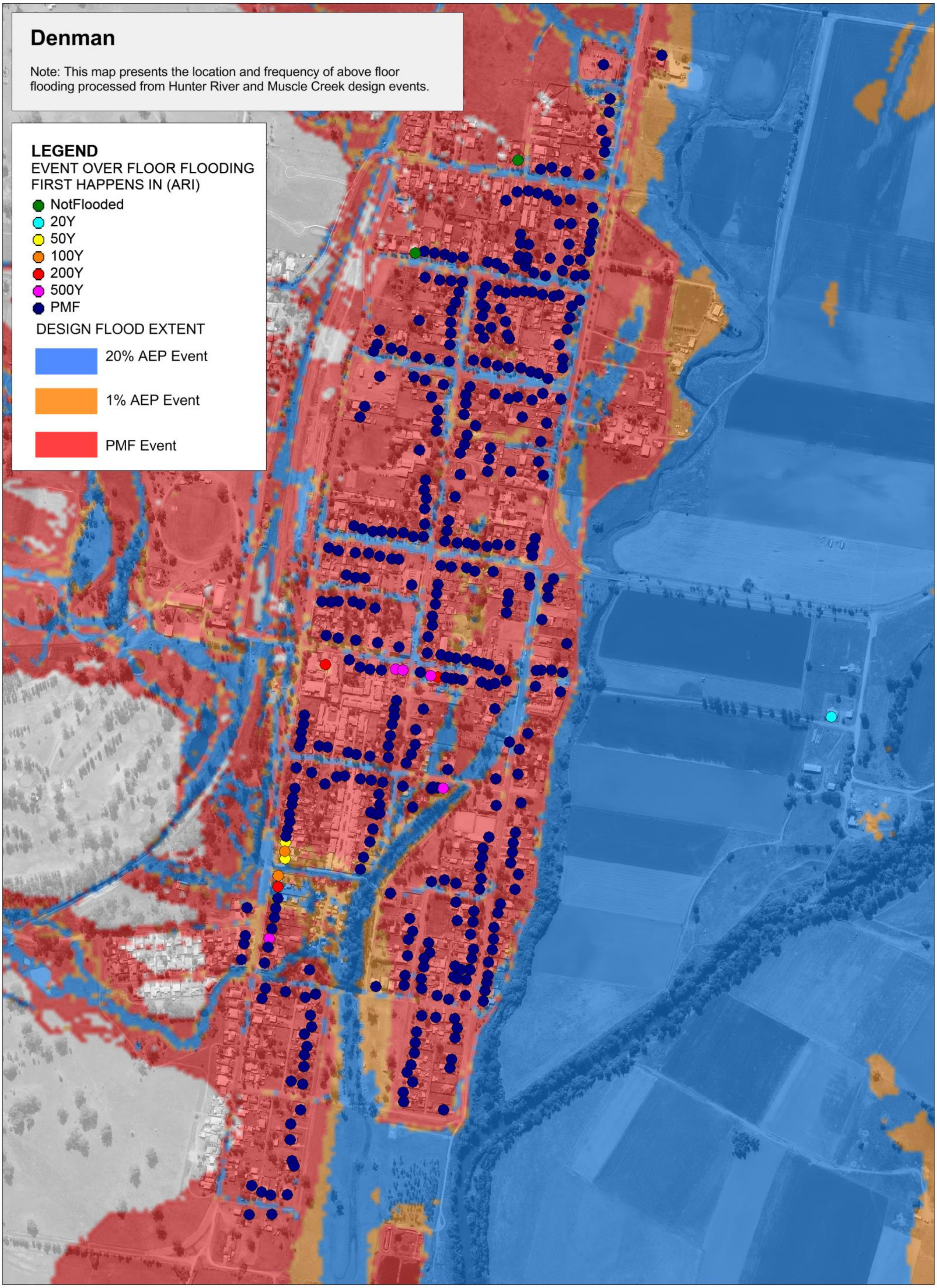

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FIGURE 4-7

LOCATION AND FREQUENCY OF ABOVE FLOOR FLOODING IN DENMAN

NORTH

0 100 200m
Approx. Scale

SCALE 1:10,000 PAGE SIZE A4

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4.2.3 *Flood Damages Assessment*

Background

Flood damages are typically divided at the primary level, into tangible and intangible damages and at a secondary level, as direct and indirect damages. Tangible damages are those for which a monetary value can easily be assigned. Intangible damages are those to which a monetary value cannot easily be attributed and arise from social and environmental effects caused by flooding including factors such as: loss of life and injury, inconvenience, disruption of family and social activities, stress, anxiety and physical and psychological ill-health.

Tangible damages may be direct or indirect flood damages. Direct damages are directly attributed from the actions of flooding (inundation and flow), on property and structures, while indirect damages arise from the disruptions to physical and economic activities caused by flooding. Examples of indirect damages include: losses due to the disruption of business, expenses of alternative accommodation, disruption of public services, emergency relief aid and clean-up costs. This study estimates only the tangible, direct damages which are appropriate for the comparison of flood mitigation options.

Given the variability of property and content values, the total likely damages estimate for any given flood event is approximate only and while useful to gauge the magnitude of the flood problem, it is of little value for absolute economic evaluation. Given that the primary purpose of the flood damages estimates are to evaluate the economic effectiveness of proposed mitigation options, the methods used are considered appropriate.

The Average Annual Damage (AAD) is the main comparative factor derived from this flood damages assessment which is used to evaluate the effective of proposed mitigation options. The AAD represents the estimated tangible damages sustained every year on average over a given ‘long’ period of time and is determined using the full range of flood events considered in the FRMS. The AAD damage calculation considers that in many years there may be no flood damage, in some years there will be minor damage (caused by small, relatively frequent floods) and, in a few years, there will major flood damage (caused by large, rare flood events). Estimation of the AAD provides a basis for comparing the effectiveness of different floodplain management measure (i.e. the reduction in the AAD) as presented in **Section 6**.

Damages Methodology

The approach developed to calculate flood damages for the study area is based upon the development of a representative damage curve for typical structures in the floodplain after WorleyParsons (2014). Flood damages were calculated for the study area based on different types of land use along the floodplain, including:

- Residential
- Commercial, and
- Industrial.

Commercial properties include shops, pubs, offices and large shopping complexes, while industrial premises in include metal fabrication works and distribution warehouses. The residential damages were assessed on the basis of the type of residential dwelling and categorised as either:

- Single storey set directly on the ground
- Single storey building set on piers (high set), or

- Double storey building set directly on the ground.

Stage-damage curves reflect the potential flood damage as a function of depth of over floor flooding of a building. The stage-damage curves adopted by WorleyParsons (2014) reproduced in **Figure 4-8** were used to maintain consistency between the previous 2014 flood study and the present 2017 revised flood study and FRMP.

Further details of the flood damage assessment methodology used are outlined under Section 8 of WorleyParsons (2014).

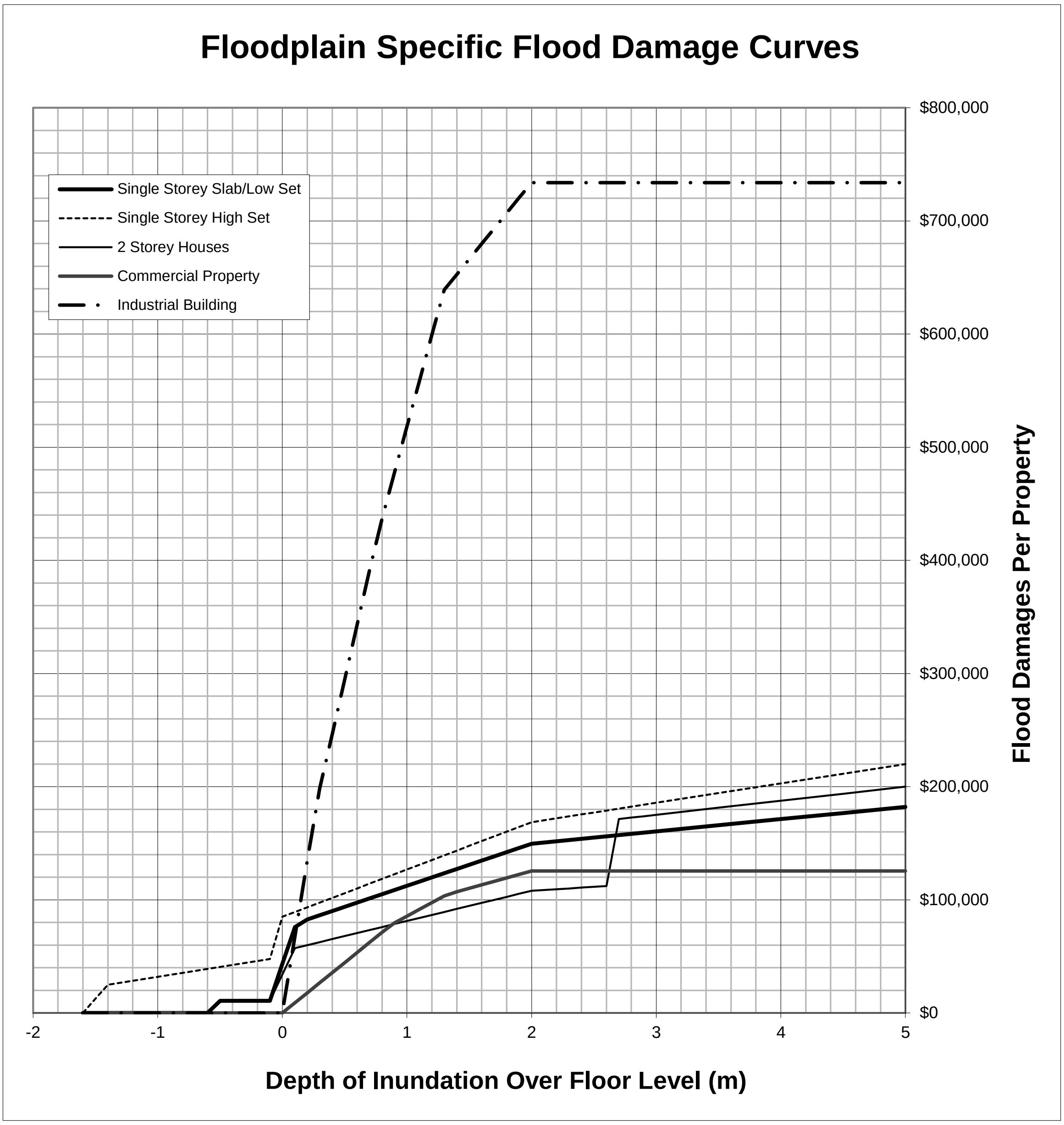

Figure 4-8: Adopted Stage Damage Curves for Hunter River (Source: WorleyParsons (2014))

Results of Damages Assessment

The results of the damages assessment is presented as follows:

- **Table 4-5** provides a summary of flood damages ($) by flood mechanism and property type;
- **Table 4-6** contains the above data showing the percentage flood damages by flood mechanism and property type;
- **Table 4-7** summarises the flood damages in terms of each events contribution to the annual average damage (AAD) quantity (as previously described) and also defines how many properties are inundated in a given event; and
- **Table 4-8** provides a summary of net present value (NPV) calculations which uses the AAD value to calculate the total damages over a 50 year forward timeframe in term of today's costs for a range of discount factors.

A number of key points regarding flood damages for the existing conditions include:

- In the 1% AEP (100-year ARI) event, it is estimated that $20.8 Million of tangible flood damages would occur in the study area. The majority (i.e. 79%, $16.9 Million) of these damages are attributed to main stream flooding on the Hunter River floodplain. During a 1% AEP event, flood damages from Muscle Creek are estimated to be $3.0 Million, and for the township of Denman approximately $1.6 Million.
- In the 1% AEP (100-year ARI) event, residential properties make up 93% (i.e. $20.0 Million) and non-residential (i.e. either commercial or industrial) properties estimated to incur an estimated $1.5 Million worth of flood damages.
- With the exception of the PMF event, the majority (greater than 75%) of flood damages occur in the Hunter River floodplain area with the Muscle Creek area accounting for most of the remainder and the Denman area accounting for typically less than 10% of the damaged properties. During the PMF event, however, the number of properties with above floor flooding in the Denman area increases substantially accounting for 35% of the total.
- Residential properties account for between 89% and 96% of the flood damage costs for events greater than the 10% AEP. For the 10% AEP, flood damage costs are entirely related to residential properties.

A summary of flood damages (AAD Contribution) and property inundation is presented in **Table 4-7** which shows that the 2% AEP (i.e. 50-year ARI) and PMF events, contribute significantly (over 27% and 23% respectively) to the damages in the AAD value. Notable AAD contributions are also associated with the 100-year ARI and 200-year ARI events. Calculation of the average annual damages (AAD) costs for the study area suggests that over a sufficiently long period of time (in which the full range of design floods occurs), flood damages average out to approximately $1.1 Million per year. Assuming no inflation and a 50 year timeframe, damages for the study area are estimated to be $56.1 Million. As economic theory shows that todays $56.1 Million dollars, will not buy $56.1 Million dollars of goods in 50 years' time, it is important to carry out a net present values (NPV) calculation to understand the cost of covering future damages in terms of dollars now. Adopting a 7% discount rate (which is typical for this type of study and the likely future economic conditions) shows that over a 50 year time frame, the damages in today's dollars is reduced to $16.6 Million. **Table 4-8** shows the impact on the NPV calculation of adopting a higher or lower discount rate. A 7% discount rate was adopted for the assessment of mitigation option presented in **Section 6**.

Table 4-5: Summary of Flood Damages by Flood Mechanism and Property Type

AEP / ARI	Study Area (i.e. Total)	Hunter River	Muscle Creek	Denman	Residential	Non-Residential
PMF	$189,481,398	$99,934,999	$24,088,925	$65,457,475	$169,336,852	$20,144,546
0.2% / 500yr	$36,278,067	$26,630,994	$6,380,333	$3,266,740	$33,710,928	$2,567,139
0.5% / 200yr	$28,018,307	$21,267,272	$4,626,814	$2,124,221	$26,037,876	$1,980,430
1% / 100yr	**$21,609,129**	**$16,972,782**	**$3,038,027**	**$1,598,321**	**$20,057,605**	**$1,551,525**
2% / 50yr	$15,170,036	$12,006,896	$2,017,650	$1,145,490	$14,078,536	$1,091,501
5% / 20yr	$4,880,386	$2,906,121	$1,337,931	$636,334	$4,683,134	$197,252
10% / 10yr	$924,614	$154,726	$224,088	$545,800	$924,609	$5
AAD	**1,123,046**	**$746,232**	**$191,857**	**$183,063**	**$1,045,424**	**$75,727**

Table 4-6: Summary of Percentage Flood Damage by Flood Mechanism and Property Type

AEP / ARI	Study Area (i.e. Total)	Hunter River	Muscle Creek	Denman	Residential	Non-Residential
PMF	$189,481,398	53%	13%	35%	89%	11%
0.2% / 500yr	$36,278,067	73%	18%	9%	93%	7%
0.5% / 200yr	$28,018,307	76%	17%	8%	93%	7%
1% / 100yr	**$21,609,129**	**79%**	**14%**	**7%**	**93%**	**7%**
2% / 50yr	$15,170,036	79%	13%	8%	93%	7%
5% / 20yr	$4,880,386	60%	27%	13%	96%	4%
10% / 10yr	$924,614	17%	24%	59%	100%	0%
AAD	**$1,123,046**	67%	17%	16%	93%	7%

Table 4-7: Summary of Flood Damages (AAD Contribution) and Property Inundation

AEP / ARI	Total Damages	Contribution to AAD ($)	Contribution to AAD (%)	Cumulative Contribution to AAD (%)	Properties Above Floor	Properties (Underfloor / Grounds)
PMF	$189,481,398	$226,525	23%	100%	1239	1253
0.2% / 500yr	$36,278,067	$96,445	9%	77%	360	713
0.5% / 200yr	$28,018,307	$124,069	12%	68%	283	611
1% / 100yr	$21,609,129	$183,896	18%	56%	220	534
2% / 50yr	$15,170,036	$300,756	27%	39%	150	448
5% / 20yr	$4,880,386	$145,125	11%	12%	37	269
10% / 10yr	$924,614	$46,231	1%	1%	0	59
AAD	**-**	**$1,123,046**	100%		-	-

Table 4-8: Summary of NPV of Damages over 50 Years for a Range of Discount Factors

Discount Factor	NPV of Damages over 50 Years
0%	$56,152,324.93
4%	$25,248,539
7%	$16,621,926
11%	$11,277,243

4.3 Road & Rail Inundation Assessment

An assessment of potential road and rail inundation during flood events has been undertaken to assist in the formulation of effective evacuation strategies. An assessment of the frequency of closure for significant transport routes is outlined below. The specific locations of closures have been provided to Council & OEH in GIS format and was also used to inform **Section 4.6** (Access and Evacuation Constraints (ERP Classification)) of this report.

The large size of the Hunter River catchment means that longer duration road closures are likely, typically ranging from 4 to 24 hours depending on the duration and magnitude of the events. However, it may also be possible for longer duration road closure events of up to 48 hours could occur. Due to the size of the catchment, Muscle Creek Road closures are likely to be for a short-moderate duration say 1-6 hours depending on the duration and magnitude of the events. Road closures from the local Denman catchment flood mechanism are only likely to be for 1 to 2 hours.

Bridge Road / Subway (Muscle Creek) – Elevation of the bridge deck and approach road (subway under rail bridge) is 141.5 m AHD. The road is submerged by approximately 1 m from a tailwater from the Hunter River in as little at the 50% AEP (i.e. 2yr ARI). Once Bridge Street is submerged the only other main cross-town access road is the Bell Street crossing which is described below.

Bell Street (Muscle Creek) – Elevation of the bridge deck is 148.0 m AHD though the elevation of the approach road is 147.2 m AHD. Road receives minor inundation in the 10% AEP (10yr ARI), and is likely to be inaccessible to 2wd cars in the 5% AEP (20yr ARI). Once Bell Street is cut, cross-town access in Muswellbrook is lost, which may cause emergency service access issues as the hospital is located on the north side of Muscle Creek.

Note: a long distance diversion eastward along Muscle Creek Road, then north towards Muswellbrook Coal Mine then west along Coal Road back to Muswellbrook may be an alternate route though this route does require a crossing of Muscle Creek outside the study area. Alternatively emergency services from Singleton may be required.

Wilkinson Avenue (Muscle Creek) – Elevation of the bridge deck is 147.0 m AHD and the bridge appears to be flood free up to the 0.2% AEP (i.e. 500yr ARI), though the approach is lower and is cut in the 2% AEP (i.e. 50yr ARI) flood event.

Maitland Street / New England Highway (adjacent to Muscle Creek) – The New England Hwy (heading east out of Muswellbrook) could become inundated in events great than the 5% AEP (i.e. 20yr ARI). However, alternative routes around these flooded low points are available.

Clifford, Gyarran and Wilder Streets (Muscle Creek) – These minor local urban roads are inundated in the 5% AEP (20yr ARI). Flash flooding from Muscle Creek could cause rapid and unpredictable flooding which could result in evacuation difficulties and unsafe conditions.

Lorne Street (Muscle Creek) – is predicted to have < 0.15m inundation in the 2% AEP (50yr ARI) event, though would be closed in the 1% AEP (100yr ARI).

Railway Bridge Crossing of Muscle Creek – The first rail crossing of Muscle Creek (heading east out of Muswellbrook) appears to be flood free in all events apart from the PMF. It is likely that two subsequent rail crossing have a similar level of flood immunity though these are outside the study area and have not been assessed.

Sydney Street (Hunter River eastern bank) – Sydney Street is flood free in the 10% AEP (i.e. 10yr ARI) but is inundated in the 5% AEP (20yr ARI) and above. While alternate traffic routes are available, the evacuation of residents on the river side of the street would be required.

Bengalla / Ulan Railway (Hunter River Floodplain crossing) – Begins to be inundated in the 10% AEP (i.e. 10yr ARI).

New England Highway, north of Muswellbrook (Hunter River eastern bank) - flood free in the 5% AEP (i.e. 20yr ARI) but is inundated in the 2% AEP (50yr ARI) and above. This is the only road between Muswellbrook and Aberdeen.

Main Northern line, north of Muswellbrook (Hunter River eastern bank) – flood free in the 5% AEP (i.e. 20yr ARI) but is inundated in the 2% AEP (50yr ARI) and above.

Koolbury Flat Row & Burtons Lane (Hunter River Floodplain crossing) – Are cut by Hunter River flood runners in events above the 5% AEP (20yr ARI). Burtons Lane can also be cut by large Sandy Creek catchment events, due to low channel capacity in Sandy Creek downstream of the New England Highway Bridge.

Kayuga Road (Hunter River Floodplain crossing) – Hunter River flood flows are generally maintained in channel up to and including the 20% AEP (i.e. 5yr ARI), however, there is a low causeway crossing of Rosebrook Creek which is flooded up to 0.5 m deep in the 20% AEP and would isolate 29 properties. In the 10% AEP (i.e. 10yr ARI) most roads in the area are likely to be impassable to cars, though trucks, 4WDs and tractors may be able to pass these roads up to the 5% AEP (i.e. 20yr ARI) event.

Wybong Road (Hunter River Floodplain crossing) – Hunter River flood flows are generally maintained in channel up to and including the 20% AEP (i.e. 5yr ARI), however, there is a low causeway crossing of Rosebrook Creek which is flooded up to 0.5 m deep in the 20% AEP and would isolate 4 properties. In the 10% AEP (i.e. 10yr ARI) most roads in the area are likely to be impassable to cars, though trucks, 4WDs and tractors may be able to pass these roads up to the 5% AEP (i.e. 20yr ARI) event.

Bengalla Road (Hunter River Floodplain crossing) – Hunter River flood flows are generally maintained in channel up to and including the 20% AEP (i.e. 5yr ARI. In the 10% AEP (i.e. 10yr ARI) most roads in the area are likely to be impassable to cars, though trucks, 4WDs and tractors may be able to pass these roads up to the 5% AEP (i.e. 20yr ARI) event.

Racecourse Road (Hunter River Floodplain crossing) – is flood free in the 10% AEP (i.e. 10yr ARI) but is inundated in the 5% AEP (20yr ARI) and above. Evacuation of the race course area should be a priority.

Brook and Lower Hill Street (Hunter River Tailwater) – These minor local urban roads are inundated in the 5% AEP (20yr ARI) by a tailwater from the Hunter River flooding Possum Gully Creek. Some 4WD access may be possible in the 5% AEP (20yr ARI). No vehicular access is likely above the 2% AEP (50yr ARI), though pedestrian access is likely to be possible behind the levee.

Denman Road (Hunter River eastern bank) - is flood free in the 5% AEP (i.e. 20yr ARI) but is inundated in the 2% AEP (50yr ARI) and above.

Golden Highway - Hunter River Floodplain crossing at Denman – is flood free in the 20% AEP (i.e. 5yr ARI) but is inundated in the 10% AEP (10yr ARI) and above. Once the highway is cut, road access to Denman from any large townships is lost.

Golden Highway - Bowmans Crossing (Hunter River Floodplain crossing) – the elevation of the low point on the bridge deck / approach road is 79.0 m AHD. The bridge/road is flood free in the 10% AEP (i.e. 10yr ARI) but is inundated in the 5% AEP (20yr ARI) and above. This crossing could also be closed due to large flows on the Goulburn River system.

Denman Local Catchment Road Closures – A number of road closures in the Denman Township catchment are possible. However, closures are likely to be limited to 1-2 hours and flow depths would generally be less than 0.5m (mostly 0.1-0.2m) though high velocity flood flows would make road crossing hazardous to all but large tractors, trucks and 4WDs. The two culvert crossing of Virginia Street could become potentially hazardous floodways during more extreme events. The Babbington Street causeway can also be impacted by a backwater from the Hunter River though alternative higher routes are available. .

4.4 True Flood Hazard Classification

The Muswellbrook Flood Study (WorleyParsons, 2014) defined the provisional hydraulic hazard based on an extension of the methodology outlined in Appendix L of the NSW Floodplain Development Manual (NSW State Government, 2005). This approach used a depth-velocity relationship to define areas as low, medium, high, very high and extreme hazard.

The current FRMS&P proposes to use the flood hazard curves proposed by Smith et al. (2014) and recommended by the Australian Emergency Management Institute (AEMI). This approach provides a range of hazard classifications which increase in severity based on the safety threat posed to vehicles, people and buildings. These classifications and the corresponding flood hazard curves are shown in **Table 4-9** and **Figure 4-9** respectively.

Table 4-9: Hazard Classifications

Hazard Classification	Description
H1	*No vulnerability constraints*
H2	Unsafe for small vehicles
H3	Unsafe for all vehicles, children and the elderly
H4	Unsafe for all people and all vehicles
H5	Unsafe for all people and all vehicles. Buildings require special engineering design and construction
H6	Unconditionally dangerous. Not suitable for any type of development or evacuation access. All building types considered vulnerable to failure.

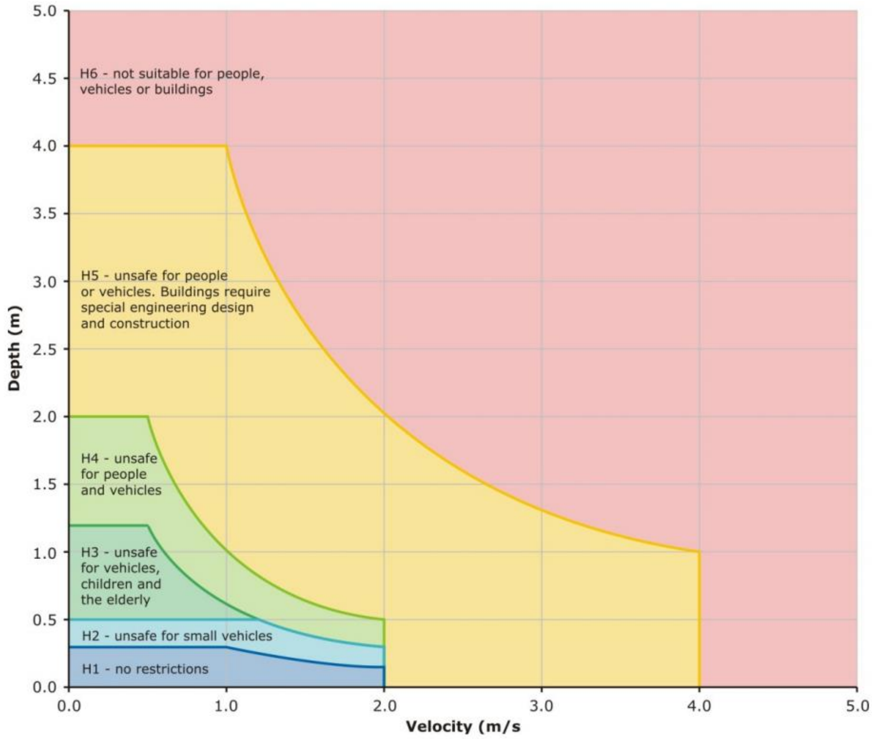

Figure 4-9: Combined Flood Hazard Curves (Smith et. al. 2014)

In conjunction with considering the hydraulic hazard using the flood depths and velocities from the hydraulic model, it is important to consider other criteria such as: size of the flood, effective warning time, flood readiness, rate of rise of floodwaters, depth and velocity of floodwaters, duration of flooding, evacuation problems, effective flood access and type of land use. These factors are assessed in **Table 4-10**.

Table 4-10: Hazard Assessment of Variables

Criteria	Weight	Comment
Size of the flood	Medium	The magnitude of a flood affects the depths and velocities produced in an event. Low flood hazard typically is associated with more frequent flood events while high hazard flows usually occur during rare (major) flood events. Typically, flood affectation in the study area increases significantly for rare events.
Depth and velocity of floodwaters	High	The flood hazard is related to the product of depths and velocity of flood waters which are influenced by the size of the flood. In Denman overland flows tend to be shallow but fast moving, while on the Hunter River deeper flood depth can be expected.
Rate of rise of floodwaters	Medium	The rate of rise of floodwaters is influenced by the catchment size, soil type, slope and land use. The spatial and temporal pattern of the rainfall is also related to the rate of rise. The rate of rise in the study area for the Denman and Muscle Creek catchments can be quite rapid due to the relatively small catchment size and shape of these catchments. The Hunter River catchment carries flow from a much larger upstream catchment and as such the rate of rise is considerably slower.

Criteria	Weight	Comment
Duration of flooding	Low	Typically, the longer the duration of flooding, the more disruption caused to the community and greater the potential flood damages. The duration of flooding from the Hunter River can be long, 12-48 hours, while flooding from the Muscle Creek is shorter 6-24 hours, and Denman catchment flooding is likely to be 1-5 hours.
Effective warning and evacuation time	Medium	Flood warning and evacuation is subject to the rate of rise, the flood awareness of the community and availably of a flood warning system. While there is a flood warning system for the Hunter River, there is currently no warning system for the Muscle Creek or the Denman catchment. While a flood warning system for the Muscle Creek should be considered, the local catchment is too small for a warning system to be of use.
Flood awareness and readiness of the community	Low	Flood awareness in the community is likely to be quite low due to considerable time since a large Hunter River flood (i.e. 2000). However, the significant June 2007 flood event on Muscle Creek means that flood awareness at this location should be reasonable. Ongoing community education is recommended to ensure awareness and readiness are developed and maintained in the future.
Effective flood access	Medium	Effective flood access is affected by depths and velocities of floodwaters, evacuation distance, the number of people using the evacuation route and effective communication. In the study area a number of streets could be inundated by floodwaters in larger events and consideration of evacuation timing is important. Flood access and evacuation issues are further discussed in Section 4.3 and 4.6.
Evacuation problems	Medium	Some flood prone areas are likely to experience evacuation problems in the catchments due to the rapid rate of rise of a flood event, the limited flood warning time and the demographics of the community. These problems could be further exacerbated by the time of day during which flooding occurs. However, in general most flood affected properties have relatively short evacuation distances.
Type of development	Medium	The type of development will influence factors such as the level of flood awareness, the mobility of occupants and population density. Long term residents are likely to have a higher level of flood awareness than those visiting the area. Further, mobility and evacuation is more difficult for a school, child care facility or aged care home.

An assessment of the variables presented in **Table 4-10** did not significantly change the flood hazard classifications using the AEMI classifications which are less influenced by these factors than the hazard classifications outlined in Appendix L of the NSW Floodplain Development Manual (NSW State Government, 2005). True flood hazard maps for the 1% AEP event are presented in the flood map compendium (Appendix A).

4.5 Hydraulic Categorisation

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringes. Descriptions of these terms within the Floodplain

Development Manual (NSW Government, 2005) are essentially qualitative in nature. Of particular difficulty is the fact that a definition of flood behaviour and associated impacts is likely to vary from one floodplain to another depending on the circumstances and nature of flooding within the catchment.

The hydraulic categories as defined in the Floodplain Development Manual are:

- **Floodway -** Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- **Flood Storage -** Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.
- **Flood Fringe -** Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

A number of approaches were considered when attempting to define flood impact categories across study catchments. Approaches to define hydraulic categories that were considered for this assessment included partitioning the floodplain based on:

- Peak flood velocity (m/s);
- Peak flood depth (m);
- Peak velocity * depth (sometimes referred to as discharge per unit width (m^2/s));
- Cumulative volume conveyed during the flood event (m^3); and
- Combinations of the above.

The definition of flood impact categories that was considered to best fit the application within the study catchments is defined in **Table 4-11**.

The hydraulic category map for 1% AEP and PMF event is included in the flood map compendium (Appendix A). It is also noted that mapping associated with the flood hydraulic categories may be amended in the future, at a local or property scale, subject to appropriate analysis that demonstrates no additional impacts (e.g. if it is to change from floodway to flood storage).

Table 4-11: Hydraulic Categories

Floodway	Velocity * Depth > 1.0 Velocity > 1.0	Areas and flowpaths where a significant proportion of floodwaters are conveyed (including all bank-to-bank creek sections).
Flood Storage	Velocity * Depth < 1.0 Velocity < 1.0 and Depth > 0.3 metres	Areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.
Flood Fringe	Velocity * Depth < 0.6 Velocity < 1.0 and Depth < 0.3 metres	Areas that are low-velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.

4.6 Access and Evacuation Constraints (ERP Classification)

In an effort to understand the potential emergency response requirements across different sections of the study area, flood emergency response precinct (ERP) classifications were prepared. The ERP classifications can be used to provide an indication of areas which may be inundated or may be isolated during floods. This information, in turn, can be used to quantify the type of emergency response that may be required across different sections of the floodplain during future floods. This information can be useful in emergency response planning.

The ERP classifications were prepared based upon information contained in the Australian Institute of Disaster Resilience's Guideline 7-2: 'Flood Emergency Response Classification of the Floodplain' (2017). This involved delineating the catchment into emergency response classifications based upon the flow chart presented in **Figure 4-10**.

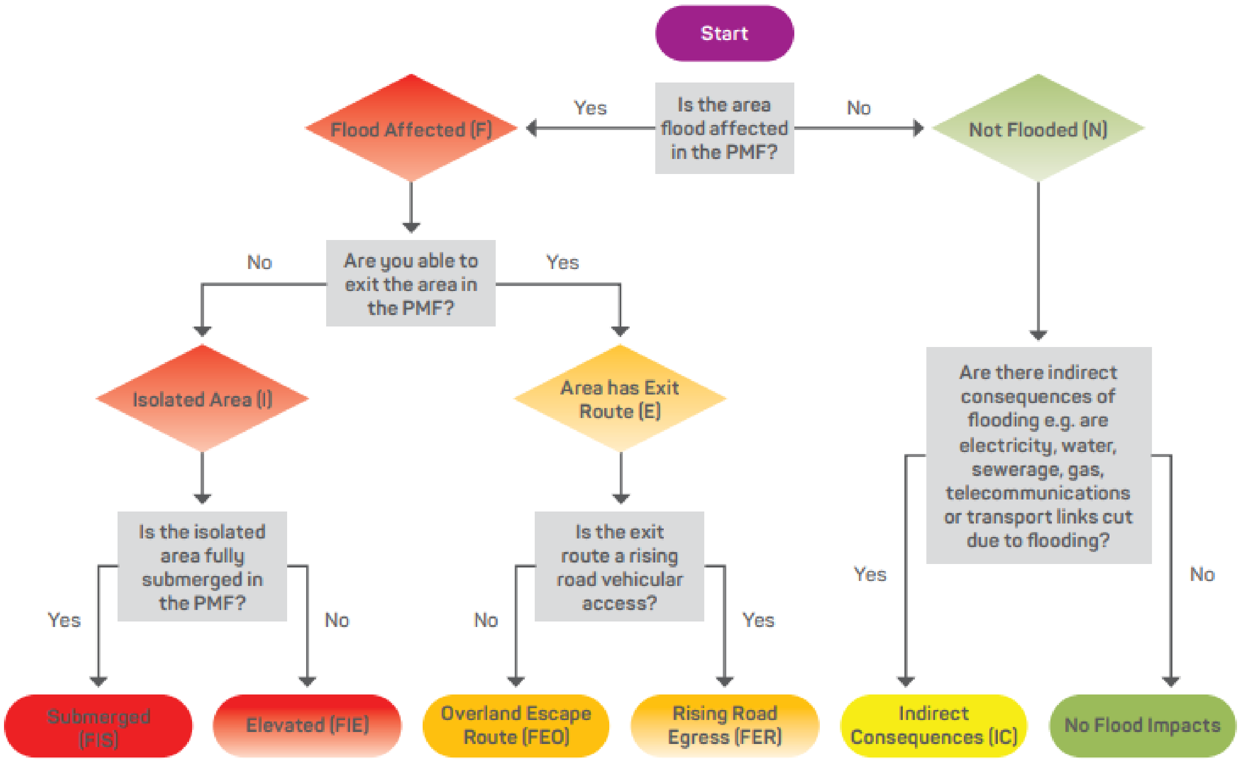

Figure 4-10: Flow chart for determining flood emergency response classifications

Source: Guideline: 7-2 Flood Emergency Response Classification of the Floodplain (AIDR 2017)

Key areas within the study area were classified based upon the ERP flow chart shown above. This was completed using the TUFLOW model results, digital elevation model and a road network GIS layer in conjunction with a consideration of the following factors:

- whether evacuation routes/roadways get "cut off" and the depth of inundation (a 0.2m depth threshold was used to define a "cut" road);
- whether evacuation routes continuously rise out of the floodplain;
- whether an area gets inundated during the nominated design flood and whether evacuation routes are cut or the lot becomes completely surrounded (i.e., isolated) by water before inundation;

- if evacuation by car was not possible, whether evacuation by walking was possible (a 0.5 metre depth threshold was used to define when a route could not be traversed by walking).

The resulting ERP classifications for the study area are provided in **Figure 4-11** and **Figure 4-12**. Classifications have been provided for 1181 out of 1239 (i.e. 95%) properties in the damages / inundation data base. The remaining 58 properties are either in the downstream 1D model section or are scattered on the Hunter River floodplain and therefore cannot be grouped into a classification area. The ERP GIS information will be provided to Council and the SES to aid evacuation and emergency response planning.

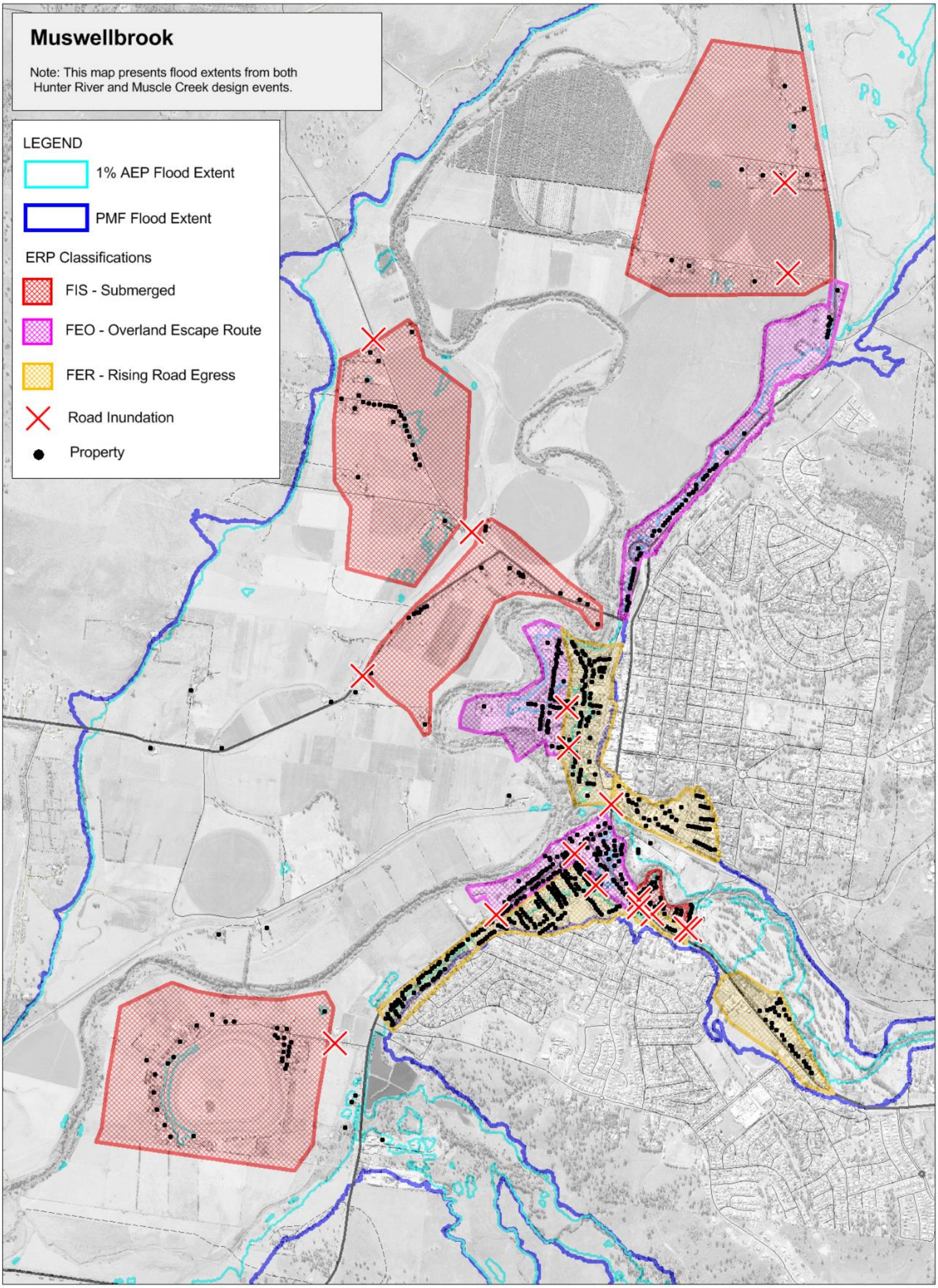

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FIGURE 4-11

EMERGENCY RESPONSE CLASSIFICATION (ERP)
MUSWELLBROOK

NORTH

0 250 500m
Approx. Scale

SCALE 1:30,000

PAGE SIZE A4

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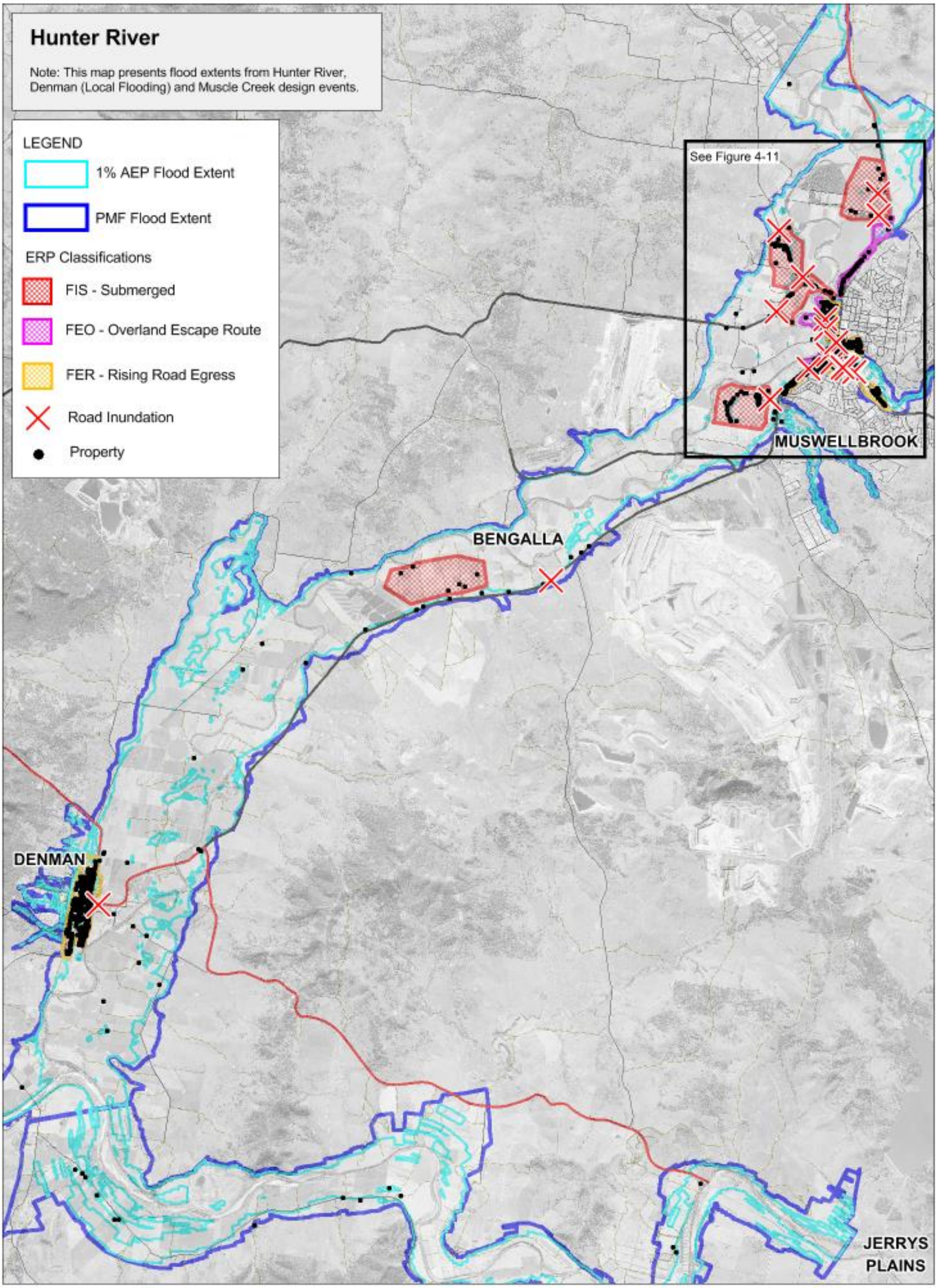

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FIGURE 4-12

EMERGENCY RESPONSE CLASSIFICATION (ERP) HUNTER RIVER (MUSWELLBROOK TO DENMAN)

NORTH

SCALE 1:125,000 PAGE SIZE A4

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, this map contains information from a number of sources - no warranty is given that the information contained on this map is free from error or omission. Any reliance placed on such information shall be the sole risk of the user. Please verify the accuracy of all information prior to using it. This map is not a design document.

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5 Review of Existing Planning Provisions

Within New South Wales, land use planning and development follows the following hierarchy, in decreasing order of seniority:

- Environmental Planning and Assessment Act (EPA Act)
- State Environmental Planning Policies (SEPP)
- Local Environmental Plans (LEPs)
- Development Control Plans (DCPs)

Land use planning and development controls are key mechanisms by which Council can manage some of the flood related risks within flood-affected areas of Muswellbrook and Denman (as well as across the wider LGA).

In the Muswellbrook LGA, development is controlled through the Muswellbrook Local Environment Plan (LEP) and various Development Control Plans (DCPs). The LEP is a planning instrument which designates land use and development in the LGA, while DCPs regulate development with specific guidelines and parameters.

A review of existing planning controls has been undertaken with the objective to:

- review the existing planning and development control framework relevant to the formulation of planning instruments and the assessment of development applications in flood affected areas, and
- make specific planning recommendations in regards to flood risk management, including an outline of suggested planning controls (refer **Section 5.4**).

5.1 Local Environment Plan

A Local Environmental Plan (LEP) is prepared in accordance with Part 3 Division 4 of the EP&A Act 1979 and operates as a local planning instrument that establishes the framework for the planning and control of land uses. The LEP defines zones, permissible land uses within those zones, and specific development standards and special considerations with regard to the use or development of land.

The Muswellbrook Local Environment Plan 2009 (LEP 2009) (Muswellbrook Shire Council, 2009) has been prepared in accordance with the NSW State Government's Standard Instrument (Local Environmental Plans) Order 2006, which requires local Council's to implement a Standard Instrument LEP. The State Government has created the Standard Instrument LEP to assist in streamlining the NSW Planning system.

5.1.1 Review of Flood Planning and Stormwater Regulations

A review of the LEP shows there are no specific clauses relating to either flooding or stormwater management. Points or references in the LEP to flood or stormwater related issues are defined below:

Point 2(d) of Clause 1.2 (aim of the plan) is flood related stating an aim of the LEP is:

"to manage development in flood-prone areas by ensuring any obstruction, re-direction or pollution of flood waters will not have adverse consequences for the environment or increase the risk of endangering life or property,"

Point 8 and 12 (defined below) of Clause 3.2 (Complying Development) states that:

(8) Drainage

(a) All roof and surface water must be drained to the street and discharged to the consent authority's nearest stormwater drainage system in accordance with an engineer's design.

(b) The drainage system must be designed for a 10 year return period, with excess flows designed to flow overland to the street.

(12) Stormwater must be disposed of by way of:

(a) a registered stormwater easement, or

(b) an inter allotment stormwater pit located within the property boundary, or

(c) a pipe that connects to the kerb and gutter, or

(d) an existing approved stormwater drain on site.

While point 3(e) of Clause 6.3 (Development control plan (DCP)) states the requirement for the provision stormwater and water quality controls are in the DCP.

5.1.2 Land Use

The Muswellbrook LEP 2009 identifies a number of land use zones including existing and future development areas, based on stated objectives for each zoning and provisions made for each zoning. The land use zones under the Muswellbrook LEP 2009 are as follows:

- Rural Zones: RU1 Primary Production, RU3 Forestry and RU5 Village;
- Residential Zones: R1 General Residential and R5 Large Lot Residential;
- Business Zones: B2 Local Centre and B5 Business Development;
- Industrial Zones: IN1 General Industrial and IN2 Light Industrial;
- Special Purpose Zones: SP2 Infrastructure;
- Recreation Zones: RE1 Public Recreation and RE2 Private Recreation;
- Environment Protection Zones: E1 National Parks and Nature Reserves, E3 Environmental Management and E4 Environmental Living; and
- Waterway Zones: W1 Natural Waterways.

Land use zones for Muswellbrook and Denman are presented in **Figure 5-1** and **Figure 5-2**. Following completion of the FRMS&P, it is recommended that a review of existing and proposed changes to land zoning be undertaken to consider the updated flood risk

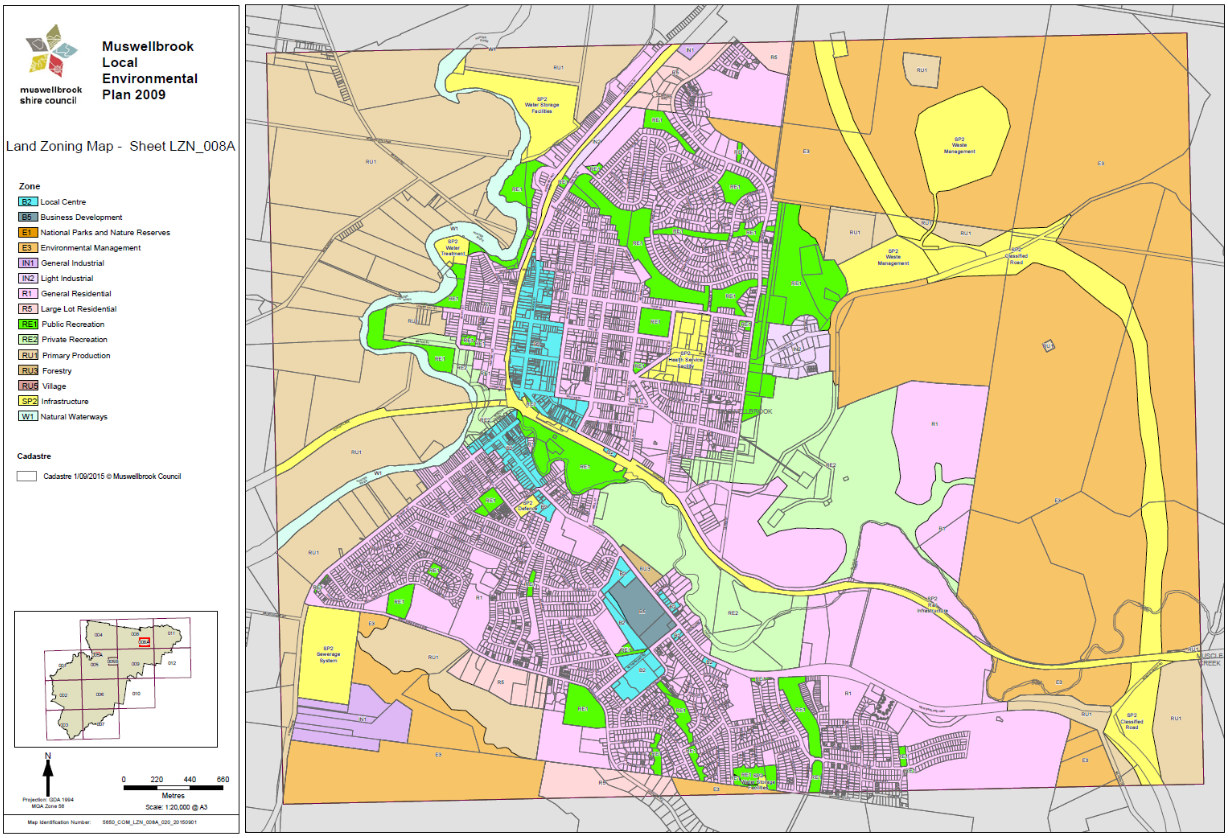

Figure 5-1: Muswellbrook Land Use Zones (LEP 2009)

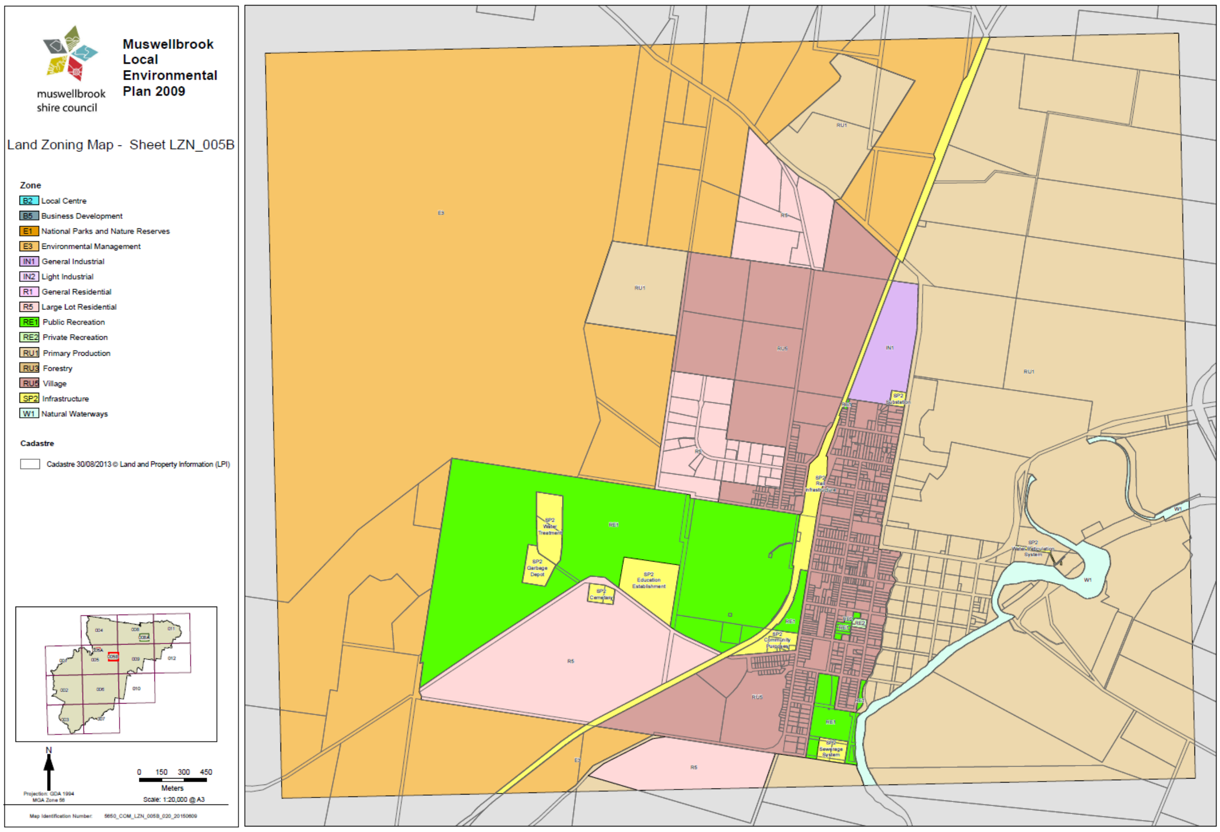

Figure 5-2: Denman Land Use Zones (LEP 2009)

5.1.3 Flood Planning Maps

The existing LEP 2009 does not currently include flood planning map. While inclusion of flood maps in the LEP is not necessarily recommended, as it can make them difficult to update, provision of the information in an online format may assist planning and emergency management activities.

5.1.4 Urban Release Area Maps

Proposed Urban Release Areas defined in the Muswellbrook LEP 2009 are presented in **Figure 5-3** and **Figure 5-4.** All areas appear to be above the mainstream PMF flood extents, though the impact of local overland flow would need to be considered.

Figure 5-3: Muswellbrook Urban Release Area (LEP 2009)

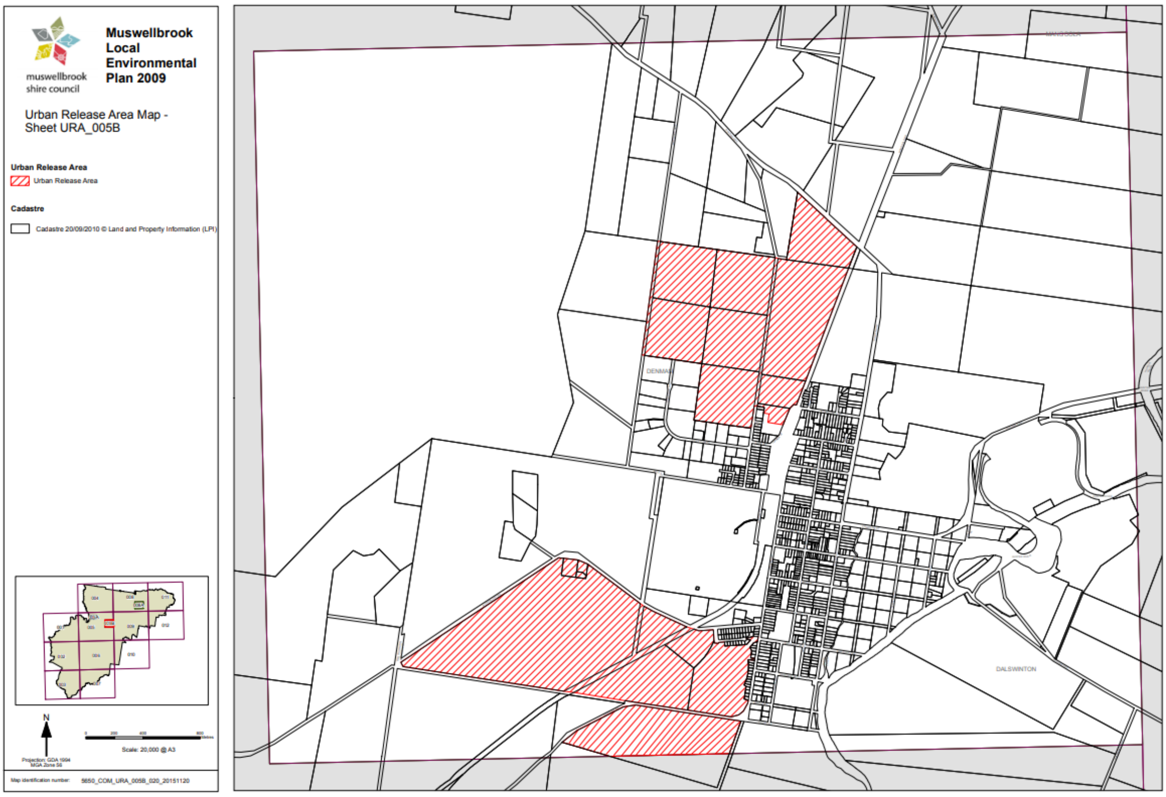

Figure 5-4: Denman Urban Release Area (LEP 2009)

5.2 Development Control Plan

A draft of the proposed update to the "Floodplain Management" section (Section 11a of Draft Muswellbrook Development Control Plan 2018), was provided to RHDHV by Council for review. The draft is expected to replace the existing Development Control Plan 2009 (DCP) which was gazetted in April 2009. It is understood that the draft "Floodplain Management" section will replace the existing Flood Prone Land chapter (Section 13 of DCP 2009).

It should be noted that the draft Floodplain Management section contains basically the same controls provided in the existing Flood Prone Land chapter (Section 13 of DCP 2009), however, it provides additional detail on the application requirements pertaining to flood related information. Specifically it defines when and the requirements of a either a Minor or Major Flood Assessment Report (FAR).

The draft Floodplain Management section also differentiates the assessment required for land between the Flood Planning Level (FPL) (i.e. 1% AEP + 0.5m free board) and the Probable Maximum Flood (PMF) and land below the FPL.

The DCP floodplain management policy is used to assess development proposals to determine if they are permissible and the required controls. A summary of key information is provided below.

5.2.1 *Development and building principles – land between the flood planning level and Probable Maximum Flood*

Development proposals on land subject to this section must be consistent with the principles contained in the NSW Floodplain Development Manual 2005, including, but not limited to consideration of the following issues:

- Evacuation
- Suitability for sensitive land uses

5.2.2 *Development and building principles – land below the flood planning level*

The following principles must be considered in Council's determination of development proposals on land below the flood planning level.

A. GENERAL PRINCIPLES APPLYING TO ALL DEVELOPMENT

Development must achieve the following:

1. Proposed development will not result in increased flood hazard or flood damage to other properties;
2. Proposed development should be of a type, height and scale that is compatible with the existing urban and historic fabric of the area;
3. Construction methods and materials for that part of the development below the Flood Planning Level should conform with section 11a.9 Flood Proofing Code;
4. Proposed development shall be able to withstand the force of flowing floodwaters, including debris and buoyancy forces;
5. Information required to be submitted with the development application proves that the above principles have been complied with; and
6. Development is undertaken in accordance with the NSW Floodplain Development Manual 2005.

In considering development, Council shall have particular regard to:

1. the primary objective of the Special Infrastructure (SP2) and Local Centre (B2) Zone, which is to facilitate the existing and continued operation of public uses;
2. the primary objective of the RE1 – Public Open Space zone, which is to facilitate the use of publicly zoned land for recreational purposes;
3. the primary objective of the RE2 - Private Open Space zone, which identifies land suitable for private public recreation use;
4. the primary purpose of the RU1 Primary Production zone, which is to preserve prime alluvial land for agricultural use. In the area covered by this Development Control Plan RU1 and W1 - Waterways zoning also recognises the eroding nature of some of the river bank;

5. The primary objective of the B2 - Local Centre zone which is to recognise the established non-retail functions of the existing business areas outside the main business centre of Muswellbrook.

In additional to the “general controls” there are six specific flood-related developments subject to additional controls including:

1. NEW RESIDENTIAL ACCOMMODATION Or ALTERATIONS AND EXTENSIONS TO RESIDENTIAL ACCOMMODATION
2. RURAL DEVELOPMENT
3. NON- RESIDENTIAL DEVELOPMENT
4. DEVELOPMENT PROTECTED BY A LEVEE
5. INTEGRITY OF THE HUNTER VALLEY FLOOD MITIGATION SCHEME
6. FENCING IN RACECOURSE ROAD AREA

A summary of key controls applied to some developments in the DCP include:

- The floor level of all habitable areas shall be at least 0.5m above the 1% AEP flood level, as determined by Council.
- Materials used are in conformity with the (provided) flood proofing code
- For Rural Areas - the afflux created at any other point on the flood plain will not be increased by more than 0.1m as a result of the development; and
- Council is satisfied the dwelling is not located in a high hazard flood area
- Floor levels for non-residential uses, excluding habitable areas, may be permitted below flood level provided the development is in accordance with the principles outlined in A. above.
- Provision shall be made for the safe storage and/or timely removal of goods, materials, plant and equipment in the event of a flood.
- An appropriate evacuation plan is considered to the satisfaction of Council
- Minimum floor levels for all developments in the township of Muswellbrook protected by the levee shall be 146.3 AHD (Australian Height Datum).
- Minimum floor levels for all developments in the township of Denman protected by the levee shall be 107.25m AHD (Australian Height Datum).
- Where new buildings or additions are proposed within 40m of the existing levee a structural engineer’s certificate shall be submitted with a construction certificate certifying that the proposed structure has been designed to withstand the flood pressures, including debris and buoyancy forces, imposed in the event of an adjacent levee failure.
- Development on and within the vicinity of structures (including levees, floodgates, spillways and drains) operated by Council, but constructed under the *Hunter Valley Flood Mitigation Scheme*, will be managed by Council under the *Water Management Act* to ensure the continuing integrity of those structures.
- Council will require lodgement of a development application for the erection of fencing in this Racecourse Road area, other than rural fences such as 5-wire fences.

There are however, some recommendations for additions to development controls including:

- Lowest habitable floor levels should be elevated above finished ground level.
- Proponents are encouraged to construct at higher levels with available flood level information across a range of design flood magnitudes (up to Extreme Flood Level (i.e. PMF)).

It should also be noted that the requirements presented for a Minor or Major Flood Assessment Report (FAR) seem to be based on older 1D flood modelling techniques (i.e. the guidelines specify the number of cross-section required). Given that LiDAR elevation data is now available for the LGA the use of 2D flood modelling should be recommended for use in the FAR.

5.3 Flood Planning Level Considerations

Department of Planning Circular PS 07—03 (see Section 5.3.1) and associated guideline on development controls on low risk flood areas states:

“unless there are exceptional circumstances, councils should adopt the 100-year flood as the FPL for residential development. In proposing a case for exceptional circumstances, a council would need to demonstrate that a different FPL was required for the management of residential development due to local flood behaviour, flood history, associated flood hazards or a particular historic flood.”

The adoption of the standard 1% AEP (100yr ARI) + 0.5m freeboard is considered appropriate for the study area (Muswellbrook to Denman) as an examination of the difference between the 0.2% AEP (500yr ARI) and 1% AEP (100yr ARI) peak flood levels (as presented in **Table 4-1**) is typically less than 0.5m. This means that even in the 0.2% event, adoption of a standard FPL would mean that most newly approved developments would not be flooded above floor level.

The difference in peak flood level between the PMF and 1% AEP (100yr ARI) is 2 to 4 m. So that in an extreme event sheltering in place would not be possible and evacuation would be required. Given the large Hunter River catchment size, availability of flood level data and generally short evacuation distances, risk to life from an extreme event could be managed through appropriate evacuation management plans.

5.3.1 Department of Planning Circular PS 07—03 (2007)

The circular and (NSW Government Department of Planning, 2007) provides an overview of a new guideline (on development controls on low risk flood areas) to the Floodplain Development Manual and changes to the Environmental Planning and Assessment Regulation 2000 and section 117 Direction on flood prone land.

Relevant sections from the Guideline are shown below.

Categories of Flood Prone Land

To balance protection of existing and future inhabitants from flood hazard and the potential danger and damage associated with use of the flood prone land, the Manual promotes the appropriate use of flood prone land by breaking it down into areas dependent upon frequency of inundation, their hydraulic function (floodways in which floodwaters are conveyed, flood storage areas where flood waters are temporarily stored during flood events, and flood fringe areas) and flood hazard (a minimum of two categories, high and low). These categories assist councils in determining appropriate development limits and controls to reflect the variation in flood risk across flood prone land and the associated consequences on residents and their property. Key categories are:

1. Floodways: Floodways are the areas of the floodplain which are essential to convey flood waters. Development of these areas would have significant adverse impacts upon flood behaviour which in turn may result in adverse effects on other development and the community. Development of floodways would also expose occupants and their property to significant levels of flood danger and damage.

2. Below the residential FPL: The area of the floodplain where residential development is subject to flood related development controls, i.e. below the residential FPL (as determined in accordance with the Floodplain Development Manual). These are the areas of the floodplain where development limits and controls are used to reduce the frequency of exposure of people and property to flood risk and the associated danger and damage. Development controls in this area need may limit the area that can be developed and may include minimum fill levels, minimum floor levels, the requirement to use flood compatible building materials and need to address emergency management issues as outlined in (3) below.

3. Above the residential FPL: The area of flood prone land above the residential FPL and therefore these are areas where residential development is not subject to flood related development controls. These areas generally have a low risk of flooding and are sometimes known as low flood risk areas. As such, they are areas where no development controls should apply for residential development but the safety of people and associated emergency response management needs to be considered and may result in:

- *Restrictions on types of development which are particularly vulnerable to emergency response, for example developments for aged care.*
- *Restrictions on critical emergency response and recovery facilities and infrastructure. These aim to ensure that these facilities and the infrastructure can fulfil their emergency response and recovery functions during and after a flood event. Examples include evacuation centres and routes, hospitals and major utility facilities.*

Standards for Flood Controls for Residential Development

Councils are responsible for determining the appropriate flood planning levels for land within their local government area. Whilst the flood used to determine the residential FPL is a decision of the local council, the Manual highlights that FPLs for typical residential development would generally be based around the 100 year flood plus an appropriate freeboard (typically 0.5m).

This Guideline confirms that, unless there are exceptional circumstances, councils should adopt the 100 year flood as the FPL for residential development. In proposing a case for exceptional circumstances, a Council would need to demonstrate that a different FPL was required for the *management of residential development due to local flood behaviour, flood history, associated flood hazards or a particular historic flood.*

Unless there are exceptional circumstances, councils should not impose flood related development controls on residential development on land with a low probability of flooding, that is, land above the residential FPL (low flood risk areas).

Justification for variations to the above should be provided in writing to, and agreed by, the Department of Natural Resources and the Department of Planning prior to exhibition of a draft local environmental plan or a draft development control plan that proposes to introduce flood related development controls on residential development.

5.4 Review of Floodplain Management Aspects of Muswellbrook Planning Policy's

A review of the floodplain management aspects of current or proposed Muswellbrook Planning Policy (i.e. LEP 2009 and the DCP) indicates that the LEP appears to be in line with regulatory requirements, however, it could be improved by considering the following point:

- The LEP could be improved by including specific clauses regarding flooding and stormwater management.

A review of the floodplain management aspects of the current or proposed Muswellbrook DCP indicates the DCP is in line with regulatory requirements (i.e. the Department of Planning Circular PS 07—03). It should be improved by considering the following points:

- Adoption of the floodplain planning control matrix (which differentiates controls depending on land use and whether they are located in the: floodway (i.e. high hazard), flood fringe (i.e. below FPL), or between FPL and PMF) that is provided in many LGA DCP's. This may simplify the DCP document.
- Ensure that sensitive uses such as: child care centres and Housing for Aged and Disabled persons" are considered separately due to the difficulties posed by evacuation of these facilities during flood events.
- It should be noted that the NSW Department of Planning & Environment is currently planning a reform of DCP's with the EP&A Act to be amended to require DCPs follow a standard format to improve consistency across local Councils and improve user navigation of the planning system and its controls (NSW Planning, 2017).

In addition to the above points the following should be considered for inclusion in the DCP:

- Lowest habitable floor levels should be elevated 0.2 m above finished ground level.
- Proponents encouraged to construct at higher levels with available flood level information across range of design flood magnitudes (up to Extreme Flood Level).
- Quantifying a practical/sensible limit on increases in flood affection. i.e. minor increases in local flooding of up to 10 cm within 10 m of a development that do not impact on an existing or planned building will be considered. Outside of this immediate area, changes of up to 2 cm will be considered on a merits based approach.

It is also recommended that flood maps are provided in an online format to assist planning and emergency management activities.

6 Assessment of Floodplain Management Measures

6.1 Identifying Floodplain Risk Management Measures

The NSW Floodplain Development Manual (NSW State Government, 2005) states that the purpose of a FRMS&P is to identify, assess and compare various flood risk management options to mitigate flood affectation and as such lower the overall flood damages and/or risk to life in the area considered by the study. This process involves assessing the flood impacts of management options for existing, future and continuing flood risk on flood behaviour and hazard and the social, economic, ecological and cultural costs and benefits of options. Assessment of these factors forms the basis for robust decision making in the management plan. The following sections assess a range of flood mitigation options to mitigate and manage flood risk in the study area.

6.2 Risk Management Measures Categories

Measures which can be employed to mitigate flooding and reduce flood damages can be separated into three broad categories:

Flood modification measures: modify the flood's physical behaviour (i.e. depth, velocity) and includes flood mitigation dams, retarding basins, on-site detention, channel improvements, levees, floodways or catchment treatments.

Ten potential flood modification measures were presented to Council in a letter dated 23 January 2018 (refer Appendix A). This was refined to a list of seven options that were modelled as part of the study as detailed in Section 6.4.

Property modification measures: modify property and land use including development controls. This is generally accomplished through such means as flood proofing (house raising or sealing entrances), planning and building regulations (i.e. zoning) or voluntary purchase.

Properties suitable for either Voluntary House Raising (VHR) and/or Voluntary Purchase (VP) have been assessed as detailed in Section 6.4.9.

Response modification measures: modify the community's response to flood hazard by informing flood-affected property owners and users about the nature of flooding so that they can make informed decisions. Examples of such measures include provision of flood warning and emergency services, improved information, awareness and education of the community and provision of flood insurance.

The development of a flood warning system for Muscle Creek has been assessed in the FRMS as detailed in Section 7.

6.3 Potential Floodplain Risk Management Measures

The following sections provide a first pass assessment of options by determining if they would be applicable/suitable to the flooding characteristics of the study area. The study area is affected by three different flood mechanisms, the mitigation options have been labelled based on the flood mechanism they are related to, including:

- HRS – Hunter River flood mechanism
- MC – Muscle Creek flood mechanism

- D – Denman local catchment flood mechanism
- P – study wide property modification measures (i.e. VHR & VP)

Section 6.3.1 provides a list of options that were considered applicable/suitable, and subjected to a detailed assessment as part of this FRMS.

6.3.1 List of potential flood mitigation options assessed in this FRMS

The following mitigation options were considered applicable/suitable for reducing flood risk in the study area, and were therefore the subject of a detailed assessment as part of this FRMS. Please refer to the appropriate report sections for detailed descriptions and assessment outcomes for each option.

Flood modification measures

HRS1 - Backwater Levee Option – Section 6.4.1

HRS2 - Sydney Street Levee Option – Section 6.4.2

HRS3 - Channel Vegetation Removal – Section 6.4.3

MC1 - Enhance creek bank adjacent to golf course – Section 6.4.4

MC2 - Golf course flood bund – Section 6.4.5

MC3 - Channel vegetation management – Section 6.4.6

D1 - Blockage / maintenance policy to unblock 2 Virginia St (Denman) culverts – Section 6.4.7

D2 - Upgrade to Virginia St (Denman) culvert (north) - Section 6.4.8

Property modification measures

P1 - Voluntary House Raising and Voluntary Purchase (properties below 1% AEP) - Section 6.4.9

P2 - Voluntary House Raising and Voluntary Purchase (properties below 2% AEP) - Section 6.4.10

P3 - Voluntary House Raising and Voluntary Purchase (properties below 5% AEP) - Section 6.4.11

Response modification measures

FW1 - Flood Warning System - The development of a flood warning system for Muscle Creek is presented in detail in Section 7.

6.4 Description and Assessment of Floodplain Management Measures

Flood modification measures

Flood modification measures refer to physical modifications on the floodplain which alter the flood behaviour and ultimately reduce the flood affectation (flood levels or velocities) in particularly vulnerable areas.

6.4.1 HRS1 – Muswellbrook Backwater Levee Option

Overview

Flood model results indicate that there are a significant number of properties located in low lying areas adjacent Possum Gully, south of Lower Hill Street and West of Ford Street that are effected by backwater flooding from the Hunter River. To protect the area from backwater flooding the levee could be extended approximately 820 m in a south easterly direction until it ties in with higher ground at the William Street rail bridge as presented in **Figure 6-1**. The existing 1% AEP (100yr ARI) water level is 145.3 m AHD while the 0.2% AEP (500yr ARI) water level is 145.6 m AHD, and the design water level reduces by 0.2 m along the length of the levee alignment. Assuming a freeboard of 0.5 m, a crest level of 145.8 m AHD to 145.6 m AHD along the length of the levee is considered appropriate. Based on this crest level, the levee ranges between 0.5 m to 2.0 m in height.

Provision of a 3.6m x 3.6m box culvert has been included to allow drainage of the Possum Creek Gully catchment. A non-return valve (i.e. flapped gate) is included to prevent backwater flooding. This culvert was considered large enough to pass the Q100 from the Possum Creek catchment (SMEC, 2013).

Figure 6-1 provides details of key components of the required works. The flood model was updated to include these features and a suite of design runs were simulated to determine the impacts of this mitigation option on flood behaviour and property inundation and damages.

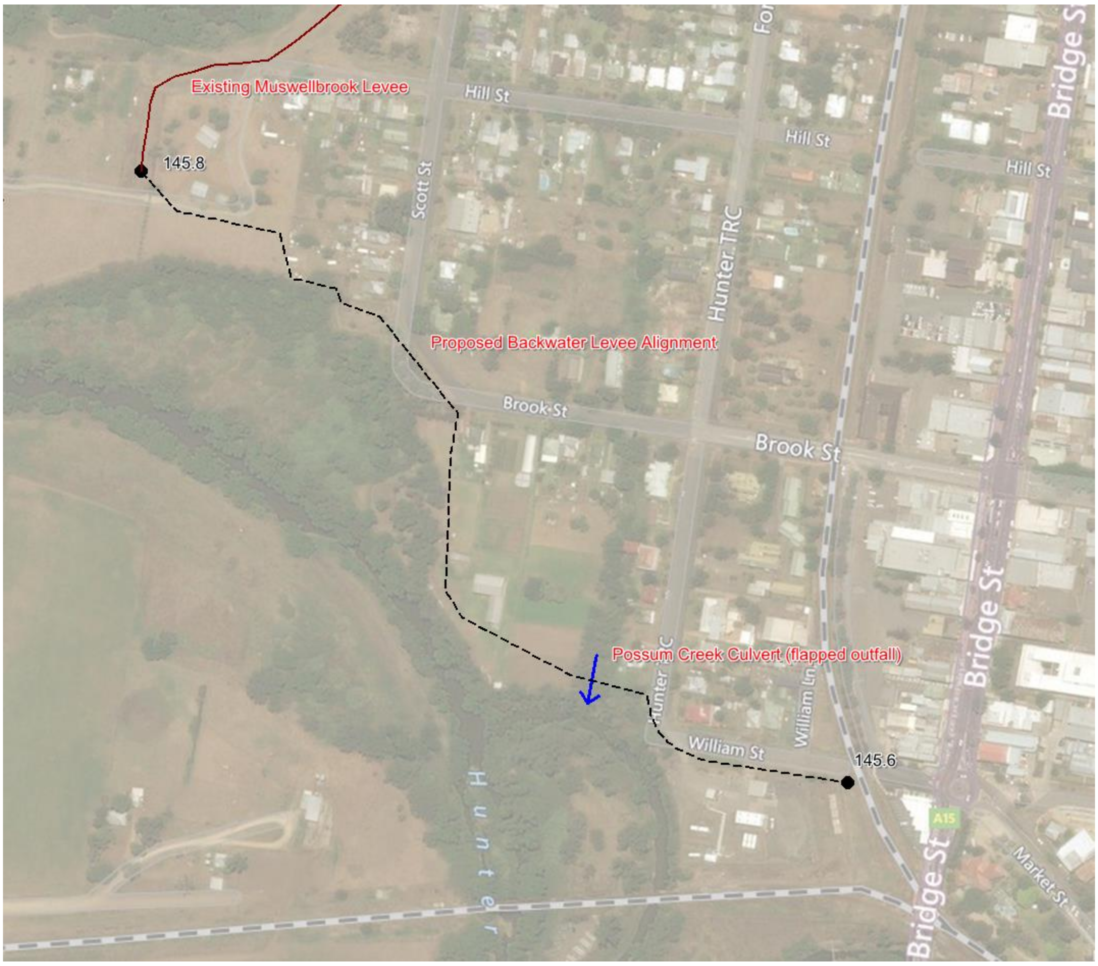

Figure 6-1: Outline Details of HRS1 – Muswellbrook Backwater Levee Option

NB: 1) Extend existing levee by 820m with a crest level of 145.8 m AHD to 145.6 m AHD

2) A 3.6m x 3.6m culvert with flapped outfall is required to drain Possum Gully catchment.

3) A typical earth embankment design with a 3m wide crest and 1 in 4 batter is appropriate

4) An allowance for 65m of sheet piling is included to reduce the levee footprint in the vicinity of the two road areas

Results

This option is able to prevent backwater flooding into the protected area, to significantly reducing the number of flood affected properties in Muswellbrook as presented in **Table 6-1**. **Table 6-2** shows that for the 1% AEP (100yr ARI) design event there is a reduction in 22 occurrences of above floor flooding and a net reduction of 73 (75 no longer flooded, though 2 newly flooded) properties experiencing yard or underfloor flooding. Due to the loss in floodplain storage 67 properties will experience slightly higher flood levels in the 1% AEP event, though the average increase is only 1cm and the maximum increase is 5cm. Changes in floodplain hydraulics elsewhere mean that some 233 properties will experience reduced flood level of up to 6cm. Because the PMF overtops the levee there is no reduced property flooding for this extreme event.

This option significantly reduces flood affectation and damages for all events up to the PMF in the Muswellbrook area by preventing backwater flooding as presented in **Table 6-1.** There is a nearly $100,000 reduction in AAD, which, over a 50 year period, is expected to reduce flood related damages by $1.45 Million. However, the cost of constructing this mitigation option is $2.25 Million (a cost breakdown for this measure can be found in **Appendix B**). The calculated benefit/cost (B/C) ratio for this option is 0.65. Since the B/C ratio is less than one, this option is unlikely to be recommended for implementation or further investigation.

Table 6-1: Change in Property Affectation and Damages for Mitigation Measure - HRS1
Muswellbrook Backwater Levee Option

Event	No. Properties No Longer Flooded Over Floor	No. Properties No Longer Yard or Under Floor Flooded	Reduction in Damages for Event
PMF	0	2	-$142,000
0.2% / 500yr	37	90	$3,525,268
0.5% / 200yr	26	81	$2,634,703
1% / 100yr	22	73	$2,194,234
2% / 50yr	15	61	$1,694,663
5% / 20yr	5	50	$637,055
10% / 10yr	0	6	$43,000
Reduction in Annual Average Damages (AAD)			**$98,250**
Reduced Damages (Over 50 years)			**$1,454,178**
Cost of Mitigation Option			**$2,250,000**
Benefit/Cost			**0.65**
Reduction in Damages (%)			**9%**

Notes: Reduction in the (net) number of properties is compared to the base case.
A negative reduction means damages have increased for this event

Table 6-2: Change in (1% AEP) Property Affectation and Flood Levels Option - HRS1

HRS1 - Backwater Levee Option		
	No. Properties Above Floor	**No. Properties Yard or Under Flood Flooded**
no longer flooded / dry	22	75
newly flooded / wet	0	2
net change	22	73
No. locations with increased flood depth		67
Av. increase (m)		0.01
max increase (m)		0.05
No. locations with reduced flood depth		233
Av. decrease (m)		0.01
max decrease (m)		0.06

Notes: Reduction in the (gross) number of properties is compared to the base case.

Social and Environmental Impacts

Construction of this Backwater Levee is only expected to impact a small number of residents as the majority of the levee can be built on public land. Negotiations with impacted residents will be required for the acquiring of the land or an easement for the construction and ongoing maintenance of the levee. As the levee construction will protect residents from flooding and reduce the resultant economic loss and disruption, it is anticipated that residents would be in support of the levee. There is also only very minor negative flood related impacts associated with this options, so it is anticipated that community opposition would be minimal as the levee can be promoted as an extension to an existing flood defence. Environmental impacts, in the form of minor vegetation loss and general construction impacts, are considered relatively minor.

6.4.2 HRS2 - Sydney Street Levee Option

Overview

Flood model results indicate that there are a significant number of properties located along Sydney Street between Forbes Street and Jordan Street which are flooded in the 2% AEP (50yr ARI) design event. To protect the area from flooding, an 840 m levee along the banks of the Hunter River is required. To prevent outflanking or inundation from Muscle Creek flood waters, the levee would then need to extend for 555m parallel to Maitland Street, tying into higher ground south of Francis Street. The proposed alignment and crest elevations are presented in **Figure 6-2**. An allowance for temporary flood barriers is required for the 4 road crossings and would need to be considered the design and operation of the option.

The design provides for approximately 0.5m freeboard for the 1% AEP (100yr ARI) and is not overtopped in the 0.2% AEP (500yr ARI) by Hunter River levels but is slightly overtopped by Muscle Creek floodwaters, though inundation extents and levels are significantly reduced compared to existing conditions. Based on the design crest level the levee ranges between 0.5 m to 2.0m in height.

Figure 6-2 provides details of key components of the required works. The flood model was updated to include these features and a suite of design runs was simulated to determine the impact of this mitigation option on flood behaviour and property inundation and damages.

Figure 6-2: Outline Details of HRS2 – Sydney Street Levee Option

NB: 1) 840 m earth levee along the banks of the Hunter River (Sydney St to Sydney St) with a crest level of 145.5 m AHD to 144.1 m AHD including allowance for local drainage.

2) To minimise property disturbance a masonry wall would for 555m parallel to Maitland Street, tying into higher ground south of Francis Street

3) A typical earth embankment design with a 3m crest and 1 in 4 batter is appropriate for (1), while a masonry wall with 2m wide footing is appropriate for (2).

4) An allowance for temporary flood barriers is required for the 4 road crossings

Results

This option is able to prevent inundation of the protected area significantly reducing the number of flood affected properties in Muswellbrook as presented in **Table 6-3**. **Table 6-4** shows that for the 1% AEP (100yr ARI) design event, there is a net reduction in 54 (61 no longer flooded, though 7 newly flooded) occurrences of above floor flooding and a net reduction of 71 (80 no longer flooded, though 9 newly flooded) properties experiencing yard or underfloor flooding. The proposed levee produces a loss in floodplain storage and changes to the available flow paths, causing a number of additional properties (mainly 7 commercial properties along Maitland Street) to be flooded in the 1% AEP event when previously they were not. In addition to these 7 newly flooded properties, another 139 properties will experience slightly higher flood levels in the 1% AEP event; though the average increase is only 8cm and the maximum increase is 43cm. Changes in floodplain hydraulics elsewhere mean that some 149 properties will experience reduced flood levels of up to 84cm. Because the PMF overtops the levee there is no reduction in property flooding for this extreme event.

This option significantly reduces flood affectation and damages for all events up to the PMF in the Muswellbrook area by preventing flooding as presented in **Table 6-3.** There is an $180,000 reduction in AAD, which, over a 50 year period, is expected to reduce flood related damages by $2.66 Million. However, the cost of constructing this mitigation option is $3.5 Million (a cost breakdown for this measure can be found in **Appendix B**). The calculated benefit/cost (B/C) ratio for this option is 0.76. Since the B/C ratio is less than one, this option is unlikely to be recommended for implementation or further investigation.

Table 6-3: Change in Property Affectation and Damages for Mitigation Measure – HRS2

Sydney Street Levee Option

Event	No. Properties No Longer Flooded Over Floor	No. Properties No Longer Yard or Under Floor Flooded	Reduction in Damages for Event
PMF	0	2	-$96,335
0.2% / 500yr	47	15	$4,049,595
0.5% / 200yr	61	49	$5,115,133
1% / 100yr	54	71	$4,780,886
2% / 50yr	45	86	$3,834,637
5% / 20yr	-4	93	$867,458
10% / 10yr	0	4	$32,299
Reduction in Annual Average Damages (AAD)			**$180,139**
Reduced Damages (Over 50 years)			**$2,666,185**
Cost of Mitigation Option			**$3,500,000**
Benefit/Cost			**0.76**
Reduction in Damages (%)			**16%**

Notes: Reduction in the (net) number of properties is compared to the base case.
A negative reduction means damages have increased for this event

Table 6-4: Change in (1% AEP) Property Affectation and Flood Levels Option – HRS2

HRS2 - Sydney Street Levee Option		
	No. Properties Above Floor	**No. Properties Yard or Under Flood Flooded**
no longer flooded / dry	61	80
newly flooded / wet	7	9
net change	54	71
No. locations with increased flood depth		139
Av. increase (m)		0.08

max increase (m)	0.43
No. locations with reduced flood depth	149
Av. decrease (m)	0.20
max decrease (m)	0.84

Notes: Reduction in the (gross) number of properties is compared to the base case.

Social and Environmental Impacts

Construction of the Sydney Street Levee will impact on a significant number of private properties. While the majority of properties will have beneficial flood outcomes due to its construction there are a number of properties along Maitland Road on the outside of the defence who will experience increased negative flood behaviour. It is also possible that the levee will block river views which may cause opposition to its construction. As most properties only experience above floor flooding in the 2% AEP (50 yr ARI) event, most residents will not have experienced significant flood losses, so may be dubious of the overall benefit of the levee. The levee is to be constructed mostly on private property which Council will need to acquire an easement for construction and ongoing maintenance.

Environmental impacts in the form of minor vegetation loss and general construction impacts are considered relatively minor.

6.4.3 HRS3 - Channel Vegetation Removal

Overview

Changes to land management along the banks of the Hunter River significantly increased the amount of near bank vegetation. The presence of vegetation increases the hydraulic roughness which for the same river discharge, produces higher local flood levels. During the update of the Flood Study model (RHDHV, 2017) it was found that a representation of the effects of increased roughness due to increased near channel vegetation (that has occurred over the past 30-40 years) was required to produce a model that could match observed flood behaviour. The areas of vegetation were digitised in a GIS layer and given a corresponding hydraulic roughness (Mannings “n”) of 0.15 whereas previously the roughness was only 0.035 which represents short grass or pasture.

By removing this layer of riparian vegetation, the hydraulic roughness is significantly reduced which will result in lower flood levels. To achieve this situation, the existing vegetation would need to be removed. To prevent vegetation from being re-established land management practices would have to revert back to what was previously carried out. It should be noted that while channel vegetation removal may result in a local reduction in flood levels, it is likely to result in increased downstream flood levels due to reduced floodplain storage effects and increases in the speed of the flood wave.

An example of the areas of vegetation removal are presented in Figure 6-3. It was assumed that all vegetation along the length of the model was removed. A total of 260 hectares of vegetation removal was modelled in this scenario. The flood model was updated to include the change in hydraulic roughness and a suite of design runs was simulated to determine the impact of this mitigation option on flood behaviour and property inundation and damages.

Figure 6-3: Outline Details of HRS3 – Channel Vegetation Removal Option

NB: 1) The above shows an example area of in-channel bank vegetation that has established in the past 30-40 years.

2) This option considers the removal and ongoing maintenance of maintained grass on these in bank areas.

3) This is assumed to result in a reduction in roughness from Mannings “n” of 0.15 to 0.035.

4) Along the approximate 40km of River in the study area a total of 260 Hectares of vegetation was mapped as requiring clearing (i.e. this is on average an approximate 60m wide strip along the river).

Results

The results suggest this option is able to significantly reduce the number and depth to which properties are flooded along the Hunter River floodplain as presented in **Table 6-5**. **Table 6-6** shows that for the 1% AEP (100yr ARI) design event there is net a reduction in 66 (68 no longer flooded, though 2 newly flooded) occurrences of above floor flooding and a net reduction of 53 (55 no longer flooded, though 2 newly flooded) properties experiencing yard or underfloor flooding. Because the option is able to nearly globally reduce flood levels, in the 1% AEP event, some 297 properties will experience reduced flood levels of an average of 25cm with maximum reductions of up to 78cm predicted. Changes in local hydraulics do still mean that a small number (24) of properties will experience increased 1% AEP flood levels of up to 16cm.

Even in the PMF this option is able to reduce the number of properties that experience above floor flooding and lower flood levels results in a significant reduction in damages for the PMF unlike all other options.

This option significantly reduces flood affectation and damages for all events up to the PMF in the Muswellbrook area by preventing flooding as presented in **Table 6-5.** There is a $327,500 reduction in AAD, which, over a 50 year period, is expected to reduce flood related damages by

$4.85 Million. However, the cost of implementing this mitigation option is $8.0 Million (a cost breakdown for this measure can be found in **Appendix B**). The calculated benefit/cost (B/C) ratio for this option is 0.61. Since the B/C ratio is less than one, this option is unlikely to be recommended for implementation or further investigation. However, it is possible that a cheaper more targeted vegetation management option that focusses on areas adjacent to Muswellbrook only may produce a B/C ratio above 1.

Table 6-5: Change in Property Affectation and Damages for Mitigation Measure – HRS3

Hunter River Channel Vegetation Removal Option

Event	No. Properties No Longer Flooded Over Floor	No. Properties No Longer Yard or Under Floor Flooded	Reduction in Damages for Event
PMF	14	0	$4,418,317
0.2% / 500yr	58	44	$5,904,670
0.5% / 200yr	80	42	$7,043,954
1% / 100yr	66	53	$6,455,685
2% / 50yr	68	85	$5,846,512
5% / 20yr	19	158	$2,581,862
10% / 10yr	0	11	$154,626
Reduction in Annual Average Damages (AAD)			**$327,523**
Reduced Damages (Over 50 years)			**$4,847,592**
Cost of Mitigation Option			**$8,000,000**
Benefit/Cost			**0.61**
Reduction in Damages (%)			**29%**

Notes: Reduction in the (net) number of properties is compared to the base case.

Table 6-6: Change in (1% AEP) Property Affectation and Flood Levels Option – HRS3

HRS3 - Hunter River Channel Vegetation Removal Option		
	No. Properties Above Floor	**No. Properties Yard or Under Flood Flooded**
no longer flooded / dry	68	55
newly flooded / wet	2	2
net change	66	53
No. locations with increased flood depth		24
Av. increase (m)		0.08
max increase (m)		0.16

No. locations with reduced flood depth	297
Av. decrease (m)	0.25
max decrease (m)	0.78

Notes: Reduction in the (gross) number of properties is compared to the base case.

Social and Environmental Impacts

Removal of channel vegetation will result in a significant loss of potential wildlife habitat and would cause a significant loss in local flora and fauna. The loss of vegetation may also result in increased bank erosion and cause increased channel mobility. These practices are also against current best management practices for river and stream management and are unlikely to gain approval from consent authorities, such as Local Land Services. Recent research has identified a need for at least 30% or greater percentage foliage cover to mitigate against erosion.

The office of Sustainable Land Management within LLS is the consent authority for vegetation removal. The legislation does not allow removal of native vegetation within 50m buffer of Hunter River.

As the option does significantly reduce flood levels and associated flood related damages the resulting social impact of floods on the community should also be reduced. However, loss of potential visual and environmental amenity should also be considered.

6.4.4 MC1 - Enhance Creek Bank adjacent to Golf Course

Overview

Flood model results indicate that there are two low points along the Muscle Creek bank adjacent to the Muswellbrook Golf Course. These low banks allow flood waters to escape the channel and form an overland flow path that floods a significant number of properties west of Bell Street. Enhancing the creek banks at these two low points could ensure floodwaters are maintained in the channel reducing the number of properties that are flooded. This option is also important to ensure emergency access across Muscle Creek. Bell Street is overtopped in the 5% AEP (20yr ARI) and Bridge Street is inundated in the 20% AEP (5yr ARI).

The location and required elevation of the two creek banks that would be enhanced is presented in **Figure 6-4**. The concept design is able to provide protection for events up to and including the 1% AEP (100yr ARI) flood. Based on this crest level the artificial bank height ranges between 0.5 m to 3.0m in height.

Provision of a 1.2m diameter pipe (and non-return valve) has been included to allow drainage of the golf course.

Figure 6-4 provides details of key components of the required works. The flood model was updated to include these features and a suite of design runs was simulated to determine the impact of this mitigation option on flood behaviour and property inundation and damages.

Figure 6-4: Outline Details of MC1 – Enhance Creek Bank adjacent to Golf Course

NB: 1) Bell Street Levee/Bank is 220m long and is typically < 1m high, though ~40m is up to 1.5m in height assuming a crest height of 148.3 m AHD

2) The Golf Course Drain Levee/Bank is 175m long and is typically < 0.5m high, though the ~25m length that would fill the drainage ditch is up to 3.0m high assuming a crest height of 148.5 m AHD. Provision of a 1.2m diameter pipe (and non-return valve) has been included to allow drainage of the golf course

3) Railway levee/bund is 200m long and 1m high – this is an optional bund to prevent water flowing north for events > 1% AEP.

4) A 90m bund on the northern creek bank protects the northern approach to the Bell St Bridge and is up to 1.5m high assuming a crest level of 149.0 mAHD

5) A typical earth embankment design with a 3m crest and 1 in 4 batter is appropriate

Results

This option is able to prevent overland flooding for a significant number of properties between the 10% AEP (10yr ARI) and 1% AEP (100yr ARI) design event as presented in **Table 6-7**. The changes to the inundation extent and peak flood levels for the 1% AEP (100yr ARI) are presented in **Figure 6-5** and show the large area either side of Maitland Street that is now flood free, or experiences significantly reduced flood levels. The figures show that in-channel flood levels upstream of the Bell Street Bridge are significantly increased and there is a small downstream area near Bridge Street with higher water levels and a slightly increased inundation extent. **Table 6-8** shows that for the 1% AEP (100yr ARI) design event there is a reduction in 31 occurrences of above floor flooding and a net reduction of 28 (30 no longer flooded, though 2 newly flooded) properties experiencing yard or underfloor flooding. The scheme includes the railway embankment to prevent the newly created overland flow path that occurs to the north of the river that would cross the railway line in event above the 1% AEP. Due to the loss in floodplain storage 6 properties will experience slightly higher flood levels in the 1% AEP event, though the average increase is only 8cm and the maximum increase is 16cm. Reduced overland flow also mean that some 47 properties will experience reduced flood levels of up to 68cm. It should be noted that the design is most effective up to the 1% AEP as the channel capacity is exceeded at other locations along the golf course in larger events.

This option significantly reduces flood affectation and damages for all events up to and including the 0.5% AEP (200yr ARI) in the Muscle Creek area by reducing an overland flow path that currently floods 17 properties in the 5% AEP (20yr ARI) event (refer **Table 6-7**). There is a $123,600 reduction in AAD, which, over a 50 year period, is expected to reduce flood related damages by $1.83 Million. The cost of constructing this mitigation option is $0.84 Million which is quite low considering the potential benefit (a cost breakdown for this measure can be found in **Appendix B**). The calculated benefit/cost (B/C) ratio for this option is 2.2. Since the B/C ratio is significantly above one, this option should be considered for further investigation and potential implementation.

Table 6-7: Change in Property Affectation and Damages for Mitigation Measure - MC1

Enhance Creek Bank adjacent to Golf Course Option

Event	No. Properties No Longer Flooded Over Floor	No. Properties No Longer Yard or Under Floor Flooded	Reduction in Damages for Event
PMF	0	0	-$9,620
0.2% / 500yr	1	4	$434,683
0.5% / 200yr	9	10	$996,073
1% / 100yr	31	28	$1,929,695
2% / 50yr	22	54	$1,824,305
5% / 20yr	17	44	$1,269,328
10% / 10yr	0	15	$224,088
Reduction in Annual Average Damages (AAD)			**$123,598**
Reduced Damages (Over 50 years)			**$1,829,339**
Cost of Mitigation Option			**$840,000**
Benefit/Cost			**2.18**
Reduction in Damages (%)			**11%**

Notes: Reduction in the (net) number of properties is compared to the base case.
A negative reduction means damages have increased for this event

Table 6-8: Change in (1% AEP) Property Affectation and Flood Levels Option – MC1

MC1 - Enhance Creek Bank adjacent to Golf Course		
	No. Properties Above Floor	**No. Properties Yard or Under Flood Flooded**
no longer flooded / dry	31	30
newly flooded / wet	0	2
net change	31	28

No. locations with increased flood depth	6
Av. increase (m)	0.08
max increase (m)	0.16
No. locations with reduced flood depth	47
Av. decrease (m)	0.34
max decrease (m)	0.68

Notes: Reduction in the (gross) number of properties is compared to the base case.

Social and Environmental Impacts

Enhancement of the creek banks adjacent to the Muswellbrook Golf Course appears to be a cost effective measure that is able to significantly reduce flood losses to the community in events up to and including the 1% AEP (100yr ARI) producing a significant overall reduction in AAD. The inclusion of the railway levee is also able to reduce flood damages for both 0.5% AEP (200yr ARI and 0.2% AEP (500yr ARI).

Construction of this option is entirely on recreation land and should have minimal impact on the operation of the Golf Course. It is anticipated that there would be minimal opposition to this option. Environmental impacts in the form of minor vegetation loss and general construction impacts are considered relatively minor and short term. Minor visual or aesthetic impact should be minimised through appropriate landscaping treatments.

Implementation of this option results in Bell Street being available as an important transport link in events up to and including the 1% AEP. Protection significantly above this level would require raising the height of the bridge which is likely to be prohibitively expensive. After implementation of MC1 the Bell Street route would only be closed at the peak of an extreme flood and would be closed for less than 4 hours.

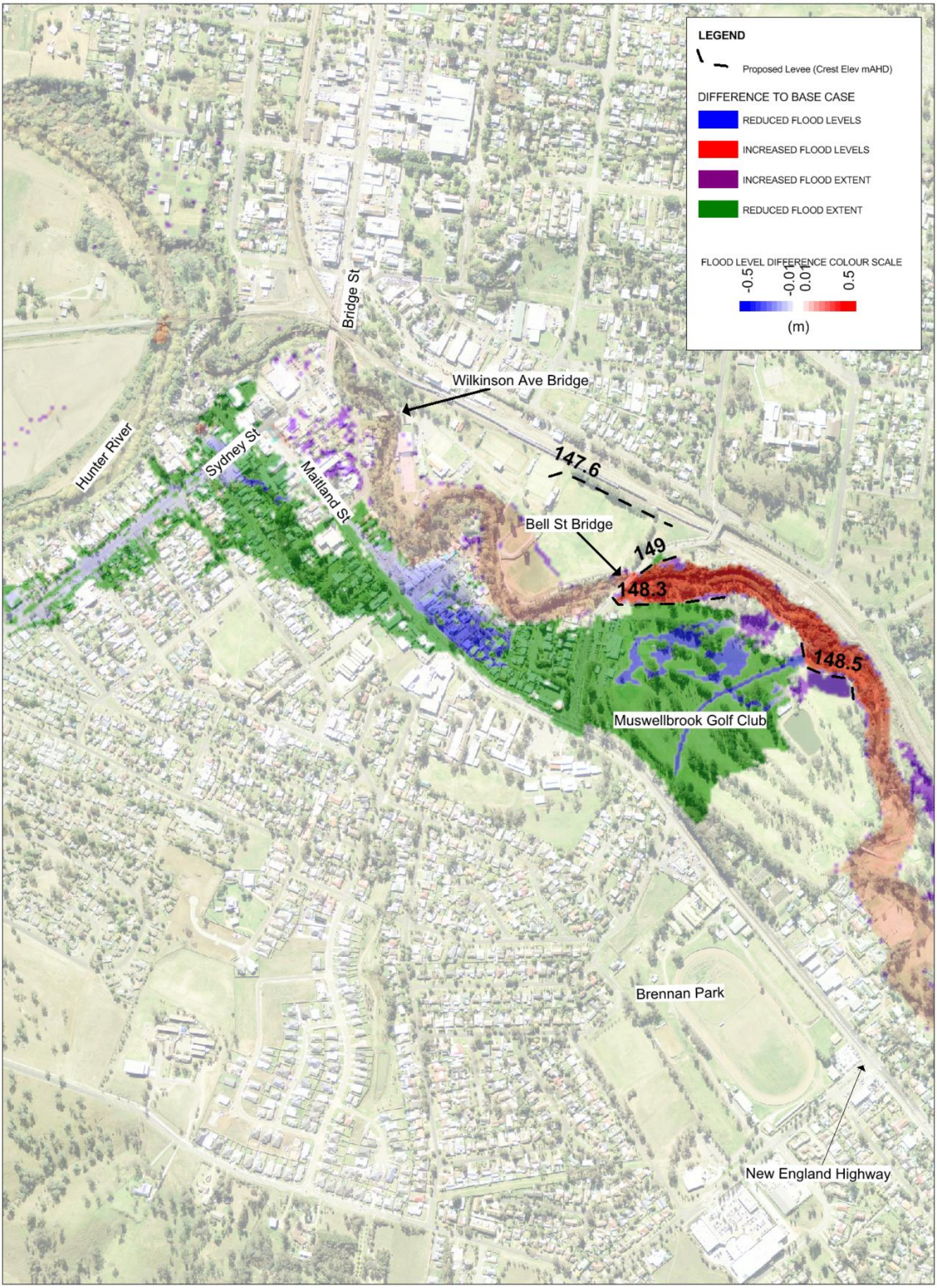

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FIGURE 6-5

Impact of Option MC1 (Enhanced Creek Banks / Levees) (1% AEP (100yr ARI) Design Event)

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6.4.5 MC2 – Muswellbrook Golf Course Flood Bund

Overview

Flood model results indicate that there are two low points along the Muscle Creek bank adjacent to the Muswellbrook Golf Course. These low banks allow flood waters to escape the channel and form an overland flow path that floods a significant number of properties. Construction of a flood bund or levee that traps the floodwaters on the Golf Course and prevents the overland flow path from occurring is considered an appropriate option to reduce flood risk in Muswellbrook. This option has a similar affect to that explored in MC1 (above), however, has the added advantage of increasing floodplain storage and detention. This option is also important to ensure emergency access across Muscle Creek. Bell Street is overtopped in the 5% AEP (20yr ARI) and Bridge Street is inundated in the 20% AEP (5yr ARI).

The location and required elevation of the bund(s) (levee) is presented in **Figure 6-6**. Based on this crest level the levee height ranges between 0.5 m to 2.5m in height.

Figure 6-6 provides details of key components of the required works. The flood model was updated to include these features and a suite of design runs was simulated to determine the impact of this mitigation option on flood behaviour and property inundation and damages.

Figure 6-6: Outline Details of MC2 – Muswellbrook Golf Course Flood Bund

NB: 1) The Golf Club Levee/Bund is 330m long and is typically 2 to 2.5 m high.

2) Railway levee/bund is 200m long and 1m high – this is an optional bund to prevent water flowing north for events > 1% AEP.

3) A 90m bund on the northern creek bank protects the northern approach to the Bell St Bridge and is up to 1.5m high assuming a crest level of 149.0 mAHD

4) A typical earth embankment design with a 3m crest and 1 in 4 batter is appropriate

Results

This option is able to prevent overland flooding for a significant number of properties between the 10% AEP (10yr ARI) and 1% AEP (100yr ARI) design event as presented in **Table 6-9**. The changes to the inundation extent and peak flood levels for the 1% AEP (100yr ARI) are presented in **Figure 6-7** and show the large area either side of Maitland Street that is now flood free, or experiences significantly reduced flood levels. The figures show that in-channel flood levels upstream of the Bell Street Bridge are significantly increased and there is a small downstream area near Bridge Street with higher water levels and a slightly increased inundation extent. **Table 6-10** shows that for the 1% AEP (100yr ARI) design event there is a reduction in 31 occurrences of above floor flooding and a net reduction of 31 (31 no longer flooded, and no newly flooded) properties experiencing yard or underfloor flooding. The scheme includes the railway embankment to prevent the newly created overland flow path that occurs to the north of the river that would cross the railway line in event above the 1% AEP. Due to changes in flowpaths, 6 properties will experience slightly higher flood levels in the 1% AEP event, though the average increase is only 7cm and the maximum increase is 14cm. Reduced overland flow also means that some 46 properties will experience reduced flood level of up to 68cm.

This option significantly reduces flood affectation and damages for all events up to and including the 0.2% AEP (500yr ARI) in the Muscle Creek area by reducing an overland flow path that currently floods 17 properties in the 5% AEP (20yr ARI) event (refer **Table 6-9**). There is a $130,500 reduction in AAD, which, over a 50 year period, is expected to reduce flood related damages by $1.9 Million. The cost of constructing this mitigation option is $1.1 Million which is quite low considering the potential benefit (a cost breakdown for this measure can be found in **Appendix B**). The calculated benefit/cost (B/C) ratio for this option is 1.7. Since the B/C ratio is significantly above one, this option should be considered for further investigation and potential implementation.

Further raising the Golf Course Levee (bund) could be considered to protect it against events up to the 0.2% AEP (500yr ARI), however the added cost may not increase the B/C ratio as the AAD is weighted to events that occur more frequently. Also as the overall channel capacity is limited, overland flows at other locations will occur and the Bell Street Bridge overtopped in the 0.5% AEP (200yr ARI) event so increased levee heights will not prevent road closure unless the Bell Street Bridge is also upgraded.

Table 6-9: Change in Property Affectation and Damages for Mitigation Measure – MC2

MC2 – Muswellbrook Golf Course Flood Bund Option

Event	No. Properties No Longer Flooded Over Floor	No. Properties No Longer Yard or Under Floor Flooded	Reduction in Damages for Event
PMF	0	0	-$3,261
0.2% / 500yr	13	8	$1,532,417
0.5% / 200yr	22	21	$1,833,237
1% / 100yr	31	31	$2,036,082
2% / 50yr	22	54	$1,824,305
5% / 20yr	17	44	$1,269,328
10% / 10yr	0	15	$224,088

Reduction in Annual Average Damages (AAD)	**$130,490**
Reduced Damages (Over 50 years)	**$1,931,342**
Cost of Mitigation Option	**$1,100,000**
Benefit/Cost	**1.76**
Reduction in Damages (%)	**12%**

Notes: Reduction in the (net) number of properties is compared to the base case.
A negative reduction means damages have increased for this event

Table 6-10: Change in (1% AEP) Property Affectation and Flood Levels Option – MC2

MC2 - Muswellbrook Golf Course Flood Bund		
	No. Properties Above Floor	**No. Properties Yard or Under Flood Flooded**
no longer flooded / dry	31	31
newly flooded / wet	0	0
net change	31	31
No. locations with increased flood depth		6
Av. increase (m)		0.07
max increase (m)		0.14
No. locations with reduced flood depth		46
Av. decrease (m)		0.36
max decrease (m)		0.68

Notes: Reduction in the (gross) number of properties is compared to the base case.

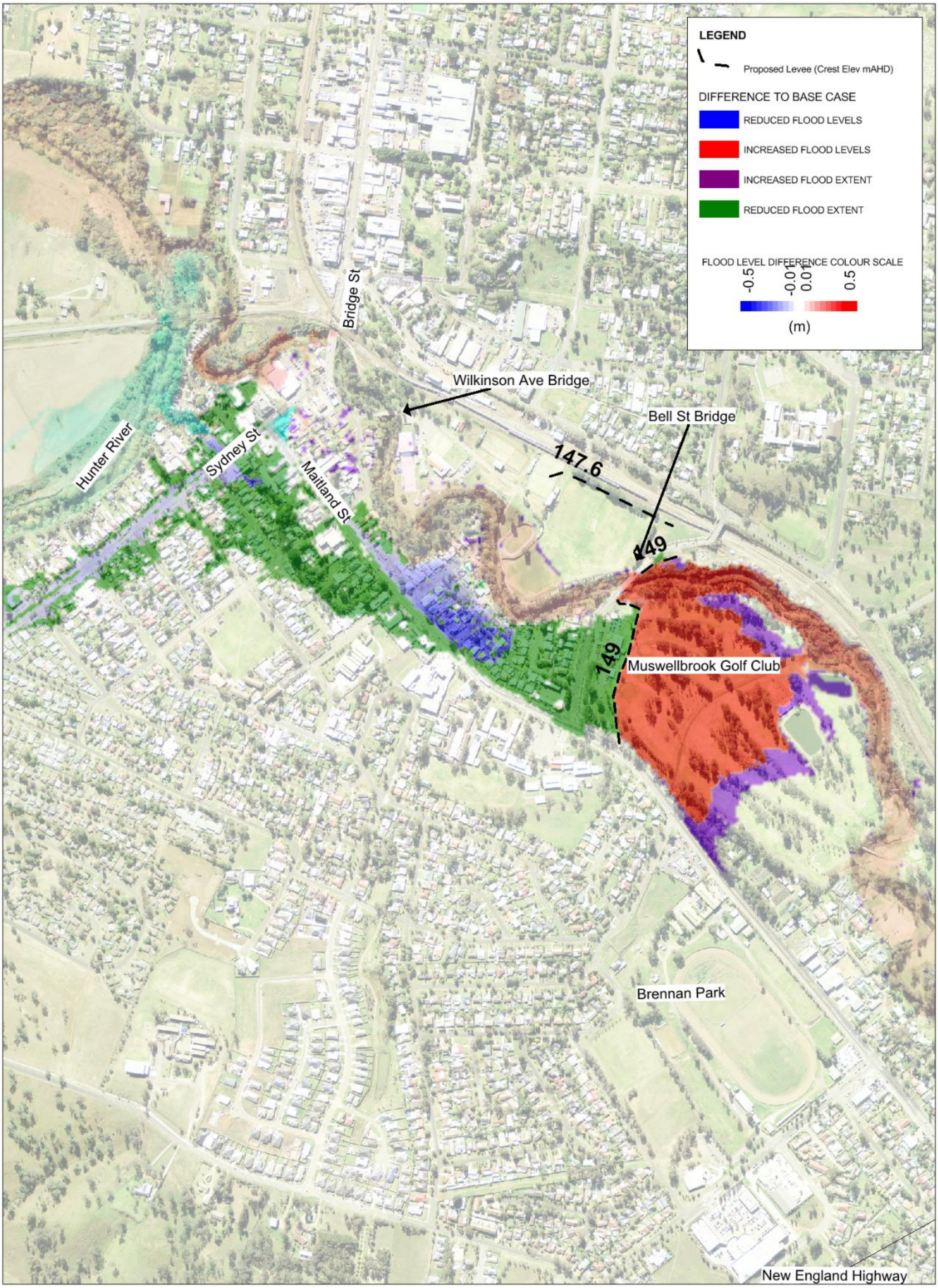

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FIGURE 6-7

Impact of Option M2 (Golf Course Bund / Levees) (1% AEP (100yr ARI) Design Event)

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Social and Environmental Impacts

Construction of a flood levee / bund adjacent to the Muswellbrook Golf Club appears to be a cost effective measure that is able to significantly reduce flood losses to the community in events up to and including the 1% AEP (100yr ARI) producing a significant overall reduction in AAD. The inclusion of the railway levee is also able to reduce flood damages for both 0.5% AEP (200yr ARI and 0.2% AEP (500yr ARI).

The construction of this option is entirely on recreation land though it may have a minor impact on the operation of the Golf Course and reduce the visual amenity of the Golf Club. Environmental impacts in the form of minor vegetation loss and general construction impacts are considered relatively minor.

Implementation of this option results in Bell Street being available as an important transport link in events up to and including the 1% AEP. Protection significantly above this level would require raising the height of the bridge which is likely to be prohibitively expensive. After implementation of MC2 the road would only be closed at the peak of the flood so would be closed for less than 4hrs.

6.4.6 MC3 – Muscle Creek Channel Vegetation Management

Overview

Improvements to riparian vegetation in Muscle Creek are proposed in the Draft Muswellbrook Urban Riparian Landcare Master Plan - Muswellbrook Shire Council Master Plan Report (GHD Woodhead, 2017). These improvements currently only target two relatively small areas (either side of the Wilkinson Avenue Bridge) and have been included in the baseline model by assuming a lower bank roughness than would otherwise be applicable (i.e. a reduction from Mannings “n” of 0.045 to 0.035). Option MC3 investigated the extension of vegetation management further upstream.

By removing this layer of near bank vegetation the hydraulic roughness is significantly reduced which will result in lower flood levels. To achieve this situation the existing vegetation would need to be removed/managed. To prevent thick vegetation from being re-established ongoing management would be required.

The areas of vegetation removal are presented in **Figure 6-8**. It was assumed that all invasive vegetation along the length of the Muscle Creek was removed. A total of 10 hectares of vegetation removal was modelled in this scenario. The flood model was updated to include the change in hydraulic roughness and a suite of design runs was simulated to determine the impact of this mitigation option on flood behaviour and property inundation and damages.

***Figure 6-8:* Outline Details of MC3 – Muscle Creek Channel Vegetation Management Option**

NB: 1) The above shows areas of in-channel bank vegetation along Muscle Creek

2) A total of 10 hectares of vegetation management/removal was modelled in this scenario.

Results

This option is able to slightly reduce the number and depth to which properties are flooded along the Muscle Creek as presented in **Table 6-11**. **Table 6-12** shows that for the 1% AEP (i.e. 100yr ARI) design event there is net a reduction in 7 occurrences of above floor flooding and a net reduction of 13 properties experiencing yard or underfloor flooding. Because the option is able to nearly globally reduce flood levels, in the 1% AEP event, some 69 properties will experience reduced flood levels of an average of 8cm though reductions of up to 18cm are predicted. This option is not predicted to produce any negative flood impacts in any events.

This option has negligible effect on the PMF as most of the flow is out of bank during this extreme flood event.

While this option does not significantly reduce property inundation it still reduces the depth of flooding which produces a reasonable reduction in overall flood damages for all events as presented in **Table 6-11.** There is a $62,300 reduction in AAD, which, over a 50 year period, is expected to reduce flood related damages by $0.92 Million. However, the cost of initial clearing and ongoing maintenance is estimated to be $1.4 Million (a cost breakdown for this measure can be found in **Appendix B**). The calculated benefit/cost (B/C) ratio for this option is 0.66. Since the

B/C ratio is less than one, this option is unlikely to be recommended for implementation or further investigation. However, it is possible that a cheaper more targeted vegetation management option that focusses on areas adjacent to key hydraulic controls (such as the Bell Street Bridge) may produce a B/C ratio above 1.

Table 6-11: Change in Property Affectation and Damages for Mitigation Measure – MC3

Muscle Creek Channel Vegetation Management Option

Event	No. Properties No Longer Flooded Over Floor	No. Properties No Longer Yard or Under Floor Flooded	Reduction in Damages for Event
PMF	1	0	$14,651
0.2% / 500yr	3	13	$598,782
0.5% / 200yr	2	4	$592,799
1% / 100yr	7	13	$535,989
2% / 50yr	6	9	$476,084
5% / 20yr	14	16	$702,688
10% / 10yr	0	15	$224,088
Reduction in Annual Average Damages (AAD)			**$62,335**
Reduced Damages (Over 50 years)			**$922,611**
Cost of Mitigation Option			**$1,400,000**
Benefit/Cost			**0.66**
Reduction in Damages (%)			**6%**

Notes: Reduction in the (net) number of properties is compared to the base case.

Table 6-12: Change in (1% AEP) Property Affectation and Flood Levels Option – MC3

MC3 - Muscle Creek Channel Vegetation Management Option		
	No. Properties Above Floor	**No. Properties Yard or Under Flood Flooded**
no longer flooded / dry	7	13
newly flooded / wet	0	0
net change	7	13
No. locations with increased flood depth		0
Av. increase (m)		n/a
max increase (m)		0.00
No. locations with reduced flood depth		69
Av. decrease (m)		0.08

max decrease (m)	0.18

Notes: Reduction in the (gross) number of properties is compared to the base case.

Social and Environmental Impacts

Removal of channel vegetation could result in a significant loss of potential wildlife habitat and would cause a significant loss in local flora and fauna. However, a more targeted vegetation management option that reduces under storey non-native invasive vegetation may result in reduced hydraulic roughness and positive flood impact. The loss of vegetation may also result in increased bank erosion and cause increased channel mobility. This option is also unlikely to be considered by the community as an effective response to the existing flood risk posed by Muscle Creek and the potential for frequent damages that result from floodwater breaking out of the channel at Muswellbrook Gold Course. This option also requires significant resources as it needs to be continuously implemented throughout the year.

6.4.7 D1 – Denman Blockage / Maintenance Policy (unblock 2 Virginia St culverts)

Overview

The occurrence of above floor flooding in Denman for events below the PMF appears to be concentrated around the two culverts under Virginia Street either side of the intersection with Rosemount Road (refer **Figure 4-7**). The location of the Virginia Street culverts is presented **Figure 6-9**. The northern culvert which comprises 5 x 0.75 m wide x 1.05 m high box culverts which were set to 40% blockage based on a site visit in 2016. The southern culvert which comprises 2 x 1.8 m wide x 0.9 m high box culverts which were set to 25% blockage based on a site visit in 2016. In order to increase culvert conveyance to reduce the occurrence of breakouts and subsequent overland flows clearing and ongoing annual maintenance may reduce the impact of flooding in Denman.

The flood model was updated to include the changes to the pipe network (i.e. blockage factor) and a suite of design runs was simulated to determine the impact of this mitigation option on flood behaviour and property inundation and damages.

Figure 6-9: Outline Details of D1 – Denman Blockage / Maintenance Policy Option

NB: 1) northern culvert which comprises 5 x 0.75 m wide x 1.05 m high box culverts (base case 40% blockage)
2) southern culvert which comprises 2 x 1.8 m wide x 0.9 m high box culverts (base case 25% blockage)
3) For this scenario blockage is reduced to 0 through initial clearing and annual maintenance

Results

This option is able to slightly reduce the number of flood affected properties in Denman as presented in **Table 6-13**. **Table 6-14** shows that for the 1% AEP (i.e. 100yr ARI) design event there is net a reduction in 2 (out of 7) occurrences of above floor flooding and a net reduction of 2 properties experiencing yard or underfloor flooding. Due to changes in flow conveyance, this option will slightly increase flood levels at 7 properties (for the 1% AEP), though the increase is less than 1cm and is considered insignificant. Reduced breakouts and overland flow also mean that some 35 properties will experience reduced flood level of up to 37cm in the 1% AEP event.

This option has negligible effect on the PMF damages which are governed by the Hunter River flood mechanism.

While this option only reduces the occurrence of above floor flooding for two premises and has a negligible impact on study wide flood damages, due to the low cost of implementation (as presented in **Table 6-13**), it is able to produce a B/C ratio above 1. There is a $4,180 reduction in AAD, which, over a 50 year period, is expected to reduce flood related damages by $61,800. However, as the cost of the maintenance is expected to only be $2,500 which using a discount rate of 5% results in a 50 year cost of only $50,000 (a cost breakdown for this measure can be found in **Appendix B**). The calculated benefit/cost (B/C) ratio for this option is 1.24. Since the B/C ratio is greater than one, this option is recommended for implementation.

Table 6-13: Change in Property Affectation and Damages for Mitigation Measure – D1

Denman Blockage / Maintenance Policy Option

Event	No. Properties No Longer Flooded Over Floor	No. Properties No Longer Yard or Under Floor Flooded	Reduction in Damages for Event
PMF	0	0	$0
0.2% / 500yr	0	1	$121,787
0.5% / 200yr	2	1	$47,363
1% / 100yr	2	2	$136,887
2% / 50yr	2	2	$132,940
5% / 20yr	0	0	$0
10% / 10yr	0	0	$0
Reduction in Annual Average Damages (AAD)			**$4,179**
Reduced Damages (Over 50 years)			**$61,849**
Cost of Mitigation Option			**$50,000**
Benefit/Cost			**1.24**
Reduction in Damages (%)			**0.37%**

Notes: Reduction in the (net) number of properties is compared to the base case.
A negative reduction means damages have increased for this event

Table 6-14: Change in (1% AEP) Property Affectation and Flood Levels Option – D1

D1 – Denman Blockage / Maintenance Policy		
	No. Properties Above Floor	**No. Properties Yard or Under Flood Flooded**
no longer flooded / dry	2	2
newly flooded / wet	0	0
net change	2	2
No. locations with increased flood depth		7
Av. increase (m)		0.00
max increase (m)		0.00
No. locations with reduced flood depth		35
Av. decrease (m)		0.03
max decrease (m)		0.37

Notes: Reduction in the (gross) number of properties is compared to the base case.

Social and Environmental Impacts

As this option reduces the occurrence of flooding and property inundation it is associated with a positive social outcome. This option is considered to a have negligible adverse environmental impact. The costs associated with this option could be considered as part of Councils annual asset management program, the option therefore has no up-front capital costs, just an ongoing annual maintenance costs.

6.4.8 D2 - Upgrade to Virginia St Culvert (north)

Overview

The occurrence of above floor flooding in Denman for events below the PMF appears to be concentrated around the two culverts under Virginia Street either side of the intersection with Rosemount Road (refer **Figure 4-7**). The location of the Virginia Street culverts is presented **Figure 6-10**. The northern culvert which comprises 5 x 0.75 m wide x 1.05 m high box culverts which were set to 40% blockage based on a site visit in 2016. The southern culvert which comprises 2 x 1.8 m wide x 0.9 m high box culverts which were set to 25% blockage based on a site visit in 2016. In order to increase culvert conveyance to reduce the occurrence of breakouts and subsequent overland flows an upgrade of the northern culvert to 5 x 1.2 m wide by 1.2 m high box culverts was investigated.

The flood model was updated to include the changes to the pipe network (i.e. culvert upgrade) and a suite of design runs was simulated to determine the impact of this mitigation option on flood behaviour and property inundation and damages.

Figure 6-10: Outline Details of D2 - Upgrade to Virginia St Culvert (north) Option

NB: 1) northern culvert which currently comprises 5 x 0.75 m wide x 1.05 m high box culverts (base case 40% blockage). In this scenario it would be upgraded to 5 x 1.2 m wide x 1.2 m high box culverts

2) southern culvert which comprises 2 x 1.8 m wide x 0.9 m high box culverts (base case 25% blockage)

3) For this scenario blockage is also reduced to 0 through initial clearing and annual maintenance

Results

This option is able to slightly reduce the number of flood affected properties in Denman as presented in **Table 6-15**. **Table 6-16** shows that for the 1% AEP (i.e. 100yr ARI) design event there is net a reduction in 4 (out of 7) occurrences of above floor flooding and a net reduction of 3 properties experiencing yard or underfloor flooding. Due to changes in flow conveyance, this option will slightly increase flood levels at 8 properties (for the 1% AEP), though the increase is less than 1cm so should be considered insignificant. Reduced breakouts and overland flow also mean that some 34 properties will experience reduced flood level of up to 37cm in the 1% AEP event.

This option has negligible effect on the PMF damages which are governed by the Hunter River flood mechanism.

While this option only reduces the occurrence of above floor flooding for four premises the actual reduction in damages compared to Option D1 (culvert maintenance) is similar, due to the higher cost of implementation (as presented in **Table 6-15**) it produced a B/C ratio well below 1. There is a $4,425 reduction in AAD, which, over a 50 year period, is expected to reduce flood related damages by $65,500. However, as the capital cost of the project is quite high (~$430,000 if undertaken by an external contractor and including a 50% contingency) (a full cost breakdown for this measure can be found in **Appendix B**). The calculated benefit/cost (B/C) ratio for this option is only 0.15. Since the B/C ratio is significantly less than one, this option is not recommended for implementation.

Table 6-15: Change in Property Affectation and Damages for Mitigation Measure – D2
Upgrade to Virginia St Culvert (north) Option

Event	No. Properties No Longer Flooded Over Floor	No. Properties No Longer Yard or Under Floor Flooded	Reduction in Damages for Event
PMF	0	0	$0
0.2% / 500yr	2	1	$121,787
0.5% / 200yr	2	1	$88,797
1% / 100yr	4	3	$147,587
2% / 50yr	2	2	$132,940
5% / 20yr	0	0	$0
10% / 10yr	0	0	$0
		Reduction in Annual Average Damages (AAD)	**$4,425**
		Reduced Damages (Over 50 years)	**$65,490**
		Cost of Mitigation Option	**$430,000**
		Benefit/Cost	**0.15**
		Reduction in Damages (%)	**0.39%**

Notes: Reduction in the (net) number of properties is compared to the base case.
A negative reduction means damages have increased for this event

Table 6-16: Change in (1% AEP) Property Affectation and Flood Levels Option – D2

D1 – Denman Blockage / Maintenance Policy		
	No. Properties Above Floor	No. Properties Yard or Under Flood Flooded
no longer flooded / dry	4	3
newly flooded / wet	0	0
net change	4	3
No. locations with increased flood depth		8
Av. increase (m)		0.00
max increase (m)		0.00
No. locations with reduced flood depth		34
Av. decrease (m)		0.03
max decrease (m)		0.37

Notes: Reduction in the (gross) number of properties is compared to the base case.

Social and Environmental Impacts

As this option reduces the occurrence of flooding and property inundation it is associated with a positive social outcome. This option is considered to a have negligible adverse environmental impact. Short term social impacts would be limited to the construction phase.

Property modification measures

6.4.9 P1 - Voluntary House Raising and Voluntary Purchase (properties below 1% AEP)

Description & Details

Voluntary House Raising (VHR) has been widely used in NSW as a means of reducing above floor flood inundation. The application of VHR is limited since it is not suitable for all building types (primarily only for single storey non-brick buildings on piers). VHR, where suitable, is cost effective because it does not require significant quantities of new material and does not “sterilise” land. It should be noted that VHR is unlikely to be approved in high hazard areas and can cause evacuation problems.

Voluntary Purchase (VP) refers to the acquisition and demolition of severely flood affected residential properties which pose a significant risk to life during flood events. Typically, these properties are frequently inundated by high hazard flows. These properties are generally removed from the floodplain and rezoned to a high hazard flood compatible use, such as open public space. The removal of these properties may also restore the hydraulic capacity of the floodplain if the properties are located in a “floodway”.

The current analysis has been undertaken assuming all properties that are slab on ground properties are eligible for VP (i.e. it does not currently consider flood hazard). The analysis also considers all properties on piers are candidates for VHR and does not consider that some properties on piers may be unsuitable for raising (i.e. if they have a brick chimney).

It should be noted that only residential properties have been considered for VHR or VP. It is assumed that VHR properties are raised 0.5 m above the 1% AEP (100yr ARI) design level, though will still occur damages due to yard and under floor flooding. Properties assumed for VP were assumed to incur no damages. Double storey (DS) properties were considered unsuitable for VHR or VP.

It was assumed that VHR properties would incur on average a cost of $50,000, while the cost of VP was assumed to be $300,000 which is based on the median property price as reported by CoreLogic which as at May 2018 was $295,000 and an allowance of $5,000 for legal/conveyancing costs.

Results

The analysis found that for the 1% AEP (100yr ARI) protection standard, 139 properties are potentially suitable for VHR, while a further 22 which cannot be raised may be suitable for VP. By targeting the properties that are frequently flooded (and hence result in a high contribution to AAD), a significant reduction in flood damages is achieved as presented in **Table 6-17.** There is a 46% reduction in AAD, which, over a 50 year period, is expected to reduce flood related damages by $7.66 Million. The cost of this mitigation option is $13.55 Million. The calculated benefit/cost (B/C) ratio for this option is 0.57. Given that the B/C ratio is less than one, this option would not be recommended for implementation or further investigation.

Table 6-17: Change in Property Affectation and Damages for VHR/VP (1% AEP)

1% AEP - VHR 139 Properties, VP 22 Properties, DS 31 Properties

Event	No. Properties No Longer Flooded Over Floor	No. Properties No Longer Yard or Under Floor Flooded	Reduction in Damages for Event
PMF	22	21	$5,341,598
0.2% / 500yr	146	22	$13,527,749
0.5% / 200yr	161	22	$13,497,237
1% / 100yr	161	22	$12,151,040
2% / 50yr	105	21	$9,919,973
5% / 20yr	18	11	$2,793,397
10% / 10yr	0	0	$0
Reduction in Annual Average Damages (AAD)			**$517,800**
Reduced Damages (Over 50 years)			**$7,663,821**
Cost of Mitigation Option			**$13,550,000**
Benefit/Cost			**0.57**
Reduction in Damages (%)			**46%**

Notes: Reduction in the (net) number of properties is compared to the base case.

Social and Environmental Impacts

As this option reduces the occurrence of above floor property inundation and associated economic and health related impacts it is associated with a positive social outcome. VHR reduces social disruption as residents are not required to be relocated. However, VHR may encourage residents to stay in their homes during a flood which may lead to evacuation issues or potential fatalities in the case of extreme floods significantly higher than the 1% AEP. VHR has a relatively low environmental impact as it makes good use of existing resources.

VP is more socially disruptive and unless flood compatible uses (i.e. community meeting areas) are available for properties the demolition of existing properties has significant environmental costs.

6.4.10 P2 - Voluntary House Raising and Voluntary Purchase (properties below 2% AEP)

Description & Details

This option is similar to that described above in Section 6.4.9, however, instead of raising properties inundated during the 1% AEP only properties inundated in the 2% AEP (50yr ARI) would be considered.

Again it was assumed that VHR properties would incur on average a cost of $50,000, while the cost of VP was assumed to be $300,000 which is based on the median property price as reported by CoreLogic which as at May 2018 was $295,000 and an allowance of $5,000 for legal/conveyancing costs.

Results

The analysis found that for the 2% AEP (50yr ARI) protection standard, 93 properties are potentially suitable for VHR, while a further 12 which cannot be raised may be suitable for VP. By targeting the properties that are frequently flooded (and hence result in a high contribution to AAD), a significant reduction in flood damages is achieved as presented in **Table 6-18.** There is a 35% reduction in AAD, which, over a 50 year period, is expected to reduce flood related damages by $5.81 Million. The cost of this mitigation option is $8.25 Million. The calculated benefit/cost (B/C) ratio for this option is 0.7. Given that the B/C ratio is less than one, this option would not be recommended for implementation or further investigation.

Table 6-18: Change in Property Affectation and Damages for VHR/VP (2% AEP)

2% AEP - VHR 93 Properties, VP 12 Properties, DS 28 Properties

Event	No. Properties No Longer Flooded Over Floor	No. Properties No Longer Yard or Under Floor Flooded	Reduction in Damages for Event
PMF	12	12	$2,955,647
0.2% / 500yr	76	12	$7,807,325
0.5% / 200yr	94	12	$8,426,498
1% / 100yr	105	12	$8,587,711
2% / 50yr	105	12	$7,502,247
5% / 20yr	18	9	$2,512,259
10% / 10yr	0	3	$291,812

Reduction in Annual Average Damages (AAD)	$392,955
Reduced Damages (Over 50 years)	$5,816,030
Cost of Mitigation Option	$8,250,000
Benefit/Cost	0.70
Reduction in Damages (%)	35%

Notes: Reduction in the (net) number of properties is compared to the base case.

Social and Environmental Impacts

As this option reduces the occurrence of above floor property inundation and associated economic and health related impacts it is associated with a positive social outcome. VHR reduces social disruption as residents are not required to be relocated. However, VHR may encourage residents to stay in their homes during a flood which may lead to evacuation issues or potential fatalities in the case of extreme floods significantly higher than the 1% AEP. VHR has a relatively low environmental impact as it makes good use of existing resources.

VP is more socially disruptive and unless flood compatible uses (i.e. community meeting areas) are available for properties the demolition of existing properties has significant environmental costs.

6.4.11 P3 - Voluntary House Raising and Voluntary Purchase (properties below 5% AEP)

Description & Details

This option is similar to that described above in Section 6.4.9, however, instead of raising properties inundated during the 1% AEP only properties inundated in the 5% AEP (20yr ARI) would be considered.

Again it was assumed that VHR properties would incur on average a cost of $50,000, while the cost of VP was assumed to be $300,000 which is based on the median property price as reported by CoreLogic which as at May 2018 was $295,000 and an allowance of $5,000 for legal/conveyancing costs.

Results

The analysis found that for the 5% AEP (20yr ARI) protection standard, 12 properties are potentially suitable for VHR, while a further 6 which cannot be raised may be suitable for VP. By targeting the properties that are frequently flooded (and hence result in a high contribution to AAD), a significant reduction in flood damages is achieved as presented in **Table 6-19.** There is a 12% reduction in AAD, which, over a 50 year period, is expected to reduce flood related damages by $2.0 Million. The cost of this mitigation option is $2.40 Million. The calculated benefit/cost (B/C) ratio for this option is 0.84. Given that the B/C ratio is less than one, this option would not be recommended for implementation or further investigation. However, it is possible that by excluding the VP properties from this analysis and considering VHR only, a B/C ratio of > 1 may occur.

Table 6-19: Change in Property Affectation and Damages for VHR/VP (5% AEP)

5% AEP - VHR 12 Properties, VP 6 Properties, DS 12 Properties

Event	No. Properties No Longer Flooded Over Floor	No. Properties No Longer Yard or Under Floor Flooded	Reduction in Damages for Event
PMF	6	6	$1,340,164
0.2% / 500yr	14	6	$1,694,268
0.5% / 200yr	15	6	$1,675,293
1% / 100yr	16	6	$1,714,390
2% / 50yr	18	6	$1,728,169
5% / 20yr	18	6	$1,447,186
10% / 10yr	0	3	$238,812
Reduction in Annual Average Damages (AAD)			**$135,481**
Reduced Damages (Over 50 years)			**$2,005,227**
Cost of Mitigation Option			**$2,400,000**
Benefit/Cost			**0.84**
Reduction in Damages (%)			**12%**

Notes: Reduction in the (net) number of properties is compared to the base case.

Social and Environmental Impacts

As this option reduces the occurrence of above floor property inundation and associated economic and health related impacts it is associated with a positive social outcome. VHR reduces social disruption as residents are not required to be relocated. However, VHR may encourage residents to stay in their homes during a flood which may lead to evacuation issues or potential fatalities in the case of extreme floods significantly higher than the 1% AEP. VHR has a relatively low environmental impact as it makes good use of existing resources.

VP is more socially disruptive and unless flood compatible uses (i.e. community meeting areas) are available for properties the demolition of existing properties has significant environmental costs.

6.4.12 Summary of Damages for Mitigation Measures

A summary of flood damages and benefit / cost (B/C) ratios for the base case (do nothing) and mitigation options is presented in **Table 6-20.**

Table 6-20: Summary of Damages and B/C Ratios for a Range of Mitigation Measures

Option	AAD	NPV of Damage	Cost Of Option	Option Benefit Relative to Base Case	Benefit/Cost Relative to Base Case	Reduction in Damages (%)
Base Case for Comparison	$1,121,152	$16,593,882	n/a	n/a	n/a	**n/a**
HRS1 - Backwater Levee Option	$1,022,901	$15,139,704	$2,250,000	$1,454,178	0.65	9%
HRS2 - Sydney Street Levee Option	$941,013	$13,927,697	$3,500,000	$2,666,185	0.76	16%
HRS3 - Channel Vegetation Removal	$793,628	$11,746,290	$8,000,000	$4,847,592	0.61	29%
MC1 - Enhance creek bank adjacent to golf course	**$997,554**	**$14,764,542**	**$840,000**	**$1,829,339**	**2.18**	**11%**
MC2 - Golf course flood bund	**$990,662**	**$14,662,540**	**$1,100,000**	**$1,931,342**	**1.76**	**12%**
MC3 - Channel vegetation management	$1,058,816	$15,671,270	$1,400,000	$922,611	0.66	6%
D1 - blockage / maintenance policy (unblock 2 Virginia St culverts)	**$1,116,973**	**$16,532,033**	**$50,000**	**$61,849**	**1.24**	**0.37%**
D2 - Upgrade to Virginia St culvert (north)	$1,116,727	$16,528,392	$430,000	$65,490	0.15	0.39%
P1 - VP/VHR below 1% AEP only	$603,352	$8,930,061	$13,550,000	$7,663,821	0.57	46%
P2 - VP/VHR below 2% AEP only	$728,197	$10,777,852	$8,250,000	$5,816,030	0.70	35%
P3 - VP/VHR below 5% AEP only	$985,670	$14,588,655	$2,400,000	$2,005,227	0.84	12%

6.4.13 Summary of Potential Mitigation Measures

A summary of all the mitigation measures considered in the FRMS is presented in **Table 6-21.**

Table 6-21: Risk Management Option – Assessment Summary and Analysis

Measure	Description	Priority	Benefit	Comments & Concerns	Responsibility for Implementation, Costs and Funding
FLOOD MODIFICATION MEASURES					
HRS1 – Muswellbrook Backwater Levee – Section 6.4.1	Option HRS1 investigated construction of a Levee to prevent backwater flooding outflanking the existing Muswellbrook Levee. A large flapped outlet is required to drain Possum Gully Creek.	**Low - Medium** Effective but costly	B/C = 0.65 Option HRS1 reduces flood damages by $1.45 Mil and is able to protect 22 properties from above floor flooding and 73 properties from under floor flooding in the 1% AEP event.	Option HRS1 is estimated to cost $2.25 Million and would require ground works and excavation which would have a negative environmental effect. However, as the levee is at the rear of properties the disruption is minimised. A minor allowance for ongoing maintenance would be required.	Council would be responsible for costs and implementation of this option. Limited funding may be available through the NSW Floodplain Management Program or other Federal Grants Programs.
HRS2 - Sydney Street Levee – Section 6.4.2	Option HRS2 investigated construction of an 840m long earth levee parallel to Sydney Street. A 550m long brickwork levee parallel to Maitland Street would also be required. The option requires 4 temporary barriers at each road crossing.	**Low - Medium** Effective but costly and difficult to implement	B/C = 0.76 Option HRS2 reduces flood damages by $2.66 Mil and is able to protect 54 properties from above floor flooding and 71 properties from under floor flooding in the 1% AEP event.	Option HRS2 is estimated to cost $3.5 Million and would require ground works and excavation which would have a negative environmental effect. Also the requirement for levee between properties would require significant negotiation with residents and make ownership, monitoring and maintenance difficult. A minor allowance for ongoing maintenance would be required. The reliance on deployment of temporary flood barrier potentially reduces the effectiveness of this option. This option also adversely affects flood levels and damages for a number of properties outside the protected area.	Council would be responsible for costs and implementation of this option. Limited funding may be available through the NSW Floodplain Management Program or other Federal Grants Programs.
HRS3 - Channel Vegetation Removal – Section 6.4.3	Option HRS3 investigated clearing the vegetation from a 40km reach of the Hunter River Channel. .	**Very Low** Only moderately effective and very costly with negative environmental impacts	B/C = 0.61 Option HRS3 reduces flood damages by $4.85 Mil and is able to protect 66 properties from above floor flooding and 53 properties from under floor flooding in the 1% AEP event. The option typically reduces flood levels by 0.3m. .	Option HRS3 is estimated to cost $8.0 Million. This option This action is contrary to recent research in the Hunter and current flood mitigation activities in the Hunter which are encouraging the maintenance and increase of in-channel woody vegetation and may also increase flooding downstream of the study area. Significant vegetation removal would result in a significant loss of wildlife habitat and could also result in stream erosion and channel migration. There is likely to be significant opposition from the community and it could be difficult to obtain approval from land management authorities. Ongoing vegetation removal and maintenance would be required.	Council would be responsible for costs and implementation of Option HRS3. Limited funding may be available through the NSW Floodplain Management Program.

Measure	Description	Priority	Benefit	Comments & Concerns	Responsibility for Implementation, Costs and Funding
MC1 - Enhance creek bank adjacent to golf course – Section 6.4.4	Option MC1 investigated the use of 3 small levees/bunds on Muscle Creek to prevent overland flows cutting Bell Street (a vital emergency access route) and causing significant flood damages to residents. A fourth levee could further reduce flood damages north of the railway.	**Medium - High** Very Effective and relatively low cost, highest B/C	B/C = 2.18 Option MC1 reduces flood damages by $1.83 Mil and is able to protect 31 properties from above floor flooding and 28 properties from under floor flooding in the 1% AEP event. MC1 also means that Bell St is accessible in the 1% AEP (currently flooded in the 5% AEP).	Option MC1 is estimated to cost $0.84 Million and would require ground works and minor excavation which would have a negative environmental effect. However, as the levee is on public land disruption and objections should be minimal. A flapped culvert would be required to ensure adequate drainage of the golf course. A staged approach may be appropriate for this option. A minor allowance for ongoing maintenance would be required. Option MC2 provides slightly lower AAD due to provision of flood storage area. Land ownership and access for construction and maintenance would need to be considered.	Council would be responsible for costs and implementation of this option. Limited funding may be available through the NSW Floodplain Management Program or other Federal Grants Programs.
MC2 - Golf course flood bund – Section 6.4.5	Option MC2 investigated the use of a large levee/bund adjacent to Muswellbrook Golf Club and a small levee/bund on the north bank of Muscle Creek to prevent overland flows cutting Bell Street (a vital emergency access route) and causing significant flood damages to residents. An additional levee could further reduce flood damages north of the railway.	**Medium - High** Very Effective and relatively low cost, 2nd highest B/C	B/C = 1.76 Option MC2 reduces flood damages by $1.93 Mil and is able to protect 31 properties from above floor flooding and 31 properties from under floor flooding in the 1% AEP event. MC2 also means that Bell St is accessible in the 1% AEP (currently flooded in the 5% AEP).	Option MC2 is estimated to cost $1.1 Million and would require ground works and minor excavation which would have a negative environmental effect. However, as the larger levee is on the Golf Course there is the potential for objections from Golf Course owners and users. MC2 provides a similar level of protection as MC1 for events up to the 1% AEP, however is able to provide a greater degree of benefit in more extreme events. A staged approach may be appropriate for this option to reduce upfront costs. A minor allowance for ongoing maintenance would be required. Land ownership and access for construction and maintenance would need to be considered.	Council would be responsible for costs and implementation of this option. Limited funding may be available through the NSW Floodplain Management Program or other Federal Grants Programs.
MC3 - Channel vegetation management – Section 6.4.6	Option MC3 investigated the management and clearing of ~10 Hectares of vegetation from a 3.5km reach of Muscle Creek. .	**Low** Only moderately effective and very costly with negative environmental impacts	B/C = 0.66 Option MC3 reduces flood damages by $0.92 Mil and is able to protect 7 properties from above floor flooding and 13 properties from under floor flooding in the 1% AEP event. The option typically reduces flood levels by 0.1m. .	Option MC3 is estimated to cost $1.4 Million over 50 years. Significant vegetation removal would result in a significant loss of wildlife habitat and could also result in stream erosion and channel migration. However, this option includes re-vegetation with native species so long term habitat loss is reduced. Because this option is mainly targeting non-native invasive species there is likely to be less opposition from the community and more support from land management authorities. Ongoing vegetation removal and maintenance would be required. This option is not able to provide the required improvements to Bell Street flood immunity.	Council would be responsible for costs and implementation of Option MC3. Limited funding may be available through the NSW Floodplain Management Program.
D1 - Blockage / maintenance	Option D1 investigated the clearance and ongoing	**Medium - High**	B/C = 1.24 Option D1 reduces flood damages	Option D1 is estimated to cost $50,000 over 50 years including an allowance for ongoing maintenance. This option has low	Council would be responsible for costs and implementation of this option. The upfront

Measure	Description	Priority	Benefit	Comments & Concerns	Responsibility for Implementation, Costs and Funding
policy to unblock 2 Virginia St (Denman) culverts – Section 6.4.7	maintenance of two culverts under Virginia Street (Denman) that are currently 45% and 20% blocked. Removal of sediment and debris	Effective and very low cost, B/C > 1	by $61,850 and is able to protect 2 properties from above floor flooding and 2 properties from under floor flooding in the 1% AEP event.	environmental impact and makes use of existing assets though increases the workload for Council staff / works teams.	and ongoing costs of this option are relatively minor. It is unlikely that this option would receive funding from the NSW Floodplain Management Program or other Federal Grants Programs.
D2 - Upgrade to Virginia St (Denman) culvert (north) - Section 6.4.8	Option D2 investigated upgrading the existing 5 x 0.75 m wide x 1.05 m high box culverts in Virginia Street (Denman) with a 5 x 1.2 m wide x 1.2 m high box culvert and the clearance and ongoing maintenance of both culverts.	**Low** Effective but high cost.	B/C = 0.15 Option D2 reduces flood damages by $65,500 and is able to protect 4 properties from above floor flooding and 3 properties from under floor flooding in the 1% AEP event.	Option D2 is estimated to cost $430,000 over 50 years including an allowance for ongoing maintenance. This option has relatively low environmental impact though does required some construction impacts and also the replacing an existing asset. Because this only provides protection to a small number of properties it is associated with a relatively low B/C ratio. If Council undertook the works there is potential to reduce the overall option costs.	Council would be responsible for costs and implementation of this option. Limited funding may be available through the NSW Floodplain Management Program or other Federal Grants Programs.
PROPERTY MODIFICATION MEASURES					
P1 - Voluntary House Raising and Voluntary Purchase (properties below 1% AEP) - Section 6.4.9	Option P1 investigated VHR for 139 properties and VP for 22 properties that are currently experience above floor flooding in the 1% AEP flood event.	**Low - Medium**	B/C = 0.57 Option P1 reduces flood damages by $7.66 Mil and is able to protect 161 properties from above floor flooding in the 1% AEP event.	The VHR of 139 properties and VP of 22 properties is estimated to cost $13.55 Mil. Further analysis is recommended to identify which of the VP properties are in a high risk area and should be prioritised. Further analysis should also be undertaken to exclude properties adjacent to Muscle Creek which can be protected by option MC1 or MC2. Options for only undertaking VHR and VP for more frequently flooded properties are provided in P2 and P3 and have a more favourable B/C ratio.	Recommendation for a Voluntary House Raising Feasibility Assessment to be conducted. 2:1 Funding may be available through the NSW Floodplain Management Program, with the resident liable for paying 1/3 the cost of raising. Recommendation for a Voluntary Purchase Feasibility Assessment to be conducted. 2:1 funding may be available through the NSW Floodplain Management Program, with Council liable for paying 1/3 the cost of the purchased property.
P2 - Voluntary House Raising and Voluntary Purchase (properties below 2% AEP) - Section 6.4.10	Option P2 investigated VHR for 93 properties and VP for 12 properties that are currently experience above floor flooding in the 2% AEP flood event.	**Low - Medium**	B/C = 0.70 Option P2 reduces flood damages by $5.82 Mil and is able to protect 105 properties from above floor flooding in the 1% AEP event.	The VHR of 93 properties and VP of 12 properties is estimated to cost $8.25 Mil. Further analysis is recommended to identify which of the VP properties are in a high risk area and should be prioritised. Further analysis should also be undertaken to exclude properties adjacent to Muscle Creek which can be protected by option MC1 or MC2. Options for only undertaking VHR and VP for more frequently flooded properties are provided in P3 and have a more favourable B/C ratio.	Recommendation for a Voluntary House Raising Feasibility Assessment to be conducted. 2:1 Funding may be available through the NSW Floodplain Management Program, with the resident liable for paying 1/3 the cost of raising. Recommendation for a Voluntary Purchase Feasibility Assessment to be conducted. 2:1 funding may be available through the NSW Floodplain Management Program, with

Measure	Description	Priority	Benefit	Comments & Concerns	Responsibility for Implementation, Costs and Funding
					Council liable for paying 1/3 the cost of the purchased property.
P3 - Voluntary House Raising and Voluntary Purchase (properties below 5% AEP) - Section 6.4.11	Option P2 investigated VHR for 12 properties and VP for 6 properties that are currently experience above floor flooding in the 5% AEP flood event.	**Low - Medium**	B/C = 0.84 Option P3 reduces flood damages by $2.02 Mil and is able to protect 18 properties from above floor flooding in the 1% AEP event.	The VHR of 12 properties and VP of 6 properties is estimated to cost $2.40 Mil. Further analysis is recommended to identify which of the VP properties are in a high risk area and should be prioritised. Further analysis should also be undertaken to exclude properties adjacent to Muscle Creek which can be protected by option MC1 or MC2. Options for only undertaking VHR only may produce a more favourable B/C ratio.	Recommendation for a Voluntary House Raising Feasibility Assessment to be conducted. 2:1 Funding may be available through the NSW Floodplain Management Program, with the resident liable for paying 1/3 the cost of raising. Recommendation for a Voluntary Purchase Feasibility Assessment to be conducted. 2:1 funding may be available through the NSW Floodplain Management Program, with Council liable for paying 1/3 the cost of the purchased property.
RESPONSE MODIFICATION MEASURES					
FW1 - Flood Warning System (see Section 7)	Option FW1 investigated the development of a flood warning system for Muscle Creek.	**Medium - High**	If MC1 or MC2 are not implemented with a 2 to 5 year timeframe, a flood warning system is recommended to reduce risk to life from rapidly rising floodwaters that sweep through residential areas of Muswellbrook to the south of Muscle Creek and can isolate the southern side of town as frequently as the 5% AEP flood event.	A suitable flood warning system for Muswellbrook is estimated to cost $50,000 to $100,000. Ongoing annual monitoring costs of ~$5,000 are likely to be required. A significant benefit of flood warning system is in intangibles including advanced warning of important road closures and the reduced likelihood of flood related loss of life. The method of warning delivery would have to be tailored to the range of residents living on the floodplain.	Following completion of the FRMS&P Council would be able to submit an application for OEH Floodplain Grants for a flood warning system for Muswellbrook. 2:1 funding is likely to be available through the NSW Floodplain Management Program, with Council liable for paying 1/3 the cost of the system.
EM1 - Emergency Management Planning	Effective emergency management planning involves the collaboration of emergency services including the SES and other rescue services to develop a Local Flood Plan.	**High**	An update to the Local Flood Plan will ensure that informed decisions can be made during a flood event and allow for flood preparedness to increase efficiency and reduce risk to residents and emergency services.	Volume 1 of the SES Flood Plan was produced in March 2013, while Volume 2 and 3 are dated August 2007. It is suggested that the documents are updates to take into account finding of the flood study, particularly new information on Muscle Creek flood issues.	The NSW SES are responsible for developing and maintaining a Local Flood Plan for the study area.
EM2 - Community Flood Education	A community flood education program would allow an increased understanding of	**Medium**	Increasing flood preparedness and maintain awareness in the community would ensure that	Community members are likely to ignore flood information if too much is given. Communication needs to be direct and concise.	Council in partnership with the SES are responsible for community education. To reduce costs, this information can be

Measure	Description	Priority	Benefit	Comments & Concerns	Responsibility for Implementation, Costs and Funding
	flood risk in Muswellbrook and Denman.		communities are informed and ultimately reduce the damages during a flood event.		incorporated with other information such as in the local paper or with Council Rates.
PLANNING and FPL CONSIDERATIONS					
P4 - Update LEP	Update the LEP …	**High**	Council will need to update the LEP to ensure that future develop considers locations with high flood risk.	If an appropriate land use zonings are not adopted, risk to life and increases in flood damages could result.	Council staff time would be required to implement and update to the LEP.

7 Assessment of a Flood Warning System for Muswellbrook

7.1 Response Modification Measures

Flood response measures encompass various means of modifying the response of the population to the flood threat. These measures aim to reduce risk to life and property during a flood event by improving factors such as flood warning and prediction, emergency management planning and community flood education.

7.1.1 Flood Warning Systems

Overview

A flood warning system provides advice on imminent flood events allowing residents to take action to minimise the flood impacts. Typically, flood warning systems integrate factors such as rainfall, river flows and weather forecasts to predict the severity and timing of flooding, then distribute warning messages to agencies such as the SES and to community members where necessary.

Flood warning systems are most effective on large river systems where there is significant warning time providing residents and emergency services with ample time to prepare. There is currently a formal flood warning service for the Hunter River provided by the Bureau of Meteorology (BoM) as discussed below.

On smaller systems such as the Muscle Creek, flood warning systems are typically harder to implement and unless they are based on forecast data, result in less warning time than large systems. However, given the relatively small number of properties and short evacuation distances, a warning system for the Muscle Creek could still be effective in reducing risk to life. Information regarding development of a suitable warning system for Muscle Creek flooding is provided below.

Smaller overland flow catchments, such as the Denman catchment study area, are typically subject to flash flooding from short intense bursts of rainfall and tend to be difficult to provide effective warning time because of their rapid onset. The implementation of a specific flood warning system for the Denman catchment is considered unnecessary given the low risk to life from this flood mechanism. Details of the existing BoM thunderstorm warnings are provided below.

Description of Available BoM Flood Warnings

The Bureau's Flood Warning Service provides:

- Early advice of possible flooding if flood producing rain is expected in the near future.
- A generalised flood warning that flooding is occurring or is expected to occur in a particular region. No information on the severity of flooding or the particular location of the flooding is provided in this instance. These warnings are issued for areas where no specialised warnings systems have been installed. As part of its Severe Weather Warning Service, the Bureau also provides warnings for severe storms that may cause flash flooding. In some areas the Bureau has implemented local monitoring systems (in collaboration with local councils) to assist with flash flood warning.
- Warnings of minor, moderate or major flooding in areas where specialised warning systems have been installed. In these areas, the flood warning message will identify the river valley,

the locations expected to be flooded, the likely severity of the flooding and when it is likely to occur.

- Predictions of expected river height at a town or other important locations and the time that this height will be reached. This particular service is the most useful because it allows local emergency authorities and people in the flood threatened zone to determine the area and likely depth of flooding. This type of warning can only be provided for locations with specialised flood warning systems and for which flood forecasting models are available.

The specialised flood warning system on the Hunter River is described below. While a flash flood warning for the Denman catchment is considered unnecessary, a warning system for Muscle Creek is recommended to reduce risk to life from floodwaters that are capable of producing high hazard conditions between Bell Street and Wilder Street in the 1% AEP (100yr ARI) design storm.

Existing BoM Hunter River Flood Warnings

The Bureau of Meteorology (BoM) currently provides a formal flood warning service for the Hunter River and provides an estimate of peak flood levels. An example of a BoM flood warning for the Williams River (at tributary of the Hunter River) is presented in **Figure 7-1**.

Flood classifications in the form of locally defined flood levels are used in flood warnings to give an indication of the severity of flooding (minor, moderate or major) expected. These levels are used by the NSW State Emergency Service (SES) and the Bureau of Meteorology (BoM) in flood bulletins and flood warnings.

The BoM/SES classifies minor, moderate and major (as defined by BoM below) flooding at two gauges on the Hunter River (Muswellbrook and Denman) as detailed in **Table 7-1**. At the Muswellbrook gauge, BoM provides a 4 hour target warning lead time of 4 hours for a Minor flood event and a 12 hours warning lead time for a Major flood event. At Denman there is an 8 hour lead time for the Major flood event.

Table 7-1: Details of Relevant Flood Warning Gauges

Source: http://www.bom.gov.au/nsw/NSW_SLS_Current.pdf

Gauge Name (Location)	Station Number BoM (DPI)	Minor (m)	Moderate (m)	Major (m)	Gauge Zero (mAHD)
Muswellbrook (under Kayuga Road Bridge)	561005 (210002)	7.2*	8.0	10.0*	136.25
Denman (~50m d/s of Golden Highway Bridge)	561015 (210055)	6.5*	7.9*	9.0*	102.0

* Note this differs from that presented in the SES Flood Plan (2013)

Minor flooding: flooding which causes inconvenience such as closing of minor roads and the submergence of low-level bridges. The lower limit of this class of flooding, on the reference gauge, is the initial flood level at which landholders and/or townspeople begin to be affected in a significant manner that necessitates the issuing of a public flood warning by the BoM.

Moderate flooding: flooding which inundates low-lying areas, requiring removal of stock and/or evacuation of some houses. Main traffic routes may be flooded.

Major flooding: flooding which causes inundation of extensive rural areas, with properties, villages and towns isolated and/or appreciable urban areas flooded.

A comparison of the Major flood level classification to the flood model results (refer Section 4.1) indicates that a Major flood level would have a design magnitude (frequency) of between a 5yr ARI (20% AEP) and 10yr ARI (10% AEP) event at the Muswellbrook gauge. An examination of the floor level database indicates that no properties (on the Hunter River floodplain) are flooded (above floor level) from a Hunter River event below a 10yr ARI (10% AEP) event in the study area. This indicates that the existing BoM flood warnings for the Hunter River provide a suitable warning system for indication of above floor flooding.

Australian Government Bureau of Meteorology, New South Wales

Final Flood Warning for the Williams River

At Dungog

Issued at 1:55 pm EDT on Saturday 18 March 2017
Flood Warning Number: 3

Rainfall has eased since 11:00 am Saturday morning over the Williams river valley, however further rainfall is forecast for the next 24 hours.
The Williams River at Dungog is expected to peak below the minor flood level.
The situation is being closely monitored and warnings and predictions will be issued if necessary.

Williams River:
The Williams River at Dungog is approaching a peak below the minor flood level

Flood Safety Advice:
FloodSafe advice is available at www.ses.nsw.gov.au

For emergency assistance call the SES on telephone number 132 500.
For life threatening emergencies, call 000 immediately.

Next issue:
This is a final warning, no further warnings will be issued for this event.

Latest River Heights:
Williams River at Dungog, 3.77, Steady, 12:45 PM SAT 18/03/17
Williams River at Mill Dam Falls, 1.48, Rising, 01:00 PM SAT 18/03/17
Allyn River at Halton, 2.01, Rising, 01:00 PM SAT 18/03/17
Paterson River at Gostwyck Bridge, 1.65, Rising, 01:00 PM SAT 18/03/17

This advice is also available by dialling 1300 659 218. Warning, rainfall and river information are available at www.bom.gov.au/nsw/flood. The latest weather forecast is available at www.bom.gov.au/nsw/forecasts.

Figure 7-1: Example BoM Flood Warning for the Williams River

From http://weather.news.com.au/warning/?id=IDN36639

Recommended Development of Muscle Creek Flood Warning System

Development of a flood warning system for Muscle Creek is recommended to reduce risk to life from potentially hazardous flood conditions that are capable of washing people or vehicles into dangerous situations. A flood warning system would also assist in the management of road and bridge closures to ensure emergency access across Muscle Creek. Bell Street is currently overtopped in the 5% AEP (20yr ARI) and Bridge Street is inundated in the 20% AEP (5yr ARI). Advanced warning of road and bridge closures would assist in the pre-deployment of emergency services to the southern suburbs of Muswellbrook. Evacuation of properties on Clifford Street could be especially problematic as the street become a flow path once water crosses Bell Street.

Figure 7-2 shows the flood hazard profiles for the 0.2% AEP (500yr ARI) event, presenting the location of properties exposed to high flood hazards (i.e. V x D > 1 m^2/s). It is also noted that properties located between Bell Street and Wilder Street will be bound by high hazard flood waters that would restrict the safe evacuation of residents during the peak of the event.

Flood Hazard Profile 0.2% AEP Event

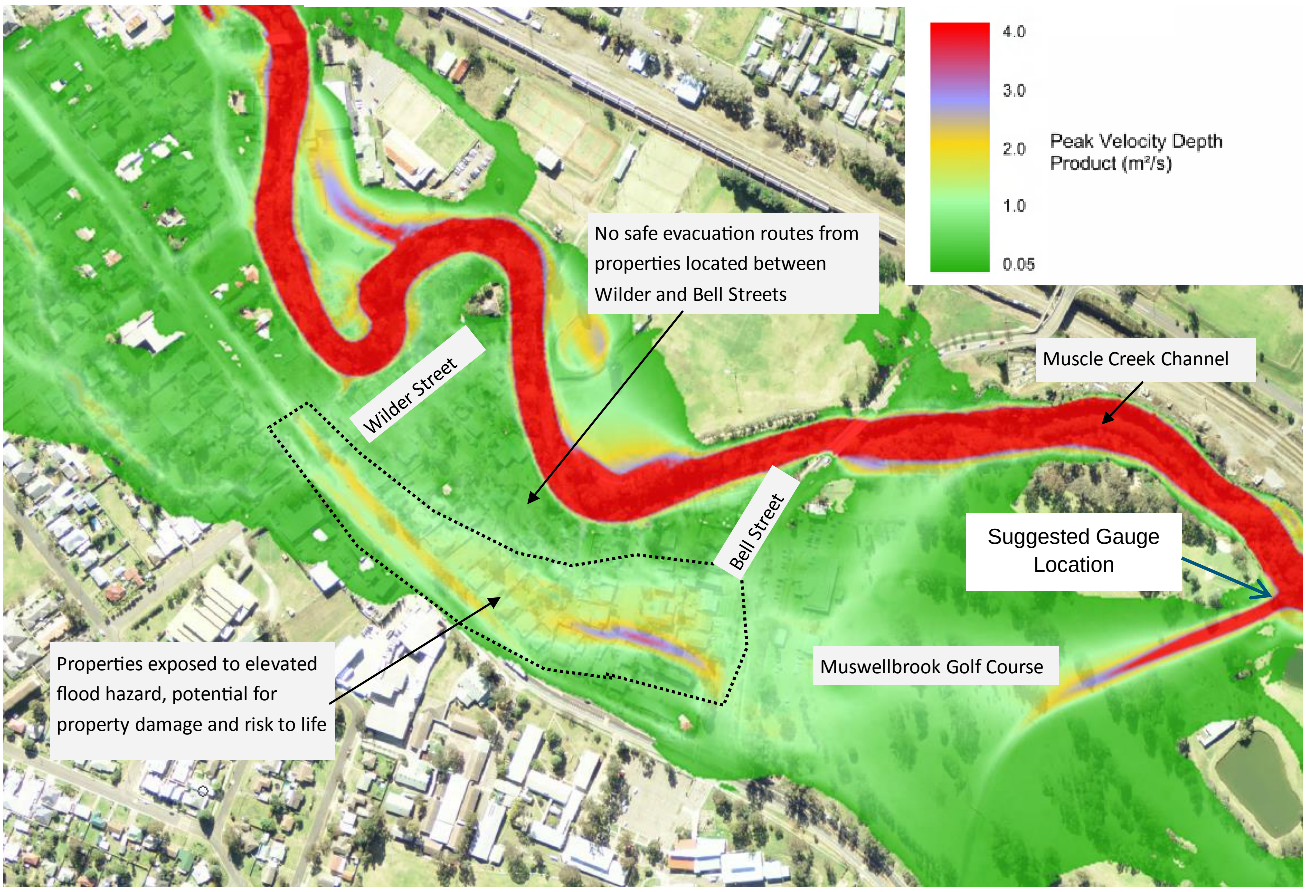

Figure 7-2: Flood Hazard Profile for the 0.2% AEP event

Figure 7-3 shows the flow distribution at Bell Street for the 0.2% AEP event. The chart compares flows through the Bell Street Bridge and Bell Street overflows to the total flow hydrograph. The model results indicate that 18 hours following the commencement of a 0.2% AEP event, flood conditions will be similar to peak 5% AEP conditions, with all flow passing under the Bell Street Bridge. Once overflows over Bell Street commence, peak 1% AEP conditions occur within 1 hour, and progressively increase for a further 2 hours before beginning to recede. This analysis indicates that without a flood warning system, emergency response services would have potentially less than an hour to safely evacuate residents located between Bell and Wilder Streets.

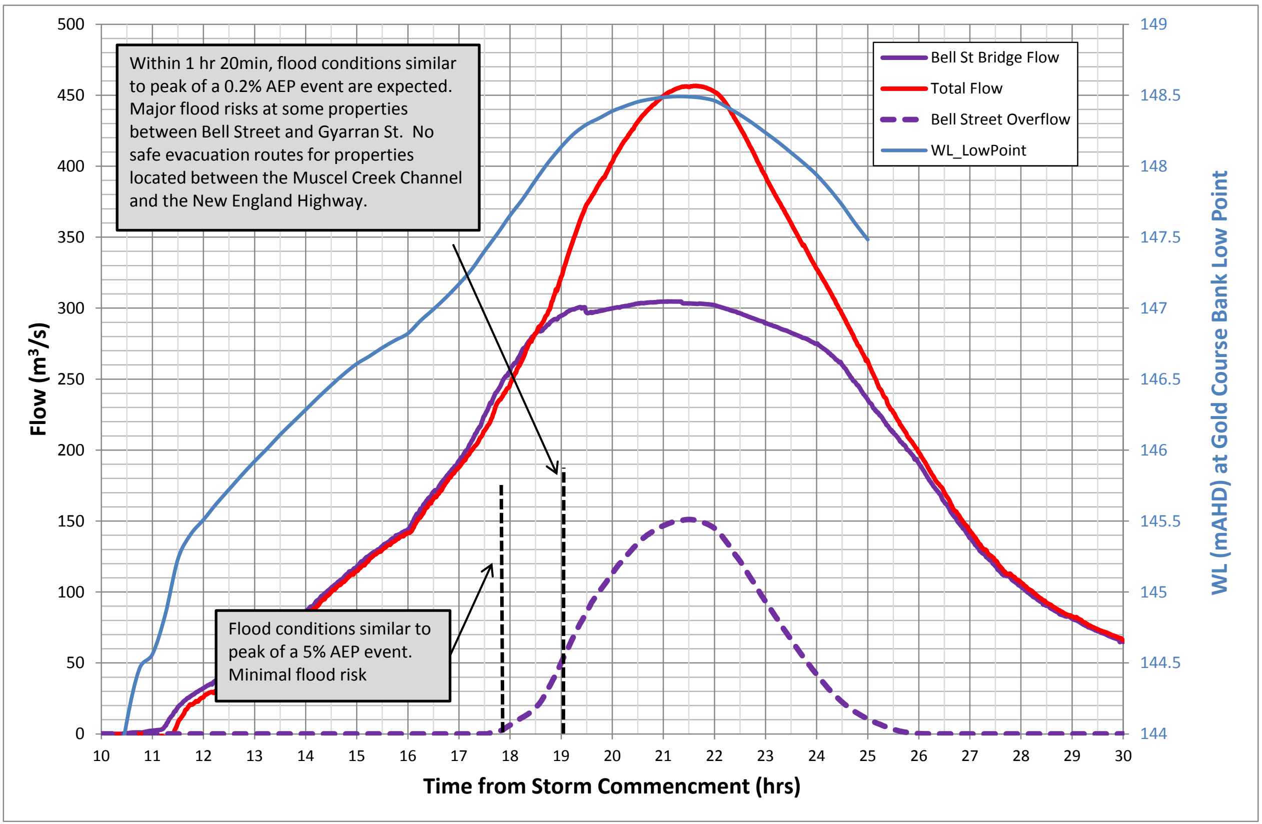

Figure 7-3: Flood Flow Distribution at Bell Street for the 0.2% AEP event

Options for Rainfall based Flood Warning System

The absence of an accurate, telemetered water level gauge in the Muscle Creek catchment means that unless a suitable water level gauge is installed, flood warnings would need to be based on observed or predicted rainfall.

BoM does not operate any flood warning rainfall gauges in the Muscle Creek though it appears there are a number of online private gauges available (www.wunderground.com/personal-weather-station). Warnings based on a specified rainfall depth in a given time could be defined to generate a number of warning levels. An example of this rainfall depth, warning type is presented in **Table 7-2.** It should be noted that the below table would need to be checked and refined prior to adoption. Due to the potential for high spatial variation in the catchment and the lack of BoM gauges, the installation of additional gauges or the use of synthetic gauges based on interrogation of rainfall radar data would be recommended. However, as described below, the development of a water level based warning system is recommended over a rainfall based system, so additional rainfall gauges are low priority, though would enhance the forecast accuracy and may increase available warning times of a flood level based system.

Table 7-2: Example of Rainfall Depth (mm) vs Warning Type for Muscle Creek Catchment

Rain Duration	Warning to Council and NSW SES	Warning for Evacuation	Immediate Evacuation
Short duration intense rain events (assumes wet catchment (i.e. >50mm in previous 24 hours))			
1 hour	40	50	60-70
2 hour	60	80	90-100
Longer duration events (warnings should consider likelihood of future rainfall (i.e. radar or meteye))			
9 hour	100	120	140-160
24 hour	150	200	250-300

Recommendations for Water Level based Flood Warning System

Due to the spatial variability in rainfall and influence of initial and continuing losses on flood levels, a water level based flood warning system is likely to be more reliable than one based on rainfall alone. A list of relevant feature elevations and suggested flood warning levels is presented in **Table 7-3**. It should be noted that these suggested levels are preliminary in nature and should be refined by a more detailed study prior to adoption. A water level gauge located adjacent to the low point in the golf course bank (drainage line) (see **Figure 7-2** for location) would be required to measure the flood/warning levels.

Table 7-3: Feature Elevations and Flood Level Warning Types

Feature	Level (mAHD)
Channel Invert near low bank	143.0
Bank Invert at Low Point	145.75
Warning to Council & SES	**146.0**
Alert to residents	**146.5**
Floodwater Spills onto Golf Course	146.7
Alert to residents – Evacuate now	**147.0**
Floodwater Spills across Bell Street	147.3
Overland flow path down Clifford St make evacuation hazardous	147.4
Above floor flooding of up to 17 properties (approx. 5% AEP event)	147.5
Above floor flooding of up to 38 properties (approx. 1% AEP event)	148.0
Above floor flooding of up to 71 properties (approx. 0.2% AEP event)	148.5
Above floor flooding of up to 168 properties (PMF/Extreme event)	150.6
Alert to Council and NSW SES – flood level has dropped below Bell St	**146.0**

Water level (i.e. rates of rise) for the 0.2% AEP (500yr ARI) design event is presented in **Figure 7-3** and shows how quickly emergency workers and residents would have to react to be able to safely evacuate the at risk area. From the figure we can see that there is less than 3 hours between water spilling onto the golf course and up to 17 properties being inundated above floor level.

Options for Advanced Hybrid Data / Model based Flood Warning System

An advanced hybrid flood warning system that integrates rainfall and water level data, rainfall radar and forecast rain could further increase available warning times and increase the accuracy of peak water level predictions. Such a system would use observed and forecast rainfall data to run flood models to predict future water levels. This type of system not only provides increased warning time and accuracy it also reduces the likelihood of false warnings being delivered. However, these systems are significantly more expensive to develop and maintain.

Communication

Effective communication of flood warnings is required to reduce the negative impacts of floods. Warning systems should be accurate, timely, reliable and be delivered through appropriate mechanisms. The advantages of a broad range of delivery mechanisms are presented in **Figure 7-4.** It is likely that a mixture of text messages (SMS), automated telephone messages (required for older residents), sirens, flashing lights and door knocking would be required. Prior community awareness of flood risk tends to make warning more effective. Due to the infrequent nature of flooding, it will be important to implement ongoing education programs to ensure residents are informed of flood.

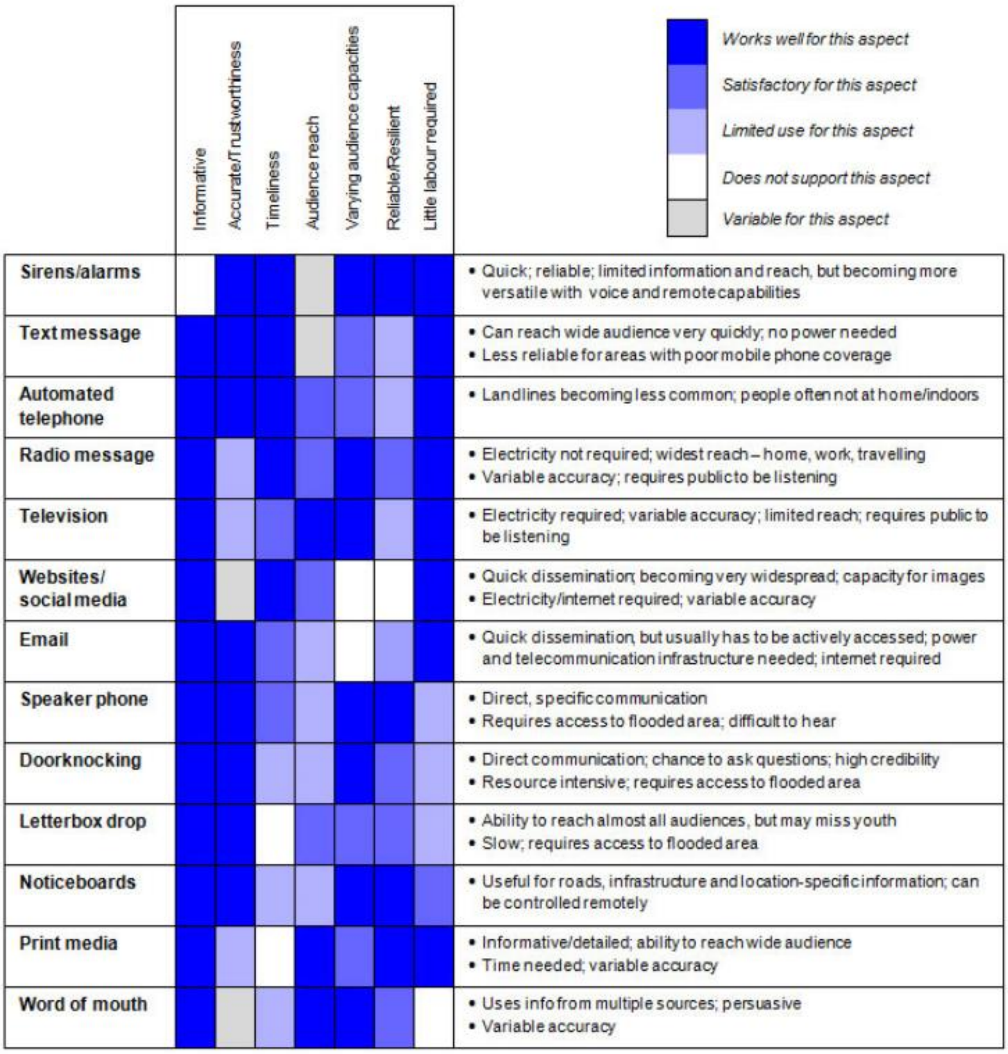

Figure 7-4: Pros and cons of different flood warning communication methods

From http://chiefscientist.qld.gov.au/publications/understanding-floods/flood-warnings (accessed 5th April 2017)

Outline of Costs for Flood Warning System Options

Approximate costs for various flood warning system configurations and options are outlined below.

A rainfall based option using rainfall gauges would be the cheapest option, though would require installation of a rain gauge in the catchment. The Australian Early Warning Network company (EWN) delivers a range of warning services to Councils and Commercial organisation throughout Australia. EWN provided the below pricing information for a rainfall based system in Muswellbrook, that would send SMS or phone messages to registered users. EWN operate a 24hr/7day a week staffed operations room and manually check all alerts before generating warnings.

- setup costs (i.e. user registration and implementation of triggers): $2000-4000
- Monthly monitoring cost $50/gauge
- $50 / event + costs of SMS / calls

An allowance for consultancy costs to undertake a desktop or model based assessment of trigger warnings (i.e. refine **Table 7-2**) of $5,000 to $15,000 should also be included. Given that two rainfall gauges would be monitored, an allowance of $1200/yr for monitoring costs would be required. Assuming 4 warnings are generated each year, with warnings distributed to 100 residents or emergency workers (@50c / txt or call), an allowance for $1600/yr is required.

Installation of an automated water level gauge is likely to cost $7,000[1] to $30,000[2]. EWN is able to provide water level based monitoring in addition to rainfall based systems so pricing would be as per above. A siren and/or strobe warning is likely to add $5,000 to $10,000 to such a system. A high powered, fully featured and tested, mass alert flood warning system for a large area could cost approximately $70,000[3].

Given the harsh operating conditions that flood warning systems are subjected to, there is usually a typical 30% failure rate of gauges and it is important to include a degree of redundancy in flood warning systems. This means it is advisable to either have dual gauges in the tailwater area or to deploy a water level gauge further up the catchment. A water level gauge higher in the catchment would increase available warning times; however, due to the branched catchment shape, two additional gauges would be desirable. The cost for each additional water level gauges is $7,000[1] to $15,000[2].

An advanced hybrid flood warning system that integrates rainfall and water level data, rainfall radar and/or forecast rain to drive a fast solving flood model would cost $80,000 to $100,000[4] to setup and commission. Annual software and licence costs are likely to be $10,000 to $20,000[4].

A summary of costs for the three options is provided in **Table 7-4**.

It is recommended that after a number of years (say 5) of operation, the system is reviewed and refined. An allowance of $10,000 - $15,000 is likely to be sufficient for an external consultant to undertake a full review.

Table 7-4: Summary of Approximate Costs for Flood Warning System Options

Item	Cost
Rainfall based system	
Supply of installation of rainfall gauge	$4,000- $6,000[5]
Consultancy costs to refine trigger warnings and assist system development	$5,000-$15,000
System setup (user registration and implementation of triggers)	$2,000-$4,000[6]
Monthly monitoring cost ($50/gauge)	$1200/year[6]
Cost to check and disseminate warnings ($50/event + SMS and calls costs) Assume 100 warnings delivered at 50c per call or SMS and 4 warnings per year.	$200/year[6]
Water Level based system using existing BoM gauges	
Consultancy cost to refine trigger warnings and assist system development	$5,000-$15,000
Supply of water level gauge (most system include a camera feature)	$7,000[1]- $30,000[2]
Additional water level gauge (most system include a camera feature)	$7,000[1]- $15,000[2]
optional siren and/or flashing lights (estimated)	$5,000- $10,000
Integrated mass warning system (Whelen WPS2903)	$70,000[3]
EWN system setup (user registration and implementation of triggers) may be included in some WL warning systems, this option could allow the use of both water level and rain based triggers	$2,000-$4,000[6]
Monthly monitoring cost ($50/gauge) single water level gauge only	$600/year[6]
Monthly monitoring cost ($50/gauge) water level only and 2 rain gauges	$1800/year[6]
Cost to check and disseminate warnings ($50/event + SMS and calls costs) Assume 100 warnings delivered at 50c per call or SMS and 4 warnings per year.	$200/year[6]
Advanced hybrid flood warning system (including flood model based forecasts)	
Development and commissioning of system	$120,000 - $170,000[4]
Annual software and licence costs are likely to be $10,000 to $50,000	$10,000 - $50,000[4]

Notes: 1) cost for dipstik system (low accuracy system with basic image output, though SMS is also available)

2) cost for Digilant system (radar based WL gauge with high functioning interface including software and SMS alerts)

3) proposed cost for Wallsend Flood Warning System using a Whelen WPS2903 based system (Prospect Environmental)

4) based on proposed cost for Parramatta CBD Flood Warning System using Lizard Portal interface and a cloud based 3Di flood model.

5) estimated

6) based discussions with EWN (The Australian Early Warning Network company)

Costs Benefit Considerations for Flood Warning Systems

The benefit of such a system is difficult to quantify. While the limited warning time is likely to allow for residents to raise some items (and therefore reducing flood damages), this cannot be relied upon to reduce damages. The main benefit of such a system is in intangibles including reduced fear in the community and also reduced likelihood of flood related loss of life.

Summary & Recommendation

Based on the information presented above, the implementation of flood warning systems is recommended for the Muscle Creek unless options MC1 or MC2 are implement in say a 5 year timeframe.

The higher degree of uncertainty associated with a solely rainfall based system is unlikely to fit in with expectations of a flood warning system. A water level based flood warning system would provide a higher degree of certainty in the warning and can be more easily related to the degree of flood risk (i.e. number of properties inundated) that exists in the area of interest. While a hybrid (model based) flood warning system may be able to produce more accurate estimates of peak water level and would provide an increase in the available warning time, given the relative ease of evacuation for properties in the area it may be difficult to justify the higher cost of such a system.

Based on the above, it is recommended that a water level based flood warning system is implemented in Muscle Creek to potentially protect against flood related tragedy. The initial cost for such a system could cost up to $55,000 (for a single water level gauge (including camera feed)), including low powered sirens or flashing light and $15,000 for consultancy, design and installation) and an annual allowance of $1600 for ongoing costs is required.

In order to increase available warning times, the addition of rainfall based triggers is recommended. The installation of one (preferably two) rainfall gauges is likely to cost $4000-$6000 and annual cost of the flood warning system would cost $1200/yr and allowance of up to $15,000 may be required to refine alert triggers. The use of predicted (i.e. forecast) rainfall products should also be considered to provide even greater flood warning times. These increased flood warning times would assist emergency services such as the SES coordinate resources during severe flood events. When developing the flood warning service, it is recommended that input from the new national Flash Flood Advisory Resource (FLARE) is sought. FLARE is an authoritative resource created to assist responsible agencies to design, implement and manage fit-for-purpose flash flood warning systems. FLARE is coordinated by the BoM and aims to help agencies, and through them the community, to increase their resilience to flash floods through better preparation and more effective response.

Royal HaskoningDHV

PART B – FLOODPLAIN RISK MANAGEMENT PLAN

8 Draft Hunter River (Muswellbrook to Denman) Floodplain Risk Management Plan

8.1 Introduction

The following section forms the draft Muswellbrook to Denman Floodplain Risk Management Plan (the FRM Plan) and provides a framework by which the plan will be implemented. The objective of this Plan is to recommend a range of property, response and flood modification measures to mitigate the existing and future flood affectation in the study area. This plan has been completed in accordance with the Floodplain Development Manual (NSW State Government, 2005).

8.2 Floodplain Risk Management Measures

The implementation program essentially forms the action list for this Plan and is shown in **Table 8-1**. The benefit of following this sequence is that gradual improvement of the floodplain occurs, as the funds become available for implementation of these options. Further steps in the floodplain management process include:

- Draft Plan to be exhibited for public comment
- Plan to be finalised incorporating public comments
- Floodplain Management Committee to consider and adopt recommendations of this Plan;
- Council to consider the Floodplain Management Committee's recommendations;
- Council to adopt the Plan and submit an application for funding assistance to OEH and other agencies as appropriate; and
- As funds become available from Council's own resources, OEH and/or other state government agencies, implement the measures in accordance with the established priorities.

Table 6-21, provides a summary and brief analysis of the all the Floodplain Risk Management options including further details of what each option entails. Full details of the options are provided in the Muswellbrook Floodplain Risk Management Study (i.e. Part A of this document (mostly in **Section 6.4**)).

The FRM Plan as detailed in **Table 8-1**, should be regarded as a dynamic instrument requiring review and modification over time. The catalyst for change could include new flood events and experiences, legislative change, alterations in the availability of funding or changes to the area's planning strategies. In any event, a thorough review every five years is warranted to ensure the ongoing relevance of the FRM Plan.

Table 8-1: Mitigation Measures Recommended for Implementation

Measure*	Description	Estimated Capital Costs and (Ongoing Costs)	Responsibility and Funding	Priority / Time frame
MC1[1] or **MC2**[1]	**Muscle Creek** Enhance creek bank adjacent to golf course Golf course flood bund	$840,000 $1,100,000	Council and OEH	**Medium - High** 2-5 years[1]
FW1[1]	Flood warning system for Muscle Creek	$50,000 to $100,000 ($5000/yr)	Council and OEH	**Medium - High** 2-3 years[1]
EM1	Emergency Management Planning (develop a Local Flood Plan)	SES and Council staff time of ~$10,000	SES	**High** <1 years
P3[3]	Consider VP and/or VHR for significant risk properties currently experience above floor flooding in the 5% AEP flood event	The VHR of 12 properties and VP of 6 properties is estimated to cost $2.40 Mil. Further analysis is recommended to identify which of the VHR/VP properties are in a high risk area and should be prioritised	VP – Council and OEH VHR - Property owner and OEH	**Low-Medium** <2 years
P4	Update the LEP	Council staff time of $5,000-10,000	Council	**High** <1 years
D1	Blockage / maintenance policy to unblock 2 Virginia St (Denman) culverts	$50,000 over 50 years	Council	**Medium - High** <1 years
EM2	Community Flood Education	Council / SES staff time ~$10,000	Council / SES.	**Medium** 2-5 years
HRS1	Muswellbrook Backwater Levee	$2.25 Million	Council and OEH	**Low** 2-10 years[2]
HRS2	Sydney Street Levee	$3.5 Million	Council and OEH	**Low** 2-10 years[2]

Notes: * details of the mitigation measures are provided in **Table 6-21** and **Section 6.4**

VP = Voluntary Purchase, VHR = Voluntary House Raising

1) If MC1 or MC2 are not implemented within a 2 to 5 year timeframe, a flood warning system is recommended to reduce risk to life from rapidly rising floodwaters that sweep through residential areas of Muswellbrook to the south of Muscle Creek and can isolate the southern side of town as frequently as the 5% AEP flood event.

2) Due to the high cost and low B/C ratio of these options they would require long term planning and it may be difficult to obtain funding from OEH until higher priority flood risks in NSW have been dealt with.

3) A desktop study into the prioritisation of all at risk properties suitable for VP or VHR should be conducted.

8.3 Funding, Implementation and Actions

8.3.1 Funding and Implementation

The timing of the implementation of recommended measures will depend on the available resources, overall budgetary commitments of Council and the availability of funds and support from other sources. It is envisaged that the FRM Plan would be implemented progressively over a 5 year time frame.

There are a variety of sources of potential funding that could be considered to implement the FRM Plan. These include:

- Council funds and staff resources;
- Section 94 contributions;
- State funding for flood risk management measures through the Office of Environment and Heritage; and
- State Emergency Service, either through volunteered time or funding assistance for emergency management measures.

State funds are available to implement measures that contribute to reducing existing flood problems. Funding assistance is likely to be available on a 2:1 (State:Council) basis. Although much of the FRM Plan may be eligible for Government assistance, funding cannot be guaranteed. Government funds are allocated on an annual basis to competing projects throughout the State. Measures that receive Government funding must be of significant benefit to the community. Funding is usually available for the investigation, design and construction of flood mitigation works included in the floodplain management plan.

9 References

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RHDHV (2016a) "Denman Levee System: Desk Study", 16 November 2016, Memo prepared for Muswellbrook Shire Council and the NSW Office of Environment & Heritage.

RHDHV (2016b) "Muswellbrook Levee System: Desk Study", 16 November 2016, Memo prepared for Muswellbrook Shire Council and the NSW Office of Environment & Heritage.

RHDHV (2017a) "Hunter River Flood Study (Muswellbrook to Denman) Model Revisions Report", 19 October 2017, Report prepared for Muswellbrook Shire Council and the NSW Office of Environment & Heritage

RHDHV (2017b) "Muscle Creek Flood Study", 30 January 2017, Report prepared for Muswellbrook Shire Council and the NSW Office of Environment & Heritage

RHDHV (2017c) "Denman Overland Flow Flood Study", 30 January 2017, Report prepared for Muswellbrook Shire Council and the NSW Office of Environment & Heritage

SMEC (2015a) "Possum Gully Catchment Stormwater Drainage Study – Options Assessment Report", Draft, June 2015, Prepared for Muswellbrook Shire Council.

SMEC (2015b) "Possum Gully Catchment Stormwater Drainage Study – Concept Design Report", November 2015, Prepared for Muswellbrook Shire Council.

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WMAwater (2013) "Aberdeen Flood Study"

Worley Parson (2014) "HUNTER RIVER FLOOD STUDY (MUSWELLBROOK TO DENMAN)" Rev C 8/9/2014, Report prepared for Muswellbrook Shire Council and the NSW Office of Environment & Heritage.

Appendix A – Muswellbrook FRMS - Compendium of Flood Maps

A separate A3 Compendium of Flood Maps is provided as a companion document to the Muswellbrook floodplain risk management study (FRMS) report. Further details of the studies used to produce inputs to the maps are provided in Section 4.1. Flood behaviour in study area was quantified for three different flood mechanisms (refer Section 2.1) during the project as reported in:

- Hunter River Flood Study (Muswellbrook to Denman) Model Revision Report (RHDHV, 2017a)
- Muscle Creek Flood Study (RHDHV, 2017b)
- Denman (Local Catchment) Overland Flow Study (RHDHV, 2017c).

Flood extents from each individual flood mechanism were combined to produce a single design flood extent which represents the magnitude of flooding for a given frequency (i.e. annual exceedance probability (AEP) or average recurrence interval (ARI)).

Each Figure contains a series of four maps including:

a) Hunter River Overview (Kyuga to Doyles Creek)
b) Muswellbrook – North
c) Muswellbrook - South
d) Denman

List of Figures:

Peak Flood Depths

Peak Flood Velocity

Provisional Flood Hazard & Hydraulic Categorisation

Appendix B – Mitigation Option Cost Calculations

Appendix B presents detailed cost estimations which been undertaken for the eight mitigation options listed below:

HRS1 - Backwater Levee Option – Section 6.4.1
HRS2 - Sydney Street Levee Option – Section 6.4.2
HRS3 - Channel Vegetation Removal – Section 6.4.3
MC1 - Enhance creek bank adjacent to golf course – Section 6.4.4
MC2 - Golf course flood bund – Section 6.4.5
MC3 - Channel vegetation management – Section 6.4.6
D1 - Blockage / maintenance policy to unblock 2 Virginia St (Denman) culverts – Section 6.4.7
D2 - Upgrade to Virginia St (Denman) culvert (north) - Section 6.4.8

These cost estimates are indicative and are based on our experience from a number of projects at a range of sites and conditions. This estimates are provided for broad guidance only and are NOT guaranteed by Royal HaskoningDHV as we have no control over contractor's prices, market forces and competitive bids from tenderers. Any construction cost estimates provided may exclude items which should be considered in a cost plan. Examples of such items are design fees, project management fees, authority approval fees, contractors risk, preliminaries and project contingencies (e.g. to account for construction and site conditions, weather conditions, ground conditions and unknown services). If a reliable cost estimate is required, an appropriately qualified Quantity Surveyor should be engaged and market feedback sought.

It should be noted that the cost estimates are suitable for the comparison and assessment of the mitigation options for the Muswellbrook Floodplain Risk Management Study.

Budget Cost Estimate

Haskoning Australia Pty Ltd

Date: 3-May-18

Client: Muswellbrook Shire Council

RHDHV Job No. PA1233

Project Name: Muswellbrook Floodplain Risk Management Study

OPTION HRS1 - Backwater Levee

Item #	Description	Rate (2018)	Unit	Qty	Total
1	**General**				
1.1	Site establishment	$ 20,000	item	1	$ 20,000
1.2	Supervision, management, amenities	$ 2,500	Weeks	12	$ 30,000
1.3	Survey, Service Location and setout of works by surveyor	$ 5,000	Days	3	$ 15,000
1.4	Geotechnical testing	$ 150	Tests	10	$ 1,500
1.5	Relocation and protection of Services	$ 50,000	item	1	$ 50,000
1.6	Traffic control	$ 10,000	item	1	$ 10,000
1.7	Preparation and implementation of Works EMP	$ 20,000	item	1	$ 20,000
				Subtotal	**$ 146,500**
2	**Clearing & Demoltion**				
2.1	Clear vegetation for levee alingment	$ 0.38	sqm	16,440	$ 6,247
2.2	Removal of Tree and grub up stumps	$ 161.00	no.	25	$ 4,025
2.3	Demolition and rebuilding of residential fences	$ 77.00	m	225	$ 17,325
2.4	Allowance for demolition of residential/farm sheds	$ 59.00	sqm	91	$ 5,369
				Subtotal	**$ 32,966**
3	**Topsoil, Mulch and Turf**				
3.1	Strip and Stockpile 150mm of topsoil from construction areas	$ 5.60	cum	2,466	$ 13,810
3.2	Replace 150mm topsoil on construction areas	$ 5.94	cum	2,528	$ 15,004
3.3	Turf to Embankment	$ 9.00	sqm	16,851	$ 151,659
3.4	Turf Maintenance	$ 1.09	sqm	16,851	$ 18,368
				Subtotal	**$ 198,840**
4	**Bulk Earthworks for Levee**				
4.1	Bulk Excavation to form cut-off trench (0.6m deep)	$ 50.40	cum	888	$ 44,743
4.2	Trim and compact subgrade	$ 2.43	sqm	16,440	$ 39,906
4.3	Allowance for removal and replcement of unsuitable subgrade with imported select fill as bridging layer (5% of trim area x 300mm)	$ 53.07	cum	247	$ 13,088
4.4	Geotextile Fabric	$ 6.89	sqm	16,440	$ 113,272
4.5	Imported fill for embankment and cut off trench	$ 25.00	cum	9,600	$ 240,000
4.6	Place and compact embankment material in 150mm layers (inc. cut off.)	$ 25.00	cum	9,600	$ 240,000
4.7	Trim Batters	$ 3.55	sqm	13,563	$ 48,149
				Subtotal	**$ 739,158**
5	**Sheetpile Wall**				
5.1	Sheetpilling along corner of Hunter Terrace and William St	$ 460.00	sqm	195	$ 89,700
				Subtotal	**$ 89,700**
6	**Concrete Works**				
6.1	RC Concrete Headwall foundation	$ 526.00	cu.m	2.0	$ 1,052
6.2	RC Concrete Headwall (200mm thick)	$ 456.00	sq.m	28.9	$ 13,178
6.3	Construct reinforced concrete wingwalls	$ 450.00	sqm.	2.8	$ 1,260
6.4	Construct reinforced concrete apron (300mm thick with 600mm downturn)	$ 330.00	cum.	2.0	$ 655
				Subtotal	**$ 16,146**
7	**Culverts Units (through levee)**				
7.1	Levee Culverts - Standard 3.6 x 3.6 Box Culvert Crown Units delivered to site	$ 9,010.00	item	2	$ 18,020
7.2	Levee Construction around Culvert	$ 32.70	cum	2,000	$ 65,400
7.3	Culvert flood gate	$ 1,000.00	item	1	$ 1,000
				Subtotal	**$ 84,420**
8	**Scour Protection**				
8.1	Geotextile Fabric	$ 6.89	sqm	112	$ 772
8.2	Allow for 800mm thick Rock Rip-Rap Armour	$ 159.00	sqm	112	$ 17,808
8.3	Allow for 400mm underlayer	$ 68.90	sqm	112	$ 7,717
				Subtotal	**$ 26,296**
				SUBTOTAL (excl. GST)	**$ 1,334,027**
				Muswellbrook Regional Factor	$ 120,062
				Engineering Design (4%)	$ 53,361.07
				Environmental Assessment and Approvals	$ 50,000
				Tender Preparation (0.6%)	$ 8,004
				Supervision and Contract Administration (2%)	$ 26,680.53
				Contingency (50%)	$ 667,013
				TOTAL (excl. GST)	**$ 2,259,148**
				Adopted TOTAL (excl. GST)	**$ 2,250,000**

Budget Cost Estimate

Haskoning Australia Pty Ltd

Date: 3-May-18

Client: Muswellbrook Shire Council | **RHDHV Job No.** PA1233

Project Name: Muswellbrook Floodplain Risk Management Study

OPTION HRS2 - Sydney Street Levee

Item #	Description	Rate (2018)	Unit	Qty	Total
1	**General**				
1.1	Site establishment	$ 20,000	item	1	$ 20,000
1.2	Supervision, management, amenities	$ 2,500	Weeks	12	$ 30,000
1.3	Survey, Service Location and setout of works by surveyor	$ 5,000	Days	3	$ 15,000
1.4	Geotechnical testing and certification of pavements	$ 150	Tests	10	$ 1,500
1.5	Relocation and protection of Services	$ 80,000	item	1	$ 80,000
1.6	Traffic control	$ 30,000	item	1	$ 30,000
1.7	Preparation and implementation of Works EMP	$ 20,000	item	1	$ 20,000
				Subtotal	**$ 196,500**
2	**Clearing & Demoltion**				
2.1	Clear vegetation for levee alingment	$ 0.38	sqm	15,600	$ 5,928
2.2	Removal of Tree and grub up stumps	$ 161.00	no.	32	$ 5,152
2.4	Demolition and rebuilding of residential fences	$ 77.00	m	686	$ 52,822
2.5	Allowance for demolition of residential/farm sheds	$ 59.00	sqm	1,118	$ 65,962
2.6	Sawcut Carpark Pavement	$ 10.00	m	175	$ 1,750
2.7	Break out Existing Pavement	$ 3.50	sqm	1,015	$ 3,553
				Subtotal	**$ 135,167**
3	**Topsoil, Mulch and Turf**				
3.1	Strip and Stockpile 150mm of topsoil from construction areas	$ 5.60	cum	2,340	$ 13,104
3.2	Replace 150mm topsoil on construction areas	$ 5.94	cum	2,399	$ 14,237
3.3	Turf to Embankment	$ 9.00	sqm	15,990	$ 143,910
3.4	Turf Maintenance	$ 1.09	sqm	15,990	$ 17,429
				Subtotal	**$ 188,681**
4	**Bulk Earthworks for Levee**				
4.1	Bulk Excavation to form cut- off trench (0.6m deep)	$ 50.40	cum	842	$ 42,457
4.2	Trim and compact subgrade	$ 2.43	sqm	15,600	$ 37,867
4.3	Allowance for removal and replcement of unsuitable subgrade with imported select fill as bridging layer (5% of trim area x 300mm)	$ 53.07	cum	234	$ 12,419
4.4	Geotextile Fabric	$ 6.89	sqm	15,600	$ 107,484
4.5	Imported fill for embankment and cut off trench	$ 25.00	cum	12,500	$ 312,500
4.6	Place and compact embankment material in 150mm layers (inc. cut off.)	$ 25.00	cum	12,500	$ 312,500
4.7	Trim Batters	$ 3.55	sqm	12,870	$ 45,689
				Subtotal	**$ 870,916**
5	**Sheetpile Wall**				
5.1	Sheetpilling near sydney sheet (eastern end of earth levee)	$ 460.00	sqm	315	$ 144,900
				Subtotal	**$ 144,900**
6	**Blockwork Levee Wall**				
6.1	Reinforced Concrete Footing Including Excavation (300mm thick)	$ 564	cum	466	$ 262,937
6.2	Blockwork Wall	$ 233	sqm	514	$ 119,762
				Subtotal	**$ 382,699**
7	**Temporary Flood Barriers/Gates**				
7.1	Floodgate footing with post inserts and 2x concrete end wall embedded in levee banks for Sydney St Gates	$ 18,500	item	2	$ 37,000
7.2	Portable Flood gates across Sydney St	$ 2,150	m	44	$ 94,600
7.3	Portable Floodstop barriers acros Lorne St and Francis St	$ 800	m	28	$ 22,400
7.4	Allowance for storage, transport and installation of temporary flood barriers/gates	$ 20,000	item	1	$ 20,000
				Subtotal	**$ 174,000**
8	**Relocate Driveay at 133 Sydney Street**				
8.1	Sawcut Driveway	$ 10.00	m	6	$ 60
8.2	Break out existing Driveway	$ 3.50	sqm	210	$ 735
8.3	Ecvate new alignment to reduced levels	$ 5.45	cum	75	$ 409
8.4	Cut to fill and level old alignment	$ 8.20	cum	75	$ 615
8.5	Trim and compact subgrade	$ 2.43	sqm	150	$ 365
8.6	30mm AC Concrete	$ 17.00	sqm	150	$ 2,549
8.7	7mm Primer Seal	$ 5.87	sqm	150	$ 881
8.8	150mm Basecourse	$ 15.45	sqm	150	$ 2,318
8.9	380mm Sub- base	$ 61.80	sqm	150	$ 9,270
8.10	Allowance to make smooth connection with existing road	$ 206.00	lin.m	25	$ 5,150
8.11	Upright Kerb and Gutter	$ 247.20	lin.m	14	$ 3,461
8.12	Construct new driveway entry	$ 125.00	lin.m	14	$ 1,750
				Subtotal	**$ 27,561**

SUBTOTAL (excl. GST)	**$ 2,120,424**
Muswellbrook Regional Factor	$ 190,838
Engineering Design (4%)	$ 84,816.94
Environmental Assessment and Approvals	$ 50,000
Tender Preparation (0.6%)	$ 12,723
Supervision and Contract Administration (2%)	$ 42,408.47
Contingency (50%)	$ 1,060,212
TOTAL (excl. GST)	**$ 3,561,421**
Adopted TOTAL (excl. GST)	**$ 3,500,000**

Budget Cost Estimate

Haskoning Australia Pty Ltd

Date: 3-May-18

Client: Muswellbrook Shire Council **RHDHV Job No.** PA1233

Project Name: Muswellbrook Floodplain Risk Management Study

Option HRS3 - Hunter River Vegetation Management

Item #	Description	Rate	Unit	Qty	Total
1	**General**				
1.1	Site establishment	$ 20,000	item	5	$ 100,000
1.2	Supervision, management, amenities	$ 2,500	Weeks	52	$ 130,000
1.3	Survey, Service Location and setout of works	$ 5,000	Days	20	$ 100,000
1.4	Protection of Services	$ 20,000	item	1	$ 20,000
1.5	Relocation and protection of Fauna	$ 300,000	item	1	$ 300,000
1.6	Traffic control	$ 40,000	item	1	$ 40,000
1.7	Preparation and implementation of Works EMP	$ 100,000	item	1	$ 100,000
				Subtotal	**$ 790,000**
2	**Clearing**				
2.1	Mechanical clearing of bank vegetation, grub roots, burn on site	$ 1.00	sqm	208,000	$ 208,000
2.2	Manual Clearing of bank vegetation, grub roots, burn on site	$ 1.50	sqm	39,000	$ 58,500
2.3	Remove noxious weeds	$ 10.00	sqm	13,000	$ 130,000
2.4	Tree removal, grub roots, cart away	$ 165.00	no.	400	$ 66,000
2.5	Cartage of ashes off site	$ 11.40	cum	7,657	$ 87,290
2.6	Disposal of ashes	$ 50.00	tonne	4,977	$ 248,853
				Subtotal	**$ 798,642**
3	**Bank Stabilisation with Less Dense Vegetation**				
3.1	150mm topsoil on bank areas	$ 5.94	cum	39,000	$ 231,504
3.2	Jute Mat	$ 1.10	sqm	260,000	$ 286,000
3.3	Planting	$ 15.00	sqm	130,000	$ 1,950,000
				Subtotal	**$ 2,467,504**
4	**Ongoing Maintenance of Channel Vegetation**				
4.1	Remove noxious weeds	$ 26,000	years	25	$ 452,742
4.2	Mechanical clearing of bank vegetation, grub roots, burn on site	$ 13,000	years	10	$ 110,893
				Subtotal	**$ 563,634**
				SUBTOTAL (excl. GST)	**$ 4,619,781**
				Muswellbrook Regional Factor	$ 415,780
				Landscape Design	$ 100,000
				Environmental Assessment and Approvals	$ 300,000
				Tender Preparation (0.6%)	$ 27,719
				Supervision and Contract Administration (2%)	$ 92,395.62
				Contingency (50%)	$ 2,309,890
				TOTAL (excl. GST)	**$ 7,865,566**
				Adopted TOTAL (excl. GST)	**$ 8,000,000**

Royal HaskoningDHV
Enhancing Society Together

Budget Cost Estimate

Haskoning Australia Pty Ltd

Date: 3-May-18

Client: Muswellbrook Shire Council **RHDHV Job No.** PA1233

Project Name: Muswellbrook Floodplain Risk Management Study

OPTION MC1 - Enhance Creek Bank at Golf Course

Item #	Description	Rate (2018)	Unit	Qty	Total
1	**General**				
1.1	Site establishment	$ 15,000.00	item	1	$ 15,000
1.2	Supervision, management, amenities	$ 2,500.00	Weeks	5	$ 12,500
1.3	Survey, Service Location and setout of works by surveyor	$ 5,000.00	Days	1	$ 5,000
1.4	Geotechnical testing	$ 150.00	Tests	10	$ 1,500
1.5	Preparation and implementation of Works EMP	$ 10,000.00	item	1	$ 10,000
				Subtotal	**$ 44,000**
2	**Clearing & Demoltion**				
2.1	Clear vegetation for levee alingment	$ 0.38	sqm	5,004	$ 1,902
2.2	Removal of Tree and grub up stumps	$ 161.00	no.	4	$ 644
2.3	Sawcut existing pathway near club house	$ 10.00	m	6	$ 60
2.4	Demolish existing path	$ 30.00	sqm	45	$ 1,350
				Subtotal	**$ 3,956**
3	**Topsoil, Mulch and Turf**				
3.1	Strip and Stockpile 150mm of topsoil from construction areas	$ 5.60	cum	751	$ 4,203
3.2	Replace 150mm topsoil on construction areas	$ 5.94	cum	767	$ 4,552
3.3	Turf to Embankment	$ 9.00	sqm	5,112	$ 46,012
3.4	Turf Maintenance	$ 1.09	sqm	5,112	$ 5,573
				Subtotal	**$ 60,340**
4	**Bulk Earthworks for Levee**				
4.1	Bulk Excavation to form cut-off trench (0.6m deep)	$ 50.40	cum	450	$ 22,698
4.2	Trim and compact subgrade	$ 2.43	sqm	5,004	$ 12,147
4.3	Allowance for removal and replcement of unsuitable subgrade with imported select fill as bridging layer (5% of trim area x 300mm)	$ 53.07	cum	75	$ 3,984
4.4	Geotextile Fabric	$ 6.89	sqm	5,004	$ 34,478
4.5	Imported fill for embankment and cut off trench	$ 25.00	cum	2,000	$ 50,000
4.6	Place and compact embankment material in 150mm layers (inc. cut off.)	$ 25.00	cum	2,000	$ 50,000
4.7	Trim Batters	$ 3.55	sqm	3,444	$ 12,228
				Subtotal	**$ 185,534**
5	**Concrete Works**				
5.1	Rebuild 3000mm wide pathway (150mm thick)	$ 180.00	m	15	$ 2,700
				Subtotal	**$ 2,700**

SUBTOTAL (excl. GST)	**$ 296,529**
Muswellbrook Regional Factor	$ 26,688
Engineering Design (4%)	$ 11,861.17
Environmental Assessment and Approvals	$ 50,000
Tender Preparation (0.6%)	$ 1,779
Supervision and Contract Administration (2%)	$ 5,930.58
Contingency (50%)	$ 148,265
TOTAL excluding Railway Levee (excl. GST)	**$ 541,052**
Allowance for Railway Levee (excl. GST)	**$ 300,000**
TOTAL including Railway Levee (excl. GST)	**$ 841,052**
Adopted TOTAL (excl. GST)	**$ 840,000**

Budget Cost Estimate

Haskoning Australia Pty Ltd

Date: 3-May-18

Client: Muswellbrook Shire Council — **RHDHV Job No.** PA1233

Project Name: Muswellbrook Floodplain Risk Management Study

OPTION MC2 - Golf Course Flood Bund

Item #	Description	Rate (2018)	Unit	Qty	Total
1	**General**				
1.1	Site establishment	$ 15,000.00	item	1	$ 15,000
1.2	Supervision, management, amenities	$ 2,500.00	Weeks	5	$ 12,500
1.3	Survey, Service Location and setout of works by surveyor	$ 5,000.00	Days	1	$ 5,000
1.4	Geotechnical testing	$ 150.00	Tests	10	$ 1,500
1.5	Preparation and implementation of Works EMP	$ 10,000.00	item	1	$ 10,000
				Subtotal	**$ 44,000**
2	**Clearing & Demoltion**				
2.1	Clear vegetation for levee alignment	$ 0.38	sqm	5,540	$ 2,105
2.2	Removal of Tree and grub up stumps	$ 161.00	no.	15	$ 2,415
				Subtotal	**$ 4,520**
3	**Topsoil, Mulch and Turf**				
3.1	Strip and Stockpile 150mm of topsoil from construction areas	$ 5.60	cum	831	$ 4,654
3.2	Replace 150mm topsoil on construction areas	$ 5.94	cum	852	$ 5,056
3.3	Turf to Embankment	$ 9.00	sqm	5,679	$ 51,107
3.4	Turf Maintenance	$ 1.09	sqm	5,679	$ 6,190
				Subtotal	**$ 67,006**
4	**Bulk Earthworks for Levee**				
4.1	Bulk Excavation to form cut- off trench (0.6m deep)	$ 50.40	cum	299	$ 15,078
4.2	Trim and compact subgrade	$ 2.43	sqm	5,540	$ 13,448
4.3	Allowance for removal and replcement of unsuitable subgrade with imported select fill as bridging layer (5% of trim area x 300mm)	$ 53.07	cum	83	$ 4,410
4.4	Geotextile Fabric	$ 6.89	sqm	5,540	$ 38,171
4.5	Imported fill for embankment and cut off trench	$ 25.00	cum	5,000	$ 125,000
4.6	Place and compact embankment material in 150mm layers (inc. cut off.)	$ 25.00	cum	5,000	$ 125,000
4.7	Trim Batters	$ 3.55	sqm	4,571	$ 16,225
				Subtotal	**$ 337,332**

SUBTOTAL (excl. GST)	**$ 452,858**
Muswellbrook Regional Factor	$ 40,757
Engineering Design (4%)	$ 18,114.31
Environmental Assessment and Approvals	$ 50,000
Tender Preparation (0.6%)	$ 2,717
Supervision and Contract Administration (2%)	$ 9,057.16
Contingency (50%)	$ 226,429
TOTAL excluding Railway Levee (excl. GST)	**$ 799,933**
Allowance for Railway Levee (excl. GST)	**$ 300,000**
TOTAL including Railway Levee (excl. GST)	**$ 1,099,933**
Adopted TOTAL (excl. GST)	**$ 1,100,000**

Budget Cost Estimate

Haskoning Australia Pty Ltd

Date: 3-May-18

Client: Muswellbrook Shire Council

RHDHV Job No. PA1233

Project Name: Muswellbrook Floodplain Risk Management Study

Option MC3 - Muscle Creek Vegetation Management

Item #	Description	Rate	Unit	Qty	Total
1	**General**				
1.1	Site establishment	$ 20,000	item	1	$ 20,000
1.2	Supervision, management, amenities	$ 2,500	Weeks	20	$ 50,000
1.3	Survey, Service Location and setout of works by surveyor	$ 5,000	Days	5	$ 25,000
1.4	Relocation and protection of Services	$ 20,000	item	1	$ 20,000
1.5	Relocation and protection of Fauna	$ 20,000	item	1	$ 20,000
1.6	Traffic control	$ 10,000	item	1	$ 10,000
1.7	Preparation and implementation of Works EMP	$ 20,000	item	1	$ 20,000
				Subtotal	**$ 165,000**
2	**Clearing**				
2.1	Mechanical clearing of bank vegetation, grub roots, burn on site	$ 1.00	sqm	80,000	$ 80,000
2.2	Manual Clearing of bank vegetation, grub roots, burn on site	$ 1.50	sqm	15,000	$ 22,500
2.3	Remove noxious weeds and cart away	$ 10.00	sqm	5,000	$ 50,000
2.4	Tree removal, grub roots, cart away	$ 165.00	no.	500	$ 82,500
2.5	Cartage of ashes off site	$ 2.85	cum	2,945	$ 8,393
2.6	Disposal of ashes	$ 50.00	tonne	1,914	$ 95,713
				Subtotal	**$ 339,106**
3	**Bank Stabilisation with Less Dense Vegetation**				
3.1	150mm topsoil on bank areas	$ 5.94	cum	5,000	$ 29,680
3.2	Jute Mat	$ 1.10	sqm	50,000	$ 55,000
3.3	Planting	$ 15.00	sqm	5,000	$ 75,000
				Subtotal	**$ 159,680**
4	**Ongoing Maintenance of Channel Vegetation**				
4.1	Remove noxious weeds	$ 10,000	year	25	$ 174,131
4.2	Mechanical clearing of bank vegetation, grub roots, burn on site	$ 15,000	year	10	$ 127,953
				Subtotal	**$ 302,085**

SUBTOTAL (excl. GST)	**$ 663,786**
Muswellbrook Regional Factor	$ 59,741
Landscape Design	$ 25,000
Environmental Assessment and Approvals	$ 25,000
Tender Preparation (0.6%)	$ 3,983
Supervision and Contract Administration (2%)	$ 13,275.72
Contingency (50%)	$ 331,893
TOTAL (excl. GST)	**$ 1,122,678**
TOTAL (excl. GST) Including Maintenance	**$ 1,424,762**
Adopted TOTAL (excl. GST)	**$ 1,400,000**

Budget Cost Estimate

Haskoning Australia Pty Ltd

Date: 3-May-18

Client: Muswellbrook Shire Council **RHDHV Job No.** PA1233

Project Name: Muswellbrook Floodplain Risk Management Study

OPTION D1 - Virginia St Culvert Blockage Maintenance

Item #	Description	Rate	Unit	Qty	Total
1	**Blockage Maintenance**				
1.1	Culvert cleaning & maitenance	$ 2,500	year	50	$ 47,922
				SUBTOTAL (excl. GST)	**$ 47,922**
				Tender Preparation (0.6%)	$ 288
				Superv ision and Contract Administration (2%)	$ 958.44
				Contingency (0%)	$ -
				TOTAL (excl. GST)	**$ 49,168**
				Adopted TOTAL (excl. GST)	**$ 50,000**

Value represents present v alue of $2500 payment per year at 5% inflation for 50year

Budget Cost Estimate

Haskoning Australia Pty Ltd

Date: 3-May-18

Client: Muswellbrook Shire Council

RHDHV Job No. PA1233

Project Name: Muswellbrook Floodplain Risk Management Study

OPTION D2 - Virginia St Culvert Upgrade

Item #	Description	Rate (2018)	Unit	Qty	Total
1	**General**				
1.1	Site establishment	$ 10,000	item	1	$ 10,000
1.2	Supervision, management, amenities	$ 2,500	Weeks	4	$ 10,000
1.3	Survey, Service Location and setout of works by surveyor	$ 5,000	Days	1	$ 5,000
1.4	Geotechnical testing and certification of pavements	$ 20	Tests	5	$ 100
1.5	Relocation and protection of Services	$ 10,000	item	1	$ 10,000
1.6	Traffic control	$ 10,000	item	1	$ 10,000
1.7	Preparation and implementation of Works EMP	$ 10,000	item	1	$ 10,000
				Subtotal	**$ 55,100**
2	**Clearing & Demoltion**				
2.1	Clear vegetation	$ 0.38	sqm	200.0	$ 76
2.2	Removal of Tree and grub up stumps	$ 25.00	no.	3.0	$ 75
2.3	Sawcut existing roadway & kerb	$ 10.00	m	24.0	$ 240
2.4	Break up and remove bitumen	$ 3.50	sqm	120.0	$ 420
2.5	Sawcut existing footpath	$ 10.00	m	3.0	$ 30
2.6	Demolish and remove existing foot path (inc. handrail)	$ 30.00	sqm	15.0	$ 450
2.7	Excvate around culverts	$ 5.45	cum	45.0	$ 245
2.8	Remove existing culvert cells	$ 2,500.00	Item	1.0	$ 2,500
2.9	Demolish existing headwalls and wingwalls	$ 5,000.00	Item	1.0	$ 5,000
				Subtotal	**$ 9,036**
3	**Topsoil, Mulch and Turf**				
3.1	Strip and Stockpile 150mm of topsoil from construction areas	$ 5.60	cum	30.0	$ 168
3.2	Replace and compact 150mm topsoil on construction areas	$ 5.94	cum	12.6	$ 75
3.3	Replace Turf	$ 9.00	sqm	84.0	$ 756
				Subtotal	**$ 999**
4	**Bulk Earthworks**				
4.1	Excvate trench to reduced levels and backfill	$ 5.45	cum	240.0	$ 1,308
4.2	Trench Shoring	$ 30.60	sqm	80.0	$ 2,448
4.3	Trim and compact subgrade	$ 2.43	sqm	200.0	$ 485
4.4	Allowance for removal and replcement of unsuitable subgrade with imported select fill as bridging layer (5% of trim area x 300mm)	$ 53.07	cum	3.0	$ 159
4.5	Place and compact bedding layer (150mm thk)	$ 55.00	cum	30.0	$ 1,650
4.6	Backfill sides of culvert	$ 8.20	cum	160.0	$ 1,312
				Subtotal	**$ 7,363**
5	**Culverts Units**				
5.1	Precast Box Culverts - Standard 1.2 x 1.2 Box Culvert Crown Units delivered to site	$ 1,000.00	m	100.0	$ 100,000
				Subtotal	**$ 100,000**
6	**Concrete Works**				
6.1	RC Concrete Headwall foundation	$ 526.00	cu.m	3.0	$ 1,578
6.2	RC Concrete Headwall (200mm thick)	$ 456.00	sq.m	10.0	$ 4,560
6.3	Construct reinforced concrete wingwalls (200mm thick)	$ 450.00	sqm.	2.4	$ 1,080
6.4	Construct reinforced concrete apron (300mm thick with 600mm downturn)	$ 330.00	cum.	14.2	$ 4,673
6.5	Upright Kerb and Gutter	$ 247.20	lin.m	20.0	$ 4,944
6.6	1500mm wide reinforced concrete footpath	$ 89.50	lin.m	10.0	$ 895
				Subtotal	**$ 17,730**
7	**Scour Protection**				
7.1	Geotextile Fabric	$ 6.89	sqm	100	$ 689
7.2	Allow for 800mm thick Rock Rip-Rap Armour	$ 159.00	sqm	100	$ 15,900
7.3	Allow for 400mm underlayer	$ 68.90	sqm	100	$ 6,890
				Subtotal	**$ 23,479**
8	**Roadworks**				
8.1	30mm AC Concrete	$ 17.00	sqm	120	$ 2,039
8.2	7mm Primer Seal	$ 5.87	sqm	120	$ 705
8.3	150mm Basecourse	$ 15.45	sqm	120	$ 1,854
8.4	380mm Sub-base	$ 61.80	sqm	120	$ 7,416
8.5	Allowance to make smooth connection with existing road	$ 206.00	lin.m	120	$ 24,720
				Subtotal	**$ 36,734**
9	**Ancillary Items**				
9.1	Replace Steel Handrails	$ 220.00	m	8	$ 1,760
				Subtotal	**$ 1,760**

SUBTOTAL (excl. GST)	**$ 252,200**
Muswellbrook Regional Factor	$ 22,698
Engineering Design (4%)	$ 10,088.02
Environmental Assessment and Approvals	$ 15,000
Tender Preparation (0.6%)	$ 1,513
Supervision and Contract Administration (2%)	$ 5,044.01
Contingency (50%)	$ 126,100
TOTAL (excl. GST)	**$ 432,644**
Adopted TOTAL (excl. GST)	**$ 430,000**