Muscle Creek Flood Study

For: Muswellbrook Shire Council

January 2017

PROJECT INFORMATION

Project Name:	Muscle Creek Flood Study
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PREPARATION, REVIEW AND AUTHORISATION

Revision #	Date	Prepared by	Reviewed by	Approved for Issue by
A	30/1/2017	Chris Kuczera	Ben Patterson	Ben Patterson

COMPANY DETAILS

Royal HaskoningDHV

Level 3, 2 Market Street

Newcastle, NSW, 2300

Tel. 4926 9500

www.royalhaskoningdhv.com

ABN 66 153 656 252

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ABBREVIATIONS

AHD	*Australian Height Datum*
AEP	*Annual Exceedance Probability*
AR&R	*Australian Rainfall and Runoff (1987)*
DEM	*Digital Elevation Model*
FRMS	*Flood Risk Management Study*
GSDM	*Generalised Short Duration Method*
GTSMR	*Generalised Tropical Storm Method Revised*
IEAust	*Institution of Engineers Australia*
IFD	*Intensity Frequency Distribution*
LiDAR	*Light Detection and Ranging*
PMF	*Probable Maximum Flood*
PMP	*Probable Maximum Precipitation*
RHDHV	*Royal HaskoningDHV*
TUFLOW	*A hydraulic model that is used to simulate flood events.*
XP-RAFTS	*A hydrologic model that is used to estimate runoff hydrographs.*
1D	*One-dimensional*
2D	*Two-dimensional*

1 INTRODUCTION

Royal HaskoningDHV (RHDHV) was engaged by Muswellbrook Shire Council (Council) to prepare a flood study of the lower Muscle Creek Floodplain. The study is being undertaken as part of the Hunter River (Muswellbrook to Denman) Flood Risk Management Study (FRMS) that is also being prepared by RHDHV.

The key objective of the study is to assess flooding within the Township of Muswellbrook that occurs due to runoff from the Muscle Creek Catchment. The results and key recommendations from this study will be assessed in conjunction with Hunter River flood model results as part of the FRMS.

This report documents the Muscle Creek Flood Study and is structured as follows:

- **Section 2** describes the existing catchment and floodplain features and reviews a similar study that was undertaken in 2009 by Umwelt.
- **Section 3** establishes the study objectives.
- **Section 4** describes the modelling approach and assumptions.
- **Section 5** presents model results and discusses areas of identified flood risk and potential mitigation measures that could be assessed further as part of the FRMS.

As noted above, the model results from the study will be incorporated into the FRMS.

2 REVIEW OF BACKGROUND INFORMATION

This section provides a description of the Muscle Creek Catchment and Floodplain and reviews a similar study that was completed by Umwelt in 2009. A summary of anecdotal information from the June 2007 flood event is also provided.

2.1 Catchment and Floodplain Description

Muscle Creek is a major tributary to the Hunter River. It has a catchment area of approximately 92 km^2 that extends 14 km to the south-east of the Township of Muswellbrook. 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. There are no major dams within the catchment.

Muscle Creek flows centrally through the township of Muswellbrook before joining the Hunter River. The Muscle Creek channel is approximately 50m wide (top of bank to top of bank) and 6 to 7 m deep. The channel banks are vegetated with moderately dense to dense vegetation, comprising a mixture of native and exotic species. **Photos 1** and **2** show typical sections of the Muscle Creek Channel. There are three bridge crossings within the study area located on Bell Street, Wilkinson Avenue and Bridge Street. These bridges are shown in **Photos 3** to **5** respectively. Council has recently completed rehabilitation works on the channel area downstream of the Wilkinson Avenue Bridge. **Photo 6** shows the upstream portion of the recently rehabilitated area.

During flood events, inundation is known to occur within the Muswellbrook Golf Course, which is located upstream of Bell Street. Flood waters from the golf course area are known to overtop Bell Street and flow through residential areas located between Bell Street and Wilder Street before re-entering the channel. Surface levels suggest that some flood waters will also flow down the New England Highway. If a Muscle Creek flood event occurs in conjunction with a Hunter River flood event, widespread flooding is expected to occur in the area downstream of Bell Street. This would be primarily associated with backwater flooding from the Hunter River.

Plate 2-1 locates the above-mentioned floodplain features. **Plate 2-1** also includes a floodplain cross-section along the Bell Street alignment. This section shows that the Bell Street Bridge soffit levels are approximately 800mm higher than the Bell Street road levels near the New England Highway Intersection. Accordingly, flows in excess of the channel capacity at the bridge location are expected to overflow Bell Street at the low point indicated on the section, which is approximately 200m to the south of the channel.

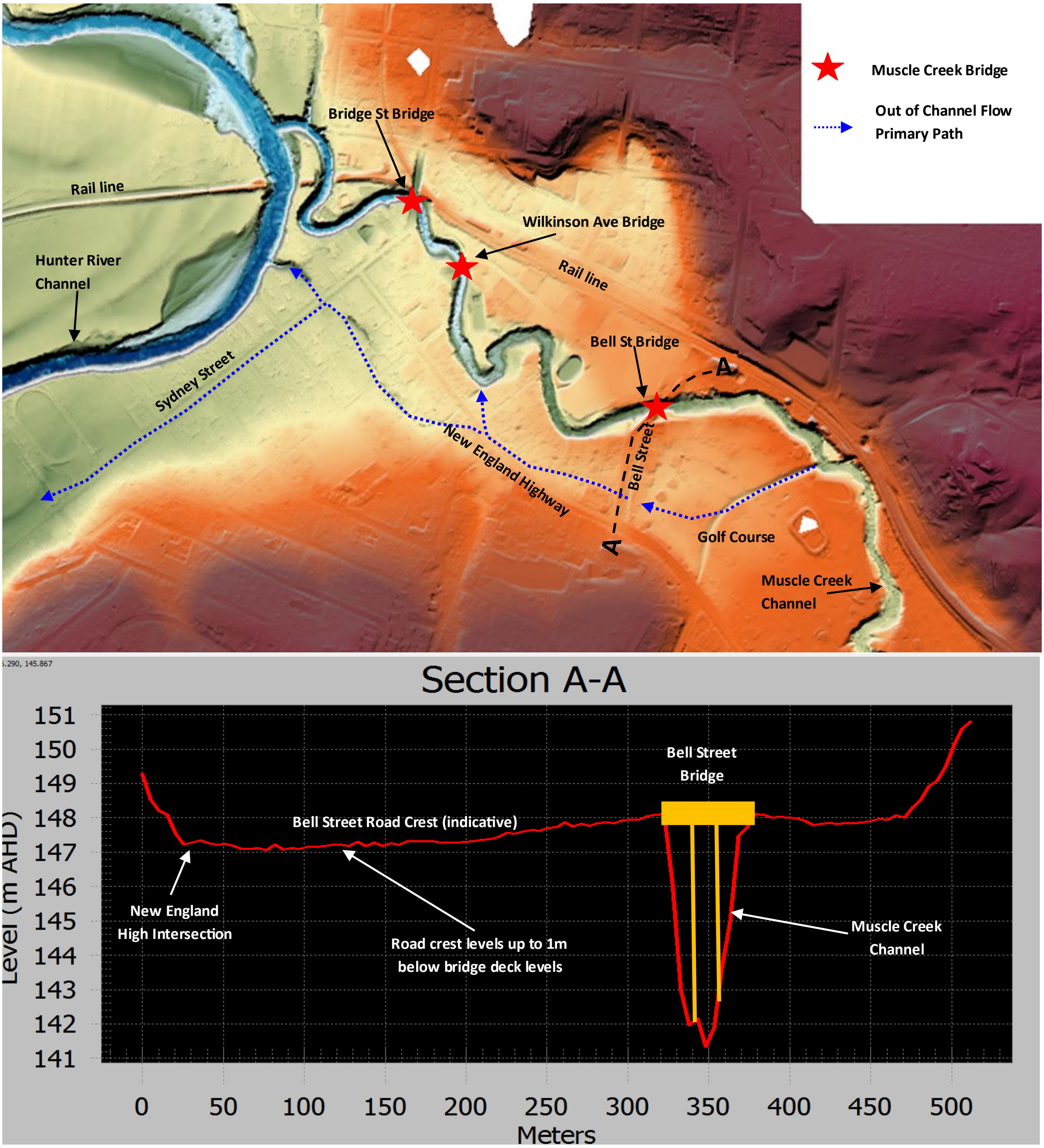

***Plate 2-1**– Floodplain Features*

Photo 1 *shows a typical section of the Muscle Creek Channel that comprises dense vegetation on the channel banks*.

Photo 2 *shows a typical section of the Muscle Creek Channel that comprises moderately dense vegetation on the channel banks.*

Photo 3 *shows the Bell Street Bridge (looking upstream)*

Photo 4 *shows the Wilkinson Avenue Bridge (looking upstream)*

Photo 5 *shows the Bridge Street Bridge (looking downstream)*

Photo 6 *shows the rehabilitated section of channel that is located between the Wilkinson Avenue and the Bridge Street Bridges.*

2.3 Previous Studies

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 this current study.
- The hydrologic and hydraulic were applied to assess the June 2007 and 1% AEP design events.

The study also assessed the following potential mitigation measures:

1) Widening 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.

2.4 June 2007 Event

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). Anecdotal observations from the June 2007 event are documented in Table 2 of the Umwelt report (2009). This table is reproduced as **Appendix B**. **Plate 2-2** shows the estimated June 2007 flood extent (Umwelt, 2009).

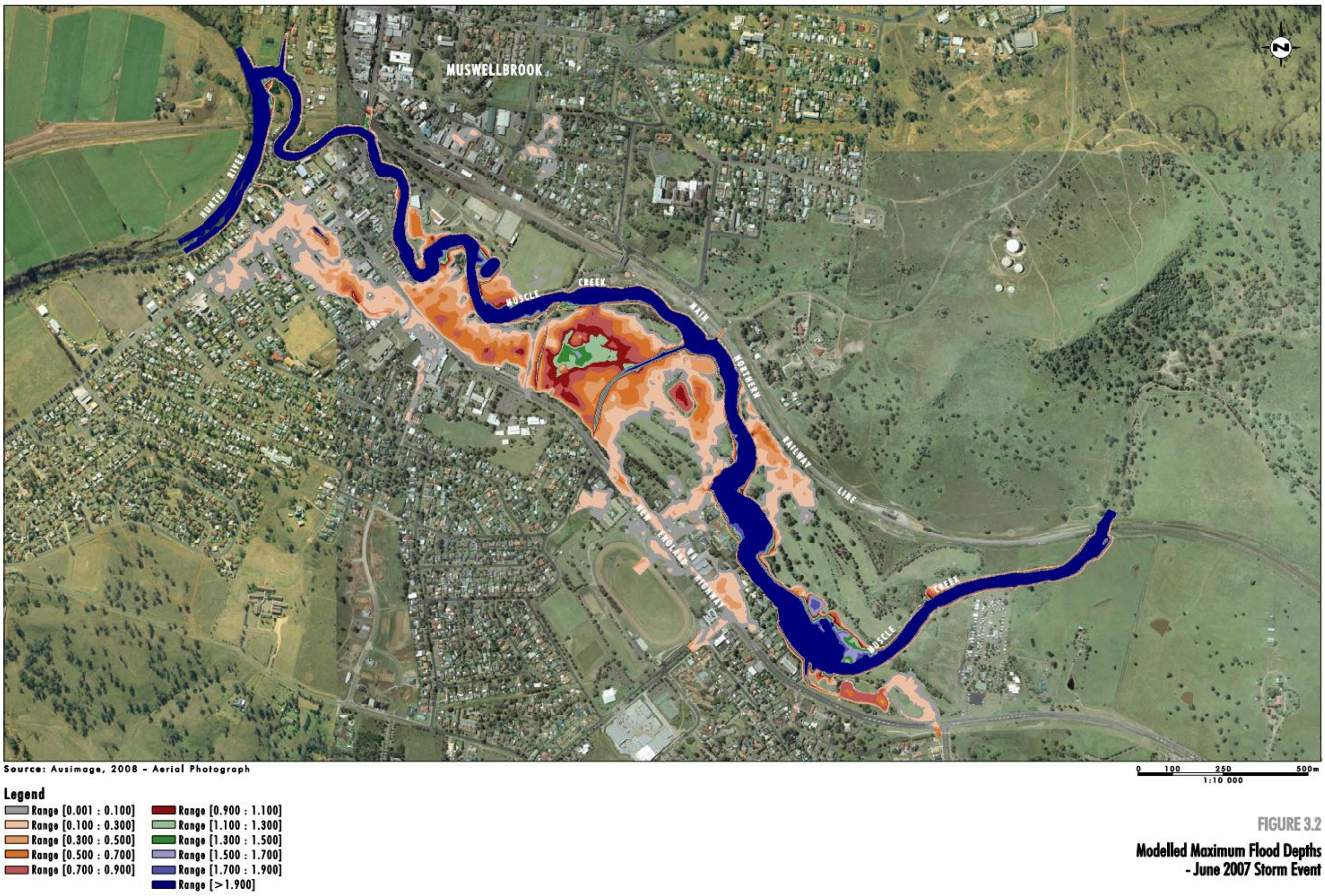

***Plate 2-2** – June 2007 flood extent (Umwelt, 2009)*

Some photographs of the June 2007 flood were provided by local residents who responded to a community survey that was issued as part of the FRMS in June 2016. **Photo 7** shows flooding in the backyards of properties located on St Andrews Place and **Photo 8** shows flood damage inside a garage located on Gyarran Street.

Photo 7 *shows flooding in the backyards of properties located on St Andrews Place (upstream of the golf course).*

Photo 8 *shows flood damage in a garage on Gyarran Street*

3 STUDY OBJECTIVES

This flood study has the following key objectives:

- Develop a hydrologic model that is capable of simulating runoff hydrographs from the Muscle Creek Catchment.
- Develop a two-dimensional hydraulic model that is capable of simulating flooding within the Lower Muscle Creek Floodplain.
- Simulate the 50, 20, 10, 5, 2, 1, 0.5 and 0.2 % AEP and Probable Maximum Flood (PMF) events and produce flood maps depicting peak flood depth and the peak velocity x depth product.
- Identify portions of the study area that have elevated flood risk.
- Identify potential mitigation works for further assessment in the FRMS.

It is noted that flood risks on the Muscle Creek Floodplain associated with Hunter River flooding are assessed separately in the FRMS.

4 ASSESSMENT METHODOLOGY

This section describes the methodology and assumptions that were applied to developing hydrologic and hydraulic models that were used in this study. Model results are discussed in **Section 5**.

4.1 Available Data

The following data was provided by Council for use in the study:

- Surface levels from a LiDAR survey.
- A high resolution aerial image of the study area.

As part of this study, Royal HaskoningDHV undertook a site inspection to gain an understanding of the floodplain characteristics within the study area. During the site inspection, RHDHV undertook key measurements of the three bridge structures that are located within the model domain. Collectively, sufficient data from the above data sources was available to enable a combined hydraulic model to be developed for the study area.

4.2 Modelling Approach

The following approach was applied to the flood modelling:

- **Data Review and Interpretation** – the following data review and interpretation tasks were undertaken:
  - All data provided by Council was initially reviewed for completeness and reliability. This process identified data that was suitable for use in the study.
  - A Digital Elevation Model (DEM) was established for the study area from LiDAR data provided by Council.
- **Hydrologic Modelling** – was undertaken using the XP-RAFTS modelling platform. The model was applied to estimate runoff hydrographs for the 50, 20, 10, 5, 2, 1, 0.5 and 0.2% AEP events using the methods described in AR&R (1987). Runoff hydrographs for the PMF event were estimated using the Generalised Short Duration Method (GSDM) that is described in BoM (2003).
- **Hydraulic Modelling** – was undertaken using the TUFLOW modelling platform. TUFLOW is a two-dimensional hydraulic model that is widely used in NSW for flood assessments. The model was applied to estimate flood characteristics for the 50, 20, 10, 5, 2, 1, 0.5 and 0.2 % AEP and PMF events.
- **Model Verification** – The hydrologic and hydraulic model results were verified by comparing the 2% AEP results to anecdotal information available from the June 2007 event, which is estimated to be similar to a 2% AEP event.
- **Results Processing** – Hydraulic model results were processed using MAPINFO. Model output included flood maps that depict peak flood depth and extents and peak flood hazard (velocity x depth product) for all events simulated.

4.3 Methodologies and Assumptions

4.3.1 Hydrologic Model Development

Hydrologic modelling was undertaken using the XP-RAFTS modelling platform. The model was applied to estimate runoff hydrographs for the 50, 20, 10, 5, 2, 1, 0.5 and 0.2 % AEP and PMF events.

Model Development

A hydrologic model of the catchments of Muscle Creek Catchment was developed using the XP-RAFTS modelling platform. The total catchment area was divided into 9 sub-catchments that were differentiated based on the topographic characteristics of the catchment. **Plate 4-1** shows the adopted sub-catchment extents.

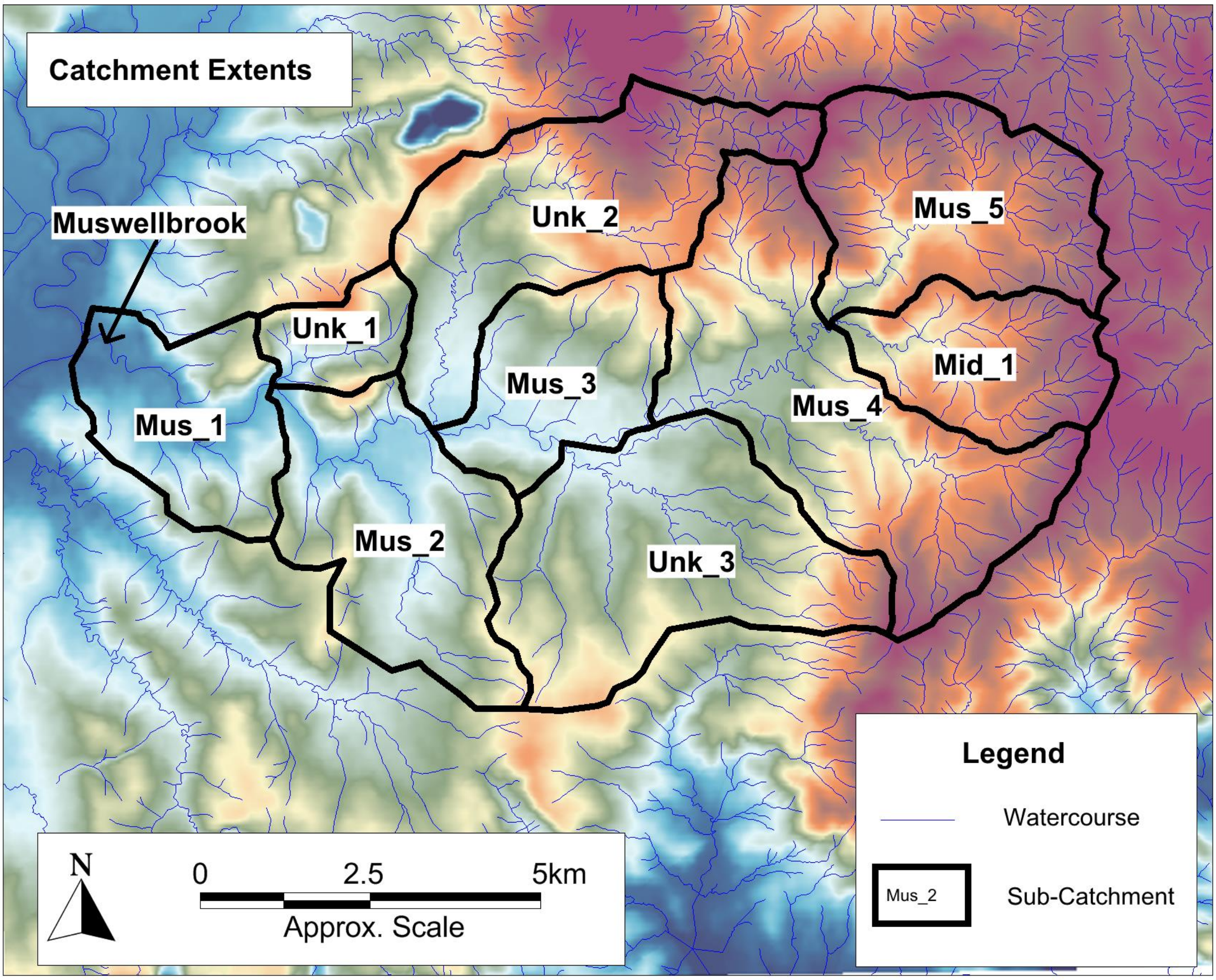

***Plate 4-1** – Muscle Creek sub-catchment extents.*

The following methodologies and assumptions were applied to establish parameters for each sub-catchment:

- **Impervious Area**: Only the lower sub-catchment (Mus_1) comprises material areas of urban land use. The extent of impervious areas within this catchment was estimated from aerial photography.

- **Catchment Roughness**: values were established based on the land-use, with the following typical values adopted:

    - Urban land use (impervious areas) **– 0.03**

    - Rural land use **– 0.05**

    - Forested land use - **0.07**

- **Catchment Slopes**: were digitised using Shuttle Radar Topography Mission (SRTM) data.

- **Rainfall Loss Rates**: XP-RAFTS applies initial and continuing losses to calculate runoff depth for each model time step. The following loss rates were adopted from the hydrologic model prepared for the Hunter River Flood Study (Worley Parsons, 2014):

    - Initial loss – 20 mm

    - Continuing loss – 2.5 mm/hr

- **Storage Coefficient Multiplication Factor (Bx):** The default Bx factor of 1 was adopted.

- **Sub-Catchment Lag Times**: were estimated based on average watercourse gradients and longitudinal channel distances. Initial lag times were adjusted as part of the model verification process. Adopted lag times and the calculation methodology are provided in **Appendix A**.

- **Intensity Frequency Duration (IFD) Data**: IFD data from AR&R (1987) for the Muscle Creek Catchment was used in this assessment. IFD coefficients are provided in **Appendix A**. An aerial reduction factor of 0.96 was applied in accordance with the methods documented in AR&R (1987). A number of design storm durations were assessed using the hydrologic model. This process identified the 36hr design storm to produce the highest peak flows for all design events.

- **Probable Maximum Precipitation (PMP) Calculation:** The PMP for the catchment was estimated using the Generalised Short Duration Method (GSDM) that is documented in BoM (2003). The model was also applied to estimate the governing PMP event. This process identified that the 5hr PMP produced the highest peak flows at Muswellbrook. Parameters used in the derivation of the PMP are available in **Appendix A**. The estimated rainfall depths were applied to the XP-RAFTS hydrologic model to estimate the runoff hydrographs of the Probable Maximum Flood (PMF).

Adopted parameters for each sub-catchment are provided in **Appendix A**.

4.3.2 Hydraulic Model Development

Hydraulic modelling was undertaken using the TUFLOW modelling platform. TUFLOW is a two-dimensional hydraulic model that is widely used in NSW for flood assessments. The model was applied to estimate flood characteristics for the 50, 20, 10, 5, 2, 1, 0.5 and 0.2 % AEP and PMF events.

Model Domain and Grid Size

The 2D hydraulic model domain encompasses the Muscle Creek Floodplain area between the Great Northern Railway Bridge and the confluence of Muscle Creek and the Hunter River. The model domain also includes the Hunter River Channel and immediate floodplain area. **Figure 2** shows the model domain.

A three metre (3m) grid was generated from the DEM for use in the TUFLOW model. This grid size is expected to provide sufficient resolution to enable channel and floodplain flows to be reliably simulated across the semi-rural and urban landscape.

Bridges

The Bell Street, Wilkinson Avenue and Bridge Street bridges were deemed to be key hydraulic controls and were represented in the model using 2D layered flow constriction cells. The 2D layered flow constriction cells enable unique blockage factors and form losses to be applied to the following bridge layers:

- **Layer 1** represents the channel area under the bridge structure.
- **Layer 2** represents the bridge deck.
- **Layer 3** represents the bridge hand rails and any accumulated debris.

The following methodology and assumptions were applied to establishing flow constriction cell attributes:

- Deck levels were estimated from LiDAR and deck and handrail thickness were measured by RHDHV during a site inspection.
- Abutment widths and locations were estimated by RHDHV during a site inspection.
- Form loss coefficients and blockage factors for each layer were estimated based on site observations and typical values. **Table 4-1** provides the adopted values.

***Table 4-1** – Adopted blockage and form loss coefficients*

	Blockage Factor[1]			Form Loss[2 & 3]		
	L1	**L2**	**L3**	**L1**	**L2**	**L3**
Bell Street Bridge	10%	100%	80%	0.1	N/A	0.02
Wilkinson Avenue Bridge	0%	100%	80%	0.1	N/A	0.02
Bridge Street Bridge	20%	100%	50%	0.1	N/A	0.02

Note 1: The blockage factor reduces the flow conveyance area within the layer by the given percentage.

Note 2: The blockage factor for Layer 1 represents blockage due to the bridge abutments and debris accumulation around the abutments. The Wilkson Avenue Bridge is a single span bridge so no blockage was applied to Layer 1.

Note 3: The blockage for Layer 3 represents blockage due to the bridge deck handrails and associated debris accumulation. A higher blockage factor was applied to the Bell Street and Wilkinson Avenue Bridges due to the finer spacing handrails, which are more likely to accumulate debris.

Note 4: Form losses are irrelevant to layers that are fully blocked as no flow conveyance is applied through the layer.

Hunter River Tailwater Levels

Flooding on the Lower Muscle Creek Floodplain can occur in isolation or in conjunction with flooding from the Hunter River. The June 2007 event is an example of Muscle Creek flooding occurring in isolation of any significant flooding from the Hunter River.

The intention of this flood study is to assess flood characteristics and risks associated with a Muscle Creek flood event occurring in isolation to any major flooding in the Hunter River. In some cases, this can result in shallower but faster moving floodwaters that have a higher hazard profile than deeper slower moving floodwaters that would occur during a combined event. Hence, assessment of Muscle Creek flooding occurring in isolation to any major flooding in the Hunter River will enable the reliable assessment of:

- Flood risks to property and life, including risks associated with limited flood warning time and safe evacuation routes.
- Peak flow velocities. Peak flow velocities may be required to inform future engineering designs of instream works such as creek rehabilitation and bridge and service crossings.
- Flood impacts associated with future development on the lower Muscle Creek floodplain can be more reliably assessed using a model that applies no Hunter River tailwater.

Accordingly, for the purposes of this study, Hunter River tailwater was nominally applied so that flows in the Hunter River are approximately 1m below bank full for all events.

It is noted that the Hunter River flood model developed for the Hunter River Flood Study (Muswellbrook to Denman) (Worley Parsons, 2014) includes inflows from Muscle Creek and adequately assesses the flood characteristics associated with combined flooding in the Muscle Creek and the Hunter River. The flood risk assessment and mapping that will be completed as part of the FRMS will apply the governing model results from Muscle Creek flooding with no substantial Hunter River tailwater and combined Hunter River and Muscle Creek flooding.

Hydraulic Roughness

Hydraulic roughness parameters are used to represent friction between water and the surface of a channel or a floodplain. Generally higher roughness values imply increased friction (or energy loss) and higher flood levels. The assumed roughness of channel zones can also influence the conveyance capacity of the channel and the distribution of channel and out of channel flows.

The model domain was divided into the following hydraulic roughness categories based on site observations and review of aerial photography:

- High density urban – 0.10
- Medium density urban – 0.06
- Road reserve corridor (includes road verge) – 0.02
- Moderately vegetated channel – 0.06
- Lightly vegetated channel – 0.035
- Vegetated floodplain – 0.05
- Grassed floodplain – 0.035
- Rail line – 0.05

Figure 3 shows the adopted roughness map for the model domain. It is noted that the channel roughness values were adjusted during the model verification process which is described in **Section 4.3.3**.

Establishing representative roughness parameters in urban areas is difficult as the effects of structures and fences on flow conveyance can vary significantly. For example, a house that has a suspended deck construction will enable some flow conveyance through the building footprint, while a house with slab on ground construction will form a complete blockage. Fences can also significantly impeded flow, but can suddenly fail and open up new flow conveyance areas. Accordingly, the effect of urban development on floodplain conveyance can vary significantly between different floodplain areas and for different flood events.

As it is not possible to reliably simulate these effects on a lot by lot basis, the roughness values for a medium density urban lot (0.06) and high density urban lot (0.1) have been estimated to account for average hydraulic influence of urban development on floodplain conveyance. These roughness values would be subject to adjustment if the model is calibrated at a later date.

4.3.3 Model Verification Approach

The hydrological and hydraulic models were verified using anecdotal observations from the June 2007 event that are documented in Table 2 of (Umwelt, 2009). This table is reproduced as **Appendix B**. As discussed in **Section 3**, the June 2007 event is estimated to be similar to a 2% AEP event. Accordingly, the 2% AEP model results were compared to the above-mentioned information to verify the model results. The following adjustments were made to the hydrologic and hydraulic models during the model verification process:

- Catchment lag times were reduced by a factor of 0.6 to increase peak flows.

- The hydraulic roughness values for the Muscle Creek Channel of between 0.04 and 0.06 were evaluated. A value of 0.06 produced the best representation of the observed flood conditions and was therefore adopted for the Moderately Vegetated Channel roughness category.

5 RESULTS ANALYSIS

This section presents and discusses the flood model results and is structured as follows:

- **Section 5.1** presents hydrologic model results.
- **Section 5.2** presents the hydraulic model results.
- **Section 5.3** documents a preliminary assessment of flood risks.
- **Section 5.4** discusses potential mitigation measures that could be assessed further as part of the FRMS.

It is noted that flood risks on the Muscle Creek Floodplain associated with Hunter River flooding are assessed separately in the FRMS.

5.1 Hydrologic Model Results

The XP-RAFTS hydrologic model was applied to simulate the 50, 20, 10, 5, 2, 1, 0.5 and 0.2% AEP and PMP events. For each event, a range of storm durations were assessed to identify the governing duration. The 36 hour duration event was found to produce the highest peak flows at Muswellbrook for all design events and the 5hr duration PMP produced the highest peak flows for the PMF event. These storm durations were adopted for all design events.

Table 5-1 compares the peak flow estimates for all events to peak flow estimates published in the Flood Assessment of Bell Street, Muswellbrook (Umwelt, 2009) and Hunter River Flood Study (Worley Parsons, 2014). It is noted that the hydrologic model developed for the Hunter River Flood Study (Worley Parsons, 2014) was configured to estimate runoff hydrographs from the Hunter River Catchment, which is substantially larger than the Muscle Creek Catchment. This has resulted in the following discrepancies between the two modelling approach:

- An Aerial Reduction Factor of 0.9 was applied to the Hunter River Flood Study Model. This compares to an Aerial Reduction Factor of 0.96 that was adopted for this study. The lower Aerial Reduction Factor moderately reduces the rainfall intensities applied to the hydrologic model.
- Due to the larger catchment size, the PMP for the Hunter River Flood Study Model was calculated using the *Generalised Tropical Storm Method Revised* (GTSMR) method. This method is not considered suitable for estimating the PMP in the Muscle Creek Catchment and should not be directly compared to the PMP estimates made in this study.

***Table 5-1** – Summary of peak flows*

	This Study	Umwelt (2009)	Worley Parsons (2013)[1]
50% AEP	101 m^3/s	Not assessed	72 m^3/s
20% AEP	160 m^3/s	Not assessed	130 m^3/s
10% AEP	194 m^3/s	Not assessed	165 m^3/s
5% AEP	240 m^3/s	Not assessed	200 m^3/s
2% AEP	284 m^3/s	Not assessed	245 m^3/s
1% AEP	331 m^3/s	371 m^3/s	295 m^3/s
0.5% AEP	382 m^3/s	Not assessed	345 m^3/s
0.2% AEP	454 m^3/s	Not assessed	420 m^3/s
PMF	3000 m^3/s	Not assessed	560 m^3/s[2]

Note 1: Results from the Hunter River Flood Study Model were extracted from the XP-RAFTs model provided (node Muscle C). Flows are moderately higher than those reported in Table 6.2 of the flood study report as these flows were extracted from catchment node Muscle B, which is upstream of Muscle C.

Note 2: Due to the larger catchment size, the PMP estimate from Hunter River Flood Study Model was calculated using the *Generalised Tropical Storm Method Revised* (GTSMR) method. This method is not considered suitable for estimating the PMP in the Muscle Creek Catchment and should not be directly compared to the PMP estimates made for this study.

Model results presented in **Table 5-1** indicate that peak flows estimated for this study are:

- Moderately (10 to 20%) higher than the peak flows estimated by Hunter River Flood Study (Worley, Parsons, 2014). This is partially attributed to a higher Aerial Reduction Factor.
- Moderately (10%) lower than the than the peak flow estimated for the Flood Assessment of Bell Street, Muswellbrook (Umwelt, 2009) for the 1% AEP event.
- Significantly higher for the PMF event (due to the above-mentioned reasons). This will materially change the PMF flood extents and risk profile in Muswellbrook.

5.2 Hydraulic Model Results

The TUFLOW model was applied to simulate the 50, 20, 10, 5, 2, 1, 0.5 and 0.2% AEP and PMF events. Model results for all events are presented in a series of flood maps that are attached. The flood maps provide the following information:

- Peak flood depths throughout the study area.

- Peak flood hazard (velocity x depth) throughout the study area.

Table 5-2 provides a figure schedule for the attached flood maps.

***Table 5-2** – Flood map figure schedule*

	Peak Flood Depth	Peak Velocity x Depth
50% AEP	Figure 4	Figure 13
20% AEP	Figure 5	Figure 14
10% AEP	Figure 6	Figure 15
5% AEP	Figure 7	Figure 16
2% AEP	Figure 8	Figure 17
1% AEP	Figure 9	Figure 18
0.5% AEP	Figure 10	Figure 19
0.2% AEP	Figure 11	Figure 20
PMF	Figure 12	Figure 21

Model results indicate that:

- For the 50, 20% and 10% AEP events, flooding is expected to be predominately confined to the Muscle Creek Channel. However, some inundation of the Muswellbrook Golf Course occurs.

- For the 5% AEP event, minor flows are expected to spill over Bell Street, into residential areas. This indicates that the capacity of the Bell Street Bridge is similar to the 5% AEP flow (240 m^3/s).

- For 2% AEP and greater magnitude events, the Bell Street road embankment and bridge becomes a significant hydraulic control, with all flows in excess of the bridge capacity spilling over Bell Street into residential areas. The flood risks downstream of Bell Street increase substantially with high magnitude events, in line with the increase in the overflow rate over Bell Street. Flood risks are discussed further in **Section 5.3**.

- Dwellings located adjacent to the Muscle Creek Channel, upstream of the golf course, do not appear to be inundated for events up to and including the 0.5% AEP event. This will be confirmed when flood damages are calculated as part of the FRMS.

- A PMF event would inundate the entire Lower Muscle Creek Floodplain, with high hazard flow conditions expected in most areas that are inundated.

Flood risks are discussed further in **Section 5.3.**

5.3 Preliminary Flood Risk Assessment

A flood risk assessment will be undertaken as part of the FRMS. The risk assessment will apply the model results from the Muscle Creek and Hunter River flood models and will include:

- The calculation of flood damages using surveyed floor levels.
- Flood risk category mapping.
- Assessment of flood warning times and evacuation issues.

The section provides preliminary information on key flood risks associated with Muscle Creek flooding.

5.3.1 Flood Risks to Property

Model results indicate that floodwaters will inundate properties downstream of Bell Street in 5% AEP and greater magnitude events. It is expected that numerous properties will experience over floor flooding during a 1% AEP event. The extent of over floor flooding in each event will be assessed as part of the FRMS.

5.3.2 Risk to Life

Model results indicate that all flows in excess of the Bell Street Bridge capacity will spill over Bell Street into residential areas. Bell Street overflows are expected in the 5% AEP and greater magnitude flood events. Overflows will generally follow the out of channel flow paths that are indicated in **Plate 2-1** (refer to **Section 2**). These flow paths are defined by subtle depressions in the topography and include both residential properties and road reserves. Accordingly, Bell Street overflows present a material risk to the local community.

With reference to the flood hazard maps presented in **Figures 13** to **21**, velocity depth products (VD) exceeding 1 and 2.5 m^2/s are predicted in residential areas for the 1 and 0.2% AEP events respectively, indicating that the flood hazards associated with Bell Street overflows increase substantially in greater magnitude events.

Plate 5-1 shows the flood hazard profiles for the 0.2% AEP event, noting properties exposed to high flood hazards (i.e VD > $1m^2/s$). 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.

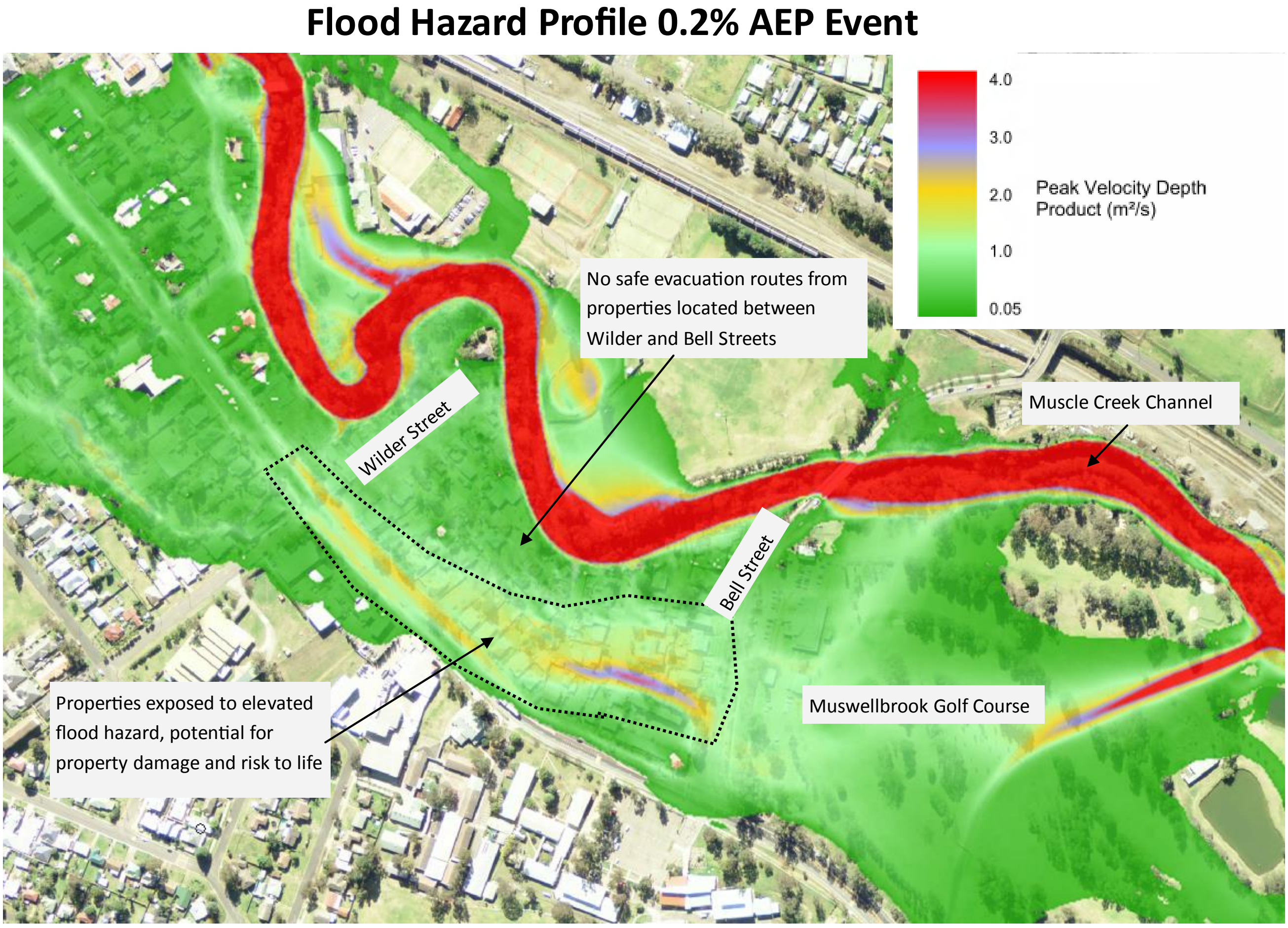

***Plate 5-1** – Flood Hazard Profile for the 0.2% AEP event*

Plate 5-2 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.

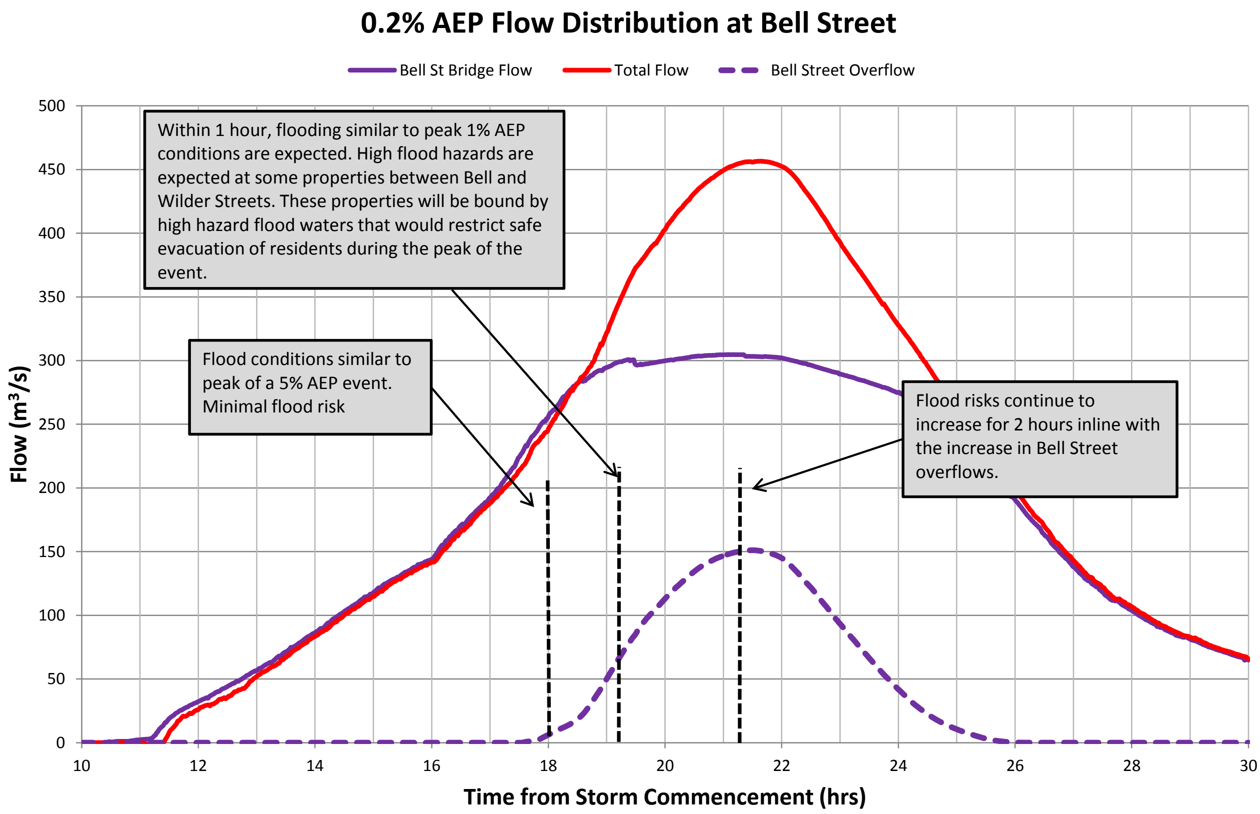

Plate 5-2 *– Flood distribution at Bell Street for the 0.2% AEP event.*

The PMF flood hazard results presented in **Figure 21** indicate that extreme flood hazard conditions would occur within residential areas located downstream of Bell Street.

5.4 Potential Mitigation Measures

Key risks identify by this flood study include:

- Potential for property damage and risks to life associated with Bell Street overflows in 5% AEP and greater magnitude events.
- Risks associated with limited effective flood warning time.

Potential flood mitigation measures that could be assessed further as part of the FRMS include:

- Establishing a flood warning system in the Muscle Creek Catchment.
- Extending the Muscle Creek rehabilitation to upstream of Bell Street to improve channel conveyance.
- Construction of a Bell Street levee and alternative overflow arrangement.

Table 5-3 provides an overview of each of these options. Additional options such as raising floor levels, property acquisition and flood planning controls will be considered as part of the FRMS.

***Table 5-3** – Potential flood mitigation measures*

	Description	Potential Benefit	Potential Constraints
Muscle Creek flood warning System	A Muscle Creek flood warning system would comprise a number of integrated rainfall and stream gauges that would provide real time flood forecasting information.	Substantially increases flood warning time and time available for the safe evacuation of high risk areas. This would substantially reduce the risk to life in an extreme Muscle Creek flood event.	None other than cost
Extend Creek rehabilitation to beyond Bell Street	Remove exotic weeds that have established on the channel banks and re-vegetate with lower density native species.	Lower vegetation destines will result in a modest increase in channel flow conveyance, reducing Bell Street overflows. Only minor flood mitigation benefits would be expected.	• Cost benefit may not be favourable. • Requires ongoing maintenance
Bell Street levee and alternative overflow arrangements.	There is potential to reduce Bell Street overflows by either reconstructing the southern portion of Bell Street to higher levels or building a levee around the eastern side of the golf club house. An alternative overflow arrangement would also need to be established as the existing bridge has a limited capacity. Alternative overflow arrangements could include: • increasing the capacity of the Bell Street Bridge by constructing high flow structures (such as large culverts) adjacent to the bridge opening; or • lower road levels to the north of the bridge to enable overflows. These concepts are shown diagrammatically in **Plate 5-3.**	The frequency and magnitude of Bell Street overflows could be materially reduced, resulting in reduced flood risk profiles in downstream areas.	• Potential flood impacts associated with the redistribution of flows and higher flood levels upstream of the levee. • Works required on private land. • Impacts to golf course and club house. • Road design constraints (i.e. driveway access and minimum vertical curves). • Cost benefit may not be favourable.

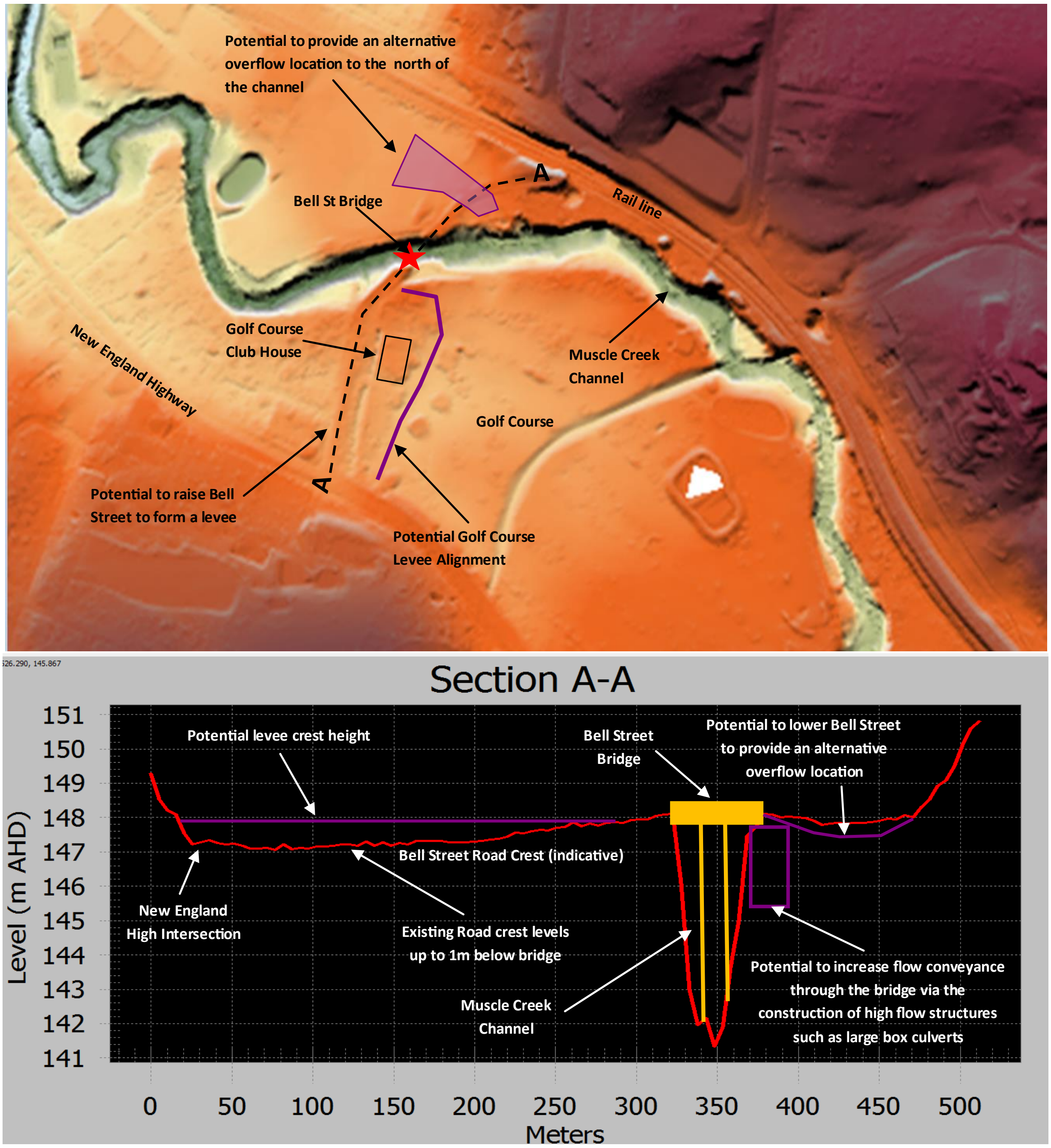

***Plate 5-3** – Bell Street Levee and alternative overflow arrangement concept.*

6 SUMMARY

Royal HaskoningDHV (RHDHV) was engaged by Muswellbrook Shire Council (Council) to prepare a flood study of the lower Muscle Creek Floodplain. The study is being undertaken as part of the Hunter River (Muswellbrook to Denman) Flood Risk Management Study (FRMS) that is also being prepared by RHDHV.

The key objective of the study is to assess flooding within the Township of Muswellbrook that occurs from runoff from the Muscle Creek Catchment. The results and key recommendations from this study will be assessed in conjunction with Hunter River flood model results as part of the FRMS.

This report documents the study and includes:

- A description of the assessment methodologies and the data used to inform the assessment.
- Detailed flood maps that depict the extent and nature of flooding on the Lower Muscle Creek Floodplain for the 50, 20, 10, 5, 2, 1, 0.5 and 0.2 % AEP and Probable Maximum Flood (PMF) events/
- A preliminary assessment of flood risks
- Information on potential flood mitigation measures that could be assessed further as part of the FRMS.

7 REFERENCES

1) Institution of Engineers Australia (1987), '*Australian Rainfall and Runoff – A Guide to Flood Estimation'*

2) New South Wales Government (2005), *'Floodplain Development Manual – The Management of Flood Liable Land'*

3) *Umwelt (2009), 'Flood Assessment of Bell Street, Muswellbrook'*

4) *Worley Parson (2013), 'Hunter River Flood Study (Muswellbrook to Denman)'*

IFD Coefficients (AR&R 1987)			
	1hr	12hr	72hr
2yr	23.27	4.93	1.38
50yr	42.52	8.92	2.87
Skew	0.23		
F2	4.33		
F50	15.9		

Aerial Reduction Factor 0.96

Adjusted IFD Coefficients			
	1hr	12hr	72hr
2yr	22.34	4.73	1.32
50yr	40.82	8.56	2.76
Skew	0.23		
F2	4.33		
F50	15.9		

PMP Parameters

Muscle Creek Catchment - PMP Calculation

Applying the Generalised Short-Duration Method (AR&R 2003)

PMP Parameters	Value	Units	Source
Mean Elevation	*123*	*m HAD*	Estimated from LiDAR
EAF	*1*	-	*S 4.3*
MAF	*0.73*	-	Figure 3
S	*0*	-	*S 4.2*
R	*1*	-	*S 4.2*
Catchment Area	*94.36*	*km2*	
Maximum Duration	*6*	*hr*	*Figure 2*

Appendix A – *Hydrologic Assumptions*

Adopted Sub-catchment Parameters

Sub Catchment ID	Description	Total Area	Impervious Areas	Sub Area 1 - (Pervious Areas)						Sub Area 2 - (Impervious Areas)					
				Area	Average Slope	Roughness	%Impervious	Initial Loss	Continuing Loss	Area	Average Slope	Roughness	%Impervious	Initial Loss	Continuing Loss
		(ha)	*(%)*	*(ha)*	*(%)*	*(n)*	*(%)*	*(mm)*	*(mm/hr)*	*(ha)*	*(%)*	*(n)*	*(%)*	*(mm)*	*(mm/hr)*
Mid_1	Rural	*689.4*	*0%*	689.4	4.2	*0.05*	0%	20	2.5	N/A	N/A	N/A	N/A	N/A	N/A
Mus_1	Rural / urban	*749.7*	30%	524.8	0.3	*0.05*	0%	20	2.5	224.9	0.3	0.03	100%	1.5	1.0
Mus_2	Rural / urban	1163.5	2%	1140.2	1.4	0.05	0%	20	2.5	23.3	1.4	0.03	100%	1.5	1.0
Mus_3	Rural	727.0	0%	727.0	2.1	0.05	0%	20	2.5	N/A	N/A	N/A	N/A	N/A	N/A
Mus_4	Rural	1767.5	0%	1767.5	2.6	0.05	0%	20	2.5	N/A	N/A	N/A	N/A	N/A	N/A
Mus_5	Forest / Rural	1147.8	0%	1147.8	3.9	0.05	0%	20	2.5	N/A	N/A	N/A	N/A	N/A	N/A
Unk_1	Rural	288.3	0%	288.3	3.8	0.07	0%	20	2.5	N/A	N/A	N/A	N/A	N/A	N/A
Unk_2	Forest / Rural	1367.5	0%	1367.5	2.4	0.07	0%	20	2.5	N/A	N/A	N/A	N/A	N/A	N/A
Unk_3	Forest / Rural	1535.6	0%	1535.6	2.4	0.07	0%	20	2.5	N/A	N/A	N/A	N/A	N/A	N/A

Adopted Catchment Lag Paramters

ID	From	To	Flow Length	Upper Elev	Lower Elev	Avg Grade	Avg Velocity	Initial Lag Time	Adjustment Factor	Adjusted Lag Time
	(SC ID)	(SC ID)	(m)	(m AHD)	(m AHD)	(%)	(m/s)	(min)	(frac)	(min)
Mid_1 to Mus_4	Mid_1	Mus_4	5744.2	211.6	187.2	0.4%	0.7	147	0.6	88.1
Mus_2 to Mus_1	Mus_2	Mus_1	4930.8	151.2	135.8	0.3%	0.6	147	0.6	88.1
Mus_3 to Mus_2	Mus_3	Mus_2	3896.5	168.6	151.2	0.4%	0.7	97	0.6	58.4
Mus_4 to Mus_3	Mus_4	Mus_3	4590.6	187.2	168.6	0.4%	0.6	120	0.6	72.1
Mus_5 to Mus_4	Mus_5	Mus_4	5744.2	211.6	187.2	0.4%	0.7	147	0.6	88.1
Unk_03 to Mus_3	Unk_0	Mus_3	2693.1	177.9	168.6	0.3%	0.6	76	0.6	45.8
Unk_1 to Mus_1	Unk_1	Mus_1	4930.8	151.2	135.8	0.3%	0.6	147	0.6	88.1
Unk_2 to Mus_2	Unk_2	Mus_2	3896.5	168.6	151.2	0.4%	0.7	97	0.6	58.4

IFD Coefficients

Intensity-Frequency-Duration Table

Location: 32.275S 150.900E NEAR.. Muswelbrook Issued: 4/7/2016

Rainfall intensity in mm/h for various durations and Average Recurrence Interval

Duration	Average Recurrence Interval						
	1 YEAR	2 YEARS	5 YEARS	10 YEARS	20 YEARS	50 YEARS	100 YEARS
5Mins	58.9	77.3	103	119	141	171	195
6Mins	55.0	72.3	95.9	111	131	159	182
10Mins	44.9	58.8	77.3	89.1	105	126	144
20Mins	32.6	42.4	54.8	62.5	72.9	87.1	98.3
30Mins	26.4	34.2	43.8	49.7	57.7	68.7	77.3
1Hr	17.8	22.9	29.1	32.8	37.9	44.8	50.3
2Hrs	11.7	15.0	18.9	21.3	24.5	28.9	32.3
3Hrs	9.07	11.6	14.6	16.5	18.9	22.3	24.9
6Hrs	5.87	7.53	9.45	10.6	12.2	14.4	16.1
12Hrs	3.77	4.84	6.11	6.89	7.94	9.36	10.5
24Hrs	2.37	3.06	3.92	4.46	5.17	6.16	6.93
48Hrs	1.43	1.87	2.45	2.82	3.31	4.00	4.54
72Hrs	1.03	1.36	1.81	2.10	2.48	3.02	3.45

(Raw data: 23.27, 4.93, 1.38, 42.52, 8.92, 2.87, skew=0.23, F2=4.33, F50=15.9)

Copy Table

Appendix B – *June 2007 Observations*

Note this table has been reproduced from (Umwelt, 2009)

Table 2 – June 2007 Storm Event Flood Observations

ID	Location	Description	Time	Source of Flood Observation	Estimated Flood Depth (mm)	Comments	Comparison with Flood Modelling
1	Footbridge over Muscle Creek, approximately 350 metres upstream of Thompson Street drain.	Debris levels on tree next to bridge, bridge rails damaged / removed by flood waters.	after flood event	Photograph - P1010009.JPG		Flood levels appear to have reached least to top level of bridge, estimated to be at 147.7 mAHD with bed of creek at 142.1 mAHD on aerial photogrammetry survey.	Maximum flood level approximately 1.5 metres above bridge deck.
2	Downstream of Eastbrook Estate culvert (New England Highway).	Flood debris left on first fence wire, videos indicate that flow was at right angles to New England Highway.	after flood event	Maitland St - Golf Course 9.jpg	250	Also from videos (not as good quality).	300 mm flood depth.
3	Junction of New England Highway and Bell Street, looking north into Bell Street.	Photo shows flooding over Bell Street junction. Estimated water 50 mm over traffic island triangle at left turn on to New England Highway. Also shows a thin strip of land between drain and road that only has surface flooding (i.e. < 50 mm depth).	photo info 2007:06:08 12:58:33	2007-06-08 Golf Course 4.jpg, 2007-06-08 Golf Course 3.jpg			100 mm flood depths over the traffic island. Not sufficient detail in base survey to pick up variation between edge of road and drain.
4	From New England Highway, east of junction with Bell Street, looking north across golf course to club house.	Photo shows flooding extent, to at least the edge of batter on New England Highway and around golf course club house.	photo info 2007:06:08 12:57:58	Maitland St - Golf Course 2.jpg		No depths able to be defined.	Modelling confirms flood extent near edge of New England Highway. Flood depths around golf course club house range from 800 mm at north-east corner to 150 mm at south-west corner.
5	Steps on northern bank of Muscle Creek, downstream of Wilkinson Avenue.	Shows flood debris up to first platform on steps.	after flood event	2007-06-08 Muscle Ck flood level 03.jpg			Unable to determine flooding depths at location due to vegetation cover on aerial photograph.
6	Downstream of subway, showing carrier main on Muscle Creek.	Shows broken main and debris/flood mark levels on southern bank.	after flood event	Damaged Carrier Main 2-1 at Muscle Creek 5.jpg			Maximum flood depth at carrier main crossing in the order of 7 metres. Maximum velocities at carrier main crossing in the order of 2.1 m/s.
7	Bell Street.	Water levels rose suddenly in about 20 minutes, flooding stayed around for approximately 2 hours.		Flood information sourced from residents at Community BBQ on 30 July 2008.			Flood modelling confirms similar timeframes.
8	Clifford Street.	Flooding extended to approximately the third house from the corner (6 Clifford Street).		Flood information sourced from residents at Community BBQ on 30 July 2008.			Flood extent extends one house further to the north.
9	6 Clifford Street.	Flooding out the front of house at approximately 450 mm deep.		Flood information sourced from residents at Community BBQ on 30 July 2008.	450		400 mm flood depth.
10	Clifford Street.	Flood waters flowed westward at the corner of Clifford Street into the laneway/easement. At the end of the laneway the flows split into two directions.		Flood information sourced from residents at Community BBQ on 30 July 2008.			Flood model flows in same direction.
11	1 Gyarran Street.	Flood depths estimated at 450 mm.		Flood information sourced from residents at Community BBQ on 30 July 2008.	450		630 mm flood depth at rear of house, 400 mm flood depth at front of house.
12	Gyarran Street.	Flood depths estimated at 450 mm.		Flood information sourced from residents at Community BBQ on 30 July 2008.	450		Flood depth ranges between 0 mm and 630 mm along Gyarran Street.
13	1 Gyarran Street.	Flood levels were not significant to the north of this property.		Flood information sourced from residents at Community BBQ on 30 July 2008.			Flood extent joins at low levels to Muscle Creek. Part of Gyarran Street approximately 20 metres to the north-west of 1 Gyarran Street is not flooded.
14	62 to 64 New England Highway (hotel).	Flood debris mark on gas tank at side of property. Approximately 350 mm above ground level.		Site inspection 30 July 2008.	350		250 mm flood depth.