CABONNE COUNCIL

MOLONG FLOOD STUDY

NOVEMBER 2023

DRAFT REPORT FOR PUBLIC EXHIBITION

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FOREWORD

The NSW State Government's Flood Prone Land Policy is directed at providing solutions to existing flooding problems in developed areas and to ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

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

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

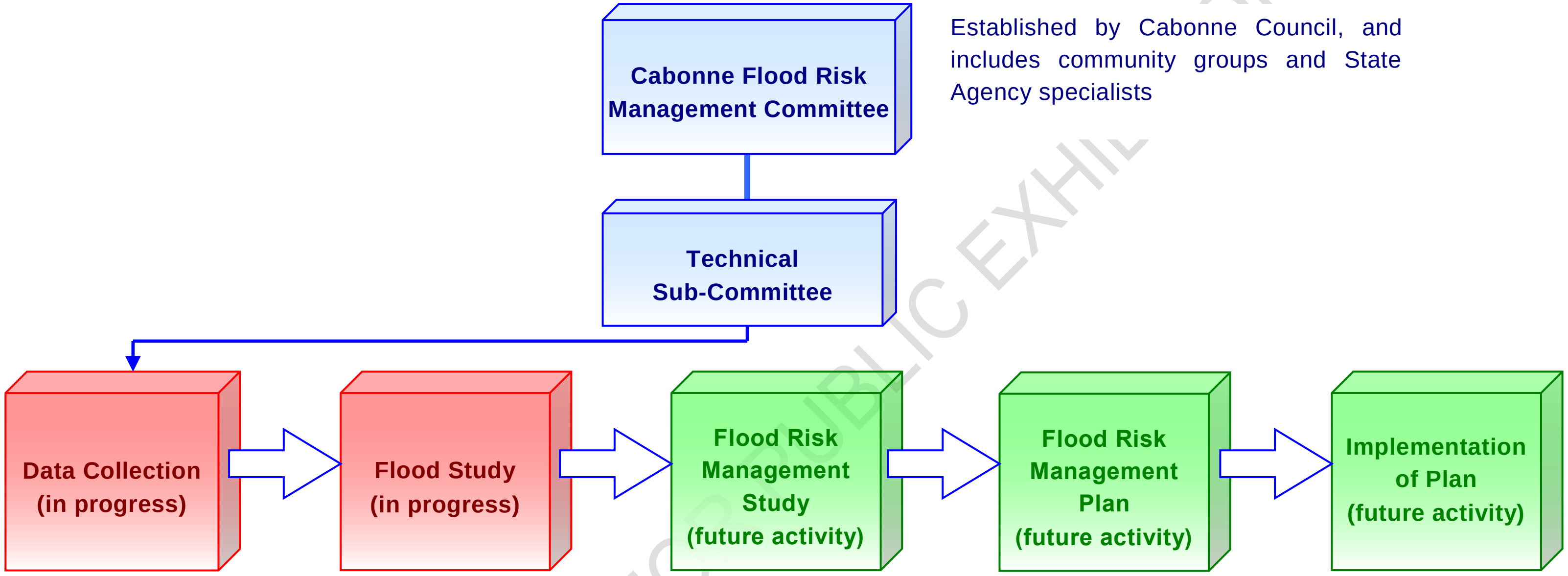
1.	Flood Study	Determines the nature and extent of flooding.
2.	Flood Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed development.
3.	Flood Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
4.	Implementation of the Plan	Construction of flood mitigation works to protect existing development. Use of Local Environmental Plans to ensure new development is compatible with the flood hazard. Improvements to flood emergency management measures.

The *Molong Flood Study* is jointly funded by Cabonne Council and the NSW Government, via the Department of Planning and Environment. The Flood Study constitutes the first and second stage of the Flood Risk Management process (refer over) for this area and has been prepared for Cabonne Council to define flood behaviour under current conditions.

ACKNOWLEDGEMENT

Cabonne Council has prepared this document with financial assistance from the NSW Government through its Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Department of Planning and Environment.

FLOOD RISK MANAGEMENT PROCESS



Involves the compilation and review of existing data and the collection of additional data.

Involves detailed hydrologic and hydraulic modelling of the existing stormwater drainage system at Molong.

The Flood Risk Management Study will determine options which will seek to reduce the impact of flooding on the community in consideration of social, ecological and economic factors.

Preferred flood management options will be publicly exhibited and the responses from the community incorporated in the Plan. The Plan will then be formally approved by Council following the public exhibition period.

Implementation of the Plan will allow Council to reduce the impact of flooding on the community through flood, property, and response modification measures. The measures may include structural works, planning controls, flood warnings, flood readiness and response plans, ongoing data collection and monitoring.

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NOTE ON FLOOD FREQUENCY

The frequency of floods is generally referred to in terms of their Annual Exceedance Probability (**AEP**) or Average Recurrence Interval (**ARI**). For example, for a flood magnitude having 5% AEP, there is a 5% probability that there will be floods of greater magnitude each year. As another example, for a flood having a 5 year ARI, there will be floods of equal or greater magnitude once in 5 years on average. The approximate correspondence between these two systems is:

Annual Exceedance Probability (AEP) (%)	Average Recurrence Interval (ARI) (years)
0.2	500
0.5	200
1	100
2	50
5	20
10	10
20	5

The report also refers to the Probable Maximum Flood (**PMF**). This flood occurs as a result of the Probable Maximum Precipitation (**PMP**). The PMP is the result of the optimum combination of the available moisture in the atmosphere and the efficiency of the storm mechanism as regards rainfall production. The PMP is used to estimate PMF discharges using computer models which simulates the conversion of rainfall to runoff. The PMF is defined as the limiting value of floods that could reasonably be expected to occur. It is an extremely rare flood, generally considered to have a return period greater than 1 in 10^6 years.

NOTE ON QUOTED LEVEL OF ACCURACY

Peak flood levels have on occasion been quoted to more than one decimal place in the report in order to identify minor differences in values. For example, to demonstrate minor differences between peak heights reached by both historic and design floods and also minor differences in peak flood levels which will result from, for example, a partial blockage of hydraulic structures. It is not intended to infer a greater level of accuracy than is possible in hydrologic and hydraulic modelling.

ABBREVIATIONS

AEP	Annual Exceedance Probability (%)
AHD	Australian Height Datum
AMC	Antecedent Moisture Condition
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval (years)
ARR	Australian Rainfall and Runoff
AWS	All Weather Station
BoM	Bureau of Meteorology
Council	Cabonne Council
DEM	Digital Elevation Model
DPE	Department of Planning and Environment
FRMM	Flood Risk Management Manual (NSW Government, 2023)
FPL	Flood Planning Level
FPA	Flood Planning Area
FRMS&P	Flood Risk Management Study and Plan
GDSM	Generalised Short Duration Method
GS	Gauging Station
IFD	Intensity-Frequency-Duration
LiDAR	Light Detecting and Ranging (type of aerial based survey)
NSW SES	New South Wales State Emergency Service
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
TUFLOW	A true two-dimensional hydrodynamic computer model which has been used to define flooding patterns as part of the present study.

Chapter 8 of the report contains definitions of flood-related terms used in the study.

SUMMARY

S.1 Study Objective

The objective of the study was to define the nature of the following two types of flooding that are experienced at the township of Molong for flood frequencies ranging between 20 (1 in 5) and 0.2 (1 in 500) per cent Annual Exceedance Probability (**AEP**), together with the Probable Maximum Flood (**PMF**):

- **Main Stream Flooding** which occurs when floodwater surcharges the inbank area of Molong Creek, Reedy Creek, Boree Hollow, Moss Hollow Creek and Foys Creek. Main Stream Flooding is typically characterised by relatively deep and fast flowing floodwater but can include shallower and slower moving floodwater on the overbank of the aforementioned creeks.
- **Major Overland Flow**, which is experienced during periods of heavy rain and is generally characterised by relatively shallow and slow-moving floodwater that is conveyed overland in an uncontrolled manner toward the abovementioned watercourses.

The findings of the study will be used as the basis for preparing the future *Molong Flood Risk Management Study and Plan* (***Molong FRMS&P***) which will assess options for flood mitigation and prepare a plan of works and measures for managing the existing, future and continuing flood risk at Molong.

S.2 Study Area

While the definition of flood behaviour was limited to the township of Molong and its immediate environs, the present study assessed the runoff potential of the whole of the Molong Creek catchment. **Figures 1.1** and **2.1** bound in **Volume 2** of this report show the extent of the 300 km^2 Molong Creek catchment upstream of its confluence with the Bell River, the western boundary of which forms the divide between the Macquarie and Lachlan River basins, while **Figure 2.2** (3 sheets) shows the key features of the existing stormwater drainage system within the urbanised parts of Molong.

S.3 Study Method

The flood study involved the following activities:

- The forwarding of a *Community Newsletter and Questionnaire* to approximately 1,500 residents and business owners in the study area. The *Community Newsletter and Questionnaire*, a copy of which is contained in **Appendix A** of this report, introduced the study objectives and sought information on historic flood behaviour. Of those that responded, more than half noted that they had observed flooding in or adjacent to their property. Respondents provided information on flooding that occurred on a number of occasions, the most notable of which were:
  - 19-20 April 1990 and 1-2 August 1990;
  - 8 November 2005;
  - 26 November 2021; and
  - 13-14 November 2022
- The collection of flood data, details of which are set out in **Appendix B** of this report. Pluviographic rainfall data recorded by a Bureau of Meteorology (**BoM**) and WaterNSW operated rain gauges in the vicinity of Molong were obtained, while stream flow data recorded by the network of WaterNSW stream gauges that are located on Molong Creek

were also obtained. A number of photographs were provided by Council and respondents to the *Community Questionnaire* showing historic flood behaviour in the study area, copies of which are contained in **Appendix C** of this report.

- The hydrologic modelling of the Molong Creek catchment. The RAFTS and ILSAX sub-models in the DRAINS software were used to simulate the hydrologic response of the rural and urbanised parts of the Molong Creek catchment, respectively. The software generated discharge hydrographs resulting from historic and design storms.
- Application of the discharge hydrographs to a hydraulic model of Molong Creek and its major tributaries, as well as the Major Overland Flow paths that are present in the urbanised parts of Molong and their immediate surrounds. The TUFLOW two-dimensional modelling system was used for this purpose.
- Presentation of study results as diagrams showing indicative extents and depths of inundation, flood hazard vulnerability and the hydraulic categorisation of the floodplain into floodway, flood storage and flood fringe areas.
- An assessment of the economic impacts of flooding, including the number of affected properties and an estimation of flood damages.
- Sensitivity studies to assess the effects on model results resulting from variations in model parameters such as hydraulic roughness of the floodplain and a potential partial blockage of hydraulic structures. The effects that a potential increase in rainfall intensities associated with future climate change could have on flood behaviour were also assessed.

After calibrating the hydrologic and hydraulic models (collectively referred to herein as "the flood models") using data that were available for the August 1990, November 2005, November 2021 and November 2022 flood events, design storm rainfalls ranging between 20 and 0.2% AEP were derived using procedures set out in the 2019 edition of *Australian Rainfall and Runoff* (Geoscience Australia, 2019) (**ARR 2019**) and applied to the hydrologic models in order to derive discharge hydrographs. The PMF was also modelled.

S.4 Flood Model Development and Calibration

As mentioned, the flood models were calibrated using data that were available for the August 1990, November 2005, November 2021 and November 2022 flood events. **Figure 2.3** (3 sheets) shows a comparison between the rainfall that was recorded during a number of the storm events and design intensity-frequency-duration curves, while **Figure 2.4** (2 sheets) shows the cumulative rainfall, as well as recorded stage and rating-curve-derived discharge hydrographs at WaterNSW's *Molong Creek at Downstream Borenore Creek* (GS 421178) and *Molong Creek at Molong* (GS 421049) stream gauges.

Figures 2.5, **2.6**, **2.7** and **2.8** show the spatial and temporal variation in rainfall which was applied to the hydrologic model for the floods that occurred in August 1990, November 2005, November 2021 and November 2022, respectively, while **Figures 3.1** and **4.1** show the layout of the flood models that were developed as part of the present investigation.

Figure 4.3 (2 sheets) shows water surface profiles along the main arm of Molong Creek in the vicinity of Molong for the four historic flood events, while **Figures 4.4**, **4.5**, **4.6** and **4.7** (3 sheets each) show the indicative extent and depth of inundation defined by the hydraulic model for the August 1990, November 2005, November 2021 and November 2022 floods, respectively.

Through the model calibration process, the August 1990, November 2005, November 2021 and November 2022 floods were found to have AEPs of about 10% (1 in 10), 2% (1 in 50), 7.7% (1 in 13) and 0.23% (1 in 430), respectively.

S.5 Design Flood Estimation

Figures 6.1 to **6.8** show the TUFLOW model results for the 20% (1 in 5), 10% (1 in 10), 5% (1 in 20), 2% (1 in 50), 1% (1 in 100), 0.5% (1 in 200) and 0.2% (1 in 500) AEP storm events, together with the PMF. These diagrams show the indicative extent and depth of inundation resulting from both Main Stream Flooding and Major Overland Flow at Molong for each design storm event.

Figure 6.9 shows design water surface profiles along the main arm of Molong Creek at Molong, while **Figure 6.10** shows stage hydrographs at selected road/rail crossings throughout the study area. **Table F1** in **Appendix F** sets out peak flood levels and the depth of inundation at selected road/rail crossings, while **Table G1** in **Appendix G** sets out design peak flows and corresponding critical storm durations at various locations in the study area.

Figure 6.11 shows the indicative extent and depth of Major Overland Flow in the immediate vicinity of the Molong CBD absent elevated water levels in Molong Creek for design storms with AEPs of 5% (1 in 20) and 1% (1 in 100).

The key findings of the present study in relation to Main Stream Flooding at Molong were as follows:

i. While floodwater surcharges the banks of Molong Creek during floods as frequent as 20% (1 in 5) AEP, affected areas are generally confined to undeveloped areas that are located along the western side of Betts Street and the northern side of Hills and Thistle streets.

ii. Floodwater commences to surcharge the left (western) bank of Molong Creek and overtop the Orange-Broken Hill Railway upstream (south) of Euchareena Road during floods larger than about 10% (1 in 10) AEP where it impacts existing development that is located in the vicinity of the Molong Central Business District (**CBD**).

iii. While the Euchareena Road and Orange-Broken Hill railway crossings of Molong Creek (denoted herein as the ‘Euchareena Road Bridge” and “Molong Creek Rail Bridge”, respectively) increase peak flood levels a short distance upstream of their location, they are not the main cause of the aforementioned breakout of floodwater which impacts the Molong CBD. Rather, it is the natural shape of the floodplain that dictates that during major flood events, the left (western) overbank of Molong Creek naturally functions as a conveyor of floodwater.

iv. Due to the relatively steep-sided nature of the floodplain at Molong, the majority of the floodplain is active at the 5% (1 in 20) AEP level of flooding, with only incremental increases in the extent of inundation apparent with increasing flood magnitude.

v. For the same reason, peak PMF levels along the main arm of Molong Creek are about 5 m higher than corresponding peak 1% (1 in 100) AEP flood levels.

vi. Access between the NSW SES Molong headquarters which is located on William Street, and the main parts of Molong would be cut when Hill Street becomes inundated by floodwater from Boree Hollow in a 0.5% (1 in 200) AEP flood.

i. The low point in Market Street adjacent to its intersection with End Street is set at a lower elevation than the obvert of the Moss Hollow Creek culvert crossing that is located approximately 90 m to the north. As a result, floodwater commences to overtop Market Street before the culverts are pressurised, where it flows in an easterly direction through existing residential development before discharging to Molong Creek upstream of its confluence with Moss Hollow Creek.

The key findings of the present study in relation to Major Overland Flow at Molong were as follows:

i. The piped drainage elements beneath the road crossings of the major drainage line that runs through Pillans Park (denoted herein as the "Pillans Park Drainage Line") have a capacity of less than 20% (1 in 5) AEP, whereby the resulting surcharge flow discharges through adjacent residential development.

ii. Floodwater commences to surcharge the piped drainage system on the Pillans Park Drainage Line between Iceworks Lane and Watson Street in a 5% (1 in 20) AEP storm event.

iii. With the exception of six locations in Molong, depths of inundation along roads attributable to Major Overland Flow are generally less than 0.2 m.

iv. In the instance when intense rain falls directly over Molong in the absence of elevated water levels in Molong Creek, ponding of Major Overland Flow would occur to maximum depths of about 0.4 m and 0.5 m for design storms with AEPs of 5% (1 in 20) and 1% (1 in 100), respectively at the following locations in the vicinity of the Molong CBD:

   - in Watson Street south of its intersection with Banks Street;
   - in Banks Street west of its intersection with Watson Street; and
   - in Hills Street near its intersection with Gidley Street.

   Stormwater ponding in the road reserve at the above locations is shown to extend into adjacent commercial and residential development, albeit generally at reduced depths.

A detailed description of the nature of both Main Stream Flooding and Major Overland Flow over the full range of design flood events is provided in **Section 6.2.4** of the report.

S.6 Economic Impact of Flooding

The 10% (1 in 10) AEP flood event is considered to be the "threshold" at which the number of individual buildings that would experience above-floor inundation increases significantly at Molong. For example, a total of 36 buildings (24 commercial, six residential and six public buildings) would be subject to above-floor inundation in a 10% (1 in 10) AEP, resulting in total flood damages of about $2.7 Million. The total number of buildings inundated above-floor level increases to about 94 (44 commercial, 41 residential and nine public buildings) in a 1% (1 in 100) AEP flood event resulting in total flood damages of about $11.8 Million. **Figures 6.1** to **6.8** show the indicative depth of above-floor inundation that would be experienced in individual buildings at Molong during flood events ranging between 20% (1 in 5) AEP and the PMF.

The *"Present Worth Value"* of tangible damages at Molong resulting from all floods up to the 1% (1 in 100) AEP event is about $12.0 Million for both Main Stream Flooding and Major Overland Flow, while the *Present Worth Value* of tangible damages for flooding purely from Molong Creek at the 5% (1 in 20) and 1% (1 in 100) AEP level of flooding is about $4.8 Million and $8.0 Million, respectively. Therefore, one or more schemes costing up to these amounts could be economically justified if they eliminated the associated flood damages for all flood events up to this level. While schemes costing more than this value would have a benefit/cost ratio less than 1, they may still be justified according to a multi-objective approach which considers other criteria in addition to economic feasibility.

Appendix H of this report contains further details on the economic assessment that was undertaken as part of the study.

S.7 Flood Hazard Classification and Hydraulic Categorisation

Diagrams showing the flood hazard vulnerability classification for the 5% (1 in 20), 2% (1 in 50) and 1% (1 in 100) AEP flood events are shown on **Figures 6.12**, **6.13** and **6.14**, respectively. The flood hazard vulnerability classification is dependent on the depth and velocity of flow on the floodplain. Flood affected areas in the study area have been divided into the following six flood hazard vulnerability categories on the basis of these two variables and the relationships presented in ARR 2019:

- H1, which is considered to be safe for people, vehicles and buildings.
- H2, which is considered to be unsafe for small vehicles.
- H3, which is considered to be unsafe for vehicles, children and the elderly.
- H4, which is considered to be unsafe for people and vehicles.
- H5, which is considered to be unsafe for people and vehicles, and where all buildings would be vulnerable to structural damage, with some less robust building types vulnerable to failure.
- H6, which is considered to be unsafe for people and vehicles, and where all buildings are considered to be vulnerable to failure.

The present study found that at the 1% (1 in 100) AEP level of flooding:

- areas classified as H6 are generally confined to the inbank area of Molong Creek;
- large areas of H5 are located on the overbank area Molong Creek and along its tributary arms;
- the majority of the Molong CBD is classified as H4, with isolated pockets of both H3 and H5; and
- areas affected by Major Overland Flow are generally classified as either H1 or H2, with the exception of areas where floodwater ponds on the upstream side of roads where it is generally classified as either H3 or H4.

The hydraulic categorisation of the floodplain for the 5% (1 in 20), 2% (1 in 50) and 1% (1 in 100) AEP flood events is shown on **Figures 6.15**, **6.16** and **6.17**, respectively. The hydraulic categorisation requires the assessment of the main flow paths. Those areas of the floodplain where a significant discharge of water occurs during floods are denoted Floodways. Floodways are areas that, even if only partially blocked, would cause a significant re-distribution of flood flow or a significant increase in flood levels. The remainder of the floodplain is denoted *Flood Storage* or *Flood Fringe* areas.

The relatively steep-sided nature of the floodplain at Molong results in the majority of the overbank area of Molong Creek and its major tributaries operating as floodways during major flood events. This includes the western overbank of Molong Creek within the flood affected parts of the Molong CBD.

S.8 Sensitivity Analyses

Analyses were undertaken to test the sensitivity of flood behaviour to:

i. An increase in hydraulic roughness. **Figure 6.18** shows the effects a 20 per cent increase in the adopted 'best estimate' hydraulic roughness values would have on flood behaviour at the 1% AEP level of flooding.

ii. A partial blockage of major hydraulic structures by debris. **Figure 6.19** shows the effects a partial blockage of hydraulic structures would have on flood behaviour at the 1% AEP level of flooding.

iii. The removal of the Orange-Broken Hill Railway and Euchareena Road bridges and their raised approaches. **Figure 6.20** shows the impact that the removal of the rail bridges and their raised would have on flood behaviour, while **Figure 6.21** shows the impact that the removal of both the rail and road bridges and their raised approaches would have on flood behaviour. **Figure 6.22** shows the reduction that the removal of the rail and road bridges, together with their raised approaches would have on design water surface profiles along the main arm of Molong Creek.

iv. Increases in rainfall intensity associated with future climate change. **Figures 6.23**, **6.24** and **6.25** show the effects a 10 and 30 per cent increase in design 1% AEP rainfall intensities would have on flood behaviour in the study area.

The sensitivity analyses identified that:

- peak 1% AEP flood levels could be increased by a maximum of about 240 mm as a result of changes in hydraulic roughness;
- while a partial blockage of the hydraulic structures generally has a negligible impact on flood behaviour at the 1% AEP level of flooding, a partial blockage of the road crossings of Shingle Ridge Creek and Foys Creek could cause localised increases in peak flood levels of up to 400 mm;
- while the removal of the rail bridges north of Thistle Street and their raised approaches would reduce peak flood levels on the Molong Creek floodplain, the greatest benefits would be limited to the reach of creek extending downstream of the Dr Ross Memorial Recreation Ground;
- while the removal of the Euchareena Road Bridge and its raised approaches has a greater impact in terms of reducing peak flood levels on the main arm of Molong Creek immediately upstream of its location, both the road bridge and nearby Molong Creek Railway Bridge contribute about equally to increased flood levels in the Molong CBD;[1] and
- an increase in the intensity of rainfall associated with future climate change has the potential to increase peak 1% AEP flood levels by a maximum of about 500 mm.

[1] While not assessed as part of the present study, the effects of the Molong Creek Railway Bridge and its raised approaches on flooding conditions in the Molong CBD is likely exacerbated by the presence of the Euchareena Road Bridge and its raised approaches given the water surface profiles would not be as high adjacent to the breakout absent the road crossing.

S.9 Interim Flood Planning Area

Figure 6.26 (3 sheets) shows the extent of the Interim Flood Planning Area (**FPA**) at Molong as it relates to both Main Stream Flooding and Major Overland Flow. The extent of the Interim FPA has been defined as follows:

- Interim Main Stream Flooding FPA – Land which is subject to inundation as a result of floodwater that surcharges the inbank area of Molong Creek and its major tributaries, and which also lies at or below the peak 1% (1 in 100) AEP flood level plus 0.5 m freeboard.
- Interim Major Overland Flow FPA – Land which lies outside the Main Stream Flooding FPA but would be subject to depths of inundation of greater than 0.1 m in a 1% (1 in 100) AEP storm event.

Pending the completion of the future *Molong FRMS&P*, it is recommended that the habitable floor levels of future development be set a minimum 0.5 m above the corresponding peak 1% (1 in 100) AEP flood level, noting that the future study may determine that the freeboard provision may be reduced in areas that lie within the extent of the Major Overland Flow FPA. An assessment should also be undertaken by Council as part of any future Development Application to confirm that the proposed development will not form an obstruction to the passage of overland flow through the subject site.

Figure 6.26 also shows the extent of the *Outer Floodplain*, which is the area which lies between the Interim FPA and the extent of the PMF. It is recommended that Council consider precluding critical, sensitive and vulnerable type development such as hospitals with emergency facilities, emergency services facilities, utilities, community evacuation centres, aged care homes, seniors housing, group homes, boarding houses, hostels, caravan parks, schools and childcare facilities in this area.

1 INTRODUCTION

1.1 Study Background

This report presents the findings of an investigation of flooding at the township of Molong in the Cabonne Council (**Council**) Local Government Area (**LGA**). The study has been commissioned by Council with financial and technical support from the NSW Government, via the Department of Planning and Environment (**DPE**). **Figure 1.1** shows the extent of the study catchment at Molong.

The study objective was to define flood behaviour in terms of flows, water levels and velocities for floods ranging between 20 and 0.2 per cent Annual Exceedance Probability (**AEP**), as well as for the Probable Maximum Flood (**PMF**). The investigation involved rainfall-runoff hydrologic modelling of the catchments to assess flows in the drainage systems of the study catchment and application of these flows to a hydraulic model to assess peak water levels and flow velocities (collectively referred to herein as 'flood modelling'). The model results were interpreted to present a detailed picture of flooding under present day conditions.

The study focuses on the following two types of flooding which are present in different parts of the study area:

- **Main Stream Flooding** which occurs when floodwater surcharges the inbank area of Molong Creek, Reedy Creek, Boree Hollow, Moss Hollow Creek and Foys Creek. Main Stream Flooding is typically characterised by relatively deep and fast flowing floodwater but can include shallower and slower moving floodwater on the overbank of the aforementioned creeks.
- **Major Overland Flow**, which is experienced during periods of heavy rain and is generally characterised by relatively shallow and slow-moving floodwater that is conveyed overland in an uncontrolled manner toward the abovementioned watercourses.

The study forms the first and second step in the flood risk management process for Molong (refer process diagram presented in the Foreword) and is a precursor of the future *Molong Flood Risk Management Study and Plan* (***Molong FRMS&P***) which will consider measures which are aimed at reducing the existing, future and continuing flood risk in the town.

1.2 Community Consultation and Available Data

To assist with data collection and promotion of the study to the community, a *Community Newsletter* and *Questionnaire* was distributed by Council in February 2023 to residents and business owners in the study area. A copy of the *Community Newsletter* and *Questionnaire* is contained in **Appendix A** of this report.

Council advised that approximately 1,500 *Community Newsletters* and *Questionnaires* were distributed to residents and business owners in the study area, with a total of 129 responses received by the closing date of submissions (a response rate of less than six per cent). Of the 129 respondents, 85 noted that they had been affected by flooding.

The following events were identified by respondents to the *Community Questionnaire*:

- March 1956 (day not specified);
- February 1972 (day not specified);
- 19-20 April 1990;
- 1-2 August 1990;
- 28 January 2018;
- 26 January 2020;
- 26 January 2021;
- 26 November 2021

- 8 November 2005;
- 2010 (month not specified);
- 20 July 2016;
- September 2017 (day not specified);
- October 2022 (day not specified);
- 1 November 2022; and
- 13-14 November 2022.

The most frequently identified floods were also the most recent, with the 13-14 November 2022, 26 November 2021 and 8 November 2005 storms identified by 77 respondents, 63 respondents and 33 respondents, respectively. Information on historic flooding patterns obtained from the responses assisted with "ground-truthing" the results of the flood modelling.

Appendix B contains details of the data that were available for the present study, while **Appendix C** contains several photos that were provided by Council and respondents to the *Community Questionnaire* which show historic flood behaviour at Molong during storms that occurred on 8 November 2005, 20 July 2016, 26 January 2020, 26 November 2021 and 13-14 November 2022.

1.3 Previous Investigations

The following flooding investigations have been undertaken in the immediate vicinity of the study area:

- *New South Wales Inland Rivers Flood Plain Management Studies – Macquarie Valley* (Sinclair, Knight and Partners, 1984)
- *Molong Flood Study* (Department of Land and Water Conservation, 1995)
- *Molong Floodplain Management Study* (Bewsher Consulting, 1997)
- *Molong Flood Study Options Report* (Ecclestone, 2010)
- *Review of Molong Floodplain Risk Management Study* (URS, 2011)
- *Examining the resilience of rural communities to flooding emergencies* (Manock, Ian, 2012)
- *Cabonne Shire Local Flood Plan* (NSW SES, 2013)
- *Proposed Molong Town Levee – Feasibility Study – Levee Options Assessment* (SMEC, 2018)
- *Molong Creek Flood Study & Action Plan* (growMOLONG, 2019)
- *Flood Impact Assessment – Market St, End St Intersection, Molong, NSW 2866* (Calare Civil, 2022)

Chapter B2 of **Appendix B** contains a summary of the above studies.

1.4 Layout of Report

Chapter 2 contains background information including a brief description of the study catchment and its drainage systems, a brief history of flooding and an analysis of the available rain gauge record.

Chapter 3 deals with the hydrology of the study catchment and describes the development and calibration of the DRAINS-based hydrologic model that was used to generate discharge hydrographs for input to the hydraulic model.

Chapter 4 deals with the development and calibration of the TUFLOW hydraulic model which was used to analyse flood behaviour in the study area.

Chapter 5 deals with the derivation of design discharge hydrographs, which involved the determination of design storm rainfall depths over the catchment for a range of storm durations and conversion of the rainfalls to discharge hydrographs.

Chapter 6 details the results of the hydraulic modelling of the design floods in the study area. Results are presented as plans showing indicative extents and depths of inundation for a range of design flood events up to the PMF. This chapter also includes an assessment of flood hazard and hydraulic categorisation. It also presents the results of various sensitivity studies undertaken using the TUFLOW model, including the effects changes in hydraulic roughness, a partial blockage of the hydraulic structures and potential increases in rainfall intensities due to future climate change will have on flood behaviour. This chapter also deals with the derivation of *Flood Planning Levels* for the study area.

Chapter 7 contains a list of references, whilst **Chapter 8** contains a list of flood-related terminology that is relevant to the scope of the study.

The following appendices are included in the report:

- **Appendix A**, which contains a copy of the *Community Newsletter* and *Questionnaire* that were distributed at the commencement of the study to residents and business owners in the study area.
- **Appendix B**, which contains a list of data that were available for the present study, a review of flooding investigations that have previously been undertaken at Molong, as well as a summary of the responses to the *Community Questionnaire*.
- **Appendix C**, which contains photographs showing flood behaviour in the study area during storms that occurred on 8 November 2005, 20 July 2016, 26 January 2020, 26 November 2021 and 13-14 November 2022.
- **Appendix D**, which contains a copy of the design input data that were extracted from the *Australian Rainfall and Runoff* (**ARR**) *Data Hub* for the study area.
- **Appendix E**, which summarises design blockage values that were assigned to the transverse drainage structures in the TUFLOW.
- **Appendix F**, which contains a table setting out flood related data at individual road crossing at Molong.
- **Appendix G**, which contains a table listing the peak flow at key locations in the study area for the full range of design storm events.
- **Appendix H**, which contains an assessment of the economic impacts of flooding to existing residential, commercial and industrial development, as well as public buildings in Molong.

Figures referred to in the main body of the report are bound separately in **Volume 2**.

2 BACKGROUND INFORMATION

2.1 Catchment Description

2.1.1. General

The township of Molong has a population of about 1,600 and is located on the banks of Molong Creek in the Cabonne Council LGA. **Figure 1.1** shows that Molong is located in the headwaters of the Macquarie River Valley catchment. Molong Creek flows in a northerly direction through the urbanised parts of Molong and has a total catchment area of about 300 km^2 at the point at which it discharges to the Bell River approximately 13 km to the north of the town.

Figure 2.1 shows the extent of the catchments which contribute to flow in Molong Creek at the location of two WaterNSW operated stream gauges that are located on the watercourse, and at its confluence with the Bell River. **Figure 2.2** (3 sheets) shows details of the existing stormwater drainage system in the urbanised parts of the town.

The right-hand side of **Figure 2.1** shows the extent of land zoned for urban type develop in the vicinity of the town (herein referred as the “study area”). The study area comprises both general and large lot residential type development on both banks of the creek. The commercial centre of the town which comprises both general residential and commercial type development is located on the left (western) bank of the creek in the area bounded by Hill Street to the north, Watson Street to the east, Riddell Street to the south and Edward Street to the north (referred herein as the “Molong CBD”). There are isolated pockets of industrial zoned land at the following locations:

- on the eastern and western side of the railway to the north of Marsden Street;
- in the area bounded by Riddell Street to the north, George Street to the east, Wellington Street to the south and Boree Hollow to the west;
- in the vicinity of the intersection of Starrlea Road and Hill Street; and
- in the vicinity of the intersection of Market Street and Castle Street.

Figure 2.2 (sheets 2 and 3) shows the layout of the existing piped drainage system which generally comprises piped and culvert crossings beneath the roads and grass lined table drains that convey overland flow towards Molong Creek and its tributaries. Enclosed drainage systems comprising piped elements and stormwater inlet pits are present at the following locations:

- between Park Street and South Street to the east of Gidley Street;
- in the vicinity of the intersection of the Mitchell Highway and Wellington Street;
- along Riddell Street between Edward Street and Molong Creek;
- in the vicinity of the intersection of Watson Street and Bank Street; and
- along Gidley Street between Bank Street and Molong Creek.

Figure 2.2 (sheets 2 and 3) shows the location of eight flood gates that have been fitted to the outlets of the existing piped drainage system to prevent floodwater in Molong Creek backing up the local drainage system, the location of which were based on the information contained in SMEC, 2018.

Figure 2.2 shows that Reddy Creek, Boree Hollow, Moss Hollow Creek and Foys Creek discharge to Molong Creek in the vicinity of the town, as do a number of unnamed drainage lines that flow through the study area and discharge to the main arm of the creek. **Figure 2.2** (sheet 3) shows the alignment of a concentrated flow path that runs through the urbanised part of Molong between Pillans Park and Molong Creek (herein denoted the "Pillans Park Drainage Line").

The following sections of this report provide a description of the various watercourses which contribute to flooding in the study area.

2.1.2. Molong Creek

Figure 1.1 shows that the headwaters of Molong Creek are located approximately 30 km to the south of Molong in the vicinity of Mount Canobolas. **Figure 1.1** also shows that the following stream gauges are located in the Molong Creek catchment:

1. The WaterNSW operated *Molong Creek at Downstream Borenore Creek* (GS 421178) stream gauge (**Borenore stream gauge**) which was installed in December 2000 based on a recommendation contained in Bewsher, 1999. The Borenore stream gauge is located approximately 18 km upstream of the township, immediately downstream of the confluence between Molong Creek and Borenore Creek. The gauge has not been gauged and is primarily used for flood warning purposes.
2. The manually read NSW SES operated Wellington Street stream gauge, which is located on the right (eastern) bank of Molong Creek on the northern (downstream) side of the Marsden Street Bridge. The manually read stream gauge is primarily used by NSW SES for flood warning purposes.
3. The *Molong Creek at Molong* (GS 421049) stream gauge (**Molong stream gauge**), which was located on the right (eastern) bank of the watercourse, upstream of the Euchareena Road Bridge. The Molong stream gauge was in operation between July 1965 and January 1997.
4. The *Molong Creek at Copper Hill* (GS 421159) stream gauge (**Cooper Hill stream gauge**), which was located on the left (western) bank of the watercourse approximately 9 km downstream of the town. The Cooper Hill stream gauge was in operation between December 2000 and February 2005.

Figure 2.1 shows the location of three existing dams that are located in the Molong Creek catchment. The Molong Creek and Borenore Creek dams are water supply dams for Molong, while Lake Canobolas is used for recreational purposes. DLWC, 1995 found that the dams are maintained near full supply level and have a negligible effect on peak flows in Molong Creek.

The inbank area of Molong Creek generally comprises an incised 20 m wide by 3 m deep channel which has a grade of about 3.5% where it runs through the urbanised parts of Molong. **Figure 2.2** shows the location of the following five bridge crossings of Molong Creek at Molong:

- **Marsden Street Bridge**, which comprises a three span 35 m wide bridge structure;
- **Euchareena Road Bridge**, which comprises a two span 27.5 m wide bridge structure;
- **Molong Creek Railway Bridge**, which comprises a three span 33 m wide bridge structure that is skewed approximately 25˚ to the direction of flow;
- **Broken Hill Railway Bridge No. 1**, which comprises an eight span 56 m wide viaduct type structure; and
- **Broken Hill Railway Bridge No. 2**, which comprises a five span 34 m long viaduct type structure on the left overbank area of Molong Creek.

Also shown on **Figure 2.2** is the location of the following two inline weirs on Molong Creek:

- **Gamboola Weir**, which is located approximately 950 m upstream of the Marsden Street bridge.
- **Molong Weir**, which is located approximately 80 m upstream of the Euchareena Road Bridge.

2.1.3. Boree Hollow

The headwaters of the Boree Hollow catchment are located approximately 10 km to the south of Molong. Boree Hollow generally runs in a northerly direction through the study area, with the exception of a 250 m reach of the watercourse that runs in an easterly direction on the northern side of Riddell Street. Boree Hollow has a total catchment area of about 16.1 km^2 at the point at which it discharges to Molong Creek on the southern (upstream) side of the Orange-Broken Hill Railway Line.

There are four road crossings of Boree Hollow in the study area; one low level causeway crossing of at Riddel Street and three higher level road crossings at Wellington Street, Willams Street and Hill Street.

Boree Hollow is an ephemeral stream that generally has an undefined channel upstream of Wellington Street. Downstream of this location, the watercourse comprises a 10 m wide by 2 m deep channel where it runs in a northerly direction between Wellington Street and Riddel Street before meandering in an easterly direction through private property where it is about 5 m in width and 1 m in depth. An engineered 10 m wide by 1.5 m deep grass swale is located on the right (eastern) overbank of Boree Hollow where it runs in an easterly direction in the Riddel Street road reserve upstream of Williams Street.

On the downstream side of Williams Street, Boree Hollow continues as a 20 m wide by 1.5 m deep grassed swale before continuing in a northerly direction as an ill-defined channel through private property to Hill Street. The reach of Boree Hollow between Hill Street and the point at which it discharges to Molong Creek comprises a 5 m wide by 2 m deep channel.

2.1.4. Moss Hollow Creek

Moss Hollow Creek runs in a north-westerly direction through the study area and has a catchment area of about 13.3 km^2 at its point of discharge to Molong Creek. Moss Hollow Creek generally comprises a 5 m wide by 1 m deep channel which has a grade of about 1% where it runs through the study area.

There are six road crossings of Moss Hollow in the study area: at Packham Drive, Quarry Road, Starrlea Road, Banjo Patterson Way, End Street and Market Street.

2.1.5. Foys Creek

Foys Creek runs in a north-westerly direction through the study area and has a catchment area of about 6.9 km^2 at its point of discharge to Molong Creek. Foys Creek generally comprises a 10 m wide channel that is between 1-3 m deep and has a grade of about 1.7%.

There is a low-level crossing of Foys Creek at Shreeve Road and a higher-level road crossing where the Mitchell Highway crosses the watercourse immediately upstream of its confluence with Molong Creek.

2.1.6. Pillans Park Drainage Line

Figure 2.1 (sheet 2) shows that the Pillans Park Drainage Line runs in a northerly direction from the intersection of Edward Place and Smith Street to Wellington Street, and then continues in an easterly direction across Gidley Street, Watson Street and the Orange-Broken Hill Railway before discharging to Molong Creek about 90 m downstream of the Marsden Street Bridge. The total catchment area of the Pillans Park Drainage Line is about 0.28 km^2.

The Pillans Park Drainage Line consists of overland flow paths of varying degrees of definition, with short sections of pipe culverts beneath roads, with the exception of the 130 m reach of the watercourse between Iceworks Lane and the eastern side of Watson Street which comprises a single 1200 mm diameter pipe that transitions to twin 1050 mm diameter pipes beneath Watson Street. The Pillans Park Drainage Line has a grade of about 5%.

2.2 Flood History and Analysis of Historic Rainfall

Respondents to the *Community Questionnaire* identified a number of notably intense storm events that have been experienced in the study area, the dates of which are given in **Section 1.2** of the report. A number of respondents also provided photographic evidence (refer **Appendix C**), as well as descriptions of the patterns of overland flow in the vicinity of their properties. Of the flood events identified by the response to the *Community Questionnaire*, the 14 November 2022 is considered to be the flood of record at Molong.

During major floods on Molong Creek, floodwater surcharges the left (western) bank of Molong Creek where it overtops the Orange-Broken Hill Railway upstream of the Euchareena Road Bridge. Floodwater that overtops the railway at this location flows in a northerly direction along Watson Street and into Bank Street, impacting a larger number of residential and commercial properties that are located in and immediately adjacent to the Molong CBD.

Based on anecdotal information provided by the community, it is understood that the buildings in Bank Street initially block the flow of water until such time as the doors and windows give way, after which time floodwater more freely flows through the affected buildings towards Gasworks Lane. Floodwater that inundates the Molong CBD eventually discharges back into Molong Creek in the vicinity of the intersection of Hill Street and Gidley Street.

The railway is known to have been overtopped by floodwater on six occasions since 1928, those being in February 1928, March 1956, August 1990, November 2005, November 2021 and November 2022.

2.3 Analysis of Stream Gauge Data

Column B in **Table 2.1** over sets out the results of a flood frequency analysis that was undertaken as part of DLWC, 1995 using the 28 years of annual peak flows at the Molong stream gauge, while. Column C shows that the results of a flood frequency that was undertaken as part of the present study using the TUFLOW Flike software for the same period of record. By inspection, the peak flows derived using the TUFLOW Flike software are comparable to those derived as part of the previous investigation.

TABLE 2.1
FLOOD FREQUENCY DERIVED DESIGN PEAK FLOW ESTIMATES
MOLONG STREAM GAUGE

Design Event [A]	DLWC, 1995	Present Study	
	1966-1994 All Flows [B]	1966 – 1993 All Flows [C]	1966 – 1993 + 3 x Historic Floods [D]
1% AEP	280	265	295
2% AEP	230	210	240
5% AEP	165	155	182
10% AEP	120	116	138
20% AEP	80	77	90
50% AEP	50	28	28

It is noted that the November 2005, November 2021 and November 2022 floods were all larger than the August 1990 flood, which is the largest flood in the 28 years of annual maxima peak flow data upon which the flood frequency analysis was based. Column D of **Table 2.1** shows the results of incorporating the three larger historic flood events that have occurred between 1994 and 2022 in the flood frequency analysis. It was found that incorporating the three larger floods had a negligible impact on the design peak flow estimates at Molong.

Ultimately, DLWC, 1995 deemed the results of the flood frequency analysis to only be applicable for the more frequent flood events given the relatively short period of record. As the inclusion of the three larger events as part of the present study did not significantly increase the peak flow estimates for the rarer events, it is concluded that the values in Column D of **Table 2.1** should also not be relied upon for design flood estimation purposes.

2.4 Analysis of Historic Rainfall

2.4.1. General

Figure 1.1 shows the location of the nearby Bureau of Meteorology (**BoM**) and WaterNSW operated pluviographic rain gauges that are located in the vicinity of the study area.

Figure 2.3 (2 sheets) shows design versus historic intensity-frequency-duration (**IFD**) curves for the three BoM and one WaterNSW operated rain gauges for the storm events identified by the respondents to the *Community Questionnaire*, while **Table 2.2** at the end of this chapter gives the approximate AEP of the recorded rainfall for durations ranging between 0.25 and 24 hours.

Table 2.2 and **Figure 2.3** show that the storms identified by the respondents to the *Community Questionnaire* varied in intensity. The two storms that occurred on 8 November 2005 and 14 November 2022 were equivalent to design storms with AEPs of up to about 0.5% (1 in 200). The storm that occurred on 31 October to 1 November 2022 was equivalent to about a 1% (1 in 100) AEP event for a storm duration of 1-1.5 hours, while the 26 December 2010 storm was equivalent to up to about a 2% (1 in 50) AEP event for storm durations ranging between 1 and 24 hours. The remaining storm events that were identified by respondents to the *Community Questionnaire* were generally equivalent to design storms with AEPs of 10% (1 in 10) or less.

Based on the availability of historic flood data (refer **Appendix B** for discussion), the storm events that occurred on 1-2 August 1990, 8 November 2005, 26 November 2021 and 14 November 2022 were selected for use in the calibration of the hydrologic and hydraulic models that were developed as part of the present study. **Figure 2.4** shows the cumulative rainfall that was recorded at the nearby rain gauges for these four storm events.

2.4.2. 1-2 August 1990 Storm Event

A total of 15 respondents to the *Community Questionnaire* indicated that they had experienced flooding as a result of the August 1990 storm event. **Figure 2.4**, sheet 1 shows that rainfall fell relatively consistently between 12:00 hours on 1 August and 12:00 hours on 2 August 1990, with flood levels peaking at around 09:00 hours on 2 August 1990. **Figure 2.5** shows that the rainfall was relatively uniform across the study catchment, with rainfall totals of about 70-80 mm shown to have occurred.

2.4.3. 8 November 2005 Storm Event

A total of 33 respondents to the *Community Questionnaire* indicated that they were affected by flooding on 8 November 2005. **Figures 2.4**, sheet 1 shows that flooding occurred after between about 73 mm and 85 mm of rain fell between 22:30 hours on 7 November 2005 and 04:00 hours on 8 November 2005. **Figures 2.3**, sheet 1 and **Table 2.2** shows that the recorded rainfall was equivalent to a design storm event with an AEP of about 0.5% (1 in 200) at the centre of the study catchment at the *Molong Creek at Downstream Borenore Creek* rainfall gauge, and only equivalent to about a 2% AEP event in the headwaters of the catchment in the vicinity of the *Orange Agricultural Institute* rainfall gauge.

It is noted that while growMOLONG, 2019 states that "*in the top end of town itself residents recorded 250 mm*" of rainfall, a review of the rainfall recorded at the BoM operated daily rainfall gauges at the Molong Post Office (GS 65041) and Hill Street (65023) found that the total depth of rainfall that was recorded by the two official gauges in town was 93.2 mm and 95.0 mm, respectively.

Figure 2.4, sheet 1 shows that flood levels peaked at the Borenore stream gauge at around 02:30 hours on 8 November 2005, while growMOLONG, 2019 indicates that the flood wave hit the Molong CBD shortly after 03:00 hours on 8 November 2005.

While **Appendix C** contains a number of photos showing flood behaviour at Molong during the 8 November 2005 flood, the photos are taken during daylight hours which is likely after the peak of the flood had passed through the town. **Plates C1.3**, **C1.4**, **C1.5** and **C1.6** show floodwater inundating the railway between the grain silos and the railway station, while **Plates C1.9** and **C1.11** show floodwater flowing in a northerly direction along Watson Street in the vicinity of its intersection with Bank Street. **Plates C1.8**, **C1.10** and **C1.12** shows floodwater ponding in Bank Street, while **Plate C1.14** shows floodwater flowing in a northerly direction between two buildings that are located on the northern side of Bank Street. **Plate C1.18** shows the build-up of debris on the upstream side of the Molong Creek Railway Bridge during the 8 November 2005 flood.

TABLE 2.2
APPROXIMATE AEPs OF RECORDED RAINFALL FOR HISTORIC STORM EVENTS[1]
(% AEP)

Historic Storm Event	Gauge Number[2]	Gauge Name[2]	Storm Duration										
			30 minute	**1 hour**	**1.5 hrs**	**2 hrs**	**3 hrs**	**4.5 hrs**	**6 hrs**	**9 hours**	**12 hrs**	**18 hrs**	**24 hrs**
1-2 August 1990	63254	Orange Agricultural Institute	>50%	>50%	>50%	>50%	>50%	>50%	>50%	>50%	50-20%	50-20%	20%
8 November 2005	63254	Orange Agricultural Institute	>50%	50-20%	20-10%	10-5%	5%	2%	5-2%	10-5%	20-10%	50-20%	50-20%
	421178	Molong Creek at Downstream Borenore Creek	5%	5%	10-5%	5-2%	2-1%	0.5%	1-0.5%	2%	5-2%	10-5%	10%
26 December 2010	421178	Molong Creek at Downstream Borenore Creek	20	2%	5%	2%	5-2%	5%	5%	5-2%	5	2%	5-2%
20 July 2016	421178	Molong Creek at Downstream Borenore Creek	>50%	>50%	>50%	>50%	>50%	>50%	>50%	>50	>50%	>50%	>50%
28 January 2018	421178	Molong Creek at Downstream Borenore Creek	>50%	>50%	>50%	>50%	>50%	>50%	>50%	>50	>50%	>50%	>50%
26 January 2020	421178	Molong Creek at Downstream Borenore Creek	>50%	>50%	>50%	>50%	>50%	>50%	>50%	>50	>50%	>50%	>50%
26 November 2021	421178	Molong Creek at Downstream Borenore Creek	10%	10	10%	10-20	20%	50-20%	50%	50%	50%	10-20%	20%
31 October - 1 November 2022	421178	Molong Creek at Downstream Borenore Creek	>50%	1%	1%	50-20%	20%	20%	20%	50-20	50-20%	50%	50%
14 November 2022	63254	Orange Agricultural Institute	50-20%	20%	5-2%	5-2%	2-1%	2-1%	1%	2-1%	2%	5-2%	5%
	65110	Borenore (Lynden-Brae)	50-20%	<20%	<10%	5-2%	1%	1%	1-0.5%	1-0.5%	<1%	2%	2%
	421178	Molong Creek at Downstream Borenore Creek	20-10%	2%	2-1%	1%	1-0.5%	1-0.5%	2-1%	2-1%	5-2%	5%	5%
	65041	Molong Post Office	10-5%	2%	1%	1-0.5%	0.5%	1-0.5%	1%	2-1%	5-2%	5-2%	5%
	62106	Molong (Bonnie Doon)	50-20%	>50%	20-10%	20%	50-20%	50-20%	50-20%	>50%	>50%	>50%	>50%

1. Unless otherwise noted, storm frequency is given as % AEP.
2. Refer **Figure 1.1** for location.

2.4.4. 26 November 2021 Storm Event

A total of 63 respondents to the *Community Questionnaire* indicated that they were affected by flooding on 26 November 2021. **Figure 2.3**, sheet 1 and **Table 2.2** shows that the rainfall that was recorded by the Molong Creek at Downstream Borenore Creek rain gauge during the storm event had an AEP of about 10% (1 in 10).

Figures 2.4, sheet 2 shows that there were three bursts of rainfall over the period 06:00 hours on 25 November 2021 and 16:00 hours on 26 November 2021:

- The first burst of about 26 mm fell between 06:00 and 15:00 hours on 25 November 2021 and resulted in a minor increase in peak flood levels in Molong Creek which peaked at around 18:00 hours at the Borenore stream gauge.
- The second burst of 37 mm of rainfall fell between 01:00 and 03:00 hours on 26 November 2021 and caused another increase in peak flood levels at the Borenore stream gauge which peaked at around 05:15 hours on the same day.
- The third burst of about 35 mm fell between 11:30 hours and 16:00 hours and resulted in another peak at the Borenore stream gauge that occurred at 16:30 hours on 26 November 2021.

While **Figure 2.4**, sheet 2 shows that the second burst of rainfall produced the highest peak flood level at the Borenore stream gauge, there is no photographic evidence showing flooding in the town on the morning of 26 November 2021.

Information provided by the respondents to the *Community Questionnaire* indicates that the flooding was experienced along Molong Creek, Boree Hollow, Moss Hollow Creek and the Pillans Park Drainage Line during the afternoon of 26 November 2021, which was in response to the third burst of rainfall. **Plates C4.1** to **C4.5** show flooding along the Pillans Park Drainage Line at around 15:00 hours on 26 November 2021, while **Plate C4.6** shows floodwater originating from Boree Hollow inundating Riddell Street at 14:20 hours on the same day. **Plate C4.7** shows floodwater originating from Molong Creek inundating Hill Street in the vicinity of its intersection with Gidley Street at around 14:50 hours, while **Plate C4.8** shows floodwater originating from Moss Hollow Creek overtopping the low point in Market Street in the vicinity of its intersection with End Street at around 16:35 hours.

2.4.5. 14 November 2022 Storm Event

The flood that occurred in Molong on 14 November 2022 is considered the flood of record at the town, with 77 of the respondents to the *Community Questionnaire* indicating that they were affected by flooding during the event. **Figure 2.4**, sheet 2 shows that about 17-25 mm of rain fell across the study catchment between 06:00 hours and 21:00 hours on 13 November 2022, followed by a burst of 80-90 mm over the following six hours.

Figure 2.3, sheets 1 and 2, and **Table 2.2** show that the rainfall recorded at the five BoM operated Flood Warning Network rain gauges in the vicinity of Molong were equivalent to a design storm event with an AEP of about 1% (1 in 100) and 0.5% (1 in 200), except at the Molong (Bonnie Doon) which is located about 15 km to the north of the town where the rainfall was equivalent to only about a 10% AEP design storm event.

Figure 2.4, sheet 2 shows that flood levels peaked at the Borenore stream gauge at around 00:30 hours on 14 November 2022, while anecdotal evidence provided by respondents to the *Community Questionnaire* indicate that flood levels peaked in town about 2.5 hours later at 03:00 hours on 14 November 2022. While the flood appears to have peaked in town at around 03:00 hours, **Plates C5.3** and **C5.4** show that floodwater was ponding in Bank Street as early as 01:20 hours on 14 November 2022.

Plates C5.5 and **C5.6** show floodwater flowing in a northerly direction along Watson Street, while video evidence shows that the force of the floodwater was strong enough to transport a shipping container along the road at this location. **Plate C5.14** shows that the shipping container was eventually stopped by the concrete safety barrier that is present on the outside of the bend in the highway at the intersection of Watson Street and Hill Street.

Plate C5.7 shows the flood level in Bank Street almost reached the ceiling in the commercial premises that is located on the southwestern corner of Bank Street and Watson Street, while information provided by the respondents to the *Community Questionnaire* shows that properties in the Molong CBD were subject to above-floor inundation ranging between 0.5 m and 1.8 m.

Table 2.3 shows the results of the rapid impact assessment that was undertaken by NSW SES immediately following the November 2022 flood which documented the level of damage that was experience in individual properties.

TABLE 2.3
LEVEL OF PROPERTY DAMAGE EXPERIENCED AT MOLONG[1,2]
NOVEMBER 2022 FLOOD

Level of Property Damage	Number of Buildings in Each Category			
	Residential	Commercial/Industrial	Other	Outbuildings
Affected – Habitable	3	4	0	0
Damaged - Habitable	1	1	0	0
Damaged - Uninhabitable	13	26	0	0
Destroyed - Uninhabitable	1	4	2	2

1. Source: NSW SES Rapid Damage Assessment
2. Limited to properties located with the study area at Molong.

3 HYDROLOGIC MODEL DEVELOPMENT AND CALIBRATION

3.1 Hydrologic Modelling Approach

The present study required the use of a hydrologic model which is capable of representing the rainfall-runoff processes that occur within both the rural and urbanised parts of the study catchments. For hydrologic modelling, the practical choice is between the models known as DRAINS, RAFTS, RORB and WBNM. Whilst there is little to choose technically between these models, Hortonian and IL-CL loss models within the DRAINS software have been developed primarily for use in modelling the passage of a flood wave through urban catchments, whilst RAFTS, RORB and WBNM have been widely used in the preparation of rural flood studies.

Both the IL-CL and RAFTS modelling approaches which are built into the DRAINS software were used to generate discharge hydrographs from urban and rural areas, respectively, as this combined approach was considered to provide a more accurate representation of the rainfall runoff process. The discharge hydrographs generated by applying the IL-CL and RAFTS modelling approaches were applied to the TUFLOW hydraulic model as either point or distributed inflow sources (refer **Section 4.4** of this report for further details).

3.2 Hydrologic Model Layout

Figure 3.1 shows the layout of the hydrologic model that was developed as part of the present study (**Molong DRAINS Model**). Careful consideration was given to the definition of the sub-catchments which comprise the hydrologic model to ensure peak flows throughout the drainage system would be properly routed through the hydraulic model. In addition to using the Light Detecting and Ranging (**LiDAR**) based contour data, the location of inlet pits and headwalls were also taken into consideration when deriving the boundaries of the various sub-catchments. The study area was split into a total of 444 sub-catchments.

As the primary function of the hydrologic model was to generate discharge hydrographs for input to the TUFLOW hydraulic model, individual reaches linking the various sub-catchments were not incorporated in the model.

Percentages of impervious area were based on a visual inspection of the aerial photography and experience in determining appropriate values for different land-use types. The Total Impervious Area (**TIA**) was used as input to the hydrologic model as questions have been raised in the industry about the appropriateness of adopting the Effective Impervious Area (**EIA**) approach set out in ARR 2019 (Kus et al, 2018). One of the identified issues with the approach is that it is based on a volume check rather than a peak flow check, with the adjustment factor seen as taking account of additional losses that occur in the urban environment. However, Kus et al, 2018 found that the adoption of TIA in DRAINS more closely reproduced peak flows generated by an urban catchment, as well as those derived by other peak flow estimation methods.

The adoption of the EIA approach when using a hydrologic model to generate inflow hydrographs to a two-dimensional hydraulic model is also problematic, as it is accounting for a loss of volume from each sub-catchment possibly from additional depression storage, as well as surface runoff ponding behind solid structures such as buildings and fences, a feature which is also partially accounted for in the two-dimensional model domain. If the TIA is reduced by up to 40% as recommended in ARR 2019, then the total volume and also the peak flow being input to the two-dimensional hydraulic model would be significantly reduced. This fact, coupled with the additional flood storage that is present in the two-dimensional model domain has the potential to result in an under-estimation of peak flow and volume estimates, and hence peak flood levels throughout the catchment.

Figure 3.1 shows that the RAFTS modelling approach has been used for sub-catchments predominately comprising the rural portion of the study catchment, while the IL-CL modelling approach has been applied in the urbanised parts of Molong.

Sub-catchment slopes used for input to the hydrologic model were derived using the vectored average slope approach for sub-catchments characterised as rural (which are modelled using the RAFTS approach) and the average sub-catchment slope approach for sub-catchments characterised as urbanised (which are modelled using the IL-CL approach). Digital Elevation Models (**DEMs**) derived from the available LiDAR survey data were used as the basis for computing the slope.

3.3 Hydrologic Model Testing

3.3.1. General

Historic flood data suitable for use in the model calibration process comprises surveyed flood marks, as well as photographic and anecdotal evidence of flooding patterns for the floods that occurred on 2 August 1990, 8 November 2005, 26 November 2021 and 14 November 2022. As discussed in **Section 2.2**, the floods for which data were available are equivalent to between 10% (1 in 10) and 0.23% (1 in 430) AEP design storm events.

The historic data on storm flows were limited to a recorded discharge hydrograph at the discontinued Molong stream gauge for the August 1990 flood event. For the other modelled historic flood events, the procedure adopted for the calibration of the hydrologic model involved an iterative process sometimes referred to as “tuning”. This process involved the generation of discharge hydrographs for the historic storm events using a starting set of hydrologic model parameters. The discharge hydrographs were then input to the TUFLOW hydraulic model, which was then run with an initial set of hydraulic roughness parameters and the resulting flooding patterns compared with the photographic and anecdotal evidence.

Minimal iterations of this process were required, whereby changes were made to the hydrologic model parameters, after which the resulting adjusted discharge hydrographs were input to the hydraulic model until a good fit with recorded data was achieved (refer **Chapter 4** for further details).

3.3.2. Application of Historic Rainfall to the Hydrologic Model

Figure 2.4 (2 sheets) shows the bursts of rainfall that were incorporated in the hydrologic model for the four floods of interest. **Figures 2.5**, **2.6**, **2.7** and **2.8** show the extent over which the recorded rainfall was applied to the various sub-catchments comprising the hydrologic model, as well as isohyetal contours showing the cumulative depth of rainfall that was recorded over the Molong Creek catchment over the rain days of 2-3 August 1990, 8 November 2005, 26-27 November 2021 and 13-14 November 2022, respectively.

3.3.3. Hydrologic Model Parameters

A Manning’s n value of 0.04 was applied to sub-catchments primarily characterised as rural pastoral land, while a value of 0.06 was applied to sub-catchments comprising a mixture of cleared pastoral land and dense vegetation. A Manning’s n value of 0.08 was applied to sub-catchments comprising mostly dense vegetation. A Bx routing parameter of 0.8 was adopted for sub-catchments that were modelled in RAFTS.

The IL-CL hydrologic modelling approach in the DRAINS software requires information on the losses to be applied to determine the depth of rainfall excess. These loss rates differ for sub-catchment areas categorised as either impervious or pervious. Infiltration losses are of two types: an initial loss arising from water which is held in depressions which must be filled before runoff commences, and a continuing loss rate which depends on the type of soil and the duration of the storm event. The IL-CL approach also requires information on flow path characteristics in order to compute the time of travel of the flood wave through the sub-catchments.

The initial and continuing loss rates used to derive the discharge hydrographs are set out in **Table 3.1**. These discharge hydrographs were then applied to the TUFLOW model as inflows, and "tuned" to give a good match with the available historic flood data.

TABLE 3.1
ADOPTED INITIAL AND CONTINUING LOSS VALUES
HISTORIC STORM EVENTS

Historic Flood	Initial Loss (mm)		Continuing Loss (mm/hr)	
	Impervious Area	Pervious Area	Impervious Area	Pervious Area
2 August 1990	0	20	0	0.8
8 November 2005	0	40	0	2.5
26 November 2021	0	30	0	2.5
14 November 2022	0	30	0	2.5

3.3.4. Results of Model Testing

Table 3.2 sets out the Molong DRAINS Model derived peak flows at the location of the two stream gauges for the assessed historic flood events, as well as the approximate AEP of each based on the design flood modelling that has been undertaken as part of the present study (refer **Section 5.3** for further discussion) . The initial and continuing loss values of 20 mm and 0.8 mm/hr, respectively that were adopted for the August 1990 storm event are the same values that were found to give a good match with the recorded discharge hydrograph at the Molong stream gauge for the same historic event as part of DLWC, 1995. **Figure 2.4**, sheet 1 shows that the Molong DRAINS Model derived discharge hydrograph at the Molong stream gauge is comparable to the recorded hydrograph.

TABLE 3.2
MODELLED PEAK FLOW AT BORENORE AND MOLONG STREAM GAUGES
HISTORIC FLOOD EVENTS

Historic Flood	Peak Flow (m^3/s)		Approximate AEP[1]
	Borenore Stream Gauge	Molong Stream Gauge	
2 August 1990	114	199	10% (1 in 10) AEP
8 November 2005	249	335	2% (1 in 50) AEP
26 November 2021	93	226	7.7% (1 in 13) AEP
14 November 2022	412	577	0.23% (1 in 430) AEP

1. Based on the flows at the discontinued Molong Creek at Molong stream gauge.

It was not possible to compare the results of the Molong DRAINS Model to recorded discharge hydrographs at the Molong and Borenore stream gauges for the November 2005, November 2021 and November 2022 storm events as it has not been gauged. In order to validate the hydrologic response time of the Molong DRAINS Model during the more recent storm events, the time of the recorded peak flood level at the Borenore stream gauge was compared to the time of the modelled peak flow at the same location.

Table 3.3 shows that the time of the flood peak at the Borenore stream gauge in the Molong DRAINS Model is within 3 hours of the recorded peak. It was not possible to achieve an exact match between the recorded and modelled time of flood peak as the rainfall that was applied to the Molong DRAINS Model for the 8 November 2005 and 26 November 2021 floods is considered not to be representative of the spatial and temporal distribution of rainfall that occurred across the whole of the study catchment. While rainfall recorded at four rain gauges were applied to the Molong DRAINS Model for the 14 November 2022 flood, it was still not possible to achieve an exact match between the recorded and modelled time of flood peak, which again is considered to be a function of the recorded rainfall not accurately reflecting the spatial and temporal variation of rainfall across the whole of the study catchment.

TABLE 3.3
COMPARISON OF MODELLED AND RECORDED TIME OF FLOOD PEAK AT BORENORE STREAM GAUGE

Historic Storm Event	Time of Flood Peak		Difference in Flood Peak
	Recorded[1]	Molong DRAINS Model[2]	
2 August 1990	-[3]	02/08/1990 05:00 hours	-[3]
8 November 2005	08/11/2005 02:30 hours	08/11/2005 05:30 hours	+3 hours
26 November 2021	26/11/2021 05:15 hours	26/11/2021 03:45 hours	-1.5 hours
14 November 2022	14/11/2022 00:30 hours	14/11/2022 02:30 hours	+2 hours

1. Based on recorded stage hydrographs at Borenore stream gauge.
2. Derived from the results of the Molong DRAINS Model.
3. Gauge not in operation during 2 August 1990 flood.

In addition to the above calibration and validation of the Molong DRAINS Model, as well as the iterative process of running both the hydrologic and hydraulic models, it was found that the discharge hydrographs generated by the Molong DRAINS Model, when applied to the hydraulic model, gave reasonable correspondence with observed flood behaviour (refer **Section 4.5** for more detail). The IL-CL and RAFTS hydrologic model parameters set out in this chapter were therefore adopted for design flood estimation purposes.

4 HYDRAULIC MODEL DEVELOPMENT AND CALIBRATION

4.1 General

The present study required the use of a hydraulic model that is capable of analysing the time varying effects of flow in the local stormwater drainage system and the two-dimensional nature of flow on the floodplain and in the steeper parts of the study area that are subject to overland flow. The TUFLOW modelling software was adopted as it is one of only a few commercially available hydraulic models which contain all the required features.

This chapter deals with the development and calibration of the TUFLOW model that was then used to define the nature of flooding in the study area for a range of design storm events (refer **Chapter 6** for further details).

4.2 The TUFLOW Modelling Approach

TUFLOW is a true two-dimensional hydraulic model which does not rely on a prior knowledge of the pattern of flood flows in order to set up the various fluvial and weir type linkages which describe the passage of a flood wave through the system.

The basic equations of TUFLOW involve all of the terms of the St Venant equations of unsteady flow. Consequently, the model is "fully dynamic" and once tuned will provide an accurate representation of the passage of the floodwave through the drainage system (both surface and piped) in terms of extent, depth, velocity and distribution of flow.

TUFLOW solves the equations of flow at each point of a rectangular grid system which represent overland flow on the floodplain and along streets. The choice of grid point spacing depends on the need to accurately represent features on the floodplain which influence hydraulic behaviour and flow patterns (e.g. buildings, streets, changes in channel and floodplain dimensions, hydraulic structures which influence flow patterns, hydraulic roughness etc.).

Piped drainage and channel systems can be modelled as one-dimensional elements embedded in the larger two-dimensional domain, which typically represents the wider floodplain. Flows are able to move between the one and two-dimensional elements of the model, depending on the capacity characteristics of the drainage system being modelled.

The TUFLOW model developed as part of the present study will allow for the future assessment of potential flood management measures, such as detention storage, increased channel and floodway dimensions, augmentation of culverts and bridge crossing dimensions, diversion banks and levee systems.

4.3 TUFLOW Model Setup

4.3.1. Model Structure

Figure 4.1 shows the layout of the TUFLOW model that was developed as part of the present study (**Molong TUFLOW Model**). The model comprises the pit and pipe drainage system, while the inbank, overbank and shallow "overland" flow are modelled by the rectangular grid.

The following sections provide further details of the model development process.

4.3.2. Two-dimensional Model Domain

An important consideration of two-dimensional modelling is how best to represent the roads, fences, buildings and other features which influence the passage of flow over the natural surface. Two-dimensional modelling is very computationally intensive, and it is not practicable to use a mesh of very fine elements without excessive times to complete the simulation, particularly for long duration flood events. The requirement for a reasonable simulation time influences the way in which these features are represented in the model.

A grid spacing of 3 m with a smaller 1.5 m grid spacing embedded internal to the model along the 1 km reach of Molong Creek between the projections of Dean Street and Gidley Street (refer **Figure 4.1** for extent) was found to provide an appropriate balance between the need to define features on the floodplain versus model run times and was adopted for the investigation. Ground surface elevations for model grid points were initially assigned using the LiDAR derived DEMs for the study area.

Ridge and gully lines were added to the TUFLOW model where the grid spacing was considered to be too coarse to accurately represent important topographic features which influence the passage of overland flow. The elevations for these ridge and gully lines were determined from inspection of the LiDAR survey data or site-based measurements.

Gully lines were also used to represent the major creeks and watercourses in the study area. The use of gully lines ensured that positive drainage was achieved along the full length of these watercourses, and thus avoided creation of artificial ponding areas as artefacts of the 'bumpy' nature of the underlying LiDAR survey data.

The five existing bridge structures were incorporated in the two-dimensional domain as layered flow constriction elements based on cross sectional survey data. The bridge deck and hand rails (if present) were assumed to be 100% blocked (i.e. impervious to flow). The piers of the Marsden Street Bridge and Broken Hill Railway Bridges No. 1 and 2 were modelled by assigning a loss coefficient based on the width of piers versus width of waterway area relationship contained in Austroads, 1994. As the Euchareena Bridge and Molong Creek Railway Bridge are located within the smaller 1.5 m grid area that was incorporated in the Molong TUFLOW Model, the piers associated with these two structures were incorporated in the model by blocking out a row of cells along the alignment of the piers, which in the case of the Molong Creek Railway Bridge, are not perpendicular to the direction of flow in the watercourse.

The footprints of individual buildings located in the two-dimensional model domain were digitised and assigned a high hydraulic roughness value relative to the more hydraulically efficient roads and flow paths through allotments. This accounted for their blocking effect on flow while maintaining a correct estimate of floodplain storage in the model.

It was not practicable to model the individual fences surrounding the many allotments in the study area. For the purpose of the present study, it was assumed that there would be sufficient openings in the fences to allow water to enter the properties, whether as flow under or through fences and via openings at driveways. Individual allotments where development is present were digitised and assigned a high hydraulic roughness value (although not as high as for individual buildings) to account for the reduction in conveyance capacity which will result from obstructive fences, such as Colorbond or brick, and other obstructions stored on these properties.

4.3.3. One-dimensional Model Elements

Survey data provided by *Diverse Project Solutions Yass* were used as the primary source of details of the piped drainage system which were incorporated into the TUFLOW model. These data were supplemented with field measurements and Council's observations. **Table 4.1** over the page summarises the pit and pipe data that were incorporated into the Molong TUFLOW Model.

Several types of pits are identified on **Figure 4.1**, including junction pits which have a closed lid and inlet pits which are capable of accepting overland flow. Inlet pit types and dimensions were incorporated in the TUFLOW model based on a visual inspection of the existing stormwater drainage system. Inlet pit capacity relationships were taken from those in-built to the DRAINS software where appropriate, else they were calculated using an in-house spreadsheet model.

TABLE 4.1
SUMMARY OF MODELLED DRAINAGE STRUCTURES

Pipes		Box Culverts		Inlet Pits	Junction Pits	Headwalls
No.	Length (m)	No.	Length (m)	No.	No.	No.
227	4,270	47	830	108	41	271

Pit losses throughout the various piped drainage networks were modelled using the Engelhund approach in TUFLOW. This approach provides an automatic method for determining time-varying energy loss coefficients at pipe junctions that are recalculated each time step based on a range of variables including the inlet/outlet flow distribution, the depth of water within the pit, expansion and contraction of flow through the pit, and the horizontal deflection and vertical drop across the pit. The losses derived using the automated Engelhund approach in TUFLOW are generally within the range of expected values derived using other methods.

4.3.4. Model Parameters

The main physical parameter for TUFLOW is the hydraulic roughness. Hydraulic roughness is required for each of the various types of surfaces comprising the overland flow paths, as well as inbank areas of the creeks. In addition to the energy lost by bed friction, obstructions to flow also dissipate energy by forcing water to change direction and velocity and by forming eddies. Hydraulic modelling traditionally represents all of these effects via the surface roughness parameter known as "Manning's n". Flow in the piped system also requires an estimate of hydraulic roughness.

Manning's n values along the channel and immediate overbank areas along the modelled length of creeks were varied, with the values in **Table 4.2** over the page providing reasonable correspondence between recorded and modelled flood levels.

The adoption of a value of 0.02 for the surfaces of roads, along with an adequate description of their widths and centreline/kerb elevations, allowed an accurate assessment of their conveyance capacity to be made. A relatively high roughness value of 0.1 has been applied to the grassed and paved inter-allotment area to account for the blocking effect that various features in private properties such as fences, landscaping, vegetation etc. will have on flood behaviour.

Based on anecdotal information provided by the community, it is understood that the lower lying buildings on the Molong Creek floodplain, such as those located at the eastern end of Bank Street initially block the flow of water until such time as the doors and windows give way, after which time floodwater more freely discharges through the affected buildings. As it was not possible to model the failure mode of individual facades, doors and, through an iterative process it was found that the application of a Manning's n roughness value of 1 to the footprint of the affected buildings generally achieved a reasonable match with surveyed flood levels (refer **Section 4.5** for further discussion). A Manning's n value of 10 was applied to the footprint of all other buildings in the two-dimensional model domain to reflect their increased blocking effect on flow, while maintaining flood storage in the model.

TABLE 4.2
BEST ESTIMATE HYDRAULIC ROUGHNESS VALUES

Surface Treatment	Manning's n Value
Concrete piped elements	0.015(1)
Asphalt or concrete road surface; invert of concrete lined reach of Boundary Creek	0.02
Invert of Molong Creek	0.03
Overbank area, including grass and lawns	0.045
Lightly vegetated areas	0.06
Moderately vegetated areas; vegetated banks of Molong Creek	0.08
Allotments (between buildings)	0.10
Densely vegetated banks of Molong Creek	0.12
Buildings (low-lying building on Molong Creek floodplain)	1
Buildings	10

1. It has been assumed that the piped elements are old and have a slightly higher Manning's n value than a new concrete pipe.

Figure 4.2 is a typical example of flow patterns derived from the above roughness values. This example applies to the November 2022 flood event and shows flooding patterns in the vicinity of the intersection of Bank Street and Watson Street. The left hand side of the figure shows the roads and inter-allotment areas, as well as the outlines of buildings, which have all been assigned different hydraulic roughness values in the model. The right hand side shows the resulting flow paths in the form of scaled velocity vectors and the depths of inundation. The buildings with their high values of hydraulic roughness block the passage of flow, although the model recognises that they store floodwater when inundated and therefore correctly accounts for flood storage.[2] Similar information to that shown on **Figure 4.2** may be presented at any location within the model domain and will be of assistance to Council in assessing individual flooding problems in the study area.

4.4 Model Boundary Conditions

The locations where sub-catchment inflow hydrographs were applied to the TUFLOW model are shown on **Figure 4.1**. These comprise both point-source inflows at selected locations around the perimeter of the two-dimensional model domain, as well as internal to the model (for example, at the location of surface inlet pits) and as distributed inflows via "Rain Boundaries".

[2] Note that the depth grid has been trimmed to the building polygons as based on previous experience, residents tend to interpret the figure as showing the depth of above-floor inundation, when in fact it is showing the depth of above-ground inundation over the footprint of the building. The same approach has been adopted for presenting the results for the various design flood events, details of which are contained in **Chapter 6**.

The Rain Boundaries act to “inject” flow into the TUFLOW model, firstly at a point which has the lowest elevation, and then progressively over the extent of the Rain Boundary as the grid in the two-dimensional model domain becomes wet as a result of overland flow. The Rain Boundaries have been digitised at the outlet of the catchment in order to reduce the “double-routing” of runoff from the sub-catchment.

Figure 4.1 shows the downstream boundary of the model comprises a TUFLOW-derived normal depth relationship which is located approximately 1 km downstream of the confluence of Molong Creek and Back Creek. The downstream boundary has been located a sufficient distance downstream of the urbanised parts of Molong so as to not impact flood behaviour in the area of interest.

4.5 Hydraulic Model Calibration

4.5.1. General

As previously mentioned, the hydrologic and hydraulic models were tested for floods that occurred on 2 August 1990, 8 November 2005, 26 November 2021 and 14 November 2022 using the available rain gauge data. The TUFLOW model was run using discharge hydrographs that were generated by the Molong DRAINS Model, parameters for which are set out in **Section 3.3**.

While changes have been made to the Molong Creek floodplain since 1990 (for example the construction of the Mitchell Highway railway overpass to the south of its intersection with Wellington Street, the filling and leveling of the hockey fields and the construction of the concrete safety barrier at the intersection of Hill Street and Watson Street), it was not possible to replicate floodplain conditions at the time of the 2 August 1990 and 8 November 2005 floods in the Molong TUFLOW Model as no 3D ground level data are available pre-2011.

As these works are located upstream of the Marsden Street Bridge, they would have a negligible impact on flood behaviour downstream of the bridge crossing. As such, the Molong TUFLOW Model results for the 2 August 1990 and 8 November 2005 floods may differ from what was observed in discrete locations.

Sections 4.5.2 to **4.5.5** contain a comparison of the modelled versus observed flood behaviour for the 2 August 1990, 8 November 2005, 26 November 2021 and 14 November 2022 floods, while **Section 4.5.6** discusses the impact that the existing bridge structures had on flood behaviour during the four assessed historic floods.

4.5.2. 2 August 1990 Flood

Figure 4.3 (2 sheets) shows the modelled water surface profile along a 5.5 km reach of Molong Creek for the 2 August 1990 flood, while **Figure 4.4** (3 sheets) shows the TUFLOW model results. **Figure 4.4** also shows the plan location of 42 surveyed flood marks from the August 1990 flood which were taken from DLWC, 1995, while **Table 4.4** at the end of this chapter shows a comparison of the modelled and recorded peak flood levels.

Figure 2.4, sheet 1 shows a comparison of the modelled and recorded discharge hydrograph at the Molong stream gauge, noting the model shows the stream flow peaked at approximately 07:00 hours on 2 August 1990 which is about 2 hours later than the recorded peak.

As set out in **Table 4.4**, the Molong TUFLOW Model generally achieved a good match with the surveyed flood marks with the following exceptions:

- in the vicinity of the hockey fields, where the ground levels in the Molong TUFLOW Model do not represent floodplain conditions that were present at the time of the flood;

- at the Molong Creek Railway Bridge where a partial blockage of the bridge structure may have resulted in a localised rise in peak flood levels; and
- along the 200 m reach of Molong Creek immediately upstream of the Euchareena Road Bridge, where anecdotal evidence suggests that stream clearing has since been undertaken.

4.5.3. 8 November 2005 Flood

Figure 4.3 (2 sheets) shows the modelled water surface profile along a 5.5 km reach of Molong Creek for the 8 November 2005 flood, while **Figure 4.5** (3 sheets) shows the TUFLOW model results. **Figure 4.5** also shows the plan location of four (4) peak flood depths which were provided by NSW SES, noting that the locations are approximate only.

Table 4.5 at the end of this chapter shows a comparison of the modelled and recorded peak flood depths. The Molong TUFLOW Model generally achieved a good match with the observed flood depths, except on Watson Street between its intersection with Gidley Street and Bundella Close (refer Point No. 2005.01) where the modelled flood depth is about 500 mm lower than was observed. The reason for this difference is not able to be determined as there is no detailed description of the source of the flood mark and its exact location.

Figure 2.4, sheet 1 shows the modelled discharge hydrograph at the location of the Molong stream gauge, noting that it peaked at approximately 05:30 hours on 8 November 2005. The model shows that floodwater commenced to surcharge the left bank of Molong Creek, where it overtopped the railway and discharged to Watson Street and Bank Street at about 04:00 hours on 8 November 2005, which is generally consistent with the observation made in an ABC news report that "*Molong Creek broke its banks at 5:00am AEDT*" (https://www.abc.net.au/news/2005-11-08/flash-flooding-causes-evacuations-in-central/2140696).

4.5.4. 26 November 2021 Flood

Figure 4.3 (2 sheets) shows the modelled water surface profile along a 5.5 km reach of Molong Creek for the 26 November 2021 flood, while **Figure 4.6** (3 sheets) shows the TUFLOW model results. **Figure 4.6** also shows the plan location where respondents to the *Community Questionnaire* observed flooding in or adjacent to their property during the flood event, while **Table4.6** at the end of this chapter provides a comparison of the modelled and observed flood behaviour.

As set out in **Table 4.6**, the Molong TUFLOW Model reproduced flood behaviour that was observed in areas subject to Main Stream Flooding along Molong Creek (refer Observed Flood Behaviour (**OFB**) identifier OFB_01 to OFB_03) and Moss Hollow Creek (refer OFB_04), as well as in areas subject to Major Overland Flow along the Pillans Park Drainage Line (refer OFB_05 to OFB_07).

The model indicates that floodwater surcharged the left bank of Molong Creek and overtopped the railway before discharging to Watson Street and Bank Street between about 04:00 hours and 06:00 hours on 26 November 2021, and then again at about 17:30 hours on the same day. While there is no anecdotal or photographic evidence of the earlier flood peak, respondents to the *Community Questionnaire* provided photographs showing Watson Street, Bank Street and Hill Street inundated between 14:50 hours and 18:00 hours on 26 November 2021.

The differences in the timing of the flood can be attributed to the available data, whereby the rainfall that was recorded at the Molong Creek at D/S Borenore Creek rain gauge was not representative of the temporal and spatial distribution of rainfall across the whole of the Molong Creek catchment.

4.5.5. 14 November 2022 Flood

Figure 4.3 (2 sheets) shows the modelled water surface profile along a 5.5 km reach of Molong Creek for the 14 November 2022 flood, while **Figure 4.7** (3 sheets) shows the TUFLOW model results. **Figure 4.7** also shows the plan location where respondents to the *Community Questionnaire* observed flooding in or adjacent to their property during the flood event, while **Table 4.7** at the end of this chapter provides a comparison of the modelled and observed flood behaviour. **Figure 4.7** also shows the plan location of 21 flood marks that were surveyed by Orange City Council shortly after the flood event, while **Table 4.8** at the end of this chapter provides a comparison of the modelled and observed flood levels.

As set out in **Tables 4.7** and **4.8**, the Molong TUFLOW Model was generally able to reproduce observed flood behaviour and levels, with the exception being the flood levels that were experienced in the buildings that are located on the northern side of Bank Street. As discussed in **Section 4.3.4**, the failure mode of features internal to the affected buildings could not be accurately represented in the model, hence the differences in modelled and observed flood behaviour in these areas. **Table 4.7** shows that the Molong TUFLOW Model reproduced the time of the observed flood peak to within 1.5 hours.

4.5.6. Impact of Existing Bridge Structures on Flood Behaviour

Figure 4.3 shows the water surface profiles at the Marsden Street Bridge, Euchareena Road Bridge, Molong Creek Railway Bridge and Broken Hill Railway Bridge No. 1 for the four assessed historic floods, while **Table 4.9** at the end of this chapter sets out the head drop (i.e. difference in peak flood level) across the existing bridge structures and their approximate zone of influence.[3]

A summary of the impact that the existing bridges had on flood behaviour is as follows:

<u>Marsden Street Bridge</u>

- The head drop across the bridge for the floods that did not reach the underside of the structure (2 August 1990 and 26 November 2021 floods) is about 0.2 m and the impacts extended about 100 m in an upstream direction.
- For the flood where the underside of the bridge deck was pressurised but did not overtop (8 November 2005 flood), the head drop increased to 0.36 m.
- For the flood where the bridge was overtopped (14 November 2022 flood), the head drop increased to 0.68 m and the impacts extended about 150 m in an upstream direction.

<u>Euchareena Road Bridge</u>

- The head drop across the bridge was between 0.19 m and 0.29 m for the floods that pressurised the underside of the structure but did not overtop the bridge deck (2 August 1990, 8 November 2005 and 26 November 2021 floods).
- For the flood where the bridge was overtopped (14 November 2022 flood), the head drop increased to about 0.37 m.
- The bridge structure impacted peak flood levels on Molong Creek for a distance of about 90 m in an upstream direction for the four assessed historic floods.

[3] The zone of influence is the distance that the backwater effect of the bridge structure extends in an upstream direction.

Molong Creek Railway Bridge

- The head drop across the bridge structure was about 0.2 m for the four assessed historic floods.
- The backwater impact of the bridge structure extended about 100 m upstream to the Euchareena Road Bridge, thereby potentially influencing peak flood levels on the upstream side of the road bridge.

Broken Hill Railway Bridge No. 1

- The head drop across the bridge for the two floods that did not reach the underside of the structure (2 August 1990 and 26 November 2021 floods) was about 0.1 m, with the impact not extending further than about 10 m from the upstream face of the structure.
- For the floods where the bridge was overtopped (8 November 2005 and 14 November 2022 floods), the head drop increased to about 0.2 m and the impacts extended about 240 m in an upstream direction.

Broken Hill Railway Bridge No. 2

- The head drop across the bridge structure was between about 0.5 m and 0.7 m for the four assessed historic floods.
- The backwater impact of the bridge structure extended about 360 m in an upstream direction.

4.5.7. Summary

Based on the findings of the model testing process, the hydrologic and hydraulic models were considered to satisfactorily reproduce observed flood behaviour. As such, the hydraulic model parameters set out in **Sections 4.3** and **4.4**, and in particular the hydraulic roughness values set out in **Table 4.2,** were considered appropriate for use in defining flood behaviour in the study area over the full range of design flood events. Further discussion and presentation of hydrologic and hydraulic model parameters that were adopted for design flood estimation purposes is provided in **Chapter 5**.

TABLE 4.4
COMPARISON OF MODELLED VERSUS RECORDED PEAK FLOOD LEVELS
AUGUST 1990 FLOOD

Point No.[1]	Location	Peak Flood Level (m AHD)		Difference[2] (m)	Comment
		Recorded	Modelled		
1990.01	Molong Creek - Abutment of Marsden Street bridge	531.25	531.28	+0.03	Good match
-	Wellington Street stream gauge	531.26	531.17	-0.09	Good match
1990.02	Tennis courts	531.15	531.17	+0.02	Good match
1990.03	Tennis courts	531.08	531.1	+0.02	Good match
1990.04	Hunter Caldwell Park	530.84	530.99	+0.15	Reasonable match
1990.05	Molong hockey fields	530.62	530.98	+0.36	It is understood that the hockey fields have been filled/raised since 1990. Therefore, the topography in the Molong TUFLOW Model is not representative of ground levels that were present at the time of the flood.
1990.06	29 Betts Street	530.59	530.52	-0.07	Good match
1990.07	Intersection of Watson Street and Riddel Street	529.41	529.82	+0.41	Accuracy of flood mark is questionable as it is the same elevation as the surveyed flood mark that is located 160 m to the north in the vicinity of the intersection of Watson Street and Bank Street.
1990.08	25-27 Betts Street	530.66	530.31	-0.35	The Molong TUFLOW Model does not reproduce the observed flood slope along the right bank of Molong Creek in the August 1990 flood. While it is understood that riparian vegetation has anecdotally been cleared in this area since 1990, the extent of the clearing is not able to be determined.
1990.09	19 Betts Street	530.53	530.3	-0.23	
1990.1	17 Betts Street	530.7	530.29	-0.41	
1990.11	15 Betts Street	530.33	530.27	-0.06	
1990.12	7 Betts Street	530	530.13	+0.13	
1990.13	3 Betts Street	529.92	530.12	+0.20	
1990.14	5 Euchareena Road	530	530.11	+0.11	
1990.15	Intersection of Watson Street and Bank Street	529.41	529.63	+0.22	

Refer over for footnotes to table.

Cont'd Over

TABLE 4.4 (Cont'd)
COMPARISON OF MODELLED VERSUS RECORDED PEAK FLOOD LEVELS
AUGUST 1990 FLOOD

Point No.[1]	Location	Peak Flood Level (m AHD)		Difference[2] (m)	Comment
		Recorded	Modelled		
1990.16	Euchareena Road	529.86	529.81	-0.05	Good match
1990.17	6 Euchareena Road	529.86	529.8	-0.06	Good match
1990.18	6 Euchareena Road	529.83	529.81	-0.02	Good match
1990.19	8 Euchareena Road	529.78	529.8	+0.02	Good match
1990.20	8 Euchareena Road	529.77	529.78	+0.01	Good match
1990.21	8 Euchareena Road	529.69	529.73	+0.04	Good match
1990.22	Molong Creek Railway Bridge	529.78	529.49	-0.29	Recorded flood level may have been higher due to localised blockage of the Molong Creek Railway Bridge.
1990.23	Bank Street	529.43	529.54	+0.11	Reasonable match
1990.24	Gasworks Lane	528.67	528.82	+0.15	Reasonable match
1990.25	Molong Caravan Park	529.22	529.21	-0.01	Good match
1990.26	Molong Caravan Park	529.13	528.92	-0.21	
1990.27	Hill Street (Adjacent to Molong Swimming Pool)	528.69	528.68	-0.01	Good match
1990.28	Molong Swimming Pool	528.5	528.48	-0.02	Good match
1990.29	10 Hill Street	528.45	528.45	0	Good match
1990.3	12 Hill Street'	528.35	528.33	-0.02	Good match
1990.31	14 Hill Street	528.25	528.29	+0.04	Good match
1990.32	2 Gidley Street	528.22	528.21	-0.01	Good match
1990.33	Intersection of Gidley Street and Hill Street	528.1	528.17	+0.07	Good match

Refer over for footnotes to table.

Cont'd Over

TABLE 4.4 (Cont'd)
COMPARISON OF MODELLED VERSUS RECORDED PEAK FLOOD LEVELS
AUGUST 1990 FLOOD

Point No.[1]	Location	Peak Flood Level (m AHD)		Difference[2] (m)	Comment
		Recorded[2]	Modelled		
1990.34	Intersection of Gidley Street and Hill Street	528.17	528.13	-0.04	Good match
1990.35	Hill Street	527.69	527.86	+0.17	Reasonable match
1990.36	Hill Street	528.1	528.04	-0.06	Good match
1990.37	Hill Street	527.64	527.79	+0.15	Reasonable match
1990.38	Dr Ross Memorial Recreational Ground	527.75	527.7	-0.05	Good match
1990.39	Dr Ross Memorial Recreational Ground	527.64	527.68	+0.04	Good match
1990.4	Dr Ross Memorial Recreational Ground	527.72	527.67	-0.05	Good match
1990.41	Dr Ross Memorial Recreational Ground	527.64	527.55	-0.09	Good match
1990.42	Molong Police Station	527.46	527.42	-0.04	Good match

1. Refer **Figure 4.4** (3 sheets) for location of flood marks.
1. Source of recorded peak flood levels: DLWC, 1995.
2. Note that a positive value indicates that the modelled flood level is higher, and conversely a negative value indicates that the m odelled flood level is lower than the observed flood level.

TABLE 4.5
COMPARISON OF MODELLED VERSUS OBSERVED PEAK FLOOD DEPTHS
NOVEMBER 2005 FLOOD

Point No.[1]	Location	Peak Flood Depth (m)		Difference[3] (m)	Comment
		Observed[2]	Modelled		
2005.01	Watson Street between its intersection with Bank Street and Riddell Street	2.1	1.6	-0.5	Flood depth not able to be reproduced.
2005.02	Bank Street between its intersection with Watson Street Gidley Street	1.3	1.3	0	Good match
2005.03	South-east if the intersection of Hill Street and Gasworks Lane	0.5	0.6 - 0.8	+0.1 to +0.3	Exact location that flood depth was observed is not able to be determined.
2005.04	Adjacent to Molong Police Station	0.5	0.4 – 0.7	-0.1 to +0.2	Reasonable match

1. Refer **Figure 4.5** (3 sheets) for location of flood marks.
2. Recorded peak flood levels were based on peak flood depths at locations that were provided by NSW SES and are approximate only.
3. Note that a positive value indicates that the modelled flood level is higher, and conversely a negative value indicates that the modelled flood level is lower than the observed flood level.

TABLE 4.6
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR
NOVEMBER 2021 FLOOD

Response Identifier(1)	Watercourse	Observed Flood Behaviour/ Other Comment	Model Verification Comments
OFB_01	Molong Creek	• Dwelling inundated to a depth of about 1 m.	• TUFLOW model results show the depth of inundation adjacent to the dwelling is between 0.6 m and 0.8 m.
OFB_02		• Depth of above-floor inundation was about 0.5 m.	• TUFLOW model results show the depth of above-floor inundation is about 0.6 m (based on surveyed floor level contained in Ecclestone, 2010).
OFB_03		• Depth of above-floor inundation was about 0.1 m deep.	• TUFLOW model results show the depth of above-floor inundation is about 0.4 m (based on surveyed floor level contained in Ecclestone, 2010)
OFB_04	Moss Hollow Creek	• Floodwater originating from Moss Hollow Creek inundated Market Street to a depth of about 1-2 feet (i.e. 0.3-0.6 m).	• TUFLOW model results show the depth of inundation along the centreline of Market Street of about 0.3 m.
OFB_05	Pillans Park Drainage Line	• Video shows shallow overtopping of Lee Street where it crosses the Pillans Park Drainage Line.	• TUFLOW model results show that Lee Street is inundated to depths less than 0.1 m.
OFB_06		• Culvert beneath Gidley Street surcharged, and stormwater flowed in easterly direction across street into private property.	• TUFLOW model results show Gidley Street culvert surcharging and inundating Gidley Street to a maximum depth of about 0.25 m.
OFB_07		• The culvert that runs beneath the property was blocked with debris.	• A blockage factor of 50 % was applied to the culvert.
		• Floodwater inundated the premises to a depth of about 0.25 m.	• TUFLOW model results show the maximum depth of inundation in the property of about 0.28 m.

1. Refer **Figure 4.6** (3 sheets) for location of observed flood behaviour.

TABLE 4.7
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR
NOVEMBER 2022 FLOOD

Response Identifier (1)	Watercourse	Observed Flood Behaviour/ Other Comment	Model Verification Comments
OFB_08	Molong Creek	• Flood levels in Molong Creek stayed elevated until about 06:00 hours.	• TUFLOW model results indicate that flood levels peaked upstream of Marsden Street at around 04:20 hours and had commenced receding by about 06:00 hours.
OFB_09		• Molong Creek overtopped Marsden Street Bridge.	• TUFLOW model results show Marsden Street bridge inundated.
OFB_10		• The depth of flow through property was "probably" over 2 m.	• TUFLOW model results show that the property was inundated to a maximum depth of about 1.9 m.
OFB_11		• The extent of inundation reached the front of the house.	• TUFLOW model results show depth of inundation at the front of the house was about 0.6 m.
OFB_12		• Dwelling was destroyed from floodwater (northern wall came away from building).	• TUFLOW model results show the depth of inundation adjacent to the building was about 1.8 m.
OFB_13		• Floodwater inundated shed to a depth of about 1.5 m.	• TUFLOW model results show that the depth of inundation adjacent to the shed is about 1.4 m.
OFB_14		• The depth of above-floor inundation was about 1.8 m.	• TUFLOW model results show that the building was inundated to a depth of about 1.7 m.
OFB_15		• Garden inundated to a maximum depth of between 0.6 m and 0.8 m.	• TUFLOW model results show that the maximum depth of inundation in the garden is about 0.8 m.
OFB_16		• The depth of above-floor inundation was about 0.5 m.	• TUFLOW model results show that the depth of above-floor inundation was about 1.1 m.(2)
OFB_17		• The depth of above-floor inundation was about 1.4 m.	• TUFLOW model results show that the depth of above-floor inundation was about 1.6 m.(2)
OFB_18		• The depth of above-floor inundation was about 1 m.	• TUFLOW model results show that the depth of inundation adjacent to the doorways on the northern and eastern side of the building was about 0.8 m.(2)

Refer over for footnotes to table.

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TABLE 4.7 (Cont'd)
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR
NOVEMBER 2022 FLOOD

Response Identifier (1)	Watercourse	Observed Flood Behaviour/ Other Comment	Model Verification Comments
OFB_19	Molong Creek	• The depth of overland flow through the Molong Caravan Park was about 3-4 feet (0.9 m – 1.2 m).	• TUFLOW model results show that the caravan park was generally inundated to a depth of between 0.8 m and 1.2 m, with a maximum depth of inundation of about 1.5 m occurring on eastern side of park.
OFB_20	Molong Creek	• Garage inundated to a depth of about 1.2 m.	• TUFLOW model results show the depth of inundation in the vicinity of the garage is about 1.1 m.
OFB_21	Molong Creek	• Front yard inundated to a depth of about 1.5 m deep in front yard. • Flood levels peaked at about 03:00 hours on 14 November 2022.	• TUFLOW model results show the depth of inundation in the front yard was about 1.2 m deep. • TUFLOW model results indicate that flood levels peaked at around 04:30 hours.
OFB_22	Molong Creek	• The depth of inundation adjacent to the rear of the house was about 1.3 m.	• TUFLOW model results show the maximum depth of inundation adjacent to the house was about 1.3 m.
OFB_23	Boree Hollow	• Back yard was inundated to a depth of about 1 m.	• TUFLOW model results show yard inundated to a maximum depth of about 0.9 m.
OFB_24	Moss Hollow Creek	• Floodwater originating from Moss Hollow Creek inundated Market Street to a depth of about 2-3 feet (i.e. 0.6 m – 0.9 m).	• TUFLOW model results show the maximum depth of inundation along the western side of Market Street was about 0.3 m..
OFB_25	Pillans Park Drainage Line	• Culvert beneath Gidley Street surcharged, and stormwater flowed in easterly direction across street into private property. • Photo shows stormwater flowed into properties at 23:00 hours on 13 November 2022.	• TUFLOW model results show Gidley Street culvert surcharging and inundating road to a maximum depth of about 0.25 m. • TUFLOW model results show stormwater overtopping Gidley Street between 20:30 hours on 13 November and 00:30 hours on 14 November 2022.
OFB_26	-	• Stormwater flowed in easterly direction through property which inundated house and garage.	• Observed flood behaviour not reproduced by the Molong TUFLOW Model. May be due to localised storm activity not replicated in rainfall data.
OFB_27	-	• Local stormwater rushes down land and erodes/scours private property.	• Local stormwater drainage issues not able to be represented in the Molong TUFLOW Model.
OFB_28	-	• Runoff from neighbouring "uphill" properties inundated back yard to a depth of about 0.15 m to 0.18 m.	• Local stormwater drainage issues not able to be represented in the Molong TUFLOW Model.

Refer over for footnotes to table.

Cont'd Over

TABLE 4.7 (Cont'd)
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR
NOVEMBER 2022 FLOOD

Response Identifier (1)	Watercourse	Observed Flood Behaviour/ Other Comment	Model Verification Comments
OFB_29	-	• Floodwater surcharged northern kerb of Riddell Street and flows in north-easterly direction through property	• TUFLOW model results show shallow overland flow less than 0.1 m deep across southern portion of property.
OFB_30	-	• Heavy rainfall causes inundation of backyard originating from properties uphill	• Local stormwater drainage issues not able to be represented in the Molong TUFLOW Model.
OFB_31	-	• Stormwater flows in northerly direction over Castle Street, overwhelms recently constructed grass drain on northern side and ponded to depths of up to 0.2 m against brick wall in front of property.	• Local stormwater drainage issues not able to be represented in the Molong TUFLOW Model. May have resulted from blockage of pipe drainage system at intersection of Castle Street and King Street.

1. Refer **Figure 4.7** (3 sheets) for location of observed flood behaviour.
2. As discussed in **Section 4.3.4**, the failure modes of features internal to the affected buildings could not be accurately represented in the model, hence the differences in modelled and observed flood behaviour in these areas.

TABLE 4.8
COMPARISON OF MODELLED VERSUS RECORDED PEAK FLOOD LEVELS
NOVEMBER 2022 FLOOD

Point No.[(1)]	Location	Peak Flood Level (m AHD)		Difference[(2)] (m)	Comment
		Recorded[(2)]	Modelled		
-	Wellington Street Gauge	533.17	532.85	-0.32	Surveyed flood level not consistent with model results. Surveyed level may have been influenced by localised build-up of debris on Marsden Street Bridge.
2022.01	Molong Hockey Field	531.86	531.79	-0.07	Good match
2022.02	Molong Hockey Field	531.86	531.78	-0.08	Reasonable match
2022.03	Molong Hockey Field	531.86	531.77	-0.09	Reasonable match
2022.04	25-27 Betts Street	531.29	531.27	-0.02	Good match
2022.05	Railway Land adjacent to Molong Street	530.99	531.46	0.47	Accuracy of flood mark questionable as it is lower than flood marks further downstream (2022.06, 2022.07 and 2022.08).
2022.06	Intersection of Watson Street and Riddell Street	531.26	531.32	0.06	Good match
2022.07	Intersection of Watson Street and Riddell Street	531.24	531.31	0.07	Good match
2022.08	16 Watson Street	531.08	531.21	0.13	Good match
2022.09	4 Budella Cl	531.02	531.19	0.17	Reasonable match
2022.10	Intersection of Watson Street and Bank Street	530.83	530.89	0.06	Good match
2022.11	Intersection of Watson Street and Bank Street	530.48	530.55	0.07	Good match
2022.12	Intersection of Watson Street and Bank Street	530.38	530.29	-0.09	Good match
2022.13	Intersection of Watson Street and Bank Street	530.41	530.41	0	Good match
2022.14	6 Euchareena Road	530.12	530.62	0.5	Surveyed flood levels are not consistent with debris overtopping railway bridge that is located immediately downstream of 6 Euchareena Road.
2022.15	6 Euchareena Road	530.13	530.62	0.49	

Refer over for footnotes to table.

Cont'd Over

TABLE 4.8 (Cont'd)
COMPARISON OF MODELLED VERSUS RECORDED PEAK FLOOD LEVELS
NOVEMBER 2022 FLOOD

Point No.[1]	Location	Peak Flood Level (m AHD)		Difference[2] (m)	Comment
		Recorded[2]	Modelled		
2022.16	Hill Street (Adjacent to Molong Swimming Pool)	529.34	529.42	0.08	Good match
2022.17	Hill Street (Adjacent to Molong Swimming Pool)	529.34	529.41	0.07	Good match
2022.18	Intersection of Hill Street and Gidley Street	528.99	529.04	0.05	Good match
2022.19	Intersection of Hill Street and Gidley Street	529.02	528.91	-0.11	Good match
2022.20	Recreation Ground Amenities Block	528.60	528.59	-0.01	Good match

1. Refer **Figure 4.7** (3 sheets) for location of flood marks.
2. Source of recorded peak flood levels: Orange City Council.
3. Note that a positive value indicates that the modelled flood level is higher, and conversely a negative value indicates that the modelled flood level is lower than the observed flood level.

TABLE 4.9
HEAD DROP AND ZONE OF INFLUENCE AT EXISTING BRIDGE STRUCTURES
HISTORIC FLOODS
(m)

Bridge	2 August 1990		8 November 2005		26 November 2021		14 November 2022	
	Head Drop (m)	Zone of Influence(1) (m)	Head Drop (m)	Zone of Influence(1) (m)	Head Drop (m)	Zone of Influence(1) (m)	Head Drop (m)	Zone of Influence(1) (m)
Marsden Street Bridge	0.19	100	0.36	120	0.22	100	0.68	150
Euchareena Road Bridge	0.16	80	0.29	90	0.19	80	0.37	90
Molong Creek Railway Bridge	0.19	100(2)	0.26	100(2)	0.23	100(2)	0.21	100(2)
Broken Hill Railway Bridge No. 1	0.08	10	0.19	200	0.11	10	0.22	240
Broken Hill Railway Bridge No. 2	0.47	230	0.64	330	0.5	230	0.71	360

1. The zone of influence is the distance that the backwater effect of the bridge structure extends in an upstream direction.
2. The impacts of the Molong Creek Railway Bridge extend upstream to the Euchareena Road Bridge.

5 DERIVATION OF DESIGN FLOOD HYDROGRAPHS

5.1 Design Storms

5.1.1. Rainfall Intensity

The procedures used to obtain temporally and spatially accurate and consistent Intensity-Frequency-Duration (**IFD**) design rainfall curves for the assessment of flood behaviour in the study area are presented in the 2019 edition of *Australian Rainfall and Runoff* (Geoscience Australia, 2019) (**ARR 2019**). Design storms for frequencies of 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP were derived for storm durations ranging between 15 minutes and seven days. The IFD dataset was downloaded from the BoM's *2016 Rainfall IFD Data System*.

5.1.2. Areal Reduction Factors

The rainfalls derived using the processes outlined in ARR 2019 are applicable strictly to a point. In the case of a catchment of over tens of square kilometres area, it is not realistic to assume that the same rainfall intensity can be maintained. An Areal Reduction Factor (**ARF**) is typically applied to obtain an intensity that is applicable over the entire catchment.

While ARFs of between 0.85 and 0.95 are applicable on the 211 km^2 catchment contributing to flow in Molong Creek at the Molong stream gauge, a single value of 0.90 was found to achieve a good match with the peak flows generated by the Molong DRAINS Model and those derived as part of previous investigations (refer **Section 5.3** for further discussion).

It is noted that it is not appropriate to apply the above ARF to all sub-catchments in the Molong DRAINS Model as the purpose of the present study was to also define flood behaviour along the tributaries of Molong Creek, as well as in areas subject to Major Overland Flow where the contributing catchments are substantial smaller. As such, an ARF value of 1.0 was applied to all sub-catchments contributing to flow in Reedy Creek, Boree Hollow, Moss Hollow Creek, Foys Creek, Pillans Park Drainage Line, as well as those contributing to Major Overland Flow through the urbanised parts of Molong.

5.1.3. Temporal Patterns

ARR 2019 prescribes the analysis of an ensemble of 10 temporal patterns per storm duration for various zones in Australia. These patterns are used in the conversion of a design rainfall depth with a specific AEP into a design flood of the same frequency. The patterns may be used for AEPs down to 0.2 per cent where the design rainfall data is extrapolated for storm events with an AEP less than 1 per cent.

The temporal pattern ensembles that are applicable to Frequent (more frequent than 14.4% AEP), Intermediate (between 14.4% and 3.2% AEP) and Rare (rarer than 3.2% AEP) storm events were obtained from the ARR Data Hub[4], while those for the very rare events were taken from BoMs update of *Bulletin 53* (BoM, 2003) and Jordan et. al., 2005.

A copy of the data extracted from the ARR Data Hub is contained in **Appendix D**.

[4] It is noted that the temporal pattern data set for the *Murray-Darling Basin* region is suitable for use in the study area.

5.1.4. Probable Maximum Precipitation

Estimates of Probable Maximum Precipitation (**PMP**) were made using the Generalised Short Duration Method (**GSDM**) as described in the BoM, 2003. This method is appropriate for estimating extreme rainfall depths for catchments up to 1000 km^2 in area and storm durations up to 3 hours.

The steps involved in assessing PMP for the study catchments are briefly as follows:

- Calculate PMP for a given duration and catchment area using depth-duration-area envelope curves derived from the highest recorded US and Australian rainfalls.
- Adjust the PMP estimate according to the percentages of the catchment which are meteorologically rough and smooth, and also according to elevation adjustment and moisture adjustment factors.
- Assess the design spatial distribution of rainfall using the distribution for convective storms based on US and world data but modified in the light of Australian experience.
- Derive storm hyetographs using the eleven temporal distributions contained in BoM, 2003, and Jordan et. al., 2005 which are based on pluviographic traces recorded in major Australian storms.

Figure 5.1 shows the location and orientation of the PMP ellipses which were used to derive the rainfall estimates for the present study. Note that two orientations of the PMP ellipses were adopted for Molong Creek (refer PMP Ellipse Alignment 1), its tributaries and areas subject to Major Overland Flow (refer PMP Ellipse Alignment 2) in order to accurately derive the upper limit of flooding in the study area.

5.2 Design Rainfall Losses

Table 5.1 over the page sets out the initial and continuing loss values that are recommended for use in the vicinity of Molong in *Initial Losses for Design Flood Estimation in New South Wales* (Walsh et al, 1991) (refer Column C) (**Walsh et. al. Loss Values**), as well as those that were adopted as part of DLWC, 1995 (refer Column D) (**DLWC Loss Values**) and URS, 2011 (Column E) (**URS Loss Values**). It is noted that the DLWC and URS Loss values are at the upper bound of the values that are recommended in Walsh et. al., 1991.

Column F of **Table 5.1** shows that initial and continuing loss values that were required to calibrate the Molong DRAINS Model as part of the present investigation (**Model Calibration Loss Values**), noting that a continuing loss value of 2.5 mm/hr was adopted for the November 2005, November 2021 and November 2022 flood events, while 0.8 mm/hr was adopted for the August 1990 flood.

Column G sets out the loss values that were derived using the NSW jurisdictional specific procedures set out in the *ARR Data Hub* (**ARR Data Hub Loss Values**) which are generally lower than Walsh et. al., DLWC, URS and Model Calibration Loss Values.

It was not possible to achieve a match with design peak flows derived by alternate procedures using the ARR Data Hub Loss Values. While use of the DLWC Loss Values achieved a reasonable match between the results of the Molong DRAINS Model and design peak flows derived as part of previous investigations, the loss values are on the higher side of those recommended as part of Walsh et. al., 1991 and hence may underestimate design peak flows at Molong.

The loss values set out in Column H of **Table 5.1** (**Flood Study Loss Values**) have been adopted for design flood estimation as part of the present study, noting that they are based on the loss values recommended in Walsh et. al., 1991.

TABLE 5.1

COMPARISON OF DESIGN LOSS VALUES
DESIGN FLOOD ESTIMATION

Loss Parameter [A]	Storm Event [B]	Previous Investigations			Present Study		
		Walsh et al Loss Values(1) [C]	DLWC Loss Values(2) [D]	URS Loss Values(3) [E]	Model Calibration Loss Values [F]	ARR Data Hub Loss Values [G]	Flood Study Loss Values(3) [H]
Initial Loss (mm)	PMF	0	0	0	20 – 40	0	0
	1% AEP	15 (+/- 15)	30	24		4.0 - 16.3	15
	2% AEP	15 (+/- 15)	35	29		8.4 - 21.4	15
	5% AEP	20 (+/- 15)	39	34		9.6 - 24.0	20
	10% AEP	20 (+/- 15)	38	31		9.9 - 22.5	20
	20% AEP	25 (+/- 15)	39	34		10.1 - 21.3	25
Continuing Loss (mm/hr)	20% AEP - PMF	2.5	2.5	2.5	0.8 – 2.5	1.68(4)	2.5

1. Values recommended in *Initial Losses for Design Flood Estimation in New South Wales* (Walsh et al, 1991).
2. Values that were relied upon for design flood estimation as part of DLWC, 1995.
3. Values that were relied upon for design flood estimation as part of URS, 2011.
4. Derived by multiplying the raw *ARR Data Hub* continuing loss value of 4.2 mm/hr by a factor of 0.4.

5.3 Derivation of Design Discharges

The Molong DRAINS Model was run for a range of design storms using the design rainfall data set out in **Sections 5.1** and **5.2,** as well as the initial and continuing loss values set out in Column H of **Table 5.1** in order to obtain design discharge hydrographs for input to the TUFLOW model.

Table 5.2 at the end of this chapter shows a comparison of design peak flows derived from the Molong DRAINS Model with the results of DLWC, 1995 and URS, 2011, as well as those derived using the Probabilistic Rational Method (**PRM**) (procedures for which are set out in the 1987 edition of *Australian Rainfall and Runoff* (The Institution of Engineers Australia, 1987) (**ARR 1987**) and the Regional Flood Frequency Estimation (**RFFE**) Model (procedures for which are set out in ARR 2019). The peak flow comparison was undertaken by reference to the following locations (refer **Figure 3.1**):

- Molong Creek at the location of the discontinued Molong stream gauge where the total catchment area is 214 km^2 (refer Q_MC);
- Boree Hollow at a location approximately 700 m to the south of South Street where the total catchment area is 14.6 km^2 (refer Q_BC); and
- Moss Hollow Creek at a location approximately 600 m to the south of Packham Street where the total catchment area is 8.4 km^2 (refer Q_BC).

The key findings of the peak flow comparison are as follows:

i) Column C shows the peak flows that were generated by the RORB Model that was developed as part of DLWC, 1995 (**DLWC RORB Model**), noting that the peak flows for the 20%, 10% and 5% AEP were tuned to the results of a flood frequency analysis that was undertaken on the 28 years of annual maxima peak flows between 1965 and 1993 at the discontinued Molong stream gauge, while the peak 1% AEP flow was tuned to the PRM.[5]

   As discussed in **Section 2.3** the suitability of the flood frequency analysis that was undertaken as part of DLWC, 1995 for use in defining design peak flows at Molong is questionable given that the largest flood included in the annual maxima (i.e. August 1990 flood) is smaller than the three floods that have occurred since the gauge was decommissioned (i.e. November 2005, November 2021 and November 2022).

ii) Column D shows the peak flows that were generated by the DLWC RORB Model which was updated as part of URS, 2011 to incorporate ARFs. **Table 5.2** shows that lower initial loss values were adopted as part of URS, 2011 in order to achieve a match with the results of DLWC, 1995 (Column C).[6]

iii) Column E shows the design peak flow estimates that were derived as part of the present study using the PRM. While the PRM is no longer recommended for use as part of ARR 2019, the results have been included in **Table 5.2** for comparison purposes, noting that the peak 1% AEP flow derived using the PRM is slightly higher than that derived as part of DLWC, 1995 (Column C) and URS, 2011 (Column D).

iv) Column F shows the results of the RFFE which are generally comparable with those derived using the PRM for the three assessed catchments. It is noted that there are generally limitations with RFFE derived peak flow estimates as they are based on flood frequency relationships that have been derived on nearby gauged catchments that don't necessarily take into account the inaccuracies in the high flow ratings curves that have been used to generate the annual maxima peak flows at each gauge.

v) Column G shows that the design peak flow estimates derived by incorporating the ARR Data Hub Loss Values (refer Column G in **Table 5.1**) in the Molong DRAINS Model are 20%-40% higher than those derived using the alternative methods discussed above. As discussed in the **Section 5.2**, the ARR Data Hub Loss Values are generally lower than the Model Calibration Loss Values and have therefore been deemed unsuitable for use in design flood estimation as part of the present study.

vi) While Column H shows that the design peak flows derived by incorporating the DLWC Loss Values in the Molong DRAINS Model are generally comparable to those derived as part of the previous flooding investigations, the flows on Boree Hollow and Moss Hollow are lower than the peak flow estimates derived by the PRM (Column E) and RFFE (Column F). As discussed above, the previous investigations may underestimate the design peak flows due to the lack of significant flood events that were incorporated in the underlying flood frequency analysis.

   It was also found that adopting the DLWC Loss Values resulted in zero runoff from short duration storms with AEPs of 10% and 20%.

vii) Column I shows that the peak flows derived by incorporating the base initial loss values recommended in Walsh et. al., 1991 are higher than those derived as part of previous investigations.

[5] Boree Hollow and Moss Hollow Creek were not assessed as part of DLWC, 1995.

[6] Boree Hollow and Moss Hollow Creek were not assessed as part of URS, 2011.

As set out in items i) to iv) above, there are concerns that DLWC, 1995 (and therefore URS, 2011), and the RFFE underestimate the design peak flows at Molong due to the underlying data that has been relied upon for each method. Due to the uncertainties in the underlying data, the present study has relied upon the initial and continuing loss values recommended as part of Walsh at. al, 1991 for design flood estimation.

TABLE 5.2
COMPARISON OF DESIGN PEAK FLOW ESTIMATES AT MOLONG

Catchment[1]	Storm Event	Previous Investigations		Present Study				
		ARR 1987			ARR 2019			
		DLWC, 1995	URS, 2011	PRM	RFFE	Molong Drains Model		
		[DLWC Loss Values]	[URS Loss Values]			[ARR Data Hub Loss Values]	[DLWC Loss Values]	[Walsh et al Loss Values]
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]
Molong Creek	PMF	4,700[2]	6,114[3]	Not Assessed	Not Assessed	4,693		
	0.2% AEP	Not Assessed	Not Assessed			719	523	595
	0.5% AEP					620	439	500
	1% AEP	370	367	399	379	538	364	418
	2% AEP	260	272	302	285	434	321	352
	5% AEP	165	164	204	186	335	179	261
	10% AEP	120	120	144	128	268	131	206
	20% AEP	80	79	105	81.7	221	94	147
Boree Hollow	PMF	Not Assessed	Not Assessed	Not Assessed	Not Assessed	652		
	0.2% AEP					136.0	93.5	122
	0.5% AEP					115.0	75.2	101
	1% AEP			76.3	73.2	99.7	61.3	84.9
	2% AEP			57.4	55.0	83.1	43.8	70.2
	5% AEP			38.5	35.9	65.9	34.1	49.2
	10% AEP			26.8	24.7	51.9	26.3	37.0
	20% AEP			18.8	15.7	36.8	24.0	25.1

Refer over for footnotes to table.

TABLE 5.2 (Cont'd)
COMPARISON OF DESIGN PEAK FLOW ESTIMATES AT MOLONG

Catchment[1]	Storm Event	Previous Investigations		Present Study				
		ARR 1987			ARR 2019			
		DLWC, 1995	URS, 2011	PRM	RFFE	Molong Drains Model		
		[DLWC Loss Values]	[URS Loss Values]			[ARR Data Hub Loss Values]	[DLWC Loss Values]	[Walsh et al Loss Values]
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]
Moss Hollow Creek	PMF	Not Assessed	Not Assessed	Not Assessed	Not Assessed	460		
	0.2% AEP					88.8	58.9	79.5
	0.5% AEP					75.4	47.3	66.2
	1% AEP			58.3	64.7	65.1	37.0	55.3
	2% AEP			44.3	48.5	55.2	26.8	45.3
	5% AEP			28.8	31.7	43.2	19.0	29.6
	10% AEP			20.2	21.8	33.6	15.9	22.7
	20% AEP			14.3	13.9	24.8	13.8	16.3

1. Refer **Figure 3.1** for extent of catchment.
2. Derived using the Generalised-Short-Duration-Method (**GSDM**) based on the procedures set out in BoM, 1994.
3. Derived using the Generalised-Short-Duration-Method (**GSDM**) based on the updated procedures set out in BoM, 2003.

6 HYDRAULIC MODELLING OF DESIGN FLOOD EVENTS

6.1 Hydraulic Model Structure

6.1.1. Partial Blockage of Hydraulic Structures

As per the requirements of ARR 2019, the potential for the existing drainage system to experience a partial blockage during a flood event was taken into account when deriving the design flood envelopes. **Table E1** in **Appendix E** provides a summary of the blockage factors that were derived for each individual headwall and bridge structure in the study area based on the procedures set out in ARR 2019. As per the recommendations in ARR 2019, an L_{10}[7] of 1.5 m was adopted for the blockage assessment, which is the recommended minimum value that should be adopted for urban areas in the absence of a record of past debris accumulated at the structure. **B**lockage factors of 20% and 50% were applied to on-grade and sag stormwater inlet pits, respectively.

6.2 Presentation and Discussion of Results

6.2.1. Accuracy of Hydraulic Modelling

The accuracy of results depends on the precision of the numerical finite difference procedure used to solve the partial differential equations of flow, which is also influenced by the time step used for routing the floodwave through the system and the grid spacing adopted for describing the natural surface levels in the floodplain. Channels are described by cross-sections normal to the direction of flow, so their spacing also has a bearing on the accuracy of the results. The results are also heavily dependent on the size of the two-dimensional grid, as well as the accuracy of the LiDAR survey data which has a design accuracy based on 95% of points within +/- 150 mm. Given the uncertainties in the LiDAR survey data and the definition of features affecting the passage of flow, maintenance of a depth of flow of at least 200 mm is required for the definition of a "continuous" flow path in the areas subject to shallow overland flow. Lesser modelled depths of inundation may be influenced by the above factors and therefore may be spurious, especially where that inundation occurs at isolated locations and is not part of a continuous flow path. In areas where the depth of inundation is greater than the 200 mm threshold and the flow path is continuous, the likely accuracy of the hydraulic modelling in deriving peak flood levels is considered to be between 100 and 150 mm.

Use of the flood study results when applying flood related controls to development proposals should be undertaken with the above limitations in mind. Proposals should be assessed with the benefit of a site survey to be supplied by applicants in order to allow any inconsistencies in results to be identified and given consideration. This comment is especially appropriate in the areas subject to shallow overland flow, where the inaccuracies in the LiDAR survey data or obstructions to flow would have a proportionally greater influence on the computed water surface levels than in the deeper flooded areas.

6.2.2. Critical Duration and Temporal Pattern Assessment

The critical storm durations and associated median temporal patterns for the design storm events were derived based on the results of running both the DRAINS and TUFLOW models in tandem. For example, design discharge hydrographs for the ensemble of temporal patterns for storm

[7] L_{10} is defined as the average length of the longest 10% of the debris reaching the site.

durations ranging between 15 minutes and 18 hours were exported from the DRAINS model and input to the TUFLOW model. The assessment was undertaken for the 20%, 5% and 1% AEP storm events which represent the three temporal pattern bins (i.e. frequent, infrequent and rare, respectively) that were downloaded from the *ARR Data Hub.*

A similar process was adopted for determining the critical durations for the PMF using the procedures set out in BoM, 2003 and Jordan et al., 2005, whereby design discharge hydrographs for storm durations ranging between 15 minutes and 3 hours were exported from the DRAINS model and input to the TUFLOW model.

Table 6.1 sets out the storm durations and temporal patterns that were adopted as being critical for AEPs ranging from 50% and 0.2%, as well as the PMF.

TABLE 6.1
CRITICAL DURATIONS AND TEMPORAL PATTERNS

Design Storm Event	Temporal Pattern Bin	Critical Storm Duration and Temporal Pattern[1]
20%	Frequent	30 minute, temporal pattern 8 [2148] 1.5 hour, temporal pattern 6 [2248] 2 hour, temporal pattern 1 [2268] 3 hour, temporal pattern 8 [2318] 9 hour, temporal pattern 6 [2413]
10% 5%	Infrequent	30 minute, temporal pattern 7 [2135] 1 hour, temporal pattern 3 [2189] 1.5 hour, temporal pattern 6 [2231] 2 hour, temporal pattern 8 [2262] 6 hour, temporal pattern 2 [2367]
2% 1% 0.5% 0.2%	Rare	30 minute, temporal pattern 7 [2126] 1 hour, temporal pattern 2 [1999] 2 hour, temporal pattern 6 [2225] 3 hour, temporal pattern 4 [2199] 6 hour, temporal pattern 3 [2322]
PMF	Very Rare	15 minute, Melbourne 1972 temporal pattern 45 minute, Melbourne 1972 temporal pattern 2 hour, Melbourne 1972 temporal pattern 3 hour, Melbourne 1972 temporal pattern

1. Value in [ ] represent the Event ID for the critical storm duration and temporal pattern.

6.2.3. Design Flood Extents, Depths and Elevations

Figures 6.1 to **6.8** (3 sheets each) show the TUFLOW model results for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP floods, together with the PMF. These diagrams show the indicative extent and depth of inundation for the full range of design storm events throughout the study area.

In order to create realistic results which remove most of the anomalies caused by inaccuracies in the LiDAR survey data, a filter was applied to remove depths of inundation over the natural surface less than 100 mm. This has the effect of removing the very shallow depths which are more prone to be artefacts of the model, but at the same time giving a reasonable representation of the various overland flow paths. The depth grids shown on the figures have also been trimmed to the building polygons, as experience has shown that property owners incorrectly associate depths of above-ground inundation at the location of buildings with depths of above-floor inundation.

Water surface profiles for the modelled design storm events along a 5.5 km reach of Molong Creek are shown on **Figure 6.9** (2 sheets). **Figure 6.10** (2 sheets) shows stage hydrographs at selected road/rail crossings throughout the study area, while **Table F1** in **Appendix F** sets out the peak flood level and maximum depth of inundation at each crossing. **Table G1** in **Appendix G** sets out design peak flows and corresponding critical storm durations at key locations throughout the study area.

Figure 6.11 shows the indicative extent and depth of Major Overland Flow in the immediate vicinity of the Molong CBD absent elevated water levels in Molong Creek for design storms with AEPs of 5% (1 in 20) and 1% (1 in 100).

The sensitivity studies and discussion presented in **Section 6.5** provide guidance on suitable freeboard provisions under present day climatic conditions, as well as the findings of a study that was undertaken to assess the impact that the removal of the Orange-Broken Hill Railway and Euchareena Road bridges and their raised approaches would have on flood behaviour.

In accordance with DPE recommendations (DECC, 2007), sensitivity studies have also been carried out to assess the potential impacts of future climate change on flood behaviour (refer **Section 6.6**). While increases in flood levels due to future increases in rainfall intensities may influence the selection of Flood Planning Levels (**FPLs**), final selection of FPLs is a matter for more detailed consideration during the preparation of the future *Molong FRMS&P*.

6.2.4. Description of Flood Behaviour

The key features of Main Stream Flooding along Molong Creek are as follows:

i. Floodwater surcharges the banks of Molong Creek in flood events as frequent as 20% AEP, where it inundates the following roads:
   a. Hill Street at its intersection with Gidley Street; and
   b. Edward Street at its intersection with Thistle Street.

ii. Floodwater that surcharges the right (eastern) bank of Molong Creek commences to inundate existing development that is located on the western side of Betts Street and Euchareena Road in a 20% AEP flood.

iii. Floodwater commences to surcharge the left (western) bank of Molong Creek and overtop the railway upstream of Euchareena Road where it discharges through existing development that is located on Bank Street in a 10% AEP flood (refer Peak Flow Location (**PFL**) Q05b). A comparison of PFL Q05a and Q05b in **Table G1** of **Appendix G** shows that during flood events rarer than 10% AEP, about 20% of the total flow in Molong Creek surcharges the creek at this location and flows through the aforementioned development.

iv. **Figure 6.10** and **Table F1** in **Appendix F** show that the road and rail crossings of Molong Creek commence to become inundated as follows:

a. The Molong Creek Railway Bridge (refer Peak Flood Level Location (**PFLL**) H03) commences to be overtopped in a 5% AEP flood.

b. The Broken Hill Railway Line commences to be overtopped in the vicinity of the Broken Hill Railway Bridge No. 1 (refer PFFL H04) in a 2% AEP flood.

c. The Euchareena Road Bridge (refer PFFL H02) commences to be overtopped in a 1% AEP flood.

d. The low point in Marsden Street that is located immediately to the east of the Marsden Street Bridge (refer PFFL H01) commences to be inundated in a 0.5% AEP flood, which cuts access between the eastern and western sides of Molong.

v. **Table 6.3** sets out the head drop (i.e. difference in peak flood level) across the existing bridge structures of Molong Creek. A summary of the findings are as follows:

a. The head drop across the Marsden Street Bridge is between 0.52 m and 0.78 m during floods larger than 2% AEP.

b. The head drop across the Euchareena Road Bridge is generally between about 0.2 m and 0.3 m.

c. The head drop across the Molong Creek Railway Bridge is generally between about 0.2 m and 0.3 m.

d. The head drop across the Broken Hill Railway Bridge No. 1 is generally less than 0.3 m, as once the railway is overtopped, it acts as a broad crested weir and has a relatively high conveyance capacity.

e. The head drop across the Broken Hill Railway Bridge No. 2 is between about 0.4 m and 0.7 m.

Section 6.5.4 sets out the findings of a sensitivity study that was undertaken to assess the impact that the removal of the Orange-Broken Hill Railway and Euchareena Road bridges and their raised approaches would have on flood behaviour

TABLE 6.3
HEAD DROP AT EXISTING BRIDGE STRUCTURES
DESIGN FLOODS
(m)

Bridge	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
Marsden Street Bridge	0.20	0.24	0.35	0.52	0.70	0.75	0.78	0.10
Euchareena Road Bridge	0.16	0.19	0.25	0.34	0.37	0.40	0.43	0.22
Molong Creek Railway Bridge	0.19	0.27	0.34	0.31	0.29	0.26	0.23	0.05
Broken Hill Railway Bridge No. 1	0.09	0.11	0.16	0.23	0.24	0.24	0.24	0.13
Broken Hill Railway Bridge No. 2	0.38	0.48	0.58	0.66	0.70	0.72	0.76	0.25

vi. **Figures 6.1** to **6.8** show that a hillock on the right (eastern) overbank of Molong Creek immediately upstream of its confluence with Boree Hollow (refer PFL Q08 for location) causes a significant reduction in the width of the floodplain. The constriction imposed on flow by the hillock causes a rise in flood levels of about 0.7 m upstream of its location (refer Figure 6.9).

vii. **Figures 6.1** to **6.8** shows another key constriction on the Molong Creek floodplain is the reduction in the width of the floodplain extending for a distance of about 300 m downstream of the Molong Creek Railway Bridge.

viii. **Table F1** in **Appendix F** shows that the peak PMF flow in Molong Creek is about ten times the corresponding peak 1% AEP flow.

ix. **Figure 6.9** shows that peak flood levels along Molong Creek in a PMF are about 3.5 to 6 m higher than the corresponding 1% AEP flood levels.

The key features of Main Stream Flooding along Boree Hollow are as follows:

i. **Figure 6.10** and **Table F1** in **Appendix F** show that the road crossings of Boree Hollow commence to become inundated as follows:

    a. The Riddell Street Causeway (refer PFFL H07) will be inundated during freshes in the watercourse.

    b. The low level Williams Street crossing (refer PFFL H08) is inundated in a 20% AEP flood.

    c. The Wellington Street crossing (refer PFFL H06) commences to be overtopped in a 5% AEP flood.

    d. Hill Street (refer PFFL H09) commences to be overtopped in a 0.5% AEP flood.

ii. Access between the NSW SES Molong headquarters, which is located on William Street, and the main parts of Molong will be cut when Hill Street becomes inundated in a 0.5% AEP flood.

iii. Floodwater surcharges Boree Hollow in a 20% AEP flood and inundates existing development at the following locations:

    a. Upstream of the Riddell Street causeway, where floodwater flows in a north-easterly direction through the Council depot.

    b. Downstream of Hill Street, where floodwater surcharges the banks of the watercourse where it inundates the rear of residential allotments that are located on Old Dairy Lane and Kite Street.

iv. **Table G1** in **Appendix G** shows that the peak PMF flow in Boree Hollow is about ten times the corresponding peak 1% AEP flow.

The key features of Main Stream Flooding along Moss Hollow Creek are as follows:

i. **Figure 6.10** and **Table F1** in **Appendix F** show that the road crossings of Moss Hollow Creek commence to become inundated as follows:

    a. The Starrlea Road causeway crossing is inundated during freshes in the creek.

    b. The low level crossings at Quarry Road (refer PFFL H11) and End Street (refer PFFL H13) are inundated in a 20% AEP flood.

c. The low point in Market Street that is located adjacent to its intersection with End Street (refer PFFL H13) is inundated in a 20% AEP flood.

d. The Banjo Patterson Way Street crossing (refer PFFL H12) commences to overtop in a 5% AEP flood.

e. While the Packham Drive crossing (refer PFFL H10) remains flood free up to the PMF, floodwater originating from Moss Hollow Creek inundates the low point in the road approximately 50 m to the east in a 10% AEP flood.

ii. The low point in Market Street adjacent to its intersection with End Street is set at an elevation of about RL 583.0 m AHD, while the obvert of the Moss Hollow Creek culvert crossing is set at about RL 583.2 m AHD. As a result, floodwater commences to overtop Market Street before the culverts are pressurised. Floodwater that overtops Market Street at this location flows in an easterly direction through existing residential development, where it discharges to Molong Creek upstream of its confluence with Moss Hollow Creek.

iii. Floodwater surcharges the banks of the creek and inundates the land zoned *IN1 General Industrial* immediately downstream of Starrlea Road in a 20% AEP flood to depths of up to about 0.5 m.

iv. **Table G1** in **Appendix G** shows that the peak PMF flow in Moss Hollow Creek is about 11 times the corresponding peak 1% AEP flow.

The key features of Main Stream Flooding along Shingle Ridge Creek and Foys Creek are as follows:

i. **Figure 6.10** and **Table F1** in **Appendix F** show that the Mitchell Highway crossing of Foys Creek commences to be overtopped in a 0.5% AEP flood, while the Banjo Patterson Way crossing of Shingle Ridge Creek commences to be overtopped in a 0.2% AEP flood.

ii. The low level Shreeves Road crossing of Foys Creek will be inundated during freshes in the watercourse.

iii. **Table G1** in **Appendix G** shows that the peak PMF flow in Shingle Ridge Creek and Foys Creek is about ten times the corresponding peak 1% AEP flow.

The key features of Major Overland Flow in the Pillans Park Drainage Line are as follows:

i. The piped drainage elements beneath the road crossings of the Pillans Park Drainage Line have a capacity of less than 20% AEP, whereby the resulting surcharge flow discharges through adjacent residential development.

ii. **Figure 6.3** shows that floodwater commences to surcharge the piped drainage system between Iceworks Lane and Watson Street in a 5% AEP storm event.

iii. Elevated tailwater levels in Molong Creek commence to cause a backwater in the culverts beneath the railway and the private access road off Marsden Street in a 20% AEP flood event, significantly impacting the capacity to drain the Pillans Park Drainage Line. Once the capacity of these culverts is restricted, floodwater surcharges the left (northern) bank of the Pillans Park Drainage Line between Watson Street and the industrial land that is located to the east of the railway, where it flows in a northerly direction on the eastern side of the railway.

iv. **Table G1** in **Appendix G** shows that the peak PMF flow in the Pillans Park Drainage Line is about ten times the corresponding peak 1% AEP flow.

The key features of Major Overland Flow in the remainder of the study area are as follows:

i. In the instance when intense rain falls directly over Molong in the absence of elevated water levels in Molong Creek, ponding of Major Overland Flow would occur to maximum depths of about 0.4 m and 0.5 m for design storms with AEPs of 5% (1 in 20) and 1% (1 in 100), respectively at the following locations in the vicinity of the Molong CBD:

   - in Watson Street south of its intersection with Banks Street;
   - in Banks Street west of its intersection with Watson Street; and
   - in Hills Street near its intersection with Gidley Street.

   Stormwater ponding in the road reserve at the above locations is shown to extend into adjacent commercial and residential development, albeit generally at reduced depths.

ii. Floodwater inundates roads to depths greater than 0.2 m in a 1% AEP storm event at the following locations:

   - Back Saleyards Road to the south-east of the Molong Golf Course.
   - Back Saleyards Road immediately to the north of its intersection with Marsden Street;
   - Marsden Street adjacent to its intersection with Back Saleyards Road;
   - Deight Street approximately 250 m to the south of its intersection with Marsden Street;
   - Starrlea Road approximately 130 m to the north of the Moss Hollow Creek causeway; and
   - Starrlea Road approximately 170 m to the north of its intersection with Banjo Patterson Way.

6.2.5. Comparison with Previous Studies

Table 6.4 over the page shows a comparison of the design peak flood levels derived as part of the present study with those derived as part of URS, 2011. The key findings of the comparison are as follows:

i. The design peak flood levels derived as part of the present study are significantly higher than the URS, 2011 derived peak flood levels as the adopted peak 5% AEP flow is about 60% higher in the current study.

ii. While the design peak flood levels derived as part of the two studies are generally comparable for the 2% and 1% AEP floods, the Molong TUFLOW Model derived peak flood levels in the Molong CBD are generally higher due to the blocking effect of the buildings, noting that the Molong TUFLOW Model is considered to give a more accurate representation of flood behaviour in this area as it was calibrated to flood marks that were surveyed following the November 2022 flood.

iii. The peak flood levels in the PMF are generally lower than those that were derived as part of URS, 2011, as a peak PMF flow derived as part of the present study is significantly lower than that which was adopted as part of the previous investigation.

TABLE 6.4
COMPARISON OF DESIGN PEAK FLOOD LEVELS DERIVED AS PART OF PREVIOUS INVESTIGATIONS

Location	MIKE 11 Branch Name	MIKE 11 Section No.	5% AEP			2% AEP			1% AEP			PMF		
			URS, 2011 (m)	Present Study (m)	Difference[1] (m)	URS, 2011 (m)	Present Study (m)	Difference[1] (m)	URS, 2011 (m)	Present Study (m)	Difference[1] (m)	URS, 2011 (m)	Present Study (m)	Difference[1] (m)
Upstream Gamboola Weir	Molong Creek	1.4	536.0	536.4	+0.4	536.5	536.7	+0.2	536.8	537.0	+0.2	542.1	541.3	-0.8
Upstream Marsden Street Bridge		2.25	530.6	531.7	+1.1	531.6	532.2	+0.6	532.2	532.7	+0.5	537.9	537.7	-0.2
Dean Street		2.52	530.2	531.2	+1.0	530.9	531.5	+0.6	531.3	531.8	+0.5	536.9	537.3	+0.4
Molong Railway Station		2.84	529.2	530.4	+1.2	530.1	530.8	+0.7	530.7	531.0	+0.3	536.1	536.2	+0.1
Upstream Euchareena Road Bridge		2.91	529.0	530.3	+1.3	530.1	530.6	+0.5	530.5	530.9	+0.4	536.0	535.8	-0.2
Upstream Molong Creek Railway Bridge		3.03	529.0	529.8	+0.8	529.9	530.1	+0.2	530.3	530.4	+0.1	535.8	535.1	-0.7
Molong Swimming Pool		3.27	528.2	528.6	+0.4	528.6	528.9	+0.3	529.1	529.2	+0.1	534.5	534.1	-0.4
Upstream confluence with Boree Hollow		3.83	527.0	527.7	+0.7	527.5	528.0	+0.5	527.8	528.2	+0.4	534.2	532.6	-1.6
Upstream Broken Hill Railway Bridges No. 1 and 2		4.2	525.7	526.3	+0.6	526.2	526.7	+0.5	526.7	526.9	+0.2	533.5	531.6	-1.9
Speedy Street		4.9	523.8	523.9	+0.1	524.2	524.3	+0.1	524.6	524.5	-0.1	530.7	529.7	-1.0
Riddell Street	Watson Hill Street	0.12	529.6	530.3	+0.7	530.1	530.8	+0.7	530.1	531.1	+1.0	536.4	536.9	+0.5
Bundella Close		0.24	529.0	530.3	+1.3	529.7	530.7	+1.0	530.1	531.0	+0.9	535.9	536.6	+0.7
Bank Street		0.38	528.9	529.9	+1.0	529.6	530.3	+0.7	530.0	530.6	+0.6	535.5	535.6	+0.1
Hill Street		0.66	527.8	528.8	+1.0	528.6	529.2	+0.6	529.1	529.4	+0.3	534.5	534.3	-0.2

1. A positive value indicates that the design peak flood levels derived as part of the present study are higher, and conversely a negative value indicates they are lower than those derived as part of URS, 2011.

6.3 Economic Impacts of Flooding

Table 6.5 sets out the number of properties that are flood affected in the study area and the estimated damages which would occur for storm events of varying AEP for combined Main Stream Flooding and Major Overland Flow, as well as Main Stream Flooding along Molong Creek in isolation. **Figures 6.1** to **6.8** show the indicative depth of above-floor inundation that would be experienced in individual properties during flood events ranging between 20% AEP and the PMF.

TABLE 6.5
SUMMARY OF FLOOD DAMAGES

Flooding Mechanism	Design Flood Event (% AEP)	Number of Properties						Total Damage ($ Million)
		Residential		Commercial/ Industrial		Public		
		Flood Affected	Flood Above Floor Level	Flood Affected	Flood Above Floor Level	Flood Affected	Flood Above Floor Level	
Main Stream Flooding and Major Overland Flow	20	21	3	10	7	4	4	1.05
	10	34	6	25	24	11	6	2.69
	5	51	18	37	35	11	7	5.58
	2	63	31	41	39	12	9	8.69
	1	68	41	46	44	12	9	11.78
	0.5	77	48	49	48	12	10	14.02
	0.2	79	55	51	49	12	11	16.46
	PMF	256	196	66	65	18	17	77.38
Main Stream Flooding on Molong Creek Only	20	4	1	6	5	4	4	0.42
	10	10	3	25	24	8	6	1.93
	5	22	13	36	34	8	7	4.45
	2	28	19	39	37	9	8	6.67
	1	34	25	44	42	9	8	9.03
	0.5	37	29	46	46	9	8	10.88
	0.2	40	35	48	47	9	9	12.89
	PMF	151	146	62	62	14	14	64.01

The 10% AEP flood event is considered to be the "threshold" for which the number of individual buildings that would experience above-floor inundation increases significantly at Molong. For example, a total of 36 buildings (24 commercial, six residential and six public buildings) would be subject to above-floor inundation in a 10% AEP, resulting in total flood damages of about $2.7 Million. The total number of buildings inundated above-floor level increases to about 94 (44 commercial, 41 residential and nine public buildings) in a 1% AEP flood event resulting in total flood damages of about $11.8 Million.

During a PMF event, 196 dwellings, 65 commercial/industrial type buildings and 17 public building would experience above-floor inundation, resulting in total flood damages of about $77.4 Million.

The present study found that flooding from Molong Creek accounts for the majority of the commercial/industrial and public flood damages that are experienced at Molong, while it accounts for about 63% of the total residential flood damages.

For a discount rate of 7% pa, the *Present Worth Value* of total damages for all flood events up to the 1% AEP flood at Molong due to both Main Stream Flooding and Major Overland Flow is about $12.0 Million, while the *Present Worth Value* of total damages for flooding purely from Molong Creek at the 5% and 1% AEP level of flooding is about $4.8 Million and $8.0 Million, respectively. Therefore, one or more schemes costing up to these amounts could be economically justified if they eliminated damages in the study area for all flood events up to this level. While schemes costing more than this value would have a benefit/cost ratio less than 1, they may still be justified according to a multi-objective approach which considers other criteria in addition to economic feasibility.

Appendix G of this report contains further details on the economic assessment that was undertaken as part of the present study.

URS, 2011 found that a total of 64 (23 residential and 41 non-residential) buildings would be inundated above-floor level in a 1% AEP due to Molong Creek flooding compared with a total of 76 (25 residential, 41 commercial and 9 public) buildings that were identified as part of the present study. While the total number of buildings that are subject to above-floor inundation is comparable, the flood damages at the 1% AEP level of flooding derived as part of URS, 2011 was found to total about $4.67 Million compared with about $9.03 Million as part of the present study.

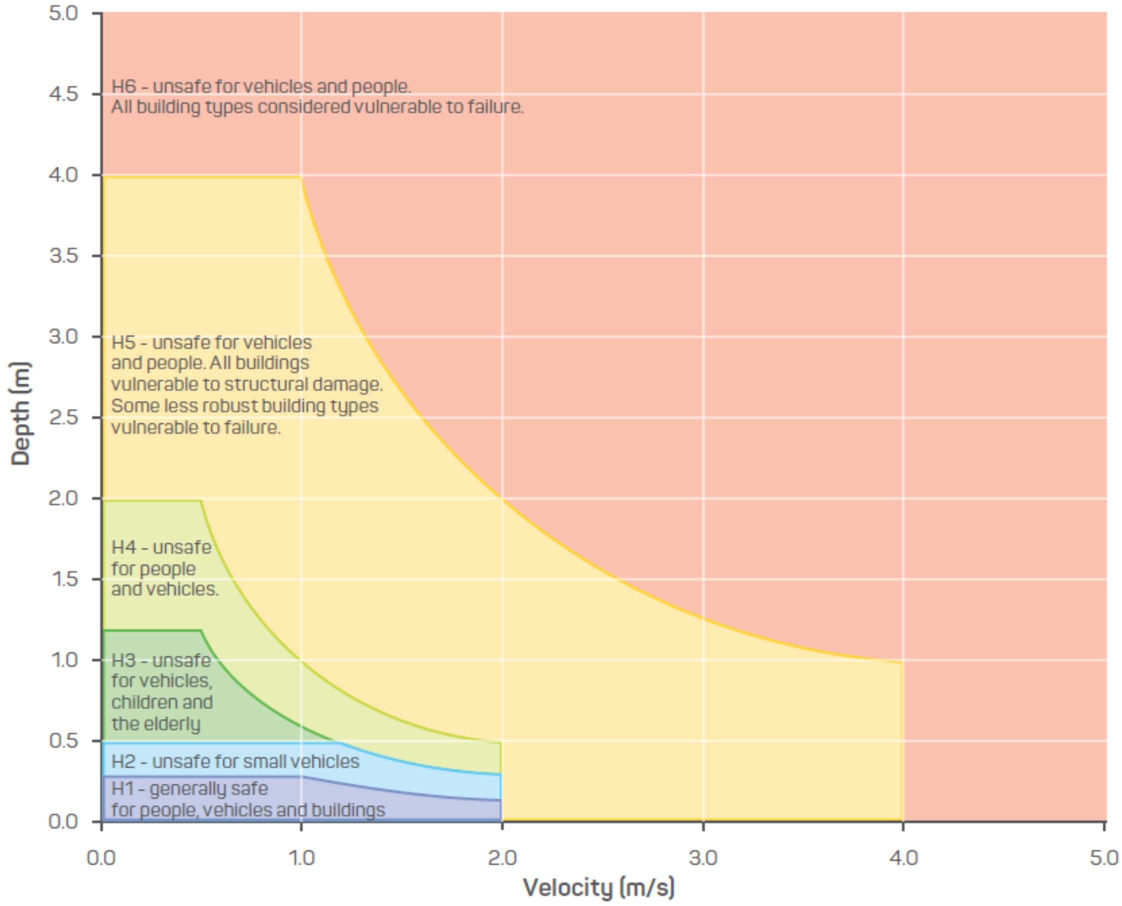
6.4 Flood Hazard Zones and Floodways

6.4.1. Flood Hazard Vulnerability Classification

Flood hazard categories may be assigned to flood affected areas in accordance with the definitions set out in ARR 2019. Flood prone areas may be classified into six hazard categories based on the depth of inundation and flow velocity that relate to the vulnerability of the community when interacting with floodwater as shown in the illustration over which has been taken from ARR 2019.

Flood Hazard Vulnerability Classification diagrams for the 5%, 2% and 1% AEP flood events based on the procedures set out in ARR 2019 are presented on **Figures 6.12**, **6.13** and **6.14**, respectively. It was found that areas classified as H6 are generally limited to the inbank area of Molong Creek in flood events up a 1% AEP, with large areas of H5 located on its overbank area and along its tributary arms.

Figure 6.14 shows that the majority of the Molong CBD is classified as H3, with isolated pockets of H4 in a 5% AEP flood event. **T**he hazard classification in the Molong CBD generally increases to H4 with isolated pockets of H5 in a 2% AEP flood, with the extent of land classified as H5 increasing further in a 1% AEP flood. It is important to note that upstream buildings have the effect of "shielding" downstream buildings from hazardous flooding conditions. Sensitivity analyses undertaken as part of the present study found that the extent of land classified as H5 in a 1% AEP increases in the vicinity of Bettes Street and the Molong CBD if the buildings are removed from the floodplain.



The flood hazard in the vicinity of existing development that is located on the western side of Betts Street and Euchareena Road is generally classified as H3 in a 5% AEP event, increasing to H4 in a 2% and 1% AEP flood.

Areas classified as H5 and H6 in a 1% AEP flood event are shown to be present in the vicinity of existing development at the following locations:

- on the left (western) overbank of Molong Creek in the vicinity of the Dr Ross Memorial Recreation Ground;
- in the vicinity of the intersection Thistle Street and Edward Street;
- on the left (western) and right (eastern) overbank of Boree Hollow between King Street and William Street;
- on the eastern side of Market Street to the south Moss Hollow Creek; and
- along the western kerb line of Baker Street where it runs between Loftus Street and Polaris Street.

The Major Overland Flow paths in the urbanised parts of Molong are generally classified as either H1 or H2 in a 1% AEP storm event, with the exception of areas where floodwater ponds on the upstream side of roads where it is generally classified as either H3 or H4.

6.4.2. Hydraulic Categorisation of the Floodplain

According to the *FDM*, the floodplain may be subdivided into the following three hydraulic categories:

- Floodways;
- Flood storage; and
- Flood fringe.

Floodways are those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with obvious naturally defined channels. Floodways are the areas that, even if only partially blocked, would cause a significant re-distribution of flow, or a significant increase in flood level which may in turn adversely affect other areas. They are often, but not necessarily, areas with deeper flow or areas where higher velocities occur.

Flood storage areas are those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.

Flood fringe is the remaining area of land affected by flooding, after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.

Floodplain Risk Management Guideline No. 2 Floodway Definition, offers guidance in relation to two alternative procedures for identifying floodways. They are:

- **Approach A**. Using a *qualitative approach* which is based on the judgement of an experienced hydraulic engineer. In assessing whether or not the area under consideration was a floodway, the qualitative approach would need to consider; whether obstruction would divert water to other existing flow paths; or would have a significant impact on upstream flood levels during major flood events; or would adversely re-direct flows towards existing development.
- **Approach B**. Using the hydraulic model, in this case TUFLOW, to define the floodway based on *quantitative experiments* where flows are restricted or the conveyance capacity of the flow path reduced, until there was a significant effect on upstream flood levels and/or a diversion of flows to existing or new flow paths.

One quantitative experimental procedure commonly used is to progressively encroach across either floodplain towards the channel until the designated flood level has increased by a significant amount (for example 0.1 m) above the existing (un-encroached) flood levels. This indicates the limits of the hydraulic floodway since any further encroachment will intrude into that part of the floodplain necessary for the free flow of flood waters – that is, into the floodway.

The *quantitative assessment* associated with **Approach B** is technically difficult to implement. Restricting the flow to achieve the 0.1 m increase in flood levels can result in contradictory results, especially in unsteady flow modelling, with the restriction actually causing reductions in computed levels in some areas due to changes in the distribution of flows along the main drainage line.

Accordingly the *qualitative approach* associated with **Approach A** was adopted, together with consideration of the portion of the floodplain which conveys approximately 80% of the total flow and also the findings of *Howells et al, 2004* who defined the floodway based on velocity of flow and depth. Based on the findings of a trial and error process, the following criteria were adopted for identifying those areas which operate as a "floodway" in a 1% AEP event:

- Velocity x Depth greater than 0.25 m^2/s **and** Velocity greater than 0.25 m/s; or
- Velocity greater than 1 m/s.

Flood storage areas are identified as those areas which do not operate as floodways in a 1% AEP event but where the depth of inundation exceeds 300 mm. The remainder of the flood affected area was classified as flood fringe.

Figures 6.15, **6.16** and **6.17** show the division of the floodplain into floodway, flood storage and flood fringe areas for the 5%, 2% and 1% AEP storm events, respectively.

As the hydraulic capacity of the watercourses is not large enough to convey the flow in a 5%, 2% and 1% AEP flood, the overbank areas also function as a floodway. As the ground levels rise relatively steeply at the edge of the floodplain, the majority of the floodplain is considered floodway at a number of locations.

Figure 6.15 shows that the floodway is confined to the road reserves in the vicinity of the Molong CBD in a 5% AEP flood, while **Figure 6.16** shows that floodways commence to operate between the buildings in this area in a 2% AEP flood. **Figure 6.17** shows that a large portion of the Molong CBD is categorised as floodway in a 1% AEP flood, noting that sensitivity testing undertaking as part of the present investigation found that preventing flow from discharging through the Molong CBD (similar to **Approach A**) increased peak flood levels on Molong Creek upstream of Euchareena Road Bridge by up to 0.3 m, indicating that this area is important for the conveyance of flood flows.

Flood storage areas are confined to the major ponding areas which are located on the upstream side of the road and railway embankments, as well as in the local farm dams that have been constructed to capture surface runoff in different parts of the study area.

6.5 Sensitivity Studies

6.5.1. General

The sensitivity of the hydraulic model was tested to variations in model parameters such as hydraulic roughness and the partial blockage of the major hydraulic structures by woody debris. The main purpose of these studies was to give some guidance on:

a) the freeboard to be adopted when setting minimum floor levels of development in flood prone areas, pending the completion of the future *Molong FRMS&P*; and

b) areas where additional flood related planning controls should be implemented due to the development of new hazardous flow paths.

In addition to the abovementioned studies, the sensitivity of flood behaviour on the Molong Creek floodplain to the removal of the Orange-Broken Hill Railway and Euchareena Road bridges and their raised approaches would have on flood behaviour has also been assessed.

6.5.2. Sensitivity of Flood Behaviour to an Increase in Hydraulic Roughness

Figure 6.17 shows the difference in peak flood levels (i.e. the "afflux") for the 1% AEP event resulting from an assumed 20% increase in hydraulic roughness (compared to the values given in **Table 4.2**).

The typical increases in peak flood level in the areas subject to Main Stream Flooding are generally in the range 50 to 200 mm, with increases of up to 240 mm show to occur in isolated areas. Increases in peak flood levels along the tributary arms of the three main flow paths and in other areas subject to Major Overland Flow are generally in the range 10 to 50 mm.

6.5.3. Sensitivity of Flood Behaviour to a Partial Blockage of Hydraulic Structures

The mechanism and geometrical characteristics of blockages in hydraulic structures and piped drainage systems are difficult to quantify due to a lack of recorded data and would no doubt be different for each system and also vary with flood events. Realistic scenarios would be limited to waterway openings becoming partially blocked during a flood event (no quantitative data are available on instances of blockage of the drainage systems which may have occurred during historic flood events).

A blockage assessment was undertaken for the study area based on the procedures set out in ARR 2019. Blockage factors of 25% and 50% were generally found to be applicable for the piped drainage lines within the urbanised parts of the study area, while blockage factors of 15% and 25% were generally found to be applicable for the footbridge crossings of the Main Drain and Major Overland Flow paths.[8]

Figure 6.18 shows that a partial blockage of the main road crossings of Molong Creek and its tributaries generally increases peak flood levels by up to 50 mm, with the exception of the Marsden Street Bridge, where a partial blockage increases peak flood levels by up to 80 mm. The combined partial blockage of the Molong Creek Railway and Euchareena Road Bridges increases peak flood levels in the Molong CBD by up to 40 mm. A partial blockage of the road crossings of Shingle Ridge Creek and Foys Creek causes localised increases in peak flood levels of up to 400 mm.

A partial blockage of the piped drainage system in areas subject to Major Overland Flow is generally negligible, except along the Pillans Park Drainage Line where the blockage of the culvert in the vicinity of Iceworks Lane increases peak flood levels by up to 120 mm.

6.5.4. Sensitivity of Flood Behaviour to the Removal of Rail and Road Infrastructure

Concerns have been raised in the local community that the Orange-Broken Hill Railway and more specifically the deck of the Molong Creek Railway Bridge, exacerbates flooding conditions in the Molong CBD due to its blocking effects on flood flows. The illustration over is a heat map showing the relative difference in existing surface levels on the floodplain of Molong Creek at Molong, noting that the warmer colours (i.e. reds and oranges) indicate higher elevations, while the cooler colours (i.e. mauves and blues) indicate lower elevations. The key features that influence the nature of flooding at Molong as observed in the illustration are as follows:

- The railway line is raised above natural surface levels where it crosses the floodplain of Molong Creek adjacent to the Molong CBD. It is noted that the raised section of railway line to the south of the creek crossing principally comprises ballast which is about 0.3 m in height, while the section to its north comprises a combination of ballast and earth embankment.

[8] Note that an L_{10} value of 1.5 m was adopted for the blockage assessment.

- The railway station and its adjacent car parking area is raised above adjacent natural surface levels.
- The approaches to the Euchareena Road Bridge are raised above the level of the adjacent floodplain and rail levels.
- The bowling greens in the Molong Bowling Club are elevated above the adjacent floodplain, noting that the elevation of the area bordering each green approximates the elevation of the adjacent railway line.
- The Molong CBD is located on the natural overbank area of Molong Creek, the lowest point of which runs diagonally from about the intersection of Watson Street and Bank Street to the intersection of Gidley Street and Hill Street.

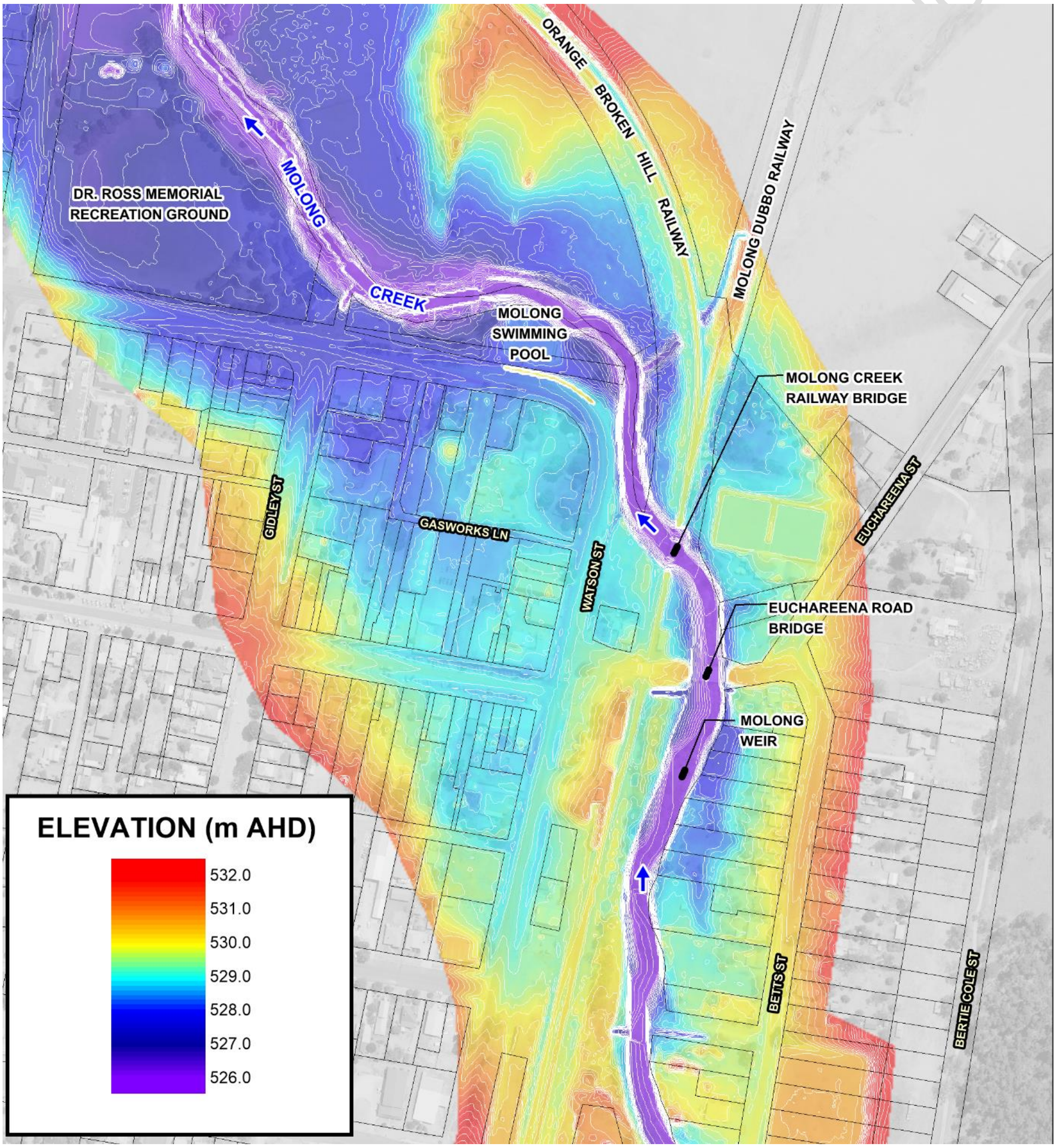


Illustration highlighting difference in existing surface levels on the floodplain of Molong Creek at Molong (derived from the available LiDAR and inbank survey data)

To assess the impact that the Molong Creek Railway Bridge and its raised approaches has on flood behaviour, the structure of the Molong TUFLOW Model was modified whereby details of the bridge and its raised approaches were removed. As part of the same assessment, the section of rail line that crosses the Molong Creek floodplain north of Thistle Street and its associated bridges was also removed from the model.

Figures 6.20 and **6.22**, as well as the values set out in columns D, E and F of **Table 6.6** over, show the reduction in peak flood levels that would result from the removal of the rail bridges and their raised approaches for floods with AEPs of 10%, 5% and 1%. While the removal of the rail bridges north of Thistle Street and their raised approaches reduces peak flood levels upstream of their location, the benefits are generally limited to the reach of Molong Creek extending downstream of the Molong Swimming Pool. Furthermore, while the removal of the Molong Creek Railway Bridge and its raised approaches reduces peak flood levels by up to 0.32 m immediately upstream of its location, reduction in peak flood levels within the Molong CBD are generally no greater than about 0.2 m.

The effects of the Molong Creek Railway bridge on flood behaviour is felt greatest by the community during the more frequent, bank-full type floods, for the reason that its deck extends below the top-of-bank level of the creek. During these type of flood events, the bridge deck pressurises and water levels in Molong Creek rise rapidly upstream of its location. The rise in water level results in floodwater surcharging the left (western) bank of Molong Creek upstream of the Euchareena Road Bridge where it builds up against the rail ballast, which as mentioned, is about 0.3 m in height. Due to the porous nature of the ballast, floodwater discharges onto Watson Street and thence Banks Street prior to the overtopping of the rail line, inundating a number of commercial properties, albeit to relatively shallow depths.

By inspection of the relative levels of the Molong Creek Railway Bridge and the Euchareena Road Bridge shown on **Figure 6.22**, the underside of the road bridge will pressurise before water levels reach the deck level of the rail bridge. The present investigation found that similar to the rail bridge, water levels upstream of the road bridge rise rapidly once the deck is pressurised, resulting in the premature overtopping of the rail line upstream of its location. **Figures 6.21** and **6.22**, as well as the values set out in columns G, H and I of **Table 6.6** show that the removal of both the road and rail bridges in combination with their raised approaches results in the greatest reduction in both the extent and depth of inundation in the Molong CBD.

6.6 Climate Change Sensitivity Analysis

6.6.1. General

At the present flood study stage, the principal issue regarding climate change is the potential increase in flood levels and extents of inundation throughout the study area. In addition it is necessary to assess whether the patterns of flow will be altered by new floodways being developed for key design events, or whether the provisional flood hazard will be increased.

DPE recommends that its guideline *Practical Considerations of Climate Change, 2007* be used as the basis for examining climate change induced increases in rainfall intensities in projects undertaken under the State Floodplain Management Program and NSWG, 2005. The guideline recommends that until more work is completed in relation to the climate change impacts on rainfall intensities, sensitivity analyses should be undertaken based on increases in rainfall intensities ranging between 10 and 30 per cent.

TABLE 6.6
REDUCTION IN PEAK FLOOD LEVELS ATTRIBUTABLE TO THE REMOVAL OF RAIL AND ROAD INFRASTRUCTURE

Flood Level Comparison ID	Watercourse	Location	Orange-Broken Hill Railway Bridges and Raised Approaches Removed			Orange-Broken Hill Railway and Euchareena Road Bridges and Raised Approaches Removed		
			10% AEP	5% AEP	1% AEP	10% AEP	5% AEP	1% AEP
[A[	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]
A01	Molong Creek	Marsden Street Bridge	-0.01	-0.01	-0.01	-0.02	-0.02	-0.02
A02	Molong Creek	Dean Street	-0.02	-0.03	-0.02	-0.04	-0.04	-0.05
A03	Molong Creek	Adjacent to Breakout on Left (Western) Overbank of Molong Creek	-0.06	-0.10	-0.07	-0.12	-0.17	-0.21
A04	Molong Creek	Euchareena Road Bridge	-0.10	-0.19	-0.12	-0.19	-0.32	-0.39
A05	Molong Creek	Molong Creek Railway Bridge	-0.16	-0.32	-0.25	-0.14	-0.30	-0.24
A06	Molong Creek	Molong Swimming Pool	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
A07	Molong Creek	Dr Ross Memorial Recreation Ground	-0.12	-0.11	-0.10	-0.12	-0.11	-0.09
A08	Molong Creek	Broken Hill Railway Bridge No. 1	-0.02	-0.12	-0.27	-0.02	-0.12	-0.27
A09	Molong Creek	Broken Hill Railway Bridge No. 2	-0.29	-0.40	-0.54	-0.29	-0.4	-0.54
A10	Molong CBD	Bundella Close	-0.14	-0.19	-0.07	-0.29	-0.35	-0.22
A11	Molong CBD	Bank Street	-0.09	-0.14	-0.08	-0.20	-0.25	-0.20
A12	Molong CBD	Gasworks Lane	-0.06	-0.07	-0.05	-0.14	-0.12	-0.08
A13	Molong CBD	Hill Street	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05

On current projections the increase in rainfalls within the service life of developments or flood management measures is likely to be around 10 per cent, with the higher value of 30 per cent representing an upper limit. Under present day climatic conditions, increasing the 1% AEP design rainfall intensities by 10 per cent would produce a 0.5% AEP flood; and increasing those rainfalls by 30 per cent would produce a 0.2% AEP event.

The impacts of climate change and associated effects on the viability of floodplain risk management options and development decisions may be significant and will need to be taken into account in the future *Molong FRMS&P* for the two towns using site specific data.

In the *Molong FRMS&P* it will be necessary to consider the impact of climate change on flood damages to existing development. Consideration will also be given both to setting floor levels for future development and in the formulation of works and measures aimed at mitigating adverse effects expected within the service life of development.

Mitigating measures which could be considered in the *Molong FRMS&P* include the implementation of structural works such as levees and channel improvements, improved flood warning and emergency management procedures and education of the population as to the nature of the flood risk.

6.6.2. Sensitivity to Increased Rainfall Intensities

As mentioned, the investigations undertaken at the flood study stage are mainly seen as sensitivity studies pending more detailed consideration in the *Molong FRMS&P*. For the purposes of the present study, the design rainfalls for 0.5 and 0.2 per cent AEP events were adopted as being analogous to flooding which could be expected should present day 1% AEP rainfall intensities increase by 10 and 30 per cent, respectively.

Figure 6.23 shows the increase in peak flood levels resulting from a 10 per cent increase in 1% AEP rainfall intensities. The increase in peak flood levels along Molong Creek varies between 100 to 300 mm, while increases in peak flood levels of generally up to 100 mm are shown to occur along its major tributaries. Peak flood levels in areas subject to Major Overland Flow are generally shown to increase by up to 50 mm.

Figure 6.24 shows the afflux for a 30 per cent increase in 1% AEP rainfall intensities. Peak flood levels along Molong Creek are increased by up to 500 mm, while increases in peak flood levels of up to 300 mm are shown to occur along its major tributaries. Peak flood levels in areas subject to Major Overland Flow are generally shown to increase by up to 100 mm.

Figure 6.25 shows the increase in the extent of land that would be affected by floodwater should 1% AEP rainfall intensities increase by 10 or 30 per cent. The extent of land that would be inundated by floodwater should 1% AEP rainfall intensities increase by up to 30% is negligible due to the relatively steep sided nature of the floodplain adjacent to the relatively flat overbank areas.

Consideration will need to be given to the identified changes that occur in flood behaviour during the preparation of the future *Molong FRMS&P*.

6.7 Selection of Interim Flood Planning Levels

After consideration of the TUFLOW model results and the findings of sensitivity analyses outlined in **Sections 6.5** and **6.6**, the following criteria were adopted for defining the Interim FPA:

- in areas subject to Main Stream Flooding, the extent of the FPA was defined as land lying at or below the peak 1% AEP flood level plus a freeboard allowance of 0.5 m; and
- in areas subject to Major Overland Flow and that also lie outside the extent of the Main Stream Flooding FPA, the extent of the FPA was defined as land inundated to a depth greater than 100 mm or within the extent of the floodway.[9]

Figure 6.26 (3 sheets) shows the extent of the Interim FPA in the study area. In areas that lie within the extent of the Interim FPA it is recommended that a freeboard of 0.5 m be applied to peak 1% AEP flood levels when setting the minimum habitable floor levels of future development. An assessment should also be undertaken by Council as part of any future Development Application to confirm that the proposed development will not form an obstruction to the passage of flow through the subject site.

Consideration will need to be given during the preparation of the future *Molong FRMS&P* to the appropriateness of the adopted freeboard allowance of 0.5 m given the impact changes in hydraulic roughness and future increases in rainfall intensity could have on peak flood levels. Consideration will also need to be given to the setting of an appropriate freeboard for areas subject to Major Overland Flow given that the adopted value of 0.5 m may be found to be too conservative.

Figure 6.26 also shows the extent of the *Outer Floodplain*, which is the area which lies between the FPA and the extent of the PMF. It is recommended that Council consider precluding critical, sensitive and vulnerable type development such as hospitals with emergency facilities, emergency services facilities, utilities, community evacuation centres, aged care homes, seniors housing, group homes, boarding houses, hostels, caravan parks, schools and childcare facilities in this area.

[9] The extent of Major Overland Flow FPA was filtered to remove pockets of flooding where the area was less than 100 m^2.

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8 FLOOD-RELATED TERMINOLOGY

Note: For an expanded list of flood-related terminology, refer to glossary contained within the Floodplain Development Manual, NSW Government, 2005).

TERM	DEFINITION
Afflux	Increase in water level resulting from a change in conditions. The change may relate to the watercourse, floodplain, flow rate, tailwater level etc.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 50 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 50 m^3/s or larger events occurring in any one year (see average recurrence interval).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	The average period in years between the occurrence of a flood of a particular magnitude or greater. In a long period of say 1,000 years, a flood equivalent to or greater than a 100 year ARI event would occur 10 times. The 100 year ARI flood has a 1% chance (i.e. a one-in-100 chance) of occurrence in any one year (see annual exceedance probability).
Catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
Critical Duration	The storm duration which produces the highest peak flood level for a given design flood event.
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving (e.g. metres per second [m/s]).
Flood fringe area	The remaining area of flood prone land after floodway and flood storage areas have been defined.
Flood Planning Area (FPA)	The area of land inundated at the Flood Planning Level.
Flood Planning Level (FPL)	A combination of flood level and freeboard selected for planning purposes, as determined in floodplain risk management studies and incorporated in floodplain risk management plans.
Flood prone land	Land susceptible to flooding by the Probable Maximum Flood. Note that the flood prone land is synonymous with flood liable land.
Flood storage area	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
Floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event (i.e. flood prone land).

TERM	DEFINITION
Floodplain Risk Management Plan	A management plan developed in accordance with the principles and guidelines in the *Floodplain Development Manual, 2005*. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
Floodway area	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Freeboard	A factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. It is usually expressed as the difference in height between the adopted Flood Planning Level and the peak height of the flood used to determine the flood planning level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such and wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as “greenhouse” and climate change. Freeboard is included in the flood planning level.
High hazard	Where land in the event of a 1% AEP flood is subject to a combination of flood water velocities and depths greater than the following combinations: 2 metres per second with shallow depth of flood water depths greater than 0.8 metres in depth with low velocity. Damage to structures is possible and wading would be unsafe for able bodied adults.
Low hazard	Where land may be affected by floodway or flood storage subject to a combination of floodwater velocities less than 2 metres per second with shallow depth or flood water depths less than 0.8 metres with low velocity. Nuisance damage to structures is possible and able bodied adults would have little difficulty wading.
Main stream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
Mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
Merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well-being of the State’s rivers and floodplains.
Major overland flow	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
Peak discharge	The maximum discharge occurring during a flood event.

TERM	DEFINITION
Peak flood level	The maximum water level occurring during a flood event.
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land (i.e. the floodplain). The extent, nature and potential consequences of flooding associated with events up to and including the PMF should be addressed in a floodplain risk management study.
Probability	A statistical measure of the expected chance of flooding (see annual exceedance probability).
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall which actually ends up as stream flow, also known as rainfall excess.
Stage	Equivalent to water level (both measured with reference to a specified datum).

APPENDIX A

COMMUNITY NEWSLETTER AND QUESTIONNAIRE

MOLONG FLOOD STUDY

COMMUNITY NEWSLETTER

Cabonne Council has engaged consultants to undertake a flood study for the town of Molong which will define mainstream flooding patterns along Molong Creek, Boree Hollow, Moss Hollow Creek and Foys Creek. The study will also define flood behaviour in areas that are subject to major overland flow which occurs as a result of surcharge of the local stormwater drainage system. Please see the back of this page for the approximate extent of the study areas.

The study is being undertaken by Council with funding assistance from the NSW Department of Planning and Environment which aims to build community resilience towards flooding through informing better planning of development, emergency management and community awareness. Council has established a Floodplain Risk Management Committee which is comprised of relevant council members, state government agencies and community representatives.

The *Flood Study* is an important first step in the floodplain risk management process for this area and will be managed by Council according to the NSW Government's Flood Prone Lands Policy.

The various stages of the *Flood Study* will be as follows:

- Review previous flooding investigations that have been undertaken at Molong.
- Undertake survey of the creeks and stormwater drainage system, as well as the collection of data on historic flooding.
- Preparation of state-of-the-art computer models of the creeks and stormwater drainage system to determine flooding and drainage patterns, flood levels, flow velocities and depths of inundation.
- Preparation of a *Flood Study* report which will document the findings of the investigation. The draft *Flood Study* report will be placed on public exhibition following completion of the investigation seeking community feedback on its findings.

Following the completion of the *Flood Study*, the consultants will undertake the preparation of a *Floodplain Risk Management Study and Plan* which will assist Council in refining strategic plans for mitigating and managing the effects of the existing, future and continuing flood risk at Molong.

An important first step in the preparation of a *Flood Study* is to identify the availability of information on historic flooding in the study area. The attached *Community Questionnaire* has been provided to residents and business owners to assist the consultants in gathering this important information. All information provided will remain confidential and for use in this study only. Please return the completed questionnaire in the reply-paid envelope provided by **Tuesday 28 February 2023**.

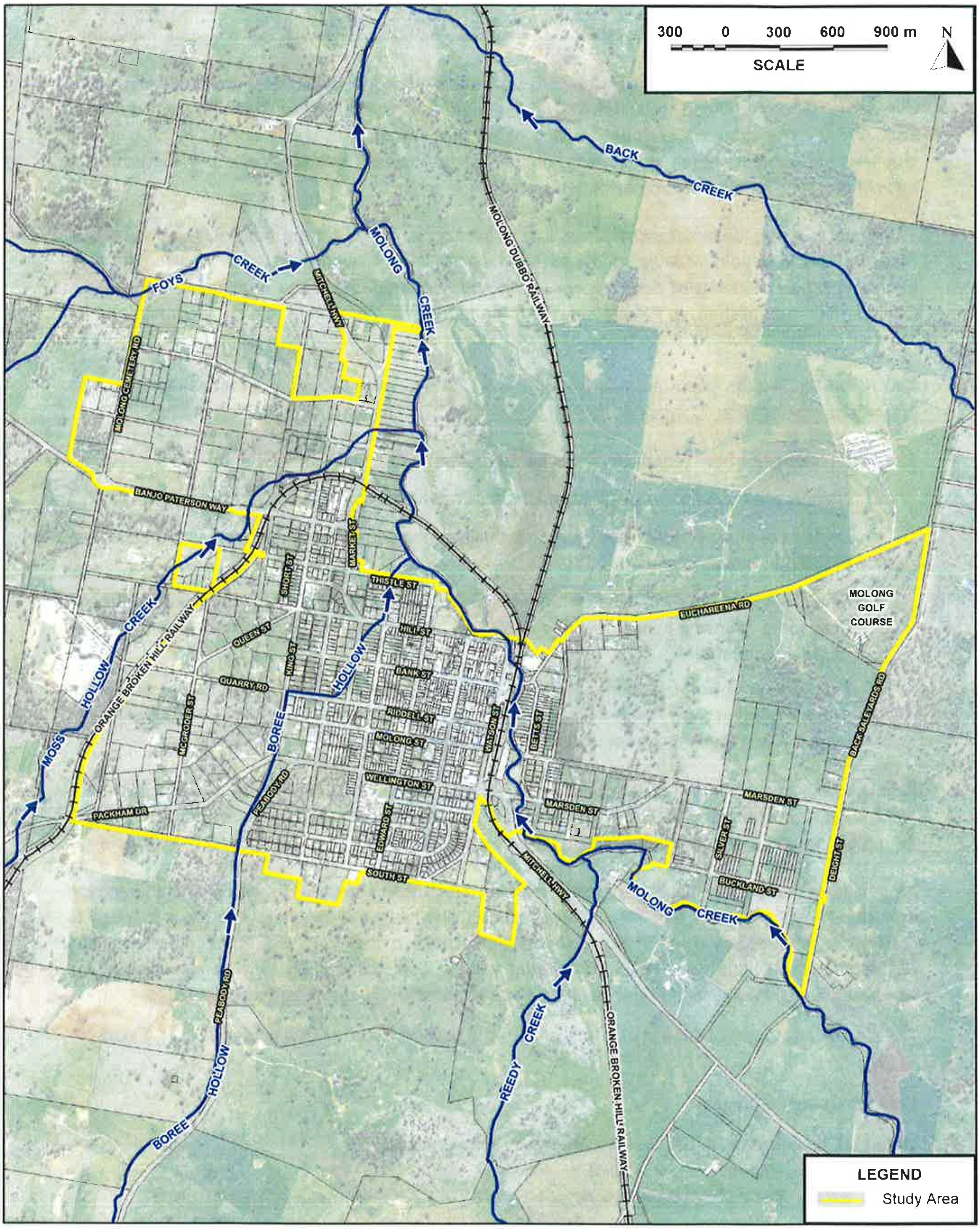
The Community Questionnaire is also available online at www.cabonne.nsw.gov.au/Molong-Flood-Study

Contact: Cabonne Council

Matthew Christensen | Deputy General Manager - Infrastructure
Phone: (02) 6392 3200
Email: Council@cabonne.nsw.gov.au

CABONNE COUNCIL

STUDY AREA



300 0 300 600 900 m
SCALE
N
BACK CREEK
MOLONG CREEK
FOYS CREEK
MITCHELL HWY
MOLONG DUBBO RAILWAY
MOLONG CEMETERY RD
BANJO PATERSON WAY
MARKET ST
SHORT ST
THISTLE ST
BUCHAREENA RD
MOLONG GOLF COURSE
HILL ST
QUEEN ST
KING ST
HOLLOW CREEK
MOSS HOLLOW CREEK
ORANGE BROKEN HILL RAILWAY
QUARRY RD
BANK ST
BOREE HOLLOW
RIDDELL ST
MOLONG ST
WATSON ST
BETTS ST
BACK SALEYARDS RD
MCGRODER ST
PEABODY RD
WELLINGTON ST
MARSDEN ST
PACKHAM DR
EDWARD ST
SILVER ST
SOUTH ST
BUCKLAND ST
DEIGHT ST
REEDY CREEK
LEGEND
Study Area

MOLONG FLOOD STUDY

COMMUNITY QUESTIONNAIRE

This questionnaire is part of the *Molong Flood Study*, which is currently being prepared by Cabonne Council with the financial support of the NSW Department of Planning and Environment. Your responses to the questionnaire will help us determine the flood issues that are important to you.

Please return your completed questionnaire in the reply paid envelope provided by **Tuesday 28 February 2023**. No postage stamp is required. If you have misplaced the supplied envelope or wish to send an additional submission the address is:

Lyall & Associates Consulting Water Engineers
Reply Paid 85163
NORTH SYDNEY NSW 2060

1. YOUR DETAILS:

a) Name (Optional):______________________________

b) Address:______________________________

c) Phone Number (Optional):______________________________

d) Email (Optional): ______________________________

2. WHAT TYPE OF PROPERTY DO YOU LIVE IN / OWN?:

☐ Residential
☐ Commercial
☐ Industrial
☐ Vacant Land
☐ Other (please specify):______________________________

3. WHAT IS THE OCCUPIER STATUS OF THIS PROPERTY?:

☐ Owner occupied
☐ Rental property
☐ Business
☐ Other (please specify):______________________________

4. HOW LONG HAVE YOU LIVED, WORKED OR OWNED PROPERTY IN THE AREA?

a) At this address?

☐ 0-5 years ☐ 5-10 years ☐ 10-20 years ☐ More than 20 years

b) In the general area?

☐ 0-5 years ☐ 5-10 years ☐ 10-20 years ☐ More than 20 years

5. HAVE YOU EVER BEEN AFFECTED BY FLOODING?

☐ Yes ☐ No

6. IF YOU ANSWERED YES TO QUESTION 5, WHEN AND HOW WERE YOU AFFECTED BY FLOODING?

	Flood # 1	Flood #2
Date of flood	☐ March 1956 ☐ February 1972 ☐ April 1990 ☐ August 1990 ☐ November 2005 ☐ November 2021 ☐ November 2022 ☐ Other (please specify):__________	☐ March 1956 ☐ February 1972 ☐ April 1990 ☐ August 1990 ☐ November 2005 ☐ November 2021 ☐ November 2022 ☐ Other (please specify):__________
How were you affected	☐ Roadway was cut by water ☐ My front/back yard was flooded ☐ My garage was flooded ☐ My house/business was flooded ☐ Other (please specify): __________	☐ Roadway was cut by water ☐ My front/back yard was flooded ☐ My garage was flooded ☐ My house/business was flooded ☐ Other (please specify): __________
Description of flood behaviour (i.e. depths, levels, duration of inundation etc. - please be as descriptive as possible)		

Please use the area provided at the end of this Questionnaire if you require additional space to answer Question 6.

7. DO YOU HAVE ANY PHOTOS OR VIDEOS OF THESE FLOODS?

☐ Yes ☐ No

If yes, a copy of these photos/videos would assist the study. Please email a copy of the photos /videos to molong@lyallandassociates.com.au.

8. IN YOUR OPINION, WHAT WAS THE MAIN CAUSE OF THE FLOODING? (YOU CAN SELECT MORE THAN ONE OPTION)

- ☐ Insufficient creek capacity
- ☐ Insufficient stormwater capacity
- ☐ Blockage of creeks, stormwater inlets, bridges or drains by debris
- ☐ Overland flow impediments (i.e. fences, buildings)
- ☐ Other (please specify): ______________________________

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9. PLEASE WRITE ANY ADDITIONAL COMMENTS, INFORMATION OR SUGGESTION THAT YOU THINK MAY ASSIST THE STUDY:

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APPENDIX B

DETAILS OF AVAILABLE DATA
AND COMMUNITY CONSULTATION

TABLE OF CONTENTS

Page No.

ANNEXURES

LIST OF FIGURES (BOUND IN VOLUME 2)

B1 BACKGROUND INFORMATION

B1.1 Airborne Laser Scanning Survey

Table B1.1 sets out the details of the two sets of LiDAR survey data that cover the study area, the extent of which are shown on **Figure B1.1**. The data comprising each set were captured in accordance with the International Committee on Surveying and Mapping guidelines for digital elevation data with a 95% confidence interval on horizontal accuracy of ±800 mm and a vertical accuracy of ±150 mm.

TABLE B1.1
LiDAR SURVEY DATA SPECIFICATIONS

Data Set	Date of Capture	Data Provider
Molong202203	March 2022	Geoscience Australia
Molong201108	August 2011	

B1.2 Existing Stormwater Drainage Network

Figure B1.1 shows the layout of the existing stormwater drainage network in the study area. Details of the existing stormwater drainage network were taken from the detailed structure survey that were undertaken by Diverse Project Solutions Yass (**DPS Yass**) in February 2023 and supplemented by field measurements and Council data. The structure survey were provided as point data in 12da format which was then linked together as part of the present study.

B1.3 Cross Sectional Survey Data

DPS Yass was also engaged to undertake inbank cross sectional survey at regular intervals along Molong Creek (refer **Figure B1.1** for location). Cross sectional survey were also captured of the five bridge and two weir structures that are located on the Molong Creek floodplain. Cross section data were provided as 3d lines in the 12da format which were used to derive tabulations of offset versus elevation in an Excel spreadsheet. A photographic record of each cross section was also compiled by the surveyor.

B1.4 Historic Rainfall Data

Rainfall data were available at one All Weather Station (**AWS**) and seven flood warning network rain gauges that are operated by the Bureau of Meteorology (**BoM**) and one pluviographic rainfall gauge that is operated by WaterNSW. **Figure 1.1** of the Main Report shows the plan location of the abovementioned gauges, while **Table B1.2** sets out the details of the available rain gauge network.

TABLE B1.2
SUMMARY OF AVAILABLE PLUVIOGRAPHIC RAIN GAUGE DATA[(1)]

Gauge Type	Gauge Number	Gauge Name	Site Commence	Site Cease
BoM AWS	63303	Orange Airport AWS	October 2010	Ongoing
BoM Flood Warning Network	65110	Borenore (Lynden-Brae)	Gauge data only recorded when BoM's flood warning system is activated	
	65010	Cudal Post Office		
	65051	Cumnock Tm		
	65022	Manildra (Hazeldale)		
	62106	Molong (Bonnie Doon)		
	65041	Molong Post Office		
	63254	Orange Agricultural Institute		
WaterNSW Pluviograph	421178	Molong Creek at Downstream Borenore Creek	February 2002	Ongoing

1. Refer **Figure 1.1** of the Main Report for location.

B1.5 Stream Gauge Data

Figure B1.1 shows the location of three WaterNSW operated stream gauges and one manually read stream gauge that are located on Molong Creek, while **Table B1.3** sets out the details of each.

TABLE B1.3
SUMMARY OF AVAILABLE STREAM GAUGE DATA[(1)]

Gauge Operator	Gauge Number	Gauge Name	Site Commence	Site Cease	Available Data	
					Level	Discharge
WaterNSW	421049	Molong Creek at Molong	July 1965	January 1997	Yes	Yes
	421159	Molong Creek at Copper Hill	December 2000	February 2005	Yes	Yes
	421178	Molong Creek at Downstream Borenore Creek	February 2002	Ongoing	Yes	No
NSW SES	10456	Wellington Street Gauge	Unknown[(2)]	Ongoing	Yes	No

1. Refer **Figure B1.1** for location.
2. While the date that the Wellington Street gauge was established is not known, records at the gauge site are available dating back to 1956.

B1.6 Flood Marks

Figure B1.1 shows the location of surveyed flood marks for the March 1956, April 1990 and August 1990 flood events that were taken from DLWC, 1995, as well as twenty flood marks from the November 2022 flood that were surveyed by Orange City Council. **Figure B1.1** also shows the location where the approximate depth of inundation for the November 2005 were provided by NSW SES.

B1.7 Surveyed Floor Levels

The *Molong Flood Study Options Report* which was prepared by David Ecclestone in November 2010 contains surveyed floor levels of 37 buildings that are located on Bank Street where it runs between Watson Street and Gidley Street

B1.8 Photographic Record

Appendix C of this report contains a number of photographs that were provided by respondents to the *Community Newsletter and Questionnaire* showing flood behaviour in the study area during storms that occurred on 8 November 2005, 20 July 2016, 26 January 2020, 26 November 2021 and 13-14 November 2022.

B2 REVIEW OF PREVIOUS REPORTS

B2.1 New South Wales Inland Rivers Flood Plain Management Studies – Macquarie Valley (Sinclair, Knight and Partners, 1984)

The *New South Wales Inland Rivers Flood Plain Management Studies – Macquarie Valley* (Sinclair, Knight and Partners (**SKP**), 1984) was commissioned by the Water Resources Commission (now DPE) as the first phase of a comprehensive study to establish the needs for flood mitigation measures for both rural and urban areas in the Macquarie Valley.

SKP, 1984 found that the flood that occurred in 1956 was the largest flood to have occurred at Molong in recent history. SKP, 1984 found that during the March 1956 event, floodwater surcharged the left bank of Molong Creek and overtopped the railway upstream of the railway station, where it flowed in a north-westerly direction through Molong, inundating the commercial centre to depths of up to one metre.

SKP, 1984 identified that Council had upgraded the Old Shades Road (now Euchareena Road) and Wellington Street bridge crossing of Molong Creek since the 1956 flood to achieve a 1% AEP standard. It also found that Council had undertaken extensive stream clearing along a 4.2 km reach of Molong Creek between Copper Street and the downstream railway bridge between 1971 and 1980.

SKP, 1984 identified that the two single span railway bridge crossings of Molong Creek have a significant impact on the conveyance capacity of the creek. It was found that the bridges partially obstruct flow in the creek because:

a) their piers are not constructed parallel to the stream flow; and

b) a large amount of debris becomes entangled in the timber trestles during flood events.

The recommendations of SKP, 1984 were as follows:

- Upgrade the rail bridge crossings of the creek to have equivalent effective waterway areas to the recently upgraded Council bridges.
- Any future expansion of the town occur to the west of the existing urban centre.
- Additional stream clearing works should be undertaken both upstream and downstream of the area where clearing has already occurred.
- A hinged reflux valve be fitted to the stormwater outlet to Molong Creek (immediately upstream of Euchareena Road).
- Voluntary purchase of a single dwelling that is located within the floodway on the right bank of Molong Creek immediately downstream of Euchareena Road.

B2.2 Molong Flood Study (Department of Land and Water Conservation, 1995)

The *Molong Flood Study* (Department of Land and Water Conservation (**DLWC**), 1995) defined the nature of flooding from Molong Creek at Molong. DLWC, 1995 contains a description of historic flooding at Molong, which includes three floods that overtopped the railway and inundated the commercial centre of town in February 1928, March 1956 and August 1990. DLWC, 1995 contains details of five flood marks from the March 1956 flood that were taken from the *Molong 1983 Flood Map* (Water Resources Commission, 1983) (refer **Figure B1.1** for their plan location), as well as 34 flood marks from the April 1990 and 42 flood marks from the August 1990 flood that were surveyed by Council immediately after the respective events.

Table B2.1 sets out the results of a flood frequency analysis was undertaken as part of DLWC, 1995 using the 28 years of annual peak flows at the *Molong Creek at Molong* stream gauge (GS 421049) (**Molong stream gauge**). **Tables B2.1** also sets out the design peak flow estimates that were derived using the Probabilistic Rational Method (**PRM**), procedures for which are contained in the 1987 edition of *Australian Rainfall and Runoff* (**ARR 1987**) (The Institution of Engineers Australia, 1987).

A hydrologic model of the Molong Creek catchment was developed as part of DLWC, 1995 using the RORB software (**DLWC RORB Model**). While storage details of Molong Creek Dam and Borenore Creek Dam were incorporated in the DLWC RORB Model, sensitivity analyses found that omitting the dams from the hydrologic model had no effect on the design peak flows at the town. The DLWC RORB Model was calibrated to recorded data at the Molong stream gauge for flood events that occurred in April 1990 and August 1990, noting that storage parameters (k_c) of 8.5 and 9.8 were found to achieve a good match between the recorded and modelled hydrographs at the gauge.

Table B2.1 sets out the design peak flow estimates at the Molong stream gauge that were derived as part of DLWC, 1995. Initial loss values of between 30 mm and 40 mm in combination with a continuing loss value of 2.5 mm/hr were required to achieve a reasonable match with the results of the flood frequency analysis for flood events with a magnitude of 2% AEP and greater, while it was not possible to match the peak 1% AEP flood frequency derived flow using reasonable initial loss values. As a result, an initial loss value of 30 mm was adopted for deriving the peak 1% AEP flow based on the procedures set out in Walsh, 1991.

TABLE B2.1
DESIGN PEAK FLOW ESTIMATES AND INITIAL LOSS VALUES
DERIVED AS PART OF PREVIOUS INVESTIGATIONS

Design Event	DLWC, 1995				URS, 2011	
	Flood Frequency Analysis	PRM	DLWC RORB Model		URS RORB Model	
	Discharge (m^3/s)	Discharge (m^3/s)	Initial Loss(1) (mm)	Discharge (m^3/s)	Initial Loss(1) (mm)	Discharge (m^3/s)
[A]	[B]	[C]	[D]	[E]	[F]	[G]
PMF	-	-	0	4,700	0	6,114
1% AEP	280	400	30	370	24	367
2% AEP	230	300	35	260	29	272
5% AEP	165	205	39	165	34	165
10% AEP	120	145	38	120	31	120
20% AEP	80	-	39	80	34	80
50% AEP	50	-	30	50	27	50

The peak PMF flow at the Molong stream gauge was derived using the Generalised-Short-Duration-Method (**GSDM**) based on the procedures set out in BoM, 1994. **Table B2.1** shows that the peak PMF flow of 4,700 m^3/s is about 13 times the peak 1% AEP flow.

Discharge hydrographs derived from the DLWC RORB Model were input to a hydraulic (MIKE 11) model which comprised a 5.5 km reach of Molong Creek in the vicinity of Molong (**DLWC MIKE 11 Model**). The DLWC MIKE 11 Model was calibrated to the April 1990 and August 1990 floods. It was then used to define peak flood levels for the 5%, 2% and 1% AEP flood events, as well as the Extreme Flood (assumed to have a peak flow three times that of the 1% AEP flood) and the PMF. The peak 1% AEP flood levels were found to be about 700 mm higher than the recorded August 1990 flood levels.

B2.3 Molong Floodplain Management Study (Bewsher Consulting, 1997)

The DLWC RORB and MIKE 11 models that were developed as part of DLWC, 1995 were relied upon for the preparation of the *Molong Floodplain Management Study* (Bewsher, 1997). **Table B2.2** sets out the results of a flood damages assessment that was undertaken as part of Bewsher, 1997 which found that a total of 70 properties (28 dwellings and 42 non-residential buildings) would be subject to above-floor inundation in a 1% AEP flood event, resulting in about $1.86 Million worth of damage. The present-worth of flood damages was found to be $0.75 Million in 1997 dollars.

TABLE B2.2
SUMMARY OF FLOOD DAMAGES ASSESSMENT
UNDERTAKEN AS PART OF BEWSHER, 1997

Design Flood Event	No. of Properties				Total Flood Damages ($ Million)
	Flood Affected		Flooded Above-Floor Level		
	Residential	Non-Residential	Residential	Non-Residential	
PMF	102	71	96	70	9.05
3 x 100	58	57	50	57	6.56
200	42	50	34	45	2.64
100	36	46	28	42	1.86
50	31	41	16	35	0.97
20	11	17	2	12	0.1
10	3	5	0	3	0.02
5	0	0	0	0	0

A range of measures aimed at mitigating and managing the impact of flooding at Molong were assessed as part of Bewsher, 1997. **Table B2.3** over the page contains a summary of the recommended set of measures which were incorporated in the draft *Floodplain Management Plan* (***Molong FMP 1997***).

The widening of Molong Creek was assessed as part of Bewsher, 1997 but not incorporated in the *Molong FMP 1997* due to the significant impact that the works would have on vegetation and bank stability. While the upgrade of the Southern Railway Bridge was also not recommended in the *Molong FMP 1997*, Bewsher, 1997 recommended that Council should advise the Railway Services Authority of the impact that the bridge has on flooding, and request that any future bridge upgrades have a minimal impact on flood levels.

TABLE B2.3
RECOMMENDED FLOODPLAIN MANAGEMENT MEASURES
INCORPORATED IN *MOLONG FMP 1997*

Option No.	Description	Priority
1.6	Floodgates on stormwater drain outlets (subject to completion of Options 1.7 or 2.1).	Medium
1.7	Vegetation management, including the phased removal of exotic vegetation between the Gamboola Weir and the Broken Hill Railway Bridges.	High
1.8	Velocity dissipater at southern end of Betts Street to reduce flow velocities and improve evacuation conditions from existing development that is located on Betts Street.	Medium
1.9	Stabalise creek banks in the vicinity of the Molong Swimming Pool.	Medium
2.1 (a)	Voluntary purchase of 5 properties in Betts Street and Euchareena Road.	Medium
2.3	Building and development controls.	High
3.1	Community awareness and education.	High
3.2	Flood warning system, including the utilisation of BoM's existing flood warning network of rain gauges and the installation of two telemetered stream gauges; one in the township and the other downstream of the confluence of Molong Creek and Borenore Creek.	High
3.3	Emergency planning and management, including the provision of flood free access to the local NSW SES headquarters.	High

Construction of a levee to contain Molong Creek floodwaters was also assessed as part of Bewsher, 1997. It was found that in order to achieve a 1 m freeboard above the 1% AEP flood levels, the levees along the western and eastern bank of the creek would need to 2.7 m and 2.2 m high, respectively, which would reduce the visual amenity of the floodplain area. in order to facilitate the construction of the levee Bewsher, 1997 found that two dwellings would need to be purchased and the highway would need to be realigned through the existing caravan park. While it was also noted that overtopping of the levee would cause significant problems to the town, the extent of these problems were not defined. Based on the above, Bewsher, 1997 did not recommend construction of a levee for further consideration.

B2.4 Molong Flood Study Options Report (Ecclestone, 2010)

The *Molong Flood Study Options Report* prepared by David Ecclestone in November 2010 contains a preliminary analysis of a channel widening scheme which was aimed at reducing the impact of flooding on the commercial centre of Molong. The scheme included the following:

- purchase of 12 properties that are located on the western side of Betts Street;
- channel widening and lowering works along the 1.6 km reach of Molong Creek between Marsden Street Bridge and the confluence with Boree Hollow to create overland flow paths that are between 34 m and 60 m wide;
- upgrading the Euchareena Road bridge to include an additional 15 m wide bridge on the eastern side of the existing bridge; and
- upgrading the Southern Railway Bridge to include an additional 20 m wide bridge on the southern side of the existing bridge and realigning the piers so that they are aligned with the direction of flow in the creek.

While Ecclestone, 2010 states that the aim of the scheme was to prevent floodwater from Molong Creek overtopping the railway in the vicinity of Ridell Street and inundating the commercial centre of the town, the impacts that the proposed works would have on flood behaviour were not assessed. Ecclestone, 2010 estimated that the total cost of the scheme would be $7.8 Million (in 2010 dollars).

Ecclestone, 2010 contains surveyed floor levels for 37 buildings that are located along Bank Street where it runs between Watson Street and Gidley Street.

B2.5 Review of Molong Floodplain Risk Management Study (URS, 2011)

Following publication of the NSW Floodplain Development Manual in 2005, Council engaged URS to undertake the *Review of the Molong Floodplain Risk Management Study*. The DLWC RORB and MIKE 11 Models were updated as part of URS, 2010 to the latest version of their respective software (**URS RORB** and **MIKE 11 Models**).

Rainfall data for the November 2005 storm event were input to the URS RORB Model to generate discharge hydrographs which were then input to the URS MIKE 11 Model. While there were no stream gauge records available to calibrate the flows that were generated by the URS RORB Model for the November 2005 storm event, the results of the URS MIKE 11 Model achieved a reasonable match with flood levels that were recorded by NSW SES "through the middle of town"[1]. URS, 2011 found that the peak flow at the Molong stream gauge in the November 2005 was about 440 m^3/s (based on the results of the URS RORB Model contained in Annexure C of the study), noting that initial and continuing losses of 35 mm and 2.5 mm/hr were applied.

The design flood modelling originally undertaken as part of DLWC, 1995 was also updated as part of URS, 2011. While the structure of the DLWC RORB Model was not updated, the hydrologic model parameters relied upon for design flood modelling were updated to include the application of Aerial Reduction Factors (**ARFs**). The derivation of the PMF was also updated using the Generalised Short Duration Method procedures for which are set out on BoM, 2003.

Column G of **Table B2.1** shows the design peak flows generated by the URS RORB Model are comparable to those derived as part of DLWC, 1995, noting that lower initial loss values (refer Column F of **Table B2.1**) were adopted in URS, 2011 compared to the earlier study.

A hydrologic and hydraulic (DRAINS) model was developed as part of URS, 2011 to assess the impacts of local catchment flooding on the town centre of Molong, in particular at the intersection of Bank Street and Watson Street (**URS DRAINS Model**). The URS DRAINS Model was based on 1 m contour data and hard copy plans of the drainage system, and was used to map the approximate extent of inundation in the town centre for the 5% and 1% AEP design storm events.

Table B2.4 over the page sets out the results of a flood damages assessment that was undertaken as part of URS, 2011 for both Main Stream Flooding (along Molong Creek only) and Major Overland Flow based on the results of the URS MIKE 11 Model and URS DRAINS Model, respectively. While the number of properties that are impacted by flooding is comparable to those derived as part of Bewsher, 1997, the total flood damages derived as part of the more recent study are significantly higher as they are based on *Floodplain Risk Management Guideline No. 4, 2007* (**Guideline No. 4**) which was published by the Department of Environment and Climate Change (**DECC**) (now DPE) in 2007.

[1] URS, 2011 does not provide any further detail regarding the flood levels provided by NSW SES.

TABLE B2.4
SUMMARY OF URS, 2011 FLOOD DAMAGES ASSESSMENT

Flooding Mechanism	Design Flood Event	Number of Properties				Total Damage ($ Million)
		Residential		Non-Residential		
		Flood Affected	Flood Above Floor Level	Flood Affected	Flood Above Floor Level	
Main Street (Molong Creek) Flooding	3 x 1% AEP	57	49	58	56	11.25
	PMF	105	101	72	71	19.21
	1% AEP	32	23	44	41	4.67
	2% AEP	24	10	41	33	2.46
	5% AEP	2	0	5	2	0.09
Major Overland Flow	1% AEP	48	3	57	30	1.34
	5% AEP	48	3	57	25	1.16

A range of structural and non-structural measures including, but not limited to those contained in the *Molong FMP 1997* were assessed part of URS, 2011. URS, 2011 recommended the following measures for incorporation in the *Molong Floodplain Risk Management Plan* (***Molong FRMP 2011***):

Flood Modification Measures

- Upgrade local drainage system to contain minor flows to drainage system and major flows to road reserves.
- Consider temporary flood protection measures such as flood gates.
- Include specific measures in Council's Asset Management Plan to ensure the long-term maintenance of the existing flood gates in town.

Property Modification Measures

- Update the Cabonne Shire LEP using the Standard Instrument (Local Environmental Plans) Order 2006.
- Implement the draft Development Control Plan (**DCP**) which is contained in Appendix H of URS, 2011 and adopt Flood Planning Levels equal to the peak 1% AEP flood level plus 500 mm freeboard.
- Prepare and adopt specific statements for issue with Certificates under Section 149(2) and 149(5) of the EP&A Act in relation to floodplain risk management.
- Implement a graded set of land use controls to reflect the flood risk and proposed land use.
- Consider the matters set out in Section 79C of the EP&A Act when assessing development applications.
- Incorporate relevant section of the management plan in Council's LEP, flood related DCP and/or policy.

Response Modification Measures

- Council work with the NSW SES to update the Cabonne Local Flood Plan.
- Establish a "floodsafe" program for operating the caravan park in the town.
- Development and implementation of a community flood awareness program.

While not included in the recommendation for inclusion in the *Molong FMP 2011*, URS, 2011 states that the voluntary purchase program that was recommended as part of Bewsher, 1997 is continued. URS, 2011 also states that construction of a levee to contain floodwaters in Molong Creek "*is not supported for economic reasons and its impact of additional flooding in Betts Street*."

B2.6 Examining the resilience of rural communities to flooding emergencies (Manock, Ian, 2012)

Examining the resilience of rural communities to flooding emergencies is a technical paper that was written by Ian Manock and presented at the Australian & New Zealand Disaster and Emergency Management Conference in Brisbane on 16-18 April 2012. The paper examines the resilience of an Australian rural community (being Molong) to the impact of flood emergencies. Postal surveys were disseminated to about 730 residents and business owners and a community focus group meeting was held in February 2012 as part of the study.

Manock, 2012 found that even though the Molong community appears to be generally aware of the existing flood risk and resilient to the impact of flooding, it has a significant economic and psychological effect on the community. Manock, 2012 also found that there is a general frustration amongst the community at "*the lack of pro-active measures taken by local government in the form of construction of levee banks and other engineering solutions to reduce the impact of flash flooding on the town*".

The recommendations of Manock, 2012 were that a) Council work with the community to continue to examine the feasibility of a levee system; and b) Council, NSW SES and the NSW Ministry of Health work together with the community to develop strategies for the implementation of short, medium and long term psychological support for those community members affected by floods.

B2.7 Cabonne Shire Local Flood Plan (NSW SES, 2013)

The *Cabonne Shire Local Flood Plan* (NSW SES, 2013) covers preparedness measures, the conduct of response operations and the coordination of immediate recovery measures for all levels of flooding. NSW SES, 2013 provides a description of the historic flooding patterns in the vicinity of Molong and the effects of flooding on the community. Minor, Moderate and Major classifications have not been defined at any of the stream gauges that are located along Molong Creek.
NSW SES, 2013 states that flooding is known to have inundated the commercial areas in the vicinity of Bank Street on four occasions. NSW SES, 2013 identifies the November 2005 as the largest flood to have occurred at Molong. During this event, ten dwellings and seven commercial buildings were flooded, as was the caravan park, police station and ambulance station.

NSW SES, 2013 states that evacuations should be considered in Molong when the Wellington Street gauge is expected to exceed 4.0 m. The Molong RSL on Riddell Street is identified as the primary evacuation centre at Molong.

B2.8 Proposed Molong Town Levee – Feasibility Study – Levee Options Assessment (SMEC, 2018)

SMEC undertook the *Proposed Molong Town Levee – Feasibility Study – Levee Options Assessment* in 2018 to consider the feasibility and viability of a levee that provides a lower level of protection than 1% AEP. The study was commissioned after Bewsher, 1997 and URS, 2011 both determined that a levee that protects the town from a 1% AEP event was not viable.

SMEC, 2018 relied upon the URS RORB Model to define design flows on Molong Creek, while the URS MIKE 11 Model was updated to include additional cross sections between the Euchareena Bridge and Molong Creek Railway Bridge (**SMEC MIKE 11 Model**). After a review of the URS DRAINS Model found that it was not fit-for-purpose, SMEC developed a new DRAINS Model of the local catchment (**SMEC DRAINS Model**). SMEC, 2018 contains details of the ten piped drainage outlets that discharge to Molong Creek between the Marsden Street Bridge and its confluence with Boree Hollow.

Figure 8-7 from SMEC, 2018 (a copy of which is contained in **Annexure B1** of this Appendix) shows the details of the following three levee alignments that were assessed as part of the study:

- Levee Alignment No. 1 – western side of Molong Creek only;
- Levee Alignment No. 2 – eastern and western sides of Molong Creek; and
- Levee Alignment No. 3 – eastern and western sides of Molong Creek, with the eastern levee set at a lower elevation.

The SMEC MIKE 11 Model was used to assess the three different levee alignment options for three levels of protection (i.e. 20%, 5% and 2% AEP). The assessment found that there is no economic justification for pursuing a 20% or 5% AEP level of protection as the reduction in flood damages is limited and significantly outweighed by the relatively high costs.

While SMEC, 2018 identified Levee Alignment No. 1 with a 2% AEP level of protection as the preferred levee option, it was noted that this option will increase peak flood levels in East Molong by up to 220 mm in a 2% AEP flood event. While Levee Alignment No. 1 would reduce above-floor inundation in 31 properties on the western side of the railway in a 2% AEP flood event, it would also increase the depth of above-floor inundation in seven buildings in East Molong.

SMEC, 2018 found that the total cost of Levee Alignment No. 1, which comprises six sections of earth embankment (total length of about 640 m), four sections of concrete wall type levee (total length of about 200 m), two temporary flood gate structures at road crossings (total length of about 35 m) and creek bank stabilisation works at two locations (total length of about 260 m), was about $2.1 Million.

The key recommendations of SMEC, 2018 were as follows:

i) Levee Alignment No. 1 with a 2% AEP level of protection is the preferred levee option and has a benefit cost ratio of 0.4.

ii) Undertake a feasibility assessment for a pump system to drain the ponded area at the intersection of Hill Street and Gidley Street.

iii) Consider potential liability issues and the possible provision of compensatory measures in East Molong due to increased peak flood levels.

iv) Consider further voluntary purchase in East Molong, as it will enhance the merit of the levee scheme.

v) Develop a 1D/2D hydraulic model to rigorously assess Molong Creek and local overland flooding, including the assessment of the impact that riparian vegetation has on flood behaviour.

vi) Confirm ownership of rain and river gauges, procedures and protocols for issuing rainfall alerts, forecasting flood levels and issuing flood warning for Molong and update the Cabonne Shire Local Flood Plan.

B2.9 Molong Creek Flood Study & Action Plan (growMOLONG, 2019)

The *Molong Creek Flood Study and Action Plan 2019* was instigated by growMOLONG members and the flood sub-committee to document their experiences of flooding at Molong (particularly during the November 2005 flood) and outline the main constraints on flow in the adjacent watercourses.

growMOLONG, 2019 includes photos taken during the November 2005 flood event (a number of which have been reproduced in **Appendix C** of this report) and anecdotal descriptions of flood behaviour during this event, including the observation that "*in the top end of town itself residents recorded 250 mm*" of rainfall.

growMOLONG, 2019 states that the main flow constraints on Molong Creek are:

i) the railway bridge crossings of the creek (particularly the Molong Creek Railway Bridge);

ii) the two pinch points on Molong Creek where it meanders between Marsden Street Bridge and Hunter Caldwell Park; and

iii) the local stormwater drainage system which conveys local catchment runoff to the creek.

The following potential solutions are proposed:

a) increasing the waterway area of the Molong Creek Railway Bridge;

b) widening the floodplain as per Ecclestone, 2010; and

c) diverting stormwater from the local catchment that contributes to flow in the piped drainage system at Bank Street in a northerly direction along Edward Street and Gidley Street, utilising the venturi effect in flood events to draw water out of the local drainage system.

growMOLONG, 2019 concludes by stating that "*we need a comprehensive engineering plan and the will of Governments at all levels to help deliver a solution*".

B2.10 Flood Impact Assessment – Market St, End St Intersection, Molong, NSW 2866 (Calare Civil, 2022)

Council engaged Calare Civil to investigate options for reducing the impact of flooding in the vicinity of the Market Street crossing of Moss Hollow Creek. The report was commissioned following the November 2021 flood event where floodwater surcharged the right bank of Moss Hollow Creek and overtopped Market Street adjacent to its intersection with End Street, where it flowed in an easterly direction through residential allotments.

A single catchment hydrologic (DRAINS) model was developed as part of Calare Civil, 2022 to derive design hydrographs at Market Street. The DRAINS derived peak flows for the 20% and 1% AEP storm events of 19.2 m^3/s and 89.0 m^3/s, respectively matched the peak flows that were derived using the Regional Flood Frequency Estimation (**RFFE**) Model, procedures for which are set out in ARR 2019.

The DRAINS derived discharge hydrographs were then input to a 2D hydraulic (HECRAS) model of a short reach of Moss Hollow Creek in the immediate vicinity of Market Street which was used to assess options for reducing the impact of flooding on existing development that is located on the eastern side of Market Street.

Calare Civil, 2022 found that regrading and lowering the existing laneway on the eastern side of Market Street by up to 1 m and the construction of a 1.0-1.3 m high bund on the eastern side of the lane would protect the properties in a 20% AEP storm event. Calare Civil, 2022 states that further analysis would be required to determine measures that would protect the properties in a 1% AEP storm event.

B3 COMMUNITY CONSULTATION

B3.1 Background

At the commencement of the study, the Consultants prepared a *Community Newsletter* and *Questionnaire*, both of which were distributed by Council to residents and business owners in the study area (a copy of which is contained in **Appendix A** of this report).

The purpose of the *Community Newsletter* was to introduce the objectives of the study so that the community would be better able to respond to the *Community Questionnair*e and contribute to the study process. The *Community Newsletter* contained a plan showing the extent of the study area and a summary of the proposed methodology and outcomes.

The *Community Questionnaire* was structured with the objectives of collecting information on historical flood behaviour in the study area.

The *Community Newsletter* and *Questionnaire* were advertised in the local newspaper and Council's website in early February 2023 and posted to 1,500 residents and business owners in the study area on 6 February 2023.

B3.2 Summary of Findings

B3.2.1. General

Residents and business owners were requested to complete the *Community Questionnaire* and return it to the Consultants by 28 February 2023. The deadline was extended to include any submissions that were received after this date. The Consultants received 129 responses in total, which amounted to about six per cent of the total number of questionnaires that were distributed to the community.

The collated responses to the *Community Questionnaire* are shown in graphical format in **Annexure B2** of this Appendix.

B3.2.2. Resident Profile

The first four questions of the *Community Questionnaire* canvassed the community for information such as the respondents address and contact details, the type of property (e.g. residential, commercial, industrial etc.) , whether the respondent was a resident or business owner and length of time that the respondent has resided/worked at the property.

Of the 129 responses, 109 respondents occupied residential type property (**Question 2**), twenty occupied commercial type property, eleven were occupants of rural-residential type property and six occupied industrial type property. Two responses received was concerned with property which is vacant land, while two respondents were concerned with the Molong Caravan Park.

In response to **Question 3**, approximately 81% of respondents were property owners and about 13% rented the property, while 6% of respondents did not provide a response to the question.

The length of time respondents had been at their current address was found to be varied, with approximately 22% of respondents having lived at the residence for between '0-5 years', 12% for '5 to 10 years', 22% for '10 to 20 years', and 31% for 'more than 20 years' (**Question 4a**).[2] In response to Question 4b, it was found that respondents had lived in the general area for a longer

[2] About 12% of respondents did not provide a response to Question 4a.

period than they had lived in their current residence, with approximately 12% of respondents having lived in the general area for between '0-5 years', 3% for '5 to 10 years', 10% for '10 to 20 years', and 43% for 'more than 20 years' (**Question 4a**).[3]

B3.2.3. Experiences of Flooding

In **Question 5**, 85 of the respondents indicated that they had been affected by flooding while 39 had not been affected.[4] Of those respondents that had been affected by flooding, about 50% had been affected by floodwater that had originated from a creek or defined watercourse, while about 35% had been affected by stormwater runoff generated by heavy localised rainfall in the vicinity of their property. The remaining 15% did not indicate the nature of flooding that they had been affected by.

In response to **Question 6a**, the majority of respondents to the *Community Questionnaire* had been affected by flooding as a result of flood events that occurred in March 1956 (five respondents), February 1972 (five), April 1990 (14), August 1990 (15), November 2005 (33 respondents), November 2021 (63) and more recently in November 2022 (77). Respondents had also been affected by storm events that occurred on the following dates:

- 2010 (month not specified);[5]
- 20 July 2016;
- September 2017 (day not specified)[6];
- 28 January 2018;[7]
- 26 January 2020;
- 26 January 2021;[8]
- October 2022 (day not specified)[9]; and
- 1 November 2022.

Of those that have been affected by flooding, 32 indicated that their house or business was flooded, 32 indicated that their garage was flooded and 49 indicated that their front or back yard was inundated (**Question 6b**). A total of 43 respondents had experienced roadways being cut off by floodwater. Other ways that respondents were impacted by flooding included damage/destruction of fences, disruption to business, isolation from town (for periods ranging from 4 hours to 4 days), disrupted access to supermarket and shops, and impacts on their mental health.

In **Question 7**, respondents were asked if they have photographs that show the flooding and to provide them directly to the Consultant. **Appendix C** of this report contains a number of photographs that were provided by respondents to the *Community Questionnaire* showing flood

[3] 32% of respondents did not provide an answer to Question 4b.

[4] Five respondents did not provide an answer to Question 5.

[5] A review of the water level recorded at the WaterNSW operated Borenore Creek stream gauge found that the largest recorded gauge height in 2010 occurred on 26 December 2010.

[6] A review of the rainfall recorded at the BoM operated Molong Post Office daily rainfall rain gauge found that a total of 14 mm of rain fell over the month of September in 2017.

[7] A review of the rainfall recorded at the BoM operated Molong Post Office daily rainfall rain gauge found that a total of 11 mm of rain fell over the rainday of 29 January 2018.

[8] It is possible that the respondent mistakenly referred to 26 January 2021 instead of 26 January 2020 as a review of rainfall recorded at nearby rain gauges found that there was a negligible amount of rainfall in the vicinity of Molong on 26 January 2021.

[9] A review of the rainfall recorded at the BoM operated Molong Post Office daily rainfall rain gauge found that a total of 53 mm of rain fell over the rainday of 1 November 2022, while a review of the water level recorded at the WaterNSW operated Borenore Creek stream gauge found that the highest recorded gauge height in October 2022 occurred on 31 October 2022.

behaviour in the study area during storms that occurred on 20 July 2016, 26 January 2020, 26 November 2021 and 13-14 November 2022.

In **Question 8**, respondents were asked what the main cause of flooding was in the study area. The majority of respondents indicated it was blockage of creeks, stormwater inlets, bridges and drains (90). The main concern of the respondents to the *Community Questionnaire* was the perceived blocking effect that the Molong Creek Rail Bridge has on the conveyance of flow in the creek. A number of the respondents stated that the piers do not lie parallel to the direction of flow in the creek which restricts the flow of water through the bridge, which in turn traps floating debris during flood events and further reduces the capacity of the bridge (refer **Plates C1.18**, **C5.17**, **C5.18** and **C5.19** in **Appendix C** for photos of the build up of debris at the Molong Creek Rail Bridge after the November 2022 flood event). A number of respondents also noted that historic photographs of the Molong Creek Rail Bridge (a copy of which is shown in **Plate C6.1** in **Appendix C**) shows that the pier alignment of the old bridge had significantly less impact on the conveyance of floodwater in Molong Creek.

Insufficient stormwater capacity (75) and insufficient creek capacity (59) were also identified by respondents to the *Community Questionnaire* as the main cause of flooding, while 37 respondents identified that overland flow impediments (i.e. fences, buildings etc.) were the main cause of flooding. Other causes of flooding identified by respondents were:

- lack of maintenance of drainage lines and creeks;
- lack of kerb and gutter / drains in rural areas; and
- saturation of water table combined with historically high rainfall events.

Question 9 of the *Community Questionnaire* asked respondents to provide any additional comments, information or suggestions that may assist the study. In regards historic flood events, respondents made the following observations:

i) the November 2022 flood arrived quicker and without warning when compared with previous flood events; and

ii) flooding during the November 2005 event only occurred along Molong Creek and not in any of its tributaries that are located in the vicinity of Molong.

Respondents to the *Community Questionnaire* offered the following suggestions on how to reduce the impact that future flood events have in Molong;

a) upgrade the rail bridges;

b) development of a better flood warning system;

c) continue the voluntary purchase of the flood prone dwellings in Betts Street;

d) move the commercial centre of the town to higher (flood-free) ground such as the land that is located to the east of the Molong Golf Course;

e) construction of a levee bank along the left bank of Molong Creek to prevent floodwater overtopping the railway and inundating Bank Street;

f) channel widening works to increase the capacity of the creek;

g) improve the functionality of the flood gates that are connected to the outlets of the piped stormwater drainage system; and

h) remove the concrete wall that has been constructed adjacent to the swimming pool.

B4 REFERENCES

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Water Resources Commission, 1983. ***"Molong 1983 Flood Map"***

ANNEXURE B1

EXTRACTS FROM SMEC, 2018

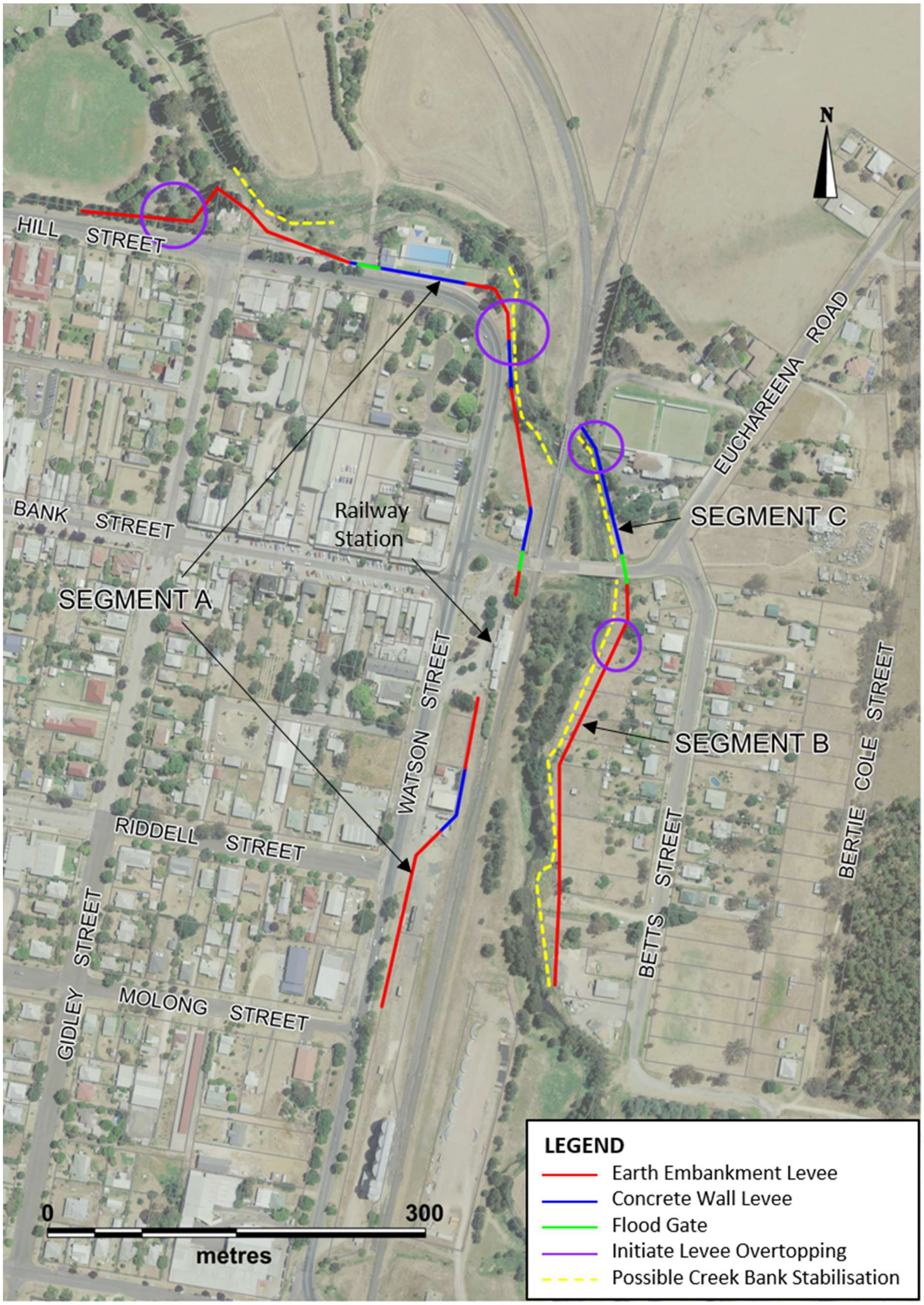


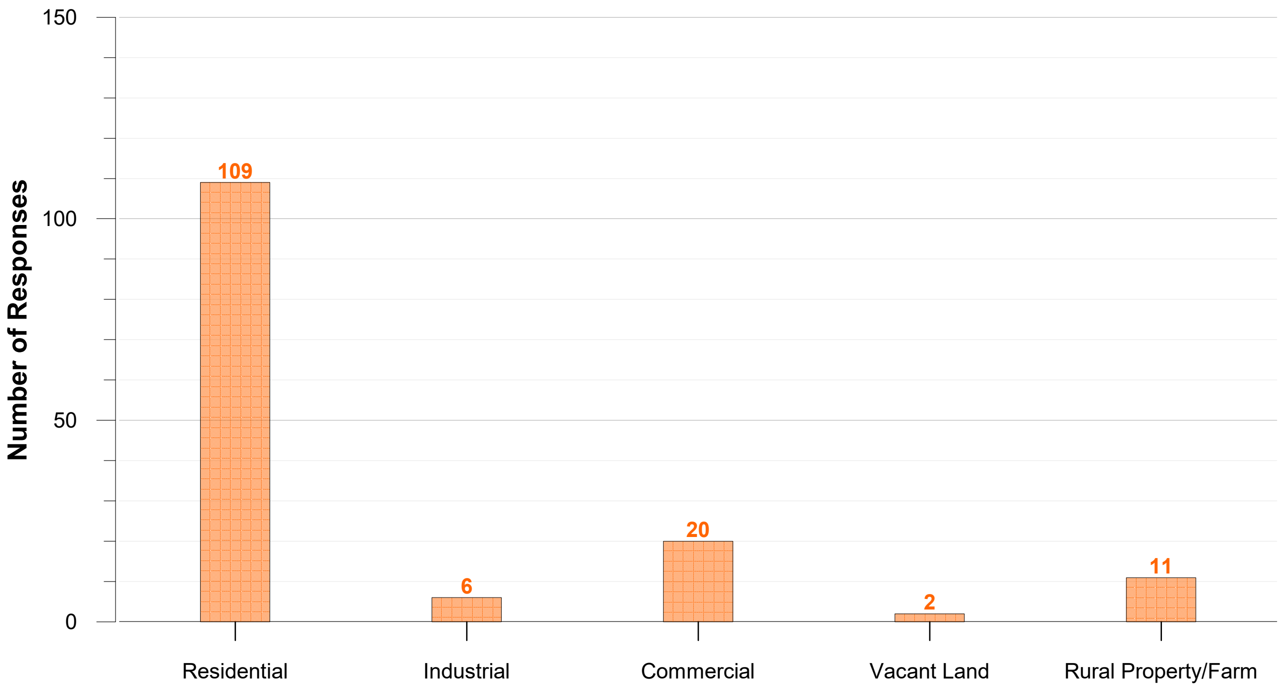
Figure 8-7: Indicative Works1,2 for Molong Town Levee (50 year ARI protection)

*Note 1: Internal town drainage outlets are part of levee system, but not shown for clarity. Refer **Figure 6-1** for details.*
*Note 2: For levels of protection less than 50 year ARI, a higher proportion of earth embankment levee can be used relative to a concrete wall levee (refer **Table 8-1**).*

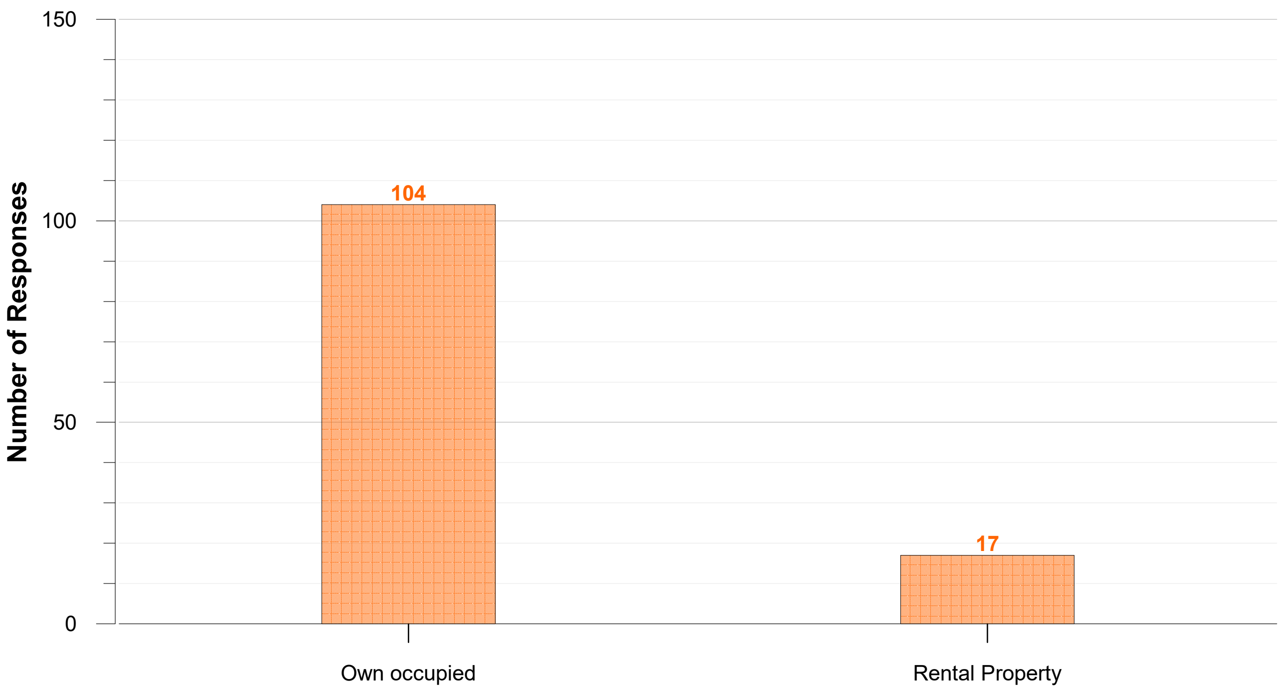
ANNEXURE B2

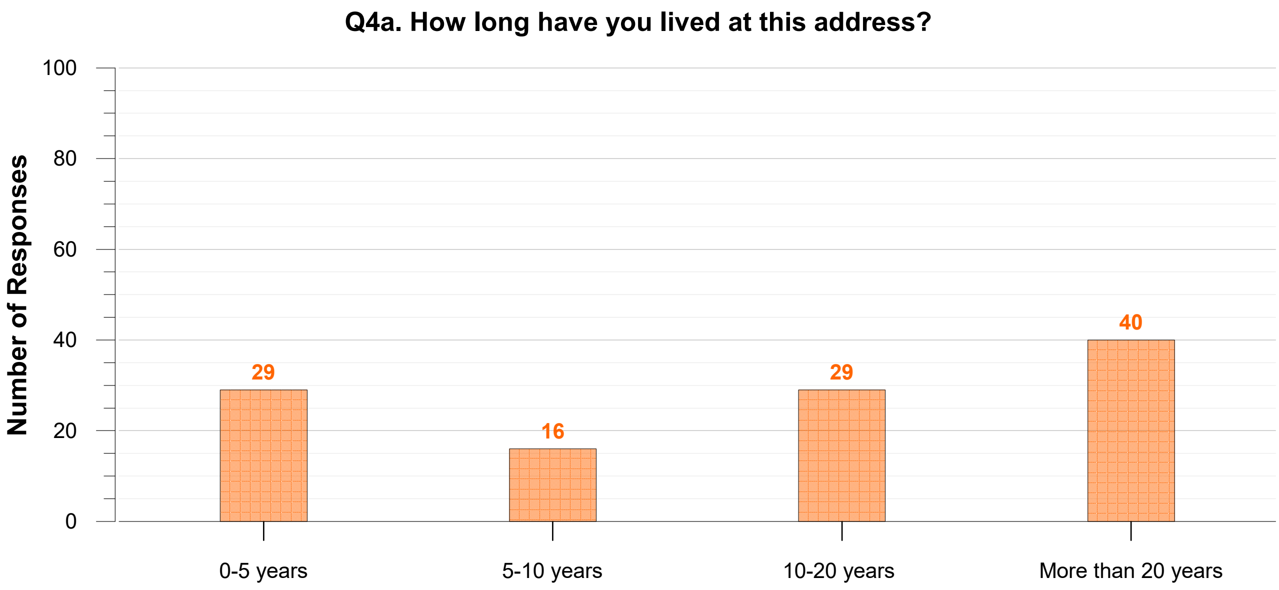
RESPONSES TO COMMUNITY QUESTIONNAIRE

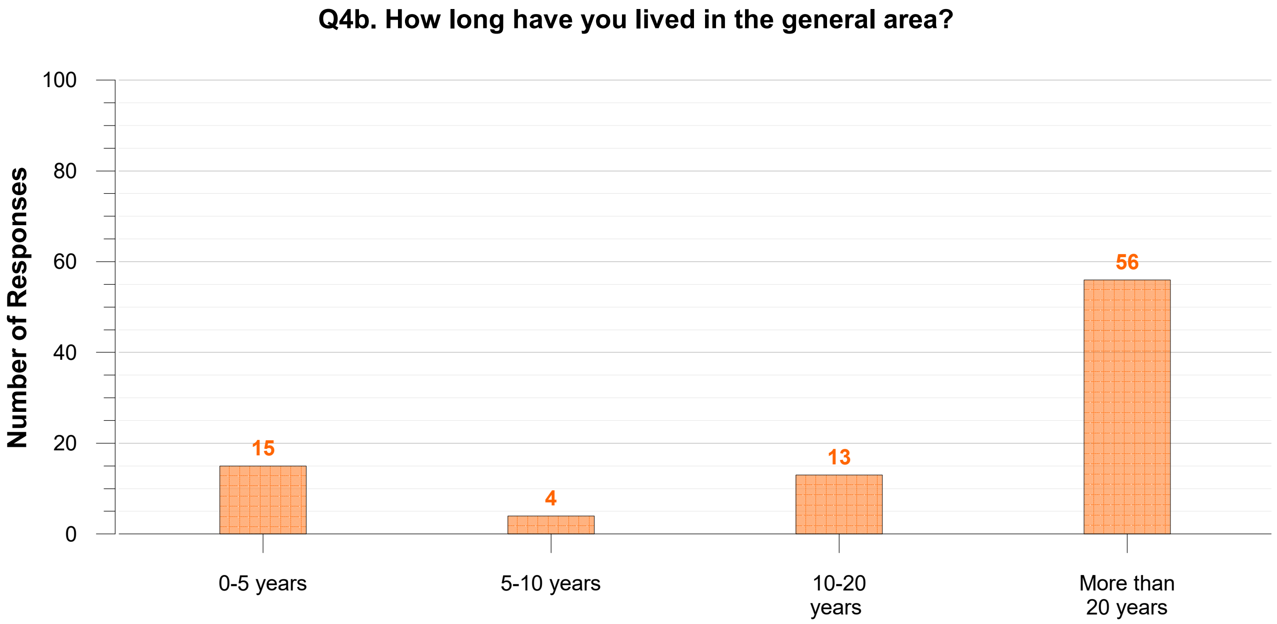
Q2. Property Type

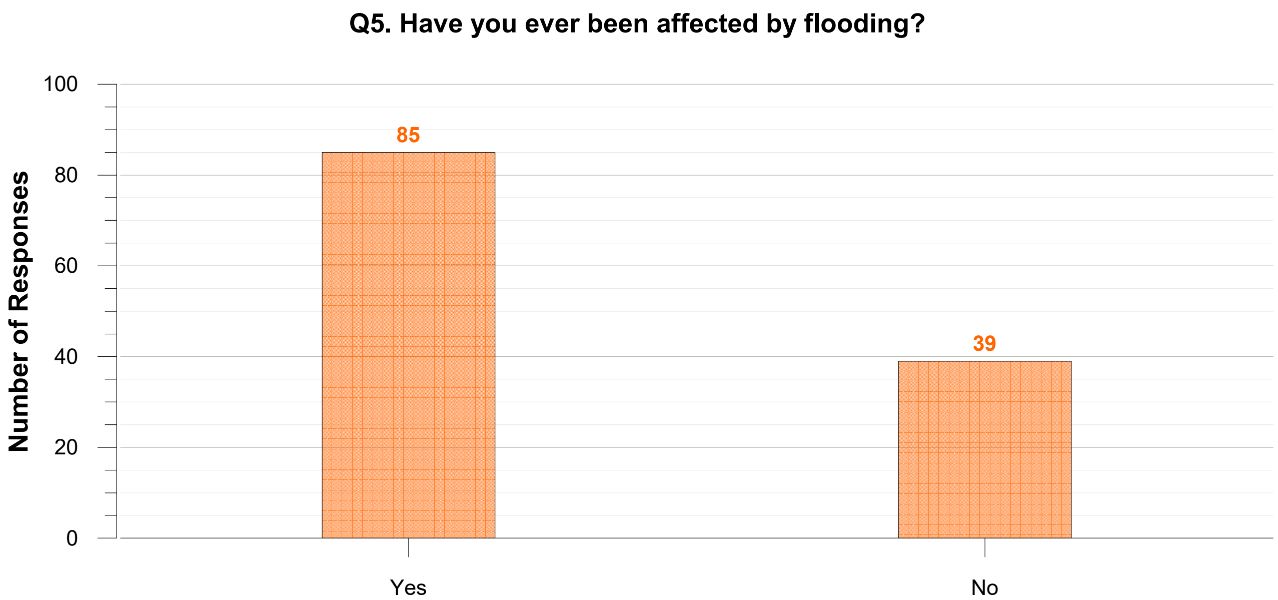


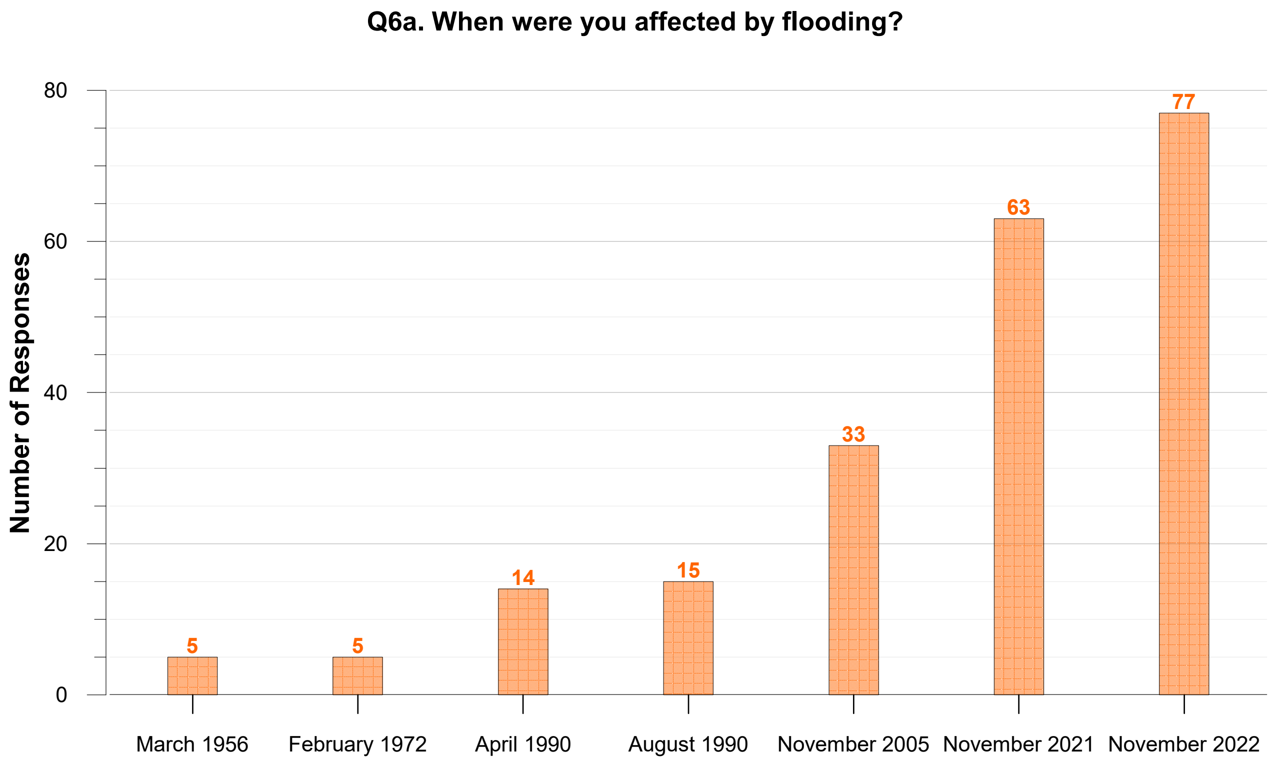
Q3. Property Status

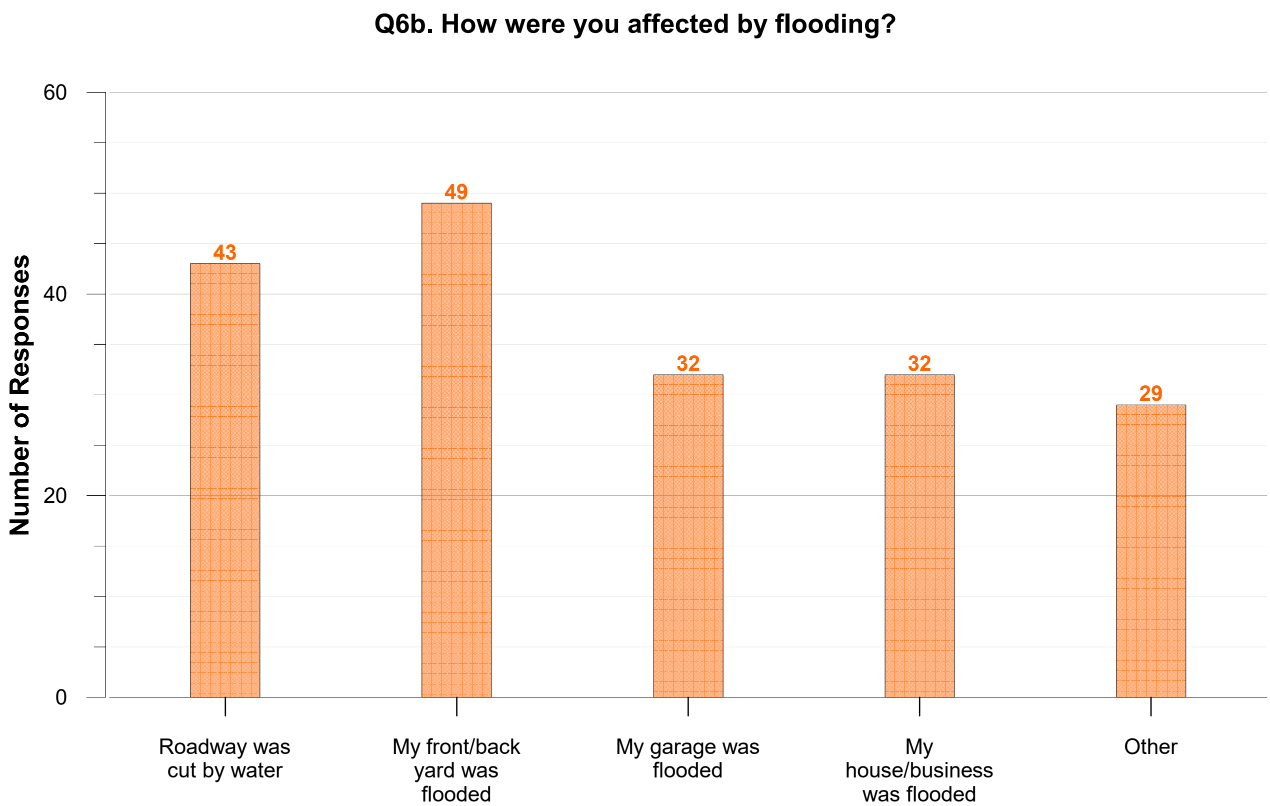



Q4a. How long have you lived at this address?
Number of Responses
100
80
60
40
20
0
29
16
29
40
0-5 years
5-10 years
10-20 years
More than 20 years

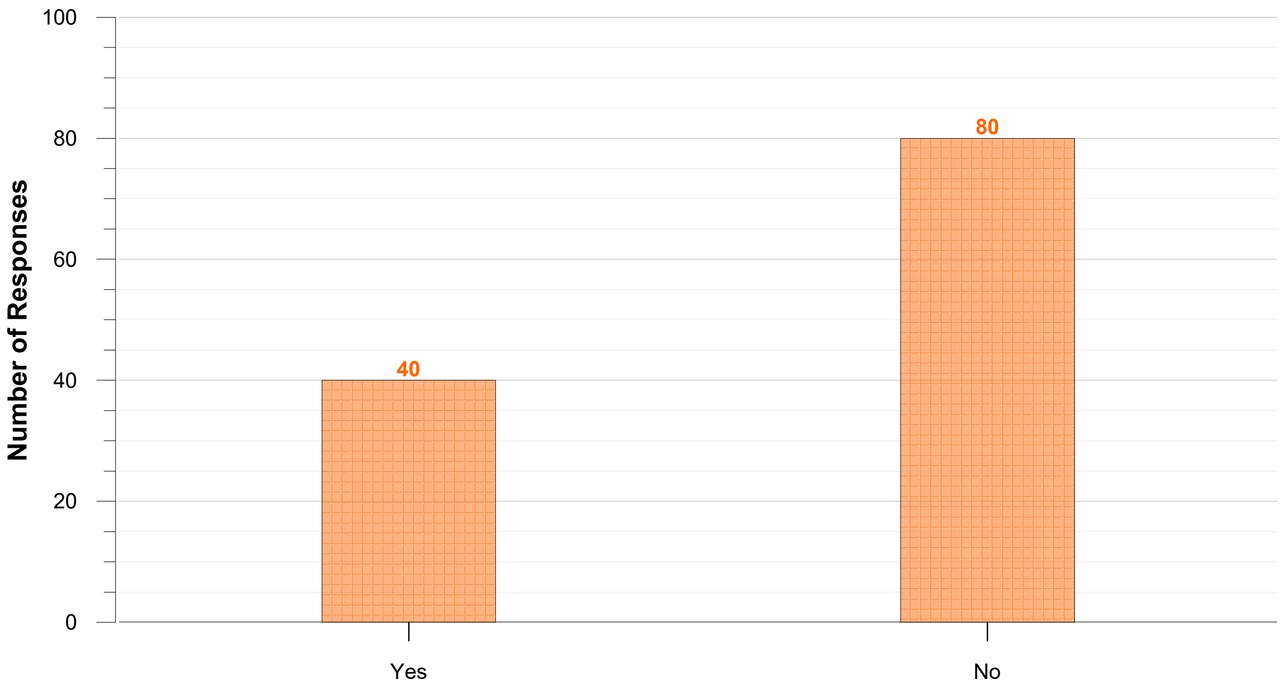

Q4b. How long have you lived in the general area?
Number of Responses
100
80
60
40
20
0
15
4
13
56
0-5 years
5-10 years
10-20 years
More than 20 years


Q5. Have you ever been affected by flooding?
Number of Responses
100
80
60
40
20
0
85
39
Yes
No

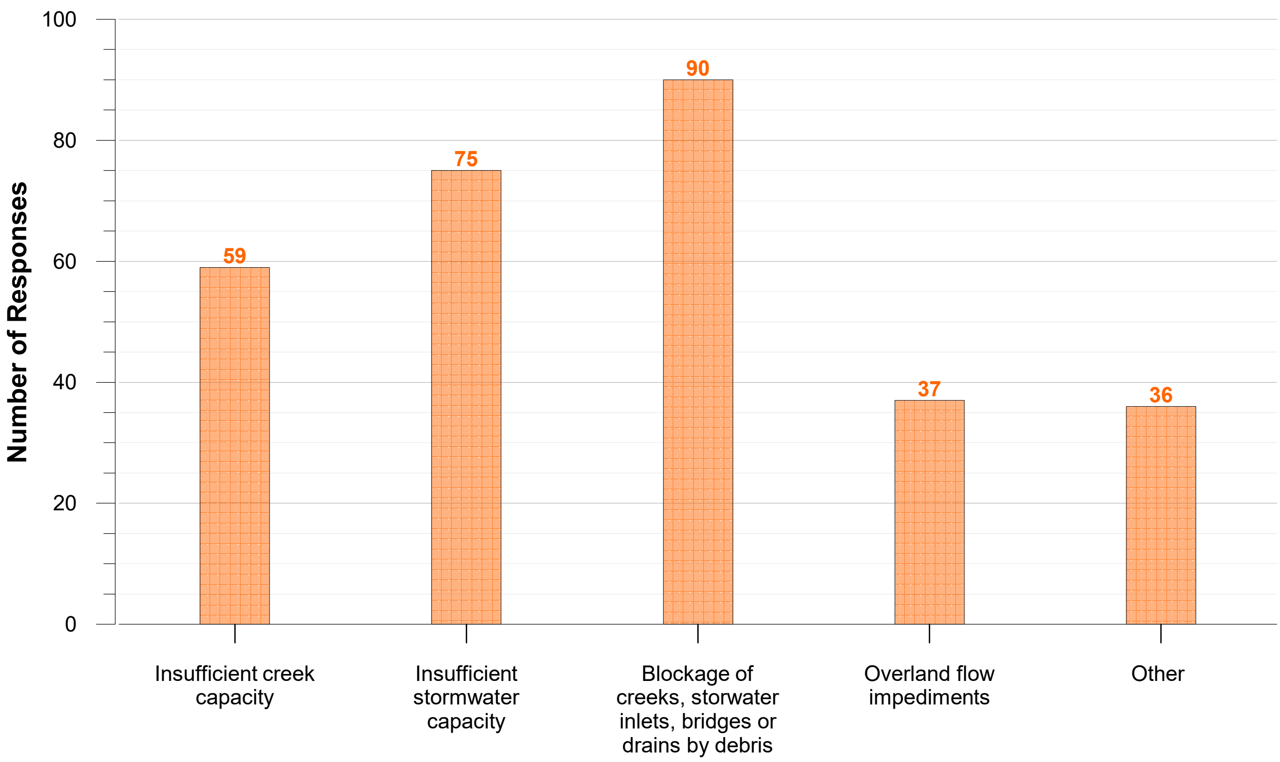

Q6a. When were you affected by flooding?
Number of Responses
0
20
40
60
80
5
5
14
15
33
63
77
March 1956
February 1972
April 1990
August 1990
November 2005
November 2021
November 2022


Q6b. How were you affected by flooding?
Number of Responses
0
20
40
60
43
49
32
32
29
Roadway was cut by water
My front/back yard was flooded
My garage was flooded
My house/business was flooded
Other

Q7. Do you have any photos or videos of these floods?



Q8. In your opinion, what was the main cause of the flooding?



APPENDIX C

PHOTOGRAPHS SHOWING OBSERVED FLOOD BEHAVIOUR AT MOLONG

8 NOVEMBER 2005

(Source: growMOLONG, 2019)

Plate C1.1 – (unknown time) Upstream side of Molong Creek Railway Bridge.

Plate C1.2 – (unknown time) Looking north along Watson Street from its intersection with Riddell Street.

Plate C1.3 – (unknown time) Floodwater overtopping the railway line to the east of the intersection of Watson Street and Riddell Street.

Plate C1.4 – (time unknown) Looking north along Railway from the old Mitchell Highway rail overpass.

Plate C1.5 – (time unknown) Looking north from the old water tank that is located adjacent to the intersection of Watson Street and Wellington Street.

8 NOVEMBER 2005

(Source: growMOLONG, 2019)

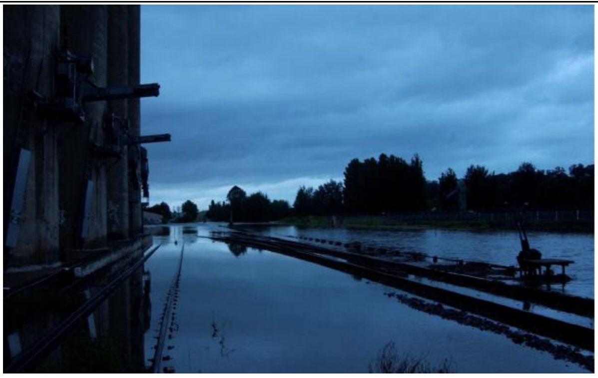


Plate C1.6 – (unknown time) Looking north along Railway adjacent to grain silos.

Plate C1.7 – (unknown time) Looking west along Molong Creek from Hunter Caldwell Park.

Plate C1.8 – (unknown time) Bank Street immediately west of its intersection with Watson Street.

Plate C1.9 – (unknown time) Looking east along Euchareena Road from its intersection with Watson Street.

Plate C1.10 – (unknown time) Looking west along Bank Street from its intersection with Watson Street.

Plate C1.11 – (unknown time) Watson Street at its intersection with Bank Street.

8 NOVEMBER 2005

(Source: growMOLONG, 2019)

Plate C1.12 – (unknown time) Looking west along Bank Street from its intersection with Watson Street.

Plate C1.13 – (unknown time) Looking north across Hill Street at its intersection with Gidley Street.

Plate C1.14 – (unknown time) Looking north along laneway adjacent to supermarket.

Plate C1.15 – (unknown time) Betts Street.

Plate C1.16 – (unknown time) Looking east along the Molong Creek floodplain to the north of Thistle Street.

Plate C1.17 – (unknown time) Longing north along Molong Creek from Hunter Caldwell Park.

8 NOVEMBER 2005

(Source: growMOLONG, 2019)

Plate C1.18 – (unknown time) Debris build up on the upstream side of the Molong Creek Railway Bridge.

Plate C1.19 – (unknown time) Looking east along Molong Creek floodplain upstream of Broken Hill Railway.

20 JULY 2016

Plate C2.1 – (Photo taken at 13:00 hours) William Street crossing of Boree Hollow.

Plate C2.2 – (Photo taken at 13:00 hours) Broken Hill Railway Bridge No. 1 crossing of Molong Creek.

Plate C2.3 – (Photo taken at 14:00 hours) Looking north along left bank of Molong Creek downstream of Molong Creek Railway Bridge.

Plate C2.4 – (Photo taken at 14:00 hours) Looking south along left bank of Molong Creek upstream Marsden Street Bridge.

Plate C2.5 – (Photo taken at 14:00 hours) Looking east at downstream side of Molong Creek Railway Bridge.

26 JANUARY 2020

Plate C3.1 – (unknown time) Floodwater that surcharged Pillans Park Drainage Line at Pillans Park flowing in a northerly direction along the eastern side of Edward Street.

26 NOVEMBER 2021

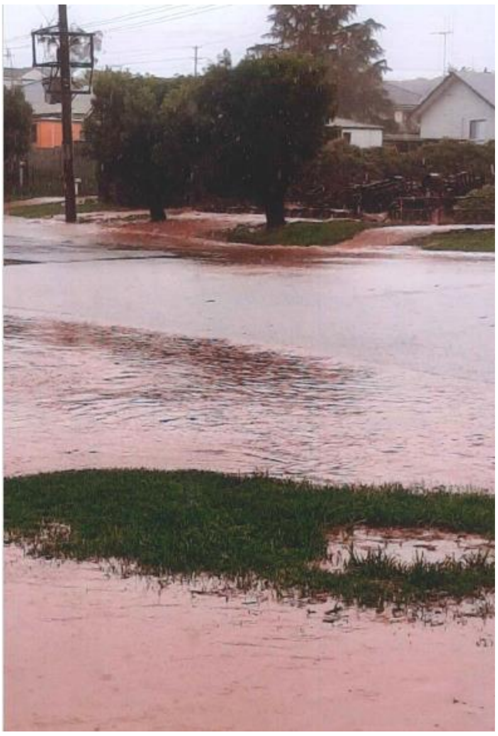


Plate C4.1 – (unknown time) Floodwater surcharging Pillans Park Drainage Line onto Gidley Street.

Plate C4.2 – (time unknown) Floodwater discharging to property on southern side of Gidley Street.

Plate C4.3 – (Photo taken at 15:35 hours) Lee Street crossing of Pillans Park Drainage Line.

Plate C4.4 – (Photo taken at 15:35 hours) Pillans Park Drainage Line downstream of Lee Street.

26 NOVEMBER 2021

Plate C4.5 – (time unknown) Norman Lane crossing of Pillans Park Drainage Line.

Plate C4.6 – (Photo taken at 14:20 hours) Looking east along Riddell Street at Boree Hollow.

Plate C4.7 – (Photo taken at 14:50 hours) Looking east along Hill Street at its intersection with Gidley Street.

Plate C4.8 – (Photo taken at 16:35 hours) Looking north along Market Street in the vicinity of its intersection with End Street.

Plate C4.9 – (Photo taken at 16:50 hours) Looking north along Molong Creek floodplain upstream of Broken Hill Railway.

Plate C4.10 – (Photo taken at 17:30 hours) Looking east along Bank Street.

26 NOVEMBER 2021

Plate C4.11 – (time unknown) Looking west along Boree Hollow at intersection of King Street and Riddell Street.

Plate C4.12 – (time unknown) Aerial view of Boree Hollow crossing of Riddell Street adjacent to Council Depot.

Plate C4.13 – (time unknown) Looking north along Molong Creek at Marsden Street bridge.

Plate C4.14 – (time unknown) Aerial view of floodwater ponding in Banks Street.

Plate C4.15 – (time unknown) Looking north along Molong Creek at Euchareena Road bridge.

26 NOVEMBER 2021	
	
Plate C4.16 – (Photo taken at 18:00 hours) Floodwater ponding in Bank Street.	**Plate C4.17** – (Photo taken at 18:00 hours) Floodwater ponding in Bank Street.

13-14 NOVEMBER 2022

Plate C5.1 – (Photo taken at 23:30 hours) Floodwater discharging to property on southern side of Gidley Street.

Plate C5.2 – (Photo taken at 00:40 hours) Floodwater ponding in Hill Street at its intersection with Gidley Street.

Plate C5.3 – (Photo taken at 01:20 hours) Floodwater ponding in Bank Street.

Plate C5.4 – (Photo taken at 01:20 hours) Floodwater ponding in Bank Street.

Plate C5.5 – (unknown time) Looking south along Watson Street from its intersection with Bank Street.

Plate C5.6 – (unknown time) Looking north along Watson Street from its intersection with Bank Street.

13-14 NOVEMBER 2022

Plate C5.7 – (time unknown) Floodwater ponding in Bank Street at its intersection with Watson Street.

Plate C5.8 – (Photo taken at 05:30 hours [approx.]) Looking south across Molong Creek immediately downstream of Gamboola Weir.

Plate C5.9 – (Photo taken at 05:40 hours) Floodwater ponding in Bank Street.

Plate C5.10 – (Photo taken at 05:45 hours) Floodwater ponding in Hill Street at its intersection with Gidley Street.

Plate C5.11 – (Photo taken at 06:15 hours) Floodwater ponding in Bank Street.

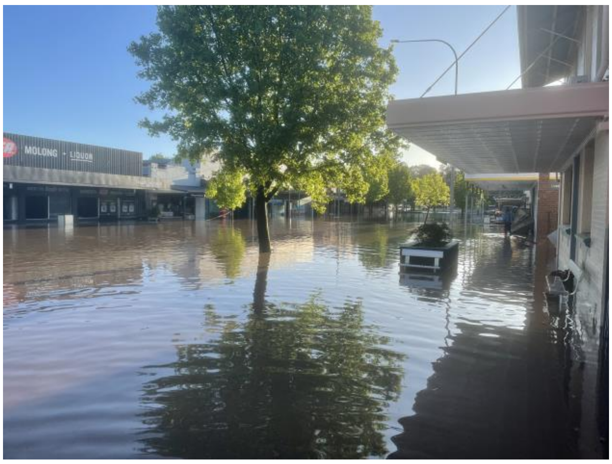


Plate C5.12 – (Photo taken at 06:45 hours) Floodwater ponding in Bank Street.

13-14 NOVEMBER 2022

Plate C5.13 – (Photo taken at 07:00 hours) Floodwater ponding in Hill Street at its intersection with Gidley Street.

Plate C5.14 – (Photo taken at 14:30 hours) Debris left behind at the intersection of Watson Street and Hill Street.

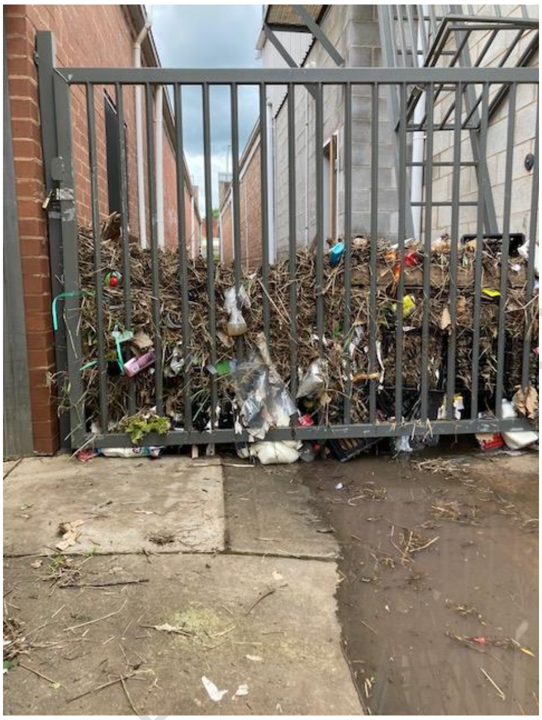


Plate C5.15 – (Photo taken at 14:30 hours) Debris build-up on gate between Molong Post Office and Supermarket.

Plate C5.16 – (Photo taken at 14:30 hours) Looking north across Molong Creek immediately downstream of the swimming pool.

13-14 NOVEMBER 2022

Plate C5.17 – (time unknown) Debris build-up on upstream side of Molong Creek Railway Bridge.

Plate C5.18 – Extract of Molong Express showing build-up of debris on upstream side of Molong Creek Railway Bridge.

Plate C5.19 – (time unknown) Debris build-up on Molong Creek Railway Bridge.

DATE NOT KNOWN

Plate C6.1 – Old Molong Creek Railway Bridge crossing of Molong Creek.

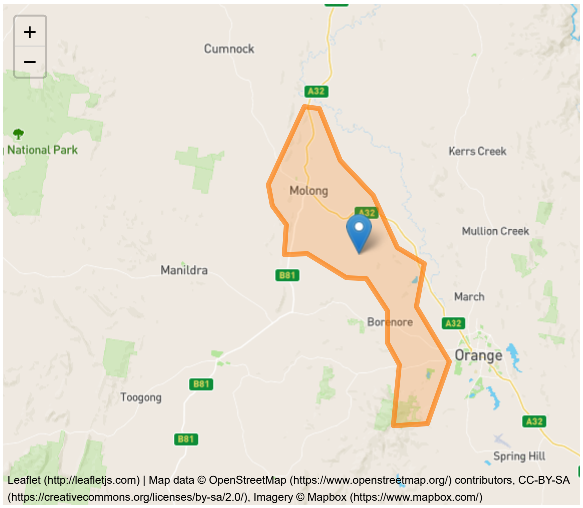
APPENDIX D

DESIGN INPUT DATA FROM ARR DATA HUB

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	148.932
Latitude	-33.166
Selected Regions (clear)	
River Region	show
ARF Parameters	show
Storm Losses	show
Temporal Patterns	show
Areal Temporal Patterns	show
BOM IFDs	show
Median Preburst Depths and Ratios	show
10% Preburst Depths	show
25% Preburst Depths	show
75% Preburst Depths	show
90% Preburst Depths	show
Interim Climate Change Factors	show
Probability Neutral Burst Initial Loss (./nsw_specific)	show



Data

River Region

Division	Murray-Darling Basin
River Number	22
River Name	Macquarie-Bogan Rivers
Shape Intersection (%)	96.0

Layer Info

Time Accessed	01 June 2023 01:38PM
Version	2016_v1

ARF Parameters

$$ARF = Min\left\{1, \left[1 - a\left(Area^b - c\log_{10}Duration\right)Duration^{-d} + eArea^f Duration^g\left(0.3 + \log_{10}AEP\right) + h10^{iArea\frac{Duration}{1440}}\left(0.3 + \log_{10}AEP\right)\right]\right\}$$

Zone	a	b	c	d	e	f	g	h	i	Shape Intersection (%)
Central NSW	0.265	0.241	0.505	0.321	0.00056	0.414	-0.021	0.015	-0.00033	100.0

Layer Info

Time Accessed	01 June 2023 01:38PM
Version	2016_v1

Short Duration ARF

$$ARF = Min\left[1, 1 - 0.287\left(Area^{0.265} - 0.439\log_{10}(Duration)\right).Duration^{-0.36} + 2.26 \text{ x } 10^{-3} \text{ x } Area^{0.226}.Duration^{0.125}\left(0.3 + \log_{10}(AEP)\right) + 0.0141 \text{ x } Area^{0.213} \text{ x } 10^{-0.021\frac{(Duration-180)^2}{1440}}\left(0.3 + \log_{10}(AEP)\right)\right]$$

Storm Losses

Note: Burst Loss = Storm Loss - Preburst

Note: These losses are only for rural use and are **NOT FOR DIRECT USE** in urban areas

Note: As this point is in NSW the advice provided on losses and pre-burst on the NSW Specific Tab of the ARR Data Hub (./nsw_specific) is to be considered. In NSW losses are derived considering a hierarchy of approaches depending on the available loss information. The continuing storm loss information from the ARR Datahub provided below should only be used where relevant under the loss hierarchy (level 5) and where used is to be multiplied by the factor of 0.4.

Storm Initial Losses (mm)	23.0
Storm Continuing Losses (mm/h)	4.2

Layer Info

Time Accessed	01 June 2023 01:38PM
Version	2016_v1

Temporal Patterns | Download (.zip) (static/temporal_patterns/TP/CS.zip)

code	CS
Label	Central Slopes
Shape Intersection (%)	96.4

Layer Info

Time Accessed	01 June 2023 01:38PM
Version	2016_v2

Areal Temporal Patterns | Download (.zip) (./static/temporal_patterns/Areal/Areal_CS.zip)

code	CS
arealabel	Central Slopes
Shape Intersection (%)	96.4

Layer Info

Time Accessed	01 June 2023 01:38PM
Version	2016_v2

BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-33.165756298&longitude=148.931799893&sc to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	01 June 2023 01:38PM

Median Preburst Depths and Ratios

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.6 (0.028)	0.9 (0.033)	1.1 (0.034)	1.4 (0.035)	1.0 (0.022)	0.8 (0.015)
90 (1.5)	1.2 (0.051)	0.9 (0.028)	0.7 (0.018)	0.5 (0.011)	0.4 (0.007)	0.3 (0.006)
120 (2.0)	0.9 (0.033)	0.7 (0.021)	0.7 (0.016)	0.6 (0.013)	0.5 (0.010)	0.5 (0.008)
180 (3.0)	0.9 (0.031)	1.0 (0.026)	1.1 (0.024)	1.2 (0.023)	0.8 (0.013)	0.5 (0.008)
360 (6.0)	0.5 (0.012)	0.8 (0.016)	1.0 (0.017)	1.2 (0.018)	5.0 (0.065)	7.8 (0.092)
720 (12.0)	0.0 (0.000)	1.0 (0.015)	1.6 (0.022)	2.2 (0.026)	7.6 (0.079)	11.7 (0.109)
1080 (18.0)	0.0 (0.000)	0.9 (0.013)	1.5 (0.018)	2.1 (0.022)	4.4 (0.039)	6.1 (0.050)
1440 (24.0)	0.0 (0.000)	0.2 (0.002)	0.3 (0.003)	0.4 (0.004)	1.7 (0.014)	2.6 (0.019)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.4 (0.003)	0.7 (0.005)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	01 June 2023 01:38PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

10% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
90 (1.5)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
120 (2.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
180 (3.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
360 (6.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
720 (12.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1080 (18.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	01 June 2023 01:38PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

25% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.0 (0.000)	0.0 (0.001)	0.0 (0.001)	0.1 (0.001)	0.0 (0.000)	0.0 (0.000)
90 (1.5)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
120 (2.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
180 (3.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
360 (6.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
720 (12.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1080 (18.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	01 June 2023 01:38PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

75% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	9.8 (0.469)	9.3 (0.330)	9.0 (0.269)	8.7 (0.224)	8.5 (0.186)	8.4 (0.163)
90 (1.5)	13.8 (0.580)	11.2 (0.350)	9.4 (0.250)	7.8 (0.179)	7.8 (0.152)	7.9 (0.137)
120 (2.0)	11.9 (0.457)	11.3 (0.325)	10.9 (0.267)	10.6 (0.224)	9.9 (0.179)	9.5 (0.152)
180 (3.0)	9.4 (0.318)	14.5 (0.369)	17.9 (0.388)	21.2 (0.399)	18.3 (0.294)	16.1 (0.232)
360 (6.0)	10.3 (0.276)	12.8 (0.260)	14.5 (0.251)	16.1 (0.244)	30.0 (0.390)	40.4 (0.472)
720 (12.0)	7.3 (0.153)	11.6 (0.186)	14.5 (0.199)	17.3 (0.209)	30.8 (0.318)	40.8 (0.380)
1080 (18.0)	4.3 (0.079)	9.7 (0.135)	13.3 (0.159)	16.8 (0.176)	23.3 (0.210)	28.2 (0.229)
1440 (24.0)	0.8 (0.013)	4.2 (0.053)	6.4 (0.070)	8.6 (0.082)	12.1 (0.099)	14.7 (0.109)
2160 (36.0)	0.1 (0.001)	1.9 (0.021)	3.0 (0.029)	4.2 (0.035)	7.1 (0.051)	9.3 (0.061)
2880 (48.0)	0.0 (0.000)	1.4 (0.015)	2.3 (0.021)	3.2 (0.025)	4.9 (0.033)	6.2 (0.037)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.6 (0.004)	1.1 (0.006)

Layer Info

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Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

90% Preburst Depths

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	30.0 (1.433)	27.1 (0.960)	25.2 (0.754)	23.4 (0.605)	29.5 (0.645)	34.1 (0.664)
90 (1.5)	33.8 (1.424)	34.1 (1.069)	34.3 (0.910)	34.5 (0.793)	35.3 (0.687)	35.8 (0.624)
120 (2.0)	35.0 (1.348)	34.3 (0.986)	33.8 (0.826)	33.4 (0.707)	48.7 (0.877)	60.2 (0.969)
180 (3.0)	33.6 (1.135)	42.8 (1.088)	49.0 (1.059)	54.9 (1.034)	60.0 (0.963)	63.8 (0.918)
360 (6.0)	20.3 (0.544)	34.0 (0.689)	43.1 (0.748)	51.8 (0.787)	63.7 (0.828)	72.7 (0.848)
720 (12.0)	18.9 (0.396)	36.8 (0.586)	48.6 (0.666)	59.9 (0.723)	74.4 (0.768)	85.2 (0.792)
1080 (18.0)	19.2 (0.350)	28.0 (0.388)	33.8 (0.404)	39.4 (0.414)	55.6 (0.501)	67.7 (0.550)
1440 (24.0)	7.6 (0.127)	17.6 (0.222)	24.1 (0.262)	30.4 (0.291)	36.8 (0.302)	41.6 (0.308)
2160 (36.0)	6.3 (0.092)	10.3 (0.115)	13.0 (0.124)	15.5 (0.131)	28.2 (0.204)	37.8 (0.247)
2880 (48.0)	6.5 (0.088)	11.1 (0.114)	14.1 (0.125)	17.1 (0.133)	17.6 (0.118)	18.1 (0.109)
4320 (72.0)	0.7 (0.009)	3.0 (0.028)	4.5 (0.036)	6.0 (0.042)	12.3 (0.074)	17.0 (0.093)

Layer Info

Time Accessed	01 June 2023 01:38PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

Interim Climate Change Factors

	RCP 4.5	RCP6	**RCP 8.5**
2030	**0.972 (4.9%)**	0.847 (4.2%)	**1.052 (5.3%)**
2040	**1.225 (6.2%)**	1.127 (5.7%)	**1.495 (7.6%)**
2050	**1.452 (7.3%)**	1.406 (7.1%)	**1.971 (10.1%)**
2060	**1.653 (8.4%)**	1.685 (8.6%)	**2.480 (12.9%)**
2070	**1.827 (9.3%)**	1.963 (10.1%)	**3.023 (15.9%)**
2080	**1.974 (10.1%)**	2.241 (11.6%)	**3.599 (19.2%)**
2090	**2.095 (10.8%)**	2.518 (13.1%)	**4.208 (22.8%)**

Layer Info

Time Accessed	01 June 2023 01:38PM
Version	2019_v1
Note	ARR recommends the use of RCP4.5 and RCP 8.5 values. These have been updated to the values that can be found on the climate change in Australia website.

Probability Neutral Burst Initial Loss

min (h)\AEP(%)	50.0	20.0	10.0	5.0	2.0	1.0
60 (1.0)	17.2	10.2	9.9	10.6	10.1	8.6
90 (1.5)	16.1	10.1	9.9	10.7	9.9	8.7
120 (2.0)	16.3	10.7	10.1	10.9	9.6	8.1
180 (3.0)	16.4	10.7	9.5	9.6	8.6	6.4
360 (6.0)	17.7	12.5	11.1	10.6	8.4	4.4
720 (12.0)	18.7	13.3	12.0	11.2	8.7	4.0
1080 (18.0)	19.6	14.7	13.8	13.1	11.3	6.1
1440 (24.0)	22.3	17.4	16.6	16.3	14.5	8.6
2160 (36.0)	23.2	19.1	19.1	20.0	17.2	9.7
2880 (48.0)	23.4	19.2	19.2	20.9	18.8	13.1
4320 (72.0)	24.7	21.3	22.5	24.0	21.4	16.3

Layer Info

Time Accessed	01 June 2023 01:38PM
Version	2018_v1
Note	As this point is in NSW the advice provided on losses and pre-burst on the NSW Specific Tab of the ARR Data Hub (./nsw_specific) is to be considered. In NSW losses are derived considering a hierarchy of approaches depending on the available loss information. Probability neutral burst initial loss values for NSW are to be used in place of the standard initial loss and pre-burst as per the losses hierarchy.

Download TXT (downloads/ef9cd31c-e5dd-40b7-b2da-b4e4d09fd8b4.txt)

Download JSON (downloads/4be3d806-fcbc-429f-850c-1bd2541cca1e.json)

Generating PDF... (downloads/51bda7a1-dbaa-49e8-988a-c61e8e0014b5.pdf)

APPENDIX E

ARR 2019 DESIGN BLOCKAGE ASSESSMENT AT DRAINAGE STRUCTURES

TABLE E1

ARR, 2019 DESIGN BLOCKAGE ASSESSMENT AT HYDRAULIC DRAINAGE STRUCTURES

ID[1]	Structure Details				Floating Debris												Non-Floating Debris									Adopted Design Blockage B_{DES}%		
	Structure Type[2]	Width	Height (m)	No. of Barrels	L_{10}[3]	Debris Availability	Debris Mobility	Debris Transportability	Debris Potential	Debris Potential at Structure	Adjusted Debris Potential			Most Likely Design Inlet Blockage (B_{DES}%)			Max V (m/s)	Likelihood of Deposition	Debris Potential at Structure	Adjusted Debris Potential			Most Likely Design Barrel Blockage (B_{DES}%)					
											> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	Max			> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP
MOL_1	C Culvert	1	0	1	1.5	M	H	M	MHM	Medium	Low	Medium	High	25%	50%	100%	3.667	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_2	R Culvert	0.57	0.4	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.923	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_3	R Culvert	0.9	0.44	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.052	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_4	C Culvert	0.45	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.414	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_5	C Culvert	0.9	0	2	1.5	M	M	M	MMM	Medium	Low	Medium	High	25%	50%	100%	3.607	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_6	R Culvert	3	1.55	3	1.5	M	M	M	MMM	Medium	Low	Medium	High	0%	10%	20%	3.069	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%
MOL_7	C Culvert	0.6	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.947	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_8	C Culvert	0.9	0	3	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.311	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_9	C Culvert	0.375	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.033	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_10	C Culvert	0.75	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.054	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_11	C Culvert	0.72	0	1	1.5	M	H	L	MHL	Medium	Low	Medium	High	25%	50%	100%	1.888	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_12	C Culvert	1.2	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.277	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_13	C Culvert	0.72	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.088	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_14	C Culvert	0.75	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	0.892	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_15A	R Culvert	1.84	1.7	1	1.5	M	M	L	MML	Low	Low	Low	Medium	0%	0%	10%	1.131	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
MOL_16	C Culvert	0.58	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	0.544	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_17	C Culvert	0.58	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.623	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_18	R Culvert	1.22	1.22	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	0.71	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_19	C Culvert	0.9	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.732	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_24	C Culvert	0.9	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.338	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_25	R Culvert	0.57	0.34	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	0.901	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_26	C Culvert	0.6	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.487	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_27	R Culvert	0.88	0.47	3	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.67	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_28	C Culvert	0.45	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.605	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_29	C Culvert	0.45	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.689	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_30	C Culvert	0.45	0	1	1.5	M	H	L	MHL	Medium	Low	Medium	High	25%	50%	100%	3.262	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_31	C Culvert	0.75	0	2	1.5	M	H	M	MHM	Medium	Low	Medium	High	25%	50%	100%	3.471	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_32	R Culvert	1.51	2.18	4	1.5	M	M	M	MMM	Medium	Low	Medium	High	0%	10%	20%	3.513	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%
MOL_33	C Culvert	0.45	0	1	1.5	M	H	L	MHL	Medium	Low	Medium	High	25%	50%	100%	3.28	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_34	R Culvert	0.57	0.34	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	0.929	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_35	C Culvert	0.45	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.734	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_36	R Culvert	0.58	0.38	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	0.851	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_37	R Culvert	2.4	0.87	3	1.5	L	M	M	LMM	Low	Low	Low	Medium	0%	0%	10%	2.058	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
MOL_38	C Culvert	0.5	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	1.456	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_39	C Culvert	0.5	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	2.879	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_41	R Culvert	0.6	0.4	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	3.733	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_48	C Culvert	0.45	0	1	1.5	L	H	M	LHM	Medium	Low	Medium	High	25%	50%	100%	1.879	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_49	C Culvert	0.28	0	1	1.5	L	H	M	LHM	Medium	Low	Medium	High	25%	50%	100%	1.597	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_52	C Culvert	0.45	0	1	1.5	L	H	M	LHM	Medium	Low	Medium	High	25%	50%	100%	2.577	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_53	C Culvert	0.45	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	2.781	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_55	C Culvert	0.375	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	1.354	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_56	C Culvert	0.45	0	1	1.5	M	H	M	MHM	Medium	Low	Medium	High	25%	50%	100%	1.473	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_57	C Culvert	0.9	0	1	1.5	M	M	M	MMM	Medium	Low	Medium	High	25%	50%	100%	2.644	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_59	C Culvert	0.45	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	5.316	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_62	C Culvert	0.6	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	3.782	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_74	C Culvert	0.75	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	2.722	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_77	C Culvert	1.35	0	1	1.5	M	M	M	MMM	Medium	Low	Medium	High	25%	50%	100%	2.036	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_78	C Culvert	0.9	0	2	1.5	M	M	M	MMM	Medium	Low	Medium	High	25%	50%	100%	2.004	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_80	C Culvert	0.75	0	1	1.5	M	H	L	MHL	Medium	Low	Medium	High	25%	50%	100%	0.968	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_83	C Culvert	0.375	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.041	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_84	C Culvert	0.45	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.585	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_85	C Culvert	4.64	0	3	1.5	M	M	M	MMM	Medium	Low	Medium	High	0%	0%	10%	1.296	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%
MOL_86	C Culvert	3.23	0	3	1.5	M	M	M	MMM	Medium	Low	Medium	High	0%	10%	20%	2.556	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%
MOL_87	C Culvert	0.6	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.918	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_88	C Culvert	0.75	0	1	1.5	M	M	M	MMM	Medium	Low	Medium	High	25%	50%	100%	2.973	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_89	C Culvert	0.45	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.933	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_90	C Culvert	0.375	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.11	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_91	C Culvert	0.375	0	1	1.5	M	H	L	MHL	Medium	Low	Medium	High	25%	50%	100%	2.618	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%
MOL_92	C Culvert	0.375	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.659	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_93	C Culvert	0.375	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.619	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MOL_94	C Culvert	0.3	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.487	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%

TABLE E1

ARR, 2019 DESIGN BLOCKAGE ASSESSMENT AT HYDRAULIC DRAINAGE STRUCTURES

ID[(1)]	Structure Details				Floating Debris												Non-Floating Debris									Adopted Design Blockage B_{DES}%			
	Structure Type[(2)]	Width	Height (m)	No. of Barrels	L_{10}[(3)]	Debris Availability	Debris Mobility	Debris Transportability	Debris Potential	Debris Potential at Structure	Adjusted Debris Potential			Most Likely Design Inlet Blockage (B_{DES}%)			Max V (m/s)	Likelihood of Deposition	Debris Potential at Structure	Adjusted Debris Potential			Most Likely Design Barrel Blockage (B_{DES}%)						
											> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	Max			> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	
MOL_95	C Culvert	1.47	0	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	2.656	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_96	R Culvert	3	3	3	1.5	M	M	M	MMM	Medium	Low	Medium	High	0%	10%	20%	2.081	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%	
MOL_97	R Culvert	0.6	0.3	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	3.911	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_98	R Culvert	3	2.48	2	1.5	M	M	M	MMM	Medium	Low	Medium	High	0%	10%	20%	4.412	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%	
MOL_99	C Culvert	0.3	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	0.597	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_103	C Culvert	0.3	0	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.526	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_104	C Culvert	0.3	0	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	2.074	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_105	C Culvert	0.45	0	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	3.046	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_106	C Culvert	0.45	0	1	1.5	M	M	M	MMM	Medium	Low	Medium	High	25%	50%	100%	3.024	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%	
MOL_109	C Culvert	0.83	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.722	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_110	C Culvert	0.9	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	3.293	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_111	C Culvert	0.91	0	1	1.5	M	M	M	MMM	Medium	Low	Medium	High	25%	50%	100%	2.428	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%	
MOL_112	C Culvert	1.2	0	1	1.5	M	M	M	MMM	Medium	Low	Medium	High	25%	50%	100%	3.038	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%	
MOL_113	C Culvert	0.6	0	6	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.313	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_114	C Culvert	0.72	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	0.986	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_115	C Culvert	0.72	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.254	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_116	C Culvert	1.3	0	3	1.5	M	M	M	MMM	Medium	Low	Medium	High	25%	50%	100%	1.923	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%	
MOL_117	R Culvert	0.76	0.44	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	3.275	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_118	C Culvert	0.75	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	3	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_124	R Culvert	0.59	0.4	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	1.695	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_126	R Culvert	0.62	0.4	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	2.761	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_129	C Culvert	0.45	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	0.738	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_130	R Culvert	2.13	0.93	1	1.5	M	M	M	MMM	Medium	Low	Medium	High	0%	10%	20%	1.911	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%	
MOL_131	C Culvert	1.2	0	2	1.5	M	M	M	MMM	Medium	Low	Medium	High	25%	50%	100%	4.274	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%	
MOL_132	R Culvert	1.5	0.73	2	1.5	M	M	M	MMM	Medium	Low	Medium	High	0%	10%	20%	1.946	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%	
MOL_133	C Culvert	0.45	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.024	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_134	C Culvert	0.6	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	3.004	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_135	C Culvert	0.45	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.634	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_136	C Culvert	0.3	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.253	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_137	R Culvert	2.78	2.12	2	1.5	M	M	M	MMM	Medium	Low	Medium	High	0%	10%	20%	2.264	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%	
MOL_138	C Culvert	0.45	0	1	1.5	H	H	M	HHM	High	Medium	High	High	50%	100%	100%	5.303	Low	High	Medium	High	High	15%	25%	25%	50%	100%	100%	
MOL_139	C Culvert	1.1	0	1	1.5	H	H	L	HHL	Medium	Low	Medium	High	25%	50%	100%	1.383	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%	
MOL_140	C Culvert	1.1	0	1	1.5	H	H	L	HHL	Medium	Low	Medium	High	25%	50%	100%	2.076	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%	
MOL_151	C Culvert	0.45	0	1	1.5	M	H	M	MHM	Medium	Low	Medium	High	25%	50%	100%	2.151	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%	
MOL_156	R Culvert	1.5	1.25	2	1.5	M	M	M	MMM	Medium	Low	Medium	High	0%	10%	20%	1.747	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%	
MOL_157	R Culvert	1.8	0.72	3	1.5	M	M	M	MMM	Medium	Low	Medium	High	0%	10%	20%	3.423	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%	
MOL_158	R Culvert	3.1	3.07	4	1.5	L	M	M	LMM	Low	Low	Low	Medium	0%	0%	10%	1.952	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%	
MOL_159	R Culvert	2.13	2.13	2	1.5	M	H	M	MHM	Medium	Low	Medium	High	0%	10%	20%	3.772	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%	
MOL_160	R Culvert	0.88	0.48	0	1.5	M	M	M	MMM	Medium	Low	Medium	High	25%	50%	100%	6.062	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%	
MOL_185	R Culvert	0.6	0.4	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	2.881	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_186	C Culvert	0.25	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	2.523	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_189	C Culvert	0.4	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	1.483	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_190	C Culvert	0.4	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	0.451	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%	
MOL_191	C Culvert	0.3	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	0.733	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_193	C Culvert	0.45	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	1.323	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_202	C Culvert	0.45	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	1.65	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_225	C Culvert	1.2	0	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	2.076	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_226	R Culvert	1.2	0.6	1	1.5	M	M	M	MMM	Medium	Low	Medium	High	25%	50%	100%	4.137	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%	
MOL_229	R Culvert	0.85	0.45	1	1.5	L	M	M	LMM	Low	Low	Low	Medium	25%	25%	50%	5.291	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_232	C Culvert	0.6	0	1	1.5	M	M	M	MMM	Medium	Low	Medium	High	25%	50%	100%	1.16	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%	
MOL_268	C Culvert	0.6	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.332	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_269	C Culvert	0.45	0	1	1.5	H	H	L	HHL	Medium	Low	Medium	High	25%	50%	100%	2.947	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%	
MOL_270	C Culvert	0.45	0	1	1.5	H	H	L	HHL	Medium	Low	Medium	High	25%	50%	100%	3.345	Low	Medium	Low	Medium	High	0%	15%	25%	25%	50%	100%	
MOL_271	C Culvert	0.6	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.642	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_272	C Culvert	0.45	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	2.99	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_Rail	R Culvert	8	3	0	1.5	M	M	M	MMM	Medium	Low	Medium	High	0%	0%	10%	2.19	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%	
MOL_15	R Culvert	1.84	1.2	1	1.5	M	M	L	MML	Low	Low	Low	Medium	0%	0%	10%	1.807	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%	
MOL_273	R Culvert	1.86	1.2	1	1.5	M	M	L	MML	Low	Low	Low	Medium	0%	0%	10%	1.08	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%	
MOL_277	C Culvert	0.45	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	1.678	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	
MOL_292	C Culvert	0.45	0	1	1.5	M	M	L	MML	Low	Low	Low	Medium	25%	25%	50%	-	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%	MOL_292
Bridge 1	Bridge	10	-	-	1.5	M	H	H	MHH	High	Medium	High	High	0%	10%	10%	-	Low	High	Medium	High	High	15%	25%	25%	15%	25%	25%	

TABLE E1

ARR, 2019 DESIGN BLOCKAGE ASSESSMENT AT HYDRAULIC DRAINAGE STRUCTURES

ID[(1)]	Structure Details				Floating Debris												Non-Floating Debris									Adopted Design Blockage B_{DES}%		
	Structure Type[(2)]	Width	Height (m)	No. of Barrels	L_{10}[(3)]	Debris Availability	Debris Mobility	Debris Transportability	Debris Potential	Debris Potential at Structure	Adjusted Debris Potential			Most Likely Design Inlet Blockage (B_{DES}%)			Max V (m/s)	Likelihood of Deposition	Debris Potential at Structure	Adjusted Debris Potential			Most Likely Design Barrel Blockage (B_{DES}%)					
											> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	Max			> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP
Bridge 2	Bridge	13.4	-	-	1.5	M	H	H	MHH	High	Medium	High	High	0%	10%	10%	-	Low	High	Medium	High	High	15%	25%	25%	15%	25%	25%
Bridge 3	Bridge	8.6	-	-	1.5	M	H	H	MHH	High	Medium	High	High	0%	10%	10%	-	Low	High	Medium	High	High	15%	25%	25%	15%	25%	25%
Bridge 4	Bridge	7	-	-	1.5	M	M	H	MMH	Medium	Low	Medium	High	0%	0%	10%	-	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%
Bridge 5	Bridge	7	-	-	1.5	M	M	H	MMH	Medium	Low	Medium	High	0%	0%	10%	-	Low	Medium	Low	Medium	High	0%	15%	25%	0%	15%	25%

1. Note that the plan location of each structure can be identified in the GIS layers contained in the data handover for the present study.
2. C Culvert = Circular Pipe Culvert, R Culvert = Rectangular Box Culvert
3. L_{10} is the average length of the longest 10% of the debris that could arrive at the culvert.

APPENDIX F

FLOOD DATA FOR INDIVIDUAL ROAD CROSSINGS AT MOLONG

TABLE F1
PEAK FLOOD LEVEL AND MAXIMUM DEPTH OF INUNDATION AT INDIVIDUAL ROAD AND RAIL CROSSINGS AT MOLONG[1,2]

ID[3]	Tributary	Road Name	Road/ Rail Level (m AHD)	August 1990		November 2005		November 2021		November 2022		20% AEP		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMP	
				Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[T]	[U]	[V]	[W]	[X]	[Y]	[Z]	[AA]	[AB]
H01	Molong Creek	Marsden Street[4]	532.7	531.4	NF	532.0	NF	531.4	NF	532.8	0.1	531.0	NF	531.3	NF	531.7	NF	532.2	NF	532.6	NF	532.9	0.2	533.1	0.4	537.6	4.9
H02	Molong Creek	Euchareena Road Bridge	530.7	530.0	NF	530.4	NF	530.0	NF	531.0	0.3	529.6	NF	529.9	NF	530.3	NF	530.6	NF	530.9	0.2	531.1	0.4	531.3	0.6	535.8	5.1
H03	Molong Creek	Molong Creek Railway Bridge	530.0	529.5	NF	529.9	NF	529.5	NF	530.4	0.4	529.6	NF	529.9	NF	530.3	0.3	530.6	0.6	530.9	0.9	531.1	1.1	531.3	1.3	535.0	5.0
H04	Molong Creek	Broken Hill Railway Bridge No. 1	526.3	526.0	NF	526.4	0.1	526.0	NF	527.0	0.7	525.8	NF	525.9	NF	526.2	NF	526.6	0.3	526.9	0.6	527.1	0.8	527.3	1.0	531.6	5.3
H05	Molong Creek	Broken Hill Railway Bridge No. 2	527.7	526.2	NF	526.6	NF	526.1	NF	527.1	NF	525.8	NF	526.0	NF	526.3	NF	526.7	NF	527.0	NF	527.2	NF	527.4	NF	531.5	3.8
H06	Boree Hollow	Wellington Street	539.0	537.9	NF	539.2	0.2	539.0	NF	539.4	0.4	538.5	NF	539.0	NF	539.2	0.2	539.3	0.3	539.4	0.4	539.4	0.4	539.5	0.5	541.2	2.2
H07	Boree Hollow	Riddell Street Causeway	533.2	534.4	1.2	534.8	1.6	534.7	1.5	535.0	1.8	534.4	1.2	534.5	1.3	534.5	1.3	534.6	1.4	534.7	1.5	534.8	1.6	534.9	1.7	537.6	4.4
H08	Boree Hollow	William Street	533.0	533.1	0.1	533.6	0.6	533.4	0.4	533.9	0.9	533.3	0.3	533.4	0.4	533.5	0.5	533.7	0.7	533.8	0.8	533.9	0.9	534.0	1.0	537.2	4.2
H09	Boree Hollow	Hill Street	529.8	528.3	NF	529.5	NF	529.1	NF	529.9	0.1	528.8	NF	529.0	NF	529.2	NF	529.6	NF	529.8	NF	529.9	0.1	530.0	0.2	532.3	2.5
H10	Moss Hollow Creek	Packham Drive	564.3	562.7	NF	563.7	NF	563.7	NF	564.1	NF	563.4	NF	563.6	NF	563.8	NF	563.9	NF	564.1	NF	564.2	NF	564.3	NF	566.3	2.0
H11	Moss Hollow Creek	Quarry Road	548.8	549.4	0.6	550.1	1.3	550.1	1.3	550.3	1.5	549.8	1.0	549.9	1.1	550.0	1.2	550.2	1.4	550.3	1.5	550.3	1.5	550.4	1.6	551.7	2.9
H12	Moss Hollow Creek	Banjo Patterson Way	536.8	535.6	NF	536.9	0.1	536.9	0.1	537.2	0.4	536.1	NF	536.6	NF	536.9	0.1	537.1	0.3	537.2	0.4	537.3	0.5	537.5	0.7	539.6	2.8
H13	Moss Hollow Creek	End Street	527.2	528.0	0.8	528.4	1.2	528.4	1.2	528.6	1.4	528.1	0.9	528.2	1.0	528.3	1.1	528.5	1.3	528.5	1.3	528.6	1.4	528.7	1.5	530.9	3.7
		Market Street	528.0	528.0	NF	528.4	0.4	528.4	0.4	528.6	0.6	528.1	0.1	528.2	0.2	528.3	0.3	528.5	0.5	528.5	0.5	528.6	0.6	528.7	0.7	530.9	2.9
H14	Shingle Ridge Creek	Banjo Patterson Way	569.8	567.3	NF	568.3	NF	568.6	NF	569.2	NF	567.7	NF	568.1	NF	568.4	NF	569.0	NF	569.3	NF	569.6	NF	570.0	0.2	571.2	1.4
H15	Foys Creek	Mitchell Highway	529.8	527.1	NF	528.6	NF	528.9	NF	529.2	NF	527.8	NF	528.1	NF	528.7	NF	529.2	NF	529.8	NF	529.9	0.1	530.1	0.3	531.3	1.5

1. Elevations and Depths rounded to nearest 0.1 m.
2. NF = Not Flooded.
3. Refer **Figures 6.1** to **6.8** for location of Peak Flood Level Location.
4. Elevation of low point in Marsden Street that is located approximately 50 m to the east of the Marsden Street Bridge.

APPENDIX G

DESIGN PEAK FLOWS

TABLE G1
DESIGN PEAK FLOWS DERIVED BY TUFLOW MODEL[1]

Peak Flow Location Identifier[2]	Watercourse	Location	20% AEP			10% AEP			5% AEP			2% AEP			1% AEP			0.5% AEP			0.2% AEP			PMF	
			Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[T]	[U]	[V]	[W]	[X]	[Y]	[Z]
Q01	Molong Creek	Deight Street	156.0	540	6	199	360	2	255	360	2	322	360	3	405	360	3	472	360	3	555	360	3	4,120	180
Q02		Gamboola	159.0	540	6	202	360	2	259	360	2	329	360	3	414	360	3	483	360	3	567	360	3	4120	180
Q03		Marsden Street	177.0	540	6	217	360	2	278	360	2	372	360	3	465	360	3	538	360	3	624	360	3	4,600	180
Q04a		Dean Street	177.0	540	6	215	360	2	276	360	2	364	360	3	433	360	3	477	360	3	528	360	3	-	-
Q04b		Surcharge left bank upstream of Dean Street	0.0	540	6	0	360	2	0	360	2	3.7	360	3	23	360	3	48.9	360	3	85.9	360	3	-	-
Q04c		Downstream Molong Street	1.0	540	6	2.2	360	2	2.6	360	2	8.2	360	3	32.4	360	3	63.1	360	3	103	360	3	-	-
Q05a		Upstream Euchareena Road	177.0	540	6	207	360	2	233	360	2	283	360	3	336	360	3	378	360	3	431	360	3	-	-
Q05b		Surcharge left bank of Molong Creek	0.0	540	6	6.9	360	2	42.1	360	2	80.3	360	3	96.2	360	3	99.4	360	3	100	360	3	-	-
Q05c		Bank Street	0.1	540	6	9.3	360	2	44.7	360	2	88.3	360	3	128	360	3	160	360	3	198	360	3	-	-
Q06		Molong Creek Railway Bridge	177.0	540	6	207	360	2	233	360	2	283	360	3	338	360	3	382	360	3	438	360	3	-	-
Q07		Gidley Street	178.0	540	6	217	360	2	278	360	2	373	360	3	466	360	3	541	360	3	632	360	3	4,605	180
Q08		Upstream Confluence with Boree Hollow	179.0	540	6	217	360	2	278	360	2	371	360	3	461	360	3	535	360	3	621	360	3	-	-
Q09		Broken Hill Railway Line	191.0	540	6	226	360	2	289	360	2	399	360	3	494	360	3	571	360	3	664	360	3	4,900	180
Q10		Downstream Confluence with Moss Hollow Creek	202.0	540	6	233	360	2	301	360	2	422	360	3	524	360	3	608	360	3	710	360	3	5,215	180
Q11		Downstream Confluence with Foys Creek	206.0	540	6	240	360	2	310	360	2	429	360	3	533	360	3	619	360	3	723	360	3	5,485	180
Q12	Reedy Creek	Upstream Railway Line	34.0	180	8	48.2	120	8	62.2	120	8	82.2	180	4	101	180	4	117	180	4	139	180	4	930	180
Q13	Boree Hollow	Upstream South Street	24.7	180	8	35.8	120	8	46.3	120	8	64.6	120	6	79.4	120	6	93.7	120	6	112	120	6	795	120
Q14		Wellington Street	25.3	180	8	35.6	120	8	46.8	120	8	65.1	120	6	79.8	120	6	94.1	120	6	112	120	6	830	120
Q15		Molong Street	25.4	180	8	35.6	120	8	46.8	120	8	65	120	6	79.6	120	6	93.9	120	6	112	120	6	-	-
Q16		William Street	25.5	180	8	35.6	120	8	46.8	120	8	65	120	6	79.4	120	6	93.6	120	6	112	120	6	848	180
Q17		Bank Street	25.5	180	8	35.5	120	8	46.8	120	8	64.9	120	6	79.6	180	4	93.6	180	4	111	180	4	856	180
Q18		Hill Street	25.5	180	8	35.5	120	8	46.8	120	8	64.9	120	6	80	180	4	94	180	4	112	180	4	-	-

Refer over for footnote to table

TABLE G1 (Cont'd)
DESIGN PEAK FLOWS DERIVED BY TUFLOW MODEL(1)

Peak Flow Location Identifier(2)	Watercourse	Location	20% AEP			10% AEP			5% AEP			2% AEP			1% AEP			0.5% AEP			0.2% AEP			PMF	
			Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[T]	[U]	[V]	[W]	[X]	[Y]	[Z]
Q19	Moss Hollow Creek	Packham Drive	21.1	120	1	29.8	120	8	37.7	120	8	53.1	120	6	63.5	120	6	74.9	120	6	88.7	120	6	601	120
Q20		Quarry Road	22.3	120	1	31.6	120	8	39.8	120	8	55.5	120	6	65.6	120	6	77.5	120	6	93.6	180	4	-	-
Q21		Hill Street	22.6	120	1	31.9	120	8	40.5	120	8	56	120	6	66.3	120	6	78.5	180	4	94.9	180	4	714	120
Q22		Banjo Paterson Way	22.6	120	1	31.9	120	8	40.5	120	8	56.1	120	6	66.3	120	6	78.5	180	4	94.9	180	4	-	-
Q23		Upstream End Street	25.4	180	8	34.9	120	8	45.5	120	8	61.4	120	6	73.4	120	6	85.4	180	4	103	180	4	835	120
Q24a		Downstream End Street	16.9	180	8	21.1	120	8	25	120	8	29.4	120	6	31.5	120	6	32.8	180	4	33.1	180	4	-	-
Q24b		Overtopping Market Street	8.6	180	8	13.9	120	8	20.5	120	8	31.4	120	6	41	120	6	52	180	4	70.2	180	4	-	-
Q25		Market Street culvert	17.0	180	8	21.2	120	8	25.1	120	8	29.5	120	6	32.1	120	6	33.8	180	4	33.5	180	4	-	-
Q26	Shingle Ridge Creek	Banjo Patterson Way	6.8	120	1	10.5	120	8	12.7	120	8	17.6	120	6	20.8	120	6	24	180	4	28.4	180	4	211	120
Q27	Foys Creek	Downstream Shingle Ridge Creek confluence	14.5	120	1	20.1	120	8	25.6	90	6	36.8	120	6	43.2	120	6	49.9	120	6	58.9	180	4	454	120
Q28		Mithcell Highway	17.6	120	1	23.9	90	6	31.5	90	6	44.2	120	6	52	120	6	60.3	120	6	70.3	120	6	552	120
Q29	Pillans Park Drainage Line	Smith Street	0.5	30	8	0.7	30	7	0.9	30	7	1.1	30	7	1.3	30	7	1.4	30	7	1.6	30	7	12.9	15
Q30		Lee Street	0.9	30	8	1.1	30	7	1.5	30	7	1.8	30	7	2.1	30	7	2.3	30	7	2.7	30	7	21.3	15
Q31		Wellington Street	1.1	30	8	1.4	30	7	1.9	30	7	2.4	30	7	2.8	30	7	3.1	30	7	3.6	30	7	30.5	15
Q32		Gidley Street	1.6	30	8	2.3	30	7	3	30	7	4	30	7	4.7	30	7	5.3	30	7	6.1	30	7	45.7	15
Q33		Davimac Lane	1.5	30	8	2.2	30	7	3	30	7	4.1	30	7	4.8	30	7	5.5	30	7	6.3	30	7	46.1	15
Q34	Major Overland Flow	Back Saleyards Road	8.0	120	1	11.7	90	6	15.3	90	6	21.4	120	6	24.6	120	6	28	120	6	32.7	60	2	185	45
Q35		Marsden Street	1.3	90	6	2	90	6	2.6	90	6	3.5	180	4	4.1	180	4	4.8	60	2	5.9	30	7	44.2	45
Q36		Upstream Buckland Street	11.4	120	1	16.5	90	6	21.8	90	6	30.6	120	6	35.5	120	6	40.4	120	6	48	60	2	357	45
Q37		Marsden Street	1.0	120	1	1.6	120	8	2.2	90	6	3.4	120	6	4	120	6	4.6	120	6	5.4	180	4	59	45
Q38		Upstream Marsden Street	0.7	120	1	1.1	60	3	1.5	60	3	2.1	30	7	2.5	30	7	2.8	30	7	3.3	30	7	30.1	45
Q41		0	2.6	90	6	3.9	90	6	5.3	90	6	7.3	120	6	8.5	120	6	9.8	30	7	12.4	30	7	93.9	45

Refer over for footnote to table

TABLE G1 (Cont'd)
DESIGN PEAK FLOWS DERIVED BY TUFLOW MODEL[1]

Peak Flow Location Identifier[2]	Watercourse	Location	20% AEP			10% AEP			5% AEP			2% AEP			1% AEP			0.5% AEP			0.2% AEP			PMF	
			Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Temporal Pattern[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[T]	[U]	[V]	[W]	[X]	[Y]	[Z]
Q42	Major Overland Flow	Upstream Railway	4.4	90	6	6.6	90	6	8.5	90	6	11.6	180	4	13.9	180	4	15.9	180	4	18.6	60	2	-	-
Q39		South Street	1.8	120	1	2.5	60	3	3.3	60	3	4.6	30	7	5.7	30	7	6.7	30	7	8	30	7	57.4	15
Q40		Upstream Mitchell Highway	2.9	120	1	3.8	90	6	5.4	60	3	7.3	30	7	9.3	30	7	11	30	7	13.3	30	7	94.8	15
Q43		Upstream Peabody Road	0.8	30	8	1.2	30	7	1.5	30	7	1.8	30	7	2.1	30	7	2.4	30	7	2.7	30	7	22.1	15
Q44		Downstream Bloomfield Road	3.6	120	1	5	90	6	6.5	90	6	8.7	120	6	10.7	30	7	13.5	30	7	17.4	30	7	116	15
Q45		Starrlea Road	1.2	90	6	1.7	90	6	2.2	60	3	2.8	60	2	3.4	30	7	4.2	30	7	5.2	30	7	38	45

1. Peak flows less than 100 m^3/s have been quoted to one decimal place in order to show minor differences.
2. Refer **Figures 6.1** to **6.8** for location of Flow Location Identifiers.
3. Relates to storm duration that is critical for maximising the peak flood level at each location, not necessarily the peak flow.
4. Relates to temporal pattern that is critical for maximising the peak flood level at each location, not necessarily the peak flow.

APPENDIX H

FLOOD DAMAGES

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FIGURES
(BOUND IN VOLUME 2)

H1. INTRODUCTION AND SCOPE

H1.1 Introduction

Damages from flooding belong to two categories:

- **Tangible Damages**
- **Intangible Damages**

Tangible damages are defined as those to which monetary values may be assigned and may be subdivided into direct and indirect damages. Direct damages are those caused by physical contact of floodwater with damageable property. They include damages to commercial and residential building structures and contents as well as damages to infrastructure services such as electricity and water supply. Indirect damages result from the interruption of community activities, including traffic flows, trade, industrial production, costs to relief agencies, evacuation of people and contents and clean up after the flood.

Generally, tangible damages are estimated in dollar values using survey procedures, interpretation of data from actual floods and research of government files.

The various factors included in the **intangible damage** category may be significant. However, these effects are difficult to quantify due to lack of data and the absence of an accepted method. Such factors may include:

- inconvenience
- isolation
- disruption of family and social activities
- anxiety, pain and suffering, trauma
- physical ill-health
- psychological ill-health.

H1.2 Scope of Investigation

In the following sections, tangible damages to residential, commercial and industrial properties, and public buildings have been estimated resulting from flooding in the study area. Intangible damages have not been quantified. The threshold floods at which damages may commence to infrastructure and community assets have also been estimated, mainly from site inspection and interpretation of flood level data. However, there are no data available to allow a quantitative assessment of damages to be made to this category.

H1.3 Terminology

Definitions of the terms used in this Appendix are presented in **Section G8** which also summarises the value of Tangible Flood Damages.

H2. DESCRIPTION OF APPROACH

The damage caused by a flood to a particular property is a function of the depth of flooding above floor level and the value of the property and its contents. The warning time available for residents to take action to lift property above floor level also influences damages actually experienced. A spreadsheet model which has been developed by DPE for estimating residential damages and an in-house spreadsheet model which has been developed for previous investigations of this nature for estimating commercial, industrial and public building damages were used to estimate damages on a property by property basis according to the type of development, the location of the property and the depth of inundation.

Using the results of the hydraulic modelling, a peak flood elevation was derived for each event at each property. The property flood levels were input to the spreadsheet model which also contained property characteristics and depth-damage relationships. The depth of flooding was computed as the difference between the interpolated flood level and the floor elevation at each property.

The floor levels of individual dwellings/buildings were assessed by adding the height of floor above a representative natural surface within the allotment (as estimated by visual inspection) to the natural surface elevation determined from LiDAR survey. The type of structure and potential for property damage were also assessed during the visual inspection. If a property was not accessible to undertake a visual inspection, the height of the floor was assumed to be 300 mm above the adjacent natural surface level.

The depth-damage curves for residential damages were determined using procedures described in the publication *Floodplain Risk Management Guideline No. 4, 2007* (**Guideline No. 4**) published by the Department of Environment and Climate Change (**DECC**) (now DPE). Damage curves for other categories of development (commercial/industrial and public buildings) were derived from previous floodplain management investigations.

It should be understood that this approach is not intended to identify individual properties liable to flood damages and the values of damages in individual properties, even though it appears to be capable of doing so. The reason for this caveat lies in the various assumptions used in the procedure, the main ones being:

- the assumption that computed water levels and topographic data used to define flood extents are exact and without any error;
- the assumption that the water levels as computed by the hydraulic model are not subject to localised influences;
- the estimation of property floor levels by visual inspection rather than by formal field survey;
- the use of "average" stage-damage relationships, rather than a unique relationship for each property;
- the uncertainties associated with assessing appropriate factors to convert *potential damages* to *actual flood damages* experienced for each property after residents have taken action to mitigate damages to contents.

The consequence of these assumptions is that some individual properties may be inappropriately classified as flood liable, while others may be excluded. Nevertheless, when applied over a broad area these effects would tend to cancel, and the resulting estimates of overall damages, would be expected to be reasonably accurate.

For the above reasons, the information contained in the spreadsheets used to prepare the estimates of flood damages for the study area should not be used to provide information on the depths of above-floor inundation of individual properties.

H3. SOURCES OF DATA

H3.1 General

To estimate A*verage Annual Flood Damages* for a specific area it is necessary to estimate the damages for several floods of different magnitudes, i.e., of different frequencies, and then to integrate the area beneath the damage – frequency curve over the whole range of frequencies. To do this it is necessary to have data on the damages sustained by all types of property over the likely range of inundation. There are several ways of doing this:

- The ideal way would be to conduct specific damage surveys in the aftermath of a range of floods, preferably immediately after each. An example approaching this ideal is the case of Nyngan where surveys were conducted in May 1990 following the disastrous flood of a month earlier (DWR, 1990). This approach is not possible in the study area as specific damage surveys have not been conducted following the historic flood events.
- The second best way is for experienced loss adjusters to conduct a survey to estimate likely losses that would arise due to various depths of inundation. This approach is used from time to time, but it can add significantly to the cost of a floodplain management study (LMJ, 1985). It was not used for the present investigation.
- The third way is to use generalised data such as that published by CRES (Centre for Resource & Economic Studies, Canberra) and used in the Floodplain Management Study for Forbes (SKM, 1994). These kinds of data are considered to be suitable for generalised studies, such as broad regional studies. They are not considered to be suitable for use in specific areas unless none of the other approaches can be satisfactorily applied.
- The fourth way is to adapt or transpose data from other flood liable areas. This was the approach used for the present study. As mentioned, the *Guideline No 4* procedure was adopted for the assessment of residential damages. The approach was based on data collected following major flooding in Katherine in 1998, with adjustments to account for changes in values due to inflation, and after taking into account the nature of development and flooding patterns in the study area. The data collected during site inspection in the flood liable areas assisted in providing the necessary adjustments. Commercial and industrial damages were assessed via reference to recent floodplain management investigations of a similar nature to the present study (L&A, 2019).

H3.2 Property Data

The properties were divided into three categories: residential, commercial/industrial and public buildings.

For residential properties, the data used in the damages estimation included:

- the location/address of each property
- an assessment of the type of structure
- representative natural surface level of the allotment
- floor level of the residence

For commercial/industrial properties, the data used in the damages estimation included:

- the location of each property
- the nature of each enterprise
- an estimation of the floor area
- natural surface level
- floor level

The property descriptions were used to classify the commercial/industrial and public developments into categories (i.e., high, medium or low value properties) which relate to the magnitude of likely flood damages.

The total number of residential properties, commercial / industrial and public buildings in the study area is shown in **Table H3.1**.

TABLE H3.1
NUMBER OF PROPERTIES INCLUDED IN DAMAGES DATABASE

Development Type	Number of Properties
Residential	413
Commercial / Industrial	76
Public	23
Total	**512**

H3.3 Flood Levels Used in the Analysis

Damages were computed for the design flood levels determined from the hydraulic models that were developed as part of the present investigation. The design levels assume that the drainage system is operating at optimum capacity. They do not allow for any increase in levels resulting from wave action and debris build-ups in the channels which may result in conversions of flow from the supercritical to the subcritical flow regime, as well as other local hydraulic effects. These factors are usually taken into account by adding a factor of safety (freeboard) to the “nominal” flood level when assessing the “level of protection” against flooding of a particular property. Freeboard could also include an allowance for the future effects of climate change.

H4. RESIDENTIAL DAMAGES

H4.1 Damage Functions

The procedures identified in *Guideline No 4* allow for the preparation of a depth versus damage relationship which incorporates structural damage to the building, damage to internals and contents, external damages and clean-up costs. In addition, there is the facility for including allowance for accommodation costs and loss of rent. Separate curves are computed for three residential categories:

- Single storey slab on ground construction
- Single storey elevated floor
- Two storey residence

The level of flood awareness and available warning time are taken into account by factors which are used to reduce "potential" damages to contents to "actual" damages. "Potential" damages represent losses likely to be experienced if no action were taken by residents to mitigate impacts. A reduction in the potential damages to "actual" damages is usually made to allow for property evacuation and raising valuables above floor level, which would reduce the damages actually experienced. The ability of residents to take action to reduce flood losses is mainly limited to reductions in damages to contents, as damages to the structure and clean-up costs are not usually capable of significant mitigation.

The reduction in damages to contents is site specific, being dependent on a number of factors related to the time of rise of floodwaters, the recent flood history and flood awareness of residents and emergency planning by the various Government Agencies (BoM and NSW SES).

Flooding in the study area is "flash flooding" in nature, with surcharge of the watercourses and various drainage lines occurring within three hours of the onset of flood producing rain. Consequently, there would be very limited time in advance of a flood event in which to warn residents located along the various flow paths and for them to take action to mitigate flood losses.

Provided adequate warning were available, house contents may be raised above floor level to about 0.9 m, which corresponds with the height of a typical table/bench height. The spreadsheet provides two factors for assessing damages to contents, one for above and one for below the typical bench height. The reduction in damages is also dependent on the likely duration of inundation of contents, which would be limited to no more than an hour for most flooded properties. **Table H4.1** over sets out the parameters and resulting factors that were adopted for converting potential to actual damages in the study area.

Table H4.2 over shows total flood damages estimated for the three classes of residential property using the procedures identified in *Guideline No. 4*, for typical depths of above-floor inundation of 0.5 m and 1.0 m. A typical ground floor area of 240 m^2 was adopted for the assessment. The values in **Table H4.2** allow for damages to buildings and contents, as well as external damages and provision for alternative accommodation.

TABLE H4.1
DAMAGE ADJUSTMENT FACTORS/PARAMETERS FOR RESIDENTIAL DEVELOPMENT

Property Damage	Parameter/Factor	Adopted Value
Building	Regional Cost Variation Factor	1.10
	Post Late-2002 Adjustments	2.07
	Post Flood Inflation Factor	1.50
	Typical Duration of Immersion (hours)	6
	Building Damage Repair Limitation Factor	0.85
	Total Building Adjustment Factor	2.90
Contents	Contents Damage Repair Limitation Factor	0.75
	Level of Flood Awareness	Low
	Effective Warning Time	0
	Typical Table/Bench Height (TTBH) (m)	0.9
	Total Contents Adjustment Factor (Above-Floor Depth <= TTBH)	1.55
	Total Contents Adjustment Factor (Above-Floor Depth > TTBH)	1.55

1. Maximum value permitted in damages spreadsheet.

TABLE H4.2
DAMAGES TO RESIDENTIAL PROPERTIES

Type of Residential Construction	0.5 m Depth of Inundation Above Floor Level	1.0 m Depth of Inundation Above Floor Level
Single Storey Slab on Ground	$101,964	$124,559
Single Storey High Set	$115,648	$141,992
Double Storey	$71,374	$87,191

Note: These values allow for damages to buildings and contents, as well as external damages and provision for alternative accommodation.

H4.2 Total Residential Damages

Table H4.3 over summarises the residential damages in the study area for a combination Main Stream Flooding and Major Overland Flow, and Main Stream Flooding on Molong Creek only. The damage estimates were carried out for floods between the 20% AEP and the PMF which were modelled hydraulically as part of the present study. **Figures 6.1** to **6.8** of the Main Report show the plan location and approximate depth of above-floor inundation in dwellings for the range of assessed flood events.

While a small number of dwellings are inundated above-floor level in a 20% AEP flood, the 5% AEP flood event is the threshold at which the number of dwellings subject to above-floor inundation commences to increase significantly. At the 1% AEP level of flooding, 41 dwellings would experience above-floor inundation due to Main Stream Flooding and Major Overland Flow, resulting in a total flood damages of about $5 Million.

Of the 41 dwellings that would be flooded above-floor level during a 1% AEP event, 25 would be inundated by floodwater that surcharges the banks of Molong Creek, with the total damages amounting to about $3.15 Million (or about 63% of the total damages attributable to flooding at Molong).

During a PMF event, 196 individual dwellings would experience above-floor inundation in the study area. The maximum depth of above-floor inundation in the worst affected dwelling would increase from about 1.4 m at the 1% AEP level of flooding to about 6.8 m in a PMF event.

TABLE H4.3
TOTAL RESIDENTIAL FLOOD DAMAGES

Design Flood Event (%AEP)	Main Stream Flooding and Major Overland Flow			Main Stream Flooding on Molong Creek Only		
	No. of Allotments Flood Affected	No. of Dwellings Flooded Above Floor Level	Damages $ Million	No. of Allotments Flood Affected	No. of Dwellings Flooded Above Floor Level	Damages $ Million
20	21	3	0.64	4	1	0.11
10	34	6	1.17	10	3	0.46
5	51	18	2.44	22	13	1.56
2	63	31	3.91	28	19	2.41
1	68	41	5.00	34	25	3.15
0.5	77	48	5.82	37	29	3.73
0.2	79	55	6.83	40	35	4.57
PMF	256	196	35.28	151	146	28.04

H5. COMMERCIAL AND INDUSTRIAL DAMAGES

H5.1 Direct Commercial and Industrial Damages

The method used to calculate damages requires each property to be categorised in terms of the following:

- damage category;
- floor area; and
- floor elevation.

The damage category assigned to each enterprise may vary between "low", "medium" or "high", depending on the nature of the enterprise and the likely effects of flooding. Damages also depend on the floor area.

It has recently been recognised following the 1998 flood in Katherine that previous investigations using stage damage curves contained in proprietary software tend to seriously underestimate true damage costs (*Guideline No 4*). DPE are currently researching appropriate damage functions which could be adopted in the estimation of commercial and industrial categories as they have already done with residential damages. However, these data were not available for the study area.

On the basis of previous investigations, the following typical damage rates are considered appropriate for potential external and internal damages and clean-up costs for both commercial and industrial properties. They are indexed to a depth of inundation of 2 metres. At floor level and 1.2 m inundation, zero and 70% of these values respectively were assumed to occur:

Low value enterprise	$280/m^2	(e.g., Commercial: small shops, cafes, joinery, public halls. Industrial: auto workshop with concrete floor and minimal goods at floor level, Council or Government Depots, storage areas.)
Medium value enterprise	$420/m^2	(e.g., Commercial: food shops, hardware, banks, professional offices, retail enterprises, with furniture/fixtures at floor level which would suffer damage if inundated. Industrial: warehouses, equipment hires.)
High value enterprise	$650/m^2	(e.g., Commercial : electrical shops, clothing stores, bookshops, newsagents, restaurants, schools, showrooms and retailers with goods and furniture, or other high value items at ground or lower floor level. Industrial: service stations, vehicle showrooms, smash repairs.)

The factor for converting potential to actual damages depends on a range of variables such as the available warning time, flood awareness and the depth of inundation. Given sufficient warning time a well prepared business will be able to temporarily lift property above floor level. However, unless property is actually moved to flood free areas, floods which result in a large depth of inundation, will cause considerable damage to stock and contents.

For the present study, the above potential damages were converted to actual damages using a multiplier which ranged between 0.5 and 0.8 depending on the depth of inundation above the floor. At relatively shallow depths it would be expected that owners may be able to take significant action to mitigate damages, even when allowing for the flash flooding nature of inundation. Consequently, a multiplier of 0.5 was adopted to convert potential to actual damages for depths of inundation up to 1.2 m, and a multiplier of 0.8 for greater depths.

H5.2 Indirect Commercial and Industrial Damages

Indirect commercial and industrial damages comprise costs of removal of goods and storage, loss of trading profit and loss of business confidence.

Disruption to trade takes the following forms:

- The loss through isolation at the time of the flood when water is in the business premises or separating clients and customers. The total loss of trade is influenced by the opportunity for trade to divert to an alternative source. There may be significant local loss but due to the trade transfer this may be considerably reduced at the regional or state level.
- In the case of major flooding, a downturn in business can occur within the flood affected region due to the cancellation of contracts and loss of business confidence. This is in addition to the actual loss of trading caused by closure of the business by flooding.

Loss of trading profit is a difficult value to assess, and the magnitude of damages can vary depending on whether the assessment is made at the local, regional or national level. Differences between regional and national economic effects arise because of transfers between the sectors, such as taxes, and subsidies such as flood relief returned to the region.

Some investigations have lumped this loss with indirect damages and have adopted total damage as a percentage of the direct damage. In other cases, loss of profit has been related to the gross margin of the business, i.e., turnover less average wages. The former approach has been adopted in this present study. Indirect damages have been taken as 50% of direct actual damages. A clean-up cost of $15/m^2$ of floor area of each flooded property was also included.

H5.3 Total Commercial and Industrial Damages

Table H5.1 over summarises the estimated commercial and industrial damages in the study area for combined Main Stream Flooding and Major Overland Flow, and Main Stream Flooding on Molong Creek only, while **Figures 6.1** to **6.8** of the Main Report show the plan location and approximate depth of above-floor inundation in commercial buildings for the range of assessed flood events.

Floodwater commences to surcharges the left bank of Molong Creek and overtop the railway upstream of Euchareena Road in a 10% AEP, which is considered the threshold for which commercial damages commence to occur at Molong. A total of 44 commercial buildings would be subject to above-floor inundation in a 1% AEP flood, resulting in a total flood damages of about $6.04 Million.

Of the 44 commercial/industrial buildings that would be flooded above-floor level during a 1% AEP event, 42 would be inundated by floodwater that surcharges the banks of Molong Creek, indicating that almost all of the affected buildings are impacted by floodwater which originates from the creek.

A total of 65 commercial/industrial buildings would experience above-floor inundation in a PMF event. The maximum depth of above-floor inundation in the worst affected commercial/industrial building would increase from about 2.0 m at the 1% AEP level of flooding to about 7.5 m in a PMF event.

TABLE H5.1
COMMERCIAL / INDUSTRIAL FLOOD DAMAGES

Design Flood Event (%AEP)	Main Stream Flooding and Major Overland Flow			Main Stream Flooding on Molong Creek Only		
	No of Allotments Flood Affected	No. of Buildings Flooded Above Floor Level	Damages $ Million	No. of Allotments Flood Affected	No. of Buildings Flooded Above Floor Level	Damages $ Million
20	10	7	0.27	6	5	0.17
10	25	24	1.21	25	24	1.21
5	37	35	2.76	36	34	2.56
2	41	39	4.23	39	37	3.78
1	46	44	6.04	44	42	5.25
0.5	49	48	7.3	46	46	6.39
0.2	51	49	8.56	48	47	7.41
PMF	66	65	35.24	62	62	31.34

H6. DAMAGES TO PUBLIC BUILDINGS

H6.1 Direct Damages – Public Buildings

Included under this heading are government buildings, churches, swimming pools and parks. Damages were estimated individually on an areal basis according to the perceived value of the property. Potential internal damages were indexed to a depth of above floor inundation of 2 m as shown below. At floor level and 1.2 m depth of inundation, zero and 70% of these values respectively were assumed to occur.

Low value	\$280/m^2	(e.g. amenities block, clubhouses)
Medium value	\$420/m^2	(e.g. council buildings, SES HQ, fire station)
High value	\$650/m^2	(e.g. schools)

These values were obtained from the Nyngan Study (DWR, 1990) as well as commercial data presented in the Forbes Water Studies report (WS, 1992). External and structural damages were taken as 4 and 10% of internal damages, respectively.

H6.2 Indirect Damages – Public Buildings

A value of \$15/m^2 was adopted for the clean-up of each property. This value is based on results presented in the Nyngan Study and adjusted for inflation. Total "welfare and disaster" relief costs were assessed as 50% of the actual direct costs.

H6.3 Total Damages – Public Buildings

Table H6.1 over summarises the estimated public damages in the study area for combined Main Stream Flooding and Major Overland Flow, and Main Stream Flooding on Molong Creek only, while **Figures 6.1** to **6.8** of the Main Report show the plan location and approximate depth of above-floor inundation in public buildings for the range of assessed flood events.

Damage to public buildings occurs during floods as frequent as 20% AEP, where floodwater surcharging the left (western) bank of Molong Creek inundates the swimming pool complex, as well as the community church building, amenities block and clubhouse that are located on the northern side of the Dr Ross Memorial Recreation Ground. The Molong Police Station that is located on Edward Street also commences to become inundated in a 2% AEP flood.

A total of nine public buildings would experience above-floor inundation in a 1% AEP event, eight of which are impacted by floodwater which surcharges the banks of Molong Creek. The total damages to public buildings at the 1% AEP level of flooding would be about \$0.74 Million.

A total of 17 public buildings would experience above-floor inundation in a PMF event. The maximum depth of above-floor inundation in the worst affected public building would increase from about 1.5 m at the 1% AEP level of flooding to about 6.4 m in a PMF event.

TABLE H6.1
PUBLIC FLOOD DAMAGES

Design Flood Event (%AEP)	Main Stream Flooding and Major Overland Flow			Main Stream Flooding on Molong Creek Only		
	No. of Allotments Flood Affected	No. of Buildings Flooded Above Floor Level	Damages $ Million	No. of Allotments Flood Affected	No. of Buildings Flooded Above Floor Level	Damages $ Million
20	4	4	0.14	4	4	0.14
10	11	6	0.31	8	6	0.26
5	11	7	0.38	8	7	0.33
2	12	9	0.55	9	8	0.48
1	12	9	0.74	9	8	0.63
0.5	12	10	0.90	9	8	0.76
0.2	12	11	1.07	9	9	0.91
PMF	18	17	6.86	14	14	4.63

H7. DAMAGES TO INFRASTRUCTURE AND COMMUNITY ASSETS

No data are available on damages experienced to infrastructure and community assets during historic flood events. However, a qualitative matrix of the effects of flooding on important assets in the study area is presented in **Table H7.1**.

TABLE H7.1
QUALITATIVE EFFECTS OF FLOODING ON
INFRASTRUCTURE AND COMMUNITY ASSETS AT MOLONG

Damage Sector	Design Flood Event (AEP)							
	20%	10%	5%	2%	1%	0.5%	0.2%	PMF
Roads	X	X	X	X	X	X	X	X
Parks and Gardens	X	X	X	X	X	X	X	X
Electricity	O	O	O	O	O	O	O	O
Water Supply	O	O	O	O	O	O	O	O
Telephone	O	O	O	O	O	O	O	X

Notes: O = No significant damages likely to be incurred.
X = Some damages likely to be incurred.

H8. SUMMARY OF TANGIBLE DAMAGES

H8.1 Tangible Damages

Flood damages have been computed for a range of flood frequencies from 20% AEP up to the PMF. For the purposes of assessing damages, the 50% AEP was adopted as the “threshold” flood at which damages commence at Molong. From **Table H8.1** over, about $11.78 Million of damages would be incurred at the 1% AEP level of flooding at Molong due to Main Stream Flooding and Major Overland Flow, about $9.03 Million of which can be attributed to Main Stream Flooding on Molong Creek alone. **Figure H8.1** shows the damage frequency curves for residential, commercial/industrial and public buildings in the study area.

H8.2 Definition of Terms

Average Annual Damages (also termed “expected damages”) are determined by integrating the area under the damage-frequency curve. They represent the time stream of annual damages, which would be expected to occur on a year by year basis over a long duration.

Using an appropriate discount rate, average annual damages may be expressed as an equivalent “*Present Worth Value”* of damages and used in the economic analysis of potential flood management measures.

A flood management scheme which has a design 1% AEP level of protection, by definition, will eliminate damages up to this level of flooding. If the scheme has no mitigating effect on larger floods then these damages represent the benefits of the scheme expressed on an average annual basis and converted to the *Present Worth Value* via the discount rate.

Using the procedures outlined in *Guideline No. 4*, as well as current NSW Treasury guidelines, economic analyses were carried out assuming a 50 year economic life for projects and discount rates of 7% pa. (best estimate) and 11% and 4% pa (sensitivity analyses).

H8.3 Average Annual Damages

The average annual damages for all flood events up to the PMF are shown below in **Table H8.2**. Note that values have been quoted to two decimal places to highlight the relatively small recurring damages.

H8.4 Present Worth of Damages

The *Present Worth Value* of damages likely to be experienced for all flood events up to the 1% AEP and PMF, for a 50 year economic life and discount rates of 4, 7 and 11 per cent are shown in **Table H8.3**.

For a discount rate of 7% pa, the *Present Worth Value* of total damages for all Main Stream Flooding and Major Overland Flow flood events up to the 1% AEP flood at Molong is about $12.0 Million. Based on this finding, one or more schemes costing up to this amount could be economically justified if they eliminated damages at Molong for all flood events up to the 1% AEP event. While schemes costing more than this value would have a benefit/cost ratio less than 1, they may still be justified according to a multi-objective approach which considers other criteria in addition to economic feasibility.

In regards Molong Creek flooding in isolation, the *Present Worth Value* of total damages for all floods up to the 5% AEP flood is about $4.8 Million, increasing to $8 Million at the 1% AEP level of flooding. Based on this finding, one or more schemes costing up to these amounts could be economically justified if they eliminated damages resulting from floodwater that surcharges the banks of Molong Creek for all flood events up to the 5% and 1% AEP events, respectively.

TABLE H8.1
TOTAL FLOOD DAMAGES
$ MILLION

Design Flood Event (%AEP)	Main Stream Flooding and Major Overland Flow				Main Stream Flooding on Molong Creek Only			
	Residential	Commercial/ Industrial	Public	Total	Residential	Commercial/ Industrial	Public	Total
20	0.64	0.27	0.14	1.05	0.11	0.17	0.14	0.42
10	1.17	1.21	0.31	2.69	0.46	1.21	0.26	1.93
5	2.44	2.76	0.38	5.58	1.56	2.56	0.33	4.45
2	3.91	4.23	0.55	8.69	2.41	3.78	0.48	6.67
1	5.00	6.04	0.74	11.78	3.15	5.25	0.63	9.03
0.5	5.82	7.3	0.9	14.02	3.73	6.39	0.76	10.88
0.2	6.83	8.56	1.07	16.46	4.57	7.41	0.91	12.89
PMF	35.28	35.24	6.86	77.38	28.04	31.34	4.63	64.01

TABLE H8.2
AVERAGE ANNUAL DAMAGES
$ MILLION

Design Flood Event (%AEP)	Main Stream Flooding and Major Overland Flow				Main Stream Flooding on Molong Creek Only			
	Residential	Commercial/ Industrial	Public	Total	Residential	Commercial/ Industrial	Public	Total
20	0.1	0.04	0.02	0.16	0.02	0.03	0.02	0.07
10	0.19	0.11	0.04	0.34	0.04	0.09	0.04	0.17
5	0.28	0.21	0.06	0.55	0.1	0.19	0.06	0.35
2	0.37	0.32	0.08	0.77	0.15	0.28	0.07	0.5
1	0.42	0.37	0.08	0.87	0.18	0.33	0.07	0.58
0.5	0.44	0.4	0.09	0.93	0.2	0.36	0.08	0.64
0.2	0.46	0.43	0.09	0.98	0.21	0.38	0.08	0.67
PMF	0.51	0.47	0.1	1.08	0.24	0.42	0.08	0.74

TABLE H8.3
PRESENT WORTH VALUE OF DAMAGES
$ MILLION

Flooding Mechanism	Discount Rate (%)	Nominal Flood Level Case		
		All Floods up to 5% AEP	All Floods up to 1% AEP	All Floods up to PMF
Main Stream Flooding and Major Overland Flow	4	11.8	18.7	23.2
	7	7.6	12.0	14.9
	11	5.0	7.8	9.7
Main Stream Flooding on Molong Creek Only	4	7.5	12.5	15.9
	7	4.8	8.0	10.2
	11	3.2	5.2	6.7

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