YASS VALLEY COUNCIL

MURRUMBATEMAN, BOWNING, BOOKHAM AND BINALONG FLOOD STUDY

AUGUST 2020

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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:

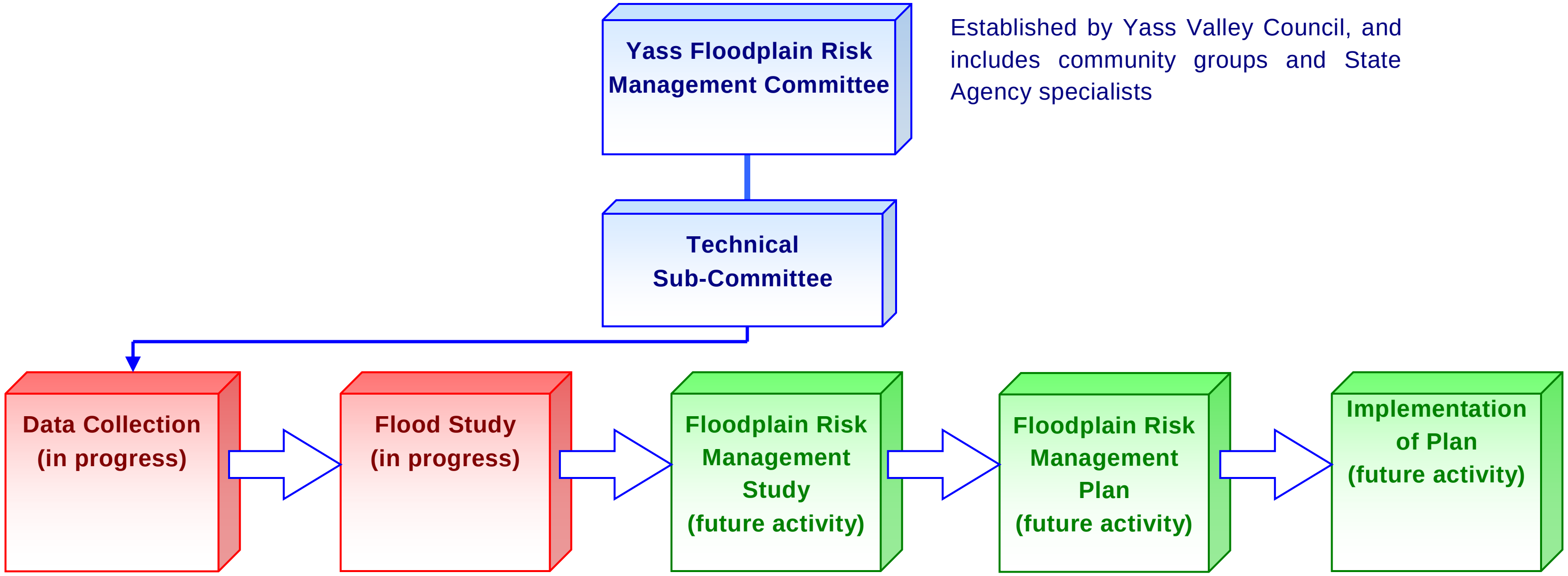
1.	Flood Study	Determines the nature and extent of flooding.
2.	Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed development.
3.	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the 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 Murrumbateman, Bowning, Bookham and Binalong Flood Study is jointly funded by Yass Valley Council and the NSW Government, via the Department of Planning, Industry and Environment. The Flood Study constitutes the first and second stage of the Floodplain Risk Management process (refer over) for this area and has been prepared for Yass Valley Council to define flood behaviour under current conditions.

ACKNOWLEDGEMENT

Yass Valley 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, Industry and Environment.

FLOODPLAIN RISK MANAGEMENT PROCESS



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

Involves detailed hydrologic and hydraulic modelling of the existing stormwater drainage system at Murrumbateman, Bowning, Bookham and Binalong.

The Floodplain 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 floodplain 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.

TABLE OF CONTENTS

Page No.

Cont'd Over

TABLE OF CONTENTS (Cont'd)

Page No.

APPENDICES

A. Community Newsletter and Questionnaire

B. Details of Available Data

C. Photographs Showing Historic Flood Behaviour in Murrumbateman and Binalong

D. Design Input Data from ARR Data Hub

E. Hydraulic Modelling of Design Floods at Murrumbateman (Bound in **Volume 2**)

F. Hydraulic Modelling of Design Floods at Bowning (Bound in **Volume 3**)

G. Hydraulic Modelling of Design Floods at Bookham (Bound in **Volume 3**)

H. Hydraulic Modelling of Design Floods at Binalong (Bound in **Volume 3**)

I. Design Peak Flows

J. Flood Damages

LIST OF MAIN REPORT FIGURES
(BOUND IN VOLUME 2)

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 a model 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 (Geoscience Australia, 2019)
AWS	All Weather Station
BoM	Bureau of Meteorology
DEM	Digital Elevation Model
DPIE	Department of Planning, Industry and Environment
DTM	Digital Terrain Model
EY	Exceedances per Year
FDM	Floodplain Development Manual (NSW Government, 2005)
FPL	Flood Planning Level
FPA	Flood Planning Area
FRMS&P	Floodplain Risk Management Study and Plan
GDSM	Generalised Short Duration Method
GS	Gauging Station
Council	Yass Valley Council
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 investigation.

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

SUMMARY

S.1 Study Objective

The study objective was to define the nature of both main stream flooding and major overland flow at the villages of Murrumbateman, Bowning, Bookham and Binalong for flood frequencies ranging between 20 and 0.2 per cent Annual Exceedance Probability (**AEP**), as well as for the Probable Maximum Flood (**PMF**).

The *Flood Study* is the source of present day flooding conditions and will be used as the basis for preparing the future *Floodplain Risk Management Study and Plan* (***FRMS&P***) which will assess options for flood mitigation and prepare a Plan of works and measures for managing the present and future flood risk in the four villages.

S.2 Background Information

The villages of Murrumbateman, Bowning, Bookham and Binalong lie within the headwaters of the Murrumbidgee River catchment and are located on the following major creek systems:

- McClungs Creek, Big Hill Creek and Gooda Creek at Murrumbateman.
- Bowning Creek at Bowning.
- Jugiong Creek and Bogolong Creek at Bookham.
- Balgalal Creek at Binalong.

The urbanised parts of the four villages are subject to main stream flooding as a result of floodwater which surcharges the above watercourses and their associated tributaries, as well as major overland flow which occurs as a result of local catchment runoff, as well as surcharges of the local stormwater drainage system during periods of heavy rain.

S.3 Study Method

The flood study involved the following activities:

- The forwarding of a *Community Newsletter and Questionnaire* to approximately 2090 residents and business owners at the four villages, 1140 of which reside in Murrumbateman, 230 in Bowning, 110 in Bookham and 610 in Binalong. The *Community Newsletter and Questionnaire*, a copy of which is contained in **Appendix A** of the report, introduced the study objectives and sought information on historic flood behaviour. Of those that responded, about one third noted that they had observed flooding in or adjacent to their property. Whilst one respondent provided information on flooding that occurred in "1998 or 1999", the majority of respondents identified more recent storm events that occurred on the following dates:
    - 22-23 September 2009
    - 13-15 February 2010
    - 27 February – 5 March 2012
    - 28 February – 1 March 2013
    - 17-18 September 2013
    - 25 January 2015
    - 4-6 June 2016
    - 20 June 2016
    - 22-23 July 2016
    - 31 August 2016
    - 21-22 September 2016

- The collection of flood data, details of which are set out in **Appendix B** of the report. Pluviographic rainfall data recorded by a series of Bureau of Meteorology operated rain gauges in the vicinity of the study catchments were obtained. A number of photographs were provided by respondents to the *Community Newsletter and Questionnaire* showing flood behaviour in Murrumbateman and Binalong, copies of which are contained in **Appendix C** of the report.
- The hydrologic modelling of the McClungs Creek and upper Big Hill Creek and Gooda Creek catchments at Murrumbateman, the Bowning Creek catchment at Bowning, the Jugiong Creek catchment at Bookham and the Balgalal Creek catchment at Binalong. The RAFTS sub-model in the DRAINS software was used to simulate the hydrologic response of the predominately rural parts of the study catchments, while the ILSAX sub-model in DRAINS was used to stimulate the hydrologic response of the urban parts of the four villages. The software generated discharge hydrographs resulting from historic and design storms.
- Application of the discharge hydrographs to hydraulic models comprising the main arms of the aforementioned creeks, their major tributaries and major overland flow paths. The TUFLOW two-dimensional modelling system was adopted for the hydraulic analysis.
- Presentation of study results as water surface profiles, as well 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.
- Sensitivity studies to assess the effects on model results resulting from variations in model parameters such as hydraulic roughness of the floodplain, the effects of a partial blockage of hydraulic structures, and the effects on flooding patterns resulting from future climate change.

After testing the models for the February 2010 and September 2016 storm 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) and applied to the hydrologic models to determine discharge hydrographs. The PMF was also modelled.

S.4 Design Flood Estimation

Figures 6.1 to **6.8** in **Appendices E**, **F**, **G** and **H** show the TUFLOW model results for the 20, 10, 5, 2, 1, 0.5 and 0.2 per cent AEP floods, together with the PMF at Murrumbateman, Bowning, Bookham and Binalong, respectively. These diagrams show the indicative extent and depth of inundation along the creeks and tributaries at the four villages, as well as along the major overland flow paths for the range of design flood events.

Water surface profiles along the major drainage lines at the four villages are shown on **Figure 6.9** in **Appendices E** to **H** for the modelled design floods events. **Figure 6.10** shows stage and discharge hydrographs at selected locations throughout the study areas, while **Table I1** in **Appendix I** sets out design peak flows and corresponding critical storm durations at the each location.

Flooding patterns derived by TUFLOW for the design storm events are described in **Chapter 6** of the report, with exhibits presented in **Volumes 2** and **3**.

S.5 Economic Impact of Flooding

At the 1% AEP level of flooding, 20 residential properties would be flood affected (i.e. floodwater on the allotment to a depth exceeding 100 mm) (13 at Murrumbateman, two at Bowning and five at Binalong), of which three would experience above-floor inundation (one each at Murrumbateman, Bowning and Binalong). No commercial/industrial and public buildings would experience above-floor inundation during a 1% AEP event. The total flood damages at the 1% AEP level of flooding are $0.23 Million at Murrumbateman, $0.16 Million at Binalong, $0.09 Million at Bowning and zero at Bookham.

The *"Present Worth Value"* of damages resulting from all floods up to the magnitude of the 1% AEP at Murrumbateman and Binalong are $0.04 Million and $0.02 Million, respectively. These values represent the amount of capital spending which would be justified if one or more flood mitigation schemes prevented flooding for all properties up to the 1% AEP event in the respective village.

The *Present Worth Value* of total damages at Bowning and Bookham for all flood events up to the 1% AEP flood is zero. As a result it is not possible to economically justify any works which are aimed at mitigating the impact of flooding on existing development up to the 1% AEP level in these two villages

Appendix J of the report contains further details on the economic impacts of flooding at the four villages.

S.6 Flood Hazard and Hydraulic Categorisation

Diagrams showing the flood hazard vulnerability classification for the 5, 1, and 0.2% AEP flood events, as well as the PMF are shown on **Figures 6.11**, **6.12**, **6.13** and **6.14** of **Appendices E** to **H**, respectively, while the hydraulic categorisation of the floodplain for the same four design flood events are shown on **Figures 6.15**, **6.16**, **6.17** and **6.18** of **Appendices E** to **H.**

The flood hazard vulnerability classification is dependent on the depth and velocity of flow in the channels and the floodplains. The floodplain has been divided into six hazard categories areas on the basis of these two variables based on the relationships set out in the publication entitled "*Managing the Floodplain: A Guide to Best practice in Flood Risk Management in Australia*" (Australian Institute for Disaster Resilience (**AIDR**), 2017).

The study found that at the 1% AEP level of flooding areas classified as either H5 or H6 are generally limited to the inbank areas of the major watercourses and local farm dams that are scattered through the study catchments, while the major overland flow paths which are located within urbanised areas are generally classified as either H1 or H2. The exception to the latter is in areas where floodwater ponds on the upstream side of road formations, where the resultant flooding is generally classified as either H3 or H4.

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 and are often aligned with naturally defined channels. 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.

As the hydraulic capacity of the creek channels is not large enough to convey the 1% AEP flow, a significant portion of the total flow in conveyed on the floodplain. As a result, areas which lie on the overbank area also function as a floodway during the 1% AEP flood event. Floodways are also generally present along the major overland flow paths, while flood storage areas are generally confined to the major ponding areas which are typically located on the upstream side of road formations and in local farm dams.

S.7 Flood Emergency Response Classification

Diagrams showing the flood emergency response for the 5, 1 and 0.2% AEP flood events, as well as the PMF based on the procedures set out in "*Managing the Floodplain: A Guide to Best practice in Flood Risk Management in Australia*" (Australian Institute for Disaster Resilience (**AIDR**), 2017) are presented on **Figures 6.19**, **6.20**, **6.21** and **6.22**, respectively of **Appendices E** to **H**. The flood emergency response classifications are based on whether or not the area is flooded during a PMF event, whether the area has an exit to flood-free land in a flood event and the consequence of flooding on the area.

S.8 Sensitivity Analyses

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

a. An increase in hydraulic roughness. **Figure 6.23** of **Appendices E** to **H** shows the effects a 20 per cent increase in the adopted 'best estimate' hydraulic roughness values would have on flooding behaviour at the 1% AEP level of flooding.

b. A partial blockage of major hydraulic structures by debris. **Figure 6.24** of **Appendices E** to **H** shows the effects a partial blockage of both bridges and major culvert structures would have on flooding behaviour at the 1% AEP level of flooding.

c. The approach to design flood estimation set out in the 1987 and 2019 editions of *Australian Rainfall and Runoff*. **Figures 6.25** and **6.26** of **Appendices E** to **H** show the difference in the extent and depth of inundation based on the two approaches for the 5% and 1% AEP flood events, respectively.

d. Increases in rainfall intensity associated with future climate change. **Figures 6.27**, **6.28** and **6.29** of **Appendices E** to **H** show the effects a 10 and 30 per cent increase in design 1% AEP rainfall intensities would have on flooding behaviour.

The sensitivity analyses identified that:

- peak 1% AEP flood levels could be increased by up to 500 mm as a result of changes in hydraulic roughness;
- increases in peak 1% AEP flood levels of generally up to 500 mm would occur should certain hydraulic structures experience a partial blockage by debris during a major storm event, with the exception of Bookham where increases of up to 1.5 m could occur;
- peak flood levels derived using the procedures set out in the 2019 edition of *Australian Rainfall and Runoff* are generally about 50-100 mm lower than those derived using the earlier edition of the document; 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.

S.9 Interim Flood Planning Area and Levels

The Flood Planning Area (**FPA**) and Flood Planning Levels *(***FPLs***)* for main stream flooding at the four villages are shown on **Figure 6.30** of **Appendices E** to **H**. The FPA represents the area which will be subject to flood related development controls for main stream flooding and comprises the area lying within the extent of the 1% AEP flood plus an allowance of 500 mm for freeboard. Also shown on **Figure 6.30** are the individual allotments that are inundated by major overland flow to depths greater than 150 mm (refer yellow hatched allotments which have been denoted “Flood Control Lots”).

Consideration will need to be given during the preparation of the future *FRMS&P* to the appropriateness of the adopted freeboard allowance of 500 mm for main stream flooding given the impact changes in hydraulic roughness and future increases in rainfall intensity could have on peak flood levels, especially in the case of Bookham. 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 500 mm may be found to be too conservative. The adoption of an allotment based approach to the identification of individual properties subject to major overland flow related planning controls should also be considered.

In allotments that lie outside the extent of the FPA for main stream flooding where the depth of overland flow is greater than 150 mm (refer blue shaded area on **Figure 6.30**) it is recommended that a freeboard of 300 mm be applied to peak 1% AEP flood levels when setting the minimum floor level 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 overland flow through the subject site.

1 INTRODUCTION

1.1 Study Background

This report presents the findings of an investigation of flooding at the villages of Murrumbateman, Bowning, Bookham and Binalong in the Yass Valley 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, Industry and Environment (**DPIE**). **Figure 1.1** shows the extent of the study catchment at each of the four villages.

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 catchments, and application of these flows to a hydraulic model to assess peak water levels and flow velocities. The model results were interpreted to present a detailed picture of flooding under present day conditions.

The scope of the study included investigation of main stream flood behaviour along McClungs Creek, Big Hill Creek and Gooda Creek at Murrumbateman, Bowning Creek at Bowning, Jugiong Creek and its associated tributaries at Bookham and the Balgalal Creek and its associated tributaries at Binalong. The scope of the study also included the investigation of major overland flow which occurs during periods of heavy rain.

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

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 November 2018 to residents and business owners in the four villages. A copy of the *Community Newsletter and Questionnaire* which was prepared by the Consultants is attached in **Appendix A** of this report.

Council advised that approximately 2090 *Community Newsletters and Questionnaires* were distributed to the residents and business owners in the four villages, 1140 of which reside in Murrumbateman, 230 in Bowning, 110 in Bookham and 610 in Binalong. A total of 48 responses were received by the closing date of submissions (a response rate of about 2 per cent), 29 from residents or business owners of Murrumbateman, five from Bowning, zero from Bookham and 14 from Binalong.

Of those that responded, about one third noted that they had observed flooding in or adjacent to their property. Whilst one respondent provided information on flooding that occurred in the 1998 or 1999, the majority of respondents identified more recent storm events that occurred on the following dates:

- 22-23 September 2009
- 13-15 February 2010
- 27 February – 5 March 2012
- 28 February – 1 March 2013
- 17-18 September 2013
- 25 January 2015
- 4-6 June 2016
- 20 June 2016
- 22-23 July 2016
- 31 August 2016
- 21-22 September 2016

A community forum was also held in Yass on the evening of 17 October 2019, during which time additional information on the September 2016 storm event at Murrumbateman was made available to the consultants.

Information on historic flooding patterns obtained from the responses assisted with "ground-truthing" the results of the hydraulic modelling.

Appendix B contains details of the data that were available for the present study, while **Appendix C** contains several photos which show historic flood behaviour in Murrumbateman during storms that occurred on 14 February 2010, 18 June 2016 and 21 September 2016, and in Binalong during storms that occurred on 14 February 2010, 24 January 2015, 31 August 2016 and 21 September 2016.

The draft Flood Study was placed on public exhibition over a four week period commencing 28 June 2020. Due to the COVID-19 situation in NSW, no public workshops were held during the public exhibition period. Rather a short pre-recorded Powerpoint presentation was posted on Council's web site which set out the aims and objectives of the study, as well as its key findings. No submissions were received by the closing date of submissions.

1.3 Previous Investigations

The following flooding investigations have been undertaken in the Yass Valley Council Local Government Area:

- *Yass Flood Study* (WMAwater (**WMA**), 2016a)
- *Sutton Flood Study* (WMA, 2016b)
- *Gundaroo Flood Study* (WMA, 2016c)
- *Sutton Floodplain Risk Management Study and Plan* (WMA, 2016d)
- *Gundaroo Floodplain Risk Management Study and Plan* (WMA, 2016e)
- *MR15 Barton Highway Duplication, Hall to Yass – Flood Impact Assessment Report* (J. Wyndham Prince, 2018)

1.4 Layout of Report

Chapter 2 contains background information including a brief description of the study catchments and their drainage systems, details of previous investigations, a brief history of flooding at the four villages and an analysis of the available rain gauge record.

Chapter 3 deals with the hydrology of the study catchments and describes the development and calibration of the hydrologic models that were used to generate discharge hydrographs for input to the hydraulic model.

Chapter 4 deals with the development and calibration of the TUFLOW hydraulic models which was used to analyse flood behaviour at the four villages.

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 four villages. Results are presented as water surface profiles and plans showing indicative extents and depths of inundation for a range of design flood events up to the PMF. A summary of the economic impacts of flooding to existing development in the four village is presented in the chapter, along with a provisional assessment of flood hazard and hydraulic categorisation. (The assessment of flood hazard according to velocity and depth of floodwaters is necessarily *"provisional"*, pending a more detailed assessment which includes other flood related criteria, to be undertaken during the preparation of the future *FRMS&P*.)

Chapter 6 also details the results of various sensitivity studies undertaken using the TUFLOW model are also presented, 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 flooding behaviour. This chapter also deals with the selection of *Interim Flood Planning Levels* for the four villages.

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 Questionnaires* that were distributed at the commencement of the study to residents and business owners in the four villages.
- **Appendix B**, which contains a list of data that were available for the present study.
- **Appendix C** contains photographs showing flood behaviour in Murrumbateman during storms that occurred on 14 February 2010, 18 June 2016 and 21 September 2016, and in Binalong during storms that occurred on 14 February 2010, 24 January 2015, 31 August 2016 and 21 September 2016.
- **Appendix D** contains a copy of the design input data that were extracted from the Australian Rainfall and Runoff (**ARR**) Data Hub for the four villages.
- **Appendix E** (bound is **Volume 2**) and Appendices **F**, **G** and **H** (bound in **Volume 3**), respectively contain figures showing flooding patterns at Murrumbateman, Bowning, Bookham and Binalong for the full range of design flood events.
- **Appendix I** contains a table showing the peak flows taken from the TUFLOW model for both historic and design storm events.
- **Appendix J** contains an assessment of the economic impacts of flooding to existing residential, commercial and industrial development, as well as public buildings in the four villages.

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

2 BACKGROUND INFORMATION

2.1 Catchment Description

2.1.1. General

Figure 1.1 shows that the villages of Murrumbateman, Bowning, Bookham and Binalong lie within the headwaters of the Murrumbidgee River catchment, while **Figure 2.1** shows the layout of the following major creek and river systems in the vicinity of the four villages, as well as the extent of their contributing catchments:

- McClungs Creek, which drains the northern portion of Murrumbateman and joins Murrumbateman Creek immediately north of the village, before discharging to the Yass River about 15 km upstream of Yass.
- Big Hill Creek and Gooda Creek, both of which drain the southern portion of Murrumbateman and the latter which discharges to the Murrumbidgee River about 13 km upstream of Burrinjuck Dam.
- Bowning Creek, which drains in a southerly direction through Bowning where it discharges to the Yass River about 8 km upstream of Burrinjuck Dam.
- Bogolong Creek, which drains in a westerly direction to the north of Bookham and discharges where it discharges to Jugiong Creek.
- Balgalal Creek, which drains in a southerly direction through Binalong where it discharges to Jugiong Creek about 21 km downstream of its confluence with Bogolong Creek.
- Jugiong Creek, which drains to the west of Bookham and discharges to the Murrumbidgee River about 50 km downstream of its confluence with Balgalal Creek.

The following sections provides a brief description of each village and their drainage system.

2.1.2. Murrumbateman

The village of Murrumbateman has a population of about 1,730 people and is located on the catchment divide between the Yass River and the upper Murrumbidgee River. **Figure 2.2**, sheet 1 shows the extent of the 37 km^2 McClungs Creek catchment which drains in a northerly direction to Murrumbateman Creek. **Figure 2.2**, sheet 1 also shows the extent of the 10 km^2 and 12 km^2 catchments draining to Big Hill Creek and Gooda Creek in the vicinity of the village.

The portion of the McClungs Creek catchment that is located to the east of McIntosh Circuit drains to an unnamed watercourse that runs in a northerly direction on the eastern side of the Barton Highway (herein referred to as the **Unnamed Tributary**). The Unnamed Tributary joins McClungs Creek immediately upstream of its confluence with Murrumbateman Creek.

The topography at Murrumbateman is generally undulating in nature with several minor gullys discharging to the abovementioned creeks as shown on **Figure 2.2**. There are a large number of local farm dams along the minor gullys throughout the catchments.

The study catchments generally comprise rural pastoral land and large lot/low density residential allotments. The more highly urbanised part of the village is located in the area bounded by McClung Drive to the north, the Barton Highway to the east, South Street to the south and existing development and Keith Street to the west (herein denoted the **Village Centre**). There is a small pocket of commercial development located along Hercules Street in the vicinity of its intersection with the Barton Highway.

Figure 2.2 (sheets 2 to 8) show the layout of the existing stormwater drainage system at Murrumbateman. While the stormwater drainage system generally comprises roadside table drains with piped crossings at road intersections, there are two piped drainage lines that run through the Village Centre (refer sheet 4): one which controls runoff from the recently constructed Fairley Village and the other which drains the southern part of the Village Centre. The two piped drainage lines discharge to Unnamed Tributary on the eastern side of the Barton Highway.

Figure 2.2, sheet 3 shows the location of two existing detention basins, details of which are given in **Table 2.1**. The two basins are aimed at mitigating the impact that the subdivision of land for rural residential purposes would have otherwise had on flow in the receiving drainage lines.

TABLE 2.1
DETAILS OF EXISTING REGIONAL FLOOD DETENTION BASINS AT MURRUMBATEMAN

Basin ID	Basin Name	Year of Construction	Outlet Structure(2)		Spillway Elevation (m AHD)
			Dimensions (mm)	Invert Level (m AHD)	
B01	Carrington Park Detention Basin	2011	4 off 525 RCPs	587.98	590.50
B02	Merryville Estate Dam No. 1	1994	6 off 900 x 600 RCBCs	586.82	587.90

1. RCP = reinforced concrete pipe, RCBC = reinforced concrete box culvert.
2. Refer **Figure 2.2**, sheet 3 for location.

2.1.3. Bowning

The village of Bowning has a population of about 280 people and is centred on Bowning Creek. The village is bounded by the Main Southern Railway to the north, the Hume Highway to the south and rural land to its east and west. **Figure 2.3** (2 sheets) shows the extent of the 20.8 km^2 catchment which contributes to flow in Bowning Creek at Bowning Road. **Figure 2.3** also shows the extent of the 2.8 km^2 catchment which contributes to flow in a watercourse that runs in a westerly direction through the town (herein denoted the **Bowning Tributary**) and discharges to Bowning Creek immediately upstream of Bowning Road.

The headwaters of the Bowning Creek catchment are located about 7 km to the north of the village. The catchment is characterised by undulating pastoral land. Several minor gullys discharge to Bowning Creek in the vicinity of the village as shown on **Figure 2.3** (sheet 2).

Figure 2.3, sheet 2 shows the layout of the existing stormwater drainage system at Bowning. The stormwater drainage system generally comprises roadside table drains with piped crossings at road intersections. There are three major crossings of Bowning Creek: the Main Southern Railway bridge crossing, the low level Bowning Road bridge crossing and the dual Hume Highway Bridges. There is one bridge crossing of Bowning Tributary at Leake Street, the upgrade of which was recently completed by Council.

2.1.4. Bookham

The village of Bookham has a population of about 160 people and is located on the southern side of the Hume Highway about 25 km to the west of Yass. **Figure 2.4**, sheet 1 shows that Bookham is bounded by Jugiong Creek to its west, Bogolong Creek to its north and existing rural land to its east and west. Jugiong Creek, which drains in a northerly direction at Bookham has a catchment area of about 85.8 km^2 km at its confluence with Bogolong Creek, which drains in a westerly direction and has a total catchment area of about 79.9 km^2 at the same location.

Figure 2.4, sheet 2 shows the layout of the existing stormwater drainage system at Bookham. The stormwater drainage system generally comprises roadside table drains with piped crossings at road intersections. There is one major crossing of Bogolong Creek at Illalong Road. The Hume Highway bisects the study area in an east-west direction and spans the natural low points in the floodplain causing local catchment runoff from the catchments that are located to its south to pond on its upstream (southern) side. There are a series of pipe culverts through the highway embankment that discharge local catchment runoff to Bogolong Creek.

2.1.5. Binalong

The village of Binalong, which has a population of about 330 people, is located on the southern (left) bank of Balgalal Creek. **Figure 2.5** (4 sheets) shows that Balgalal Creek generally runs in a southerly direction and has a catchment area of about 39.7 km^2 at Armours Road. The creek then flows in a westerly direction through the village to a location about 0.5 km downstream of Burley Griffin Way where it joins Bobbara Gully and continues in a southerly direction, discharging to Jugiong Creek a further 13 km to the south. Bobbara Gully has a total catchment area of 4.8 km^2 at its confluence with Balgalal Creek.

Figure 2.5 shows the extent of a 2.7 km^2 catchment that contributes to flow in a watercourse that runs in a northerly direction through the village (herein denoted the **Balgalal Tributary**) and discharges to Balgalal Creek west of Fitzroy Street. Several other minor gullys discharge to Balgalal Creek in the vicinity of the village.

The urbanised part of Binalong are located in the area bounded by Manning Street to the west, Balgalal Creek to the north, the Main Southern Railway to the east and the Mylora Street road reserve to the south. There is a small pocket of commercial development located in the vicinity of the intersection of Fitzroy Street and Queen Street.

Figure 2.5, sheets 2, 3 and 4 show the layout of the existing stormwater drainage system at Binalong. The stormwater drainage system generally comprises roadside table drains with piped crossings at road intersections. There are two major crossings of Balgalal Creek in the study area: a low-level crossing at Armours Road and an elevated road crossing that spans the 350 m wide floodplain at Burley Griffin Way.

2.2 Flood History and Analysis of Historic Rainfall

2.2.1. General

Respondents to the *Community Newsletter and Questionnaire* identified a number of notably intense storm events that have been experienced at Murrumbateman and Binalong, the dates of which are given in **Section 1.2** of the report. No information was provided about historic flooding patterns at Bowning and Bookham. 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.

Figure 2.6 (4 sheets) shows design versus historic intensity-frequency-duration (**IFD**) curves for seven nearby Bureau of Meteorology (**BoM**) operated All Weather Station (**AWS**) rain gauges for the abovementioned bursts of rainfall, while **Table 2.2** at the end of this chapter gives the approximate AEP of the recorded rainfall for durations ranging between 1 and 12 hours. **Figure 1.1** shows that the BoM operated pluviographic rainfall gauges lie between 40 and 150 km from Murrumbateman and between 60 and 100 km from Binalong.

Figure 2.6 and **Table 2.2** show that the majority of the storms identified by the respondents to the *Community Questionnaire* were less intense than a storm that occurs once every year on average (i.e. less than 1 Exceedance per Year (**EY**)), with the exception of the 27 February – 5 March 2012 and 4 – 6 June 2016 storm which were equivalent to a design storm event with an AEP of about 5 per cent.

Based on the availability of historic flood data, the storm events that occurred on 14 February 2010 and 21 September 2016 were selected for use in calibrating the hydrologic and hydraulic models that were developed as part of the present study. **Figure 2.7** shows the cumulative rainfall that was recorded at the nearby rain gauges for these two events, while **Table 2.3** and **2.4** at the end of this chapter show a comparison of the recorded daily rainfall depths at Murrumbateman and Binalong, respectively, and those recorded at the BoM operated pluviographic rainfall gauges that were in operations at the time of the event.

2.2.2. February 2010 Storm Event

<u>Murrumbateman</u>

Based on photographic evidence provided by respondents to the *Community Questionnaire*, flooding occurred at Murrumbateman between 12:30 and 15:00 hours on 14 February 2010. **Plates C2.1** to **C2.8** in **Appendix C** show overland flow through the rear of a number of properties that are located in Broughton Close in the Ambleside Estate.

Table 2.3 shows that the recorded rainfall depths at the Murrumbateman (McIntosh Circuit) gauge (about 95.0 mm) are similar to that which fell at the Canberra Airport AWS (about 99.0 mm) which is located about 40 km south of Murrumbateman. **Table 2.2** and **Figure 2.6**, sheet 1 show that this event was less intense than a storm that occurs once every year on average (i.e. less than 1 EY).

Based on the rainfall recorded at the Canberra Airport AWS, flooding occurred after 58.2 mm of rain fell between 09:00 hours on 13 February 2010 and 09:00 hours on 14 February 2010, in addition to a further 33.4 mm which fell between 09:00 and 15:00 hours on 14 February 2010.

One respondent to the *Community Questionnaire* noted that the flooding occurred after 164 mm of rain had fallen,[1] which is about 1.7 times that which was recorded at the nearby rain gauges.

<u>Binalong</u>

Table 2.4 shows that the recorded rainfall depths at Binalong are similar to that which fell at the Canberra Airport AWS which is located about 88 km south-east of Binalong. **Table 2.2** and **Figure 2.6**, sheet 1 show that based on the rainfall recorded at the Canberra Airport AWS, this event was less intense than a storm that occurs once every year on average (i.e. less than 1 EY).

Plates C1.1 and **C1.2** in **Appendix C** show that the Balgalal Tributary was running full on the upstream side of Monteagle Street at about 11:00 hours on 14 February 2010, while **Figure 2.7** shows that the flooding occurred following significant rainfall over the preceding 36 hours.

[1] The respondent did not provide any information regarding the period over time over which the rain fell.

2.2.3. September 2016 Storm Event

Murrumbateman

Photographic evidence provided by respondents the *Community Questionnaire* showed that flooding on 21 September 2016 occurred in the eastern parts of Murrumbateman at around 13:00 hours in the vicinity of the Ambleside Estate. Anecdotal and video evidence provided by residents at the community forum indicated that the flood peak occurred at about 07:30 hours in the western parts of Murrumbateman in the vicinity of the McClungs Creek crossing of Merryville Drive.

Plates C7.1 and **C7.2** in **Appendix C** show the presence of major overland flow in the Dundoos and Ambleside Estates to the north-east of the intersection of Murrumbateman Road and Elrington Close, while **Plate C7.3** shows that the culverts under Murrumbateman Road were half full at the time of the photography.

Table 2.3 shows that the recorded rainfall depths at Murrumbateman are similar to that which fell at the Canberra Airport AWS which is located about 40 km south of Murrumbateman. **Table 2.2** and **Figure 2.6**, sheet 1 show that this event was less intense than a storm that occurs once every year on average (i.e. less than 1 EY).

Figure 2.7 shows that based on the rainfall recorded at the Canberra Airport AWS, the flooding occurred as a result of rain which commenced to fall at 06:00 hours on 21 September 2016.

Binalong

Plates B6.2 to **C6.3** in **Appendix C** show that the banks of Balgalal Creek was overtopping at the northern end of Stephens Street at about 15:00 hours on 21 September 2016. Residents of Binalong provided anecdotal evidence that floodwater from Balgalal Creek inundated the rear of residential properties that are located on the northern side of Queen Street. They also indicated that floodwater inundated the Burley Griffin Way crossing of Balgalal Creek, resulting in its temporarily closure by the local New South Wales State Emergency Service (**NSW SES**) unit.

Table 2.4 shows that the recorded rainfall depths at Binalong are similar to that which fell at the Canberra Airport AWS which is located about 59 km north-west of Binalong. **Table 2.2** and **Figure 2.6**, sheet 3 show that this event was less intense than a storm that occurs once every year on average (i.e. less than 1 EY).

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

Storm Event	Rain Gauge(2)	Storm Duration (hours)					
		1	2	3	6	9	12
22-23 September 2009	Canberra Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Mount Ginini AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Tuggeranong (Isabella Plains) AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
13-15 February 2010	Canberra Airport	<1 EY	<1 EY	<1 EY	1 EY	50	20-50
	Mount Ginini AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Tuggeranong (Isabella Plains) AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
27 February - 5 March 2012	Canberra Airport	<1 EY	<1 EY	<1 EY	50	20	20
	Goulburn Airport AWS	<1 EY	<1 EY	<1 EY	1 EY	50	20
	Mount Ginini AWS	<1 EY	50	50	20	20	10
	Temora Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Tuggeranong (Isabella Plains) AWS	50	50	1 EY	20	20	10
	Young Airport	50	10	5	5	5	5
	Burrinjuck Dam	50	20	20	5	5	5
28 February - 1 March 2013	Canberra Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Goulburn Airport AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Mount Ginini AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Temora Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Tuggeranong (Isabella Plains) AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Young Airport	1 EY	50	50	50	50	20

Refer over for footnote to table

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

Storm Event	Rain Gauge[2]	Storm Duration (hours)					
		1	2	3	6	9	12
17-18 September 2013	Canberra Airport	<1 EY	<1 EY	<1 EY	50	50	50
	Goulburn Airport AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Mount Ginini AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	1 EY
	Temora Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Tuggeranong (Isabella Plains) AWS	<1 EY	<1 EY	<1 EY	50	50	20
	Young Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
25 January 2015	Canberra Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Goulburn Airport AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Mount Ginini AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Temora Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Tuggeranong (Isabella Plains) AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Young Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
4-6 June 2016	Canberra Airport	<1 EY	<1 EY	<1 EY	50	20	10
	Goulburn Airport AWS	<1 EY	1 EY	50	20	10	10
	Mount Ginini AWS	<1 EY	<1 EY	50	20	20	20
	Temora Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Tuggeranong (Isabella Plains) AWS	<1 EY	1 EY	50	20	10	5
	Young Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY

Refer over for footnote to table

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

Storm Event	Rain Gauge[2]	Storm Duration (hours)					
		1	2	3	6	9	12
17-18 June 2016	Canberra Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Goulburn Airport AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Mount Ginini AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Temora Airport	<1 EY	<1 EY	1 EY	1 EY	<1 EY	<1 EY
	Tuggeranong (Isabella Plains) AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Young Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
22-23 July 2016	Canberra Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Goulburn Airport AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Mount Ginini AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Temora Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Tuggeranong (Isabella Plains) AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Young Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
21-22 September 2016	Canberra Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Goulburn Airport AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Mount Ginini AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Temora Airport	<1 EY	<1 EY	<1 EY	<1 EY	50	50
	Tuggeranong (Isabella Plains) AWS	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY
	Young Airport	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY	<1 EY

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

TABLE 2.3
RECORDED DAILY RAINFALL TOTALS RELEVANT TO MURRUMBATEMAN
FOR HISTORIC STORM EVENTS

Historic Storm	Rainday	Daily Rainfall Total(1,2) (mm)						
		Murrumbateman (McIntosh Circuit) (GS 70344) [0 km]	Canberra Airport (GS 70351) [40 km]	Goulburn Airport AWS (70330) [65 km]	Mount Ginini AWS (GS 70349) [68 km]	Temora Airport (GS 73151) [150 km]	Tuggeranong (Isabella Plains) (GS 70339) [49 km]	Young Airport (GS 73138) [108 km]
February 2010	13	3.4	12	Not in operation	1	Not in operation	20.2	Not in operation
	14	58.2	54.6		28.4		23	
	15	33.4	32.4		21.4		26.4	
September 2016	21	12.8	6.8	4	6	28.4	6.6	17.8
	22	24	24.2	19.4	13.8	32.8	20.2	30.6

1. Number in [ ] indicates the distance between the gauge and Murrumbateman.
2. Refer **Figure 1.1** for gauge location.

TABLE 2.4
RECORDED DAILY RAINFALL TOTALS RELEVANT TO BINALONG
FOR HISTORIC STORM EVENTS

<table>
<tr><th rowspan="2">Historic Storm</th><th rowspan="2">Rainday</th><th colspan="8">Daily Rainfall Total[1,2]
(mm)</th></tr>
<tr><th>Binalong Post Office (GS 73005)
[0 km]</th><th>Kangiara (Laverstock) (GS 73023)
[16 km]</th><th>Canberra Airport (GS 70351)
[88 km]</th><th>Goulburn Airport AWS (GS 70330)
[101 km]</th><th>Mount Ginini AWS (GS 70349)
[97 km]</th><th>Temora Airport (GS 73151)
[106 km]</th><th>Tuggeranong (Isabella Plains) (GS 70339)
[93 km]</th><th>Young Airport (GS 73138)
[59 km]</th></tr>
<tr><td rowspan="3">February 2010</td><td>13</td><td>0</td><td>0.4</td><td>12</td><td rowspan="3">Not in operation</td><td>1</td><td rowspan="3">Not in operation</td><td>20.2</td><td rowspan="3">Not in operation</td></tr>
<tr><td>14</td><td rowspan="2">81[3]</td><td>67</td><td>54.6</td><td>28.4</td><td>23</td></tr>
<tr><td>15</td><td>Not in operation</td><td>32.4</td><td>21.4</td><td>26.4</td></tr>
<tr><td rowspan="2">September 2016</td><td>21</td><td rowspan="2">Not in operation</td><td>7.8</td><td>6.8</td><td>4</td><td>6</td><td>28.4</td><td>6.6</td><td>17.8</td></tr>
<tr><td>22</td><td>32.2</td><td>24.2</td><td>19.4</td><td>13.8</td><td>32.8</td><td>20.2</td><td>30.6</td></tr>
</table>

1. Number in [ ] indicates the distance between the gauge and Binalong.
2. Refer **Figure 1.1** for gauge location.
3. Two-day rainfall total over 14-15 February 2010.

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 ILSAX, RAFTS, RORB and WBNM. Whilst there is little to choose technically between these models, ILSAX has 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 ILSAX 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 in the study catchments. The discharge hydrographs generated by ILSAX and RAFTS 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

Figures 3.1, **3.2**, **3.3** and **3.4** show the layout of the hydrologic models that were developed for the Murrumbateman (**Murrumbateman Hydrologic Model**), Bowning (**Bowning Hydrologic Model**), Bookham (**Bookham Hydrologic Model**) and Binalong (**Binalong Hydrologic Model**) catchments, respectively.

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 generally not incorporated in the model. However, the outlets of the sub-catchments in the upper reaches of the study catchments at Bowning, Bookham and Binalong were linked and the lag times between each assumed to be equal to the distance along the main drainage line divided by an assumed flow velocity of 2 m/s. A small number of sub-catchments in the headwaters of the Unnamed Tributary and Gooda Creek catchments at Murrumbateman were also linked assuming a flow velocity of 0.5 m/s. Both assumed flow velocities were derived from preliminary runs of the TUFLOW model.

Careful consideration was given to the definition of the sub-catchments which comprise the hydrologic models to ensure peak flows throughout the drainage system would be properly routed through the TUFLOW model. In addition to using the 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.

Percentages of impervious area were assessed using Council's aerial photography and cadastral boundary data. Sub-catchment slopes used for input to the hydrologic models were derived using the vectored average slope approach for the relatively large sub-catchments that exist in the headwaters of the study catchments, whilst the average sub-catchment slope computed via a region inspection in the QGIS software was used for all remaining catchments of the hydrologic models. Digital Elevation Models (**DEMs**) derived from the available Light Detecting and Ranging (**LiDAR**) survey data were used as the basis for computing the slope for both methods.

3.3 Hydrologic Model Testing

3.3.1. General

Historic flood data suitable for use in the model calibration process is limited to photographic and anecdotal evidence of flooding patterns at Murrumbateman and Binalong for the storms that occurred in February 2010 and September 2016. As discussed in **Section 2.2**, the storm events for which flood data were available are generally equivalent to a 1 EY design storm event. There is no historic flood data available at Bowning and Bookham.

As there were no historic data on storm flows anywhere in the four villages, the procedure adopted for the calibration of the hydrologic models 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.

Several iterations of this process were required, whereby changes were made to the rainfall multipliers and 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. Hydrologic Model Parameters

A Manning’s n value of 0.04 was applied to the typically rural sub-catchments which are located in the headwaters of the study catchments and were modelled using the RAFTS sub-model. The initial and continuing loss rates, as well as the Bx factors that were used to derive discharge hydrographs which, when applied to the TUFLOW model, gave a good match with the historic flood data are set out in **Table 3.1** over.

The ILSAX hydrologic model requires information on the soil type and losses to be applied to storm rainfall to determine the depth of excess rainfall. Infiltration losses are of two types: 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. ILSAX also requires information on flow path characteristics in order to compute the time of travel of the flood wave through the sub-catchments.

The following ILSAX model parameters were found to give a good fit to historic flood data:

Soil and Rainfall Loss Parameters

- Soil Type = 3.0
- AMC = 3.0
- Paved area depression storage = 2.0 mm
- Grassed area depression storage = 10.0 mm

Travel Time Parameters

- Paved flow path roughness = 0.02
- Grassed flow path roughness = 0.07

TABLE 3.1
ADOPTED RAFTS MODEL PARAMETERS
HISTORIC STORM EVENTS

Historic Storm Event	Village	Pluviographic Rainfall Station		Rainfall Depth at Village			Adopted Rainfall Multiplier	Initial Loss (mm)		Continuing Loss (mm/hr)		Bx Factor
		Location	Rainfall Total[4] (mm)	Source	Rainfall Total (mm)	Rainfall Multiplier		Impervious Area	Pervious Area	Impervious Area	Pervious Area	
February 2010	Murrumbateman	Canberra Airport AWS	99.0	Resident (Respondent Y37)	168.0	1.7	1.7	2	15	0	1.5	0.8
	Binalong	Canberra Airport AWS	87.0	Binalong Post Office	81.0	0.9	0.9	2	15	0	4	0.8
September 2016	Murrumbateman	Canberra Airport AWS	31.0	Murrumbateman (McIntosh Circuit)	36.8	1.2[1]	1.7[1]	2	0	0	1.5	0.8
	Binalong	Young Airport AWS	48.4	Binalong Post Office	N/A[2]	N/A	2[3]	2	0	0	1.7	0.8

1. It was not possible to achieve a good match between the observed and modelled flood behaviour using a multiple of 1.2.
2. The BoM operated Binalong Post Office was not operational during the September 2016 storm event.
3. A rainfall multiplier of two was required in order to achieve a match between the observed and modelled flood behaviour.
4. Refer **Table 2.3** for the depth of rain which fell on consecutive rain days.

3.3.3. Application of Historic Rainfall to the Hydrologic Model

Continuous rainfall recorded at the two BoM operated AWS rain gauges set out in **Table 3.1** were used as input to the Murrumbateman and Binalong Hydrologic Models. **Table 3.1** also sets out the rainfall multipliers that needed to be applied to the rainfall recorded at the nearby AWS gauges in order to achieve a good match with the photographic and anecdotal evidence of flooding patterns.

While it was possible to achieve a good match between observed and modelled flooding patterns at Murrumbateman for the February 2010 storm event using a continuing loss value of 1.5 mm/hr, a higher value of 4.0 mm/hr was required to obtain a reasonable match with the observed flooding patterns at Binalong.

Initial loss values of zero were required in order to obtain a good match with observed flooding patterns for the September 2016 storm event at Murrumbateman and Binalong. Based on the information provided by respondents to the *Community Questionnaire*, the storm event occurred following a particularly wet three month period which would have resulted in a saturated catchment at the time of the burst. While initial losses of zero are lower than those typically expected in NSW, it was not possible to replicate the observed flooding patterns for the September 2016 storm event using the initial loss values for pervious areas similar to those that provided a good match for the February 2010 storm event (i.e. 15 mm).

While **Table 2.3** shows that the total rainfall depth recorded on the raindays of 21-22 September 2016 at Murrumbateman (36.8 mm) was similar to that recorded at Canberra Airport AWS (31.0 mm), the Canberra Airport AWS rainfall needed to be factored up by a multiple of 1.7 in order to obtain a good match between the observed and modelled flooding patterns. It is possible that the temporal distribution of rainfall across the two raindays at Canberra Airport AWS is not representative of that which fell at Murrumbateman, with the likelihood being that the rain fell over a shorter period, thereby generating higher flows in the drainage system.

As shown in **Table 2.4**, the Binalong Post Office daily rainfall gauge was not in operation at the time of the September 2016 storm event. While the total two-day rainfall depth at the Kangiara (Laverstock) rain gauge (40.0 mm), which is the closest operational rain gauge to Binalong during the event, was comparable to that recorded 59 km away at the Young Airport AWS (48.4 mm), **Table 3.1** shows that the Young Airport AWS rainfall needed to be factored up by a multiple of 2.0 in order to obtain a good match between the observed and modelled flooding patterns. Again, the need to apply a multiplication factor to the recorded rainfall in order to achieve a reasonable fit with the recorded data likely lies in differences in its temporal variability between the village and the gauge site.

3.3.4. Results of Model Testing

The discharge hydrographs generated by the hydrologic models, when applied to the TUFLOW hydraulic model, gave reasonable correspondence with observed flood behaviour. The ILSAX 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 creeks and the two-dimensional nature of flow on both the floodplain and in the steeper parts of the four villages 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 models that were then used to define the behaviour of both main stream flooding and major overland flow in the four villages 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 models 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

The layout of the TUFLOW models that were developed for Murrumbateman (**Murrumbateman TUFLOW Model**), Bowning (**Bowning TUFLOW Model**), Bookham (**Bookham TUFLOW Model**) and Binalong (**Binalong TUFLOW Model**) are shown on **Figures 4.1**, **4.2**, **4.3** and **4.4**, respectively. Within the “urbanised” areas of each village, the model comprises the pit and pipe drainage system, while the inbank, out-of-bank and shallow “overland” flow areas are modelled by the rectangular grid.

The following sections provide further details of the model development.

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 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 each village.

Ridge and gully lines were added to the TUFLOW model where the grid spacing was considered 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 LiDAR survey or site-based measurements.

Gully lines were also used to represent the major creeks and watercourses in the four villages. 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 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 four villages. 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 Property Solutions were used as the primary source of details of the piped drainage system which were incorporated into the TUFLOW models. These data were supplemented with detailed design drawings and field measurements (refer **Appendix B** for more detail). **Table 4.1** over the page summarises the pit and pipe data that were incorporated into the TUFLOW models.

Several types of pits are identified on **Figures 4.1** to **4.4** including junction pits which have a closed lid and inlet pits which are capable of accepting overland flow. Council's asset database contained reasonably detailed information in regard to inlet pit types and dimensions, however, when information was missing, inlet pit capacity relationships were incorporated in the TUFLOW models based on a visual inspection of the existing stormwater drainage system.

TABLE 4.1
SUMMARY OF MODELLED DRAINAGE STRUCTURES

TUFLOW Model	Pipes		Box Culverts		Bridges	Inlet Pits / Headwalls	Junction Pits
	No.	Length (m)	No.	Length (m)	No.	No.	No.
Murrumbateman	396	8,580	63	930	0	694	22
Bowning	52	990	4	45	5	612	0
Bookham	31	980	4	145	1	66	0
Binalong	92	1470	7	105	5	196	0

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.

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 in-bank 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. Similarly, the high value of roughness adopted for buildings recognised that these structures will completely block the flow but are capable of storing water when flooded.

Figure 4.5 is a typical example of flow patterns derived from the above roughness values. This example applies to the 1% AEP design storm event and shows flooding patterns in the Village Centre at Murrumbateman. 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 4.5** may be presented at any location within the model domain (which are shown on **Figures 4.1** to **4.4**) and will be of assistance to Council in assessing individual flooding problems in the floodplain.

TABLE 4.2
BEST ESTIMATE HYDRAULIC ROUGHNESS VALUES

Surface Treatment	Manning's n Value
Concrete piped elements	0.015
Asphalt or concrete road surface	0.02
Creeks	0.03
Overbank area, including grass and lawns	0.045
Moderately vegetated areas	0.08
Allotments (between buildings)	0.1
Buildings	10

4.4 Model Boundary Conditions

The locations where sub-catchment inflow hydrographs were applied to the TUFLOW model are shown on **Figures 4.1** to **4.4**. 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".

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 extent of each Rain Boundary has been trimmed to the outlet of the catchment in order to reduce the over-attenuation of runoff from the catchment.

The downstream boundaries of the model comprised "free discharge" outlets, where TUFLOW derived normal depth calculations were used to define hydraulic conditions at the outlet.

4.5 Hydraulic Model Calibration

4.5.1. General

As previously mentioned, the Murrumbateman and Binalong hydrologic and hydraulic models were tested for storms that occurred in February 2010 and September 2016 using the available rain gauge data. The calibrated Murrumbateman and Binalong TUFLOW Models were run using discharge hydrographs that were generated by the corresponding Murrumbateman and Binalong Hydrologic Models, parameters for which are set out in **Section 3.3**.

[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**.

4.5.2. Results of Model Testing

Figures 4.6 and **4.7** show the TUFLOW model results for the February 2010 storm, at Murrumbateman and Binalong, respectively, while **Figures 4.8** and **4.9** show similar information at the two villages for the September 2016 storm. Also shown on the figures is the plan location of the respondents who observed flooding in or adjacent to their property during the two storm events.

Tables 4.3 and **4.4** at the end of this chapter summarise the comments that were made by respondents to the *Community Questionnaire* in relation to the flooding that they observed during the February 2010 and September 2016 storm events at Murrumbateman and Binalong, respectively.

In general, the model was able to reproduce the flood levels which were approximated from the photographs provided by respondents to the *Community Newsletter and Questionnaire* to within 100 mm. However, it was not always possible to reproduce the timing of the flooding at all locations as the available pluviographic rainfall data that were taken from gauges that were located more than 30 km away from the two villages don't appear to be representative of the rainfall that fell at the villages.

4.5.3. Summary

Based on the findings of the model testing process, the Murrumbateman and Binalong hydrologic and hydraulic models were considered to give satisfactory correspondence with the available historic flood data. 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 four villages over the full range of design flood events. Further discussion and presentation of hydrologic model parameters that were adopted for design flood estimation purposes is provided in **Section 5.3**.

TABLE 4.3
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR AT MURRUMBATEMAN

Response Identifier [A]	Flood Event [B]	Observed Flood Behaviour/ Other Comment [C]	Model Verification Comments [D]
Y37(1)	13 – 15 February 2010	• 164 mm of rainfall resulted in flooding that inundated three quarters of a property that is located on Broughton Circuit. Floodwater was "over knee-deep" (greater than about 500 mm deep) at its deepest point (refer **Plates C2.1 – C2.8** in **Appendix C**). • Water flowed in westerly direction along southern boundary of a property that is located on Broughton Circuit to depth of about 300 mm. (refer **Plates C2.4**, **C2.6** and **C2.8** in **Appendix C**).	• The TUFLOW model shows approximately three quarters of the rear of the property inundated to a maximum depth of about 400 mm (i.e. about 100 mm lower than is estimated at the time the photograph was taken). • The TUFLOW model shows floodwater flowing in a westerly direction along the southern boundary of the property to a maximum depth of about 400 mm (i.e. about 100 mm higher than is estimated at the time the photograph was taken).
Y08(2)	21 – 22 September 2016	• Floodwater flowed through paddock in vicinity of driveway of a property that is located on South Street to a depth of approximately 18 inches (about 450 mm). The driveway on the property was washed away.	• TUFLOW model shows ponding to a depth of about 180 mm against the driveway (i.e. about 270 mm lower than the estimated depth of overland flow). It is possible that the localised rainfall over the 6.5 ha catchment contributing to overland flow at this location was more severe than that recorded at closest rain gauges.
Y87(2)		• Floodwater broke the left bank of the watercourse immediately downstream of Murrumbateman Road. **Plates C7.1** and **C7.2** contained in **Appendix C** show the approximate extent of floodwater. • **Plate C7.3** contained in **Appendix C** shows the 5 off 1500 mm diameter pipes beneath Murrumbateman Road are approximately half-full at the time that the photo was taken. The downstream invert of the pipes is about RL 587.75 m AHD based on survey data. Therefore the peak flood level at this location is about RL 588.50 m AHD.	• The TUFLOW model results give a good match with the flood extents shown on **Plates C7.1** and **C7.2** contained in **Appendix C**. • The modelled peak flood level immediately downstream of the Murrumbateman Road culverts is RL 588.60 m AHD (i.e. about 100 mm higher than is estimated at the time the photograph was taken)..
Y88(2)		• Floodwater in McClungs Creek was at the point of overtopping the banks on the southern (upstream) side of Merryville Drive. • Flood peaked at about 07:00 hours on 21 September 2016.	• The TUFLOW model shows McClungs Creek running full. • The flood peak occurs at 09:30 hours on 21 September 2016 in the TUFLOW model (i.e. 2.5 hours before the observed flood peak).

5. Refer **Figure 4.6** for cross reference to Response Identifier.
6. Refer **Figure 4.8** for cross reference to Response Identifier.

TABLE 4.4
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR AT BINALONG

Response Identifier **[A]**	**Flood Event** **[B]**	**Observed Flood Behaviour/ Other Comment** **[C]**	**Model Verification Comments** **[D]**
Y41(1)	13 – 15 February 2010	• Floodwater in Balgalal Tributary was almost overtopping the banks on the upstream (southern) side of Monteagle Street (refer **Plates C1.1** and **C1.2** in **Appendix C**). The top of the bank is set at an elevation of about RL 465.00 m AHD. • Flood peaked at about 11:00 hours on 14 February 2010.	• The peak flood level is about RL 464.95 m AHD in the TUFLOW model results (i.e. about 50 mm lower than is estimated at the time the photograph was taken). • The flood peak occurs at 11:30 hours on 14 February 2010 in the TUFLOW model (i.e. 30 minutes after the observed flood peak).
Y86(2)	21 – 22 September 2016	• Floodwater overtops the banks of Balgalal Creek at the northern end of Stephens Street at about 15:00 hours on 21 September 2016 (refer **Plates C6.2** and **C6.3** in **Appendix C**). The top of the bank is set at an elevation of about RL 459.70 m AHD.	• The flood peak occurs at 21:00 hours on 21 September 2016 in the TUFLOW model (i.e. 6 hours after the observed flood peak). • The peak flood level is about RL 459.80 m AHD in the TUFLOW model results (i.e. about 100 mm higher than is estimated at the time the photograph was taken).
Y42(2)		• Floodwater originating from Balgalal Creek inundated gated entrance to back paddock in a property that is locates on Queen Street. • Floodwater in Balgalal Creek overtopped Burley Griffin Way.	• TUFLOW model shows gated entrance to the back paddock inundated to a depth of about 350 mm. • TUFLOW model shows overtopping of Burley Griffin Way to depths less than 100 mm.

1. Refer **Figure 4.7** for cross reference to Response Identifier.
2. Refer **Figure 4.9** for cross reference to Response Identifier.

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 local catchment flooding at the four villages are presented in the 2019 edition of *Australian Rainfall and Runoff* (**ARR 2019**) (GA, 2019). Design storms for frequencies of 20, 10, 5, 2, 1, 0.5 and 0.2% AEP were derived for storm durations ranging between 30 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 ranging between 0.95 and 1.0 are applicable on the main arms of the watercourses that run through Bowning, Bookham and Binalong, a good match was achieved between the flows derived by the hydrologic models that were developed as part of the present study and those derived by the Regional Flood Frequency Estimation (**RFFE**) Model, the procedures for which are set out in ARR 2019 using a single value of 1.0. As the purpose of the study was to also define the nature of major overland flow which is typically associated with smaller catchments, where point rainfall is more applicable, a global ARF value of 1.0 was adopted for design flood estimation purposes.

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 3.2 and 14.4% AEP) and Rare (rarer than 3.2% AEP) storm events were obtained from the ARR Data Hub[3], while those for the very rare events were taken from the BoMs update of *Bulletin 53* (BoM, 2003). A copy of the data extracted from the ARR Data Hub for the four villages is contained in **Appendix D**.

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:

[3] It is noted that the temporal pattern data set for the *Murray Basin* region is suitable for use at all four villages.

- 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 temporal distribution contained in *Bulletin 53* (BoM, 2003), which is based on pluviographic traces recorded in major Australian storms.

Figures 3.1 to **3.4** show the location and orientation of the PMP ellipses which were used to derive the rainfall estimates for each individual sub-catchment at the four villages. Note that three orientations of the PMP ellipses were adopted at Murrumbateman in order to more accurately define the upper limit of flooding in the village.

5.2 Design Rainfall Losses

The initial and continuing loss values to be applied in flood hydrograph estimation were derive using the NSW jurisdictional specific procedures set out in the ARR Data Hub. The continuing loss values that were adopted for design flood estimation purposes are shown in **Table 5.1**, while a copy of the raw ARR Data Hub data, which includes the Probability Neutral Burst Initial Loss values that were adopted for design flood estimation purposes, is contained in **Appendix D**.

TABLE 5.1
ADOPTED CONTINUING LOSS VALUES

Village	Continuing Loss[(1)] (mm/hr)
Murrumbateman	1.5
Bowning	1.8
Bookham	1.6
Binalong	1.7

1. Derived by multiplying the raw continuing loss value taken from the ARR Data Hub by a multiple of 0.4.

5.3 Derivation of Design Discharges

The Murrumbateman, Bowning, Bookham and Binalong Hydrologic Models were run with the design rainfall data set out in **Sections 5.1** and **5.2**, as well as the hydrologic parameters set out in **Section 3.3.2** in order to obtain design discharge hydrographs for input to their respective TUFLOW Models.

Table 5.2 shows a comparison of design peak flow estimates derived from the Bowning, Bookham and Binalong Hydrologic Models compared to those derived by the RFFE Model[4], while **Figures 3.2**, **3.3** and **3.4** show the location at which the comparisons were made. The peak flow comparison was undertaken for catchments that fit the following criteria:

[4] Note that a similar comparison was not undertaken at Murrumbateman as the RFFE Model is not considered suitable to derive design peak flow estimates for catchments with total catchments areas of less than 0.5 km^2 or greater than 1,000 km^2.

- The total catchment area was greater than 0.5 km^2 and less than 1,000 km^2.
- The shape factor[5] and catchment area is comparable to those of the '*Nearby Catchments*' that are relied upon as part of the RFFE Model.[6]

Table 5.2 shows the hydrologic models developed as part of the present investigation generally provide a good match to the RFFE Model for flood events with an AEP of less than 5 per cent, but provide and overestimate for more frequent flood events.

The storm duration of 30-60 minutes was generally found to be critical for maximising peak flows for individual sub-catchments where the catchment area is less than 60 ha, with the critical storm duration generally increasing with an increase in catchment area. Peak PMF flow rates for individual sub-catchments computed by the hydrologic models for the critical 15 minute PMP storm duration were generally between 9.9 and 11.7 times greater than the corresponding 1% AEP flow rates, with an upper and lower limit of 20.7 and 6.5, respectively. These values lie within the range of expected multiples for a small urban catchment.

TABLE 5.2
COMPARISON OF DESIGN PEAK FLOW ESTIMATES
AT BOWNING, BOOKHAM AND BINALONG

Village	Identifier	AEP (%)	RFFE Derived Peak Flow (m^3/s)	Model Derived Peak Flow (m^3/s)	Discussion
Bowning(1)	Bow_RFFE1 (Catchment Area = 17.6 km^2)	20	33.5	35.1	RFFE gives higher design peak flow estimates than the *Nearby Catchments* of a similar size and is therefore considered to overestimate the design peak flow.
		10	50.1	44.5	
		5	70.5	58.5	
		2	104	77.6	
		1	136	96.9	
	Bow_RFFE2 (Catchment Area = 1.1 km^2)	20	5.3	4.6	Bow_RFFE2 catchment area is significantly smaller than the *Nearby Catchments*. RFFE estimates are therefore extrapolated from larger catchments and may have a lower level of accuracy.
		10	8.0	8.3	
		5	11.3	10.6	
		2	16.8	11.7	
		1	21.8	13.4	

Refer over for footnotes to table.

5 Defined as the shortest distance between catchment outlet and centroid divided by the square root of catchment area (GA, 2016).

6 *Nearby Catchments* are the 15 gauged catchments that are in close proximity to the study catchment and have been relied upon by the RFFE Model to estimate design peak flows at a given location.

TABLE 5.2 (Cont'd)
COMPARISON OF DESIGN PEAK FLOW ESTIMATES
AT BOWNING, BOOKHAM AND BINALONG

Village	Identifier	AEP (%)	RFFE Derived Peak Flow (m^3/s)	Model Derived Peak Flow (m^3/s)	Discussion
Bookham(2)	Bow_RFFE1 (Catchment Area = 85.7 km^2)	20	63.8	121	RFFE derived flows appear to be influenced by outlier data from *Nearby Catchments*. Modelled peak flow estimates are well within the upper and lower confidence limits.
		10	95.7	174	
		5	134	218	
		2	199	281	
		1	258	351	
	Bow_RFFE2 (Catchment Area = 37.6 km^2)	20	22	52.3	Achieves a good match between modelled and RFFE derived design peak flows.
		10	45.9	79.9	
		5	68.4	101	
		2	95.5	140	
		1	140	168	
	Bow_RFFE3 (Catchment Area = 24.4 km^2)	20	23.1	40.3	Achieves a good match between modelled and RFFE derived design peak flows.
		10	34.6	57.5	
		5	48.5	76.8	
		2	71.5	97	
		1	93	118	
Binalong(3)	Bin_RFFE1 (Catchment Area = 33.4 km^2)	20	30.4	43.2	Shape Factor matches that of *Nearby Catchments*. Considered to be a good fit with the RFFE Model.
		10	46.5	58.2	
		5	66.6	73.9	
		2	100	104	
		1	132	124	
	Bin_RFFE2 (Catchment Area = 3.0 km^2)	20	7.0	12.7	Catchment area is more than 7 km^2 less than the *Nearby Catchment*. However, results still provide a good match with the RFFE Model.
		10	10.7	18.4	
		5	15.3	23.3	
		2	23.1	27	
		1	30.5	32.7	
	Bin_RFFE3 (Catchment Area = 1.7km^2)	20	4.2	6.8	Catchment area is more than 8 km^2 less than the *Nearby Catchment*. However, results still provide a good match with the RFFE Model.
		10	6.4	10	
		5	9.2	12.6	
		2	14	15.5	
		1	18.5	18.1	

1. Refer **Figure 3.2** for location of peak flow comparison at Bowning.
2. Refer **Figure 3.3** for location of peak flow comparison at Bookham.
3. Refer **Figure 3.4** for location of peak flow comparison at Binalong.

6 HYDRAULIC MODELLING OF DESIGN STORM EVENTS

6.1 Presentation and Discussion of Results

6.1.1. Water Surface Profiles and Extents of Inundation

The results of the hydraulic modelling of design storm events at the four villages are presented in separate Appendices: Murrumbateman in **Appendix E**, Bowning in **Appendix F**, Bookham in **Appendix G** and Binalong in **Appendix H**. Any reference to a figure number in this chapter refers to the corresponding figure in **Appendices E** to **H**.

Figures 6.1 to **6.8** in **Appendices E** to **H** show the TUFLOW model results for the 20, 10, 5, 2, 1, 0.5 and 0.2 per cent AEP floods, together with the PMF. These diagrams show the indicative extent and depth of inundation along the creeks and tributaries at the four villages, as well as along the major overland flow paths for the range of design flood events.

Water surface profiles along the major drainage lines at the four villages are shown on **Figure 6.9** in **Appendices E** to **H** for the modelled design floods events. **Figure 6.10** shows stage and discharge hydrographs at selected locations throughout the four study areas, while **Table I1** in **Appendix I** sets out peak design flows and corresponding critical storm durations at each location.

In order to create realistic results which remove most of the anomalies caused by inaccuracies in the LiDAR survey data (refer below for details), 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.

6.1.2. 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 main stream areas.

Minimum floor levels for residential and commercial developments should be based on the 1% AEP flood level plus appropriate freeboard (this planning level is defined as the *"Flood Planning Level"* (**FPL**)), to cater for uncertainties such as wave action, effects of flood debris conveyed in the overland flow stream and precision of modelling. Note that a freeboard of 500 mm has been adopted for defining an interim set of FPLs (**Interim FPLs**) along the main drainage paths in the four villages pending the completion of the future *FRMS&P*. Derivation of an interim Flood Planning Area (**Interim FPA**) based on the Interim FPLs is presented in **Section 6.7**.

The sensitivity studies and discussion presented in **Section 6.5** provide guidance on the suitability of the recommended allowance for freeboard under present day climatic conditions.

In accordance with DPIE recommendations (DECC, 2007), sensitivity studies have also been carried out to assess the impacts of future climate change on flood behaviour (refer **Section 6.5**). Increases in flood levels due to future increases in rainfall intensities may influence the selection of FPLs. However, final selection of FPLs is a matter for more detailed consideration during the preparation of the future *FRMS&P*.

6.1.3. Description of Flood Behaviour

<u>Murrumbateman</u>

Figures E6.1 to **E6.8** in **Appendix E** show the TUFLOW model results at Murrumbateman for the assessed design flood events, while **Table I1** in **Appendix I** sets out design peak flows at selected locations throughout the village.
The key features of flooding in the McClungs Creek catchment are as follows:

- In Merryville Estate which is located in the headwaters of the McClungs Creek catchment, floodwater surcharges the road reserve at the following locations:
    - Merryville Drive in the vicinity of Merryville Estate Basin No. 1 (refer location of Peak Flow Location (**PFL**) MUR_01 on sheet 2 of **Appendix E** figures) in a 1% AEP event;
    - Merryville Drive at its intersection with Suffolk Avenue (refer PFL MUR_02 on sheet 2) in a 20% AEP event; and
    - Isabel Drive at a location about 250 m east of its intersection with Merryville Drive (refer PFL MUR_03 on sheet 2) in a 20% AEP event.
- The culvert beneath Merryville Drive in the vicinity of Carrington Park (refer PFL MUR_04 on sheet 2) will surcharge in events that occur more frequently than the 20% AEP. Floodwater that surcharges the culvert flows in a westerly direction along a channel that runs parallel to Merryville Drive on its southern side and discharges to McClungs Creek. Floodwater commences to surcharge the aforementioned channel and sheet flow in a northerly direction across Merryville Dive in a 5% AEP event.

- McClungs Creek commences to surcharge Merryville Drive in the vicinity of Carrington Park (refer PFL MUR_05 on sheet 2) in a 2% AEP storm event, while the Barton Highway crossing of the creek (refer PFL MUR_06 on sheet 1) will remain flood free until the 0.2 % AEP event.
- The Carrington Park Detention Basin (refer sheet 2) commences to surcharge in a 0.2% AEP event.

The key features of flooding in the Unnamed Tributary catchment are as follows:

- Murrumbateman Road will commence to overtop in a 2% AEP event at the following locations;
  - at a location about 400 m east of its intersection with Patemans Lane (refer PFL MUR_07 on sheet 5); and
  - in the vicinity of its intersection with Elrington Close (refer PFL MUR_08 on sheet 5).
- Floodwater commences to surcharge the low point in Ambleside Avenue in Ambleside Estate (refer PFL MUR_09 on sheet 3) in a 20% AEP event, resulting in the isolation of the existing dwellings that are located in the vicinity of Broughton Circuit.
- The culvert beneath the Barton Highway that is located about 600 m south of its intersection with Murrumbateman Road (refer PFL MUR_10 on sheet 3) will surcharge in a 20% AEP event and flow in a northerly direction along a channel that runs parallel to the highway on its western side and discharges a culvert that runs beneath the Barton Highway a further 200 m to the north (refer PFL MUR_11 on sheet 3). Floodwater commences to surcharge the Barton Highway at this location in a 2% AEP event.
- Floodwater commences to surcharge the low point in Dundoos Drive in Dundoos Estate (refer PFL MUR_12 on sheet 3) in a 10% AEP event, isolating the existing dwellings that are located in the estate.
- Floodwater commences to surcharge Murrumbateman Road in the vicinity of its intersection with the Barton Highway (refer PFL MUR_13 on sheet 3) in a 2% AEP event. Floodwater also surcharges the left (western) bank of the Unamed Tributary about 100 m to the north of Murrumbateman Road and inundates the Barton Highway at its intersection with South Street in a storm of this intensity.
- Floodwater surcharges the Hillview Drive crossing of the Unamed Tributary (refer PFL MUR_15 on sheet 1) in a 2% AEP event.
- Floodwater commences to surcharge the right (eastern) bank of the Unnamed Tributary and inundate the Murrumbateman Recreation Ground (refer sheet 3) in a 2% AEP event. The water supply bore and pumping station that is located in the vicinity of the Murrumbateman Recreation Ground will commence to become inundated in a 1% AEP event.
- Depths of overland flow through the Village Centre would exceed 300 mm in a 1% AEP event at the flowing locations:
  - through existing development that is bounded by West Street to the west, Hercules Street to the north, Rose Street to the east and South Street to the south; and
  - adjacent to the pedestrian footpath that is located along the southern boundary of Fairley Village between William Street and Camp Street.

The key features of flooding in the Gooda Creek catchment are as follows:

- Floodwater commences to surcharge Goldfields Lane (refer PFL MUR_09 on sheet 7) in events that occur more frequently than 20% AEP.
- Floodwater commences to surcharge the Barton Highway at a location about 100 m north of the Gooda Creek crossing (refer PFL MUR_17 on sheet 6) in a 5% AEP event.
- Floodwater commences to surcharge the Barton Highway at a location about 230 m south of its intersection with Valencia Drive (refer PFL MUR_18 on sheet 6) in a 10% AEP event.

The key feature of flooding in the Big Hill Creek catchment is that Dog Trap Road will be inundated over a distance of about 250 m to the north of the Big Hill Creek crossing in a 20% AEP event. This section of road will be inundated to depths greater than 800 mm in a 1% AEP event.

Peak PMF flow rates in the drainage lines at Murrumbateman are about 14-18 times the corresponding peak 1% AEP flow rates. This is a result of a combination of the reduced effect that temporary floodplain storage has on the attenuation of flows during extreme flood events and the fact that the rainfall excess in the PMP event is up to 12 times the 1% AEP excess for equivalent storm durations.

Bowning

Figures F6.1 to **F6.8** in **Appendix F** show the TUFLOW model results at Bowning for the assessed design flood events. **Table I1** in **Appendix I** sets out design peak flows at selected locations throughout the village.

The key features of main stream flooding in Bowning are as follows:

- As shown on **Figure F6.10**, water levels in Bowning Creek and Bowning Tributary generally commence to rise within an hour of the onset of heavy rain and typically rise to their peak within 2-5 hours. The height to which water levels reach relative to adjacent road and bridge deck levels is also shown on **Figure F6.10**.
- Floodwater is generally contained within the inbank area of Bowning Creek in a 20% AEP event with the exception of the following locations:
    - in the ponding area that is located immediately upstream of the Bowning Road crossing;
    - between Bowning Road and the Hume Highway; and
    - along the 650 m reach of Bowning Creek immediately downstream of the Hume Highway.
- Floodwater that surcharges the eastern (left) bank of Bowning Creek immediately downstream of Bowning Road cuts off access to the existing residential development that is located about 180 m to the south of its intersection with Playfair Street.
- Floodwater commences to surcharge Bowning Road (refer PFL BOW_02) in a 0.5% AEP event. The Main Southern Railway (refer PFL BOW_01) and Hume Highway (refer PFL BOW_03) will remain flood free in a 0.2% AEP event, but will be inundated in a PMF event.

- The two residential properties that are located on the south-western side of the intersection of Bowning Road and Playfair Street will become isolated in a 0.2% AEP event.
- Floodwater is generally contained within the inbank area of Bowning Tributary during storms up to 2% AEP in intensity with the exception of the following locations:
  - in the vicinity of Montem Street (refer PFL BOW_05) where floodwater surcharges the existing culverts in a 10% AEP event and inundates the road to depths of less than 100 mm. Floodwater that surcharges the existing culverts at this location commences to isolate the existing residential property that is located on the northern (right) bank of the tributary in a 5% AEP event; and
  - in the vicinity of Leake Street (refer PFL BOW_04) where floodwater that surcharges the eastern (right) bank of Bowning Tributary inundates the road in a 20% AEP event.
- Peak PMF flow rates in Bowning Creek and Bowning Tributary are about 10-13 times the corresponding peak 1% AEP flow rates. This is a result of the PMP rainfall excess being about 10-12 times the corresponding rainfall excess in a 1% AEP event.

The key features of major overland flow in Bowning are as follows:

- While depths of overland flow along existing flow paths are generally less than 300 mm for storms up to 10% AEP in intensity, they would exceed 300 mm at the following locations in a 1% AEP event:
  - on the western (right) bank of Bowning Creek in line with the projection of Juno Street;
  - between Red Hill Road and Bowning Creek on its western (right) bank at a location about 250 m upstream of the Main Southern Railway;
  - on the western side of Cossack Street between the Hume Highway and Bowning Creek;
  - on the eastern (right) and western (left) bank of Bowning Creek downstream of the Hume Highway; and
  - between Walls Junction Road and Bowning Tributary to the east of the Bowning Railway Station.
- Floodwater ponds to depths greater than 300 mm in a 1% AEP event at the following trapped low points:
  - on the northern side of the Main Southern Railway to the east of Montem Street; and
  - on the northern side of Bogolong Street at a location about 70 m west of its intersection with Bowning Road.
- Floodwater ponds to lesser depths in a 1% AEP event at the trapped low point that is located on the western side of Bowning Road between Airy Street and Red Hill Road.

Bookham

Figures G6.1 to **G6. 8** in **Appendix G** show the TUFLOW model results at Bookham for the assessed design flood events, while **Table I1** in **Appendix I** sets out design peak flows at selected locations throughout the village.

The key features of main stream flooding in Bookham are as follows:

- As shown on **Figure G6.10**, water levels in Bogolong Creek and Middletons Creek generally commence to rise within an hour of the onset of heavy rain and typically rise to their peak within 2-5 hours. The height to which water levels reach relative to adjacent road and bridge deck levels is also shown on **Figure G6.10**.
- The Bogolong Creek floodplain narrows from a width of 200 m at its confluence with Stony Creek to a width of about 70 m along a 600 m reach of the watercourse adjacent to the Bookham Recreational Ground. The floodplain then widens to about 160 m downstream of the recreation ground before narrowing to about 60 m immediately upstream of Illalong Road.
- Floodwater commences to surcharge the banks of Bogolong Creek during storms that are more frequent than 20% AEP. The overbank areas of the Bogolong Creek floodplain are generally inundated to depths greater than 1 m in a 1% AEP event. The flow velocity is about 0.8-1.2 m/s on the overbank area of Bogolong Creek and exceeds 2 m/s in the inbank area during a storm of this intensity.
- **Figure G6.10** shows that access across Bogolong Creek at Illalong Road (refer PFL BO0_01) will be cut in a 0.2% AEP event, while floodwater will commence to surcharge the Fagan Drive crossing of Middletons Creek (refer PFL BOO_02) in a 2% AEP event.
- **Table I1** in **Appendix I** shows that the peak PMF flows in Bogolong Creek and Middletons Creek are about 9-10 times the corresponding peak 1% AEP flow rates. This is a result of the PMP rainfall excess being about 7-11 times the corresponding rainfall excess in a 1% AEP event.

Heavy rainfall that falls on the catchment that is located to the south of the village generates shallow sheet flow (of generally less than 100 mm in depth) through existing development that is located on Drummond Street and Fagan Drive. This overland flow then ponds in the trapped low point that is located on the southern side of the Hume Highway, reaching a maximum depth of about 1.5 m in a 1% AEP event.

Binalong

Figures H6.1 to **H6.8** in **Appendix H** show the TUFLOW model results at Binalong for the assessed design flood events, while **Table I1** in **Appendix I** sets out design peak flows at selected locations throughout the village.

The key features of main stream flooding in Binalong are as follows:

- As shown on **Figure G6.10**, water levels in Balgalal Creek generally commence to rise about 2 hours after the onset of heavy rain and typically rise to their peak after about 4 hours, while the water levels in Balgalal Tributary generally commence to rise within one hour of the onset of heavy rain and typically rise to their peak within two hours. The height to which water levels reach relative to adjacent road and bridge deck levels is also shown on **Figure G6.10**.
- The Balgalal Creek floodplain is between 90-180 m wide where it flow pasts the urbanised parts of Binalong between Armours Road and a location about 200 m upstream of Burley Griffin Way, after which it widens to about 200-300 m. The floodplain then constricts to about 70 m wide at a location about 400 m downstream of Garryowen Road.
- Floodwater commences to surcharge the banks of Balgalal Creek during storms that are more frequent than 20% AEP. Floodwater commences to inundate the rear of the residential allotments that are located on the northern side of Queen Street in a 10% AEP event.

- The low level crossings of Balgalal Creek at Armours Road (refer PFL BIN_02 on sheet 1) and Stephen Street (refer PFL BIN_03 on sheet 2) are submerged during freshes in the creek, which isolates the rural residential properties that are located on the right (northern) bank of the creek.
- Garryowen Road (refer PFL BIN_05 on sheet 2) is submerged to depths of about 400 mm in a 20% AEP event, while floodwater commences to surcharge Burley Griffin Way at a location approximately 100 m north of the creek crossing (refer PFL BIN_04 on sheet 2) in a 10% AEP event.
- Floodwater commences to surcharge the Main Southern Railway (refer PFL BIN_01 on sheet 1) immediately to the south of the bridge crossing of Balgalal Creek in a 1% AEP event.
- Floodwater is generally contained within the inbank area of Balgalal Tributary in a 20% AEP event with the exception of the following locations:
    - in the vicinity of Richmond Street (refer PFL BIN_07 on sheet 2) where floodwater surcharges the left (southern) bank of the tributary and overtops the road by about 500 mm; and
    - upstream of Monteagle Street (refer PFL BIN_09 on sheet 2) where floodwater surcharges the left (western) bank of the creek and isolates residential development that is located on the southern side of the road. Monteagle Street is inundated to a depth of about 200 mm in an event of this intensity.
- Floodwater in Balgalal Tributary commences to surcharge Wellington Street (refer PFL BIN_08 on sheet 2) and Queen Street (refer PFL BIN_10 on sheet 2) in a 2% AEP event, which prevents access between the urbanised parts of Binalong that are located on each side of the watercourse.
- Peak PMF flow rates in Balgalal Creek and Balgalal Tributary respectively are about 12-14 and 9-10 times the corresponding peak 1% AEP flow rates. This is a result of the PMP rainfall excess being up to 13 times the corresponding rainfall excess in a 1% AEP event.

The key features of major overland flow in Binalong are as follows:

- While depths of overland flow through the urbanised parts of the village are generally less than 300 mm for storms up to 1% AEP in intensity, they would exceed that depth at the following locations in a 20% AEP event:
    - along the flow path that runs in a northerly direction through residential development that is located between Balgalal Creek and the intersection of Stephens Street and Wellington Street;
    - on the southern side of Stephens Street in the vicinity of its intersection with Beckham Street;
    - on the eastern side of the Main Southern Railway at a location about 450 m south of the Binalong Railway Station;
    - on the eastern side of Fitzroy Street at a location about 400 m south of its intersection with Wellington Street; and
    - along the flow path that runs in a northerly direction between the Binalong Railway Station and Balgalal Creek on the eastern side of Fitzroy Street.
- Depths of overland flow along the abovementioned flow paths generally exceed 1 m during a 1% AEP event at locations where floodwater ponds on the upstream side of the elevated road/rail crossings.

6.2 Economic Impacts of Flooding

Table 6.1 sets out the number of properties that are flood affected in the four villages and the estimated damages which would occur for storm events of varying AEP.

At the 1% AEP level of flooding only three dwellings would experience above-floor inundation in the four villages; one each at Murrumbateman, Bowning and Binalong, while no dwellings are inundated above-floor level at Bookham. No commercial/industrial or public buildings would be above-floor inundated in a storm of this intensity.

During a PMF event, 47 individual dwellings would experience above-floor inundation in Murrumbateman, 27 in Bowning, 19 in Binalong and two in Bookham. During a storm of this intensity, six commercial/industrial buildings (two each at Murrumbateman and Bookham and one each at Bowning and Binalong) and eight public buildings (four at Murrumbateman, two at Bookham and one each at Bowning and Binalong) would be inundated above-floor level.

The *"Present Worth Value"* of damages resulting from all floods up to the magnitude of the 1% AEP at Murrumbateman and Binalong is $0.04 Million and $0.02 Million, respectively. These values represent the amount of capital spending which would be justified if one or more flood mitigation schemes prevented flooding for all properties up to the 1% AEP event in the respective village.

The *Present Worth Value* of total damages at Bowning and Bookham for all flood events up to the 1% AEP flood is zero. As a result it is not possible to economically justify any works which are aimed at mitigating the impact of flooding on existing development up to the 1% AEP level in these two villages.

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

TABLE 6.1
SUMMARY OF FLOOD DAMAGES

Village	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	
Murrumbateman	5	5	0	0	0	0	0	0.08
	10	8	0	0	0	0	0	0.13
	20	9	0	0	0	0	0	0.14
	50	12	0	0	0	0	0	0.19
	100	13	1	0	0	0	0	0.23
	200	15	1	0	0	0	0	0.26
	500	19	3	0	0	1	0	0.41
	PMF	94	47	4	2	5	4	5.67

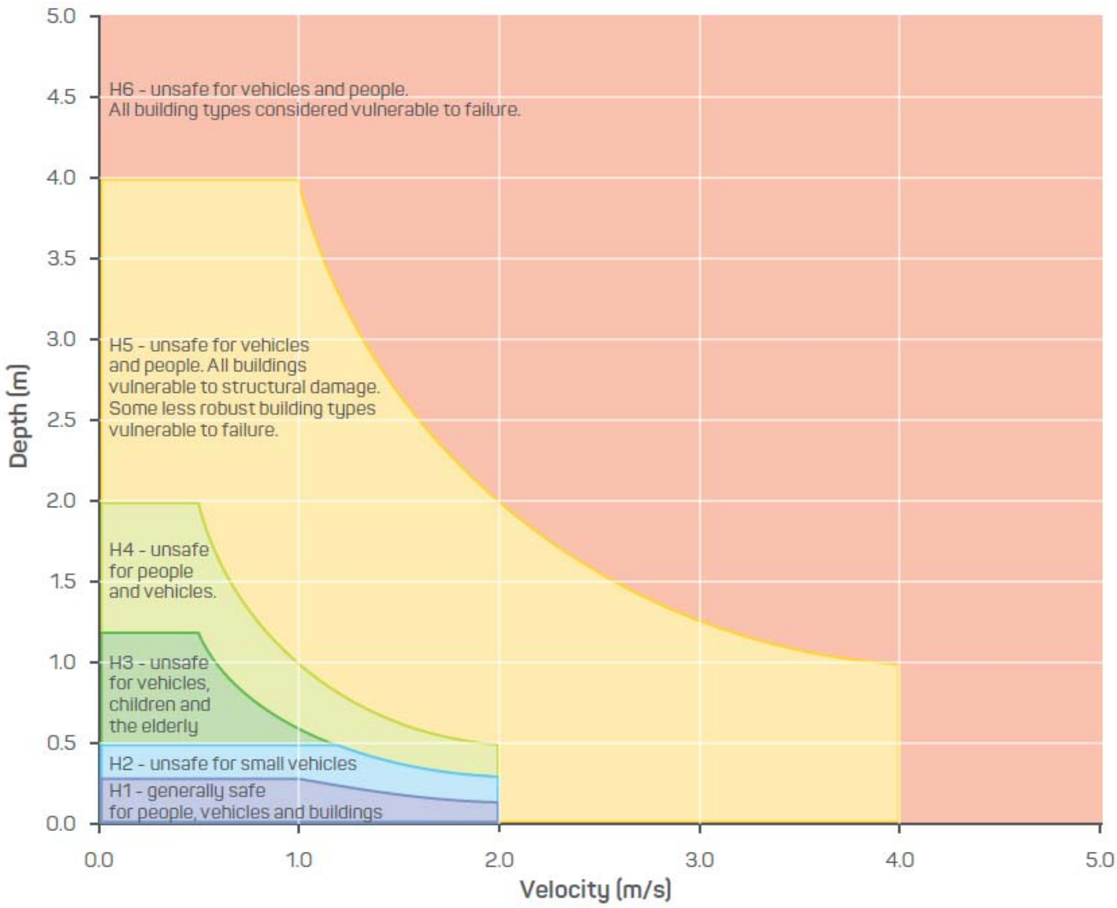
TABLE6.1 (Cont'd)
SUMMARY OF FLOOD DAMAGES

Village	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	
Bowning	5	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0
	20	1	0	0	0	0	0	0.02
	50	2	1	0	0	0	0	0.05
	100	2	1	0	0	0	0	0.09
	200	3	1	0	0	0	0	0.11
	500	5	2	0	0	0	0	0.21
	PMF	32	27	1	1	2	1	3.62
Bookham	5	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0
	20	0	0	0	0	0	0	0
	50	0	0	0	0	0	0	0
	100	0	0	0	0	0	0	0
	200	0	0	0	0	0	0	0
	500	0	0	0	0	0	0	0
	PMF	3	2	2	2	2	2	0.67
Binalong	5	2	0	0	0	0	0	0.03
	10	3	1	0	0	0	0	0.07
	20	4	1	0	0	0	0	0.13
	50	5	1	0	0	0	0	0.14
	100	6	1	0	0	0	0	0.16
	200	8	1	0	0	0	0	0.2
	500	8	1	0	0	0	0	0.2
	PMF	33	19	1	1	1	1	2.52

6.3 Flood Hazard Zones and Floodways

6.3.1. Flood Hazard Vulnerability Classification

Flood hazard categories may be assigned to flood affected areas in accordance with the definitions contained in the publication entitled "*Managing the Floodplain: A Guide to Best practice in Flood Risk Management in Australia*" (Australian Institute for Disaster Resilience (**AIDR**), 2017). 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 following illustration which has been taken from AIDR, 2017:



Flood Hazard Vulnerability Classification diagrams for the 5, 1 and 0.2% AEP flood events, as well as PMF based on the procedures set out in AIDR, 2017 are presented on **Figures 6.11**, **6.12**, **6.13** and **6.14**, respectively of **Appendices E** to **H**.

It was found that areas classified as H5 and H6 are generally limited to the inbank areas of the major watercourses and local farm dams that are scattered through the study catchments in a 1% AEP event.

The flooding that is experienced at the road crossings that are inundated in a 1% AEP event (refer **Sections 6.1.3** to **6.1.6** for locations) falls within the H1 category with the following exceptions:

Murrumbateman

- H2 at Ambleside Avenue (refer PFL MUR_09 on sheet 3);
- H2 at Murrumbateman Road (refer PFL MUR_13 on sheet 3);
- H2 at Hillview Drive (refer PFL MUR_15 on sheet 1);
- H5 at Goldfields Lane (refer PFL MUR_16 on sheet 7);

Bowning

- H2 at Montem Street (refer PFL BOW_05);
- H2 at Leake Street (refer PFL BOW_04);

Binalong

- H6 at Armours Road (refer PFL BIN_02 on sheet 1);
- H2 at Burley Griffin Way (refer PFL BIN_04 on sheet 2);
- H5 at Garryowen Road (refer PFL BIN_05 on sheet 2);
- H5 at Monteagle Street (refer PFL BOW_09 on sheet 2);

The overland flow paths in the urbanised parts of the four villages are generally classified as either H1 or H2 in a 1% AEP event, except in the areas where floodwater ponds on the upstream side of roads where it is generally classified as either H3 or H4.

For the PMF event, the width of the H5 and H6 hazard zones increases significantly, mainly along the main arms of the creeks and their major tributaries. The hazard category along the majority of the remaining drainage lines increases to between H3 and H5 during a storm event of this intensity.

6.3.2. 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. Howells et al suggested the following criteria for defining 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 400 mm. The remainder of the flood affected area was classified as flood fringe.

Figures 6.15, **6.16** and **6.17** in **Appendices E** to **H** shows the division of the floodplain into floodway, flood storage and flood fringe areas for the 5, 1 and 0.2% AEP storm events, respectively, while Figure 6.18 in **Appendices E** to **H** shows the hydraulic categorisation of the floodplain for the PMF.

As the hydraulic capacity of the creek channels is not large enough to convey the 1% AEP flow, a significant portion of the total flow in conveyed on the floodplain. As a result, areas which lie on the overbank area also function as a floodway during the 1% AEP flood event. Floodways are also generally present along the major overland flow paths described in **Sections 6.1.3** to **6.1.6**.

Flood storage areas are confined to the major ponding areas which are located on the upstream side of the roads, as well as in the local farm dams that have been constructed to capture runoff in several parts of the four villages.

6.4 Flood Emergency Response Classification

Flood emergency response categories may be assigned to flood affected areas in accordance with the definitions contained in AIDR, 2017. The flood emergency response classifications are based on whether or not the area is flooded during a PMF event, whether the area has an exit to flood-free land in a flood event and the consequence of flooding on the area. This information will assist NSW SES in emergency management planning during flood events.

Flood Emergency Response Classification diagrams for the 5, 1 and 0.2% AEP flood events, as well as the PMF based on the procedures set out in AIDR, 2017 are presented on **Figures 6.19**, **6.20**, **6.21** and **6.22**, respectively of **Appendices E** to **H**.

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 *FRMS&P*; and

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

6.5.2. Sensitivity to Hydraulic Roughness

Figure 6.23 in **Appendices E** to **H** shows the difference in peak flood levels (i.e. the “afflux”) for the 1% AEP flood event resulting from an assumed 20% increase in hydraulic roughness (compared to the values given in **Table 4.2**).

The typical increase in peak flood level in the areas subject to main stream flooding are generally in the range 20 to 100 mm, with increases of up to 200 mm at Murrumbateman, Bowning and Binalong and in the range 100 to 500 mm at Bookham.

Increases in peak flood levels along the tributary arms of the watercourses at the four villages and in areas subject to major overland flow are generally in the range 10 to 50 mm, with increases in the range 50 to 100 mm present in isolated locations. The increase in assumed hydraulic roughness in the upper reaches of the study catchments at Murrumbateman and Binalong has had an attenuating effect on the peak flow, resulting in minor reductions in peak flood levels in in the lower reaches.

6.5.3. Sensitivity to Partial Blockage

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 four villages based on the procedures set out in ARR 2019. A blockage factor of 50% was found to be applicable for the minor piped drainage lines within the urbanised parts of the villages, while blockage factors of up to 50% were found to be applicable for the culvert / bridge crossing of the major watercourses. Based on this finding, a constant blockage factor of 50 per cent was applied to all hydraulic structures in the study area for the purpose of the sensitivity analysis.

Figure 6.24 in **Appendices E** to **H** shows the afflux for a 1% AEP storm[7] resulting from a 50 per cent blockage. This represents a case which is well beyond a blockage scenario which could reasonably be expected to occur and is presented for illustrative purposes.

The effects of blockage are greatest immediately upstream of hydraulic structures and in several locations results in a redistribution of flood flows across the floodplain. While peak flood levels would increase by up to 500 mm immediately upstream of culvert and bridge crossings on the main creeks and their tributaries, and up to 200 mm along the major overland flow paths, the extent of inundation would not increase significantly in these areas. Greater increases in peak flood level and also the extent of inundation occur at Bookham where the blockage of the Middletons Creek culverts beneath the Hume Highway increases peak flood levels to its south by up to 1.5 m.[8]

6.5.4. Differences in Design Flood Estimation – ARR 1987 versus ARR 2019

For comparison purposes, design flood modelling was undertaken for the 5% and 1% AEP design storm events based on the procedures set out in the 1987 edition of *Australian Rainfall and Runoff* (**ARR 1987**) (The Institution of Engineers Australia, 1987).

Figures 6.25 and **6.26** of **Appendices E** to **H** show the difference in the extent and depth of inundation resulting on the application of the procedures set out in ARR 1987 and ARR 2019 for the 5 and 1% AEP events, respectively. Note that a positive afflux indicates that the modelled peak flood levels derived using the procedures set out in ARR 2019 are higher than those derived using ARR 1987.

In general, peak flood levels derived using the procedures set out in ARR 2019 are about 50-100 mm lower than those derived using the ARR 1987 approach to design flood estimation with the following exceptions:

- isolated pockets of larger reductions in peak flood level occur at all villages in ponding areas that are located on the upstream side of road crossings;
- isolated pockets of increases in peak flood level that are present in a small number of local farm dams; and
- the peak flow in Stony Creek at Bookham is increased by about 6% in a 5% AEP event which increases peak flood levels along Bogolong Creek by about 30 mm. The peak flow in Stony is also increased by about 15% in a 1% AEP event, but this doesn't result in increases in peak flood level along Bogolong Creek as the timing of the peak flows in the two creek systems do not coincide in larger flood events.

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[7] Note that the sensitivity analyses were undertaken for a single storm duration and temporal pattern that was found to be critical for maximising peak flood levels on the major watercourses at each village.

[8] The blockage factor applied to the twin 1.8 m diameter pipes beneath the Hume Highway at Middletons Creek is sensitive to the adopted L_{10} value. An L_{10} value that is larger than the culvert diameter (> 1.8 m) results in a blockage factor of 50 per cent, while an L_{10} value slightly smaller than the diameter (< 1.8 m) gives a blockage factor of 10 per cent. As there is no guidance in ARR 2019 regarding the L_{10} values that is suitable for application in rural areas, the conservatively high blockage factor of 50% was adopted for the purpose of undertaking the sensitivity analysis.

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 four villages. 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.

DPIE 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. 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 *FRMS&P* for the four villages using site specific data.

At the present flood study stage, the principal issue regarding climate change is the potential increase in flood levels throughout the four villages. 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.

In the *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 *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 *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 6.27 in **Appendices E** to **H** shows the afflux resulting from a 10 per cent increase in 1% AEP rainfall intensities. The increase in peak flood levels along the creeks and their tributaries varies between 50 to 300 mm at Murrumbateman, Bowning and Binalong, with increases of up to 500 mm in Bookham. Increases in peak flood levels in the range 10 to 50 mm are shown to occur along major overland flow paths.

Figure 6.28 in **Appendices E** to **H** shows the afflux for a 30 per cent increase in 1% AEP rainfall intensities. Peak flood levels along the creeks and their tributaries increase by up to 500 mm at Murrumbateman, Bowning and Binalong, with increases of over 1 m shown to occur in Bookham. Increases in peak flood levels in the range 20 to 200 mm are shown to occur along major overland flow paths.

Figure 6.29 in **Appendices E** to **H** shows the increase in the extent of land affected by floodwater should 1% AEP rainfall intensities increase by 10 or 30 per cent. The extent of land that is affected by floodwater increases significantly at the following locations:

- in the lower reaches of McClungs Creek at Murrumbateman (refer sheet 1);
- along the Unnamed Tributary and the watercourse that drains Dundoos Estate in the vicinity of the Murrumbateman Recreation Ground at Murrumbateman (refer sheet 3);
- on the left (eastern) bank of Big Hill Creek in the vicinity of Dog Trap Road at Murrumbateman (refer sheet 4);
- along a 1 km reach Gooda Creek in the vicinity of Goldfields Lane at Murrumbateman (refer sheet 7);
- on the both banks of Bowning Creek between the Main Southern Railway and the Hume Highway at Bowning; and
- on the upstream (southern) side of the Hume Highway crossing of Middletons Creek at Bookham.

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

6.7 Selection of Interim Flood Planning Levels

After consideration of the TUFLOW results and the findings of sensitivity studies 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 below the peak 1% AEP flood level plus a freeboard allowance of 500 mm; and
- in areas subject to major overland flow the extent of the FPA was define as land inundated to a depth greater than 100 mm.

Figure 6.30 in **Appendices E** to **H** show the extent of the Interim FPA in the four villages.

In areas that lie within the extent of the Interim FPA it is recommended that a freeboard of 500 mm be applied to peak 1% AEP flood levels when setting the minimum floor level 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 overland flow through the subject site.

Consideration will need to be given during the preparation of the future *FRMS&P* to the appropriateness of the adopted freeboard allowance of 500 mm given the impact changes in hydraulic roughness and future increases in rainfall intensity could have on peak flood levels, especially in the case of Bookham. 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 500 mm may be found to be too conservative.

Figure 6.30 in **Appendices E** to **H** 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.

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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.
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

MURRUMBATEMAN, BOWNING, BOOKHAM AND BINALONG FLOOD STUDIES

Community Newsletter

Yass Valley Council has engaged consultants to undertake flood studies for the villages of Murrumbateman, Bowning, Bookham and Binalong which will define mainstream flooding patterns along McClungs and Big Hill Creek (Murrumbateman), Bowning Creek (Bowning), Bogolong Creek (Booham) and Balgalal Creek and Bobbara Gully (Binalong). The study will also define 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 Office of Environment and Heritage 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. Following the completion of the *Flood Study*, a Floodplain Risk Management Study and Plan will also be completed which will include further consultation on management options.

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

- Survey along the creeks and collection of data on historic flooding.
- Preparation of computer models of the creeks and floodplain 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

An important first step in the preparation of a *Flood Study* is to identify the availability of information on historic flooding in the village. The attached **questionnaire** has been provided to residents and business owners to assist the consultants in gathering this important information. The questionnaire may also be completed online via Council's website (https://www.surveymonkey.com/r/MBBBFloodStudy). 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 **Friday 31 August 2018**.

Contact: Yass Valley Council

Joseph Cleary | Design Engineer
Phone: (02) 6226 1477
Email: Council@yass.nsw.gov.au

yass valley council
the country the people

MURRUMBATEMAN, BOWNING, BOOKHAM AND BINALONG FLOOD STUDIES

Community Questionnaire

This questionnaire is part of the *Murrumbateman, Bowning, Bookham and Binalong Flood Studies*, which is currently being prepared by Yass Valley Council with the financial and technical support of the NSW Office of Environment & Heritage. 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 **Friday 31 August 2018**. 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

Alternatively, the questionnaire can be completed online via the following link:

https://www.surveymonkey.com/r/MBBBFloodStudy

1. What village do you live in?

____

2. Your details:

Name (Optional):____

Address:____

Phone Number (Optional):____

Email (Optional): ____

3. Please tick as appropriate:

- ☐ I am a resident
- ☐ I am a business owner
- ☐ Other (please specify ______________________________)

4. How long have you been at this address?

- ☐ 1 year to 5 years
- ☐ 5 years to 20 years
- ☐ More than 20 years (___________ years)

5. **What is your property?**

- ☐ House
- ☐ Villa/Townhouse
- ☐ Unit/Flat/Apartment
- ☐ Vacant land
- ☐ Industrial unit in larger complex
- ☐ Stand alone warehouse or factory
- ☐ Shop
- ☐ Community building
- ☐ Other (____________________________________)

6. **Has your property ever been inundated by floodwaters in the past?**

[ ] Yes [ ] No

7. **If you answered yes to Question 6, when did it occur and which part(s) of your property was affected?**

(Please provide a short description such as: duration of flooding, source of water, flow directions, etc. Refer example below.)

	Location	Date / Time / Description
[✓]	**EXAMPLE ONLY** Driveway	8 March 2012 @ 2 pm – driveway flooded from direction of street, continued for 10 – 15 minutes. Floodwaters continued through property down northern side of house.
[ ]	Driveway	
[ ]	Water level below floor level in building	
[ ]	Water level above floor level in building	
[ ]	Garage	
[ ]	Front yard	
[ ]	Backyard	
[ ]	Shed	
[ ]	Other (please specify)	

8. **If flooding affected your property in the past, what damages occurred as a result?**

____

____

____

9. **Are you aware of any other flooding problems in the study area? (The attached map may be useful to mark the location of any problem areas).**

____

____

____

10. **Please provide dates of historic flooding, even if it is only the year in which the event occurred. Rank the floods from the most severe to the least severe.**

1. ___________ 2. ___________ 3. ___________ 4.___________

11. **For the floods you have listed, do you have any records of the height the floodwaters reached? For example, a flood mark on a building, shed, fence, light pole, etc.**

[ ] Yes [ ] No

12. **If you answered yes to Question 11, please provide a short description of the location of the flood mark(s), maximum depth of flooding, source and or direction of water, etc. Refer example below.**

	Location	**Maximum Depth (m)**	**Description**
[✓]	**EXAMPLE ONLY** Residential	0.3 m	8 March 2012, just after 2 pm - depth of floodwaters along northern side of house reached 0.3 m adjacent to front steps.
[ ]	Residential		
[ ]	Commercial		
[ ]	Park		
[ ]	Road/ Footpath		
[ ]	Other (please specify)		

13. **Do you have any photos, videos or other evidence of the flood marks that you have identified?**

[ ] Yes [ ] No

14. **If you answered yes to Question 13, could you please provide as much detail as possible, including whether you would be willing to provide Council with electronic copies of any photos/videos?**

You may wish to email any flood data that you have directly to Council (refer email address provided at the bottom of the attached Community Newsletter).

15. **Do you have any information on bridge or pipe blockage or the inundation of local roads due to surcharge of the existing drainage system?**

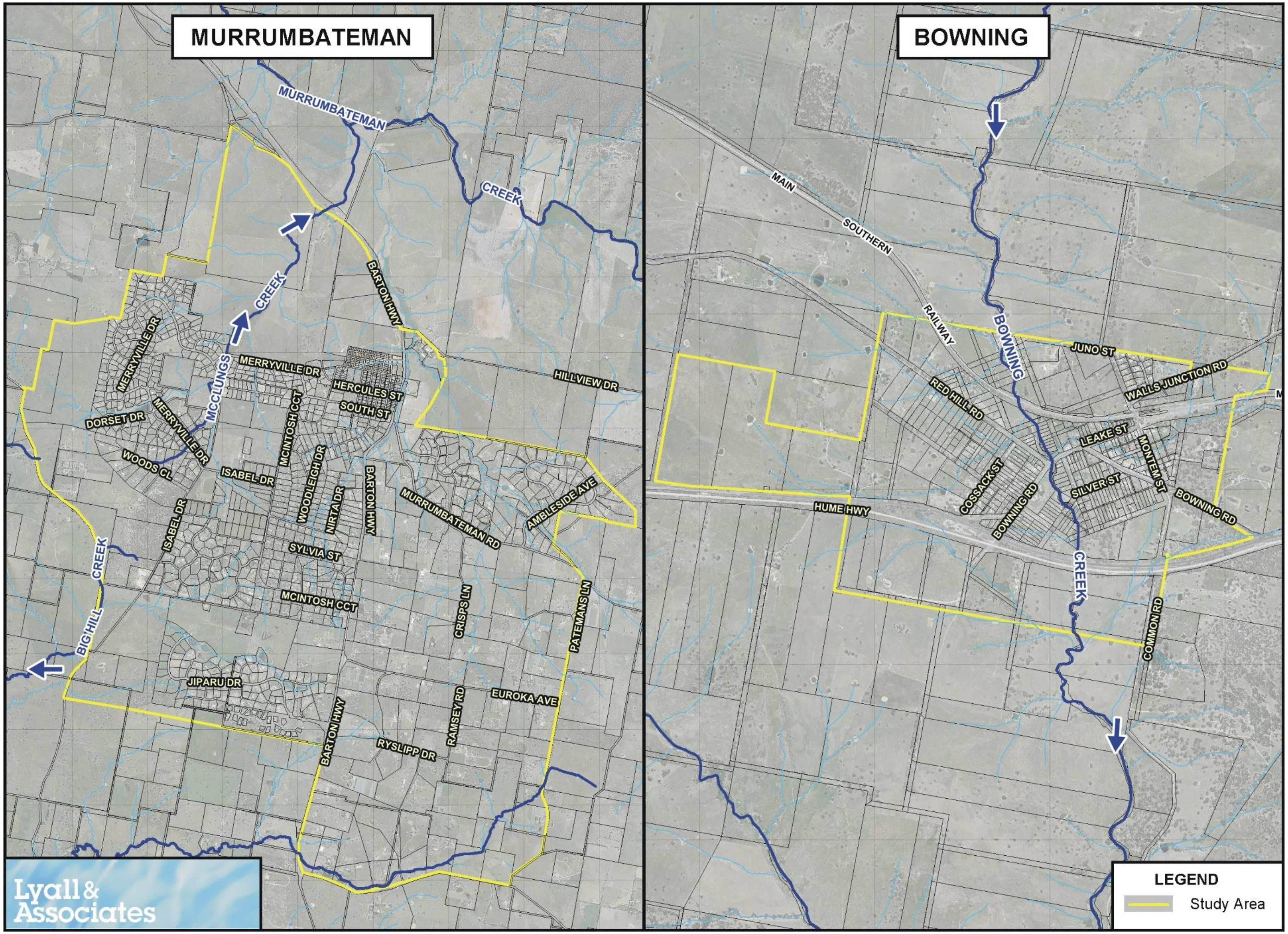
[ ] Yes [ ] No

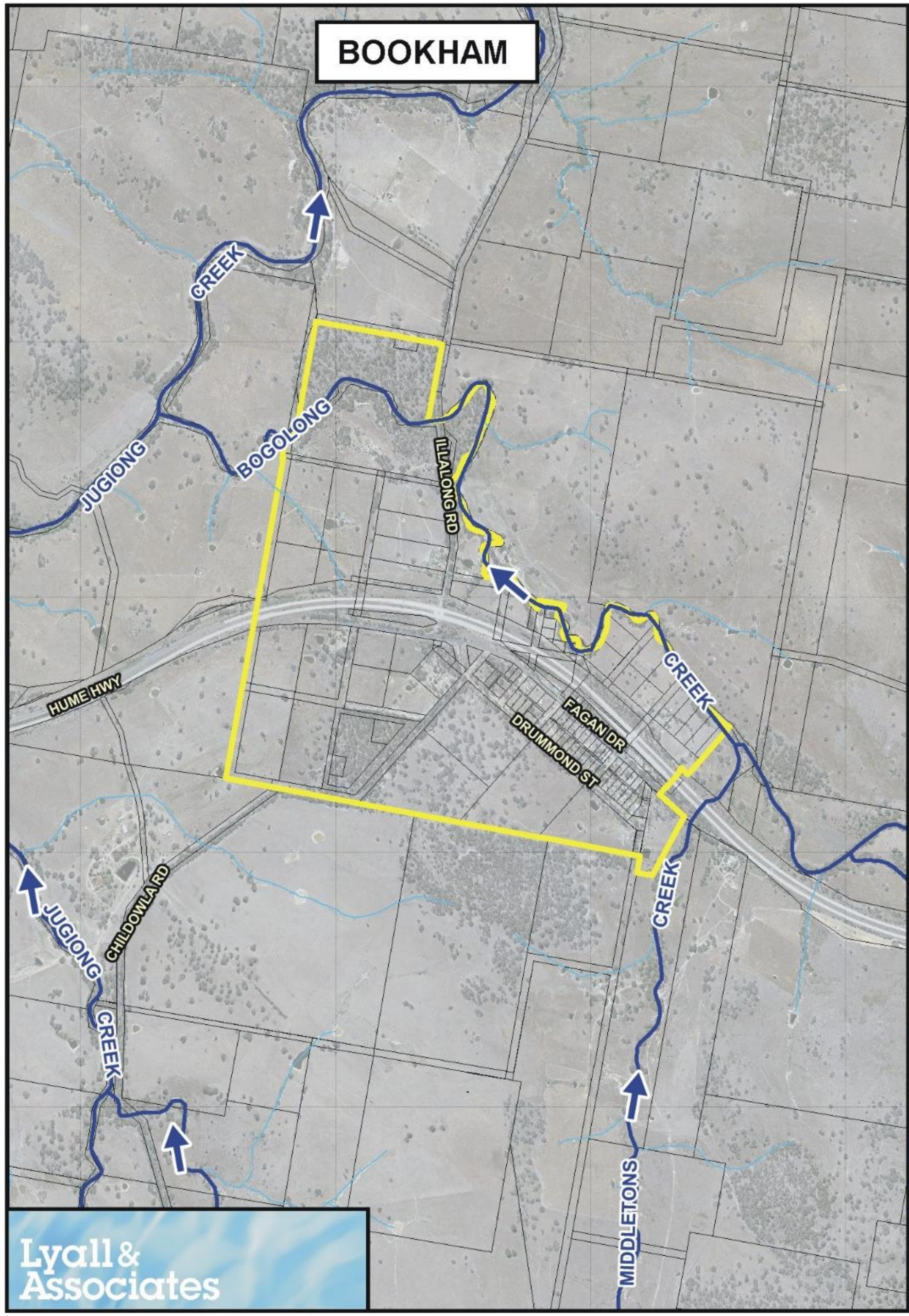
16. **If you answered yes to Question 15, could you please identify the location? Could you also comment on the nature of the blockage and/or the duration and depth of the flooding in the local road network?**

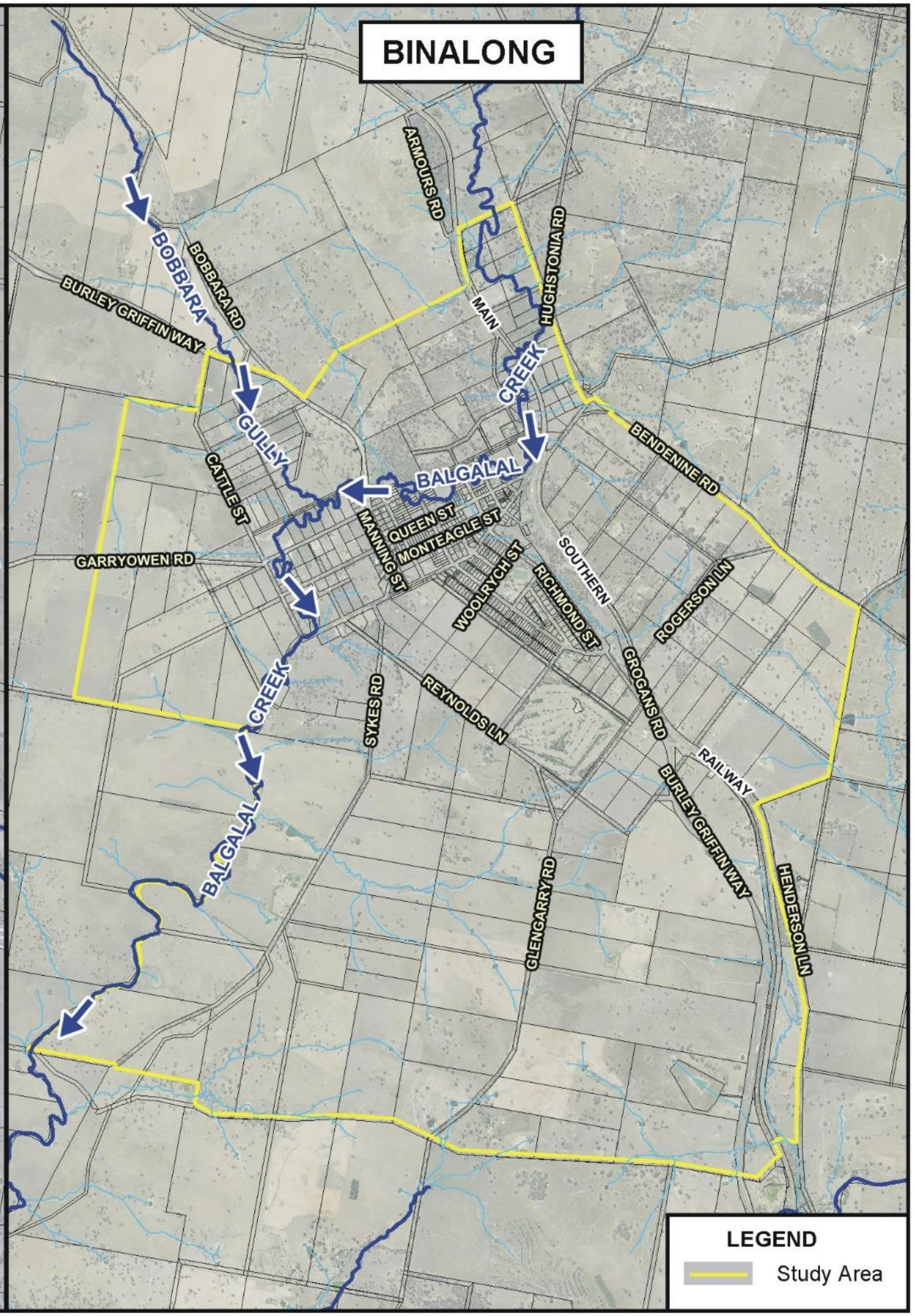
17. **Do you wish Council to contact you so you can provide further information? Please make sure you have provided your contact details in Question 1**

[ ] Yes [ ] No

18. **Please write any additional comments here:**


MURRUMBATEMAN
MURRUMBATEMAN CREEK
MCCLUNGS CREEK
BIG HILL CREEK
BARTON HWY
HILLVIEW DR
MERRYVILLE DR
HERCULES ST
SOUTH ST
DORSET DR
MCINTOSH CCT
WOODS CL
ISABEL DR
WOODLEIGH DR
NIRTA DR
MURRUMBATEMAN RD
AMBLESIDE AVE
SYLVIA ST
CRISPS LN
PATEMANS LN
JIPARU DR
RAMSEY RD
EUROKA AVE
RYSLIPP DR
BOWNING
MAIN SOUTHERN RAILWAY
BOWNING CREEK
JUNO ST
WALLS JUNCTION RD
RED HILL RD
LEAKE ST
MONTEM ST
COSSACK ST
SILVER ST
BOWNING RD
HUME HWY
COMMON RD
LEGEND
Study Area
Lyall & Associates


BOOKHAM
JUGIONG
CREEK
BOGOLONG
ILLALONG RD
HUME HWY
CREEK
FAGAN DR
DRUMMOND ST
CHILDOWLA RD
JUGIONG
CREEK
CREEK
MIDDLETONS
Lyall & Associates


BINALONG
ARMOURS RD
HUGHSTONIA RD
MAIN
BOBBARA
BOBBARA RD
BURLEY GRIFFIN WAY
CREEK
GULLY
BALGALAL
CATTLE ST
QUEEN ST
MONTEAGLE ST
MANNING ST
GARRYOWEN RD
SOUTHERN
BENDENINE RD
ROGERSON LN
WOOLRYCH ST
RICHMOND ST
CREEK
SYKES RD
REYNOLDS LN
GROGANS RD
RAILWAY
BURLEY GRIFFIN WAY
BALGALAL
GLENGARRY RD
HENDERSON LN
LEGEND
Study Area

APPENDIX B
DETAILS OF AVAILABLE DATA

B1. COLLECTION OF MISCELLANEOUS DATA

B1.1 Previous Reports

The following studies have previously been undertaken in the vicinity of the four villages:

- *Yass Flood Study* (WMA, 2016a)
- *Sutton Flood Study* (WMA, 2016b)
- *Gundaroo Flood Study* (WMA, 2016c)
- *Sutton Floodplain Risk Management Study and Plan* (WMA, 2016d)
- *Gundaroo Floodplain Risk Management Study and Plan* (WMA, 2016e)
- *MR15 Barton Highway Duplication, Hall to Yass – Flood Impact Assessment Report* (J. Wyndham Prince, 2018)

B1.2 Airborne Laser Scanning Survey

Table B2.1 sets out the details of the five sets of LiDAR survey data that cover the four villages. 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 B2.1
LiDAR SURVEY DATA SPECIFICATIONS

Data Set	Date of Capture	Data Provider
MurrumbatemanTown1212	December 2012	Lands and Property Information
BowningTown0313	March 2013	
BinalongTown201411	November 2014	
GDA94_MGA_Zone55_Murrumbateman_LIDAR_1808(1)	August 2018	AVMap Aerial Mapping & Surveying
GDA94_MGA_Zone55_Bookham_LIDAR_1808	August 2018	

1. "GDA94_MGA_Zone55_Murrumbateman_LIDAR_1808" data set covers a 1 km^2 area in the vicinity of the Fairley Village sub-division which has been constructed since the "MurrumbatemanTown1212" data set was captured in December 2012.

B1.3 Existing Stormwater Network

Figures 2.2, **2.3**, **2.4** and **2.5** of the Main Report show the plan location of the existing stormwater network at Murrumbateman, Bowning, Bookham and Binalong, respectively. Details of the stormwater network were taken from the following sources:

- **<u>Councils Stormwater Asset Database</u>**

  At the commencement of the study, Council provided a copy of its then current stormwater pit and pipe database in MAPINFO format. The database was generally limited to pipe and culvert dimensions, pipe invert levels and pit type in the vicinity of Fairley Village at Murrumbateman. Council's stormwater asset database also included the approximate alignment on the piped drainage system in the area that is bounded by Fairley Village to the north, the Barton Highway to the east, South Street to the south and West Street to the west.

The database did not contain details of the piped drainage system at Bowning, Bookham and Binalong.

- **Detailed Design Drawings**

At the commencement of the study, Council provided a hard-copy set of Work-As-Executed plans of the stormwater drainage network associated within the following residential subdivisions at Murrumbateman:

- Merryville Estate
- Jiparu Estate
- Carrington Park
- Meryville Park
- Dundoos Estate
- Ambleside Estate

The database was generally limited to pipe and culvert dimensions and alignments.

- **Road Asset Management System**

NSW Roads and Maritime Services (**Roads and Maritime**) South West Region provided details of the culvert and bridge crossings along the Barton Highway (Murrumbateman), the Hume Highway (Bowning and Bookham) and Burley Griffin Way (Binalong). The data were limited to culvert dimensions and alignment. Roads and Maritime also provided Work-As-Executed plans for the bridge structures on the aforementioned roads.

- **Structure Survey**

Diverse Property Solutions was engaged to undertake survey of the stormwater network that was not included in the available databases. Pipe and box culvert structure survey was provided as tabulations of location (coordinates set out in the MGA co-ordinate system), elevation, size and number of barrels in an Excel spreadsheet. Where the structure was a bridge, a sketch was provided showing its key dimensions. A photographic record of each structure was compiled by the surveyor.

B1.4 Floor Level Survey

A drive-by estimate of floor heights above natural surface level was undertaken by Lyall & Associates during field inspections in June 2018. The elevations of building floors were derived by adding the drive-by estimate of the above-ground floor height to the natural surface elevation determined from the available LiDAR survey data.

B1.5 Historic Rainfall Data

Rainfall data were available at five AWS and two pluviographic rain gauges, all of which are operated by BoM. **Figure 1.1** of the Main Report shows the plan location of the abovementioned gauges, while **Table B1.2** at the end of this Appendix sets out the details of the rain gauges, as well as the historic storm events for which rainfall data were available.

B1.6 Photographic Record

A number of photographs were provided by respondents to the *Community Newsletter and Questionnaire* showing flooding behaviour in in Murrumbateman during storms that occurred on 14 February 2010, 18 June 2016 and 21 September 2016, and in Binalong during storms that occurred on 14 February 2010, 24 January 2015, 31 August 2016 and 21 September 2016.

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

Gauge Number	Gauge Name	Storm Event										
		22-23 September 2009	13-15 February 2010	27 February - 5 March 2012	28 February - 1 March 2013	17-18 September 2013	25 January 2015	4-6 June 2016	20 June 2016	22-23 July 2016	31 August 2016	21-22 September 2016
70351	Canberra Airport	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
70330	Goulburn Airport AWS	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
70349	Mount Ginini AWS	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
73151	Temora Airport	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
70339	Tuggeranong (Isabella Plains) AWS	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
73138	Young Airport	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
73007	Burrinjuck Dam	No	No	Yes	No	No	No	No	No	No	No	No

1. Refer **Figure 1.1** for location.

APPENDIX C
PHOTOGRAPHS SHOWING HISTORIC FLOOD BEHAVIOUR IN MURRUMBATEMAN AND BINALONG

BINALONG – 14 FEBRUARY 2010

(Source: Beverley Pollard)

Plate C1.1 – (Photo taken at 11:00 hrs) Floodwater in channel on upstream (southern) side of Monteagle Street.

Plate C1.2 – (Photo taken at 11:00 hrs) Looking south from road reserve along channel adjacent to No. 2 Monteagle Street.

MURRUMBATEMAN – 14 FEBRUARY 2010

(Source: Simone Clark)

Plate C2.1 – (Photo taken at 12:39 hrs) Looking south-west across floodwater in the rear of No. 20 Broughton Circuit.

Plate C2.2 – (Photo taken at 12:38 hrs) Looking south from across floodwater in the rear of No. 20 Broughton Circuit.

Plate C2.3 – (Photo taken at 12:37 hrs) Looking south-east across floodwater in the rear of No. 20 Broughton Circuit.

Plate C2.4 – (Photo taken at 14:45 hrs) Looking north-west along boundary between Nos. 20 and 22 Broughton Circuit.

Plate C2.5 – (Photo taken at 14:27 hrs) Looking north-east from southern boundary of No. 20 Broughton Circuit.

Plate C2.6 – (Photo taken at 14:43 hrs) Looking north-west along boundary between Nos. 20 and 22 Broughton Circuit.

<table>
<tr><th colspan="2">MURRUMBATEMAN – 14 FEBRUARY 2010
(Source: Simone Clark)</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Plate C2.7 – (Photo taken at 14:48 hrs) Looking west along boundary between Nos. 20 and 22 Broughton Circuit.</td><td>Plate C2.8 – (Photo taken at 14:45 hrs) Photo showing approximate depth of overland flow along boundary between Nos. 20 and 22 Broughton Circuit.</td></tr>
</table>

BINALONG – 24 JANUARY 2015

(Source: Beverley Pollard)

Plate C3.1 – (Photo taken at 15:09 hrs) Looking north along channel adjacent to No. 2 Monteagle Street.

MURRUMBATEMAN – 18 JUNE 2016

(Source: Steve Hein)

	
Plate C4.1 – (Photo taken at 10:21 hrs) Looking north-west at McClungs Creek in the rear of No. 2 Woods Close.	**Plate C4.2** – (Photo taken at 10:31 hrs) Runoff flowing into existing dam at the rear of No. 2 Woods Close.

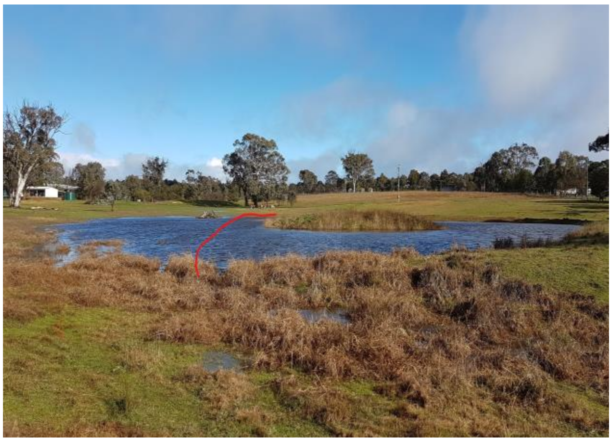



Plate C4.3 – (Photo taken on 23 Jul 10:17 hrs) Looking west across existing dam at the rear of No. 2 Woods Close. Normal dam line marked in photograph.	**Plate C4.4** – (Photo taken on 22 July 17:47 hrs) Looking south-east across existing dam at the rear of No. 2 Woods Close. Normal dam line marked in photograph.

BINALONG – 31 AUGUST 2016

(Source: Beverley Pollard)

Plate C5.1 – (Photo taken at 11:26 hrs) Looking west along channel at rear of No. 2 Monteagle Street.

Plate C5.2 – (Photo taken at 11:27 hrs) Looking west across channel adjacent to No. 2 Monteagle Street.

Plate C5.3 – (Photo taken at 11:28 hrs) Looking west across channel adjacent to No. 2 Monteagle Street.

BINALONG – 21 SEPTEMBER 2016

(Source: Luke McAlary)

Plate C6.1 – (Photo taken at 11:42 hrs) Looking north-east along Balgalal Creek from No. 32 Queen Street**.**

Plate C6.2 – (Photo taken at 14:57 hrs) Looking north across Balgalal Creek from northern end of Stephens Street.

Plate C6.3 – (Photo taken at 14:59 hrs) Looking north across Balgalal Creek from northern end of Stephens Street.

Plate C6.4 – (Photo taken at 15:12 hrs) Looking north along channel that runs parallel to Richmond Street between Monteagle Street and Queen Street.

MURRUMBATEMAN – 21 SEPTEMBER 2016

Plate C7.1 – (Photo taken at 12:50 hrs) Looking south-east from Elrington Close toward Murrumbateman Road**.** *(Source: Bob Evans)*

Plate C7.2 – (Photo taken at 12:50 hrs) Looking south-east from Elrington Close toward Murrumbateman Road**.** *(Source: Bob Evans)*

Plate C7.3 – (Photo taken at 12:50 hrs) Looking south-east from Elrington Close toward Murrumbateman Road**.** *(Source: Bob Evans)*

Plate C7.4 – (Photo taken at 17:15 hrs) Greenwood Road Crossing of Murrumbateman Creek**.** *(Source: Dennis Hogan)*

Plate C7.5 – (Photo taken at 17:30 hrs) Keirs Road Crossing of Murrumbateman Creek**.** *(Source: Dennis Hogan)*

Plate C7.6 – (Photo taken at 17:30 hrs) Keirs Road Crossing of Murrumbateman Creek**.** *(Source: Dennis Hogan)*

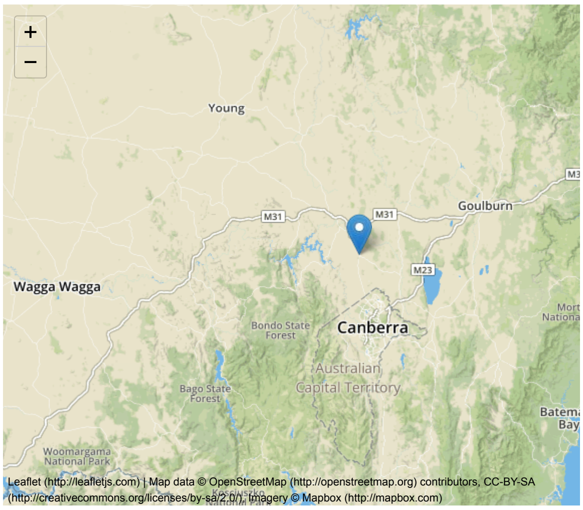
APPENDIX D
DESIGN INPUT DATA FROM ARR DATA HUB

ATTENTION: This site was updated recently, changing some of the functionality. Please see the changelog (./changelog) for further information

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	149.025
Latitude	-34.975
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	12
River Name	Murrumbidgee River

Layer Info

Time Accessed	23 July 2019 04:02PM
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
SE Coast	0.06	0.361	0.0	0.317	8.11e-05	0.651	0.0	0.0	0.0

Layer Info

Time Accessed	23 July 2019 04:02PM
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.

ID	22208.0
Storm Initial Losses (mm)	27.0
Storm Continuing Losses (mm/h)	3.7

Layer Info

Time Accessed	23 July 2019 04:02PM
Version	2016_v1

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

code	MB
Label	Murray Basin

Layer Info

Time Accessed	23 July 2019 04:02PM
Version	2016_v2

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

code	MB
arealabel	Murray Basin

Layer Info

Time Accessed	23 July 2019 04:02PM
Version	2016_v2

BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-34.975&longitude=149.025&sdmin=true&sdhr to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	23 July 2019 04:02PM

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)	0.0 (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)	0.2 (0.005)	0.4 (0.008)
120 (2.0)	0.3 (0.012)	0.2 (0.006)	0.1 (0.003)	0.1 (0.001)	0.3 (0.005)	0.4 (0.008)
180 (3.0)	0.1 (0.005)	0.9 (0.026)	1.4 (0.035)	1.9 (0.041)	0.8 (0.015)	0.0 (0.000)
360 (6.0)	0.8 (0.024)	0.5 (0.011)	0.2 (0.005)	0.0 (0.000)	0.3 (0.005)	0.5 (0.007)
720 (12.0)	0.2 (0.004)	1.4 (0.026)	2.3 (0.034)	3.1 (0.039)	5.6 (0.059)	7.5 (0.069)
1080 (18.0)	0.0 (0.000)	0.7 (0.011)	1.2 (0.015)	1.6 (0.018)	7.0 (0.064)	11.1 (0.087)
1440 (24.0)	0.0 (0.000)	0.2 (0.003)	0.3 (0.004)	0.4 (0.004)	2.8 (0.023)	4.6 (0.033)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.6 (0.004)	1.0 (0.007)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.1 (0.001)	0.2 (0.001)
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	23 July 2019 04:02PM
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	23 July 2019 04:02PM
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 (0.000)	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	23 July 2019 04:02PM
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)	10.1 (0.575)	9.3 (0.394)	8.8 (0.317)	8.3 (0.261)	10.1 (0.271)	11.4 (0.275)
90 (1.5)	8.6 (0.430)	8.1 (0.302)	7.8 (0.246)	7.5 (0.206)	10.2 (0.238)	12.2 (0.255)
120 (2.0)	11.8 (0.541)	9.7 (0.328)	8.2 (0.237)	6.8 (0.171)	10.3 (0.217)	12.8 (0.242)
180 (3.0)	10.0 (0.400)	12.4 (0.370)	14.0 (0.354)	15.6 (0.339)	12.7 (0.232)	10.6 (0.171)
360 (6.0)	7.6 (0.238)	9.2 (0.215)	10.2 (0.201)	11.3 (0.189)	20.6 (0.287)	27.7 (0.336)
720 (12.0)	7.3 (0.179)	11.1 (0.202)	13.6 (0.206)	16.0 (0.206)	29.9 (0.315)	40.3 (0.369)
1080 (18.0)	4.4 (0.092)	8.2 (0.129)	10.7 (0.140)	13.2 (0.146)	27.6 (0.250)	38.4 (0.302)
1440 (24.0)	0.2 (0.003)	3.6 (0.051)	5.8 (0.069)	8.0 (0.080)	14.8 (0.122)	19.9 (0.143)
2160 (36.0)	0.0 (0.000)	1.3 (0.016)	2.1 (0.022)	2.9 (0.026)	7.8 (0.057)	11.5 (0.074)
2880 (48.0)	0.0 (0.000)	1.3 (0.014)	2.1 (0.020)	2.9 (0.024)	5.8 (0.040)	8.0 (0.048)
4320 (72.0)	0.0 (0.000)	0.1 (0.001)	0.1 (0.001)	0.2 (0.001)	0.4 (0.002)	0.5 (0.003)

Layer Info

Time Accessed	23 July 2019 04:02PM
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)	24.5 (1.401)	21.1 (0.896)	18.8 (0.680)	16.6 (0.524)	22.8 (0.613)	27.4 (0.662)
90 (1.5)	16.7 (0.838)	18.9 (0.705)	20.3 (0.644)	21.7 (0.598)	21.8 (0.511)	21.9 (0.459)
120 (2.0)	22.5 (1.027)	22.9 (0.778)	23.1 (0.667)	23.4 (0.585)	28.9 (0.612)	33.1 (0.624)
180 (3.0)	19.9 (0.795)	22.9 (0.681)	24.8 (0.625)	26.7 (0.581)	24.2 (0.442)	22.4 (0.362)
360 (6.0)	18.2 (0.570)	24.7 (0.577)	28.9 (0.569)	33.1 (0.556)	51.6 (0.718)	65.5 (0.797)
720 (12.0)	19.6 (0.477)	31.9 (0.579)	40.0 (0.607)	47.8 (0.616)	67.7 (0.715)	82.7 (0.757)
1080 (18.0)	14.4 (0.304)	21.2 (0.333)	25.8 (0.337)	30.1 (0.333)	56.5 (0.513)	76.3 (0.601)
1440 (24.0)	6.0 (0.114)	16.4 (0.234)	23.4 (0.277)	30.0 (0.301)	36.6 (0.301)	41.5 (0.298)
2160 (36.0)	6.5 (0.110)	10.2 (0.128)	12.7 (0.132)	15.0 (0.133)	23.7 (0.173)	30.2 (0.194)
2880 (48.0)	1.3 (0.020)	8.3 (0.095)	12.9 (0.124)	17.3 (0.142)	23.2 (0.158)	27.5 (0.166)
4320 (72.0)	3.5 (0.049)	6.7 (0.070)	8.8 (0.078)	10.9 (0.082)	12.2 (0.077)	13.2 (0.074)

Layer Info

Time Accessed	23 July 2019 04:02PM
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	**0.816 (4.1%)**	0.726 (3.6%)	**0.934 (4.7%)**
2040	**1.046 (5.2%)**	1.015 (5.1%)	**1.305 (6.6%)**
2050	**1.260 (6.3%)**	1.277 (6.4%)	**1.737 (8.8%)**
2060	**1.450 (7.3%)**	1.520 (7.7%)	**2.214 (11.4%)**
2070	**1.609 (8.2%)**	1.753 (8.9%)	**2.722 (14.2%)**
2080	**1.728 (8.8%)**	1.985 (10.2%)	**3.246 (17.2%)**
2090	**1.798 (9.2%)**	2.226 (11.5%)	**3.772 (20.2%)**

Layer Info

Time Accessed	23 July 2019 04:02PM
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	20	10	5	2	1
60 (1.0)	17.7	11.9	10.8	11.0	10.6	9.4
90 (1.5)	20.2	13.7	12.2	12.3	11.5	10.7
120 (2.0)	20.8	12.8	11.9	12.4	11.5	9.7
180 (3.0)	21.0	13.4	12.1	12.6	12.8	12.1
360 (6.0)	21.4	14.9	14.2	14.6	13.2	7.6
720 (12.0)	21.4	14.9	14.5	14.5	11.4	6.9
1080 (18.0)	22.9	17.6	17.2	18.0	13.2	7.0
1440 (24.0)	25.5	20.1	19.4	20.4	17.6	9.5
2160 (36.0)	26.0	21.4	22.1	24.4	20.2	14.0
2880 (48.0)	27.3	22.3	22.5	24.9	20.9	14.3
4320 (72.0)	27.1	23.2	24.7	27.3	24.1	19.8

Layer Info

Time Accessed	23 July 2019 04:02PM
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/7a1e482b-50d7-43e9-9e77-6e3a17e7ce8e.txt)

Download JSON (downloads/ab3b9977-e111-4a35-8c18-23b700f3dda7.json)

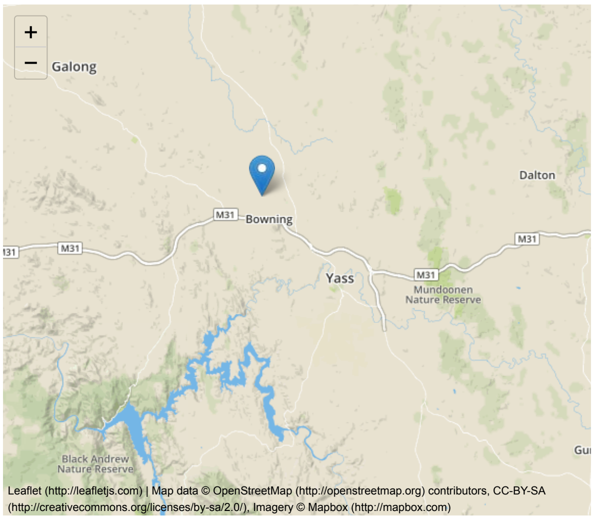
Generating PDF... (downloads/b047daa2-6454-479c-8065-9da7ca96c813.pdf)

ATTENTION: This site was updated recently, changing some of the functionality. Please see the changelog (./changelog) for further information

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	148.81
Latitude	-34.746
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	12
River Name	Murrumbidgee River

Layer Info

Time Accessed	05 August 2019 03:34PM
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
Southern Temperate	0.158	0.276	0.372	0.315	0.000141	0.41	0.15	0.01	-0.0027

Layer Info

Time Accessed	05 August 2019 03:34PM
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.

ID	4511.0
Storm Initial Losses (mm)	30.0
Storm Continuing Losses (mm/h)	4.5

Layer Info

Time Accessed	05 August 2019 03:34PM
Version	2016_v1

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

code	MB
Label	Murray Basin

Layer Info

Time Accessed	05 August 2019 03:34PM
Version	2016_v2

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

code	MB
arealabel	Murray Basin

Layer Info

Time Accessed	05 August 2019 03:34PM
Version	2016_v2

BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-34.746&longitude=148.81&sdmin=true&sdhr= to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	05 August 2019 03:34PM

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)	0.0 (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)	0.1 (0.007)	0.1 (0.003)	0.0 (0.001)	0.0 (0.000)	0.1 (0.002)	0.1 (0.003)
120 (2.0)	0.1 (0.004)	0.1 (0.004)	0.1 (0.004)	0.1 (0.004)	0.3 (0.007)	0.4 (0.008)
180 (3.0)	4.0 (0.164)	2.8 (0.085)	2.0 (0.051)	1.2 (0.026)	0.6 (0.012)	0.2 (0.003)
360 (6.0)	0.6 (0.018)	0.5 (0.011)	0.4 (0.008)	0.3 (0.006)	0.6 (0.008)	0.8 (0.010)
720 (12.0)	0.0 (0.000)	1.6 (0.028)	2.6 (0.039)	3.6 (0.047)	7.5 (0.081)	10.5 (0.099)
1080 (18.0)	0.0 (0.000)	0.6 (0.009)	1.0 (0.013)	1.3 (0.015)	5.6 (0.052)	8.8 (0.072)
1440 (24.0)	0.0 (0.000)	0.3 (0.004)	0.5 (0.006)	0.6 (0.007)	1.9 (0.016)	2.9 (0.022)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.3 (0.002)	0.5 (0.004)
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	05 August 2019 03:34PM
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	05 August 2019 03:34PM
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 (0.000)	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	05 August 2019 03:34PM
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)	6.8 (0.412)	5.3 (0.240)	4.3 (0.165)	3.3 (0.111)	5.9 (0.169)	7.9 (0.202)
90 (1.5)	7.1 (0.375)	6.2 (0.245)	5.6 (0.188)	5.1 (0.147)	9.8 (0.240)	13.3 (0.291)
120 (2.0)	12.3 (0.582)	12.7 (0.449)	12.9 (0.388)	13.2 (0.343)	13.2 (0.291)	13.3 (0.260)
180 (3.0)	16.0 (0.657)	15.1 (0.460)	14.4 (0.373)	13.8 (0.308)	11.7 (0.220)	10.2 (0.169)
360 (6.0)	9.1 (0.287)	11.5 (0.269)	13.1 (0.258)	14.6 (0.247)	20.4 (0.288)	24.8 (0.307)
720 (12.0)	3.7 (0.089)	10.0 (0.181)	14.2 (0.215)	18.3 (0.236)	30.3 (0.324)	39.3 (0.370)
1080 (18.0)	1.9 (0.040)	6.6 (0.103)	9.7 (0.127)	12.7 (0.142)	21.4 (0.198)	27.8 (0.228)
1440 (24.0)	0.9 (0.017)	4.5 (0.064)	6.9 (0.083)	9.3 (0.094)	11.2 (0.096)	12.7 (0.096)
2160 (36.0)	0.3 (0.005)	2.0 (0.025)	3.1 (0.033)	4.1 (0.037)	6.8 (0.052)	8.8 (0.060)
2880 (48.0)	0.0 (0.000)	0.2 (0.002)	0.3 (0.003)	0.5 (0.004)	4.0 (0.029)	6.6 (0.043)
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	05 August 2019 03:34PM
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)	16.9 (1.021)	20.9 (0.947)	23.5 (0.908)	26.0 (0.875)	26.0 (0.742)	25.9 (0.661)
90 (1.5)	15.3 (0.805)	17.3 (0.680)	18.6 (0.621)	19.8 (0.575)	21.7 (0.532)	23.0 (0.504)
120 (2.0)	22.1 (1.046)	25.6 (0.907)	27.9 (0.840)	30.2 (0.786)	28.5 (0.628)	27.3 (0.534)
180 (3.0)	40.4 (1.659)	34.5 (1.054)	30.6 (0.790)	26.8 (0.598)	25.7 (0.481)	24.8 (0.411)
360 (6.0)	18.4 (0.583)	25.3 (0.593)	29.8 (0.588)	34.2 (0.579)	47.4 (0.667)	57.2 (0.709)
720 (12.0)	19.0 (0.464)	33.2 (0.598)	42.6 (0.642)	51.6 (0.664)	67.1 (0.718)	78.7 (0.740)
1080 (18.0)	14.6 (0.309)	21.5 (0.337)	26.1 (0.341)	30.5 (0.340)	48.6 (0.451)	62.1 (0.508)
1440 (24.0)	11.8 (0.228)	19.2 (0.274)	24.1 (0.287)	28.8 (0.293)	30.6 (0.260)	31.9 (0.240)
2160 (36.0)	9.4 (0.161)	14.0 (0.178)	17.1 (0.182)	20.1 (0.182)	21.4 (0.164)	22.5 (0.153)
2880 (48.0)	1.2 (0.019)	5.4 (0.063)	8.1 (0.081)	10.8 (0.092)	21.0 (0.152)	28.6 (0.185)
4320 (72.0)	1.0 (0.014)	5.0 (0.054)	7.6 (0.070)	10.2 (0.080)	10.4 (0.070)	10.5 (0.064)

Layer Info

Time Accessed	05 August 2019 03:34PM
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	**0.816 (4.1%)**	0.726 (3.6%)	**0.934 (4.7%)**
2040	**1.046 (5.2%)**	1.015 (5.1%)	**1.305 (6.6%)**
2050	**1.260 (6.3%)**	1.277 (6.4%)	**1.737 (8.8%)**
2060	**1.450 (7.3%)**	1.520 (7.7%)	**2.214 (11.4%)**
2070	**1.609 (8.2%)**	1.753 (8.9%)	**2.722 (14.2%)**
2080	**1.728 (8.8%)**	1.985 (10.2%)	**3.246 (17.2%)**
2090	**1.798 (9.2%)**	2.226 (11.5%)	**3.772 (20.2%)**

Layer Info

Time Accessed	05 August 2019 03:34PM
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	20	10	5	2	1
60 (1.0)	16.8	14.4	12.1	11.5	11.4	10.0
90 (1.5)	19.2	15.3	13.4	13.1	12.6	11.5
120 (2.0)	21.2	13.5	11.8	11.7	11.7	11.3
180 (3.0)	20.5	11.5	11.3	12.7	13.1	12.3
360 (6.0)	23.8	16.2	14.8	15.2	13.1	9.0
720 (12.0)	24.5	17.2	15.7	15.2	12.7	6.3
1080 (18.0)	25.7	20.2	19.0	19.3	15.6	10.2
1440 (24.0)	26.9	21.4	20.7	22.0	19.3	14.0
2160 (36.0)	28.0	22.9	23.5	25.3	23.0	15.6
2880 (48.0)	30.1	25.2	26.4	27.6	24.2	16.6
4320 (72.0)	30.5	25.7	27.1	28.8	25.3	22.2

Layer Info

Time Accessed	05 August 2019 03:34PM
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/10b5b875-7022-48cf-ab46-628ce5765403.txt)

Download JSON (downloads/65f48c3f-6290-49eb-a957-62ab84289243.json)

Generating PDF... (downloads/39f2d2da-33f2-4628-b9d1-ccaa8452f123.pdf)

ATTENTION: This site was updated recently, changing some of the functionality. Please see the changelog (./changelog) for further information

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	148.649
Latitude	-34.854
Selected Regions (clear)	
River Region	show
ARF Parameters	show
Storm Losses	show
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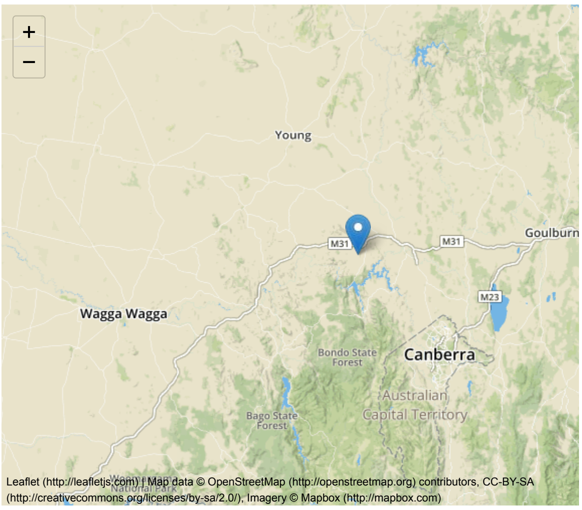
Areal Temporal Patterns	show
BOM IFDs	show
Median Preburst Depths and Ratios	show
10% Preburst Depths	show
25% Preburst Depths	show
75% Preburst Depths	show
90% Preburst Depths	show
Interim Climate Change Factors	show
Probability Neutral Burst Initial Loss (./nsw_specific)	show



Data

River Region

Division	Murray-Darling Basin
River Number	12
River Name	Murrumbidgee River

Layer Info

Time Accessed	16 August 2019 01:32PM
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
Southern Temperate	0.158	0.276	0.372	0.315	0.000141	0.41	0.15	0.01	-0.0027

Layer Info

Time Accessed	16 August 2019 01:32PM
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.

ID	18727.0
Storm Initial Losses (mm)	31.0
Storm Continuing Losses (mm/h)	4.1

Layer Info

Time Accessed	16 August 2019 01:32PM
Version	2016_v1

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

code	MB
Label	Murray Basin

Layer Info

Time Accessed	16 August 2019 01:32PM
Version	2016_v2

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

code	MB
arealabel	Murray Basin

Layer Info

Time Accessed	16 August 2019 01:32PM
Version	2016_v2

BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-34.854014&longitude=148.648668&sdmin=tru to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	16 August 2019 01:32PM

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)	1.1 (0.059)	0.6 (0.026)	0.3 (0.012)	0.1 (0.002)	0.0 (0.001)	0.0 (0.000)
90 (1.5)	1.6 (0.075)	1.1 (0.040)	0.8 (0.024)	0.5 (0.013)	0.6 (0.014)	0.7 (0.014)
120 (2.0)	1.3 (0.058)	0.9 (0.029)	0.6 (0.016)	0.3 (0.007)	0.3 (0.006)	0.2 (0.004)
180 (3.0)	2.1 (0.081)	1.8 (0.050)	1.5 (0.037)	1.3 (0.027)	0.6 (0.011)	0.1 (0.002)
360 (6.0)	3.1 (0.091)	1.9 (0.041)	1.1 (0.020)	0.3 (0.005)	0.7 (0.010)	1.1 (0.012)
720 (12.0)	0.4 (0.009)	1.8 (0.030)	2.7 (0.038)	3.6 (0.043)	7.6 (0.076)	10.6 (0.093)
1080 (18.0)	0.0 (0.000)	1.1 (0.016)	1.8 (0.022)	2.5 (0.026)	7.4 (0.064)	11.1 (0.085)
1440 (24.0)	0.0 (0.000)	0.4 (0.005)	0.7 (0.008)	1.0 (0.009)	3.6 (0.028)	5.5 (0.038)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.2 (0.002)	0.4 (0.002)
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	16 August 2019 01:32PM
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	16 August 2019 01:32PM
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 (0.000)	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)	0.2 (0.002)	0.3 (0.003)
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	16 August 2019 01:32PM
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)	10.1 (0.565)	9.8 (0.410)	9.6 (0.341)	9.4 (0.291)	10.4 (0.271)	11.2 (0.259)
90 (1.5)	12.6 (0.610)	11.6 (0.419)	10.9 (0.335)	10.3 (0.273)	12.7 (0.285)	14.5 (0.289)
120 (2.0)	12.7 (0.555)	11.9 (0.388)	11.4 (0.314)	10.8 (0.259)	10.1 (0.203)	9.5 (0.169)
180 (3.0)	11.5 (0.434)	13.6 (0.383)	15.0 (0.357)	16.3 (0.335)	14.1 (0.243)	12.5 (0.190)
360 (6.0)	14.9 (0.436)	14.7 (0.320)	14.5 (0.266)	14.4 (0.226)	22.2 (0.291)	28.1 (0.323)
720 (12.0)	9.5 (0.215)	13.0 (0.219)	15.4 (0.216)	17.6 (0.211)	30.8 (0.308)	40.7 (0.357)
1080 (18.0)	2.3 (0.044)	6.9 (0.100)	9.9 (0.121)	12.9 (0.133)	25.4 (0.219)	34.7 (0.264)
1440 (24.0)	0.9 (0.016)	4.5 (0.059)	6.9 (0.076)	9.2 (0.086)	16.0 (0.126)	21.0 (0.146)
2160 (36.0)	0.0 (0.000)	1.7 (0.020)	2.9 (0.028)	4.0 (0.033)	7.7 (0.054)	10.5 (0.065)
2880 (48.0)	0.0 (0.000)	1.5 (0.016)	2.4 (0.022)	3.4 (0.026)	6.0 (0.039)	8.0 (0.046)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.1 (0.001)	0.1 (0.001)	0.2 (0.001)	0.3 (0.002)

Layer Info

Time Accessed	16 August 2019 01:32PM
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)	24.6 (1.371)	22.2 (0.928)	20.7 (0.734)	19.2 (0.591)	21.9 (0.570)	23.9 (0.555)
90 (1.5)	24.9 (1.205)	25.5 (0.923)	25.9 (0.795)	26.3 (0.700)	29.3 (0.657)	31.6 (0.628)
120 (2.0)	33.1 (1.446)	31.2 (1.019)	30.0 (0.829)	28.8 (0.689)	32.2 (0.648)	34.7 (0.620)
180 (3.0)	20.7 (0.783)	24.9 (0.703)	27.7 (0.661)	30.4 (0.625)	31.2 (0.537)	31.8 (0.484)
360 (6.0)	27.1 (0.794)	32.2 (0.701)	35.5 (0.651)	38.8 (0.609)	56.7 (0.741)	70.1 (0.805)
720 (12.0)	25.2 (0.572)	33.0 (0.555)	38.2 (0.537)	43.2 (0.518)	68.1 (0.680)	86.9 (0.761)
1080 (18.0)	16.9 (0.329)	23.0 (0.333)	27.1 (0.328)	31.0 (0.321)	53.5 (0.463)	70.5 (0.536)
1440 (24.0)	11.0 (0.195)	17.4 (0.228)	21.6 (0.238)	25.7 (0.241)	35.2 (0.277)	42.3 (0.295)
2160 (36.0)	11.3 (0.175)	13.8 (0.159)	15.4 (0.149)	17.0 (0.141)	22.2 (0.156)	26.1 (0.163)
2880 (48.0)	3.2 (0.045)	11.2 (0.119)	16.5 (0.148)	21.6 (0.166)	24.4 (0.159)	26.5 (0.155)
4320 (72.0)	3.2 (0.042)	7.0 (0.067)	9.4 (0.076)	11.8 (0.083)	9.2 (0.055)	7.3 (0.039)

Layer Info

Time Accessed	16 August 2019 01:32PM
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	**0.816 (4.1%)**	0.726 (3.6%)	**0.934 (4.7%)**
2040	**1.046 (5.2%)**	1.015 (5.1%)	**1.305 (6.6%)**
2050	**1.260 (6.3%)**	1.277 (6.4%)	**1.737 (8.8%)**
2060	**1.450 (7.3%)**	1.520 (7.7%)	**2.214 (11.4%)**
2070	**1.609 (8.2%)**	1.753 (8.9%)	**2.722 (14.2%)**
2080	**1.728 (8.8%)**	1.985 (10.2%)	**3.246 (17.2%)**
2090	**1.798 (9.2%)**	2.226 (11.5%)	**3.772 (20.2%)**

Layer Info

Time Accessed	16 August 2019 01:32PM
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	20	10	5	2	1
60 (1.0)	18.1	13.2	11.6	11.7	12.1	11.5
90 (1.5)	20.9	13.4	11.9	12.2	12.0	11.3
120 (2.0)	22.8	12.6	12.1	12.9	12.8	11.1
180 (3.0)	23.6	14.9	13.4	13.9	13.9	12.2
360 (6.0)	21.8	15.4	14.3	15.3	13.7	8.6
720 (12.0)	23.5	17.1	16.2	16.6	13.8	6.7
1080 (18.0)	26.3	20.6	19.5	20.4	15.4	8.2
1440 (24.0)	27.9	22.4	22.5	23.5	18.4	12.2
2160 (36.0)	28.7	23.9	24.7	27.0	24.5	16.0
2880 (48.0)	30.6	25.1	25.1	27.4	24.4	16.9
4320 (72.0)	31.0	26.3	27.8	29.9	27.5	23.6

Layer Info

Time Accessed	16 August 2019 01:32PM
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/67ddea33-7b6f-45f2-a5b5-373efdb06d90.txt)

Download JSON (downloads/b0e304be-244c-42f9-8ead-e414a49567cf.json)

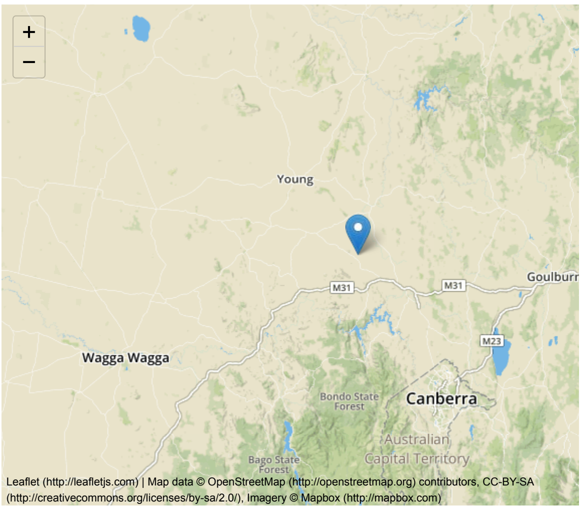
Generating PDF... (downloads/05adcb9e-ff9b-4822-ad6f-f02702baea50.pdf)

ATTENTION: This site was updated recently, changing some of the functionality. Please see the changelog (./changelog) for further information

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	148.641
Latitude	-34.658
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	12
River Name	Murrumbidgee River

Layer Info

Time Accessed	11 July 2019 02:47PM
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
Southern Temperate	0.158	0.276	0.372	0.315	0.000141	0.41	0.15	0.01	-0.0027

Layer Info

Time Accessed	11 July 2019 02:47PM
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.

ID	16012.0
Storm Initial Losses (mm)	31.0
Storm Continuing Losses (mm/h)	4.2

Layer Info

Time Accessed	11 July 2019 02:47PM
Version	2016_v1

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

code	MB
Label	Murray Basin

Layer Info

Time Accessed	11 July 2019 02:47PM
Version	2016_v2

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

code	MB
arealabel	Murray Basin

Layer Info

Time Accessed	11 July 2019 02:47PM
Version	2016_v2

BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-34.658&longitude=148.641&sdmin=true&sdh
to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	11 July 2019 02:47PM

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)	1.0 (0.058)	0.6 (0.025)	0.3 (0.010)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
90 (1.5)	1.1 (0.058)	0.7 (0.025)	0.3 (0.011)	0.0 (0.001)	0.4 (0.009)	0.7 (0.013)
120 (2.0)	0.8 (0.035)	0.5 (0.016)	0.3 (0.008)	0.1 (0.002)	0.2 (0.005)	0.3 (0.006)
180 (3.0)	2.1 (0.082)	1.6 (0.048)	1.3 (0.033)	1.1 (0.023)	0.5 (0.008)	0.0 (0.000)
360 (6.0)	2.6 (0.079)	1.5 (0.035)	0.8 (0.016)	0.2 (0.003)	0.5 (0.007)	0.8 (0.010)
720 (12.0)	0.0 (0.001)	0.9 (0.017)	1.5 (0.023)	2.1 (0.027)	6.5 (0.073)	9.8 (0.098)
1080 (18.0)	0.0 (0.000)	0.5 (0.008)	0.9 (0.012)	1.2 (0.014)	4.5 (0.044)	6.9 (0.060)
1440 (24.0)	0.0 (0.000)	0.4 (0.005)	0.6 (0.007)	0.8 (0.009)	1.6 (0.015)	2.2 (0.018)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.1 (0.001)	0.2 (0.001)
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	11 July 2019 02:47PM
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	11 July 2019 02:47PM
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 (0.000)	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	11 July 2019 02:47PM
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)	12.8 (0.737)	10.1 (0.437)	8.4 (0.307)	6.7 (0.213)	9.1 (0.245)	11.0 (0.262)
90 (1.5)	10.6 (0.531)	9.6 (0.359)	8.9 (0.284)	8.3 (0.229)	10.9 (0.254)	12.9 (0.267)
120 (2.0)	11.9 (0.540)	9.6 (0.325)	8.1 (0.232)	6.6 (0.165)	9.6 (0.202)	11.8 (0.221)
180 (3.0)	12.4 (0.492)	13.0 (0.382)	13.3 (0.333)	13.7 (0.295)	10.4 (0.190)	8.0 (0.130)
360 (6.0)	12.9 (0.399)	12.4 (0.286)	12.1 (0.236)	11.8 (0.199)	18.8 (0.267)	24.1 (0.304)
720 (12.0)	6.1 (0.146)	9.7 (0.174)	12.0 (0.183)	14.3 (0.189)	25.5 (0.284)	34.0 (0.336)
1080 (18.0)	3.1 (0.065)	6.9 (0.108)	9.4 (0.125)	11.8 (0.136)	18.9 (0.185)	24.2 (0.211)
1440 (24.0)	0.4 (0.007)	3.7 (0.053)	6.0 (0.073)	8.1 (0.086)	11.5 (0.104)	14.1 (0.113)
2160 (36.0)	0.0 (0.000)	1.8 (0.023)	3.0 (0.033)	4.2 (0.040)	5.5 (0.044)	6.4 (0.046)
2880 (48.0)	0.0 (0.000)	0.7 (0.008)	1.1 (0.011)	1.5 (0.013)	3.7 (0.028)	5.4 (0.036)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.1 (0.001)	0.1 (0.001)	0.1 (0.001)	0.2 (0.001)

Layer Info

Time Accessed	11 July 2019 02:47PM
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)	23.9 (1.378)	21.0 (0.905)	19.1 (0.698)	17.3 (0.547)	22.0 (0.590)	25.6 (0.611)
90 (1.5)	20.3 (1.018)	21.5 (0.805)	22.3 (0.708)	23.1 (0.635)	25.7 (0.598)	27.7 (0.574)
120 (2.0)	28.7 (1.308)	27.2 (0.925)	26.2 (0.755)	25.3 (0.630)	29.7 (0.625)	33.0 (0.617)
180 (3.0)	24.5 (0.968)	24.6 (0.726)	24.7 (0.617)	24.8 (0.536)	23.1 (0.421)	21.9 (0.354)
360 (6.0)	21.9 (0.676)	26.0 (0.600)	28.8 (0.561)	31.4 (0.530)	49.2 (0.698)	62.6 (0.788)
720 (12.0)	18.8 (0.453)	28.4 (0.512)	34.8 (0.531)	41.0 (0.540)	61.5 (0.685)	76.9 (0.762)
1080 (18.0)	15.4 (0.323)	21.1 (0.332)	25.0 (0.332)	28.6 (0.330)	44.9 (0.439)	57.1 (0.498)
1440 (24.0)	8.4 (0.162)	14.7 (0.211)	18.8 (0.229)	22.8 (0.241)	27.8 (0.250)	31.6 (0.254)
2160 (36.0)	5.8 (0.099)	12.0 (0.153)	16.0 (0.174)	19.9 (0.189)	19.3 (0.156)	18.8 (0.136)
2880 (48.0)	2.2 (0.035)	7.0 (0.084)	10.2 (0.104)	13.3 (0.117)	20.2 (0.152)	25.3 (0.172)
4320 (72.0)	0.7 (0.011)	5.8 (0.063)	9.1 (0.084)	12.3 (0.100)	10.3 (0.072)	8.8 (0.055)

Layer Info

Time Accessed	11 July 2019 02:47PM
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	**0.816 (4.1%)**	0.726 (3.6%)	**0.934 (4.7%)**
2040	**1.046 (5.2%)**	1.015 (5.1%)	**1.305 (6.6%)**
2050	**1.260 (6.3%)**	1.277 (6.4%)	**1.737 (8.8%)**
2060	**1.450 (7.3%)**	1.520 (7.7%)	**2.214 (11.4%)**
2070	**1.609 (8.2%)**	1.753 (8.9%)	**2.722 (14.2%)**
2080	**1.728 (8.8%)**	1.985 (10.2%)	**3.246 (17.2%)**
2090	**1.798 (9.2%)**	2.226 (11.5%)	**3.772 (20.2%)**

Layer Info

Time Accessed	11 July 2019 02:47PM
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	20	10	5	2	1
60 (1.0)	17.5	13.5	11.6	11.7	12.5	12.0
90 (1.5)	20.1	14.4	12.9	13.0	12.2	12.1
120 (2.0)	22.1	13.8	12.7	13.2	12.6	11.8
180 (3.0)	23.8	14.5	13.4	14.4	14.3	13.9
360 (6.0)	23.7	16.2	15.1	15.7	13.0	9.7
720 (12.0)	25.8	18.6	16.8	16.6	12.6	7.4
1080 (18.0)	27.0	20.8	19.9	19.3	15.5	10.0
1440 (24.0)	29.0	23.0	22.2	22.3	19.3	13.3
2160 (36.0)	30.1	24.7	24.2	25.2	22.9	18.7
2880 (48.0)	31.2	25.9	26.0	27.1	23.6	18.2
4320 (72.0)	31.9	26.8	27.1	27.8	25.9	22.9

Layer Info

Time Accessed	11 July 2019 02:47PM
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/0d39b1b1-95ed-49cb-bd91-7120ee5b350a.txt)

Download JSON (downloads/23280114-a173-454b-b062-079049022512.json)

Generating PDF... (downloads/7444cfb6-be03-4488-9a57-fb4a533d6785.pdf)

APPENDIX I
DESIGN PEAK FLOWS

TABLE I1
DESIGN PEAK FLOWS(1)

Peak Flow Location Identifier(2)	Village	Tributary/ Catchment	Location	Design Flood Events																						
				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 Storm Burst(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Storm Burst(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Storm Burst(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Storm Burst(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Storm Burst(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Storm Burst(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Storm Burst(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]	[AA]
MUR_01	Murrumbateman	McClungs Creek	Merryville Drive	2.5	540	2	4.3	540	2	5.3	540	2	7.7	180	9	10.5	180	1	14.4	180	8	18.5	180	7	173.0	60
MUR_02			Merryville Drive	1.6	180	3	2.1	120	3	2.7	120	3	3.5	90	1	5.0	270	1	5.8	270	5	7.0	270	5	-	-
MUR_03			Isabel Drive	2.0	180	3	2.6	120	3	3.3	120	3	3.8	360	2	5.6	270	1	7.1	270	1	8.7	270	2	-	-
MUR_04			Merryville Drive	3.1	180	8	4.0	120	3	5.1	120	3	6.6	180	5	8.1	270	1	9.7	270	1	12.1	270	1	-	-
MUR_05			Merryville Drive	9.2	270	4	13.8	540	2	16.8	540	2	25.4	180	9	33.5	180	1	43.0	180	8	55.2	180	8	503.0	60
MUR_06			Barton Highway	16.5	180	3	23.8	540	2	30.4	540	2	39.3	180	1	50.6	180	1	64.1	180	8	82.2	180	8	904.0	90
MUR_07		Unnamed Tributary	Murrumbateman Road	2.4	180	3	3.5	120	6	4.5	120	3	6.0	90	1	9.1	270	5	10.3	270	2	12.5	270	2	-	-
MUR_08			Murrumbateman Road	9.9	270	4	14.9	540	2	18.7	540	2	28.3	180	1	38.2	180	8	46.7	180	8	60.5	180	7	600.0	60
MUR_09			Ambleside Avenue	8.5	180	3	12.4	120	6	16.6	120	6	21.5	90	1	27.9	270	1	36.7	270	1	48.8	270	2	-	-
MUR_10			Barton Highway	4.3	270	4	6.8	540	2	8.0	540	2	10.9	180	9	13.7	180	9	16.9	180	1	21.9	180	8	-	-
MUR_11			Barton Highway	1.2	180	8	1.6	120	6	2.0	120	3	2.9	180	9	4.1	180	9	5.6	180	9	6.8	180	8	-	-
MUR_12			Dundoos Drive	0.8	270	4	1.4	120	6	2.2	120	3	2.7	90	3	3.5	270	1	4.6	270	1	6.3	270	1	50.0	30
MUR_13			Murrumbateman Road	8.2	180	8	12.3	540	2	15.2	180	1	21.5	180	8	27.1	180	1	34.3	180	9	44.3	180	8	119.0	90
MUR_14			Barton Highway	8.7	180	8	12.9	540	2	15.6	180	1	22.4	180	9	28.7	180	8	34.5	180	9	44.7	180	8	-	-
MUR_15			Hillview Drive	28.2	270	4	42.7	540	2	53.8	540	2	71.4	180	9	97.0	270	6	122.0	180	8	156.0	180	8	-	-
MUR_16		Gooda Creek	Goldfields Lane	11.8	180	3	16.8	120	6	23.0	120	3	30.0	180	8	36.7	90	3	45.4	270	1	62.4	270	1	-	-
MUR_17			Barton Highway	12.4	540	7	17.0	180	1	22.5	180	1	30.8	180	8	32.0	120	6	34.6	120	6	38.0	270	1	-	-
MUR_18			Barton Highway	1.8	180	3	3.4	120	3	5.3	60	7	7.3	90	1	10.8	270	2	13.1	270	2	16.7	270	2	165.0	30

Refer over for footnotes of Table.

TABLE I1 (Cont'd)
DESIGN PEAK FLOWS[1]

Peak Flow Location Identifier[2]	Village	Tributary	Location	Design Flood Events – 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 Storm Burst[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Storm Burst[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Storm Burst[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Storm Burst[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Storm Burst[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Storm Burst[4]	Peak Flow (m^3/s)	Critical Storm Duration[3] (minutes)	Critical Storm Burst[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]	[AA]
BOW_01	Bowning	Bowning Creek	Main Western Railway	38.6	180	3	49.5	720	9	63.1	120	3	83.8	180	8	102	360	6	119	360	6	145	360	2	1305	90
BOW_02			Bowning Road	51.1	180	3	62.6	120	6	79.5	120	6	104	180	8	123	180	8	140	360	6	170	360	6	-	-
BOW_03			Hume Highway	51.1	180	3	62.7	120	6	79.8	120	6	104	180	8	122	180	8	140	360	6	170	360	6	1578	120
BOW_04		Bowning Tributary	Leake Street	8.4	180	3	11.7	120	3	16.5	120	2	21.2	270	1	27.1	270	5	30.7	270	5	36.3	270	5	282	30
BOW_05			Montem Street	8.5	180	3	11.7	120	3	16.6	120	2	21.4	270	1	26.6	270	5	30.2	270	5	35.6	270	5	295	30
BOO_01	Bookham	Bogolong Creek	Illalong Road	124.0	720	10	181.0	720	1	235.0	720	2	295.0	360	7	354.0	270	6	406.0	270	6	486.0	270	8	3165	180
BOO_02		Middletons Creek	Hume Highway	10.4	180	3	14.7	120	6	19.0	120	3	21.9	180	8	26.8	360	2	30.5	360	2	35.3	360	2	262	90
BIN_01	Binalong	Balgalal Creek	Main South Railway	57.5	270	4	80.3	720	1	102	720	1	131	180	8	156	180	8	183	270	6	216	180	8	-	-
BIN_02			Armours Road	57.5	270	4	80.3	720	1	102	720	2	131	180	8	156	180	8	183	270	5	216	270	6	2190	120
BIN_03			Stephens Street	64.3	270	4	91.8	720	1	114	720	2	154	180	8	184	180	6	218	180	10	262	180	8	2345	120
BIN_04			Burley Griffin Way	64.6	270	4	92.3	720	1	114	720	2	156	360	7	185.	180	6	219	180	6	264	180	8	-	-
BIN_05			Garryowen Road	74.7	360	4	98.5	540	2	128	540	2	177	360	7	209	270	7	245	180	8	299	180	8	2610	120
BIN_06		Balgalal Tributary	Fitzroy Street	6.0	180	3	8.0	120	8	10.3	60	9	12.3	90	1	15.2	270	1	17.1	270	5	18.9	270	2	160.0	60
BIN_07			Richmond Street	7.9	180	3	11.1	120	3	13.2	90	8	18.2	90	1	22.0	270	1	25.9	270	1	30.3	270	2	196.0	60
BIN_08			Wellington Street	8.3	180	3	11.2	120	3	13.5	120	3	19.1	90	1	22.9	270	1	27.2	270	1	32.6	270	1	214.0	60
BIN_09			Monteagle Street	8.4	180	3	11.3	120	3	13.8	120	3	19.4	90	1	23.3	90	3	27.8	270	1	33.3	270	1	217.0	60
BIN_10			Queen Street	8.3	180	3	11.3	120	3	13.9	120	3	19.4	90	1	23.4	90	3	27.9	270	1	33.5	270	1	-	-

1. Peak flows less than 100m^3/s have been quoted to one decimal place in order to show minor differences.
2. Refer to relevant figures in **Volume 2** 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 J

FLOOD DAMAGES

TABLE OF CONTENTS

Page No.

J1. INTRODUCTION AND SCOPE

J1.1 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.

J1.2 Scope of Investigation

In the following sections, tangible damages to residential, commercial and industrial properties, and public buildings have been estimated resulting from flooding at the four villages. 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.

J1.3 Terminology

Definitions of the terms used in this Appendix are presented in **Section J8** which also summarises the value of Tangible Flood Damages.

J2. 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 DPIE 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 elevations of building floors 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.

The depth-damage curves for residential damages were determined using procedures described in *"Floodplain Management Guideline No 4. Residential Flood Damage Calculation"*, *2007* published by DECC. Damage curves for other categories of development (commercial and industrial, 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 catchments should not be used to provide information on the depths of above-floor inundation of individual properties.

J3. SOURCES OF DATA

J3.1 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 at the four villages 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 *DECC Guideline No 4, 2007* 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).

J3.2 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 Property Survey obtained information regarding:

- 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 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 at the four villages is shown in **Table J3.1**.

TABLE J3.1
NUMBER OF PROPERTIES INCLUDED IN DAMAGES DATABASE

Development Type	Number of Properties			
	Murrumbateman	Bowning	Bookham	Binalong
Residential	147	46	7	45
Commercial / Industrial	9	1	2	2
Public	5	2	3	1
Total	**161**	**49**	**12**	**48**

J3.3 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, debris build-ups in the channels which may cause a partial blockage of bridges and 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.

J4. RESIDENTIAL DAMAGES

J4.1 Damage Functions

The procedures identified in *DECCW Guideline No 4, 2007* 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 four villages is "flash flooding" in nature, with surcharge of the watercourses and various drainage lines occurring less than one hour after 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 J4.1** over sets out the parameters and resulting factors that were adopted for converting potential to actual damages in areas subject to both main stream flooding and major overland flow.

Table J4.2 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 0.3 m and 1.0 m. A typical ground floor area of 240 m^2 was adopted for the assessment. The values in **Table J4.2** allow for damages to buildings and contents, as well as external damages and provision for alternative accommodation.

TABLE J4.1
DAMAGE ADJUSTMENT FACTORS/PARAMETERS FOR RESIDENTIAL DEVELOPMENT AT THE FOUR VILLAGES

Property Damage	Parameter/Factor	Adopted Value
Building	Typical Duration of Immersion (hours)	2
	Building Damage Repair Limitation Factor	0.85
	Total Building Adjustment Factor	1.60
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)	1.37
	Total Contents Adjustment Factor (Above-Floor Depth > TTBH)	1.37

1. Maximum value permitted in damages spreadsheet.

TABLE J4.2
DAMAGES TO RESIDENTIAL PROPERTIES

Type of Residential Construction	0.3 m Depth of Inundation Above Floor Level	1.0 m Depth of Inundation Above Floor Level
Single Storey Slab on Ground	$68,074	$92,761
Single Storey High Set	$74,801	$102,386
Double Storey	$47,652	$64,933

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

J4.2 Total Residential Damages

Table J4.3 over summarises residential damages for the range of floods at the four villages. 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.

At the 1% AEP level of flooding only three dwellings would experience above-floor inundation in the four villages; one each at Murrumbateman, Bowning and Binalong, while no dwellings are inundated above-floor level at Bookham. During a PMF event, 47 individual dwellings would experience above-floor inundation in Murrumbateman, 27 in Bowning, 19 in Binalong and two in Bookham.

TABLE J4.3
RESIDENTIAL FLOOD DAMAGES

Design Flood Event (%AEP)	Murrumbateman			Bowning			Bookham			Binalong		
	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	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	5	0	0.08	0	0	0	0	0	0	2	0	0.03
10	8	0	0.13	0	0	0	0	0	0	3	1	0.07
5	9	0	0.14	1	0	0.02	0	0	0	4	1	0.13
2	12	0	0.19	2	1	0.05	0	0	0	5	1	0.14
1	13	1	0.23	2	1	0.09	0	0	0	6	1	0.16
0.5	15	1	0.26	3	1	0.11	0	0	0	8	1	0.20
0.2	19	3	0.41	5	2	0.21	0	0	0	8	1	0.20
PMF	94	47	4.60	32	27	3.11	3	2	0.28	33	19	2.22

J5. COMMERCIAL AND INDUSTRIAL DAMAGES

J5.1 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 (*DECC Guideline No 4, 2007*). DPIE 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 four villages study.

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 hire.)
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 four villages 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.

J5.2 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.

J5.3 Total Commercial and Industrial Damages

Table J5.1 over summarises estimated commercial and industrial damages in the four villages. No commercial or industrial buildings would experience above-floor inundation in a 1% AEP event, while six buildings (two each at Murrumbateman and Bookham and one each at Bowning and Binalong) would be above-floor inundated during a PMF event.

TABLE J5.1
COMMERCIAL / INDUSTRIAL FLOOD DAMAGES

Design Flood Event (%AEP)	Murrumbateman			Bowning			Bookham			Binalong		
	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	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	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
0.5	0	0	0	0	0	0	0	0	0	0	0	0
0.2	0	0	0	0	0	0	0	0	0	0	0	0
PMF	4	2	0.88	1	1	0.47	2	2	0.25	1	1	0.27

J6. DAMAGES TO PUBLIC BUILDINGS

J6.1 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	
Medium value	\$420/m^2	(eg. council buildings, SES HQ, fire station)
High value	\$650/m^2	(eg. 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.

J6.2 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.

J6.3 Total Damages – Public Buildings

Table J6.1 over summarises estimated damages to public buildings in the four villages. No public buildings would experience above-floor inundation in a 1% AEP event, while eight buildings (four at Murrumbateman, two at Bookham and one each at Bowning and Binalong) would be above-floor inundated during a PMF event.

TABLE J6.1
PUBLIC FLOOD DAMAGES

Design Flood Event (%AEP)	Murrumbateman			Bowning			Bookham			Binalong		
	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	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	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
0.5	0	0	0	0	0	0	0	0	0	0	0	0
0.2	1	0	0	0	0	0	0	0	0	0	0	0
PMF	5	4	0.19	2	1	0.04	2	2	0.14	1	1	0.03

J7. 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 around the four villages is presented in **Table J7.1**.

TABLE J7.1
QUALITATIVE EFFECTS OF FLOODING ON
INFRASTRUCTURE AND COMMUNITY ASSETS IN THE FOUR VILLAGES

Village	Damage Sector	Design Flood Event (% AEP)							
		20%	10%	5%	2%	1%	0.5%	0.2%	PMF
Murrumbateman	Roads	X	X	X	X	X	X	X	X
	Parks and Gardens	O	O	O	X	X	X	X	X
	Sewage Pumping Station	O	O	O	O	O	O	O	X
	Water Supply	O	O	O	O	X	X	X	X
Bowning	Roads	O	X	X	X	X	X	X	X
	Parks and Gardens	O	O	O	O	O	O	X	X
	Water Supply	O	O	O	O	O	O	O	O
Bookham	Roads	O	O	O	X	X	X	X	X
	Parks and Gardens	O	O	O	O	O	O	O	X
Binalong	Roads	X	X	X	X	X	X	X	X
	Parks and Gardens	O	O	O	O	O	O	O	X
	Water Supply	O	O	O	O	O	O	O	O

Notes: O = No significant damages likely to be incurred.
X = Some damages likely to be incurred.

J8. SUMMARY OF TANGIBLE DAMAGES

J8.1 Tangible Damages

Floods 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 in the drainage system. From **Table J8.1** over, significant flood damages at the four villages are limited to the PMF event, with about $0.23 Million of damages being incurred at the 1% AEP level of flooding at Murrumbateman, $0.16 Million at Binalong and $0.09 Million at Bowning. No flood damages are incurred at Bookham during a 1% AEP storm event.

J8.2 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).

J8.3 Average Annual Damages

The average annual damages for all flood events up to the PMF are shown below in **Table J8.2**. Note that values have been quoted to two decimal places to highlight the relatively small recurring damages.

J8.4 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 J8.3** over.

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 Murrumbateman and Binalong are $0.04 Million and $0.02 Million, respectively. Therefore one or more schemes costing up to these amounts could be economically justified if they eliminated damages in the two villages 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.

The *Present Worth Value* of total damages at Bowning and Bookham for all flood events up to the 1% AEP flood is zero. As a result it is not possible to economically justify any mitigation works which are aimed at reducing the impact of flooding on existing development up to the 1% AEP level in these two villages.

TABLE J8.1
TOTAL FLOOD DAMAGES
$ MILLION

Design Flood Event (%AEP)	Murrumbateman				Bowning				Bookham				Binalong			
	Residential	Commercial/ Industrial	Public	Total	Residential	Commercial/ Industrial	Public	Total	Residential	Commercial/ Industrial	Public	Total	Residential	Commercial/ Industrial	Public	Total
20	0.08	0	0	0.08	0	0	0	0	0	0	0	0	0.03	0	0	0.03
10	0.13	0	0	0.13	0	0	0	0	0	0	0	0	0.07	0	0	0.07
5	0.14	0	0	0.14	0.02	0	0	0.02	0	0	0	0	0.13	0	0	0.13
2	0.19	0	0	0.19	0.05	0	0	0.05	0	0	0	0	0.14	0	0	0.14
1	0.23	0	0	0.23	0.09	0	0	0.09	0	0	0	0	0.16	0	0	0.16
0.5	0.26	0	0	0.26	0.11	0	0	0.11	0	0	0	0	0.2	0	0	0.2
0.2	0.41	0	0	0.41	0.21	0	0	0.21	0	0	0	0	0.2	0	0	0.2
PMF	4.60	0.88	0.19	5.70	3.11	0.47	0.04	3.62	0.28	0.25	0.14	0.67	2.22	0.27	0.03	2.52

TABLE J8.2
AVERAGE ANNUAL DAMAGES
$ MILLION

Design Flood Event (%AEP)	Murrumbateman				Bowning				Bookham				Binalong			
	Residential	Commercial/ Industrial	Public	Total	Residential	Commercial/ Industrial	Public	Total	Residential	Commercial/ Industrial	Public	Total	Residential	Commercial/ Industrial	Public	Total
20	0.01	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0
10	0.02	0	0	0.02	0	0	0	0	0	0	0	0	0.01	0	0	0.01
5	0.03	0	0	0.03	0	0	0	0	0	0	0	0	0.01	0	0	0.01
2	0.03	0	0	0.03	0	0	0	0	0	0	0	0	0.02	0	0	0.02
1	0.04	0	0	0.04	0	0	0	0	0	0	0	0	0.02	0	0	0.02
0.5	0.04	0	0	0.04	0	0	0	0	0	0	0	0	0.02	0	0	0.02
0.2	0.04	0	0	0.04	0	0	0	0	0	0	0	0	0.02	0	0	0.02
PMF	0.04	0	0	0.04	0.01	0	0	0.01	0	0	0	0	0.02	0	0	0.02

TABLE J8.3
PRESENT WORTH VALUE OF DAMAGES
$ MILLION

Village	Discount Rate (%)	Nominal Flood Level Case	
		All Floods up to 1% AEP	All Floods up to PMF
Murrumbateman	4	0.9	0.9
	7	0.6	0.6
	11	0.4	0.4
Bowning	4	0	0.2
	7	0	0.1
	11	0	0.1
Bookham	4	0	0
	7	0	0
	11	0	0
Binalong	4	0.4	0.4
	7	0.3	0.3
	11	0.2	0.2

J9. REFERENCES AND BIBLIOGRAPHY

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