BLAND SHIRE COUNCIL

WYALONG AND WEST WYALONG
FLOOD STUDY

FEBRUARY 2023

VOLUME 1- MAIN REPORT

Example of flooding that was experienced during storm that occurred on 2 December 2017

Example of flooding that was experienced during storm that occurred on 23 March 2021

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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.

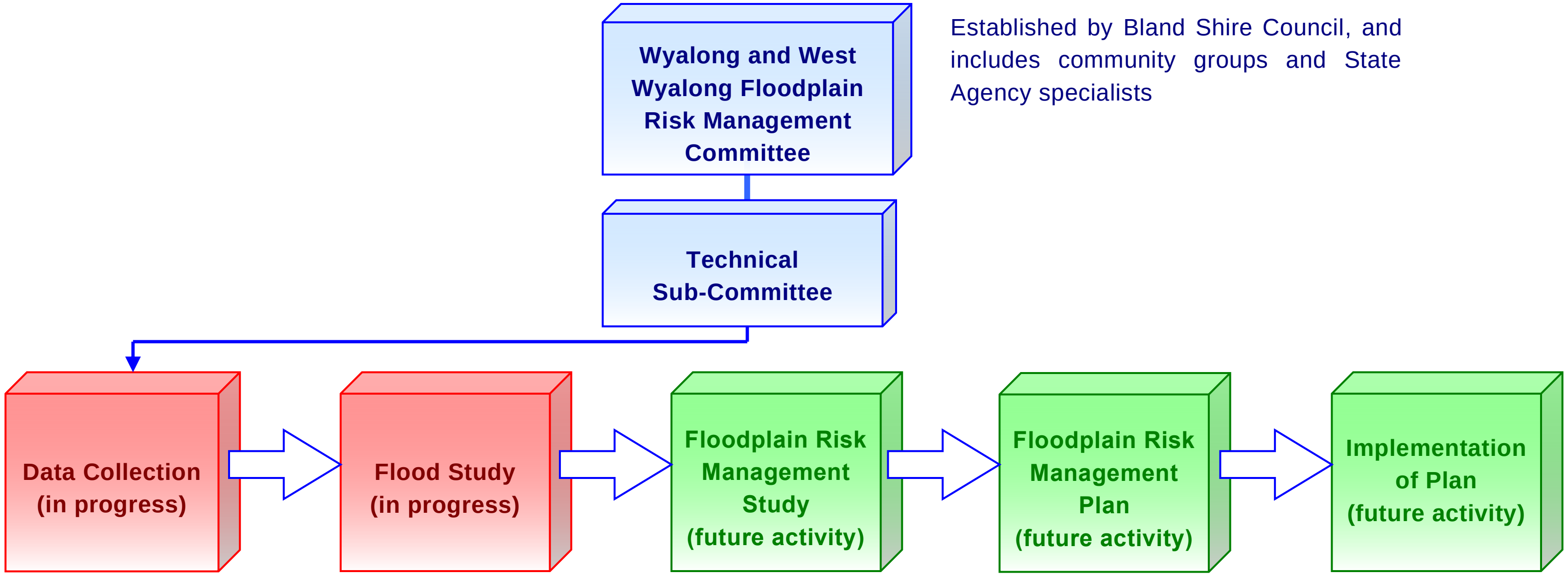
The Wyalong and West Wyalong Flood Study is jointly funded by Bland Shire Council and the NSW Government, via the Department of Planning and Environment. The Flood Study constitutes the first and second stage of the Floodplain Risk Management process (refer above and over) for this area and has been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

ACKNOWLEDGEMENT

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

Bland Shire Council acknowledges the Wiradjuri people as the traditional custodians of the land in which the study covers. Bland Shire Council also acknowledges the input from the communities of Wyalong and West Wyalong in the preparation of this document.

FLOODPLAIN RISK MANAGEMENT PROCESS



Established by Bland Shire Council, and includes community groups and State Agency specialists

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

Involves detailed hydrologic and hydraulic modelling of the existing stormwater drainage system and the definition of flood behaviour at Wyalong and West Wyalong under present day conditions.

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.

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LIST OF MAIN REPORT FIGURES
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NOTE ON FLOOD FREQUENCY

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

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

The report also refers to the Probable Maximum Flood (**PMF**). This flood occurs as a result of the Probable Maximum Precipitation (**PMP**). The PMP is the result of the optimum combination of the available moisture in the atmosphere and the efficiency of the storm mechanism as regards rainfall production. The PMP is used to estimate PMF discharges using 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
Council	Bland Shire Council
DECC	Department of Environment and Climate Change
DEM	Digital Elevation Model
DPE	Department of Planning 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
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 objective of the present study was to define the nature of both Main Stream Flooding and Major Overland Flow at the twin towns of Wyalong and West Wyalong 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 findings of the present study will be used as the basis for preparing the future *Wyalong and West Wyalong Floodplain Risk Management Study and Plan* (***Wyalong and West Wyalong FRMS&P***) which will assess options for flood mitigation and prepare a plan of works and measures for managing the existing, future and continuing flood risk in the twin towns.

S.2 Background Information

The study area comprises the urbanised parts of Wyalong and West Wyalong, as well as their immediate environs. Runoff generated by the study area generally concentrates along the alignment of the following three main flow paths (referred to collectively herein as “the three main flow paths”):

- the main arm of Yiddah Creek which generally runs in an easterly direction to the south of the urbanised parts of the twin towns;
- an unnamed watercourse which generally runs in an easterly direction through the urbanised parts of the twin towns and has been denoted herein as “the Main Drain”; and
- an unnamed flow path that runs in an easterly direction to the north of the urbanised parts of Wyalong and has been denoted herein as “the Wyalong North Drainage Line”.

Floodwater conveyed by the three main flow paths discharges to Barmedman Creek, which drains into Bland Creek, thence Lake Cowal and ultimately to the Lachlan River.

Figure 1.1 is a location plan showing the major watercourses in the vicinity of the study area, while **Figure 2.1** shows the extent of the catchments which contribute to flow in the three main flow paths. **Figure 2.2** (5 sheets) shows the key features of the existing stormwater drainage system in the study area.

S.3 Study Method

The flood study involved the following activities:

- The forwarding of a *Community Newsletter and Questionnaire* to approximately 2,400 residents and business owners in the study area. The *Community Newsletter and Questionnaire*, a copy of which is contained in **Appendix A** of this report, introduced the study objectives and sought information on historic flood behaviour. Of those that responded, more than half noted that they had observed flooding in or adjacent to their property. Respondents provided information on flooding that occurred on the following dates:
  - 9 December 2010
  - June 2016 (exact day not provided)
  - 5-6 February 2021
  - 2012 (exact date not provided)
  - 2 December 2017
  - 21 March 2021

- The collection of flood data, details of which are set out in **Appendix B** of this report. Pluviographic rainfall data recorded by a Bureau of Meteorology operated rain gauge in the vicinity of the twin towns were obtained. A number of photographs were provided by Council and respondents to the *Community Newsletter and Questionnaire* showing flood behaviour in the study area, copies of which are contained in **Appendix C** of this report.
- The hydrologic modelling of the Main Drain and Yiddah Creek catchments. 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 IL-CL sub-model in DRAINS was used to stimulate the hydrologic response of the urban parts of the twin towns. 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 watercourses, 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 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.
- The placement of the draft flood study report on public exhibition for a 28-day period in late 2022.

After testing the models for the December 2017 and March 2021 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* (Editors, 2019) (**ARR 2019**) and applied to the hydrologic models in order to derive discharge hydrographs. The PMF was also modelled.

S.4 Design Flood Estimation

Figures 6.1 to **6.8** show the TUFLOW model results for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP storm events, together with the PMF. These diagrams show the indicative extent and depth of inundation in the study area for each design storm event.

Figure 6.9 shows design water surface profiles along the Main Drain, while **Figure 6.10** shows stage hydrographs at selected road/rail crossings throughout the study area. **Table E1** in **Appendix E** sets out peak flood levels and the depth of inundation and at the aforementioned road/rail crossings, while **Table F1** in **Appendix F** sets out design peak flows and corresponding critical storm durations at various locations in the study area.

Flooding patterns derived by TUFLOW for the design storm events are described in **Chapter 6** of the report.

S.5 Economic Impact of Flooding

A storm event more frequent than 2% AEP is the threshold at which significant tangible flood damages commence to occur in the study area. For example, six residential dwellings (five in West Wyalong and one in Wyalong) and one public building (in West Wyalong) are subject to above-floor inundation to depths of up to 220 mm in a 2% AEP storm event. The total number of residential dwellings that would experience above-floor inundation increases to twelve (nine in West Wyalong and three in Wyalong) at the 1% AEP level of flooding. There are no additional commercial or public buildings subject to above-floor inundation in a flood of this magnitude.

The *"Present Worth Value"* of tangible damages resulting from all floods up to the magnitude of the 1% AEP at Wyalong and West Wyalong for a discount rate of 7% and an economic life of 50 years is $0.3 Million and $1.4 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 towns. While schemes costing more than this value would have a benefit/cost ratio less than 1, they may still be justified according to a multi-objective approach which considers other criteria in addition to economic feasibility.

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

S.6 Flood Hazard Classification and Hydraulic Categorisation

Diagrams showing the flood hazard vulnerability classification for the 5% and 1% AEP flood events, as well as the PMF are shown on **Figures 6.11**, **6.12** and **6.13**, while the hydraulic categorisation of the floodplain for a 5% and 1% AEP flood event, as well as the PMF is shown on **Figures 6.14**, **6.15** and **6.16**, respectively.

The flood hazard vulnerability classification is dependent on the depth and velocity of flow on the floodplain. Flood affected areas in the study area have been divided into the following six flood hazard vulnerability categories on the basis of these two variables and the relationships presented in ARR 2019:

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

The study found that at the 1% AEP level of flooding:

- areas classified as H6 are limited to three water containment structures, two of which are located along the central thread of the Main Drain and the third which is located in the Wyalong Sewerage Treatment Plant;
- while areas classified as H5 are generally limited to the inbank area of Yiddah Creek and along the alignment of the Main Drain, it was also found to be present in a large number of local farm dams that are scattered through the study area;
- areas classified as either H3 and H4 are generally present on the immediate overbank of the main flow paths, as well as in major ponding areas that are typically located upstream of road and rail crossings; and
- areas affected by Major Overland Flow are generally classified as either H1 or H2.

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.

Floodways are generally present along the alignment of the main flow paths, as well as the concrete lined flow paths that are present in West Wyalong. While the floodways are generally contained within the drainage and road reserve boundaries, floodways are also present in undeveloped rural type land.

S.7 Sensitivity Analyses

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

a. An increase in hydraulic roughness. **Figure 6.17** shows the effects a 20 per cent increase in the adopted 'best estimate' hydraulic roughness values would have on flood behaviour at the 1% AEP level of flooding.

b. A partial blockage of major hydraulic structures by debris. **Figure 6.18** shows the effects a partial blockage of both bridges and major culvert structures would have on flood behaviour at the 1% AEP level of flooding.

c. Increases in rainfall intensity associated with future climate change. **Figures 6.19**, **6.20** and **6.21** show the effects a 10 and 30 per cent increase in design 1% AEP rainfall intensities would have on flood behaviour in the study area.

The sensitivity analyses identified that:

- peak 1% AEP flood levels could be increased by up to 100 mm as a result of changes in hydraulic roughness;
- a partial blockage of the hydraulic structures has a negligible impact on flood behaviour; 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 150 mm.

S.7 Interim Flood Planning Area

Figure 6.22 shows the extent of the Interim Flood Planning Area (**FPA**) for the study area as it relates to both Main Stream Flooding and Major Overland Flow. The extent of the FPA has been defined as follows:

- Main Stream Flooding FPA – Land which is located along the three main flow paths and lies at or below the peak 1% AEP flood level plus 0.5 m freeboard.
- Major Overland Flow FPA – Land which lies outside the Main Stream Flooding FPA but would be subject to depths of inundation of greater than 0.1 m in a 1% AEP storm event.

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

1 INTRODUCTION

1.1 Study Background

This report presents the findings of an investigation of flooding at the twin towns of Wyalong and West Wyalong in the Bland Shire Council (**Council**) Local Government Area (**LGA**). The study has been commissioned by Council with financial and technical support from the NSW Government, via the Department of Planning and Environment (**DPE**). **Figure 1.1** shows the extent of the study catchments at Wyalong and West Wyalong.

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

- **Major Overland Flow**, which is experienced during periods of heavy rain and is generally characterised by relatively shallow and slow-moving floodwater that is conveyed overland in an uncontrolled manner toward the three main flow paths which run in an easterly direction through the study area (refer **Chapter 2** of this report for a more detailed description of these flow paths).
- **Main Stream Flooding**, which occurs when Major Overland Flow concentrates along the aforementioned flow paths. Main Stream Flooding is typically characterised by deeper and faster flowing floodwater, but can include shallower and slower moving floodwater on the overbank of the aforementioned watercourses.

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

1.2 Community Consultation and Available Data

To assist with data collection and promotion of the study to the community, a *Community Newsletter* was distributed by Council in February 2021 to residents and business owners in the study area. The *Community Newsletter* contained a QR code linking to an online version of a *Community Questionnaire*. A copy of the *Community Newsletter and Questionnaire* is contained in **Appendix A.**

Council advised that approximately 2400 *Community Newsletters* were distributed to residents and business owners in the study area, with a total of 20 responses received by the closing date of submissions (a response rate of less than 1 per cent).

Of the 20 respondents, thirteen noted that they had been affected by flooding. The following events were identified by only one respondent:

- 9 December 2010
- June 2016 (exact day not provided)
- 5-6 February 2021
- 2012 (exact date not provided)
- 2 December 2017
- 21 March 2021

The most frequently identified floods were also the most recent, with the 5-6 February 2021 and 21 March 2021 storms identified by eight respondents and two respondents, respectively. 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 that were provided by Council and respondents to the *Community Questionnaire* which show historic flood behaviour in the study area during storms that occurred on 2 December 2017, 5-6 February 2021 and 23 March 2021.

The draft flood study report was placed on public exhibition for a period of 28 days from 16 November 2022, with no comments received from the community within the nominated 42-day commentary period.

1.3 Previous Investigations

The following flooding investigations have been undertaken in the Council LGA:

- *Ungarie Floodplain Risk Management Study and Plan* (BMT, 2020)
- *West Wyalong Stormwater Management Plan* (Bland Shire Council, 2001)
- *Bland Shire Local Flood Plan* (NSW State Emergency Service (**NSW SES**), 2013)

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 twin towns 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 model that was used to generate discharge hydrographs for input to the hydraulic model.

Chapter 4 deals with the development and calibration of the hydraulic model which was used to define the nature of flooding in the study area.

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

Chapter 6 details the results of the hydraulic modelling of the design floods in the study area. Results are presented as water surface profiles and plans showing indicative extents and depths of inundation for a range of design flood events up to the PMF. A provisional assessment of flood hazard and hydraulic categorisation in the study area is also presented in the chapter.

Chapter 6 also details the results of various sensitivity studies undertaken using the hydraulic model, including the effect that changes in hydraulic roughness, a partial blockage of the hydraulic structures and potential increases in rainfall intensities due to future climate change will have on flood behaviour. This chapter also deals with the selection of *Interim Flood Planning Levels* for Wyalong and West Wyalong.

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

The following appendices are included in the report:

- **Appendix A**, which contains a copy of the *Community Newsletter* and *Questionnaire* that were distributed at the commencement of the study to residents and business owners of Wyalong and West Wyalong.
- **Appendix B**, which contains a list of data that were available for the present study, as well as a brief summary of the responses that were received to the *Community Questionnaire*.
- **Appendix C** contains photographs showing flood behaviour in the study area during storms that occurred on 2 December 2017, 5-6 February 2021 and 23 March 2021.
- **Appendix D** contains a copy of the design input data that were extracted from the *Australian Rainfall and Runoff* (***ARR***) *Data Hub* for the twin towns.
- **Appendix E** contains a table showing the peak flood level and maximum depth of inundation at a number of key road and rail crossings in the study area.
- **Appendix F** contains a table showing the peak flows taken from the hydraulic model for design storm events.
- **Appendix G** contains an assessment of the economic impacts of flooding to existing residential, commercial and industrial development, as well as public buildings in the study area.

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

The twin towns of Wyalong and West Wyalong have a population of about 450 and 2640, respectively and are located at the intersection of the Newell Highway and Mid-Western Highway in the Bland Shire Council LGA. **Figure 1.1** shows that Wyalong and West Wyalong are located in the headwaters of the Lachlan River Valley catchment.

Runoff generated by the northern portion of the study area is concentrated along two main flow paths which for the purpose of the present study have been denoted “the Main Drain” and “the Wyalong North Drainage Line”. **Figure 2.1** shows the extent of the catchments which contribute to flow in the Main Drain and the Wyalong North Drainage Line, while **Figure 2.2** (5 sheets) shows details of the existing stormwater drainage system at in the twin towns.

While the Main Drain generally comprises an incised channel to the west of Goldfields Way, the channel terminates at this location and runoff flows in an easterly direction through rural pastoral land before discharging to Barmedman Creek. The Wyalong North Drainage Line generally transverses rural residential and pastural type land where the drainage system has generally not been formalised.

Runoff generated by the southern portion of the study area drains to Yiddah Creek which flows in an easterly direction and discharges to Barmedman Creek approximately 15 km to the east of Goldfields Way. Runoff in Barmedman Creek then discharges to Bland Creek about 25 km to the north of its confluence with Yiddah Creek, before continuing to Lake Cowal and ultimately the Lachlan River.

The Main Drain, Wyalong North Drainage Line and Yiddah Creek are collectively referred to herein as “the three main flow paths”.

2.1.2. Main Drain

The headwaters of the Main Drain catchment that are located on the western (upstream) side of the Cootamundra Lake Cargelligo and West Wyalong Burcher railway lines generally comprise undeveloped undulating hilly terrain. Downstream of the railway, land use includes residential, commercial and industrial type development, as well as rural pastoral type land and bushland.

The Main Drain comprises a grass lined channel with a concrete lined invert where it runs between Main Street and Clear Ridge Road in West Wyalong (refer **Figure 2.2**, sheets 2 and 3 for alignment). Low level concrete lined causeways are present where the Main Drain crosses Camp Street, Grenfell Street, Church Street, Monash Street, Operator Street, Boundary Street and Clear Ridge Road. The Main Drain runs along the alignment of Kurrajong Street between Church Street and Monash Street which has a depressed centreline in order to convey overland flow.

The Main Drain generally comprises a grass lined channel downstream of Clear Ridge Road, with culvert crossings located at Neeld Street, Compton Road, Wargin Road and Goldfields Way. Downstream of Goldfields Way the watercourse becomes less defined, with runoff generally flowing in an easterly direction through pastoral type land.

Figure 2.2, sheet 2 shows that the drainage system in West Wyalong generally comprises concrete lined flowpaths that convey overland flow to the Main Drain, with short reaches of piped drainage systems where the flowpaths cross the Newell Highway and Main Street. **Figure 2.2**, sheet 2 also shows the location of pedestrian footbridges that have been constructed across the concrete lined flowpaths.

Figure 2.2, sheet 3 shows that the drainage system in Wyalong generally comprises piped and culvert crossings beneath the roads and grass lined table drains that convey overland flow towards the Main Drain.

2.1.3. Wyalong North Drainage Line

The headwaters of the Wyalong North Drainage Line path lie to the north of Wyalong and generally comprises rural residential and pastural type land. Runoff generated by the catchment generally flows in a southerly direction before turning east at the location where it crosses the Newell Highway immediately east of its intersection with Goldfields Way.

Figure 2.2, sheet 3 shows that the stormwater drainage system along the Wyalong North Drainage Line is generally limited to short reaches of pipe at existing road crossings.

2.1.4. Yiddah Creek

The Yiddah Creek catchment generally comprises undeveloped undulating hilly terrain with pockets of state forest. A small portion of the catchment in the vicinity of the Cootamundra Lake Cargelligo Railway comprises residential and industrial type development.

Figure 2.2, sheet 4 shows that Yiddah Creek runs in an easterly direction on the southern side of the West Wyalong Airport. Yiddah Creek is generally in its natural state where in runs through the study area. Bellarwi Road runs in a north-south direction across the Yiddah Creek floodplain and crosses the creek via a low level concrete lined causeway. As shown on **Figure 2.2**, sheet 4, several minor gullies discharge to Yiddah Creek in the vicinity of Bolts Lane and Bellarwi Road.

2.2 Flood History and Analysis of Historic Rainfall

2.2.1. General

Respondents to the *Community Questionnaire* identified a number of notably intense storm events that have recently been experienced in the study area, the dates of which are given in **Section 1.2** of this report. A number of respondents also provided photographic evidence (refer **Appendix C**) and descriptions of the patterns of overland flow in the vicinity of their properties.

The left hand side of **Figure 2.3** shows design versus historic intensity-frequency-duration (**IFD**) curves for the nearby Bureau of Meteorology (**BoM**) operated *West Wyalong Airport All Weather Station* (**AWS**) rain gauge (GS 50017) (**Airport rain gauge**) for the storm events that were identified by respondents to the *Community Questionnaire*.

Table 2.1 over the page gives the approximate AEP of the recorded rainfall for storm durations ranging between 30 minutes and 12 hours, while **Table 2.2** shows a comparison of the rainfall recorded at the Airport rain gauge with that recorded at the BoM operated *Wyalong Post Office* daily-read rain gauge (GS 73054) (**Post Office rain gauge**). **Figure 2.1**, sheet 1 shows that the Airport rain gauge is located in the Yiddah Creek catchment, approximately 1.8 km to the south of Main Street in West Wyalong, while the Post Office rain gauge is located 3.5 km to the east in Wyalong.

TABLE 2.1
APPROXIMATE AEPs OF RECORDED RAINFALL FOR HISTORIC STORM EVENTS WEST WYALONG AIRPORT AWS RAIN GAUGE (GS 50017)(1)

Storm Event	Storm Duration (hours)							
	0.5	1	2	3	6	9	12	24
3-5 June 2016	< 1 EY	< 1 EY	< 1 EY	< 1 EY	< 1 EY	< 1 EY	< 1 EY	50% AEP
20-21 June 2016	< 1 EY	< 1 EY	1 EY	50% AEP	50% AEP	50% AEP	50% AEP	50% AEP
2 December 2017	10% AEP	5% AEP	10% AEP	10% AEP	20% AEP	10% AEP	10% AEP	10% AEP
5-6 February 2021	10% AEP	10% AEP	20% AEP	20% AEP	20% AEP	20% AEP	20% AEP	20% AEP
23 March 2021	< 1 EY	< 1 EY	50% AEP	20% AEP	10% AEP	10% AEP	10% AEP	10-5% AEP

1. EY = Exceedances per Year, AEP = Average Exceedance Probability

TABLE 2.2
RECORDED DAILY RAINFALL TOTALS RELEVANT FOR HISTORIC STORM EVENTS

Historic Storm	Rainday	Daily Rainfall Total(1) (mm)	
		West Wyalong Airport AWS (GS 50017)	Wyalong Post Office (GS 73054)
December 2017	2	46.6	93.6
	3	46.8	
	4	0	0
February 2021	5	25.6	26.8
	6	56.2	59.4
	7	0	0
March 2021	22	25.2	11
	23	78.4	101
	24	16.2	12

1. Refer **Figure 2.1**, 5 sheets for gauge location.

The left hand side of **Figure 2.3** and **Table 2.1** show that the storms identified by the respondents to the *Community Questionnaire* varied in intensity. The two storms that occurred in June 2016 were equivalent to design storm events with AEPs of no greater than about 50% (1 in 2). While the three most recent storm events were generally equivalent to design storm events of between 20-10% AEP, the 2 December 2017 storm was equivalent to a design storm with an AEP of about 5% (1 in 20) for a storm duration of one hour.

It is noted that NSW SES, 2013 states that *"On 7 November 2005 very heavy rain from 9 pm to midnight caused flooding"*. While a total of 67.2 mm was recorded at the Post Office (daily-read) rain gauge on the rain day of 8 November 2005, there are no pluviographic rain gauges that were operational in the vicinity of the study area at the time of the storm event. That said, if all of the rain fell over a three hour period between 9 pm and midnight, the 7 November 2005 storm event would have been equivalent to a design storm event with an AEP of about 1% per cent.

The right hand side of **Figure 2.3** shows the cumulative rainfall that was recorded at the West Wyalong Airport AWS rain gauge for the three most recent storm events. The following sections contain a description of each.

2.2.2. December 2017 Storm Event

Table 2.2 shows that the recorded rainfall depths at the Airport rain gauge (about 93.4 mm) are similar to that which fell at the Post Office rain gauge (about 93.6 mm). The rainfall that was recorded at the Airport rain gauge is therefore considered to be representative of the rainfall that fell across the entire study area.

While the photographs provided by Council show flooding was experienced in parts of Wyalong and West Wyalong between about 09:30 hours and 11:00 hours on 2 December 2017, the right hand side of **Figure 2.3** shows that the flooding shown in **Plates C1.1** to **C1.19** in **Appendix C** occurred after about 18.8 mm of rain fell between 07:00 hours and 11:00 hours, which is less intense than a storm that occurs once every year on average (i.e. less than 1 Exceedances per Year (**EY**)). The right hand side of **Figure 2.3** also shows that an additional 59.6 mm of rain fell between 16:00 hours on 2 December 2017 and 03:00 hours on 3 December 2017, which is equivalent to a design storm with a maximum AEP of about 5%. While it is likely that the second burst of rainfall caused more significant flooding than is shown on the photographs, there is no flood data available to verify this.

Plate C1.1 shows floodwater flowing in an easterly direction along the northern side of the Mid-Western Highway to the east of its intersection with Ungarie Road, while **Plate C1.2** shows floodwater is at the point of surcharging the banks of the Main Drain where it runs in a northerly direction immediately downstream (north) of the Mid-Western Highway.

Plate C1.3 shows floodwater flowing in an easterly direction across Grenfell Road, while **Plates C1.4** to **C1.7** shows floodwater in the Main Drain where it runs through Barnado Park and discharges to Church Street. **Plate C1.8** shows floodwater flowing in an easterly direction along Kurrajong Street, while **Plates C1.9** and **C1.10** show floodwater flowing across the Operator Street and Clear Ridge Road crossings of the Main Drain, respectively.

Plate C1.12 show floodwater ponding on the western side of an unnamed road that runs along the westerns side of the wetlands, while to **Plate C1.13** shows floodwater flowing in an easterly direction over the causeway of the unnamed road at its northern end.

Plate C1.17 shows that floodwater in the Main Drain was overtopping Compton Road immediately to the south of its intersection with Cassin Street at 11:00 hours on 2 December 2017, while **Plate C1.18** shows that the Wargin Street crossing of the Main Drain was not inundated. **Plate C1.19** shows floodwater inundating the low point in Gilbert Street that is located between Wargin Street and Copeland Street.

2.2.3. February 2021 Storm Event

The right hand side of **Figure 2.3** shows that rain fell in three distinct bursts on 4 and 5 February 2021. The first burst occurred between 15:30 hours and 18:30 hours on 4 February 2021, when about 24 mm of rainfall fell, followed by a second burst of 41.8 mm that fell between 15:00 hours and 20:00 hours on 5 February 2021. A third burst 13 mm fell between 00:00 hours and 03:30 hours on 6 February 2021. The rain that fell over the first and third bursts of rainfall were less intense than a storm that occurs once every year on average (i.e. 1 EY), while the second burst of rain that occurred on the evening on 5 February 2021 was equivalent to design storm event with a maximum AEP of about 10%.

While **Plates C2.1** to **C2.7** show floodwater ponded in the vicinity of Cassin Street and Wargin Street, the exact time that these photos were taken is not known. **Plate C2.8** shows floodwater flowing along an unspecified section of Park Street, noting that while the time that the photo was taken is not known, the flooding shown occurred during the night.

Anecdotal information from one respondent to the *Community Questionnaire* also indicates that the flood levels in Wooten Street in West Wyalong peaked between 22:00 and 23:00 hours on 5 February 2021, while another respondent indicated that floodwater was about 600 mm deep at the footbridge on the southern side of Park Street to the west of its intersection with Monash Street at this time. The abovementioned flooding occurred following the second burst of rain that fell between 15:00 hours and 20:00 hours on 5 February 2021.

2.2.4. March 2021 Storm Event

The right hand side of **Figure 2.3** shows that flooding occurred on 23 March 2021 following 94.6 mm of rain that fell between 03:00 hours on 21 March 2021 and 09:00 hours on 23 March 2021. The most intense part of the storm burst occurred between 00:00 hours and 09:00 hours on 23 March 2021, when about 57 mm of rain was recorded at the Airport rain gauge. **Table 2.1** and the left hand side of **Figure 2.3** shows that the storm was equivalent to a design storm with a maximum AEP of about 5%.

Table 2.2 shows that the recorded rainfall depths at the Airport rain gauge (about 120 mm) are similar to that which fell at the Post Office rain gauge (about 124 mm). The rainfall that was recorded at the Airport rain gauge is therefore considered to be representative of the rainfall that fell across the entire study area.

Plates C3.1 to **C3.31** were taken between 11:50 hours and 13:05 hours on 23 March 2021, approximately 2 hours after the cessation of rainfall. It is noted that the hydraulic model results indicate that flood levels peaked in the study area between about 09:00 hours and 10:00 hours on 23 March 2021, which is about 2-4 hours prior to the time of photography.

Plates C3.1 to **C1.5** show flood behaviour between Showground Road and the Mid-Western Highway, noting that the roads and the Cootamundra-Lake Cargelligo Railway are not inundated at the time of the photography.

Plates C3.6 and **C3.7** show floodwater inundating the road reserve and isolating the residential allotments that are bound by Creswell Street to the south-west, Grenfell Street to the south-east and the Main Drain to the north. **Plate C3.8** shows that floodwater in the Main Drain splits at Grenfell Street and flows both in an easterly direction through Barnado Park and in a north-easterly direction along the road reserve towards School Street. **Plates C3.9** and **C3.10** show that floodwater inundated the full width of the road reserve in Kurrajong Street.

Plates C3.12 to **C3.14** show that floodwater inundates the overland flow path that runs in a southerly direction from Wootten Street and Grenfell Street on the western side of Monash Street and inundates a number of adjacent low-lying allotments. **Plates C3.15** and **C3.16** show floodwater ponding on the northern side of Park Street, while **Plates C3.17** and **C3.18** show that floodwater did not surcharge the banks of the channel that runs in a southerly direction on the eastern side of the bowling club.

Plates C3.19 and **C3.20** show that floodwater was contained within the road reserve where the Main Drain runs in an easterly direction in the vicinity of the intersection of Gorman Street and Operator Street. **Plates C3.21** to **C3.25** show flood behaviour along the Main Drain between Operator Street and Neeld Street, while **Plates C3.22** and **C3.25**, respectively showing that the Boundary Street and Clear Ridge Road causeways were inundated at the time of the photography.

While **Plates C3.26** and **C3.27** show that Neeld Street was not inundated in the vicinity of the West Wyalong Wetlands at 13:00 hours on 23 March 2021, anecdotal information provided by respondents to the *Community Questionnaire* indicates that the road was inundated at multiple locations prior to the time of the photography.

Plate C3.28 shows that floodwater surcharged the banks of the Main Drain downstream of Neeld Street and inundated low lying land adjacent to the watercourse. **Plate C3.28** also shows that Compton Road was inundated immediately to the south of its intersection with Cassin Street.

Plate C3.29 shows floodwater inundating Gilbert Road, where it ran between Mallee Street and Copeland Street, while **Plates C3.30** and **C3.31**, respectively show floodwater inundating Mallee Street north of its intersection with Conway Street and south of its intersection with Blyth Street.

2.2.5. Concluding Remarks

As the most severe flooding that was experienced during the 2 December 2017 and 5-6 February 2021 storm events occurred during the night, there is a general lack of data that are available for use in calibrating the hydrologic and hydraulic models that were developed as part of the present study. As a result, the data that are available for the storm event that occurred on 23 March 2021 were relied upon for calibration purposes. That said, the results of modelling the 2 December 2017 storm are presented in this report, as based on an analysis of the available rainfall record it represents the largest historic flood to have been experienced in parts of Wyalong and West Wyalong in recent years.

It is noted that while the date and time at which the photos shown in **Plates C4.1** to **C4.7** were taken is not known, the hydraulic model results for the 2 December 2017 and 23 March 2021 storm events confirm that these locations are subject to flooding.

3 HYDROLOGIC MODEL DEVELOPMENT AND CALIBRATION

3.1 Hydrologic Modelling Approach

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

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

3.2 Hydrologic Model Layout

Figure 3.1 (5 sheets) shows the layout of the hydrologic model that was developed for the study area. As the primary function of the hydrologic model was to generate discharge hydrographs for input to the hydraulic model, individual reaches linking the various sub-catchments were generally not incorporated in the hydrologic model. However, the outlets of the sub-catchments in the portion of the study catchments that lie outside the extent of the hydraulic model 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 1 m/s.

Careful consideration was given to the definition of the sub-catchments which comprise the hydrologic model to ensure peak flows throughout the drainage system would be properly routed through the hydraulic model. In addition to using the Light Detecting and Ranging (**LiDAR**) based contour data, the location of inlet pits and headwalls were also taken into consideration when deriving the boundaries of the various sub-catchments.

Percentages of impervious area were assessed using the available aerial photography and cadastre boundary data. Sub-catchment slopes used for input to the hydrologic model were derived using the vectored average slope approach for sub-catchments characterised as rural (which are modelled using the RAFTS approach) and the average sub-catchment slope approach for sub-catchments characterised as urbanised (which are modelled using the IL-CL approach). A digital elevation model derived from the available LiDAR survey data was 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 Wyalong and West Wyalong for the storm that occurred on 23 March 2021. As discussed in **Section 2.2**, the March 2021 storm event was equivalent to a design storm event with a maximum AEP of about 10%.

As there are no historic data on storm flows anywhere in the study area, the procedure adopted for the calibration of the hydrologic model involved an iterative process sometimes referred to as "tuning". This process involved the generation of discharge hydrographs for the historic storm events using a starting set of hydrologic model parameters. The discharge hydrographs were then input to the 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 hydrologic model parameters, after which the resulting adjusted discharge hydrographs were input to the hydraulic model until a good fit with observed data was achieved (refer **Chapter 4** for further details).

3.3.2. Hydrologic Model Parameters

Sub-catchments characterised as rural pastoral land modelled using the RAFTS hydrologic modelling approach in the DRAINS software had a Manning's n value of 0.04 applied if it was identified as cleared pastoral land. If the land was a mix of cleared pastoral land and dense vegetation, the Manning's n value was increased to 0.06. If it was mostly dense vegetation, the value was further increased to 0.08. A Bx routing parameter of 1 was adopted for sub-catchments that were modelled in RAFTS.

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

The following IL-CL model parameters were found to give a good fit to the historic flood data:

Travel Time Parameters

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

3.3.3. Application of Historic Rainfall to the Hydrologic Model

The right hand side of **Figure 2.3** shows the bursts of rainfall that was recorded at the Airport rain gauge and used as input to the hydrologic model for the 2 December 2017 and 23 March 2021 storm events, noting that **Table 2.2** shows that it was not necessary to apply a rainfall multiplier to the recorded rainfall at the Airport rain gauge in order to achieve a good match with that recorded at the Post Office rain gauge.

Figure 2.3 shows that about 11 mm and 18 mm of rain fell in the hours preceding the modelled bursts of rainfall for the 2 December 2017 and 23 March 2021 storm events, respectively. As the preceding rainfall satisfies the initial loss criteria in the hydrologic model, initial loss values of zero were applied to pervious and impervious areas, while continuing loss values of 2.0 mm/hr and 0 mm/hr were applied to pervious and impervious areas, respectively.[1]

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[1] The continuing loss value of 2.0 mm/hr was taken from the raw value recommended for Wyalong and West Wyalong on the *ARR Data Hub*, noting that this value was factored by a multiple of 0.4 for design flood modelling estimation (refer **Section 5.2** for further discussion).

3.3.4. Results of Model Testing

When applied to the hydraulic model, the discharge hydrographs that were generated by the hydrologic model gave reasonable correspondence with observed flood behaviour. The IL-CL and RAFTS hydrologic model parameters set out in this chapter were therefore adopted for design flood estimation purposes, noting that the initial and continuing loss values contained in the *Australian Rainfall and Runoff* (**ARR**) *Data Hub* were used for design flood estimation.

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 study area that are subject to overland flow. The TUFLOW modelling software was adopted as it is one of only a few commercially available hydraulic models which contain all the required features.

This chapter deals with the development and calibration of the TUFLOW model that were then used to define the behaviour of both Main Stream Flooding and Major Overland Flow in Wyalong and West Wyalong for a range of design storm events.

4.2 The TUFLOW Modelling Approach

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

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

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

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

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

4.3 TUFLOW Model Setup

4.3.1. Model Structure

The layout of the TUFLOW model that was developed for the study area is shown on **Figure 4.1** (5 sheets). Within the “urbanised” areas of Wyalong and West Wyalong, 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 digital elevation model.

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

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

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

It was not practicable to model the individual fences surrounding the many allotments in the study area. For the purpose of the present study, it was assumed that there would be sufficient openings in the fences to allow water to enter the properties, either 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 Council were used as the primary source of details of the piped drainage system which were incorporated into the TUFLOW model (refer **Appendix B** for more detail). These data were supplemented with field measurements as required. **Table 4.1** over the page summarises the pit and pipe data that were incorporated into the TUFLOW model.

Several types of pits are identified on **Figure 4.1**, including junction pits which have a closed lid and inlet pits which are capable of accepting overland flow. Inlet pit types and dimensions were incorporated in the TUFLOW model based on a visual inspection of the existing stormwater drainage system.

TABLE 4.1
SUMMARY OF MODELLED DRAINAGE STRUCTURES

Pipes		**Box Culverts**		**Footbridges**	**Inlet Pits**	**Headwalls**	**Junction Pits**
No.	**Length (m)**	**No.**	**Length (m)**	**No.**	**No.**	**No.**	**No.**
208	3906	67	1120	39	40	505	11

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 4.2 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 along the Main Drain between Creswell Street and Church Street. The left hand side of the figure shows the roads and inter-allotment areas, as well as the outlines of buildings, which have all been assigned different hydraulic roughness values in the model. The right hand side shows the resulting flow paths in the form of scaled velocity vectors and the depths of inundation. The buildings with their high values of hydraulic roughness block the passage of flow, although the model recognises that they store floodwater when inundated and therefore correctly accounts for flood storage.[2] Similar information to that shown on **Figure 4.2** may be presented at any location within the model domain (which is shown on **Figure 4.1**) and will be of assistance to Council in assessing individual flooding problems on the floodplain.

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[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**.

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 **Figure 4.1**. These comprise both point-source inflows at selected locations around the perimeter of the two-dimensional model domain, as well as internal to the model (for example, at the location of surface inlet pits) and as distributed inflows via "Rain Boundaries".

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 Results of Model Calibration Process

As previously mentioned, the hydrologic and hydraulic models were calibrated using data that were available for the storm that occurred on 23 March 2021, while the results of running the calibrated model for the 2 December 2017 storm are also presented for comparative purposes.

Figure 4.3 (2 sheets) shows water surface profiles along the Main Drain and Yiddah Creek for the two historic storm events, while **Figures 4.4** and **4.5** (5 sheets each) shows the TUFLOW model results for the 2 December 2017 and 23 March 2021 storm events, respectively. Also shown on **Figure 4.5** is the plan location of the observed flood behaviour for the 23 March 2021 storm event which were taken from photographs provided by Council and respondents to the *Community Questionnaire* (refer **Plates C3.1** to **C3.32** in **Appendix C**) and were used to validate the results of the TUFLOW model. **Table 4.3** at the end of this chapter summarises the abovementioned observed flood behaviour and sets out how they compare to the results of the TUFLOW model.

In general, the model was able to reproduce the observed flood behaviour from the 23 March 2021 storm event which was approximated from the photographs provided by respondents to the *Community Questionnaire.*

Based on the findings of the model calibration process, the 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 study area 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 MARCH 2021 STORM EVENT

Response Identifier [(1)]	Observed Flood Behaviour/ Other Comment	Model Verification Comments
FM_2021.1	• **Plate C3.1** shows Showground Road and the railway were not overtopped at about 12:00 hours on 23 March 2021 (after the peak of the flood).	• TUFLOW model results show floodwater ceased overtopping Showground Road at 12:30 hours on 23 March 2021 (i.e. 30 minutes after time of photography).
FM_2021.2	• **Plate C3.1** shows the downstream obvert of the pipes beneath Showground Road (which are set at an elevation of about RL 258.36 m AHD) are inundated at about 12:00 hours on 23 March 2021.	• TUFLOW model results show that the peak flood level on the downstream side of Showground Road is about RL 259.04 m AHD at the time of photography (i.e. 0.6 m above the obvert of the pipes).
FM_2021.3	• **Plate C3.1** shows that the downstream obvert of the pipes beneath the railway (which are set at an elevation of about RL 258.51 m AHD) were not inundated at about 12:00 hours on 23 March 2021.	• TUFLOW model results show that the peak flood level on the downstream side of railway is about RL 257.93 m AHD at the time of photography (i.e. 0.6 m below the obvert of the pipes).
FM_2021.4	• Approximate extent of flooding at about 12:00 hours on 23 March 2021 based on **Plate C3.4**.	• Modelled flood extent matches observed extent at time of photography.
FM_2021.5	• **Plates C3.2** to **C3.4** shows the Mid-Western Highway was not inundated at about 12:00 hours on 23 March 2021.	• TUFLOW model results show the Mid-Western Highway was not inundated at the time of photography.
FM_2021.6	• **Plate 3.6** shows the deck of the footbridge on the western side of Camp Street (which is set at an elevation of about RL 255.88 m AHD) was not inundated at 12:00 hours on 23 March 2021.	• TUFLOW model shows the peak flood level in the vicinity of the footbridge is about RL 255.65 at the time of photography (i.e. 0.2 m below the deck of the footbridge).
FM_2021.7	• **Plate C3.6** shows the deck of the footbridge on the eastern side of Creswell Street (which is set at an elevation of about RL 255.62 m AHD) was not inundated at 12:00 hours on 23 March 2021.	• TUFLOW model shows the peak flood level in the vicinity of the footbridge is about RL 255.30 at the time of photography (i.e. 0.3 m below the deck of the footbridge).
FM_2021.8	• **Plate C3.8** shows the deck of the footbridge in Barnado Park (which is set at an elevation of about RL 254.79 m AHD) was not inundated at 12:00 hours on 23 March 2021.	• TUFLOW model shows the peak flood level in the vicinity of the footbridge is about RL 255.62 at the time of photography (i.e. 0.2 m below the deck of the footbridge).
FM_2021.9	• **Plate C3.8** shows the crown of the Grenfell Street immediately west of its intersection with School Street was not inundated at about 12:00 hours on 23 March 2021.	• TUFLOW model shows the peak flood level in the Grenfell Street road reserve is about 0.1 m below the elevation of the crown of the road at the time of photography.

Refer over for footnotes to table.

Cont'd Over

TABLE 4.3 (Cont'd)
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR
MARCH 2021 STORM EVENT

Response Identifier (1)	Observed Flood Behaviour/ Other Comment	Model Verification Comments
FM_2021.11	• The approximate extent of inundation in Evans Street at about 12:30 hours on 23 March 2021 based on **Plate C3.11**.	• The modelled flood extent matches the observed extent at the time of photography.
FM_2021.12	• **Plate C3.12** shows shallow inundation in the rear of allotments that back onto the overland flow path at about 12:30 hours on 23 March 2021.	• TUFLOW model shows floodwater ponding to a maximum depth of about 0.2 m.
FM_2021.13	• A respondent to the *Community Questionnaire* indicated that the vacant block on the northern side of Park Street was inundated.	• TUFLOW model shows the vacant lot inundated to a depth of up to 0.3 m.
FM_2021.14	• **Plate C3.13** shows the deck of the footbridges on the northern and southern sides of Park Street (which are set at an elevation of about RL 254.79 m AHD and RL 254.66 m AHD, respectively) are not inundated at about 12:40 hours on 23 March 2021.	• TUFLOW model shows the peak flood levels of about RL 254.39 m AHD and RL 254.27 m AHD adjacent to the footbridge on the northern and southern side of the road at the time of photography, respectively.
FM_2021.15	• **Plate C3.14** shows shallow inundation of a residential allotment that is located on the northern side of Grenfell Street at about 12:40 hours on 23 March 2021.	• TUFLOW model results show allotment inundated to a maximum depth of about 0.2 m at the time of photography.
FM_2021.16	• **Plate C3.18** shows the open channel on the western side of the West Wyalong Bowling Club was flowing at "bank full" level at about 12:40 hours on 23 March 2021.	• Modelled peak flood levels in the channel are less than 0.1 m lower than the top of bank elevation.
FM_2021.17	• **Plate C3.10** shows the deck of the footbridge on the eastern side of Monash Street (which is set at an elevation of about RL 253.29 m AHD) was not inundated at about 12:50 hours on 23 March 2021.	• TUFLOW model shows the peak flood level in the vicinity of the footbridge is about RL 253.05 m AHD at the time of photography .
FM_2021.18	• **Plate C3.19** shows the deck of the footbridge on southern side of Gorman Street (which is set at an elevation of about RL 252.42 m AHD) is not inundated at about 12:40 hours on 23 March 2021.	• TUFLOW model shows the peak flood level in the vicinity of the footbridge is about RL 252.20 m AHD at the time of photography (i.e. 0.2 m below the deck of the footbridge).
FM_2021.19	• **Plate C3.10** shows the floodwater is lower than the soffit of the footbridge that is located on the eastern side of Operator Street (which is set at an elevation of about RL 252.03 m AHD) at about12:40 hours on 23 March 2021.	• TUFLOW model shows the peak flood level in the vicinity of the footbridge is about RL 251.52 m AHD at the time of photography (i.e. 0.5 m below the soffit of the footbridge).

Refer over for footnote to table.

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TABLE 4.3 (Cont'd)
SUMMARY OF QUESTIONNAIRE RESPONSES RELATED TO OBSERVED FLOOD BEHAVIOUR
MARCH 2021 STORM EVENT

Response Identifier [(1)]	Observed Flood Behaviour/ Other Comment	Model Verification Comments
FM_2021.10	• **Plate C3.9** shows that the width of flow across School Street was wider than the opening of the footbridge that is located on its western side (the width of which is about 14 m) at about 12:40 hours on 23 March 2021.	• The TUFLOW model results show the width of flow across School Street is about 20 m at the time of photography.
FM_2021.20	• **Plate C3.25** shows that floodwater was at the point of overtopping the right bank of the Main Drain at about 13:00 hours on 23 March 2021.	• TUFLOW model results show floodwater is within 0.02 m of the top of bank level at the time of photography.
FM_2021.21	• **Plate C3.32** shows shallow inundation of a vacant lot on the southern side of Neeld Street at about 07:00 hours on 23 March 2021.	• TUFLOW model shows allotment inundated to a maximum depth of about 0.15 m at the time of photography.
FM_2021.22	• **Plate C3.27** shows floodwater at the point of overtopping footbridge on the southern side of Neeld Street (which is set at an elevation of about RL 245.93 m AHD) at about 13:00 hours on 23 March 2021.	• TUFLOW model shows the peak flood level in the vicinity of the footbridge is about RL 245.90 m AHD at the time of photography (i.e. < 0.1 m below the deck of the footbridge).
FM_2021.23	• **Plate C3.27** shows that the footbridge on the southern side of Neeld Street (which is set at an elevation of about RL 246.16 m AHD) was not inundated at about 13:00 hours on 23 March 2021.	• TUFLOW model shows the peak flood level in the vicinity of the footbridge is about RL 245.77 m AHD at the time of photography (i.e. about 0.4 m below the deck of the footbridge).
FM_2021.24	• **Plate C3.28** shows shallow overtopping of Neeld Street approximately 140 m east of its intersection with Compton Road at about 13:00 hours on 23 March 2021.	• TUFLOW model results shows Neeld Street inundated to a depth of less than 0.1 m at the time of photography.
FM_2021.25	• **Plate C3.28** shows Compton Road was overtopped between the Main Drain and its intersection with Cassin Street at about 13:00 hours on 23 March 2021.	• TUFLOW model shows Compton Road inundated to a maximum depth of about 0.35 m at the time of photography.
FM_2021.26	• **Plate C3.29** shows shallow inundation of Gilbert Street between Copeland Street and Mallee Street at about 13:10 hours on 23 March 2021.	• TUFLOW model results show Gilbert Street generally inundated to depth of less than 0.1 m, with the exception of the causeway which is inundated to a maximum depth of about 0.4 m.
FM_2021.27	• **Plate C3.30** shows that Mallee Street was inundated to shallow depths north of its intersection with Conway Street at about 13:00 hours on 23 March 2021.	• TUFLOW model results show Mallee Street inundated to depths less than 0.1 m at the time of photography.
FM_2021.28	• **Plate C3.31** shows shallow inundation of the 370 m section of Wargin Road between its intersection with Blyth Street and the Main Drain at about 13:10 hours on 23 March 2021.	• TUFLOW model shows that this section of road is generally inundated to a depth of less than 0.1 m, with a 70 m section of road immediately north of the Main Drain inundated to a maximum depth of about 0.2 m.

1. Refer **Figure 4.3** 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 Wyalong and West Wyalong are presented in the 2019 edition of *Australian Rainfall and Runoff* (Editors, 2019) (**ARR 2019**). Design storms for frequencies of 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP were derived for storm durations ranging between 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 0.9 and 1.0 are applicable on the main arm of Yiddah Creek, a good match was achieved between the flows derived by the hydrologic model that was developed as part of the present study using a single ARF value of 1.0 and those derived by the Regional Flood Frequency Estimation (**RFFE**) Model, the procedures for which are set out in ARR 2019. Furthermore, 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 BoMs update of *Bulletin 53* (BoM, 2003). A copy of the data extracted from the *ARR Data Hub* for the present study area 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 BoM, 2003. This method is appropriate for estimating extreme rainfall depths for catchments up to 1000 km^2 in area and storm durations up to 3 hours.

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

- Calculate PMP for a given duration and catchment area using depth-duration-area envelope curves derived from the highest recorded US and Australian rainfalls.

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[3] It is noted that the temporal pattern data set for the *Murray Basin* region is suitable for use at Wyalong and West Wyalong.

- 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.

Figure 3.1 shows the location and orientation of the PMP ellipses which were used to derive the rainfall estimates for each individual sub-catchment at Wyalong and West Wyalong. Note that two orientations of the PMP ellipses were adopted in order to define the upper limit of flooding more accurately in both the Main Drain and Yiddah Creek catchments.

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 raw Probability Neutral Burst Initial Loss values obtained from the *ARR Data Hub* were reviewed and adjusted to remove inconsistencies in values with varying storm probability and duration. **Figure 5.1** shows the original Probability Neutral Burst Initial Loss curves derived from the tables obtained from the *ARR Data Hub*, together with the adopted PNBIL curves following the adjustments that were made as part of the present study.

The NSW jurisdictional advice recommends multiplying the raw (or unadjusted) continuing loss value of 2.0 mm/hr that is contained on the *ARR Data Hub* by a factor of 0.4. While a continuing loss value of 2.0 mm/hr (i.e. the raw continuing loss value taken from the *ARR Data Hub*) was found to achieve a reasonable match with flood behaviour that was observed during the 23 March 2021 storm event, the flood data relied upon for model calibration purposes is not considered detailed enough to rely upon for deriving a continuing loss value for design flood estimation. Therefore, a continuing loss value of 0.8 mm/hr (2.0 x 0.4 = 0.8) was therefore adopted for design flood modelling as part of the present study.

5.3 Derivation of Design Discharges

The hydrologic model was 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 the TUFLOW model.

Table 5.1 shows a comparison of design peak flow estimates derived from the hydrologic model compared to those derived by the RFFE Model, while **Figure 3.1** shows the location at which the comparisons were made. The peak flow comparison was undertaken for catchments that fit the following criteria:

- The total catchment area was greater than 0.5 km^2 and less than 1,000 km^2.
- The shape factor[4] and catchment area is comparable to those of the '*Nearby Catchments*' that are relied upon as part of the RFFE Model.

Table 5.1 shows the hydrologic model developed as part of the present study generally provide a good match to the RFFE Model for a range of assessed flood events.

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

A storm duration of 30 minutes was generally found to be critical for maximising peak flows for individual sub-catchments where the catchment area is less than 2 ha, with the critical storm duration generally increasing with increasing catchment area. Peak PMF flow rates for individual sub-catchments computed by the hydrologic model for the critical 15 minute PMP storm duration were generally between 7 and 11 times greater than the corresponding 1% AEP flow rates, with an upper and lower limit of 13 and 6 , respectively. These values lie within the range of expected multiples for a small urban catchment.

TABLE 5.1
COMPARISON OF DESIGN PEAK FLOW ESTIMATES

Identifier (1)	AEP (%)	RFFE Derived Peak Flow (m^3/s)	Model Derived Peak Flow (m^3/s)
W_RFFE1 (Catchment Area = 1.8 km^2)	20	2.2	2.8
	10	3.3	4.1
	5	4.7	5.6
	2	7.0	7.8
	1	9.1	9.5
W_RFFE2 [Yiddah Creek] (Catchment Area = 19.7 km^2)	20	14.5	15.6
	10	22.0	24.7
	5	31.3	33.6
	2	46.9	48.3
	1	61.5	58.6

1. Refer **Figure 3.1** for location of peak flow comparison at Wyalong and West Wyalong

6 HYDRAULIC MODELLING OF DESIGN STORM EVENTS

6.1 Presentation and Discussion of Results

6.1.1. Accuracy of Hydraulic Modelling

The accuracy of results depends on the precision of the numerical finite difference procedure used to solve the partial differential equations of flow, which is also influenced by the time step used for routing the floodwave through the system and the grid spacing adopted for describing the natural surface levels in the floodplain. 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.

6.1.2. Critical Duration and Temporal Pattern Assessment

The critical storm durations and associated median temporal patterns for the design storm events were derived based on the results of running both the DRAINS and TUFLOW models in tandem. For example, design discharge hydrographs for the ensemble of temporal patterns for storm durations ranging between 30 minutes and 9 hours were exported from the DRAINS model and input to the TUFLOW model. The assessment was undertaken for the 20%, 5% and 1% AEP storm events which represent the three temporal pattern bins (i.e. frequent, infrequent and rare, respectively) that were downloaded from the *ARR Data Hub.*

The full suite of storm durations were run for the PMF using the procedures set out in BoM, 2003, whereby design discharge hydrographs for storm durations ranging between 15 minutes and 3 hours were exported from the DRAINS model and input to the TUFLOW model.

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

6.1.3. Design Flood Extents and Water Surface Profiles

Figures 6.1 to **6.8** show the TUFLOW model results for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP storm events, together with the PMF. These diagrams show the indicative extent and depth of inundation in the study area for each design storm event.

Water surface profiles for the modelled design storm events along the Main Drain are shown on **Figure 6.9**. **Figure 6.10** shows stage hydrographs at selected road/rail crossings throughout the study area, while **Table E1** in **Appendix E** sets out the peak flood level and maximum depth of inundation at each crossing. **Table F1** of **Appendix F** sets out peak design flows and corresponding critical storm durations at key locations throughout the study area.

TABLE 6.1
CRITICAL DURATIONS AND TEMPORAL PATTERNS

Design Storm Event	Temporal Pattern Bin	Critical Storm Duration and Temporal Pattern(1)
20%	Frequent	30 minute, Storm Burst 8 [3838] 1 hour, Storm Burst 5 [3894] 4.5 hour, Storm Burst 4 [4014] 9 hour, Storm Burst 5 [4072]
10%	Infrequent	30 minute, Storm Burst 7 [3828] 1 hour, Storm Burst 8 [3887] 2 hour, Storm Burst 6 [3944] 6 hour, Storm Burst 7 [4039] 9 hour, Storm Burst 4 [4061]
5%		
2%	Rare	30 minute, Storm Burst 6 [3815] 1 hour, Storm Burst 6 [3873] 3 hour, Storm Burst 8 [3965] 6 hour, Storm Burst 7 [4025]
1%		
0.5%		
0.2%		

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

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.

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 Drain and Yiddah Creek pending the completion of the future *Floodplain Risk Management Study and Plan* (***FRMS&P***). Derivation of an interim Flood Planning Area (**Interim FPA**) based on the Interim FPLs is presented in **Section 6.6**.

The sensitivity studies and discussion presented in **Section 6.4** provide guidance on the suitability of the recommended allowance for freeboard under present day climatic conditions.

In accordance with DPE recommendations (DECC, 2007a), 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*.

6.1.4. Description of Flood Behaviour

While surface runoff is generally conveyed through the urbanised parts of Wyalong and West Wyalong at relatively shallow depths, it does become deeper and faster moving where it concentrates along the three main flow paths. The following discussion describes the key features of both Main Stream Flooding and Major Overland Flow in the study area.

The key features of Main Stream Flooding along the Main Drain are as follows:

- **Figure 6.10** and **Table E1** in **Appendix E** show that the road crossings of the Main Drain commence to become inundated as follows:
    - The low-level concrete encased causeways at Camp Street (refer Peak Flood Level Location (**PFLL**) H03, School Street (refer PFLL H04), Operator Street (refer PFLL H05), Boundary Street (refer PFLL H06), Clear Ridge Road (refer PFLL H07) are inundated during low flow events in the drain.
    - Compton Road (refer PFLL H09), Slee Street (refer PFLL H11) and Goldfields Way (refer PFLL H12) in a 20% AEP storm event.
    - Showground Road (refer PFLL H01) in a 10% AEP storm event.
    - Mid Western Highway (refer PFLL H02) and Neeld Street (refer PFLL H08) in a 5% AEP storm event.
    - While **Figure 6.10** indicates that Wargin Road (refer PFLL H10) is inundated in a 2% AEP storm event, **Table E1** in **Appendix E** shows that floodwater that surcharges the left bank of the Main Drain upstream of Wargin Road flows in an easterly direction where it inundates the low point in the road that is located about 70 m to the north of the drain in storm events as frequent as 20% AEP.
- The flow in the Main Drain bifurcates at the following locations:
    - At the Mid Western Highway (refer PFLL H02), where floodwater splits and flows in a northerly direction beneath the highway and in an easterly direction along Main Street before converging again in the vicinity of Grenfell Street.
    - At Church Street (refer PFLL H04), where floodwater splits and flows in an easterly direction along Kurrajong Street and in a north-easterly direction along North Street before converging again in the vicinity of Operator Street.
    - Downstream of Clear Ridge Road (refer Q07), where a portion of the total flow surcharging the left (northern bank) of the drain and continuing in an easterly direction to the north of Wyalong (refer Q21a and Q21b) and discharges to the Wyalong North Drainage Line, while the remaining portion follows the alignment of the drain to Goldfields Way (refer Q08a and Q08b).
- **Figure 6.1** shows that floodwater surcharges the Main Drain in a 20% AEP storm event at the following locations:
    - Between Camp Street and Church Street, where it inundates low lying residential allotments that are located adjacent to the drain (refer sheet 2).

  - To the east of West Wyalong Wetlands, where it flows in an easterly direction and overtops Compton Road at a low point that is located about 50 m to the south of its intersection with Cassin Street (refer sheet 3).
  - Immediately upstream (west) of Goldfields Way which is overtopped at an existing low point that is located about 100 m to the south of the culvert crossing of the Main Drain (refer sheet 3).
- **Figure 6.2** shows that floodwater commences to surcharge the Main Drain in a 10% AEP storm event at the following locations:
  - Between Monash Street and Operator Street, where it inundates the rear of existing residential allotments to the north of the drain (refer sheet 2).
  - The right bank of the drain immediately downstream (east) of Clear Ridge Road, where it inundates Neeld Street at a location about 450 m to the east of its intersection with Central Road (refer sheet 3).
- **Figure 6.3** shows that floodwater commences to surcharge the Main Drain in a 5% AEP storm event at the following locations:
  - Along the embankment of a disused railway dam that is located on the downstream side of the Cootamundra Lake Cargelligo Railway to the south of the Mid Western Highway where it flows in an easterly direction through the Ace Caravan Park that is located immediately to its east (refer sheet 2).
  - At Apex Park where it overtops the Mid Western Highway immediately to the east of its intersection with Ungarie Road and ponds in the front of the Colonial Motor Inn (refer sheet 2).
  - The right bank of the drain immediately upstream of the Mid Western Highway where it flows in an easterly direction along the southern side of Main Stream, inundating the front of existing commercial allotments that are located to the south of the road (refer sheet 2).
- **Figure 6.5** shows that floodwater originating from the Main Drain inundates existing development to depths greater than 300 mm in a 1% AEP storm event at the following locations:
  - In existing commercial and residential allotments that are located on the northern and southern sides of the Main Drain between the Mid Western Highway and Operator Street (refer sheet 2).
  - In existing residential allotments that are located on the upstream (western) side of Clear Ridge Road (refer sheet 3).
- **Table F1** in **Appendix F** shows that peak PMF flow rates in the Main Drain are about ten times the corresponding peak 1% AEP flow rates.

The key features of Main Stream Flooding along the Wyalong North Drainage Line are as follows:

- **Figure 6.10** and **Table E1** in **Appendix E** show that the road crossings of the Wyalong North Drainage Line commence to become inundated as follows:
  - Slee Street (refer PFLL H14) in a 20% AEP storm event.
  - Newell Highway (refer PFLL H15) in a 10% AEP storm event.

- **Figure 6.5** shows that floodwater originating from the Wyalong North Drainage Line inundates existing development in the vicinity of the intersection of Pine Street and Gilbert Street to depths greater than 300 mm in a 1% AEP storm event.
- **Table F1** in **Appendix F** shows that peak PMF flow rates in Wyalong North Drainage Line are between nine and thirteen times the corresponding peak 1% AEP flow rates.

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

- The Bellarwi Road crossing of Yiddah Creek which comprises a low-level causeway is inundated during low flow events in the creek. **Table E1** in **Appendix E** shows that the causeway will be inundated to a depth of about 800 mm in a 1% AEP storm event.
- The width of flow on the Yiddah Creek floodplain is generally between about 200 m and 700 m in a 1% AEP storm event, increasing to a maximum of about 1,400 m in a PMF event.
- **Table F1** in **Appendix F** shows that peak PMF flow rates in Yiddah Creek are about ten times the corresponding peak 1% AEP flow rates.

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

- As there are very limited piped drainage elements in Wyalong and West Wyalong, Major Overland Flow is primarily conveyed overland through the urbanised parts of the study area along road reserves or via concrete lined flows paths.
- While there is deeper concentrated flow along the alignment of the concrete lined flow paths shown on **Figure 2.2**, shallow overland flow is generally present in the adjacent urbanised parts of the study area during storms as frequent as 20% AEP.
- **Figure 6.5** shows that the depth of flow through existing development in the urbanised parts of the study area is generally less than 300 mm deep in a 1% AEP storm event, with the following exceptions:
    - in the rear of a number of residential allotments that are located between Dumaresq Street and Monash Street to the north of Parks Street;
    - in the rear of a number of residential allotments on the eastern side of Brown Street;
    - in existing residential development that is located to the north-east of the intersection of Monash Street and Grenfell Street; and
    - in a single residential allotment that is located on the southern side of Victory Street.
- While the runway at the West Wyalong Airport commences to be overtopped in a 10% AEP storm event, the depth of flow across the runway does not exceed 100 mm in a 1% AEP storm event.
- **Figure 6.9** shows that the depth of overland flow along the Major Overland Flow paths exceeds 500 mm during a PMF event, with depths of greater than 1 m shown to occur in a number of areas.

Table 6.2 over the page sets out the results of a qualitative assessment of the effects that flooding has on key infrastructure at Wyalong and West Wyalong. The roads and parks and gardens will be impacted during flood events as frequent as 20% AEP, while the telephone exchange in Gladstone Street will be impacted by floodwater in a PMF. The water supply and electricity infrastructure will remain flood free in a PMF

TABLE 6.2
QUALITATIVE EFFECTS OF FLOODING ON INFRASTRUCTURE AND COMMUNITY ASSETS IN WYALONG AND WEST WYALONG

Damage Sector	**Design Flood Event (AEP)**							
	20%	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.2%**	**PMF**
Roads	X	X	X	X	X	X	X	X
Parks and Gardens	X	X	X	X	X	X	X	X
Electricity	O	O	O	O	O	O	O	O
Water Supply	O	O	O	O	O	O	O	O
Telephone	O	O	O	O	O	O	O	X

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

6.2 Economic Impacts of Flooding

Table 6.3 sets out the number of properties that are flood affected in the study area and the estimated damages which would occur for storm events of varying AEP. **Figures 6.1** to **6.8** show the indicative depth of above-floor inundation that would be experienced in individual properties during storm events ranging between 20% AEP and the PMF.

A storm event more frequent than 2% AEP is the threshold at which significant tangible flood damages commence to occur in the study area. For example, six residential dwellings (five in West Wyalong and one in Wyalong) and one public building (in West Wyalong) are subject to above-floor inundation to depths of up to 220 mm in a 2% AEP storm event. **Table 6.2** shows that the total number of residential dwellings that would experience above-floor inundation increases to 12 (nine in West Wyalong and three in Wyalong) at the 1% AEP level of flooding.

During a PMF event, 433 individual dwellings (346 at West Wyalong and 87 at Wyalong), 63 commercial buildings (54 at West Wyalong and 9 at Wyalong) and seven public buildings (five at West Wyalong and two at Wyalong) would experience above-floor inundation in the study area.

The *"Present Worth Value"* of tangible damages resulting from all floods up to the magnitude of the 1% AEP at Wyalong and West Wyalong for a discount rate of 7% and an economic life of 50 years is $0.3 Million and $1.4 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 towns. While schemes costing more than this value would have a benefit/cost ratio less than 1, they may still be justified according to a multi-objective approach which considers other criteria in addition to economic feasibility.

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

TABLE 6.3
SUMMARY OF FLOOD DAMAGES

Town	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	
Wyalong	20	1	0	0	0	0	0	0.02
	10	3	0	0	0	0	0	0.06
	5	4	1	0	0	0	0	0.11
	2	6	1	0	0	0	0	0.15
	1	14	3	0	0	0	0	0.41
	0.5	19	4	0	0	0	0	0.58
	0.2	24	5	0	0	0	0	0.80
	PMF	128	87	9	9	2	2	9.53
West Wyalong	20	6	0	0	0	0	0	0.13
	10	10	1	0	0	1	1	0.25
	5	24	1	0	0	1	1	0.60
	2	55	5	3	0	1	1	1.45
	1	75	9	3	0	1	1	2.10
	0.5	95	17	5	1	1	1	2.91
	0.2	128	34	6	2	2	1	4.39
	PMF	537	346	69	54	11	5	43.9

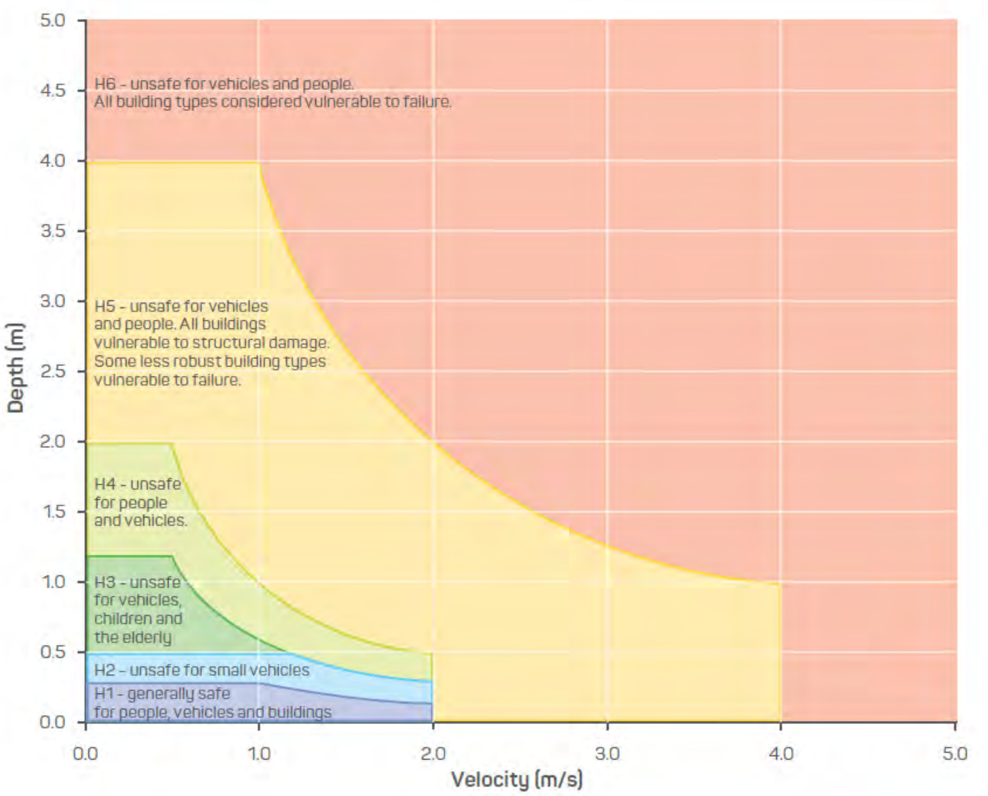
6.3 Flood Hazard Zones and Floodways

6.3.1. Flood Hazard Vulnerability Classification

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

Flood Hazard Vulnerability Classification diagrams based on the procedures set out in ARR 2019 for the 5 and 1% AEP flood events, as well as PMF are presented on **Figures 6.11**, **6.12** and **6.13**, respectively.

The study found that areas classified as H6 are limited to three water containment structures, two of which are located along the main arm of the Main Drain and the third which is located in the Wyalong Sewerage Treatment Plant. The study also found that while areas classified as H5 are generally limited to the central thread of the three main flow paths , it was also found to be present in a large number of local farm dams that are scattered through the study area.



Areas classified as either H3 and H4 are generally present on the immediate overbank of the three main flow paths, as well as in major ponding areas that are typically located upstream of road and rail crossings, while areas affected by Major Overland Flow are generally classified as either H1 or H2.

The flooding that is experienced at the road crossings that are inundated in a 1% AEP event falls within the H1 category with the following exceptions:

Main Stream Flooding along the Main Drain, Wyalong North Drainage Line and Yiddah Creek

- H5 along the 220 m long reach of the Main Drain that runs along Kurrajong Street between Church Street and Monash Street.
- H5 at the Boundary Street and Clear Ridge Road causeway crossings of the Main Drain.
- H4 at the Camp Street, Grenfell Street, Church Street, Monash Street and Operator Street crossings of the Main Drain.
- H4 at the Bellarwi Road causeway crossing of Yiddah Creek.
- H3 at the Compton Street crossing of the Main Drain.
- H3 at the Slee Street and North Street crossings of the Wyalong North Drainage Line.
- H2 at the Showground Road and the Mid Western Highway crossing of the Main Drain.

Major Overland Flow Paths in West Wyalong

- H3 at the locations where the concrete line overland flow paths in West Wyalong cross Grenfell Street, Railway Road, Victory Road, Cedar Street and Hyde Street.
- H2 at the locations where the concrete line overland flow paths in West Wyalong cross Wootten Street, Evans Street, Park Street, Court Street and Gladstone Street.

Major Overland Flow Paths in Wyalong

- H3 at the low level causeway in North Street that is located about 320 m to the east of its intersection with Slee Street.
- H2 at the low point in Cassin Street that is located between its intersections with Compton Road and Wargin Road.
- H2 at the low point in Gilbert Street that is located about 210 m to the east of its intersection with Copeland Street.
- H2 along a 250 m section of Mallee Street to the north of its intersection with North Street.

For the PMF event, the width of the H5 and H6 hazard zones increases significantly, mainly along the three main flow paths. 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 *Floodplain Development Manual* (NSW Government, 2005), the floodplain may be sub-divided into the following three hydraulic categories:

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

Floodways are those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with obvious naturally defined channels. Floodways are the areas that, even if only partially blocked, would cause a significant re-distribution of flow, or a significant increase in flood level which may in turn adversely affect other areas. They are often, but not necessarily, areas with deeper flow or areas where higher velocities occur.
Flood storage areas are those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.

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

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

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

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

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

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

- Velocity x Depth greater than 0.15 m^2/s **and** Velocity greater than 0.25 m/s; or
- Velocity greater than 1 m/s.

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

Figures 6.14, **6.15** and **6.16**, respectively show the division of the floodplain into floodway, flood storage and flood fringe areas for the 5% and 1% AEP storm event, as well as the PMF.

Floodways are generally present along the alignment of the three main flow paths, as well as the concrete lined flow paths that are present in West Wyalong. While the floodways are generally contained within the drainage and road reserve boundaries, there are floodways present in undeveloped rural type land that should be considered when assessing the suitability of future development.

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

6.4 Sensitivity Studies

6.4.1. 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.

6.4.2. Sensitivity to Hydraulic Roughness

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

The typical increases in peak flood level in the areas subject to Main Stream Flooding are generally in the range 10 to 50 mm, with increases of up to 100 mm show to occur in isolated areas. Increases in peak flood levels along the tributary arms of the three main flow paths and in other areas subject to Major Overland Flow are generally in the range 10 to 30 mm.

6.4.3. 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 study area based on the procedures set out in ARR 2019. Blockage factors of 25% and 50% were generally found to be applicable for the piped drainage lines within the urbanised parts of the study area, while blockage factors of 15% and 25% were generally found to be applicable for the footbridge crossings of the Main Drain and Major Overland Flow paths.[5]

Figure 6.18 shows the afflux for a 1% AEP event resulting from a partial blockage of the minor piped drainage network and footbridges. This represents a case which is well beyond a blockage scenario which could reasonably be expected to occur and is presented for illustrative purposes only.

Figure F6.18 shows that the effects of a partial blockage of the drainage system in the study area are generally negligible, except where road and railways traverse the floodplain, where peak flood levels could potentially increase by up to 200 mm.

6.5 Climate Change Sensitivity Analysis

6.5.1. General

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

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

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

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 *Wyalong and West Wyalong FRMS&P* for the two towns using site specific data.

In the *Wyalong and West Wyalong 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 *Wyalong and West Wyalong 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.

6.5.2. 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 *Wyalong and West Wyalong 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 6.19 shows the afflux resulting from a 10 per cent increase in 1% AEP rainfall intensities. The increase in peak flood levels along the three main flow paths and their tributaries varies between 50 to 100 mm, while increases in peak flood levels of up to 40 mm are shown to occur along a number of Major Overland Flow paths.

Figure 6.20 shows the afflux for a 30 per cent increase in 1% AEP rainfall intensities. Peak flood levels along the three main flow paths and their tributaries varies between 50 to 150 mm, while increases in peak flood levels of up to 70 mm are shown to occur along a number of Major Overland Flow paths.

Figure 6.21 shows the increase in the extent of land that would be affected by floodwater should 1% AEP rainfall intensities increase by 10 or 30 per cent. The extent of land that would be affected by floodwater increases significantly in the urbanised parts of West Wyalong that border the Main Drain where it runs between the Mid Western Highway and Operator Street.

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

6.6 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 0.5 m; and

- in areas subject to Major Overland Flow and that also lie outside the extent of the Main Stream Flooding FPA, the extent of the FPA was define as land inundated to a depth greater than 100 mm.

Figure 6.22 shows the extent of the Interim FPA in the study area. In areas that lie within the extent of the Interim FPA it is recommended that a freeboard of 0.5 m be applied to peak 1% AEP flood levels when setting the minimum habitable floor 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 *Wyalong and West Wyalong FRMS&P* to the appropriateness of the adopted freeboard allowance of 0.5 m given the impact changes in hydraulic roughness and future increases in rainfall intensity could have on peak flood levels. Consideration will also need to be given to the setting of an appropriate freeboard for areas subject to Major Overland Flow given that the adopted value of 0.5 m may be found to be too conservative.

Figure 6.22 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.

7 REFERENCES

BoM (Bureau of Meteorology), 2003. ***"The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method"***

DECC (Department of Environment and Climate Change, NSW), 2007a. ***"Floodplain Risk Management Guideline – Practical Considerations of Climate Change"****.*

Editors (Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I), 2019. ***"Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia"***

NSWG (New South Wales Government), 2005. ***"Floodplain Development Manual – The Management of Flood Liable Land"*****.**

NSW SES (NSW State Emergency Service), 2013. ***"Bland Shire Local Flood Plan"***

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

West Wyalong/Wyalong Flood Study

Bland Shire Council has engaged consultants to undertake a flood study for the towns of Wyalong and West Wyalong.

The study will define mainstream flooding patterns along the town stormwater drain that runs in an easterly direction through the towns and flood behaviour in areas that are subject to major overland flow which occurs as a result of surcharge of the local stormwater drainage system.

The study is being undertaken by Council with funding assistance from the NSW Department of Planning, Industry and Environment.

An important first step in the preparation of a Flood Study is to identify the availability of information on historic flooding in the study area.

A survey has been developed for residents and business owners to provide information regarding recent and historic flooding in Wyalong and West Wyalong to assist the consultants in gathering this important information.

Residents can access the survey by scanning the below QR code, through Council's website at www.blandshire.nsw.gov.au

BLAND SHIRE COUNCIL
west wyalong

Call in to Council's offices at 6 Shire Street, West Wyalong or phone Council on 02 6972 2266 to arrange to have a hard copy sent to you

All information provided will remain confidential and for use in this study only.

For more information about the study visit www.blandshire.nsw.gov.au

Survey closes Friday 19 March 2021

BLAND SHIRE COUNCIL
west wyalong

WYALONG / WEST WYALONG FLOOD STUDY

Community Consultation

Bland Shire Council has engaged consultants to undertake a flood study for the towns of Wyalong and West Wyalong which will define mainstream flooding patterns along the town stormwater drain that runs in an easterly direction through the towns. The study will also define flood behaviour in areas that are subject to major overland flow which occurs as a result of surcharge of the local stormwater drainage system. Please see the back of this page for the approximate extent of the study areas.

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

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

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

- 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

Following the completion of the *Flood Study*, Bland Shire Council may be eligible for further funding from the NSW Government to undertake a *Floodplain Risk Management Stud*y to assist Council in refining strategic plans for mitigating and managing the effects of the existing, future and continuing flood risk at Wyalong and West Wyalong.

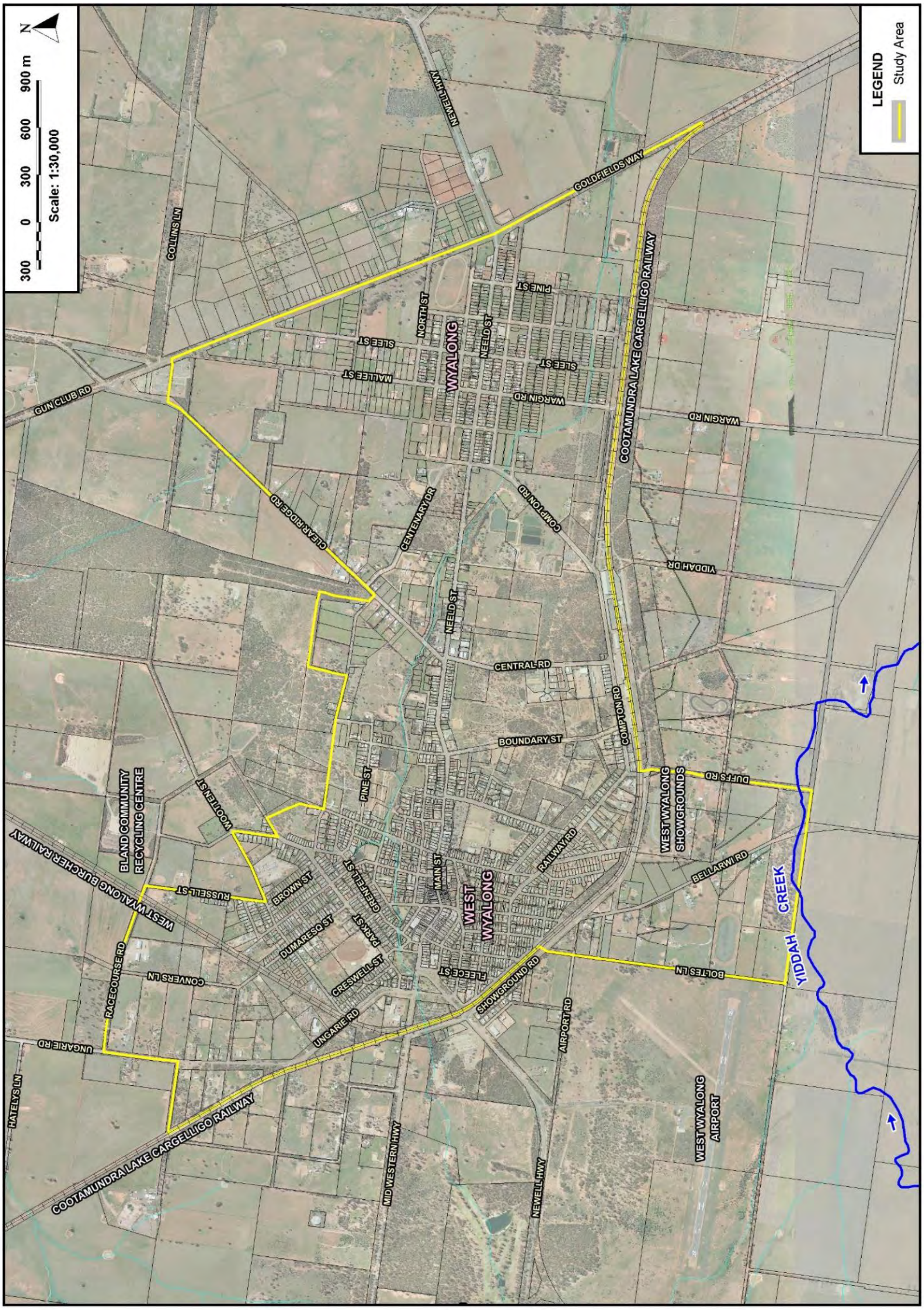
An important first step in the preparation of a *Flood Study* is to identify the availability of information on historic flooding in the study area. The attached *Community Questionnaire* has been provided to residents and business owners to assist the consultants in gathering this important information. All information provided will remain confidential and for use in this study only. Please return the completed questionnaire in the reply paid envelope provided by **Friday 19 March 2021**.

Contact: Bland Shire Council

Jamie Harwood | Manager Engineering Services
Phone: (02) 6972 2266
Email: JHarwood@blandshire.nsw.gov.au

BLAND SHIRE COUNCIL
west wyalong

Study Area



LEGEND
Study Area
Scale: 1:30,000
300
0
300
600
900 m
N
NEWELL HWY
GOLDFIELDS WAY
COLLINS LN
GUN CLUB RD
PINE ST
NORTH ST
SLEE ST
MALLEE ST
WYALONG
NEELD ST
WARGIN RD
COOTAMUNDRA LAKE CARGELLIGO RAILWAY
CLEAR RIDGE RD
CENTENARY DR
COMPTON RD
YIDDAH DR
CENTRAL RD
BOUNDARY ST
DUFFS RD
WEST WYALONG SHOWGROUNDS
BELLARWI RD
RAILWAY RD
MAIN ST
WEST WYALONG
PINES ST
WOOTTEN ST
BLAND COMMUNITY RECYCLING CENTRE
WEST WYALONG BURCHER RAILWAY
RUSSELL ST
BROWN ST
GRENFELL ST
DUMARESQ ST
PARK ST
CRESWELL ST
FLEECE ST
SHOWGROUND RD
BOLTES LN
YIDDAH CREEK
CONVERS LN
RACECOURSE RD
UNGARIE RD
HATELYS LN
AIRPORT RD
WEST WYALONG AIRPORT
MID WESTERN HWY

WYALONG / WEST WYALONG FLOOD STUDY

Community Questionnaire

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

Please return your completed questionnaire in the reply paid envelope provided by **Friday 19 March 2021**. No postage stamp is required. If you have misplaced the supplied envelope or wish to send an additional submission the address is:

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

1. Your details:

Name (Optional):____

Address:____

Phone Number (Optional):____

Email (Optional): ____

2. Please tick as appropriate:

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

3. How long have you been at this address?

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

4. **What is your property?**
   - ☐ House
   - ☐ Unit/Flat/Apartment
   - ☐ Vacant land
   - ☐ Industrial unit in larger complex
   - ☐ Stand alone warehouse or factory
   - ☐ Shop
   - ☐ Community building
   - ☐ Other (____)

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

   [ ] Yes [ ] No

6. **If you answered yes to Question 5, 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)	

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

____

____

____

8. 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).

____

____

____

9. 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.__________

10. 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

11. If you answered yes to Question 10, 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)		

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

[ ] Yes [ ] No

13. **If you answered yes to Question 12, 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).

14. **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

15. **If you answered yes to Question 14, 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?**

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

APPENDIX B
DETAILS OF AVAILABLE DATA AND COMMUNITY CONSULTATION

TABLE OF CONTENTS

Page No.

LIST OF FIGURES (BOUND IN VOLUME 2)

B1 COLLECTION OF MISCELLANEOUS DATA

B1.1 Airborne Laser Scanning Survey

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

TABLE B1.1
LiDAR SURVEY DATA SPECIFICATIONS

Data Set	Date of Capture	Data Provider
Wyalong201402	9 February 2012	Geoscience Australia

B1.2 Existing Stormwater Network

Figure B1.1 (5 sheets) shows the plan location of the existing stormwater network in the study area. Details of the stormwater drainage network were surveyed by Council in March 2021. For the purposes of the survey, the drainage structures were split into six categories; culverts, railway culverts, footbridges, stormwater pits, inlet headwalls and outlet headwalls. **Figure B1.1** shows the plan location of the surveyed structures, while **Table B1.2** sets outs out the number and type of structure, as well as the data that we provided at each.

TABLE B1.2
DETAILS OF SURVEY DATA AT WYALONG AND WEST WYALONG

Structure Type	No. of Structures	Description	Data Requirements
Culvert	108	Culvert beneath a Council owned road, access road or embankment.	• Co-ordinates and invert levels at upstream and downstream end of culvert; • Culvert dimensions; • Number of barrels; and • Photo of upstream and downstream headwall.
Railway Culvert	27	Culvert beneath the existing railway line.	• Co-ordinates and invert levels at upstream and downstream end of culvert; • Culvert dimensions; • Number of barrels; and • Photo of upstream and downstream headwall.
Footbridge	37	Elevated walkway across overland flow path.	• Co-ordinates and lowest ground elevation along upstream face of footbridge; • Elevation of walkway/ deck; • Thickness of walkway/deck; and • Size of opening beneath deck; • Height of hand rail; • Photo of footbridge.

Cont’d Over

TABLE B1.2 (Cont'd)
DETAILS OF SURVEY DATA AT WYALONG / WEST WYALONG

Structure Type	No. of Structures	Description	Data Requirements
Inlet Headwall	8	Inlet of an enclosed drainage system.	• Co-ordinates and invert levels of inlet; • Culvert dimensions; • Number of barrels; and • Photo of inlet.
Stormwater Pit	34	Grated stormwater inlet pit.	• Co-ordinates and invert levels of stormwater pit; • Dimensions and approximate orientation (i.e. North, North East etc) of all pipes entering and exiting pit; and • Photo of pit at surface level showing inlet type.
Outlet Headwall	11	Outlet of an enclosed drainage system.	• Co-ordinates and invert levels of outlet; • Culvert dimensions; • Number of barrels; and • Photo of outlet.

B1.3 Historic Rainfall Data

Rainfall data were available at one AWS and four daily read rain gauges which are operated by BoM in the vicinity of Wyalong and West Wyalong. **Figure B1.1** shows the plan location of the five rain gauges, while **Table B1.3** sets out the details of the rain gauge network.

TABLE B1.3
SUMMARY OF AVAILABLE RAIN GAUGE DATA(1)

Gauge Number	Data Time Interval	Gauge Name	Site Commence	Site Cease
50017	1 min	West Wyalong Airport AWS	April 1999	Ongoing
50103	Daily	West Wyalong Airport	August 1978	July 2016
50044		West Wyalong Post Office	February 1895	December 2002
73054		Wyalong Post Office	June 1895	Ongoing
50123		Wyalong Upper 3 Run	January 1882	February 1923

1. Refer **Figure B1.1** for location.

B1.4 Photographic Record

Appendix C contains a number of photographs that were provided by Council at the commencement of the present study showing flood behaviour in the study area during storms that occurred on 2 December 2017 and 23 March 2021, as well as photographs provided by respondents to the *Community Questionnaire* for a storm that occurred on 5-6 February 2021.

B2 COMMUNITY CONSULTATION

B2.1 Background

At the commencement of the study, the Consultants prepared a *Community Newsletter and Questionnaire*, the former of which were distributed by Council to residents and business owners in the study area (refer **Appendix A**).

The purpose of the *Community Newsletter* was to introduce the objectives of the study so that the community would be better able to respond to the *Community Questionnair*e and contribute to the study process. The *Community Newsletter* contained a summary of the proposed methodology and outcomes, as well as a QR code that the residents and business owners could use to access and online version of the *Community Questionnaire*.

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

The *Community Newsletter and Questionnaire* were advertised in the local newspaper and posted to 2,400 residents and business owners in the study area in February 2021. The *Community Newsletter and Questionnaire* were also advertised on Council's website and social media platforms.

B2.2 Summary of Findings

B2.2.1. General

Residents and business owners were requested to complete the *Community Questionnaire* by 19 March 2021. The deadline was extended to include any submissions that were received after this date. The Consultants received 20 responses in total, which amounted to about one per cent of the total number of questionnaires that were distributed to the community.

B2.2.2. Resident Profile

The first four questions of the *Community Questionnaire* canvassed resident information such as whether the respondent was a resident or business owner, length of time at the property, the type of property (e.g. house, unit/flat).

The length of time respondents had been at their current address was found to be varied, with six respondents having lived at the residence for between '0-5 years', seven for '5 to 20 years', four for 'more than 20 years', noting that the remaining three respondents did not provide an answer to this question. Of the 20 responses, 16 respondents occupied residential type property and two responses were concerned with property which is vacant land.[1]

B2.2.3. Experiences of Flooding

Respondents to the *Community Questionnaire* identified storm events that occurred on the following dates:

- 2012 (exact date not provided) (one respondent);
- 2 December 2017 (one respondent);
- June 2016 ((day not provided) (one respondent);

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[1] Two respondents did not identify what type of property they occupied.

- 9 December 2010 (one respondent);
- 5-6 February 2021 (8 respondents); and
- 21 March 2021 (two respondents).

Thirteen of the respondents indicated that they had been affected by flooding, while five had not been affected.[2] Of those that have been affected by flooding, four indicated that their house or business was inundated above-floor level, five indicated that their garage or shed was flooded and eleven indicated that their front or back yard was inundated.

Respondents also identified flooding issues at the following locations:

- the two causeways in Boundary Street;
- the intersection of Russel Street and Montgomery Street;
- Grenfell Street (exact location not specified);
- the intersection of Kurrajong Street and School Street;
- Cassin Street (exact location not specified);
- Wargin Road (exact location not specified); and
- Slee Street to the north of its intersection with North Street.

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[2] Two respondents did not provide an answer to Question 5.

APPENDIX C

PHOTOGRAPHS SHOWING OBSERVED FLOOD BEHAVIOUR IN WYALONG AND WEST WYALONG

2 DECEMBER 2017 STORM EVENT

Plate C1.1 – (Photo taken at 09:47 hrs) – Looking east along Mid-Western Highway, from its intersection with Ungarie Road.

Plate C1.2 – (Photo taken at 09:48 hrs) – Looking north-east along the Main Drain through McCann Park from Mid-Western Highway.

Plate C1.3 – (Photo taken at 09:55 hrs) – Looking north-east along Grenfell Street from its intersection with Creswell Street.

Plate C1.4 – (Photo taken at 09:59 hrs) – Looking west through Barnado Park.

2 DECEMBER 2017 STORM EVENT

Plate C1.5 – (Photo taken at 10:00 hrs) – Floodwater surrounding building in Barnado Park.

Plate C1.6 – (Photo taken at 10:01 hrs) – Looking north past the footbridge between Bernado Park and Church Street.

Plate C1.7 – (Photo taken at 10:03 hrs) – Looking west at the footbridge between Barnado Park and Church Street. Depth indicators on bridge indicate floodwater is 200 mm deep.

Plate C1.8 – (Photo taken at 10:03 hrs) – Looking East along Kurrajong Street from its intersection with Church Street.

2 DECEMBER 2017 STORM EVENT

Plate C1.9 – (Photo taken at 10:07 hrs) – Looking north along Operator Street from its intersection with the Gorman Street.

Plate C1.10 – (Photo taken at 10:19 hrs) – Looking north-east along Clear Ridge Road.

Plate C1.11 – (Photo taken at 10:23 hrs) – Looking west along Neeld Street in the vicinity of West Wyalong Wetlands Boardwalk.

Plate C1.12– (Photo taken at 10:38 hrs) – Floodwater ponding on upstream (western) side of Sewage Treatment Plant access road.

2 DECEMBER 2017 STORM EVENT

Plate C1.13 –(Photo taken at 10:38 hrs) – Floodwater flowing in a northerly direction on the eastern side of Sewage Treatment Plant access road

Plate C1.14 – (Photo taken at 10:38 hrs) – Looking north-west across the West Wyalong Wetlands Boardwalk from the Sewerage Treatment Plant.

Plate C1.15 – (Photo taken at 10:34 hrs) – Looking north across the West Wyalong Wetlands Boardwalk from the Sewerage Treatment Plant.

Plate C1.16 – (Photo taken at 10:34 hrs) – Looking east along the Main Drain from Compton Road.

2 DECEMBER 2017 STORM EVENT

Plate C1.17 – (Photo taken at 11:00 hrs) – Floodwater overtopping Compton Road at low point that is located about 60 m south of its intersection with Cassin Street.

Plate C1.18 – (Photo taken at 11:03 hrs) – Looking east along the Main Drain from Wargin Road.

Plate C1.19 - (Photo taken at 11:08 hrs) – Looking west along Gilbert Street where it runs between Wargin and Copeland Streets.

5 FEBRUARY 2021 STORM EVENT

Plate C2.1 – (Time of photo unknown) – Floodwater inundating Cassin Street between its intersections with Compton Road and Mallee Street.

Plate C2.2 – (Time of photo unknown) – Floodwater ponding on southern side of Cassin Street between its intersections with Compton Road and Mallee Street.

Plate C2.3 – (Time of photo unknown) – Looking north along channel that drains low point in Cassin Street between its intersections with Compton Road and Mallee Street.

Plate C2.4 – (Time of photo unknown) – Floodwater ponding on western side of Wargin Street at its intersection Blyth Street.

5 FEBRUARY 2021 STORM EVENT

Plate C2.5 – (Time of photo unknown) – Looking north along Wargin Road from the Main Drain.

Plate C2.6 - (Time of photo unknown) – Looking west along the Main Drain from Wargin Road.

Plate C2.7 - (Time of photo unknown) – Looking east along the Main Drain from Wargin Road.

Plate C2.8 - (Time of photo unknown) – Floodwater in Park Street (exact location unknown).

5 FEBRUARY 2021 STORM EVENT

Plate C2.9 - (Time of photo unknown) – Floodwater ponding between the railway and residential allotments on Russell Street north of its intersection with Montgomery Street.

Plate C2.10 - (Time of photo unknown) – Floodwater ponding between the railway and residential allotments on Russell Street north of its intersection with Montgomery Street.

Plate C2.9 - (Photo taken at about 22:00 hours) – Floodwater ponding in the rear of a residential property on Wooten Street.

23 MARCH 2021 STORM EVENT

Plate C3.1 – (Photo taken at 11:49 hrs) – Looking west over Showground Road and the Cootamundra Lake Cargelligo Railway, south of its intersection with the Mid-Western Highway.

Plate C3.2 – (Photo taken at 11:49 hrs) – Looking west along the Mid-Western Highway from Lions Park, across Ace Caravan Park.

Plate C3.3 – (Photo taken at 11:49 hrs) – Looking north at the intersection of the Mid-Western Highway and Ungarie Road.

Plate C3.4 – (Photo taken at 11:49 hrs) – Looking east along the Mid-Western Highway from its intersection with Ungarie Road.

23 MARCH 2021 STORM EVENT

Plate C3.5 – (Photo taken at 11:50 hrs) – Looking east along the Mid-Western Highway from its intersection with Ungarie Road.

Plate C3.6 – (Photo taken at 11:52 hrs) – Looking south-west at the intersection of Creswell Street and Camp Street.

Plate C3.7 – (Photo taken at 11:51 hrs) – Looking south at the intersection of Grenfell Street and Creswell Street.

Plate C3.8 – (Photo taken at 11:51 hrs) – Looking east at Barnado Park from Grenfell Street.

23 MARCH 2021 STORM EVENT

Plate C3.9 – (Photo taken at 12:43 hrs) – Looking west at Barnado Park from the intersection of North Street and Church Street.

Plate C3.10 – (Photo taken at 12:45 hrs) – Looking west along Kurrajong Street at its intersection with Monash Street.

Plate C3.11 – (Photo taken at 12:34 hrs) – Looking south along channel immediately downstream of Evans Street.

Plate C3.12 – (Photo taken at 12:34 hrs) – Looking south along channel between Evans Street and Park Street.

23 MARCH 2021 STORM EVENT

Plate C3.13 – (Photo taken at 12:37 hrs) – Looking west at overland flow across Park Street between Barber Street and Monash Street.

Plate C3.14 – (Photo taken at 12:36 hrs) – Looking south along Monash Street to the north of its intersection with Grenfell Street.

Plate C3.15 – (Photo taken at 12:40 hrs) – Looking west along North Street at its intersection with Barrier Street.

Plate C3.16 – (Photo taken at 12:41 hrs) – Looking east along North Street in the vicinity of its intersection with Monash Street.

23 MARCH 2021 STORM EVENT

Plate C3.17 – (Photo taken at 12:42 hrs) – Looking north along the channel that runs in a southerly direction on the eastern side of the West Wyalong Bowling Club.

Plate C3.18 – (Photo taken at 12:42 hrs) – Looking north along the channel that runs in a southerly direction on the eastern side of the West Wyalong Bowling Club.

Plate C3.19 – (Photo taken at 12:42 hrs) – Looking south along North Street from its intersection with Operator Street.

Plate C3.20 – (Photo taken at 12:42 hrs) – Looking west at the intersection of North Street and Operator Street.

23 MARCH 2021 STORM EVENT

Plate C3.21 – (Photo taken at 12:54 hrs) – Looking west along The Green Corridor from its intersection with Boundary Road.

Plate C3.22 – (Photo taken at 12:53 hrs) – Looking west over the Boundary Street causeway crossing of the Main Drain.

Plate C3.23 – (Photo taken at 12:55 hrs) – Looking east along the Main Drain from Boundary Street.

Plate C3.24 – (Photo taken at 12:53 hrs) – Looking east along the Main Drain east of Boundary Street.

23 MARCH 2021 STORM EVENT

Plate C3.25 – (Photo taken at 13:02 hrs) – Looking west along the Main Drain at Clear Ridge Road causeway.

Plate C3.26 – (Photo taken at 13:02 hrs) – Looking south across Neeld Street adjacent to the West Wyalong Wetlands.

Plate C3.27 – (Photo taken at 13:01 hrs) – Looking south across Neeld Street adjacent to the West Wyalong Wetlands.

Plate C3.28 – (Photo taken at 13:05 hrs) – Looking south-east along the Main Drain from Neeld Street.

23 MARCH 2021 STORM EVENT

Plate C3.29 – (Photo taken at 13:13 hrs) – Looking west along George Bland Avenue adjacent to Redman Oval

Plate C3.30 – (Photo taken at 13:05 hrs) – Looking north along Mallee Street north of its intersection with Conway Street.

Plate C3.31 – (Photo taken at 13:14 hrs) – Looking south along Wargin Street at its intersection with Blyth Street.

Plate C3.32 – (Photo taken at 07:00 hrs) – Floodwater ponding in vacant lot on the southern side of Neeld Street.

UNKNOWN STORM EVENT

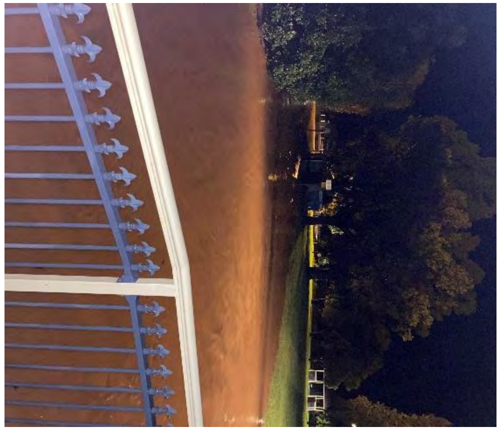


Plate C4.1 – (Time of photo unknown) – Looking east along the Main Drain towards Church Street from footbridge in Barnado Park.

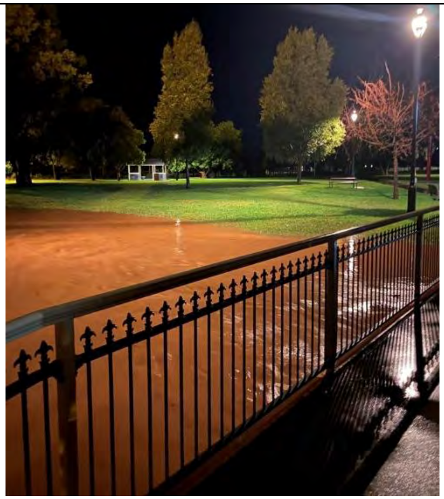


Plate C4.2 – (Time of photo unknown) – Looking west along the Main Drain towards Grenfell Street from footbridge in Barnado Park.

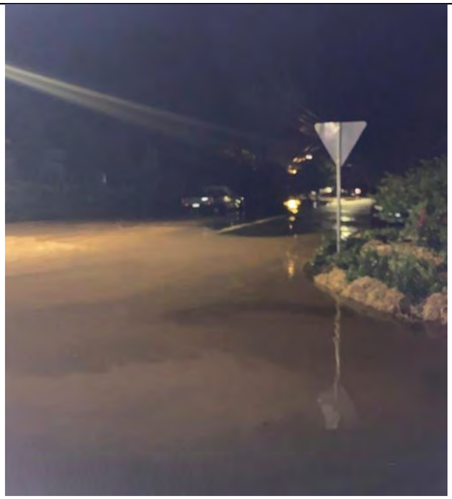


Plate C4.3 – (Time of photo unknown) – Floodwater inundating School Street at its intersection with Kurrajong Street.

Plate C4.4 – (Time of photo unknown) – Looking south along the Boundary Street causeway crossing of the Main Drain.

UNKNOWN STORM EVENT

Plate C4.5 - (Time of photo unknown) – Floodwater inundating Gilbert Street between its intersections with Mallee Street and Copeland Street.

Plate C4.6 - (Time of photo unknown) – Floodwater ponding in the northern kerb of Gilbert Street between its intersections with Mallee Street and Copeland Street.

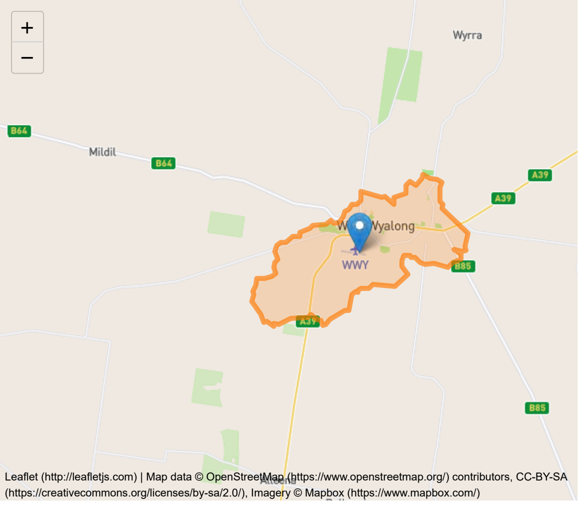
Plate C4.7 - (Time of photo unknown) – Floodwater ponding in the northern kerb of Gilbert Street between its intersections with Mallee Street and Copeland Street.

APPENDIX D
DESIGN INPUT DATA FROM ARR DATA HUB

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	147.193
Latitude	-33.94
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



Leaflet (http://leafletjs.com) | Map data © OpenStreetMap (https://www.openstreetmap.org/) contributors, CC-BY-SA (https://creativecommons.org/licenses/by-sa/2.0/), Imagery © Mapbox (https://www.mapbox.com/)

Data

River Region

Division	Murray-Darling Basin
River Number	13
River Name	Lachlan River
Shape Intersection (%)	100.0

Layer Info

Time Accessed	13 September 2021 08:55AM
Version	2016_v1

ARF Parameters

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

Layer Info

Time Accessed	13 September 2021 08:55AM
Version	2016_v1

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

Short Duration ARF

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

Storm Losses

Note: Burst Loss = Storm Loss - Preburst

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

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

Storm Initial Losses (mm)	39.0
Storm Continuing Losses (mm/h)	2.0

Layer Info

Time Accessed	13 September 2021 08:55AM
Version	2016_v1

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

code	MB
Label	Murray Basin
Shape Intersection (%)	100.0

Layer Info

Time Accessed	13 September 2021 08:55AM
Version	2016_v2

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

code	MB
arealabel	Murray Basin
Shape Intersection (%)	100.0

Layer Info

Time Accessed	13 September 2021 08:55AM
Version	2016_v2

BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-33.9395930328&longitude=147.19328921&sc to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	13 September 2021 08:55AM

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)	3.3 (0.175)	2.3 (0.086)	1.6 (0.051)	1.0 (0.026)	0.9 (0.020)	0.8 (0.016)
90 (1.5)	2.4 (0.115)	1.7 (0.056)	1.2 (0.033)	0.7 (0.016)	0.6 (0.012)	0.5 (0.009)
120 (2.0)	2.4 (0.106)	1.6 (0.049)	1.1 (0.027)	0.5 (0.011)	0.4 (0.007)	0.2 (0.004)
180 (3.0)	1.6 (0.061)	1.4 (0.037)	1.2 (0.028)	1.1 (0.021)	0.7 (0.012)	0.4 (0.006)
360 (6.0)	1.6 (0.048)	0.9 (0.019)	0.4 (0.008)	0.0 (0.000)	0.8 (0.010)	1.3 (0.015)
720 (12.0)	0.0 (0.000)	0.9 (0.016)	1.5 (0.023)	2.1 (0.027)	6.5 (0.068)	9.7 (0.090)
1080 (18.0)	0.0 (0.000)	0.5 (0.008)	0.8 (0.011)	1.2 (0.013)	3.0 (0.028)	4.4 (0.035)
1440 (24.0)	0.0 (0.000)	0.3 (0.004)	0.4 (0.005)	0.6 (0.006)	1.5 (0.013)	2.2 (0.016)
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	13 September 2021 08:55AM
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	13 September 2021 08:55AM
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)	0.1 (0.004)	0.0 (0.002)	0.0 (0.001)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
90 (1.5)	0.0 (0.001)	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	13 September 2021 08:55AM
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)	13.2 (0.707)	12.4 (0.472)	11.8 (0.375)	11.3 (0.307)	12.1 (0.274)	12.7 (0.254)
90 (1.5)	15.7 (0.739)	12.1 (0.407)	9.8 (0.273)	7.6 (0.180)	8.1 (0.161)	8.5 (0.150)
120 (2.0)	11.0 (0.475)	12.7 (0.390)	13.8 (0.353)	14.9 (0.326)	10.6 (0.194)	7.4 (0.120)
180 (3.0)	9.2 (0.350)	12.2 (0.329)	14.1 (0.318)	16.0 (0.309)	17.0 (0.275)	17.7 (0.255)
360 (6.0)	9.3 (0.284)	10.0 (0.217)	10.4 (0.189)	10.9 (0.169)	18.2 (0.237)	23.6 (0.273)
720 (12.0)	1.4 (0.036)	5.7 (0.100)	8.4 (0.124)	11.1 (0.140)	24.2 (0.253)	34.0 (0.313)
1080 (18.0)	1.5 (0.033)	5.3 (0.083)	7.8 (0.102)	10.2 (0.114)	15.7 (0.145)	19.8 (0.161)
1440 (24.0)	0.0 (0.001)	3.6 (0.052)	5.9 (0.071)	8.1 (0.083)	12.1 (0.103)	15.1 (0.112)
2160 (36.0)	0.0 (0.000)	2.1 (0.028)	3.5 (0.038)	4.9 (0.045)	5.0 (0.039)	5.2 (0.035)
2880 (48.0)	0.0 (0.000)	1.2 (0.014)	1.9 (0.020)	2.7 (0.023)	3.8 (0.027)	4.7 (0.029)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.3 (0.002)	0.5 (0.003)

Layer Info

Time Accessed	13 September 2021 08:55AM
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)	31.8 (1.707)	27.6 (1.055)	24.9 (0.789)	22.2 (0.602)	27.5 (0.622)	31.4 (0.629)
90 (1.5)	29.1 (1.374)	26.9 (0.904)	25.5 (0.711)	24.1 (0.575)	26.0 (0.520)	27.4 (0.486)
120 (2.0)	34.0 (1.466)	32.6 (1.000)	31.7 (0.809)	30.9 (0.674)	31.2 (0.572)	31.5 (0.513)
180 (3.0)	22.0 (0.836)	26.4 (0.714)	29.3 (0.661)	32.2 (0.621)	30.6 (0.495)	29.3 (0.422)
360 (6.0)	21.6 (0.660)	26.3 (0.572)	29.3 (0.533)	32.3 (0.504)	48.7 (0.635)	61.0 (0.705)
720 (12.0)	14.1 (0.348)	21.4 (0.378)	26.2 (0.386)	30.9 (0.388)	58.9 (0.617)	80.0 (0.736)
1080 (18.0)	11.3 (0.248)	18.3 (0.287)	22.9 (0.299)	27.3 (0.304)	38.0 (0.351)	46.1 (0.374)
1440 (24.0)	5.8 (0.117)	12.9 (0.187)	17.6 (0.212)	22.1 (0.227)	30.0 (0.255)	35.9 (0.268)
2160 (36.0)	2.9 (0.053)	8.8 (0.116)	12.7 (0.139)	16.5 (0.153)	19.8 (0.152)	22.3 (0.150)
2880 (48.0)	0.3 (0.005)	7.6 (0.094)	12.5 (0.128)	17.1 (0.149)	21.8 (0.157)	25.3 (0.159)
4320 (72.0)	0.0 (0.000)	1.7 (0.019)	2.8 (0.027)	3.9 (0.031)	16.7 (0.112)	26.3 (0.155)

Layer Info

Time Accessed	13 September 2021 08:55AM
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	13 September 2021 08:55AM
Version	2019_v1
Note	ARR recommends the use of RCP4.5 and RCP 8.5 values. These have been updated to the values that can be found on the climate change in Australia website.

Probability Neutral Burst Initial Loss

min (h)\AEP(%)	50.0	20.0	10.0	5.0	2.0	1.0
60 (1.0)	18.6	15.9	14.3	14.8	15.0	14.2
90 (1.5)	21.2	17.3	15.8	16.3	16.8	15.8
120 (2.0)	23.2	17.3	15.8	16.2	16.4	15.3
180 (3.0)	26.3	20.1	18.0	17.9	16.6	15.7
360 (6.0)	31.8	21.6	20.1	20.6	17.8	12.7
720 (12.0)	34.2	25.5	23.8	23.0	17.5	11.4
1080 (18.0)	35.0	26.9	25.7	25.8	22.4	14.1
1440 (24.0)	36.4	29.1	28.3	28.1	25.1	16.4
2160 (36.0)	37.6	31.0	30.7	31.3	29.3	23.4
2880 (48.0)	38.1	31.8	31.5	32.7	30.2	23.6
4320 (72.0)	38.7	33.1	34.3	35.7	32.0	24.9

Layer Info

Time Accessed	13 September 2021 08:55AM
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/0e7e6807-5517-4533-a6cd-f9a402786cf6.txt)

Download JSON (downloads/06048943-69e4-4a3f-9ca3-553c91ab1625.json)

Generating PDF... (downloads/0edf3690-61ef-445f-bd8d-6e791bdd0b4d.pdf)

APPENDIX E

FLOOD DATA FOR INDIVIDUAL ROAD CROSSINGS AT WYALONG AND WEST WYALONG

TABLE E1
PEAK FLOOD LEVEL AND MAXIMUM DEPTH OF INUNDATION AT INDIVIDUAL ROAD AND RAIL CROSSINGS AT WYALONG AND WEST WYALONG(1,2)

Peak Flood Level Location Identifier(2)	Tributary/ Catchment	Location	Road/Rail Elevation (m AHD)	Historic Storm Events				Design Storm Events															
				December 2017		March 2021		20% AEP		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
				Peak Flood Level (m AHD)	Maximum Depth of Inundation (m)	Peak Flood Level (m AHD)	Maximum Depth of Inundation (m)	Peak Flood Level (m AHD)	Maximum Depth of Inundation (m)	Peak Flood Level (m AHD)	Maximum Depth of Inundation (m)	Peak Flood Level (m AHD)	Maximum Depth of Inundation (m)	Peak Flood Level (m AHD)	Maximum Depth of Inundation (m)	Peak Flood Level (m AHD)	Maximum Depth of Inundation (m)	Peak Flood Level (m AHD)	Maximum Depth of Inundation (m)	Peak Flood Level (m AHD)	Maximum Depth of Inundation (m)	Peak Flood Level (m AHD)	Maximum Depth of Inundation (m)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[T]	[U]	[V]	[W]	[X]
H01	Main Drain	Showground Road	258.9	259.2	0.3	259.2	0.3	258.8	NF	259.1	0.2	259.2	0.3	259.2	0.3	259.2	0.3	259.3	0.4	259.3	0.4	259.7	0.8
		Cootamundra Lake Cargelligo Railway	259.1		0.1		0.1		NF		NF		0.1		0.1		0.1		0.2		0.2		0.6
H02		Mid Western Highway(4)	256.5	256.7	0.2	256.6	0.1	256.2	NF	256.5	NF	256.6	0.1	256.7	0.2	256.7	0.2	256.8	0.3	256.8	0.3	257.6	1.1
H03		Camp Street	255.0	255.5	0.5	255.4	0.4	255.3	0.3	255.3	0.3	255.4	0.4	255.5	0.5	255.6	0.6	255.6	0.6	255.7	0.7	257.0	2.0
H04		School Street	253.7	254.2	0.5	254.1	0.4	253.9	0.2	254.0	0.3	254.1	0.4	254.3	0.6	254.3	0.6	254.4	0.7	254.4	0.7	255.5	1.8
H05		Operator Street	251.6	252.1	0.5	252.0	0.4	251.9	0.3	252.0	0.4	252.0	0.4	252.2	0.6	252.3	0.7	252.4	0.8	252.4	0.8	253.7	2.1
H06		Boundary Street	249.5	250.0	0.5	249.8	0.3	250.0	0.5	250.1	0.6	250.1	0.6	250.3	0.8	250.4	0.9	250.5	1	250.6	1.1	251.7	2.2
H07		Clear Ridge Road	247.3	248.0	0.7	247.8	0.5	247.7	0.4	247.8	0.5	247.9	0.6	248.0	0.7	248.1	0.8	248.1	0.8	248.2	0.9	249.0	1.7
H08		Neeld Street(5)	246.0	246.2	0.2	246.1	0.1	246.0	NF	246.0	NF	246.1	0.1	246.2	0.2	246.2	0.2	246.2	0.2	246.3	0.3	246.8	0.8
H09		Compton Road(6)	244.1	244.5	0.4	244.4	0.3	244.2	0.1	244.3	0.2	244.4	0.3	244.5	0.4	244.6	0.5	244.7	0.6	244.7	0.6	245.1	1.0
H10		Wargin Road(7)	242.4	242.1	NF	242.6	0.2	242.6	0.2	242.6	0.2	242.6	0.2	242.6	0.2	242.7	0.3	242.7	0.3	242.7	0.3	243.3	0.9
H11		Slee Street	241.9	242.1	0.2	242.1	0.2	242.1	0.2	242.1	0.2	242.1	0.2	242.2	0.3	242.2	0.3	242.2	0.3	242.2	0.3	242.6	0.7
H12		Goldfields Way(8)	238.8	239.1	0.3	239.1	0.3	238.9	0.1	239.0	0.2	239.0	0.2	239.1	0.3	239.1	0.3	239.2	0.4	239.2	0.4	239.7	0.9
H13	Major Overland Flow	Ungarie Road	264.5	264.1	NF	263.8	NF	263.8	NF	263.8	NF	264.0	NF	264.1	NF	264.2	NF	264.3	NF	264.4	NF	264.7	0.2
H14	Wyalong North Drainage Line	Slee Street	241.9	242.4	0.5	242.4	0.5	242.3	0.4	242.3	0.4	242.4	0.5	242.5	0.6	242.5	0.6	242.5	0.6	242.6	0.7	243.3	1.4
H15		Newell Highway(9)	239.7	239.9	0.2	239.9	0.2	239.6	NF	239.8	0.1	239.8	0.1	239.9	0.2	240.0	0.3	240.0	0.3	240.1	0.4	240.7	1.0
H16	Yiddah Creek	Bellarwi Road	249.0	249.7	0.7	249.7	0.7	249.6	0.6	249.7	0.7	249.7	0.7	249.7	0.7	249.8	0.8	249.8	0.8	249.9	0.9	250.5	1.5

1. Elevations and Depths rounded to nearest 0.1 m.
2. NF = Not Flooded.
3. Refer **Figures 6.1** to **6.8** for location of Peak Flood Level Location.
4. Elevation of low point in Mid Western Highway that is located immediately to the east of its intersection with Ungarie Road.
5. Elevation of low point in Neeld Street that is located about 450 m to the east of its intersection with Central Road.
6. Elevation of low point in Compton Road that is located about 50 m to the south of its intersection with Cassin Street.
7. Elevation of low point in Wargin Road that is located about 70 m to the north of the Main Drain.
8. Elevation of low point in Goldfields Way that is located about 100 m to the south of the Main Drain.
9. Elevation of low point in Newell Highway that is located about 140 m to the east of its intersection with Goldfields Way.

APPENDIX F
DESIGN PEAK FLOWS

TABLE F1
DESIGN PEAK FLOWS(1)

Peak Flow Location Identifier(2)	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 Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[T]	[U]	[V]	[W]	[X]	[Y]	[Z]
Q01	Main Drain	Upstream Showground Road	4.0	270	4	5.6	360	7	7.4	360	7	11.8	180	8	14.1	180	8	17.4	180	8	21.5	180	8	150	60
Q02		Downstream Cootamundra Lake Cargelligo	3.0	270	4	6.3	360	7	9.6	360	7	14.3	360	7	17.7	180	8	21.7	180	8	26.8	180	8	-	-
Q03a		Downstream Main Street (Main Drain)	3.2	540	5	6	360	7	7.8	360	7	8.9	360	7	9.4	180	8	10	180	8	10.9	180	8	-	-
Q03b		Downstream Main Street (Camp Street)	0.1	540	5	0.3	360	7	2.1	360	7	6.5	360	7	9.1	180	8	13.1	180	8	17.8	180	8	-	-
Q04a		Upstream Monash Street (Main Drain)	3.8	540	5	5.6	360	7	8.3	360	7	11.8	360	7	13.5	360	7	16.1	180	8	19.9	180	8	219	60
Q04b		Upstream Monash Street (North Street)	0.4	540	5	0.9	360	7	2	360	7	5.1	360	7	6.4	360	7	8.5	180	8	11.5	180	8		
Q05		Downstream Operator Street	6.9	60	5	10.9	360	7	14.1	360	7	23.8	360	7	28.3	360	7	34.1	360	7	41.9	180	8	306	90
Q06		Boundary Street	8.8	270	4	13.6	360	7	17.6	540	4	25.8	360	7	31.8	360	7	38.1	360	7	46.1	360	7	-	-
Q07		Clear Ridge Road	10.0	270	4	15.3	360	7	20.6	540	4	28.1	360	7	35.6	360	7	42.9	360	7	51.9	360	7	-	-
Q08a		Neeld Street (West)	7.2	270	4	8.5	360	7	10.8	540	4	14.2	360	7	17.4	360	7	20.3	360	7	23.8	360	7	-	-
Q08b		Neeld Street (East)	0.7	270	4	1.9	360	7	3.3	540	4	5	360	7	6.7	360	7	7.8	360	7	8.8	360	7	-	-
Q09		Compton Street	9.0	270	4	12.4	540	4	16.8	540	4	22.4	360	7	28.6	360	7	34.5	360	7	40.2	360	7	-	-
Q10		Wargin Road (Cassin Street to Railway)	9.1	270	4	12.5	360	7	17.1	540	4	24.5	360	7	31.7	360	7	39.9	360	7	49.1	360	7	355	90
Q11		Upstream Goldfields Way	12.2	270	4	17.2	360	7	21.2	540	4	31	360	7	38.2	360	7	47.2	360	7	57.4	360	7	385	90
Q12		Downstream Goldfields Way	20.6	540	5	33.8	360	7	45.6	360	7	68.7	360	7	85.5	360	7	108	360	7	136	360	7	1055	120
Q13	Overland Flow	Upstream West Wyalong Burcher Railway	0.9	270	4	1.3	540	4	1.7	540	4	2.1	180	8	2.3	180	8	2.6	180	8	3.5	180	8	24.4	60
Q14		Wootten Street (Dumaresq Street to Monash Street)	1.1	270	4	1.8	360	7	2.3	540	4	3.3	180	8	4	180	8	4.6	180	8	5.4	180	8	-	-
Q15		Park Street (West of Monash Street)	1.3	540	5	2	360	7	2.6	360	7	3.9	360	7	4.5	360	7	5.3	180	8	6.5	180	8	32	90

Refer over for footnotes to table.

TABLE F1 (Cont'd)
DESIGN PEAK FLOWS(1)

			Design Flood Events																					
			20% AEP			10% AEP			5% AEP			2% AEP			1% AEP			0.5% AEP			0.2% AEP			PMF	
Peak Flow Location Identifier(2)	Tributary/ Catchment	Location	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[T]	[U]	[V]	[W]	[X]	[Y]	[Z]
Q16	Major Overland Flow	Wootten Street (East of Russell Street)	0.5	270	4	0.8	540	4	1.1	540	4	1.4	180	8	1.7	180	8	2.1	180	8	2.6	180	8	-	-
Q17		Park Street (East of Monash Street)	0.7	270	4	1	120	6	1.6	540	4	2.1	180	8	2.5	180	8	3.1	180	8	3.8	180	8	45	90
Q18		Grenfell Street	2.3	270	4	3.5	360	7	4.6	360	7	6.3	360	7	7.5	360	7	9.1	180	8	11.6	180	8	80	90
Q19		Victory Street	0.8	30	8	1.2	120	6	1.5	120	6	2.1	30	6	2.5	30	6	2.9	30	6	3.6	30	6	14	15
Q20		Hyde Street	1.8	60	5	2.9	120	6	3.6	120	6	4.2	60	6	4.9	60	6	5.9	60	6	7.4	30	6	-	-
Q21a		Copeland Street (Neeld Street to Gilbert Street)	1.5	270	4	2.1	360	7	2.4	540	4	2.8	360	7	3.2	360	7	3.5	360	7	4.2	360	7	-	-
Q21b		Copeland Street (North of Redman Oval)	1.4	540	5	3	360	7	5.2	540	4	8.3	360	7	12.7	360	7	17	360	7	21.8	360	7	-	-
Q22		West of Mallee Street	1.1	270	4	1.6	540	4	2.4	540	4	3	180	8	3.5	180	8	4.2	180	8	5	180	8	-	-
Q23	Wyalong North Drainage Line	North of North Street	6.0	270	4	9.1	360	7	13.6	540	4	18.7	180	8	22.6	180	8	27.5	180	8	33.9	180	8	251	60
Q24		Slee Street	8.6	270	4	15.3	360	7	20.5	540	4	32.3	360	7	40.2	360	7	51.5	360	7	61.8	180	8	555	90
Q25		North Street	8.7	540	5	15.9	360	7	21.6	360	7	34.1	360	7	42.2	360	7	54.2	360	7	68.5	360	7	-	-
Q26	Major Overland Flow	Cassin Street	0.3	270	4	0.6	360	7	1	540	4	1.7	360	7	2.3	360	7	2.9	360	7	3.7	360	7	45	90
Q27	Wyalong North Drainage Line	Newell Highway	8.8	540	5	15.9	360	7	22.3	360	7	35.7	360	7	44.6	360	7	57.2	360	7	72.7	360	7	-	-
Q28	Major Overland Flow	Yiddah Drive	2.6	270	4	4	540	4	5.7	540	4	6.6	180	8	7.5	180	8	8.8	180	8	11.2	180	8	114	60
Q29		Upstream Cootamundra Lake Cargelligo Railway	3.5	270	4	5	540	4	7.3	540	4	9.2	180	8	10.7	180	8	12.7	180	8	15.3	180	8	-	-
Q30		Upstream Cootamundra Lake Cargelligo Railway	0.8	270	4	1.2	540	4	1.7	540	4	2.2	180	8	2.6	180	8	3	180	8	3.8	60	6	28	60
Q31		Wargin Road (South of Cootamundra Lake Cargelligo Railway)	4.4	270	4	5.8	540	4	8	540	4	9	180	8	9.7	180	8	10.6	180	8	11.7	180	8	45	60

Refer over for footnotes to table.

TABLE F1 (Cont'd)
DESIGN PEAK FLOWS(1)

Peak Flow Location Identifier(2)	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 Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)	Critical Temporal Pattern(4)	Peak Flow (m^3/s)	Critical Storm Duration(3) (minutes)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[T]	[U]	[V]	[W]	[X]	[Y]	[Z]
Q32	Major Overland Flow	South of Cootamundra Lake Cargelligo Railway	0.6	270	4	1.5	360	7	2.6	540	4	4.4	360	7	5.5	180	8	7.1	180	8	8.3	180	8	13	60
Q33		South of Cootamundra Lake Cargelligo Railway	0.4	270	4	1	360	7	1.5	360	7	3	360	7	3.9	360	7	5	360	7	6.5	180	8	-	-
Q34	Yiddah Creek	2.5 km Upstream of Ballarwi Road	16.6	540	5	26.7	360	7	37.5	360	7	52.2	360	7	66.3	360	7	83.1	360	7	105	360	7	664	180
Q35		1.1 km Upstream of Ballarwi Road	25.5	540	5	39.8	360	7	55.5	360	7	79.7	360	7	99.3	360	7	123	360	7	153	360	7	954	120
Q36		Bellarwi Road	30.0	540	5	46.6	360	7	63.5	360	7	93.6	360	7	117	360	7	145	360	7	181	360	7	1140	120
Q37		1.3 km Downstream of Ballarwi Road	30.0	540	5	46.8	360	7	63.9	360	7	93.8	360	7	118	360	7	147	360	7	183	360	7	1140	120
Q38	Major Overland Flow	Downstream Boltes Lane	3.0	270	4	4.8	540	4	7.5	540	4	9.2	180	8	11.2	180	8	14.1	180	8	17.5	180	8	-	-

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

APPENDIX G
FLOOD DAMAGES

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FIGURES
(BOUND IN VOLUME 2)

G1. INTRODUCTION AND SCOPE

G1.1 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.

G1.2 Scope of Investigation

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

G1.3 Terminology

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

G2. DESCRIPTION OF APPROACH

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

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

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

The depth-damage curves for residential damages were determined using procedures described in the publication *Floodplain Risk Management Guideline No. 4, 2007* (**Guideline No. 4**) published by the Department of Environment and Climate Change (**DECC**) (now DPE). Damage curves for other categories of development (commercial 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 study area should not be used to provide information on the depths of above-floor inundation of individual properties.

G3. SOURCES OF DATA

G3.1 General

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

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

G3.2 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 in the study area is shown in **Table G3.1**.

TABLE G3.1
NUMBER OF PROPERTIES INCLUDED IN DAMAGES DATABASE

Development Type	Number of Properties	
	Wyalong	West Wyalong
Residential	165	898
Commercial / Industrial	17	143
Public	6	23
Total	**188**	**1,064**

G3.3 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.

G4. RESIDENTIAL DAMAGES

G4.1 Damage Functions

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

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

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

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

Flooding in the study area is "flash flooding" in nature, with surcharge of the watercourses and various drainage lines occurring 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 G4.1** over sets out the parameters and resulting factors that were adopted for converting potential to actual damages in the study area.

Table G4.2 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 0.1 m and 0.3 m. A typical ground floor area of 240 m^2 was adopted for the assessment. The values in **Table G4.2** allow for damages to buildings and contents, as well as external damages and provision for alternative accommodation.

TABLE G4.1
DAMAGE ADJUSTMENT FACTORS/PARAMETERS FOR RESIDENTIAL DEVELOPMENT

Property Damage	Parameter/Factor	Adopted Value
Building	Regional Cost Variation Factor	1.10
	Post Late-2002 Adjustments	1.96
	Post Flood Inflation Factor	1.00
	Typical Duration of Immersion (hours)	2
	Building Damage Repair Limitation Factor	0.85
	Total Building Adjustment Factor	1.83
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)	1.47
	Total Contents Adjustment Factor (Above-Floor Depth > TTBH)	1.47

1. Maximum value permitted in damages spreadsheet.

TABLE G4.2
DAMAGES TO RESIDENTIAL PROPERTIES

Type of Residential Construction	0.3 m Depth of Inundation Above Floor Level	0.6 m Depth of Inundation Above Floor Level
Single Storey Slab on Ground	$66,921	$74,586
Single Storey High Set	$73,666	$82,278
Double Storey	$46,845	$52,211

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

G4.2 Total Residential Damages

Table G4.3 over summarises the residential damages for the range of floods in the study area. 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.

The 10% AEP storm event is the threshold at which dwellings commence to be subject to above-floor inundation. At the 1% AEP level of flooding, three dwellings would experience above-floor inundation in Wyalong, while nine dwellings would experience above-floor inundation in West Wyalong. During a PMF event, 433 individual dwellings would experience above-floor inundation in the study area, 87 in Wyalong and 346 in West Wyalong.

TABLE G4.3
TOTAL RESIDENTIAL FLOOD DAMAGES

Design Flood Event (%AEP)	Wyalong			West Wyalong		
	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	1	0	0.02	6	0	0.13
10	3	0	0.06	10	1	0.23
5	4	1	0.11	24	1	0.57
2	6	1	0.15	55	5	1.36
1	14	3	0.41	75	9	2.01
0.5	19	4	0.58	95	17	2.76
0.2	24	5	0.8	128	34	4.19
PMF	128	87	8.73	537	346	39.0

G5. COMMERCIAL AND INDUSTRIAL DAMAGES

G5.1 Direct Commercial and Industrial Damages

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

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

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

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

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

Low value enterprise	$\$280/\text{m}^2$	(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	$\$420/\text{m}^2$	(e.g., Commercial: food shops, hardware, banks, professional offices, retail enterprises, with furniture/fixtures at floor level which would suffer damage if inundated. Industrial: warehouses, equipment hires.)
High value enterprise	$\$650/\text{m}^2$	(e.g., Commercial : electrical shops, clothing stores, bookshops, newsagents, restaurants, schools, showrooms and retailers with goods and furniture, or other high value items at ground or lower floor level. Industrial: service stations, vehicle showrooms, smash repairs.)

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

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

G5.2 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.

G5.3 Total Commercial and Industrial Damages

Table G5.1 over summarises the estimated commercial and industrial damages in the study area. No commercial or industrial buildings would experience above-floor inundation in the study area in a 1% AEP event, noting that the 0.5% AEP event is the threshold at which commercial buildings would commence to be subject to above-floor inundation. A total of 63 commercial buildings would experience above-floor inundation in a PMF event, nine in Wyalong and 54 in West Wyalong.

TABLE G5.1
COMMERCIAL / INDUSTRIAL FLOOD DAMAGES

Design Flood Event (%AEP)	Wyalong			West Wyalong		
	No of Allotments Flood Affected	**No. of Buildings Flooded Above Floor Level**	**Damages $ Million**	**No. of Allotments Flood Affected**	**No. of Buildings Flooded Above Floor Level**	**Damages $ Million**
20	0	0	0	0	0	0
10	0	0	0	0	0	0
5	0	0	0	0	0	0
2	0	0	0	3	0	0.06
1	0	0	0	3	0	0.06
0.5	0	0	0	5	1	0.12
0.2	0	0	0	6	2	0.15
PMF	9	9	0.58	69	54	4.47

G6. DAMAGES TO PUBLIC BUILDINGS

G6.1 Direct Damages – Public Buildings

Included under this heading are government buildings, churches, swimming pools and parks. Damages were estimated individually on an areal basis according to the perceived value of the property. Potential internal damages were indexed to a depth of above floor inundation of 2 m as shown below. At floor level and 1.2 m depth of inundation, zero and 70% of these values respectively were assumed to occur.

Low value	\$280/m^2	(e.g. amenities block, clubhouses)
Medium value	\$420/m^2	(e.g. council buildings, SES HQ, fire station)
High value	\$650/m^2	(e.g. schools)

These values were obtained from the Nyngan Study (DWR, 1990) as well as commercial data presented in the Forbes Water Studies report (WS, 1992). External and structural damages were taken as 4 and 10% of internal damages, respectively.

G6.2 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.

G6.3 Total Damages – Public Buildings

Table G6.1 summarises the estimated damages to public buildings in the study area, noting that the 10% AEP event is the threshold at which public buildings would commence to be subject to above-floor inundation. A single public building would experience above-floor inundation in a 1% AEP event in West Wyalong, increasing to five during a PMF event. The public buildings in Wyalong will remain flood free during flood events up to 0.2% AEP in magnitude, while two buildings would experience above-floor inundation during more intense storm events.

TABLE G6.1
PUBLIC FLOOD DAMAGES

Design Flood Event (%AEP)	Wyalong			West Wyalong		
	No. of Allotments Flood Affected	**No. of Buildings Flooded Above Floor Level**	**Damages $ Million**	**No. of Allotments Flood Affected**	**No. of Buildings Flooded Above Floor Level**	**Damages $ Million**
20	0	0	0	0	0	0
10	0	0	0	1	1	0.02
5	0	0	0	1	1	0.03
2	0	0	0	1	1	0.03
1	0	0	0	1	1	0.03
0.5	0	0	0	1	1	0.03
0.2	0	0	0	2	1	0.05
PMF	2	2	0.22	11	5	0.43

G7. DAMAGES TO INFRASTRUCTURE AND COMMUNITY ASSETS

No data are available on damages experienced to infrastructure and community assets during historic flood events. However, a qualitative matrix of the effects of flooding on important assets in the study area is presented in **Section 6.1.4** of the Main Report.

G8. SUMMARY OF TANGIBLE DAMAGES

G8.1 Tangible Damages

Flood damages have been computed for a range of flood frequencies from 20% AEP up to the PMF. For the purposes of assessing damages, the 50% AEP was adopted as the "threshold" flood at which damages commence in the drainage system. From **Table G8.1** over, about $0.41 Million of damages would be incurred at the 1% AEP level of flooding in Wyalong and about $2.10 Million in West Wyalong. **Figure G8.1** shows the damage frequency curves for residential, commercial / industrial and public buildings in the study area.

G8.2 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).

G8.3 Average Annual Damages

The average annual damages for all flood events up to the PMF are shown below in **Table G8.2**. Note that values have been quoted to two decimal places to highlight the relatively small recurring damages.

G8.4 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 G8.3**.

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 Wyalong and West Wyalong are $0.3 Million and $1.4 Million, respectively. Therefore, one or more schemes costing up to these amounts could be economically justified if they eliminated damages in the study area for all flood events up to this level. While schemes costing more than this value would have a benefit/cost ratio less than 1, they may still be justified according to a multi-objective approach which considers other criteria in addition to economic feasibility.

TABLE G8.1
TOTAL FLOOD DAMAGES
$ MILLION

Design Flood Event (%AEP)	Wyalong				West Wyalong			
	Residential	Commercial/ Industrial	Public	Total	Residential	Commercial/ Industrial	Public	Total
20	0.02	0	0	0.02	0.13	0	0	0.13
10	0.06	0	0	0.06	0.23	0	0.02	0.25
5	0.11	0	0	0.11	0.57	0	0.03	0.60
2	0.15	0	0	0.15	1.36	0.06	0.03	1.45
1	0.41	0	0	0.41	2.01	0.06	0.03	2.10
0.5	0.58	0	0	0.58	2.76	0.12	0.03	2.91
0.2	0.80	0	0	0.80	4.19	0.15	0.05	4.39
PMF	8.73	0.58	0.22	9.53	39.00	4.47	0.43	43.90

TABLE G8.2
AVERAGE ANNUAL DAMAGES
$ MILLION

Design Flood Event (%AEP)	Wyalong				West Wyalong			
	Residential	Commercial/ Industrial	Public	Total	Residential	Commercial/ Industrial	Public	Total
20	0	0	0	0	0.02	0	0	0.02
10	0.01	0	0	0.01	0.04	0	0	0.04
5	0.01	0	0	0.01	0.06	0	0	0.06
2	0.02	0	0	0.02	0.09	0	0	0.09
1	0.02	0	0	0.02	0.10	0	0	0.10
0.5	0.02	0	0	0.02	0.11	0	0	0.11
0.2	0.02	0	0	0.02	0.13	0	0	0.13
PMF	0.03	0	0	0.03	0.17	0.01	0	0.18

TABLE G8.3
PRESENT WORTH VALUE OF DAMAGES
$ MILLION

Catchment	Discount Rate (%)	Nominal Flood Level Case	
		All Floods up to 1% AEP	All Floods up to PMF
Wyalong	4	0.4	0.6
	7	0.3	0.4
	11	0.2	0.3
West Wyalong	4	2.2	3.9
	7	1.4	2.5
	11	0.9	1.6

G9. REFERENCES AND BIBLIOGRAPHY

DECC (Department of Environment and Climate Change, NSW), 2007b. ***“Floodplain Management Guideline No 4. Residential Flood Damages”***.

DWR (Department of Water Resources, NSW), 1990. ***"Nyngan April 1990 Flood Investigation"**.*

L&A (Lyall and Associates Consulting Water Engineers), 2019 ***“Braidwood Floodplain Risk Management Study and Plan”***. Report prepared for Queanbeyan-Palerang Regional Council.

LMJ (Lyall, Macoun and Joy, Willing and Partners Pty Ltd), 1985 ***"Camden Floodplain Management Study"***. Report for Water Resources Commission and Camden Municipal Council.

SKM (Sinclair Knight Merz), 1994 ***"Forbes Floodplain Management Report and Draft Floodplain Management Plan, Volume 1"***. Report prepared for Department of Land and Water Conservation.

WS (Water Studies), 1992. ***“Forbes Flood Damage Survey, August 1990 Flood”***.