PARKES SHIRE COUNCIL

BOGAN GATE
FLOOD STUDY

OCTOBER 2024

DRAFT REPORT FOR PUBLIC EXHIBITION

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FOREWORD

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

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

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

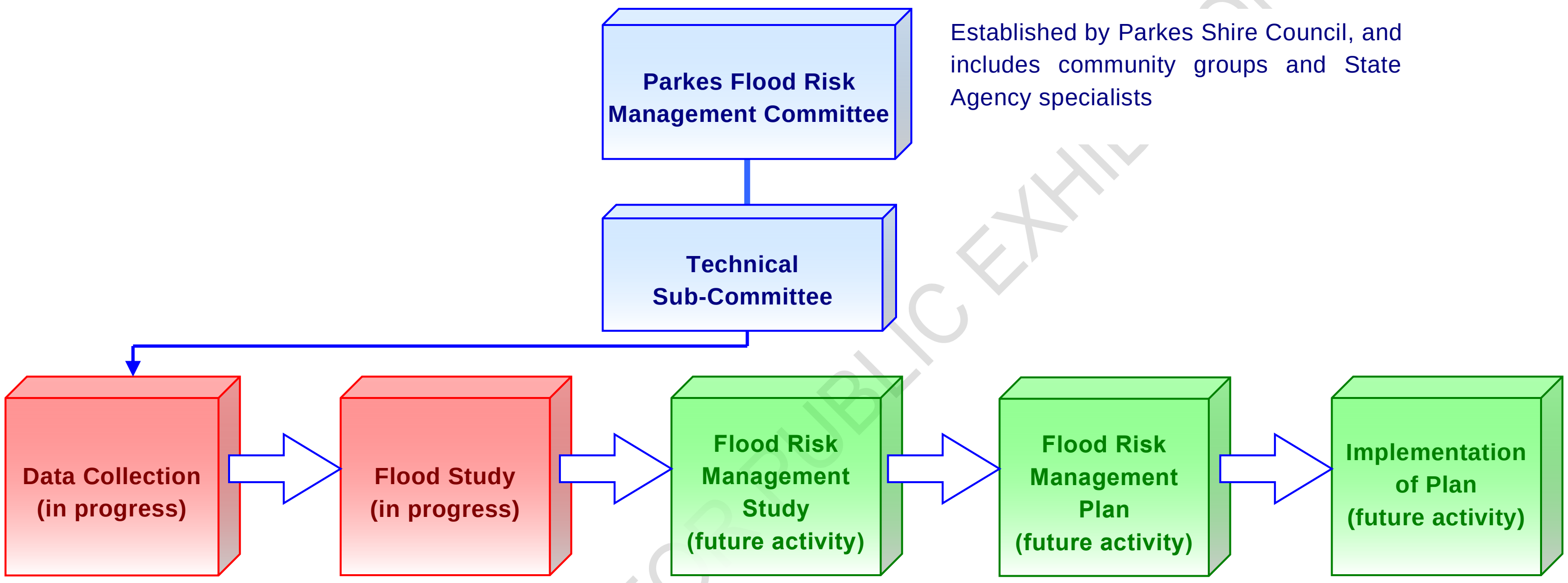
1.	Data Collection	Collects, compiles and reviews both new and existing data.
2.	Flood Study	Determines the nature and extent of flooding.
3.	Flood Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed development.
4.	Flood Risk Management Plan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

The *Bogan Gate Flood Study* is jointly funded by Parkes Shire Council and the NSW Government, via the Department of Climate Change, Energy, the Environment and Water. The *Bogan Gate Flood Study* constitutes the first and second stage of the Flood Risk Management process (refer over) for this area and has been prepared for Parkes Shire Council to define flood behaviour under current conditions.

ACKNOWLEDGEMENT

Parkes 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 Climate Change, Energy, the Environment and Water.

FLOOD RISK MANAGEMENT PROCESS



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

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

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

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

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

TABLE OF CONTENTS

Page No.

CONTINUED OVER

TABLE OF CONTENTS

Page No.

APPENDICES

LIST OF MAIN REPORT FIGURES (BOUND IN VOLUME 2)

LIST OF MAIN REPORT FIGURES (Cont'd)
(BOUND IN VOLUME 2)

NOTE ON FLOOD FREQUENCY

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

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

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

NOTE ON QUOTED LEVEL OF ACCURACY

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

ABBREVIATIONS

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

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

SUMMARY

S.1 Study Objective

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

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

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

S.2 Study Area

While the definition of flood behaviour was limited to the village of Bogan Gate and its immediate environs, the present study assessed the runoff potential of the whole of the Gunningbland Creek catchment. **Figures 1.1** and **2.1** bound in **Volume 2** of this report show the extent of the 1,030 km^2 Gunningbland Creek catchment at its confluence with Goobang Creek, while **Figure 2.2** (2 sheets) shows the key features of the existing stormwater drainage system in the vicinity of the urbanised parts of Bogan Gate.

S.3 Study Method

The flood study involved the following activities:

- The forwarding of a *Community Newsletter and Questionnaire* to approximately 180 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. In-person consultation was also undertaken by Council on 31 May 2022 and by the Consultant on 7 December 2022. Of those that responded, more than half noted that they had been affected by flooding. Respondents provided information on flooding that occurred on a number of occasions, the most notable of which occurred on 1-2 March 2012 and 14 November 2022.
- The collection of flood data, details of which are set out in **Appendix B** of this report. Pluviographic rainfall data recorded by a Bureau of Meteorology (**BoM**) and privately operated rain gauges in the vicinity of Bogan Gate were obtained. A number of photographs were provided by respondents to the *Community Questionnaire* showing historic flood behaviour in the study area, copies of which are contained in **Appendix C** of this report.

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

After calibrating the hydrologic and hydraulic models (collectively referred to herein as “the flood models”) using data that were available for the 1-2 March 2012 and 14 November 2022 storm events, design storm rainfalls ranging between 20 and 0.2% AEP were derived using procedures set out in the 2019 edition of *Australian Rainfall and Runoff* (Geoscience Australia, 2019) (**ARR 2019**) and applied to the hydrologic models in order to derive discharge hydrographs. The PMF was also modelled.

S.4 Flood Model Development and Calibration

Figure 2.3 shows a comparison between rainfall that was recorded by BoM’s *Parkes Airport* and *Forbes Airport All Weather Station* (**AWS**) and *Goonumbla (Coradgery)* Flood Warning Network rain gauge during a number of intense storms that have been experienced in the vicinity of Bogan Gate dating back to December 2010 and design intensity-frequency-duration curves, noting that the most intense burst of rain occurred on 3 December 2010.

Due to the limited availability of historic flood data at Bogan Gate, the flood models could only be calibrated using data that were recorded during the storms that occurred on 1-2 March 2012 and 14 November 2022. **Figure 2.4** shows the cumulative rainfall that was recorded by the three aforementioned rain gauges for these two historic storm events.

Figures 3.1 and **4.1** (2 sheets each) show the layout of the flood models that were developed as part of the present investigation, while **Figures 4.3** and **4.4** (2 sheets each) show the indicative extent and depth of inundation as defined by the hydraulic model for the 1-2 March 2012 and 14 November 2022 storm events, respectively.

Through the model calibration process, the 23 March 2017 and 14 November 2022 storm events were found to be equivalent to a design storm with an AEP of about 10% (1 in 10).

S.5 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** is a longitudinal section along a 10.5 km length of the Orange-Broken Hill Railway Line where it runs between Olive Grove Lane and Overland Road, while **Figure 6.10** shows stage hydrographs at selected road crossings throughout the study area.

Table F1 in **Appendix F** sets out peak flood levels and the depth of inundation and at the aforementioned road crossings, while **Table G1** in **Appendix G** sets out design peak flows and corresponding critical storm durations at various locations in the study area. **Figures H1.1** to **H1.8** shows the maximum flow velocities for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP storm events, together with the PMF.

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

S.6 Economic Impact of Flooding

While no buildings in the Village Centre would be inundated above-floor level in a 1% AEP flood event, the total flood damages during an event of this magnitude would amount to about $0.03 Million. During a PMF event, there would be a total of 24 dwellings and one public building that would be above-floor inundated, resulting in total flood damages of about $5.39 Million.

The *"Net Present Value"* of damages resulting from all floods up to the magnitude of the 1% AEP at Bogan Gate for a discount rate of 5% and an economic life of 30 years is effectively zero, increasing to about $0.1 Million for all floods up to the PMF. This latter value represents the amount of capital spending that would be justified if one or more flood mitigation schemes prevented flooding for all properties in the Village Centre up to the PMF event. While schemes costing more than this value would have a benefit/cost ratio less than 1, they may still be justified according to a multi-objective approach which considers other criteria in addition to economic feasibility.

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

S.7 Flood Hazard Classification and Hydraulic Categorisation

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

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 the latest edition of *Australian Rainfall and Runoff* (Geoscience Australian, 2019) (**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 there are no areas classified as H6 in flood events up to 0.2% AEP, while areas classified as H5 are generally limited to the inbank area of Gunningbland Creek, Blowclear Creek and Botfields Creek. **T**he majority of the Village Centre is classified as H1 or H2 in flood events up to 0.2% AEP, with H3 type flooding conditions shown to be present in the low lying land that is located on the northern side of Bogan Street.

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 either Flood Storage or Flood Fringe.

As the hydraulic capacity of the major watercourses is not large enough to convey the flow in a 5% AEP flood, their overbank areas also function as a floodway. Sheet 2 of **Figures 6.15**, **6.16** and **6.17** show that a floodway generally runs along the northern side of Henry Parkes Way between Tubby Lees Road and Cronin Lane where it then continues in a southerly direction to Gunningbland Creek. A floodway zone is also shown to be contained within the inbank area along the 5.5 km reach of Gunningbland Creek immediately downstream (south) of the Orange-Broken Hill Railway Line in flood events up to 0.2% AEP

S.8 Sensitivity Analyses

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

a. An increase in hydraulic roughness. **Figure 6.19** 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 6.20** shows the effects a partial blockage of the major culvert structures would have on flood behaviour at the 1% AEP level of flooding.

c. The removal of the earth embankments associated with Henry Parkes Way and Orange-Broken Hill Railway Line where they run between Olive Grove Land and Overland Road. **Figure 6.21** shows the effect the removal of the road and rail embankments would have on flood behaviour at the 1% AEP level of flooding.

d. Increases in rainfall intensity associated with future climate change. **Figures 6.22**, **6.23** and **6.24** 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 200 mm and 20 mm in areas that are subject to Main Stream Flooding and Major Overland Flow, respectively as a result of an increase in hydraulic roughness;
- a partial blockage of the hydraulic structures has a negligible impact on flood behaviour;

- while the removal of the road and railway embankments lowers peak flood levels on their northern (upstream) side by up to 1.2 m, peak flood levels would be increased by up to 0.4 m to their south, with the extent of inundation also greatly increased; 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 300 mm.

S.9 Interim Flood Planning Area

Figure 6.25 shows the extent of the Interim Flood Planning Area (**FPA**) in the immediate vicinity of the Village Centre 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.

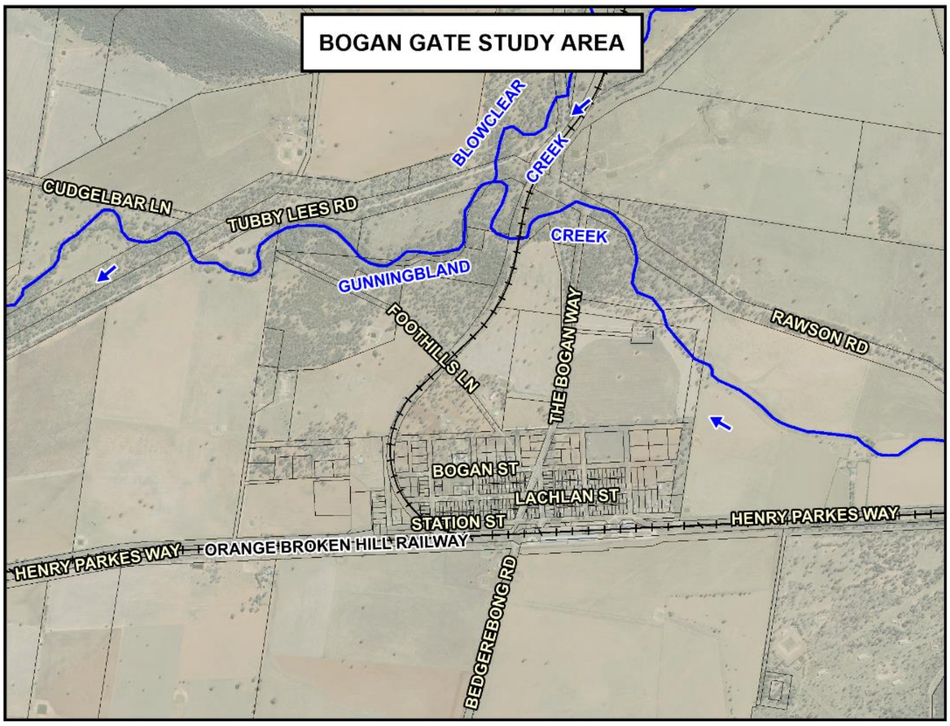
Pending the completion of the future *Bogan Gate FRMS&P*, it is recommended that the habitable floor levels of future development be set a minimum 0.5 m above the corresponding peak 1% AEP flood level, noting that the future study may determine that the freeboard provision may be reduced in areas that 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 village of Bogan Gate in the Parkes 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 Climate Change, Energy, the Environment and Water (**DCCEEW**). **Figure 1.1** shows the extent of the study catchment at Bogan Gate.

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**) within the extent of the study area shown below.



The investigation involved rainfall-runoff hydrologic modelling of the catchments to assess flows in the drainage systems of the study catchment and application of these flows to a hydraulic model to assess peak water levels and flow velocities (collectively referred to herein as 'flood modelling'). The model results were interpreted to present a detailed picture of flooding under present day conditions.

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

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

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

1.2 Community Consultation and Available Data

To assist with data collection and promotion of the study to the community, a *Community Newsletter* and *Questionnaire* was distributed by Council in May 2022 to residents and business owners in the study area. In-person consultation was also undertaken by Council in May 2022 and by the Consultants in December 2023. A copy of the *Community Newsletter* and *Questionnaire* is contained in **Appendix A** of this report.

Council advised that approximately 180 *Community Newsletters* and *Questionnaires* were distributed to residents and business owners in the study area, with a total of 13 responses received by the closing date of submissions (a response rate of less than seven per cent). Of the 13 respondents, eight noted that they had been affected by flooding.

The following events were identified during the community consultation process:

- January 1992.
- November 2005.
- December 2010
- March 2012.
- December 2012.
- February 2016.
- September 2016.
- April 2020.
- January 2021.
- November 2021.
- May 2022.
- November 2022.

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

Appendix B contains details of the data that were available for the present study, while **Appendix C** contains several photos that were provided by Council and respondents to the *Community Questionnaire* which show historic flood behaviour at Bogan Gate during storms that occurred in November 2005, December 2010, March 2012, June 2016, September 2016, May 2022 and November 2022.

1.3 Layout of Report

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

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

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

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

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

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

The following appendices are included in the report:

- **Appendix A**, which contains a copy of the *Community Newsletter* and *Questionnaire* that were distributed at the commencement of the study to residents and business owners in the study area.
- **Appendix B**, which contains a list of data that were available for the present study and a summary of the responses to the *Community Questionnaire*.
- **Appendix C**, which contains photographs showing flood behaviour in the study area during storms that occurred in November 2005, December 2010, March 2012, June 2016, September 2016, May 2022 and November 2022.
- **Appendix D**, which contains a copy of the design input data that were extracted from the *Australian Rainfall and Runoff* (**ARR**) *Data Hub* for the study area.
- **Appendix E**, which summarises design blockage values that were assigned to the transverse drainage structures in the TUFLOW.
- **Appendix F**, which contains a table containing flood data on individual road crossings at Bogan Gate.
- **Appendix G**, which contains a table listing the peak flow at key locations in the study area for the full range of design storm events.
- **Appendix H**, which contains figures showing the maximum flow velocities in the study area for the full range of assessed design storm events.
- **Appendix I**, which contains an assessment of the economic impacts of flooding to existing residential, commercial and industrial development, as well as public buildings in Bogan Gate.

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

2 BACKGROUND INFORMATION

2.1 Catchment Description

2.1.1. General

The village of Bogan Gate has a population of about 290 and is located on the left (southern) bank of Gunningbland Creek in the Parkes Shire Council LGA. **Figure 2.1** shows that Gunningbland Creek flows in a westerly direction through Bogan Gate where it discharges to Goobang Creek approximately 30 km to the west of the village. **Figure 2.1** also shows the alignment of Blowclear Creek which is a tributary of Gunningbland Creek. Gunningbland Creek and Blowclear Creek have catchment areas of 230 km^2 and 268 km^2, respectively at their confluence, while Gunningbland Creek has a total catchment area of about 1,030 km^2 where it joins Goobang Creek.

Figure 2.2 (2 sheets) shows the layout of the existing stormwater drainage system in the vicinity of Bogan Gate. The existing stormwater drainage system in the village generally comprises piped and culvert crossings beneath the roads and railway, as well as grass lined table drains that convey overland flow towards Gunningbland Creek and its tributaries. **Figure 2.2** also shows the alignment of a network of earth bunds have been constructed on the Gunningbland Creek floodplain in the vicinity of the village.

As shown on **Figure 2.2**, the extent of land zoned for urban type development in the village (herein referred as the "Village Centre") is bounded by the Orange-Broken Hill Railway Line to the south, the Tottenham Railway Line to the west and rural land to the north and east.

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

2.1.2. Gunningbland Creek

Figure 2.1 shows that the headwaters of Gunningbland Creek are located approximately 25 km to the north-east of Bogan Gate. The inbank area of Gunningbland Creek generally comprises an incised 5-10 m wide by 1.5 m deep channel which has a grade of about 0.1% where it runs between the upstream (eastern) side of the Village Centre and the location where it crosses beneath Henry Parkes Way.

There are the following 13 road crossings of Gunningbland Creek in the study area;

- nine low level causeway crossings private access roads (two off), Rawsons Road (two off), Foothills Lane, Tubby Lees Road, Leafy Tank Road, Carlachy Road and Taylor Lane; and
- four higher level bridge/culvert crossings at the Bogan Way, the Tottenham Railway Line, Henry Parkes Way, the Orange-Broken Hill Railway Line.

The Bogan Way and Tottenham Railway Line run in a north-south direction across the 2 km wide Gunningbland Creek floodplain immediately to the north of the Village Centre. While the Bogan Way is set at a similar elevation to the adjacent floodplain, the Tottenham Railway Line is elevated up to 1 m above adjacent natural surface levels.

Henry Parkes Way and the Orange-Broken Hill Railway Line run in an east-west direction across the 8.5 km wide Gunningbland Creek floodplain to the west of the Village Centre. **Figure 2.2** shows that the road and railway do not cross the floodplain in a perpendicular direction to flow as

Gunningbland Creek runs in a south-westerly direction. The Bogan Way is generally between about 0.5–1.5 m higher, while the railway line is generally between 1-1.5 m higher than adjacent natural surface levels. A 1.5 km section of the railway line immediately to the east of Overland Road is elevated up to 2.5 m higher than adjacent natural surface levels.

2.1.3. Blowclear Creek

Figure 2.1 shows that the headwaters of Blowclear Creek catchment are located approximately 25 km to the north of Bogan Gate. As shown on **Figure 2.2**, Blowclear Creek generally runs in a southerly direction through the study area where it joins Gunningbland Creek approximately 200 m downstream (west) of the Tottenham Railway Line.

The inbank area of Blowclear Creek is ill-defined where it runs between Blow Clear Road and its confluence with Gunningbland Creek. It is understood that the majority of the runoff in the Blowclear Creek system actually flows on the left overbank area on the southern side of the creek where it discharges to Gunningbland Creek immediately upstream of The Bogan Way.

There are two low level causeway crossings of Blowclear Creek along Blow Clear Road and two higher level culvert crossings at The Bogan Way and the Tottenham Railway Line.

Figure 2.1 shows the alignment of Botfields Creek which is a tributary of Blowclear Creek. Botfields Creek generally runs in a southerly direction and joins Blowclear Creek approximately 250 m upstream of The Bogan Way where it has a total catchment area of about 27 km^2.

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 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**), as well as descriptions of the patterns of overland flow in the vicinity of their properties.

Figure 1.1 shows the location of the nearby Bureau of Meteorology (**BoM**) operated rain gauges that are located in the vicinity of the study area, as well as the location of two privately owned rain gauges in the vicinity of the village. **Table 2.1** at the end of this chapter shows a comparison of the 24-hour rainfall totals at the rain gauges that are located within 20 km of the study catchment for the historic storm events that were identified during the community consultation process.

Table 2.1 shows that while the Bogan Gate Post Office daily rain gauge was operational during the January 1992 and November 2005 storm events, there were no other BoM operated rain gauges within 20 km of the village that were operational during the more recent storm events. Rainfall records at the two privately owned rain gauges in the vicinity of Bogan Gate were available for selected historic storm events.

Figure 2.3 shows design versus historic intensity-frequency-duration (**IFD**) curves for the three BoM operated pluviographic rain gauges that are located in the vicinity of Bogan Gate for the storm events identified by the respondents to the *Community Questionnaire*, while **Table 2.2** gives the approximate AEP of the recorded rainfall for durations ranging between 0.25 and 24 hours.

Table 2.2 and **Figure 2.3** show that the storms identified by the respondents to the *Community Questionnaire* varied in intensity. The storm that occurred in December 2010 was equivalent to between about 0.5% (1 in 200) and 0.2% (1 in 500) AEP design storm event at Parkes. While the storm that occurred in November 2022 was equivalent to about a 0.2% (1 in 500) AEP design storm event at Forbes, it was equivalent to about a 5% (1 in20) AEP design storm event at the Parkes and Goonumbla rain gauges which are located in close proximity to the headwaters of the Gunningbland Creek catchment. The storm that occurred in March 2012 was equivalent to about a 5% (1 in 20) and 20% (1 in 5) AEP design storm event at Parkes and Forbes, respectively. **Table 2.2** shows that the other storm events that were identified during the community consultation process were equivalent to about a 20% (1 in 5) % AEP or greater design storm event.

While a large number of photographs of the November 2005 flood were provided by respondents to the *Community Questionnaire*, there were no pluviographic rain gauges in operation in the vicinity of Bogan Gate at the time of the flood.

Based on the limited available historic flood data, the storm events that occurred on 3-4 March 2012 and 14 November 2022 were selected for use in the calibration of the hydrologic and hydraulic models that were developed as part of the present study. **Figure 2.4** shows the cumulative rainfall that was recorded at the nearby rain gauges for these two storm events, noting that the Parkes and Goonumbla (Coradegery) rain gauges are considered more representative of the rain that fell in the Gunningbland Creek catchment than the rain that was recorded at the Forbes rain gauge due to their proximity to the headwaters of the catchment.

2.2.2. 1-2 March 2012 Storm Event

Table 2.1 shows that total rainfall depths of 86 mm and 28 mm were recorded at the Myalls and Collaroy homesteads over the raindays of 2-3 March, compared with 142.2 mm and 118.8 mm at Parkes and Forbes, respectively. A total rainfall depth of 90.4 mm was recorded at the Goonumbla (Coradgery) rain gauge which is located adjacent to the headwaters of the study catchment. Based on this finding, it will be necessary to factor the rainfall that was recorded at the Parkes rain gauge to match the data that were recorded at the Goonumbla (Coradgery) daily rain gauge in order to better represent the rainfall that fell in the headwaters of the Gunningbland Creek catchment.

The left hand side of **Figure 2.4** shows that 124.6 mm of rain fell between 12:00 hours on 1 March 2012 and 18:30 hours on 2 March 2012 at the Parkes Airport AWS rain gauge which is located about 20 km east of the headwaters of the Gunningbland Creek catchment, while about 59.2 mm fell during the same period of time at the Forbes Airport AWS which is located about 30 km south of the Village Centre.

Figure 2.3 and **Table 2.2** show that the recorded rainfall at Parkes and Forbes was equivalent to about a 5% (1 in 20) and 20% (1 in 5) AEP design storm event, respectively.

While only two respondents identified that they had experienced flooding as a result of the March 2012 storm event, a number of photos were provided by a respondent to the *Community Questionnaire* showing flooding on the northern side of the Orange-Broken Hill Railway Line in the vicinity of the Neirawang homestead during the event (refer **Plates C3.1** to **C3.4** of **Appendix C**). It is understood that the paddocks in this area were inundated to depths of up to 1 m during the March 2012 flood.

It is also understood that some of the rural properties that are located on the northern side of the Orange-Hill Railway were flooded out until 8 March 2012.

2.2.3. 14 November 2022 Storm Event

Table 2.1 shows that the recorded two-day rainfall depths for the raindays of 13-14 November 2022 at the Parkes Airport AWS and the Goonumbla (Coradgery) gauge were comparable to that recorded at the privately owned Myalls rain gauge. Based on this finding, the rainfall that was recorded by both the Parkes Airport AWS and Mandagery (Rawene) rain gauges is considered to be representative of the rain that fell at Bogan Gate.

The right hand side of **Figure 2.4** shows that 79.8 mm of rain fell between 16:30 hours on 13 November 2022 and 03:30 hours on 14 November 2022 at the location of the Parkes Airport AWS rain gauge, while 75.2 mm of rain fell at the location of the Goonumbla (Coradgery) rain gauge during the same time period. **Figure 2.3** and **Table 2.2** show that the rainfall that was recorded by the two rain gauges was equivalent to a design storm with an AEP of about 5%.

Plate C7.1 of **Appendix C** shows floodwater inundating the right overbank area of Gunningbland Creek upstream of the Bogan Way, while **Plates C7.2** and **C7.3** show that floodwater breached the levee that protects the Kadina Homestead.

Plates C7.4 to **C7.18** shows that floodwater surcharged the banks of Gunningbland Creek in the vicinity of the Myalls homestead and inundated large portions of the adjacent paddocks. **Plate C7.16** shows that peak flood levels peaked approximately 1 m below the crest of the levee that protects the Myalls Homestead (which is set at an elevation of about RL 277.8 m AHD).

Plates C7.18 to **C7.21** show where the Orange-Broken Hill Railway Line embankment collapsed approximately 50 m to the east of the Overland Road level crossing.

TABLE 2.1
RECORDED DAILY RAINFALL TOTALS FOR HISTORIC STORM EVENTS(1)

Historic Storm Event	Rainday	Daily Rainfall Total													
		Daily Rain Gauges									Bom AWS		BoM FWN	Privately Owned Gauge	
		Parkes Airport AWS (GS 65068)	Forbes (Bedgerabong Rd) (GS 65114)	Forbes Airport AWS (GS 65103	Forbes (Muddy Water) (GS 65039)	Goonumbla (Coradgery) (GS 50016)	Trundle (Long St) (GS 50036)	Ootha (Mayfield) (GS 50141)	Warroo (Geeron) (GS 50020)	Bogan Gate Post Office (GS 50004)	Parkes Airport AWS (GS 65068)	Forbes Airport AWS (GS 65103)	Goonumbla (Coradgery) (GS 50016)	Myall homestead (Bogan Gate)	Collaroy Homestead (Bogan Gate)
January 1992	23 January 1992	-(2)	-(2)	-(2)	13	45.6	18.2	-(2)	0	33	-(2)	-(2)	-(3)	-(3)	-(3)
	24 January 1992	-(2)	-(2)	-(2)	19.4	18	25	-(2)	47	26	-(2)	-(2)	-(3)	-(3)	-(3)
November 2005	8 November 2005	130	-	52.6	53.5	85	205.6	67.4	40.4	60	-(2)	-(2)	-(3)	-(3)	53.5
December 2010	3 December 2010	105.6	-	12	8.4	28	17	7	0	-(2)	105.6	-(2)	-(3)	-(3)	3
	4 December 2010	21	-	74.2	36	100	25.4	2.4	9	-(2)	21	-(2)	-(3)	-(3)	5
March 2012	1 March 2012	12.6	20.4	51.2	22	11	9	11		-(2)	12.6	51.4	-(3)	3	18
	2 March 2012	94.4	28	28.2	24	50.6	42.6	9	53.0	-(2)	94.2	28.2	-(3)	67	10
	3 March 2012	35.2	33.2	39.2	37.4	39.8	59	25.4		-(2)	35.4	39.2	-(3)	16	-(3)
February 2016	Date not defined	No rainfall recorded in February 2016													
September 2016	2 September 2016	18.8	-(2)	10.2	-(2)	20.4	20	14.5	8.8	-(2)	18.6	10	-(3)	-(3)	16
	3 September 2016	40.4	-(2)	27.8	-(2)	48.6	-(2)	19	25.2	-(2)	40.6	28	-(3)	-(3)	6
April 2020	10 April 2020	18.6	50.8	53.8	47	-(2)	-(2)	42.5	0	-(2)	18.6	53.8	-(3)	-(3)	52

Refer over for footnote to table.

Cont'd Over

TABLE 2.1 (Cont'd)
RECORDED DAILY RAINFALL TOTALS FOR HISTORIC STORM EVENTS[(1)]

Historic Storm Event	Rainday	Daily Rainfall Total													
		Daily Rain Gauges									Bom AWS		BoM FWN	Privately Owned Gauge	
		Parkes Airport AWS (GS 65068)	Forbes (Bedgerabong Rd) (GS 65114)	Forbes Airport AWS (GS 65103	Forbes (Muddy Water) (GS 65039)	Goonumbla (Coradgery) (GS 50016)	Trundle (Long St) (GS 50036)	Ootha (Mayfield) (GS 50141)	Warroo (Geeron) (GS 50020)	Bogan Gate Post Office (GS 50004)	Parkes Airport AWS (GS 65068)	Forbes Airport AWS (GS 65103)	Goonumbla (Coradgery) (GS 50016)	Myall homestead (Bogan Gate)	Collaroy Homestead (Bogan Gate)
January 2021	2 January 2021	20.8	5.8	2.6	0	0	0	22	0	-(2)	20.8	2.6	-(3)	-(3)	-
	3 January 2021	52	29.2	37.6	29	28	24	19	26.2	-(2)	52	37.6	-(3)	-(3)	15.5
November 2021	11 November 2021	14	10	10	9	9.6	14.4	5.5	18.6	-(2)	14	10	-(3)	-(3)	18.5
	12 November 2021	21.4	24.8	27.8	24.8	9.4	8.2	0	25.8	-(2)	21.4	27.8	-(3)	-(3)	21
	13 November 2021	3.6	9.6	10.8	12.4	1.6	2	27.5	5.6	-(2)	3.6	10.8	-(3)	-(3)	2
	14 November 2021	8.4	5.4	5.6	8	5	2.6	0	5.2	-(2)	8.4	5.6	-(3)	-(3)	9..5
	24 November 2021	15.2	0	1.4	-(2)	18	4.2	0	4.4	-(2)	15.2	1.4	-(3)	-(3)	-(3)
	25 November 2021	27.8	7.8	12.6	-(2)	14	4.2	23	2.2	-(2)	21.6	12.6	-(3)	-(3)	-(3)
	26 November 2021	19.4	21.6	25.2	-(2)	37	43	0	23.4	-(2)	19.4	25.2	-(3)	-(3)	-(3)
	27 November 2021	36.8	31.6	24.6	-(2)	42.4	20.4	25	35	-(2)	36.8	24.6	-(3)	-(3)	-(3)
May 2022	12 May 2022	16.8	36.2	42.2	0	28	0	0	40.8	-(2)	16.6	41.6	-(3)	53	44.5
November 2022	13 November 2022	25.8	6.8	9	12.4	-(2)	14.4	13	44	-(2)	25.8	9	24	93	-(3)
	14 November 2022	80	112.2	118	104.2	-(2)	71	0	0.2	-(2)	80	118	84	18	-(3)

1. Refer **Figure 1.1** for gauge location.
2. Gauge not in operation at time of storm event.
3. Data not available for the purpose of the present study.

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

Storm Event	Rain Gauge Station Name(1)	Storm Duration (hours)						
		1	2	3	6	9	12	24
3-4 December 2010	Parkes Airport AWS (GS 65068)	2%	0.5%	0.2%	0.5%	1%	1%	2%
1-3 March 2012	Parkes Airport AWS (GS 65068)	50%	20%	10%	10%	10%	10%	5%
	Forbes Airport AWS (GS 65103)	50%	20%	20%	20%	20%	20%	50%
2-3 September 2016	Parkes Airport AWS (GS 65068)	>50%	>50%	>50%	>50%	>50%	>50%	50%
	Forbes Airport AWS (GS 65103)	>50%	>50%	>50%	>50%	>50%	>50%	50%
10 April 2020	Parkes Airport AWS (GS 65068)	>50%	>50%	>50%	>50%	>50%	>50%	>50%
	Forbes Airport AWS (GS 65103)	>50%	>50%	>50%	50%	50%	50%	50%
2-3 January 2021	Parkes Airport AWS (GS 65068)	20%	20%	50%	20%	20%	50%	50%
	Forbes Airport AWS (GS 65103)	20%	20%	20%	50%	50%	>50%	>50%
11-14 November 2021	Parkes Airport AWS (GS 65068)	>50%	>50%	>50%	>50%	>50%	>50%	>50%
	Forbes Airport AWS (GS 65103)	>50%	>50%	>50%	>50%	>50%	>50%	>50%
24-27 November 2021	Parkes Airport AWS (GS 65068)	>50%	>50%	>50%	>50%	>50%	>50%	>50%
	Forbes Airport AWS (GS 65103)	>50%	>50%	>50%	>50%	>50%	>50%	>50%

Cont'd Over

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

Storm Event	Rain Gauge Station Name[1]	Storm Duration (hours)						
		1	2	3	6	9	12	24
12 May 2022	Parkes Airport AWS (GS 65068)	>50%	>50%	>50%	>50%	>50%	>50%	>50%
	Forbes Airport AWS (GS 65103)	>50%	>50%	>50%	>50%	>50%	>50%	50%
13-14 November 2022	Parkes Airport AWS (GS 65068)	20%	10%	10%	5%	5%	5%	5%
	Forbes Airport AWS (GS 65103)	5-2%	2%	5%	0.5-0.2%	0.5%	0.5%	1%
	Goonumbla (Coradgery) (GS 50016)	20%	10%	5%	5%	5%	5%	5%

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

3 HYDROLOGIC MODEL DEVELOPMENT AND CALIBRATION

3.1 Hydrologic Modelling Approach

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

Both the IL-CL and RAFTS modelling approaches which are built into the DRAINS software were used to generate discharge hydrographs from urban and rural areas, respectively, as this combined approach was considered to provide a more accurate representation of the rainfall runoff process. The hydrologic response of the catchment on the southern side of the Orange-Broken Hill Railway immediately to the south of the Village Centre was simulated using the rainfall-on-grid approach which is built into the TUFLOW software. The discharge hydrographs generated by applying the IL-CL and RAFTS modelling approach were applied to the TUFLOW hydraulic model as either point or distributed inflow sources (refer **Section 4.4** of this report for further details).

3.2 Hydrologic Model Layout

Figure 3.1 (2 sheets) shows the layout of the hydrologic model that was developed as part of the present study (**Bogan Gate DRAINS Model**). Careful consideration was given to the definition of the sub-catchments which comprise the Bogan Gate DRAINS 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 headwalls were also taken into consideration when deriving the boundaries of the various sub-catchments. The study area was split into a total of 219 sub-catchments.

The outlets of the sub-catchments in the upper reaches of the study catchment were linked and the lag times between each assumed to be equal to the distance along the main drainage path divided by an assumed flow velocity of 0.5 m/s. Percentages of impervious area were based on a visual inspection of the aerial photography and experience in determining appropriate values for different land-use types.

Figure 3.1 shows that the RAFTS modelling approach has been used for sub-catchments predominately comprising the rural portion of the study catchment, while the IL-CL modelling approach has been applied in the more urbanised parts of Bogan Gate. The hydrologic response of the catchment to the south of the Village Centre was simulated using the rainfall-on-grid approach which is built into the TUFLOW software as the catchment delineation and flowpaths in the area were difficult to ascertain from the LiDAR survey 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). Digital Elevation Models (**DEMs**) derived from the available LiDAR survey data were used as the basis for computing the slope.

3.3 Hydrologic Model Testing

3.3.1. General

Historic flood data suitable for use in the model calibration process comprises photographic and anecdotal evidence of flooding patterns that were observed during the storms that occurred on 1-2 March 2012 and 14 November 2022. As discussed in **Section 2.2**, the storms for which data were available are equivalent to about a 5% (1 in 20) AEP event.

As there are no historic data on flood 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.

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

3.3.2. Application of Historic Rainfall to the Hydrologic Model

The rainfall burst that was recorded at the Parkes Airport AWS rain gauge shown on the left-hand side of **Figure 2.4** was input to the hydrologic model for the 1-2 March 2012 storm event, while the rainfall burst that was recorded at the Goonumbla (Coradgery) rain gauge was relied upon for the 14 November 2022 storm event. As discussed in **Section 2.2**, it was necessary to apply a rainfall multiplier to the recorded rainfall at the Parkes Airport AWS rain gauge for the March 2012 storm event in order to match the 24-hour rainfall depths that were recorded at the Goonumbla (Coradgery) rain gauge.

3.3.3. Hydrologic Model Parameters

For the sub-catchments modelled using the RAFTS hydrologic modelling approach, a Manning's n value of 0.04 was applied to sub-catchments primarily characterised as rural pastoral land, while a value of 0.06 was applied to sub-catchments comprising a mixture of cleared pastoral land and dense vegetation. A Manning's n value of 0.08 was applied to sub-catchments comprising mostly dense vegetation. A Bx routing parameter of 1.0 was adopted for sub-catchments that were modelled in RAFTS.

An initial storm loss value of 25 mm was adopted based on the data extracted from the *ARR Data Hub* (a copy of which is contained in **Appendix D)**.

It was not possible to achieve a good match with the observed flood behaviour using the NSW jurisdictional losses procedure for deriving continuing loss values by factoring the raw continuing loss value obtained from the *ARR Data Hub* of 0.7 mm/hr by a factor of 0.4. A better fit was achieved by adopting a continuing loss value of 2.5 mm/hr which is recommended for use for design flood estimation in the vicinity of Bogan Gate in *Initial Losses for Design Flood Estimation in New South Wales* (Walsh et al, 1991).

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 hydrologic model parameters set out in this chapter were therefore adopted for design flood estimation purposes, noting that due to the limited availability of historic flood related data for use in the model calibration process, the initial and continuing loss values contained in the *ARR Data Hub* were ultimately adopted for design flood estimation purposes (refer **Chapter 5** of this report for further details).

4 HYDRAULIC MODEL DEVELOPMENT AND CALIBRATION

4.1 General

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

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

4.2 The TUFLOW Modelling Approach

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

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

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

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

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

4.3 TUFLOW Model Setup

4.3.1. Model Structure

Figure 4.1 (2 sheets) shows the layout of the TUFLOW model that was developed as part of the present study (**Bogan Gate TUFLOW Model**). The Bogan Gate TUFLOW Model comprises the piped drainage system, while the inbank, overbank and shallow “overland” flow are modelled by the rectangular grid.

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

4.3.2. Two-dimensional Model Domain

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

A grid spacing of 6 m with a smaller 3 m grid spacing embedded internal to the model in the vicinity of the Village Centre in combination with a grid spacing of 12 m on the relatively flat floodplain to the south of Gunningbland Creek (refer **Figure 4.1** for extent) was found to provide an appropriate balance between the need to define features on the floodplain versus model run times and was adopted for the investigation. Ground surface elevations for model grid points were initially assigned using the LiDAR derived DEMs for the study area.

Ridge and gully lines were added to the Bogan Gate 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 local farm dams were assumed full at the start of the model simulation (i.e. at the onset of flood producing rain).

The existing bridge crossings of Gunningbland Creek were incorporated in the two-dimensional domain as a layered flow constriction elements based on cross sectional survey data. The bridge deck and handrails were assumed to be 100% blocked (i.e. impervious to flow).

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

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

4.3.3. One-dimensional Model Elements

Survey data provided by Ardnell Surveying were used as the primary source of details of the piped drainage system which were incorporated into the Bogan Gate TUFLOW Model. These data were supplemented with field measurements. **Table 4.1** over the page summarises the pit and pipe data that were incorporated into the Bogan Gate TUFLOW Model, noting that the majority of the structures shown on **Figure 4.1** comprise multiple parallel cells of pipe/box culvert.

TABLE 4.1
SUMMARY OF MODELLED DRAINAGE STRUCTURES

Pipes		Box Culverts		Headwalls
No.	**Length (m)**	**No.**	**Length (m)**	**No.**
416	3,430	66	685	250

4.3.4. Model Parameters

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

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

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

TABLE 4.2
BEST ESTIMATE HYDRAULIC ROUGHNESS VALUES

Surface Treatment	Manning's n Value
Concrete piped elements	0.015(1)
Asphalt or concrete road surface	0.02
Vegetated areas	0.08
Allotments (between buildings)	0.10
Buildings	10

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

Figure 4.2 is a typical example of flow patterns derived from the above roughness values. This example applies to the 14 November 2022 flood event and shows flooding patterns in the vicinity of the intersection of Bogan Street and Edols 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.[1] Similar information to that shown on **Figure 4.2** may be presented at any location within the model domain and will be of assistance to Council in assessing individual flooding problems in the study area.
Model Boundary Conditions

The locations where sub-catchment inflow hydrographs were applied to the Bogan Gate 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 and as distributed inflows via "Rain Boundaries".

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

The direct-rainfall-on-grid approach involves the application of rainfall excess to the two-dimensional model domain, with the routing of the rainfall excess (runoff) simulated across each grid cell within the area shown on **Figure 4.1**.

The downstream boundary of the model comprises a TUFLOW-derived normal depth relationship which is located approximately 12 km downstream (by river) of the Orange-Broken Hill Railway Line. The downstream boundary has been located a sufficient distance downstream of the study area so as to not impact flood behaviour in the area of interest.

4.4 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 1-2 March 2012 and 14 November 2022

Figures 4.3 and **4.4** (3 sheets each) show the Bogan Gate TUFLOW Model results for the 1-2 March 2012 and 14 November 2022 storm events, respectively, while **Table 4.3** over the page briefly describes the flood behaviour that was observed during each storm event and how it compares to the results of the Bogan Gate TUFLOW Model. In general, the Bogan Gate TUFLOW Model was able to reproduce the flood behaviour which was approximated from the available photographs and anecdotal descriptions of flooding for the 1-2 March 2012 and 14 November 2022 storm events.

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 which have been estimated from photographs that were provided by the community and are approximate only, noting that the accuracy of the model calibration is limited by the accuracy of the underlying flood data. In the absence of more detailed flood data 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**.

[1] 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 4.3
COMPARISON OF OBSERVED AND MODELLED FLOOD BEHAVIOUR
HISTORIC STORM EVENTS

Response Identifier(1)	Storm Event	Observed Flood Behaviour/ Other Comment	Model Verification Comments
FM_2012.1	1-2 March 2012	Paddocks inundated to depths of up to 1.0 m (refer **Plates C3.1** to **C3.4** of **Appendix C**).	The Bogan Gate TUFLOW Model results show the paddocks inundated to a maximum depth of about 0.8 m.
FM_2022.1	14 November 2022	**Plate C7.1** shows paddocks to the south of Blow Clear Road inundated with flood water.	The Bogan Gate TUFLOW Model results show the paddocks inundated to a maximum depth of about 0.9 m.
FM_2022.2		**Plates C7.2** and **C7.3** show that floodwater broke the levee that protects the Kadina homestead.	The Bogan Gate TUFLOW Model shows that floodwater overtopped the levee and ponded to depths greater than 0.8 m in the vicinity of the homestead.
FM_2022.3		Flood levels peaked approximately 1 m below the crest of the levee that protects the Myalls homestead (which is set at an elevation of about 227.8 m AHD).	The Bogan Gate TUFLOW Model shows that floodwater peaked within 0.5 m of the crest of the levee.
FM_2022.4		**Plates C7.18** to **C7.21** shows where floodwater breached the Orange-Broken Hill Railway Line immediately to the east of Overland Road.	The Bogan Gate TUFLOW Model shows that floodwater overtopped to railway to a maximum depth of about 0.2 m which may have cause the failure.

1. Refer **Figure 4.3** (3 sheets) for location of observed flood behaviour for 1-2 March 2012 storm event and **Figure 4.4** (3 sheets) for location of observed flood behaviour for 14 November 2022 storm event..

5 DERIVATION OF DESIGN FLOOD HYDROGRAPHS

5.1 Design Storms

5.1.1. Rainfall Intensity

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

5.1.2. Areal Reduction Factors

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

ARFs of between 0.9 and 0.92 are applicable on the catchments contributing to flow in Gunningbland Creek (169 km^2) and Blowclear Creek (189 km^2) at the upstream extent of the TUFLOW model for the 12 hour storm event which is critical for maximalising flows in the two creeks. Based on the above, a single ARF value of 0.92 was applied to the Gunningbland Creek and Blowclear Creek sub-catchments in the headwaters of the study area for design flood estimation purposes.

It is noted that it is not appropriate to apply the above ARF to all sub-catchments in the Bogan Gate DRAINS Model as the purpose of the present study was to also define flood behaviour in areas subject to Major Overland Flow where the contributing catchments are substantial smaller. As such, an ARF value of 1.0 was applied to all sub-catchments contributing to Major Overland Flow through the urbanised parts of the village.

5.1.3. Temporal Patterns

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

The temporal pattern ensembles that are applicable to Frequent (more frequent than 14.4% AEP), Intermediate (between 14.4% and 3.2% AEP) and Rare (rarer than 3.2% AEP) storm events were obtained from the ARR Data Hub[2], while those for the very rare events were taken from BoM's publication entitled *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method* (BoM, 2003) and Jordan et. al., 2005.

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

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

5.1.4. Probable Maximum Precipitation

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

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

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

Figure 3.1 shows the location and orientation of the PMP ellipses which were used to derive the rainfall estimates for the present study.

5.2 Design Rainfall Losses

The initial and continuing loss values to be applied in flood hydrograph estimation were derived using the NSW jurisdictional specific procedures set out in the *ARR Data Hub*. The raw Probability Neutral Burst Initial Loss (**PNBIL**) 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 PNBIL 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.

While a continuing loss value of 2.5 mm/hr was relied upon to achieve a reasonable match between observed and modelled flood behaviour for the 1-2 March 2012 and 14 November 2022 storm events, the NSW jurisdictional advice recommends multiplying the raw (or unadjusted) continuing loss value that is contained on the *ARR Data Hub* of 0.7 mm/hr by a factor of 0.4 for design flood estimation. This results in a continuing loss value of 0.28 mm/hr (0.7 mm/hr x 0.4 = 0.28 mm/hr). The following section of this report sets out the reasons supporting the adoption of a continuing loss value of 2.3 mm/hr, it being the continuing loss value has been adopted for the nearby catchments at Bogan Gate for which a companion flood study is currently being undertaken.

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 model parameters set out in **Section 3.3.3** in order to obtain design discharge hydrographs for input to the Bogan Gate TUFLOW Model.

Table 5.1 shows a comparison of design peak flow estimates derived from the Bogan Gate DRAINS Model for a range of continuing loss values compared to those derived by the Probabilistic Rational Method (**PRM**), the procedures for which are set out in the 1987 edition of *Australian Rainfall & Runoff* (The Institution of Engineers Australia, 1987) (**ARR 1987**) and the RFFE Model, the procedures for which are set out in ARR 2019, noting **Figure 3.1** shows the locations at which the comparisons were made.

TABLE 5.1
COMPARISON OF DESIGN PEAK FLOW ESTIMATES
(m^3/s)

Identifier [(1)] [A]	AEP (%) [B]	PRM [C]	RFFE [D]	Bogan Gate DRAINS Model: Adjusted PNBIL CL = 0.7 mm/hr[(2)] [E]	Bogan Gate DRAINS Model: Adjusted PNBIL CL = 0.28 mm/hr[(3)] [F]	Bogan Gate DRAINS Model: Adjusted PNBIL CL = 2.3 mm/hr[(4)] [G]
BG_RFFE1 Gunningbland Creek [Area = 167 km^2]	1	170	388	266	281	215
	2	121	289	209	223	167
	5	77	187	159	173	117
	10	51	127	122	137	85.5
	20	35	80.6	89.2	103	54.9
BG_RFFE2 Blowclear Creek [Area = 189.4 km^2]	1	185	419	341	361	279
	2	132	312	273	290	214
	5	84	202	204	219	152
	10	56	138	157	176	112
	20	39	87.2	118	137	75.1

1. Refer **Figure 3.1** for location of peak flow comparison.
2. Raw continuing loss value set out in the *ARR Data Hub*
3. Based on the NSW jurisdictional advice for deriving continuing loss values
4. Based on the continuing loss value that were found to achieve a good match with the observed flood behaviour at the nearby village of Bogan Gate

Table 5.1 shows that the Bogan Gate DRAINS Model derived design peak flow estimates for the continuing loss values of 0.7 mm/hr and 0.28 mm/hr are consistently higher than those derived using the PRM and generally less than those derived using the RFFE.

It is noted that the headwaters of the Gunningbland Creek catchment are located less than 40 km to the west of the gauged Mandagery Creek catchment where a recent study that was undertaken for NSW Reconstruction Authority on the Mandagery Creek catchment (Lyall & Associates, 2024) found that the adoption of a continuing loss value of 2.5 mm/hr best fitted the peak flow that was recorded by WaterNSWs *Mandagery Creek at Upstream Eugowra (Smithfield)* stream gauge for the November 2022 flood, as well as the design peak flow estimates that were derived from a flood frequency analysis for the same gauge.

It is also noted that the headwaters of the Gunningbland Creek catchment are located less 25 km from the Quart Pot Creek and Bartleys Creek catchments at the nearby village of Cookamidgera, for which a companion flood study is currently being undertaken and that this study found that a continuing loss value of 2.3 mm/hr best fitted the available, albeit limited, flood data. Column G in **Table 5.1** sets out the Bogan Gate DRAINS Model derived peak flows based on a continuing loss value of 2.3 mm/hr.

Based on the above findings and as per the recommended hierarchical approach that is set out in Section 3.7.1 of *Floodplain Risk Management Guide – Incorporating 2016 Australian Rainfall and Runoff in studies* (OEH, 2019), it was decided to adopt the raw continuing loss value of 2.3 mm/hr that has been adopted for design flood estimation as part of the present study given:

a) it matches the raw continuing loss value that is set out in the *ARR Data Hub* for the nearby catchments of Quart Pot Creek and Bartleys Creek, and which has been adopted for design flood estimation purposes at the nearby village of Cookamidgera;

b) it closely matches the 2.5 mm/hr that was found to best fit the available, albeit limited, flood data at Bogan Gate; and

c) it also closely matches the 2.5 mm/hr that was found to best fit both historic and design peak flow data in the nearby gauged catchment of Mandagery Creek.

6 HYDRAULIC MODELLING OF DESIGN FLOOD EVENTS

6.1 Modifications to Hydraulic Model Structure

As per the requirements of ARR 2019, the potential for the existing drainage system to experience a partial blockage during a flood event was taken into account when deriving the design flood envelopes. **Table E1** in **Appendix E** provides a summary of the blockage factors that were derived to each individual headwall and bridge structure in the study area based on the procedures set out in ARR 2019. As per the recommendations in ARR 2019, an L_{10}[3] of 1.5 m was adopted for the blockage assessment, which is the recommended minimum value that should be adopted for urban areas in the absence of a record of past debris accumulated at a structure.

6.2 Presentation and Discussion of Results

6.2.1. Accuracy of Hydraulic Modelling

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

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

6.2.2. Critical Duration and Temporal Pattern Assessment

The critical storm durations and associated median temporal patterns for the design storm events were derived based on the results of running both the DRAINS and TUFLOW models in tandem. For example, design discharge hydrographs for the ensemble of temporal patterns for storm durations ranging between 30 minutes and 18 hours were exported from the DRAINS model and input to the TUFLOW model. The assessment was undertaken for the 20%, 5% and 1% AEP storm events which represent the three temporal pattern bins (i.e. frequent, infrequent and rare, respectively) that were downloaded from the *ARR Data Hub.*

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

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

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

TABLE 6.1
CRITICAL DURATIONS AND TEMPORAL PATTERNS

Design Storm Event	Temporal Pattern Bin	Critical Storm Duration and Temporal Pattern[(1)]
20%	Frequent	3 hour, temporal pattern 3 [3982] 4.5hour, temporal pattern 6 [4016] 12 hour, temporal patterns 6 [4097]
10% 5%	Infrequent	30 minute, temporal pattern 7 [3837] 2 hour, temporal pattern 3 [3921] 6 hour, temporal pattern 6 [4038] 9 hour, temporal pattern 2 [4059]
2% 1% 0.5% 0.2%	Rare	30 minute, temporal pattern 6 [3815] 1 hour, temporal pattern 2 [3819] 2 hour, temporal pattern 4 [3934] 6 hour, temporal pattern 7 [4025] 12 hour, temporal pattern 6 [4007]
PMF	Very Rare	1.5 hour, Melbourne 1972 temporal pattern 2 hour, Melbourne 1972 temporal pattern 3 hour, Mt Kiera 1975 temporal pattern

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

6.2.3. Design Flood Extents, Depths and Elevations

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

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

Figure 6.9 is a longitudinal section along a 10.5 km length of the Orange-Broken Hill Railway Line and the adjacent Henry Parkes Way where they run between Olive Grove Lane and Overland Road, while **Figure 6.10** shows stage hydrographs at selected road and rail crossings throughout the study area.

Table F1 in **Appendix F** sets out the peak flood level and maximum depth of inundation at each crossing, while **Table G1** in **Appendix G** sets out design peak flows and corresponding critical storm durations at key locations throughout the study area. **Figures H1.1** to **H1.8** shows the maximum flow velocities for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP storm events, together with the PMF.

The sensitivity studies and discussion presented in **Section 6.5** provide guidance on suitable freeboard provisions under present day catchment and climatic conditions.

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

6.2.4. Description of Flood Behaviour

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

i. Floodwater surcharges both banks of the watercourse during flood events more frequent than 20% AEP along its entire reach.

ii. **Figure 6.2** shows that floodwater surcharges the left bank of the watercourse immediately upstream of The Bogan Way where it inundates the low lying undeveloped land in the Village Centre that is bounded by Lagoon Street to the west, Marta Lane to the north, Monomie Street to the east and Bogan Street to the south.

iii. **Figure 6.3** shows that floodwater that surcharges the left bank of the watercourse upstream of The Bogan Way commences to inundate residentially developed allotments in Hutton Street and Lachlan Street in a 10% AEP flood event.

iv. **Figure 6.4** shows that floodwater that surcharges the left bank of the watercourse upstream of The Bogan Way backs up a grass-lined drain that runs along the Lister Lane paper road reserve as far south as Lachlan Street in a 5% AEP flood event.

v. **Figure 6.5** shows that floodwater that surcharges the left bank of the watercourse upstream of The Bogan Way inundates existing residentially developed allotments to the north of Lachlan Street to a maximum depth of about 0.4 m in a 5% AEP flood event.

vi. **Figure 6.9** shows that the Henry Parkes Way and Orange-Broken Hill Railway embankments are generally elevated about 1 m and 1-1.5 m above adjacent natural surface levels. As a result, floodwater that surcharges the banks of the watercourse downstream of the Tottenham Railway line generally flows in a westerly direction through the rural land that is located on the northern side of Henry Parkes Way where it ponds on the eastern side of a hillock that is located in the vicinity of Cronin Lane (refer location of Peak Flood Level Location (**PFFL**) H05a).

vii. **Figure H1.5** in **Appendix H** shows that maximum flow velocities on the Gunningbland Creek floodplain in a 1% AEP storm event are generally in the range of 0.2 m/s to 0.7 m/s, with maximum flow velocities of greater than 1 m/s shown to occur within the inbank areas.

viii. A comparison of the peak flows set out in **Table G1** in **Appendix G** shows that the elevated road and railway embankments impact the distribution of flow on the floodplain downstream of the Village Centre, noting that the values in the square brackets represent the percentage of the total flow on the Gunningbland Creek floodplain that is conveyed on the northern and southern sides of the railway. The key findings are as follows:

a. Peak Flow Location (**PFL**) Q04 shows the total flow in the watercourse immediately downstream of the Tottenham Railway Line.

b. PFLs Q05A, Q06A and Q07A show that to the east of the location where the road and railway cross the watercourse (refer PFFL H04a and H04b), between 80-95% of the total flow on the floodplain is conveyed on the northern side of the railway.

c. PFLs Q08A and Q09A show that to the west of the location where the road and railway cross the watercourse (refer PFFL H04a and H04b), between 60-80% of the total flow on the floodplain is conveyed on the northern side of the railway.

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

a. The Tubby Lees Road crossing (refer PFLL H03) would be inundated during freshes in the watercourse.

b. The Bogan Way crossing (refer PFLL H01) is inundated in flood events more frequent than 20% AEP.

c. The Tottenham Railway Line (refer PFLL H02b) is inundated in a 10% AEP flood.

d. While the Henry Parkes Way (refer PFLL H04a) and Orange-Broken Hill Railway Line (refer PFLL H04b) crossings of the watercourse remain flood free in a PMF event, **Figure 6.9** shows that the road and railway would be inundated to the east of the crossing at in a 10% and 1% AEP flood event, respectively.

e. Henry Parkes Way (refer PFLL H05a) and the Orange-Broken Hill Railway Line will be inundated in the vicinity of their intersections with Overland Road in a 20% and 10% AEP flood event, respectively.

Section 6.5.4 sets out the findings of a sensitivity study that was undertaken to assess the impact that the removal of the raised Orange-Broken Hill Railway and Henry Parkes Way embankments would have on flood behaviour

x. **Table G1** in **Appendix G** shows that the peak PMF flow in Gunningbland Creek is about five times the corresponding peak 1% AEP flow.

xi. **Figure 6.8** shows that existing development within the extent of the Village Centre is inundated to depths of up to 1.4 m in a PMF.

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

i. **Figure 6.1** (Sheet 1) shows that the inbank area of the watercourse is not defined to the north of Blowclear Road and, as a result floodwater flows in a southerly direction through rural land where it overtops the road at multiple locations between Five Chain Lane and Mercadool Lane in flood events as frequent as 20% AEP..

ii. A comparison of PFL Q14A and Q14B in **Table G1** of **Appendix G** shows that the majority of the flow on the Blowclear Creek floodplain flows in a westerly direction on the southern side of Blowclear Road.

iii. **Figure H1.5** in **Appendix H** shows that the maximum flow velocities on the Blowclear Creek floodplain in a 1% AEP storm event are generally in the range of 0.2 m/s to 0.6 m/s, with maximum flow velocities up to 1 m/s shown to occur in isolated area.

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

a. The Leafy Tank Road crossing (refer PFLL H06) would be inundated during freshes in the watercourse.

b. The Bogan Way crossing (refer PFLL H07a) and the Tottenham Railway level crossing of The Bogan Way (refer PFFL H07b) which is located on the right overbank area of the watercourse are inundated in flood events as frequent as 20% AEP.

c. The Tottenham Railway Line (refer PFLL H06) is inundated in a 1% AEP flood.

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

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

i. Floodwater surcharges the banks of the watercourse along its entire reach in flood events more frequent than 20% AEP.

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

a. The Bogan Way crossing (refer PFLL H09) would be inundated in flood events as frequent as 20% AEP.

b. The Tottenham Railway Line (refer PFLL H02b) is inundated in a 1% AEP flood.

v. **Table G1** in **Appendix G** shows that the peak PMF flow in the watercourse is about seven times the corresponding peak 1% AEP flow.

The key features of Major Overland Flow are as follows:

- Major Overland Flow has a negligible impact on the Village Centre.
- As there is no formal kerb and gutter and/or piped drainage system in the Village Centre, stormwater runoff generally ponds in the road reserves for extended periods of time after the cessation of rainfall events.
- The existing grass-lined drain that runs in a northerly direction from the northern end of Lester Lane is of limited capacity and has a minimal grade. It is therefore unable to efficiently drain local stormwater runoff from the portion of the Village Centre that lies to the east of The Bogan Way.
- **Figure H1.5** in **Appendix H** shows that the maximum flow velocities in areas subject to Major Overland Flow generally do not exceed 0.5 m/s in a 1% AEP storm event.

6.3 Economic Impacts of Flooding

Table 6.2 sets out the number of properties that are flood affected in the Village Centre and the estimated damages which would occur for flood of varying magnitude.

While no buildings in the Village Centre would be inundated above-floor level in a 1% AEP flood event, flood damages of about $0.03 Million would still be incurred during a flood of this magnitude. During a PMF event, 24 dwellings and one public building would experience above-floor inundation, resulting in flood damages totalling about $5.39 Million.

For a discount rate of 5% pa and an economic life of 30 years, the *Net Present Worth* of damages for all flood events up to the 1% AEP is effectively zero, while for all floods up to the PMF it is about $0.1 Million. Therefore, one or more schemes costing up to this latter amount could be economically justified if they eliminated damages in the study area for all possible flood events. 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 I of this report contains further details on the economic assessment that was undertaken as part of the present study.

TABLE 6.2
SUMMARY OF FLOOD DAMAGES

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	
20	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
5	2	0	0	0	0	0	0.01
2	5	0	0	0	0	0	0.02
1	6	0	0	0	0	0	0.03
0.5	6	0	0	0	0	0	0.03
0.2	6	1	0	0	0	0	0.05
PMF	38	24	1	1	1	1	5.39

6.4 Flood Hazard Zones and Floodways

6.4.1. Flood Hazard Vulnerability Classification

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

Flood Hazard Vulnerability Classification diagrams for the 5%, 1% and 0.2% AEP flood events, as well as the PMF based on the procedures set out in ARR 2019 are presented on **Figures 6.11** to **6.14**.

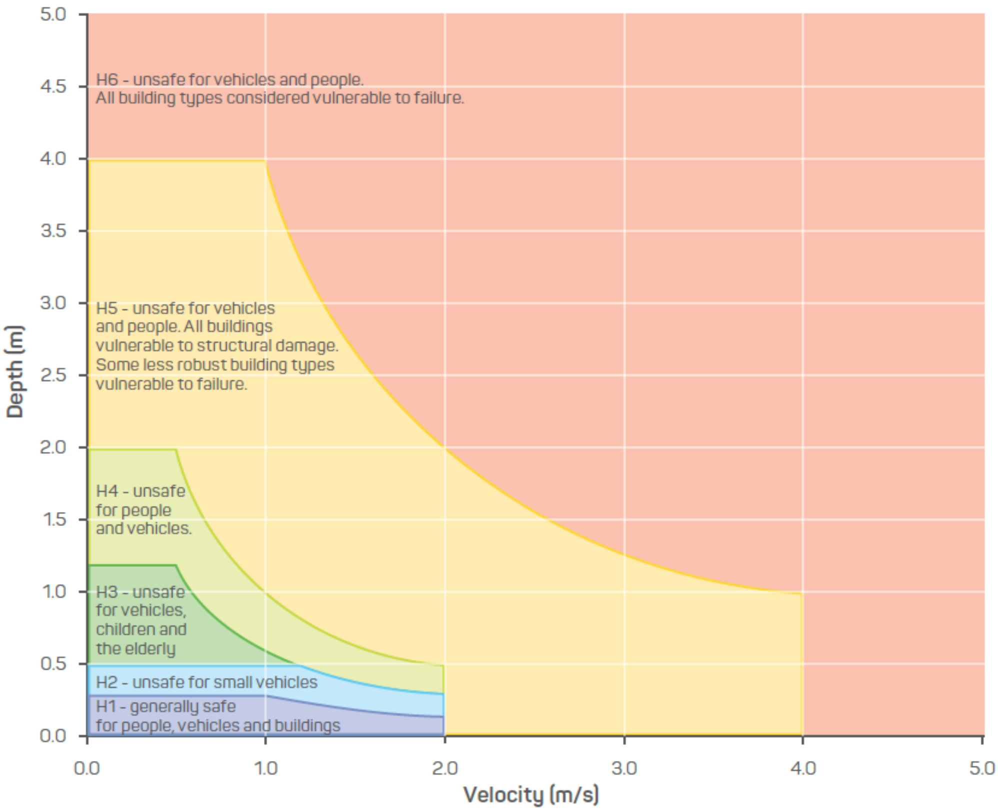
It was found that generally in flood events up to 0.2% AEP there are no areas classified as H6, while areas classified as H5 are generally limited to the inbank area of Gunningbland Creek, Blowclear Creek and Botfields Creek. The majority of the Village Centre is classified as H1 and H2 in flood events up to 0.2% AEP, with H3 type flooding shown to be present in the low lying land that is located on the northern side of Bogan Street.

For the PMF event, sections of the inbank area of Gunningbland Creek and its tributaries are classified as H6, while the width of the H5 hazard zone increases significantly. The hazard category in the majority of the Village Centre increases to H3 during a flood of this magnitude, with H4 type hazard conditions shown to be present between Lachlan Street and Marta Lane.

6.4.2. Hydraulic Categorisation of the Floodplain

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

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



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

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

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

Flood Risk Management Guideline FB02 Floodway Function, offers guidance in relation to two alternative procedures for identifying the portion of the floodplain that functions as floodways, flood storage and flood fringe areas.

The indicator technique set out in *Howells et al, 2003* was used to identify the preliminary extent of the floodway based on velocity of flow and depth. Based on the findings of a trial and error process, the following criteria were adopted for identifying those areas which operate as a “floodway” in a 1% AEP event:

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

Manual assessment and cleaning of the raw model output data was then undertaken as recommended in *Flood Risk Management Guideline FB02 Floodway Function*.

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

Figures 6.15 to **6.18** show the division of the floodplain into floodway, flood storage and flood fringe areas for the 5%, 1% and 0.2% AEP storm events, as well as the PMF.

As the hydraulic capacity of the watercourses is not large enough to convey the flow in a 5% AEP flood, their overbank areas also function as a floodway. Sheet 2 of **Figures 6.15**, **6.16** and **6.17** show that the floodway generally runs along the northern side of Henry Parkes Way between Tubby Lees Road and Cronin Lane where it then continues in a southerly direction to Gunningbland Creek. A floodway zone is also shown to be contained within the inbank area along the 5.5 km reach of Gunningbland Creek immediately downstream (south) of the Orange-Broken Hill Railway Line in flood events up to 0.2% AEP

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

6.5 Sensitivity Studies

6.5.1. General

The sensitivity of the hydraulic model to variations in model parameters such as hydraulic roughness and the partial blockage of the major hydraulic structures by woody debris was tested as part of the present study. 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 *Bogan Gate FRMS&P*; and

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

In addition to the abovementioned studies, the sensitivity of flood behaviour on the Gunningbland Creek floodplain to the removal of the raised sections of embankment associated with the Orange-Broken Hill Railway and Henry Parkes Way would have on flood behaviour has also been assessed.

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

Figure 6.19 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 20 to 100 mm, with increases of up to 200 mm shown to occur in the vicinity of the Tottenham Railway line crossing of the Gunningbland Creek floodplain. Increases in peak flood levels in areas subject to Major Overland Flow are generally in the range 10 to 20 mm.

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

As mentioned in **Section 6.1**, the design flood envelopes presented in this report incorporate the probability neutral blockage factors that are set out in **Table E1** in **Appendix E** of this report. As the degree to which each individual hydraulic structure experiences a blockage will varying during a real flood, the sensitivity of flood behaviour assuming no blockage of each structure was assessed as part of the present study.

Figure 6.20 shows that the removal of the probability neutral blockage factors has a negligible effect on flood behaviour at the 1% AEP level of flooding.

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

Concerns have been raised in the local community regarding the impact that the elevated embankments associated with the Orange-Broken Hill Railway and Henry Parkes Way have on flood behaviour in the vicinity of Bogan Gate. To assess the impact that the elevated embankments have on flood behaviour, the structure of the Bogan Gate TUFLOW Model was modified whereby the 9 km lengths of elevated road and rail embankment between Olive Grove Land and Overland Road were lowered to the elevation of the adjacent floodplain, while details of the drainage structures that are located beneath them were also removed from the model.

Figure 6.21 shows that while the removal of the elevated road and rail embankments would lower peak flood levels to their north by up to 1.2 m in a 1% AEP flood event, peak flood levels would be increased by up to 0.4 m to their south. The removal of the elevated embankments also leads to an increase in the extent of flooding to the south of the rail corridor.

6.6 Climate Change Sensitivity Analysis

6.6.1. General

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

DCCEEW recommends that the advice set out in Section 3.7.4 of its floodplain risk management guide *Incorporating 2016 Australian Rainfall and Runoff in studies* (OEH, 2019) be used as the basis for examining climate change in projects undertaken under the State Floodplain Management Program and the FRMM. The guideline recommends that until more work is completed in relation to the climate change impacts on rainfall intensities, sensitivity analyses should be undertaken based on increases in rainfall intensities ranging between 10 and 30 per cent.

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

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

In the *Bogan Gate 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 *Bogan Gate FRMS&P* include the implementation of structural works such as levees and channel improvements, improved flood warning and emergency management procedures and education of the population as to the nature of the flood risk.

6.6.2. Sensitivity to Increased Rainfall Intensities

As mentioned, the investigations undertaken at the flood study stage are mainly seen as sensitivity studies pending more detailed consideration in the *Bogan Gate 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 6.22 shows the increase in peak flood levels resulting from a 10 per cent increase in 1% AEP rainfall intensities. The increase in peak flood levels along Gunningbland Creek and its tributaries varies between 50 and 200 mm, while increases in peak flood levels of generally between 10 to 50 mm are shown to occur in areas subject to Major Overland Flow.

Figure 6.23 shows the afflux for a 30 per cent increase in 1% AEP rainfall intensities. The increase in peak flood levels along Gunningbland Creek and its tributaries varies between 100 and 300 mm, while increases in peak flood levels of generally up to 100 mm are shown to occur in areas subject to Major Overland Flow.

Figure 6.24 shows the increase in the extent of land that would be affected by floodwater should 1% AEP rainfall intensities increase by 10 or 30 per cent. The extent of land that would be inundated by floodwater should 1% AEP rainfall intensities increase by up to 30% is negligible on the northern side of the Orange-Broken Hill Railway due to the relatively steep sided nature of the floodplain in this area, while the extent of land that would be inundated increases on the southern side of the rail corridor due to its relatively flat nature.

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

6.7 Selection of Interim Flood Planning Levels

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

- in areas subject to Main Stream Flooding, the extent of the FPA was defined as land lying at or below the peak 1% AEP flood level plus a freeboard allowance of 0.5 m; and
- in areas subject to Major Overland Flow and that also lie outside the extent of the Main Stream Flooding FPA, the extent of the FPA was defined as land inundated to a depth greater than 100 mm or within the extent of the floodway.[4]

Figure 6.25 shows the extent of the Interim FPA in the vicinity of the Village Centre. In areas that lie within the extent of the Interim FPA it is recommended that a freeboard of 0.5 m be applied to peak 1% AEP flood levels when setting the minimum habitable floor levels of future development. An assessment should also be undertaken by Council as part of any future Development Application to confirm that the proposed development will not form an obstruction to the passage of flow through the subject site.

Consideration will need to be given during the preparation of the future *Bogan Gate 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 6.25 also shows the extent of the *Outer Floodplain*, which is the area that 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.

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

7 REFERENCES

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8 FLOOD-RELATED TERMINOLOGY

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

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

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

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

APPENDIX A

COMMUNITY NEWSLETTER AND QUESTIONNAIRE

Bogan Gate Flood Study

Community Newsletter

Parkes Shire Council has engaged consultants to undertake a *Flood Study* for the township of Bogan Gate which will define mainstream flooding patterns along Gunningbland Creek. The study will also define areas that are subject to major overland flow that 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 area at each village.

The study is being undertaken by Council with funding assistance from the Department of Planning and Environment and aims to build community resilience towards flooding through informing better planning of development, emergency management and community awareness. The study will also assess a range of structural type measures such as culvert and channel improvements which are aimed at reducing the impact of flooding on existing development. 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 Bogan Gate and will be managed by Council according to the NSW Government's Flood Prone Land Policy and Floodplain Development Manual. Following the completion of the *Flood Study*, a *Floodplain Risk Management Study* and *Plan* will also be completed which will include further consultation on management options.

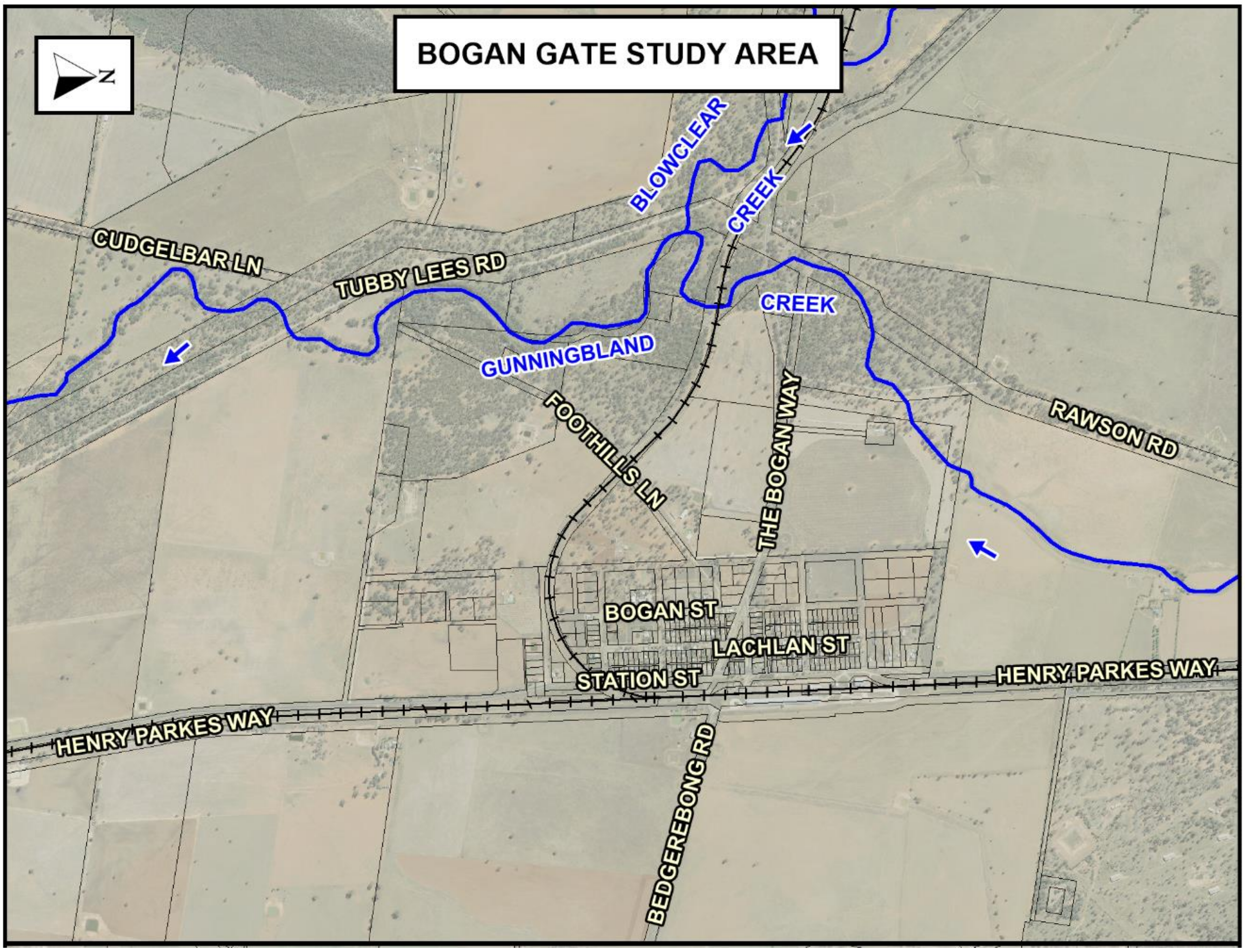
The various stages of the *Flood Study* will be as follows:

- Survey along the creeks and collection of data on historic flooding;
- Preparation of computer models of the creeks and floodplain to determine flooding and drainage patterns, flood levels, flow velocities and depths of inundation;
- Preparation of a *Flood Study* report which will document the findings of the investigation. The draft *Flood Study* report will be placed on public exhibition following completion of the investigation seeking community feedback on its findings

An important first step in the preparation of a *Flood Study* is to identify the availability of information on historic flooding in the township and up and downstream catchment. The attached **questionnaire** has been provided to residents and business owners to assist the consultants in gathering this important information. The questionnaire may also be completed online via Council's website at www.parkes.nsw.gov.au, accessible by scanning the QR code over the page. 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 **3 June 2022.** Council staff will be available at the Bogan Gate Hall on the **1 June** from **10.30 to 4.30** to assist with the completion of the survey, answer questions and scan copies of photos, documents, maps or any other information that may assist.

Bogan Gate Flood Study

Contact: Parkes Shire Council's Director of Infrastructure Andrew Francis, (02) 6861 2344 council@parkes.nsw.gov.au



Scan the QR code below to access the attached survey via an online form

Bogan Gate Flood Study

Community Questionnaire

This questionnaire is for the ***Bogan Gate Flood Study*** which is currently being prepared by Parkes Shire Council with the financial support of the Department of Planning and Environment. Your responses to the questionnaire will help us determine the flood issues that are important to you. Please note that all information provided will remain confidential and for use in this study only.

Please return your completed questionnaire in the reply-paid envelope provided by **3 June 2022**. 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

An electronic copy of the questionnaire can be completed online at www.parkes.nsw.gov.au.

1. What township do you live in?

____

2. Your details:

a. Name (Optional):____

b. Address:____

c. Phone Number (Optional):____

d. Email (Optional): ____

3. Please tick as appropriate:

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

4. How long have you been at this address?

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

5. What is your property?

- ☐ House
- ☐ Unit/Flat/Apartment
- ☐ Warehouse / Factory / Industrial Unit
- ☐ Shop / Building
- ☐ Community building
- ☐ Other

(______________________________________)

Flooding at Your Property

6. Have you ever been affected by flooding?

[ ] Yes [ ] No

7. If you answered "Yes" to Question 6, on what dates were you affected by flooding?

- ☐ November 2005
- ☐ December 2010
- ☐ December 2012
- ☐ February 2016
- ☐ January 2020
- ☐ January 2021
- ☐ Other: ________________

8. Can you please describe the flooding (flood water depth/height and location etc.) that you experienced? (Please use area provided in Question 14 if you have information for more than two floods)

	Flood #1	Flood #2
Date of flood(s)	☐ November 2005 ☐ December 2010 ☐ December 2012 ☐ February 2016 ☐ January 2020 ☐ January 2021 ☐ Other: ______________	☐ November 2005 ☐ December 2010 ☐ December 2012 ☐ February 2016 ☐ January 2020 ☐ January 2021 ☐ Other: ______________
Description of flooding (flood water depth/height and location etc.) (The attached map may be useful to mark the location of any problem areas).		

Bogan Gate Flood Study

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

   [ ] Yes [ ] No

10. **If you answered yes to Question 9, 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?**

    ____

    ____

    ____

    ____

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

    [ ] Yes [ ] No

12. **If you answered yes to Question 11, 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 page).

    ____

    ____

    ____

    ____

13. **If you are happy for us to contact you to provide further information, please provide your details below:**

    Name: ____________________

    Address: ____________________

    ____

    Phone: ____________________

    Email: ____________________

Who can I contact for further information?

Parkes Shire Council
Andrew Francis | Director of Infrastructure
Phone: (02) 6861 2344
Email: council@parkes.nsw.gov.au

14. Please write any additional comments here:

APPENDIX B
DETAILS OF AVAILABLE DATA
AND COMMUNITY CONSULTATION

TABLE OF CONTENTS

Page No.

ANNEXURES

LIST OF FIGURES (BOUND IN VOLUME 2)

B1 COLLECTION OF MISCELLANEOUS DATA

B1.1 Airborne Laser Scanning Survey

Figure B1.1 (2 sheets) shows the extent of LiDAR survey data that are available in the vicinity of Bogan Gate, while **Table B1.1** sets out the details of the available LiDAR survey data. 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 ±100 mm.

TABLE B1.1
LiDAR SURVEY DATA SPECIFICATIONS

Data Set	Date of Capture	Data Provider
BoganGate202203	15 March 2022	Aerometrex

B1.2 Existing Stormwater Network

Figure B1.1 shows the alignment of the existing stormwater drainage network in the study area. Details of the existing stormwater drainage network were taken from survey data captured by Ardnell Surveying in 2023 and ARTC, 2017 (refer **Section B1.5.1** for more details), else assumed based on a desktop analysis and verified during subsequent field measurements where possible.

B1.3 Historic Rainfall Data

Figure 1.1 shows the plan location of the two pluviographic and 11 daily-read Bureau of Meteorology operated rain gauges that are located in the vicinity of Bogan Gate, while **Table B1.2** over the page sets out the details of each. **Figure 1.1** and **Table B1.2** also show details of two privately operated rain gauges that are located in the vicinity of the Village Centre.

B1.4 Photographic Record

Appendix C contains a number of photographs that were provided by Council and respondents to the *Community Questionnaire* showing flood behaviour in the study area during storms that occurred in November 2005, December 2010, March 2012, June 2016, September 2016, May 2022 and November 2022.

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

Gauge Number	Gauge Name	Gauge Type	Site Commence	Site Cease	Distance from Bogan Gate
65068	Parkes Airport AWS	BoM All Weather Station	October 2010	Ongoing	41 km
65103	Forbes Airport AWS		January 2012	Ongoing	31 km
50016	Goonumbla (Coradgery)	Bom Flood Warning Network	Gauge data only recorded when BoM's flood warning system is activated		29 km
-	Collaroy	Private Rain Gauge	February 1992	Ongoing	5 km
-	Myalls		1995, 2012, 2022		4 km
65068	Parkes Airport AWS	BoM Daily Rain Gauge	September 1941	Ongoing	41 km
65114	Forbes (Bedgerabong Rd)		January 2012	Ongoing	32 km
65103	Forbes Airport AWS		December 1995	Ongoing	31 km
65039	Forbes (Muddy Water)		January 1969	Ongoing	25 km
50016	Goonumbla (Coradgery)		March 1882	Ongoing	29 km
50036	Trundle (Long St)		March 1895	Ongoing	22 km
50004	Bogan Gate Post Office		January 1894	August 2017	0 km
50141	Ootha (Mayfield)		November 2004	Ongoing	34 km
50020	Warroo (Geeron)		June 1889	Ongoing	32 km

1. Refer **Figure 1.1** for location

B1.5 Previous Reports

B1.5.1. ARTC – Gunningbland Creek – Flood Assessment and Upgrade Review (KBR, 2017)

The *ARTC –Gunningbland Creek – Flood Assessment and Upgrade Review* was undertaken by KBR in 2017 in response to ongoing concerns that the community has regarding the impact that the railway has on flooding in properties that are located on its northern side. The aim of the study was to develop a 2D hydraulic model to define flood behaviour under present day conditions and then assess the impact that an additional 500 m of additional culverts on either side of the existing rail bridge would have on flood behaviour.

A hydrologic model of the Gunningbland Creek catchment was developed using the XP-RAFTS software (**KBR RAFTS Model**). Initial loss values of between 0 and 15 mm and continuing loss value of 0.8 mm/hr were found to achieve a good match between the hydrologic model and design peak flow estimates derived using the Regional Flood Frequency Estimation (**RFFE**) model, procedures for which are set out in ARR, 2019.

Rainfall data recorded at Parkes during a storm event that occurred in early December 2010 were input to the KBR RAFTS Model. The model derived peak flow in Gunningbland Creek at the railway was 1,000 m^3/s which was found to be equivalent to a 1% AEP design storm event.

A hydraulic (TUFLOW) model was developed of the 22 km reach of Gunningbland Creek between the eastern extent of the Bogan Gate Village Centre and Taylor Lane (**KBR TUFLOW Model**). As there were no LiDAR survey data available at the time of the study, the underlying topography was defined using regional Shuttle Radar Topography Mission (**SRTM**) survey data. KBR, 2017 found that the SRTM survey data was up to 6.5 m higher than the surveyed elevations along to crest of the railway embankment.

Details of 43 culverts under Henry Parkes Way and the Orange – Broken Hill Railway were input to the KBR TUFLOW Model based on survey data that were captured as part of the study (refer **Figure B1.1** for location), with the invert of the culverts adjusted to line up with the adjacent SRTM survey data. Details of these culverts were incorporated into the KBR TUFLOW Model.

Discharge hydrographs derived from the KBR XP-RAFTS for the December 2010 storm were input to the KBR TUFLOW Model and used to assess the impact that an upgraded set of culverts would have on flood behaviour.

The key findings of KBR, 2017 were:

a) the flow potential through the existing rail bridge appears to be significantly restricted due to downstream tailwater levels and not by the available flow area through the bridges;

b) an area of elevated channel invert has been identified downstream of the bridge from the SRTM survey data and additional survey is required to confirm the lack of channel and potential sediment accumulation in this area;

c) the effective flow area downstream of the bridge appears to be constricted between two elevated ground areas that are located on the rail and south of the rail embankment; and

d) the flow area downstream of the bridge also appears to be constrained by an excavated dam that may have an embankment on the southern extent (to be confirmed).

Based on the above, KBR, 2017 states that they "*do not expect that additional flow area (i.e. culverts) provided to the rail embankment about the bridge to be effective as the same constriction and tailwater levels would continue to impact the flow conveyance for the additional culverts with limited benefit to flood behaviour upstream expected*".

B2 COMMUNITY CONSULTATION

B2.1 Background

At the commencement of the study, the Consultants prepared a *Community Newsletter and Questionnaire* 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 plan showing the extent of the study area and a summary of the proposed methodology and outcomes.

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

The *Community Newsletter and Questionnaire* were advertised in the local newspaper and posted to approximately 180 residents and business owners in the study area in May 2022. The *Community Newsletter and Questionnaire* were also advertised on Council's website and social media platforms. Council also undertook in-person consultation with the community on 31 May 2022 where they captured hardcopy information which was then forwarded onto the Consultants.

As the *Community Questionnaire* mail out period occurred prior to a significant storm event that occurred in November 2022, the Consultants also undertook further in-person consultation with community members on 7 December 2023.

B2.2 Summary of Findings

B2.2.1. General

Residents and business owners were requested to complete the *Community Questionnaire* by 3 June 2022. The deadline was extended to include any submissions that were received after this date. The Consultants received 13 responses in total, which amounted to about seven per cent of the total number of questionnaires that were distributed to the community.

The collated responses to the *Community Questionnaire* are shown in graphical format in **Annexure B1** of this Appendix.

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 and the type of property (e.g. residential, commercial, farm land etc.).

Of the 13 responses, 11 respondents occupied were residents (**Question 3**), three were business owners, and one was the owner of vacant land in the vicinity of Bogan Gate, noting that two of the respondents indicated that they are both a resident and a business owner.
The length of time that respondents had been at their current address was found to be varied, with three respondents having lived at the residence for between '0-5 years', three for '5-20 years', and seven for 'more than 20 years' (**Question 4**).

In response to **Question 5**, six of the respondents indicated that their property was a house. Of the nine that responded "Other" to Question 5, four owned farms and five indicated that they owned vacant land/grazing property.

B2.2.3. Experiences of Flooding

In **Question 6**, of the 13 respondents, eight advised that they had previously been affected by flooding. In response to **Question 7**, the majority of respondents to the *Community Questionnaire* indicated that they been affected by multiple flooding events, including those that occurred in:

- November 2005 (six respondents),
- December 2010 (five)
- March 2012 (two)
- December 2012 (four)
- February 2016 (five)
- April 2020 (three)
- January 2021 (five)
- November 2021 (two)
- May 2022 (six)

Questions 8 to **12** of the *Community Questionnaire* asked the respondents to describe how they were effected by flooding. A summary of the responses are as follows:

a) the table drains in the vicinity of Bogan Street in the Village Centre do not drain properly and are consistently filled with stagnant water.

b) the Henry Parkes Way and Orange Broken Hill Railway crossing of Gunningbland Creek that is located approximately 5 km to the west of the Village Centre regularly fill with sediment, which increases the frequency and magnitude of flooding in properties that are located on the northern side of the railway.

c) Tubby Lees Road is inundated whenever there is rain in the catchment which results in the isolation of the properties in Cungelbar Lane: and

d) a 10 km length of Henry Parkes Way is inundated for long periods of time during significant flooding events.

Additional documents were also provided by community members at the in-person consultation that was undertaken by Council in May 2022. A number of the documents contain correspondence between the Gunningbland Creek Flood Improvement Committee (formerly Carlachy Flood Improvement Committee) and various government agencies dating back to July 1958 regarding the impact that the Henry Parkes Way and Orange to Broken Hill Railway embankments have on flood behaviour.

The Gunningbland Creek Flood Improvement Committee states that the railway was raised in the 1950s which has resulted in floodwater ponding on the northern side of the railway and inundating rural land that had previously never been inundated. The Gunningbland Creek Improvement Committee have been lobbying to have the rail operators Australian Rail and Track Corporation (**ARTC**) investigate and mitigate the negative impacts that the raising of the rail line has had on flood behaviour.

It is understood that ARTC commission GHD to undertake a flood study 2007. While the GHD report was not available for review as part of the present investigation, it is understood that it recommended the installation of three sets of box culverts, the exact location of which are unknown, to alleviate the upstream flooding. It is also understood that following the completion of the 2007 study, ARTC installed two sets of box culverts and then raised the railway embankment by an additional 150 mm in 2011.

Following flood events that occurred in March 2012 and September 2016, ARTC then commissioned KBR to undertake another flooding investigation of Gunningbland Creek (refer **Section B1.5.1** of this Appendix for a summary of the findings.

The abovementioned documents refer to historic flood events that occurred on the following dates:

- January 1992;
- March 2012; and
- September 2016.

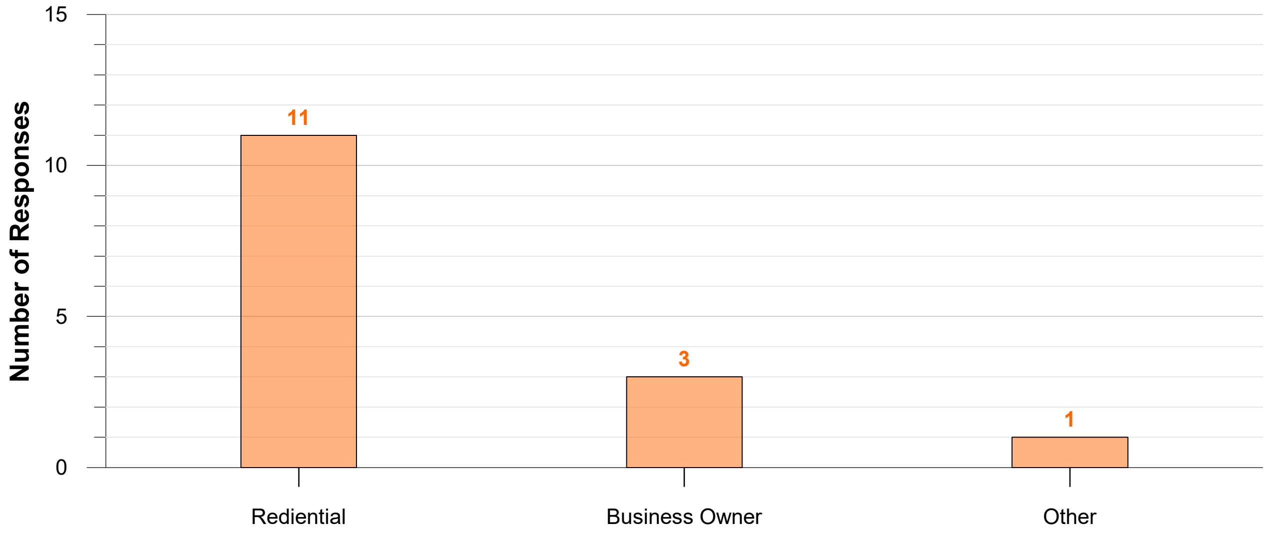
Community members provided anecdotal and photographic evidence on flood behaviour from a flood event that occurred on 14 November 2022 during the in-person consultation that was undertaken by the Consultants on 6 December 2023. The observed flood behaviour has been relied upon to validate the hydrologic and hydraulic models that have been developed as part of the present study.

Appendix C of this report contains several photographs that were provided by respondents to the *Community Questionnaire* showing flood behaviour in the study area during storms that occurred in November 2005, December 2010, March 2012, June 2016, September 2016, May 2022 and November 2022.

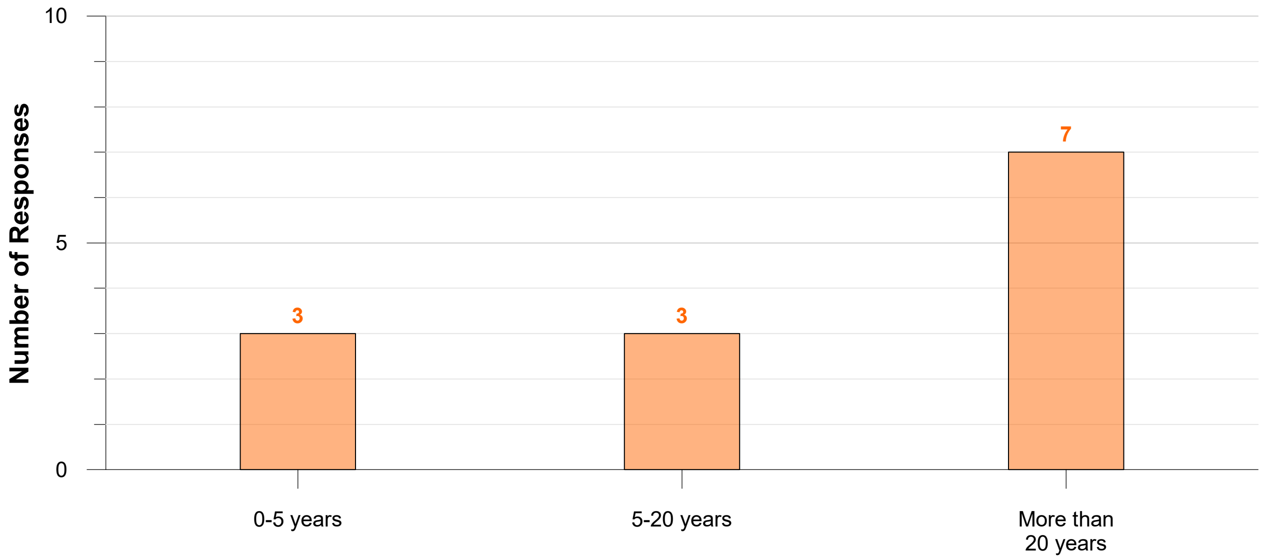
ANNEXURE B1

RESPONSES TO COMMUNITY QUESTIONNAIRE

Q3. Respondent status

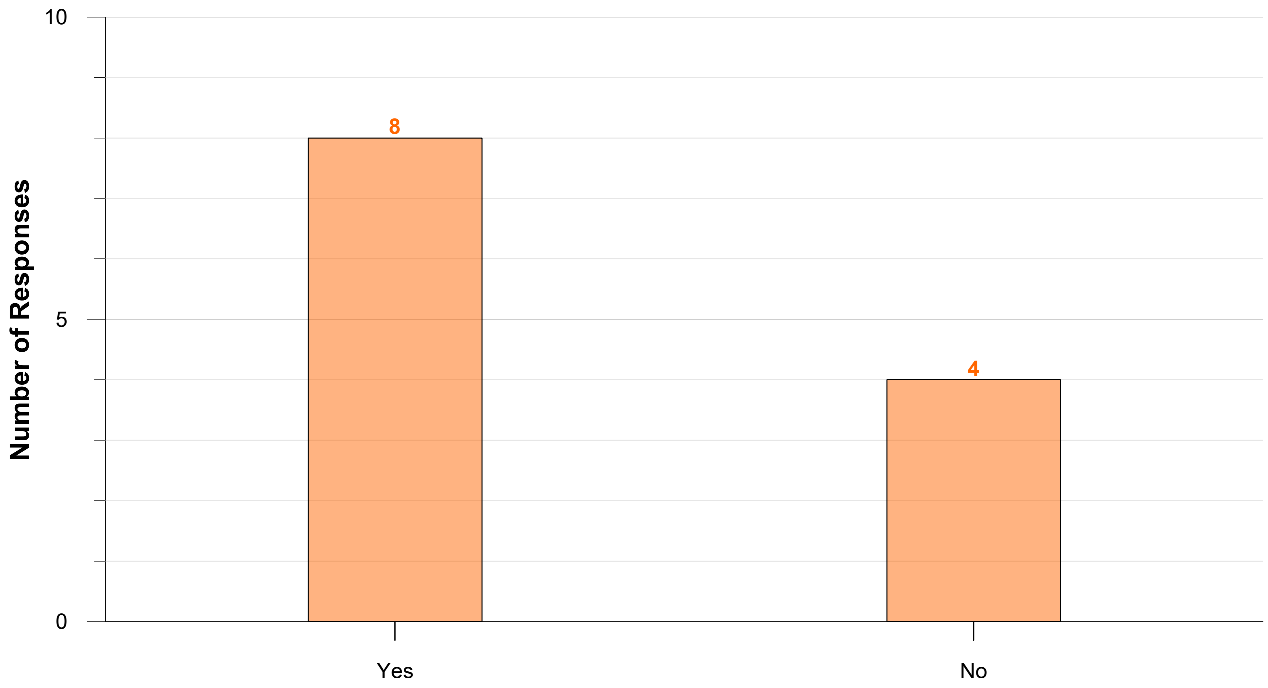


Q4. How long have you lived at this address?

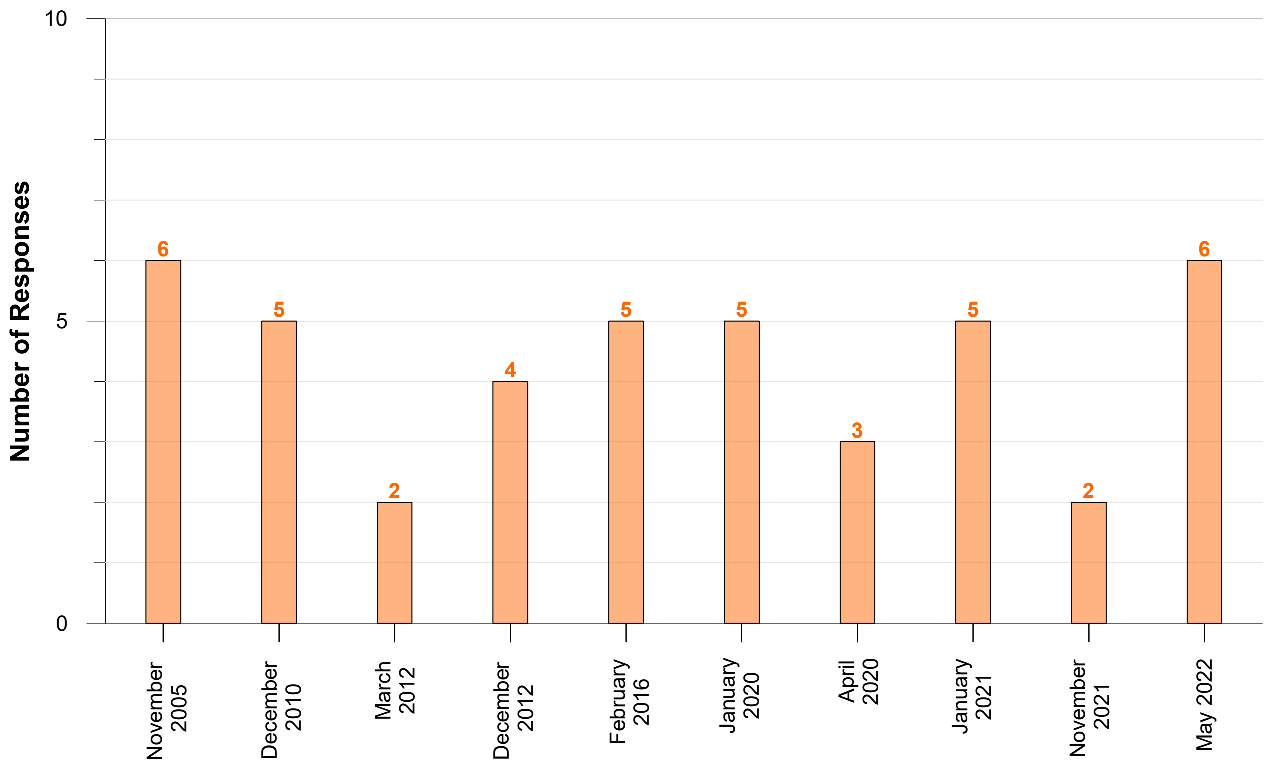


Q5. Property type

Q6. Have you ever been affected by flooding?



Q7. On what dates were you affected by flooding?



APPENDIX C
PHOTOGRAPHS SHOWING OBSERVED FLOOD BEHAVIOUR AT BOGAN GATE

NOVEMBER 2005

Plate C1.1 – Looking north across flooded rural properties on the northern side of Henry Parkes Way.

Plate C1.2 – Looking north across flooded rural properties on the northern side of Henry Parkes Way.

Plate C1.3 – Looking north across flooded rural properties on the northern side of Henry Parkes Way.

Plate C1.4 – Flooding in the vicinity of the Myalls Homestead.

Plate C1.5 – Flooding in the vicinity of the Myalls Homestead.

Plate C1.6 – Flooding in the vicinity of the Myalls Homestead.

NOVEMBER 2005

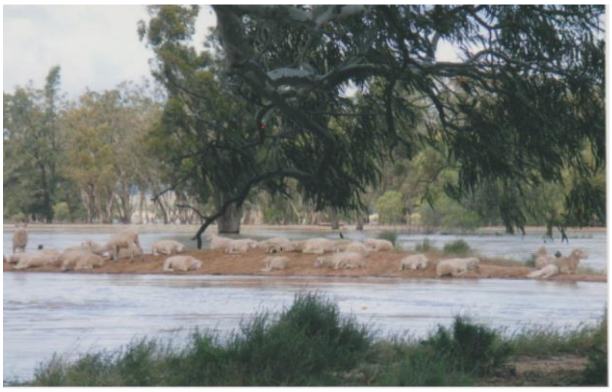


Plate C1.7 – Flooding in the vicinity of the Myalls Homestead.

Plate C1.8 – Flooding in the vicinity of the Myalls Homestead).

Plate C1.9 – Flooding in the vicinity of the Myalls Homestead.

Plate C1.10 – Looking north from Henry Parkes Road towards the Bogan Gate Golf Club.

Plate C1.11 – Looking west along Henry Parkes Way.

Plate C1.12 – Looking west along Henry Parkes Way.

NOVEMBER 2005

Plate C1.13 – Looking west along Henry Parkes Way.

Plate C1.14 – Flooding in the vicinity of the intersection of Tubby Lees Road and Henry Parkes Way.

DECEMBER 2010

Plate C2.1 – Flooding in the vicinity of the Bogan Gate Golf Club clubhouse.

Plate C2.2 – Flooding in the vicinity of the Bogan Gate Golf Club.

Plate C2.3 – Flooding in the vicinity of the Bogan Gate Golf Club.

Plate C2.4 – Flooding in the vicinity of the Bogan Gate Golf Club.

Plate C2.5 – Flooding in the vicinity of the Bogan Gate Golf Club.

Plate C2.6 – Flooding in the vicinity of the Bogan Gate Golf Club.

DECEMBER 2010	
	
Plate C2.7 – Flooding in the vicinity of the Bogan Gate Golf Club.	**Plate C2.8** – Flooding in the vicinity of the Bogan Gate Golf Club.

MARCH 2012

Plate C3.1 – Flooding in the vicinity of the Neirawang homestead.

Plate C3.2 – Flooding in the vicinity of the Neirawang homestead.

Plate C3.3 – Flooding in the vicinity of the Neirawang homestead.

Plate C3.4 – Flooding in the vicinity of the Neirawang homestead.

JUNE 2016	
	
Plate C4.1 – Flooding in the vicinity of the 8th fairway of the Bogan Gate Golf Club.	**Plate C4.2** – Flooding in the vicinity of the old bridge adjacent to the 4th fairway of the Bogan Gate Golf Club.
	
Plate C4.3 – Flooding in the vicinity of the 8th fairway of the Bogan Gate Golf Club.	**Plate C4.4** – Flooding in the vicinity of the 8th fairway of the Bogan Gate Golf Club.
	
Plate C4.5 – Flooding in the vicinity of the 6th fairway of the Bogan Gate Golf Club.	**Plate C4.6** – Flooding in the vicinity of the 6th fairway of the Bogan Gate Golf Club.

SEPTEMBER 2016

Plate C5.1 – Flooding in the vicinity of the 6th fairway of the Bogan Gate Golf Club.

MAY 2022

Plate C6.1 – Flooding in the vicinity of the Neirawang homestead.

Plate C6.2 – Flooding in the vicinity of the Neirawang homestead.

Plate C6.3 – Flooding in the vicinity of the Neirawang homestead.

Plate C6.4 – Flooding in the vicinity of the Neirawang homestead.

Plate C6.5 – Flooding in the vicinity of Cudgelbar Lane.

Plate C6.6 – Flooding in the vicinity of Cudgelbar Lane.

MAY 2022

Plate C6.7 – Floodwater inundating the Tubby Lees Road causeway crossing of Gunningbland Creek.

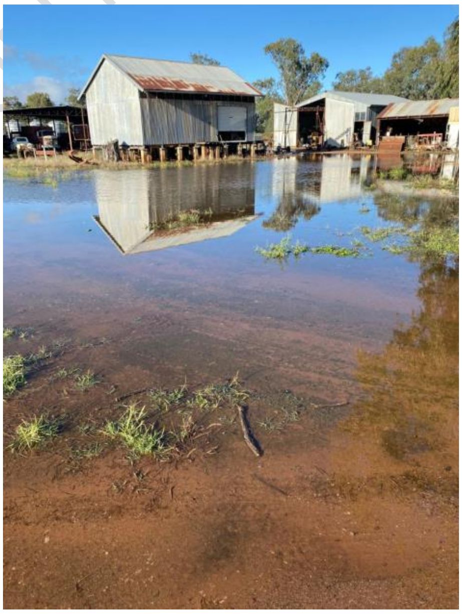
Plate C6.8 – Floodwater inundating the Tubby Lees Road causeway crossing of Gunningbland Creek.

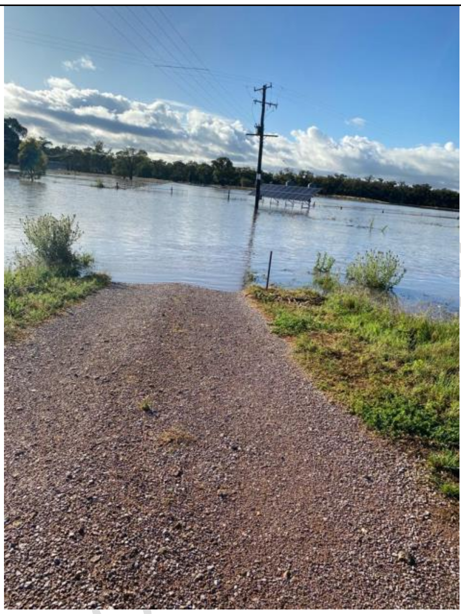
Plate C6.9 – Flooding in the vicinity of Foothills Lane.

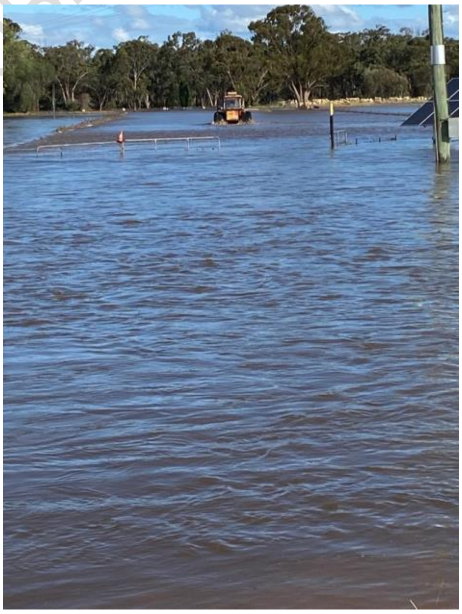
Plate C6.10 – Flooding in the vicinity of Foothills Lane.

Plate C6.11 – Flooding in Foothills Lane.

Plate C6.12 – Flooding in Foothills Lane.

NOVEMBER 2022	
	
Plate C7.1 – The Bogan Way in the vicinity of the Kadina homestead 1	**Plate C7.2** – The Bogan Way in the vicinity of the Kadina homestead 1
	
Plate C7.3 – The Bogan Way in the vicinity of the Kadina homestead 1	**Plate C7.4** – Flooding in the vicinity of the Myalls homestead.

<table>
<tr><th colspan="2">NOVEMBER 2022</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Plate C7.5 – Flooding in the vicinity of the Myalls homestead.</td><td>Plate C7.6 – Flooding in the vicinity of the Myalls homestead.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Plate C7.7 – Flooding in the vicinity of the Myalls homestead.</td><td>Plate C7.8 – Flooding in the vicinity of the Myalls homestead.</td></tr>
</table>

NOVEMBER 2022	
	
Plate C7.9 – Flooding in the vicinity of the Myalls homestead.	**Plate C7.10** – Flooding in the vicinity of the Myalls homestead.
	
Plate C7.11 – Flooding in the vicinity of the Myalls homestead.	**Plate C7.12** – Flooding in the vicinity of the Myalls homestead.

NOVEMBER 2022

Plate C7.13 – Flooding in the vicinity of the Myalls homestead.

Plate C7.14 – Flooding in the vicinity of the Myalls homestead.

Plate C7.15 – Flooding in the vicinity of the Myalls homestead.

Plate C7.16 – Flooding in the vicinity of the Myalls homestead.

Plate C7.17 – Flooding in the vicinity of the Myalls homestead.

Plate C7.18 – Flooding in the vicinity of the Myalls homestead.

NOVEMBER 2022

Plate C7.18 – Floodwater breaching the railway line immediately to the east of Overland Road.

Plate C7.19 – Collapsed section of railway immediately to the east of Overland Road.

Plate C7.20 – Collapsed section of railway immediately to the east of Overland Road.

Plate C7.21 – Collapsed section of railway immediately to the east of Overland Road.4

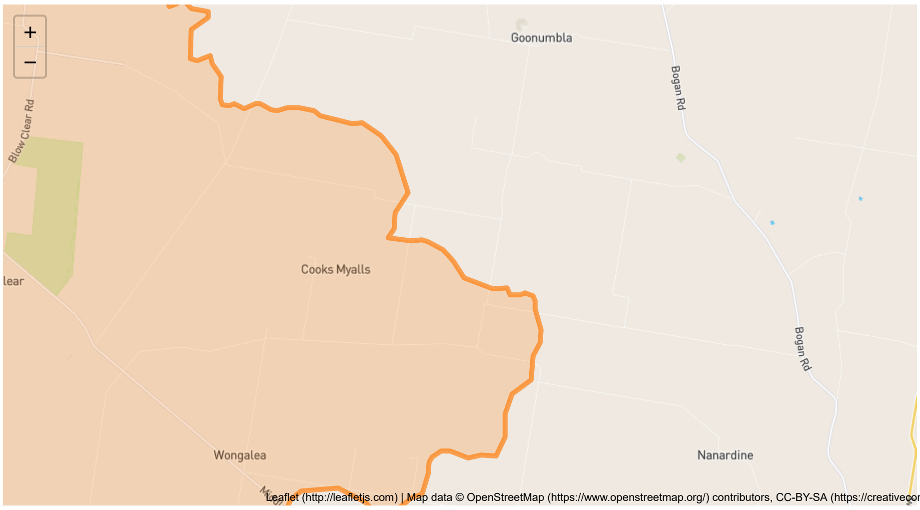
APPENDIX D

DESIGN INPUT DATA FROM ARR DATA HUB

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	147.835
Latitude	-33.038
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 (%)	99.6

Layer Info

Time Accessed	01 August 2022 12:53PM
Version	2016_v1

ARF Parameters

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

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

Short Duration ARF

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

Layer Info

Time Accessed	01 August 2022 12:53PM
Version	2016_v1

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)	25.0
Storm Continuing Losses (mm/h)	0.7

Layer Info

Time Accessed	01 August 2022 12:53PM
Version	2016_v1

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

code	MB
Label	Murray Basin
Shape Intersection (%)	98.5

Layer Info

Time Accessed	01 August 2022 12:53PM
Version	2016_v2

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

code	MB
arealabel	Murray Basin
Shape Intersection (%)	98.5

Layer Info

Time Accessed	01 August 2022 12:53PM
Version	2016_v2

BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-33.0378526143&longitude=147.835193884&sdmin=true&sdhr=true&sdday=true&user_label=) to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	01 August 2022 12:53PM

Median Preburst Depths and Ratios

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

min (h)\AEP(%)	**50**	**20**	**10**	**5**	**2**	**1**
60 (1.0)	1.2 (0.058)	0.9 (0.030)	0.7 (0.019)	0.5 (0.012)	0.5 (0.011)	0.6 (0.010)
90 (1.5)	2.2 (0.092)	1.6 (0.047)	1.2 (0.030)	0.8 (0.017)	0.5 (0.009)	0.2 (0.004)
120 (2.0)	1.9 (0.072)	1.5 (0.041)	1.3 (0.029)	1.1 (0.020)	1.0 (0.015)	0.9 (0.013)
180 (3.0)	1.5 (0.049)	1.3 (0.030)	1.1 (0.022)	1.0 (0.017)	1.0 (0.014)	1.0 (0.012)
360 (6.0)	0.8 (0.021)	1.0 (0.019)	1.1 (0.018)	1.2 (0.017)	5.4 (0.063)	8.5 (0.089)
720 (12.0)	0.1 (0.002)	2.2 (0.035)	3.6 (0.047)	4.9 (0.056)	8.1 (0.079)	10.5 (0.091)
1080 (18.0)	0.0 (0.000)	0.9 (0.013)	1.5 (0.018)	2.1 (0.021)	4.7 (0.041)	6.7 (0.052)
1440 (24.0)	0.0 (0.000)	0.0 (0.001)	0.1 (0.001)	0.1 (0.001)	1.4 (0.011)	2.4 (0.017)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.6 (0.004)	1.0 (0.007)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	01 August 2022 12:53PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

10% Preburst Depths

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

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

Layer Info

Time Accessed	01 August 2022 12:53PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

25% Preburst Depths

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

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

Layer Info

Time Accessed	01 August 2022 12:53PM
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)	11.5 (0.550)	8.6 (0.290)	6.7 (0.186)	4.9 (0.115)	8.6 (0.167)	11.3 (0.194)
90 (1.5)	18.4 (0.772)	15.8 (0.466)	14.0 (0.343)	12.4 (0.257)	15.8 (0.272)	18.3 (0.279)
120 (2.0)	15.4 (0.592)	15.0 (0.405)	14.7 (0.329)	14.4 (0.275)	17.7 (0.282)	20.2 (0.285)
180 (3.0)	12.9 (0.435)	15.3 (0.366)	16.9 (0.336)	18.4 (0.313)	21.4 (0.305)	23.7 (0.298)
360 (6.0)	10.0 (0.271)	12.3 (0.239)	13.8 (0.225)	15.3 (0.214)	34.6 (0.408)	49.1 (0.516)
720 (12.0)	7.4 (0.163)	13.7 (0.218)	17.9 (0.239)	21.9 (0.253)	35.8 (0.349)	46.2 (0.402)
1080 (18.0)	6.1 (0.119)	10.9 (0.154)	14.2 (0.168)	17.2 (0.177)	24.0 (0.209)	29.0 (0.226)
1440 (24.0)	0.3 (0.006)	3.2 (0.041)	5.0 (0.055)	6.8 (0.065)	13.1 (0.105)	17.8 (0.128)
2160 (36.0)	0.0 (0.000)	1.9 (0.023)	3.2 (0.032)	4.5 (0.038)	8.5 (0.062)	11.6 (0.075)
2880 (48.0)	0.0 (0.000)	1.1 (0.012)	1.8 (0.017)	2.5 (0.020)	5.7 (0.039)	8.1 (0.049)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.5 (0.003)	0.9 (0.005)

Layer Info

Time Accessed	01 August 2022 12:53PM
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)	27.1 (1.295)	21.7 (0.728)	18.1 (0.502)	14.7 (0.346)	29.4 (0.574)	40.4 (0.696)
90 (1.5)	38.1 (1.600)	41.9 (1.238)	44.4 (1.085)	46.8 (0.974)	54.4 (0.940)	60.0 (0.916)
120 (2.0)	32.3 (1.240)	37.5 (1.014)	40.9 (0.916)	44.2 (0.844)	56.7 (0.903)	66.1 (0.931)
180 (3.0)	31.4 (1.059)	38.7 (0.928)	43.6 (0.868)	48.3 (0.822)	57.5 (0.818)	64.4 (0.812)
360 (6.0)	17.3 (0.471)	32.5 (0.633)	42.6 (0.693)	52.3 (0.732)	91.3 (1.077)	120.6 (1.266)
720 (12.0)	20.8 (0.455)	36.0 (0.571)	46.2 (0.615)	55.9 (0.644)	75.3 (0.733)	89.9 (0.782)
1080 (18.0)	21.9 (0.427)	28.5 (0.401)	32.8 (0.389)	36.9 (0.380)	53.3 (0.464)	65.6 (0.510)
1440 (24.0)	6.5 (0.117)	13.9 (0.182)	18.9 (0.208)	23.6 (0.225)	41.0 (0.331)	54.1 (0.389)
2160 (36.0)	5.6 (0.091)	11.3 (0.134)	15.1 (0.150)	18.7 (0.161)	28.6 (0.207)	36.0 (0.233)
2880 (48.0)	2.8 (0.043)	9.0 (0.100)	13.1 (0.122)	17.1 (0.137)	21.7 (0.146)	25.1 (0.151)
4320 (72.0)	1.1 (0.016)	6.9 (0.071)	10.7 (0.092)	14.3 (0.106)	16.4 (0.102)	18.0 (0.099)

Layer Info

Time Accessed	01 August 2022 12:53PM
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	01 August 2022 12:53PM
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)	16.2	11.5	11.7	12.9	11.6	8.2
90 (1.5)	14.5	10.3	9.9	10.5	9.6	7.0
120 (2.0)	15.2	11.0	10.5	10.8	9.5	6.5
180 (3.0)	15.7	11.6	10.9	10.7	9.8	6.3
360 (6.0)	17.8	13.5	12.3	11.5	8.7	4.0
720 (12.0)	18.3	13.5	12.3	11.0	9.3	3.9
1080 (18.0)	18.8	14.9	14.3	13.3	12.0	6.0
1440 (24.0)	22.7	18.5	17.9	17.6	14.5	7.7
2160 (36.0)	23.2	19.4	18.9	20.0	16.9	10.0
2880 (48.0)	23.9	20.2	19.9	21.5	18.6	11.9
4320 (72.0)	24.5	21.1	21.0	23.1	20.5	15.6

Layer Info

Time Accessed	01 August 2022 12:53PM
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/2bd5d06d-df6e-4da6-8329-9f9cc9fee3bb.txt) Download JSON (downloads/5f9036c6-7f4c-4a47-b9c2-96079c48c6ab.json)
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APPENDIX E

ARR 2019 DESIGN BLOCKAGE ASSESSMENT AT DRAINAGE STRUCTURES

TABLE E1
ARR, 2019 DESIGN BLOCKAGE ASSESSMENT AT HYDRAULIC DRAINAGE STRUCTURES

ID[1]	Structure Details				Floating Debris												Non-Floating Debris									Adopted Design Blockage B_{DES}%		
	Structure Type[2]	Width	Height (m)	No. of Barrels	L_{10}[3]	Debris Availability	Debris Mobility	Debris Transportability	Debris Potential	Debris Potential at Structure	Adjusted Debris Potential			Most Likely Design Inlet Blockage (B_{DES}%)			Approx. Flow Velocity (m/s)	Likelihood of Deposition	Debris Potential at Structure	Adjusted Debris Potential			Most Likely Design Barrel Blockage (B_{DES}%)					
											> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP				> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP
pBG_1	R Culvert	0.9	0.3	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.7	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_2	C Culvert	0.75	0	9	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.3	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_3	R Culvert	1.2	0.4	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_4	C Culvert	0.45	0	7	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.4	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_5	C Culvert	1.1	0	20	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.2	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_6	C Culvert	0.9	0	10	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.9	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_7	R Culvert	3	1.6	22	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	0.9	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_8	C Culvert	0.95	0	16	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	2	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_10	C Culvert	0.75	0	5	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_11	C Culvert	0.75	0	7	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.7	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_12	C Culvert	0.6	0	5	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.9	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_13	C Culvert	0.8	0	6	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	2.1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_14	R Culvert	1.5	0.3	1	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.4	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_15	R Culvert	1.8	0.6	2	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.2	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_16	R Culvert	0.75	0.3	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_17	R Culvert	0.4	0.3	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.4	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_18	C Culvert	0.45	0	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.9	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_19	C Culvert	0.6	0	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_20	R Culvert	1.2	0.3	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	3.3	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_21	R Culvert	0.4	0.3	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.4	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_22	R Culvert	1.2	0.3	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.7	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_23	C Culvert	0.575	0	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_24	R Culvert	0.9	0.45	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.9	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_25	R Culvert	1.5	0.475	2	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	0.7	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_26	R Culvert	0.6	0.25	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_27	R Culvert	0.75	0.25	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.4	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_28	R Culvert	0.45	0.25	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.2	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_29	R Culvert	0.9	0.6	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_30	R Culvert	0.9	0.25	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_31	C Culvert	0.6	0	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_32	C Culvert	0.45	0	6	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.6	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_33	C Culvert	0.3	0	3	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_34	R Culvert	1.2	0.25	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.4	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_35	R Culvert	1.2	0.475	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.1	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_36	C Culvert	0.45	0	5	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.4	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_37	C Culvert	0.6	0	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_38	R Culvert	1.2	0.6	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.8	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_39	C Culvert	0.6	0	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_40	C Culvert	0.675	0	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.1	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_41	R Culvert	1.2	0.45	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.8	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_42	C Culvert	0.45	0	4	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.5	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_43	C Culvert	0.6	0	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.3	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_44	R Culvert	0.8	0.45	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.3	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_45	C Culvert	0.45	0	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_46	R Culvert	1.2	0.8	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.9	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_47	R Culvert	1.5	0.6	1	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_48	C Culvert	0.6	0	6	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_49	R Culvert	1.8	1.2	4	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	2.5	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_50	C Culvert	0.9	0	5	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.5	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_51	C Culvert	0.65	0	4	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.6	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_52	C Culvert	0.6	0	12	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.9	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_53	R Culvert	1.2	0.5	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_54	C Culvert	0.45	0	7	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.3	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_55	R Culvert	1.2	0.4	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_56	C Culvert	0.3	0	10	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_57	R Culvert	1.2	0.5	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.1	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_58	R Culvert	1.2	0.4	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.9	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_59	C Culvert	0.3	0	15	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.7	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_60	C Culvert	0.4	0	10	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.4	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_61	R Culvert	1.8	0.4	3	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.7	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_63	C Culvert	0.45	0	10	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.4	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%

TABLE E1

ARR, 2019 DESIGN BLOCKAGE ASSESSMENT AT HYDRAULIC DRAINAGE STRUCTURES

ID(1)	Structure Details				Floating Debris												Non-Floating Debris									Adopted Design Blockage B_{DES}%		
	Structure Type(2)	Width	Height (m)	No. of Barrels	L_{10}(3)	Debris Availability	Debris Mobility	Debris Transportability	Debris Potential	Debris Potential at Structure	Adjusted Debris Potential			Most Likely Design <u>Inlet</u> Blockage (B_{DES}%)			Approx. Flow Velocity (m/s)	Likelihood of Deposition	Debris Potential at Structure	Adjusted Debris Potential			Most Likely Design <u>Barrel</u> Blockage (B_{DES}%)					
											> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP				> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP
pBG_64	R Culvert	3.5	0.3	1	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.5	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_65	C Culvert	0.6	0	13	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.8	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_66	R Culvert	1.5	0.6	4	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.9	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_67	R Culvert	1.5	0.45	3	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.2	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_68	C Culvert	0.6	0	12	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.7	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_69	R Culvert	3	0.425	5	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_70	R Culvert	1.5	0.45	6	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.6	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_71	R Culvert	3	1.2	7	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	0.4	Medium	Low	Low	Low	Medium	15%	15%	40%	15%	15%	40%
pBG_72	R Culvert	1.5	0.47	2	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.6	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_73	C Culvert	0.45	0	10	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.5	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_74	R Culvert	2.1	0.78	2	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_75	C Culvert	0.62	0	10	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.9	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_76	R Culvert	1.5	0.6	1	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	0.4	Medium	Low	Low	Low	Medium	15%	15%	40%	15%	15%	40%
pBG_77	C Culvert	0.6	0	8	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	2.2	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_78	R Culvert	1.5	0.6	3	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.5	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_79	C Culvert	0.46	0	15	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	2.4	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_80	R Culvert	3.6	0.46	1	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	0.8	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_81	C Culvert	0.45	0	8	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	2.8	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_82	R Culvert	1.2	0.6	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.8	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_83	C Culvert	0.45	0	9	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	2.9	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_84	R Culvert	1.5	0.6	1	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.4	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_85	C Culvert	0.46	0	8	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	3	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_86	R Culvert	2.5	0.6	3	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.1	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_87	C Culvert	0.72	0	6	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	3.2	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_88	R Culvert	2.1	0.75	3	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	5.4	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_89	R Culvert	0.9	0.5	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.6	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_90	C Culvert	0.75	0	6	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	3.3	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_91	C Culvert	0.46	0	8	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	3.1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_92	R Culvert	2	0.8	9	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	2	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_93	R Culvert	1.5	0.75	3	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.3	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_94	C Culvert	0.65	0	5	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.3	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_95	C Culvert	0.45	0	6	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_96	C Culvert	0.6	0	3	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.7	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_97	I Culvert	1.5	1	4	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.3	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_98	I Culvert	1.5	0.5	2	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.8	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_99	I Culvert	1.5	0.5	4	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.5	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_100	I Culvert	1.5	0.5	5	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.6	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_101	C Culvert	0.45	0	5	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.6	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_102	C Culvert	0.45	0	6	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.5	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_103	C Culvert	0.65	0	3	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.8	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_104	I Culvert	1.5	0.5	7	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	2.7	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_105	C Culvert	0.9	0	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.5	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_106	C Culvert	0.9	0	5	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.5	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_107	I Culvert	1.5	1	3	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.7	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_108	C Culvert	0.9	0	6	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.7	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_109	I Culvert	1.5	1	5	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.1	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_110	C Culvert	0.75	0	6	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.6	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_111	I Culvert	1.5	1	3	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.8	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_112	C Culvert	0.75	0	4	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.1	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_113	I Culvert	1.5	1	3	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.8	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_114	I Culvert	1.5	1	5	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.1	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_115	I Culvert	1.5	1	6	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	1.5	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
pBG_116	C Culvert	0.65	0	8	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
pBG_117	R Culvert	0.6	0.3	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.4	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
pBG_118	R Culvert	1.5	1.2	12	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	3	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
MP_05	C Culvert	0.9	0	2	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	3.5	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MP_04	C Culvert	0.6	0	10	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	2.6	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MP_06	R Culvert	1.2	0.45	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0.9	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MP_03	C Culvert	0.45	0	6	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	0	Medium	Low	Low	Low	Medium	15%	15%	40%	25%	25%	50%
MP_11	R Culvert	4	0.45	1	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	10%	0.7	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
MP_02	C Culvert	0.6	0	12	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.4	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%

TABLE E1
ARR, 2019 DESIGN BLOCKAGE ASSESSMENT AT HYDRAULIC DRAINAGE STRUCTURES

ID[1]	Structure Details				Floating Debris												Non-Floating Debris										Adopted Design Blockage B_{DES}%		
	Structure Type[2]	Width	Height (m)	No. of Barrels	L_{10}[3]	Debris Availability	Debris Mobility	Debris Transportability	Debris Potential	Debris Potential at Structure	Adjusted Debris Potential			Most Likely Design Inlet Blockage (B_{DES}%)			Approx. Flow Velocity (m/s)	Likelihood of Deposition	Debris Potential at Structure	Adjusted Debris Potential			Most Likely Design Barrel Blockage (B_{DES}%)					
											> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP				> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP	> 5% AEP	5% - 0.5% AEP	< 0.5% AEP
MP_10	R Culvert	1.2	0.45	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.6	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MP_01	C Culvert	0.6	0	12	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.5	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MP_09	R Culvert	8	0.45	1	1.5	L	M	L	LML	Low	Low	Low	Medium	0%	0%	0%	0.6	Low	Low	Low	Low	Medium	0%	0%	15%	0%	0%	15%
MP_08	R Culvert	1.2	0.45	1	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	1.5	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%
MP_07	C Culvert	0.6	0	5	1.5	L	M	L	LML	Low	Low	Low	Medium	25%	25%	50%	2.2	Low	Low	Low	Low	Medium	0%	0%	15%	25%	25%	50%

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

APPENDIX F

FLOOD DATA FOR INDIVIDUAL ROAD CROSSINGS AT BOGAN GATE

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

ID[3]	Tributary	Road Name	Road/ Rail Level (m AHD)	March 2012		November 2022		20% AEP		10% AEP		5% AEP		2% AEP		1% AEP		0.5% AEP		0.2% AEP		PMF	
				Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)	Peak Flood Level (m AHD)	Depth of Overtopping (m)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[T]	[U]	[V]	[W]	[X]
H01	Gunningbland Creek	The Bogan Way	231.7	232.5	0.8	232.8	1.1	232.5	0.8	232.6	0.9	232.7	1.0	232.8	1.1	232.9	1.2	232.9	1.2	233.0	1.3	233.8	2.1
H02a		Tottenham Railway Line	232.3	232.2	-0.1	232.5	0.2	232.1	-0.2	232.3	0	232.4	0.1	232.5	0.2	232.5	0.2	232.6	0.3	232.7	0.4	233.7	1.4
H02b			232.3	232.3	0	232.5	0.2	232.3	0	232.4	0.1	232.5	0.2	232.5	0.2	232.6	0.3	232.6	0.3	232.7	0.4	233.5	1.2
H03		Tubby Lees Road	228.3	230.1	1.8	230.4	2.1	230.0	1.7	230.1	1.8	230.3	2.0	230.4	2.1	230.5	2.2	230.6	2.3	230.7	2.4	231.7	3.4
H04a		Henry Parkes Way	224.4	223.2	-1.2	223.4	-1.0	223.3	-1.1	223.3	-1.1	223.4	-1.0	223.5	-0.9	223.5	-0.9	223.6	-0.8	223.6	-0.8	224.0	-0.4
H04b		Orange Broken Hill Railway	224.7	223.2	-1.5	223.4	-1.3	223.2	-1.5	223.3	-1.4	223.3	-1.4	223.4	-1.3	223.4	-1.3	223.5	-1.2	223.5	-1.2	223.9	-0.8
H05a	Gunningbland Creek Right Overbank Area	Henry Parkes Way	218.9	219.6	0.7	219.9	1.0	219.5	0.6	219.7	0.8	219.9	1.0	219.9	1.0	220.0	1.1	220.0	1.1	220.0	1.1	220.2	1.3
H05b		Orange Broken Hill Railway	219.7	219.6	-0.1	219.9	0.2	219.4	-0.3	219.7	0	219.8	0.1	219.9	0.2	219.9	0.2	219.9	0.2	220.0	0.3	220.1	0.4
H06	Blowclear Creek	Tottenham Railway Line	233.2	232.8	-0.4	233.2	0	232.7	-0.5	232.9	-0.3	233.1	-0.1	233.2	0	233.3	0.1	233.3	0.1	233.4	0.2	234.3	1.1
H07a		The Bogan Way	231.8	232.3	0.5	232.8	1.0	232.1	0.3	232.3	0.5	232.5	0.7	232.7	0.9	232.8	1.0	233.0	1.2	233.1	1.3	234.1	2.3
H07b		The Bogan Way/ Tottenham Railway Level Crossing	232.5	232.7	0.2	232.9	0.4	232.6	0.1	232.7	0.2	232.8	0.3	232.9	0.4	232.9	0.4	233.0	0.5	233.1	0.6	234.0	1.5
H08		Leafy Tank Road	230.5	231.9	1.4	232.3	1.8	231.8	1.3	232.0	1.5	232.1	1.6	232.3	1.8	232.4	1.9	232.5	2.0	232.6	2.1	233.7	3.2
H09	Botfields Creek	The Bogan Way	232.7	233.3	0.6	233.4	0.7	233.3	0.6	233.3	0.6	233.4	0.7	233.4	0.7	233.5	0.8	233.5	0.8	233.5	0.8	234.4	1.7

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.

APPENDIX G

DESIGN PEAK FLOWS

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

Peak Flow Location Identifier[(2)]	Watercourse	Location		20% AEP			10% AEP			5% AEP			2% AEP			1% AEP			0.5% AEP			0.2% AEP			PMF	
				Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)
[A]	[B]	[C]		[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[T]	[U]	[V]	[W]	[X]	[Y]	[Z]
Q01	Gunningbland Creek			59.1	720	6	89.0	540	2	124	540	2	178	720	6	226	720	6	276	720	6	342	720	6	1,210	180
Q02				66.6	720	6	100	540	2	137	540	2	191	720	6	240	720	6	292	720	6	359	720	6	1,220	180
Q03		Upstream confluence with Blowclear Creek		65.5	720	6	100	540	2	137	540	2	191	720	6	240	720	6	292	720	6	359	720	6	1,240	180
Q04		Downstream Tottenham Railway Line		147	720	6	231	540	2	316	540	2	433	720	6	539	720	6	656	720	6	805	720	6	2,700	180
Q05A[(5)]		1.5 km east of intersection of Tubby Lees Road and Henry Parkes Way	Northern Side of Railway	147 [94%]	720	6	232 [94%]	540	2	315 [94%]	540	2	433 [94%]	720	6	539 [95%]	720	6	656 [95%]	720	6	804 [95%]	720	6	2,500	180
Q05B[(5)]			Southern Side of Railway	10.1 [6%]	720	6	14.7 [6%]	360	6	19.2 [6%]	360	6	25.3 [6%]	360	7	29.6 [5%]	360	7	34.4 [5%]	360	7	41 [5%]	120	4	240	180
Q06A[(5)]		Intersection of Tubby Lees Road and Henry Parkes Way	Northern Side of Railway	146 [93%]	720	6	233 [93%]	540	2	313 [93%]	540	2	429 [93%]	720	6	529 [93%]	720	6	634 [93%]	720	6	749 [93%]	720	6	1,890	180
Q06B[(5)]			Southern Side of Railway	11.8 [7%]	720	6	17.7 [7%]	360	6	24.5 [7%]	360	6	33.3 [7%]	360	7	39.6 [7%]	360	7	46.4 [7%]	360	7	56.9 [7%]	360	7	910-	180
Q07A[(5)]		Immediately east (upstream) of Gunningbland Creek crossing	Northern Side of Railway	142 [94%]	720	6	226 [94%]	540	2	300 [93%]	540	2	409 [92%]	720	6	494 [91%]	720	6	567 [86%]	720	6	636 [78%]	720	6	1,240	180
Q07B[(5)]			Southern Side of Railway	8.8 [6%]	720	6	15.2 [6%]	540	2	22 [7%]	360	6	33.2 [8%]	360	7	46.4 [9%]	360	7	91.6 [14%]	360	7	175 [22%]	360	7	1,620	180
Q08A[(5)]		West (downstream) of Gunningbland Creek crossing	Northern Side of Railway	112 [76%]	720	6	186 [79%]	540	2	248 [80%]	540	2	338 [79%]	720	6	410 [78%]	720	6	471 [74%]	720	6	529 [67%]	720	6	1,030	180
Q08B[(5)]			Southern Side of Railway	34.7 [24%]	720	6	50.4 [21%]	540	2	63 [20%]	540	2	88.6 [21%]	720	6	113 [22%]	720	6	168 [26%]	720	6	260 [33%]	720	6	1,800	180
Q09A[(5)]		2 km east of intersection of Cronin Lane and Henry Parkes Way	Northern Side of Railway	109 [74%]	720	6	184 [75%]	540	2	245 [77%]	540	2	343 [77%]	720	6	403 [75%]	720	6	452 [68%]	720	6	493 [60%]	720	6	-	-
Q09B[(5)]			Southern Side of Railway	38.3 [26%]	720	6	59.9 [25%]	540	2	73.3 [23%]	540	2	103 [23%]	720	6	137 [25%]	720	6	210 [32%]	720	6	322 [40%]	720	6	-	-
Q10A[(5)]		Immediately west of intersection of Cronin Lane and Henry Parkes Way	Northern Side of Railway	5 [4%]	720	6	36.6 [15%]	540	2	51.1 [17%]	540	2	59 [13%]	720	6	67.3 [13%]	720	6	60.1 [9%]	360	7	58.7 [7%]	360	7	54	180
Q10B[(5)]			Southern Side of Railway	127 [96%]	720	6	208 [85%]	540	2	253 [83%]	540	2	393 [87%]	720	6	467 [87%]	720	6	610 [91%]	720	6	767 [93%]	360	7	3,110	180

Refer over for footnotes to table.

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

Peak Flow Location Identifier[(2)]	Watercourse	Location	20% AEP			10% AEP			5% AEP			2% AEP			1% AEP			0.5% AEP			0.2% AEP			PMF	
			Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)	Critical Temporal Pattern[(4)]	Peak Flow (m^3/s)	Critical Storm Duration[(3)] (minutes)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]	[N]	[O]	[P]	[Q]	[R]	[S]	[T]	[U]	[V]	[W]	[X]	[Y]	[Z]
Q11	Botfields Creek		18.0	720	6	27.7	360	6	39.5	360	6	59.2	360	7	73.8	360	7	88.3	360	7	106	360	7	540	180
Q12		Upstream Confluence with Blowclear Creek	19.4	720	6	29.6	360	6	42.2	360	6	62.8	360	7	79.0	360	7	94.6	360	7	114	360	7	-	-
Q13	Blowclear Creek	Upstream Blowclear Road	45.1	720	6	113	540	2	158	540	2	149	720	6	206	720	6	262	720	6	337	720	6	1,560	180
Q14A		Upstream Confluence with Botfields Creek	4.7	720	6	10.5	540	2	18.3	540	2	35.7	720	6	55.2	720	6	78.7	720	6	111	720	6	-	-
Q14B			76.2	720	6	113	540	2	150	540	2	195	720	6	233	720	6	271	720	6	318	720	6	-	-
Q15	Tributary of Gunningbland Creek	Upstream confluence with Gunningbland Creek	18.1	720	6	28.4	360	6	39.9	360	6	57.2	360	7	69.8	360	7	82.4	360	7	95.0	360	7	-	-

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.
5. Values in [] indicate percentage of total flow in Gunningbland Creek being conveyed on northern and southern side of the railway.

APPENDIX I

FLOOD DAMAGES

TABLE OF CONTENTS

Page No.

I1. INTRODUCTION AND SCOPE

I1.1 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.

Intangible damages resulting from flooding includes a number of various factors that can have a significant effect on the community. Such factors may include:

a) risk of injury or loss of life;

b) mental health impacts such as depression, anxiety and post-traumatic stress disorder; and

c) social and wellbeing impacts such as isolation, inconvenience, or disruption of family and social activities.

I1.2 Scope of Investigation

In the following sections, both tangible and intangible damages to residential, commercial and industrial properties, and public buildings have been estimated resulting from flooding in the study area. While the present study defined flood behaviour in land outside of the urban centre of Bogan Gate, the flood damages assessment was only undertaken for properties that are located within the Village Centre (i.e. land that is presently zoned for urban type development).

For the present investigation, the procedures set out in *Flood Risk Management Guideline MM01 – Flood Risk Management Measures* (DPE, 2023) and the associated *NSW Flood Risk Management Tool DT01* (***FRM Tool DT01***) were used to undertake an assessment of both the tangible and intangible damages resulting from flooding at Bogan Gate.

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.

I1.3 Terminology

Definitions of the terms used in this Appendix are presented in **Section H8** which also summarises the value of Tangible Flood Damages.

I2. 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. The *FRM Tool DT01* was 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 *FRM Tool DT01* 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.

A series of depth-damages curves in the *FRM Tool DT01* were used to estimate the cost of tangible damages to residential, commercial, industrial and public properties. The spreadsheet model also includes procedures that were used to estimate intangible damages associated with:

a) risk of injury or loss of life correlated to the hazard vulnerability classification of flooding;

b) mental health costs correlated to the depth of above-floor inundation; and

c) social and wellbeing costs correlated to the frequency of above-floor inundation.

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.

I3. SOURCES OF DATA

I3.1 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. It was not used for the present investigation.
- The third way is to use generalised data that are considered to be suitable for 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. The approach set out in DPE, 2023 and the *FRM Tool DT01* is based on data collected following major flooding in various urban centres across NSW and has been adopted for the present study.

I3.2 Property Data

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

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

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

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

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

The property descriptions were used to classify the commercial/industrial 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 I3.1**.

TABLE I3.1
NUMBER OF PROPERTIES INCLUDED IN DAMAGES DATABASE

Development Type	Number of Properties
Residential	50
Commercial / Industrial	4
Public	6
Total	**60**

I3.3 Flood Levels Used in the Analysis

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

I4. RESIDENTIAL DAMAGES

I4.1 Damage Functions

The procedures identified in DPE, 2023 allow for the preparation of a depth versus damage relationship which incorporates structural damage, damage to contents, external damage, relocation costs and clean-up costs. In limited cases, the additional damage costs related to structural integrity due to building failure may also warrant consideration. Depth versus damage curves are computed for single and double storey residences.

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

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

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

The actual damage to contents in an event can be reduced by actions taken during the warning time available in response to a flood threat. The actual to potential damage ratio is dependent on the effective warning time, likely duration of inundation of contents, flood awareness of the community, the likelihood of at least one resident being present at the time of the flood, the ability of the individual to lifts goods and the height to which goods would need to be raised. As there is minimal warning time available at Bogan Gate, the default actual to potential damage ratio of 0.9 was adopted for the present study.

I4.2 Total Residential Damages

Table I4.1 over summarises the residential damages in the study area for floods between the 20% AEP and the PMF which were modelled hydraulically as part of the present study.

All dwellings in the Village Centre would remain flood free during floods up to 0.2% AEP in magnitude, while during a PMF event, 24 dwellings would experience above-floor inundation resulting in a total flood damages of about $5.2 Million. The maximum depth of above-floor inundation in the worst affected dwelling would be about 0.9 m in a PMF event.

TABLE I4.1
TOTAL RESIDENTIAL FLOOD DAMAGES

Design Flood Event (%AEP)	No. of Properties		Total Damages ($ Million)
	Flood Affected	Flooded Above Floor Level	
20% AEP	0	0	0
10% AEP	0	0	0
5% AEP	2	0	0.01
2% AEP	5	0	0.02
1% AEP	6	0	0.03
0.5% AEP	6	0	0.03
0.2% AEP	6	1	0.05
PMF	38	24	5.21

I5. COMMERCIAL AND INDUSTRIAL DAMAGES

I5.1 Damage Functions

The procedures identified in DPE, 2023 allow for the preparation of a depth versus damage relationship for commercial and industrial buildings. The damage costs include the indirect costs associated with loss of trading and post-flood clean-up for commercial and industrial buildings.

Commercial and industrial property damages are highly variable, with the particular use and associated contents (rather than the structure) generally dominating the overall damage. The damage category assigned to each enterprise may vary between "low", "medium" or "high", depending on the nature of the enterprise set out in **Table I5.1** below. Damages also depend on the floor area.

TABLE I5.1
ASSESSED COMMERCIAL AND INDUSTRIAL DAMAGE CATEGORIES

Proposed classification	Adjustment to average value curve	Representative uses
Low to medium	60% of average	Restaurants, cafes, offices, doctor's surgeries, retail/food outlets, butchers, bakeries, newsagencies, service stations, hardware
Medium/default	100%	Proposed as a representative average, where the particular use is not known
Medium to high	150% of average	Chemists, electrical goods, clothing stores, bottle shops, electronics

I5.2 Total Commercial and Industrial Damages

Table I5.2 over summarises the estimated commercial and industrial damages in the Village Centre, noting that above-floor inundation would be limited to a single commercial building during a PMF event, when the total flood damages would amount about $0.1 Million.

TABLE I5.1
COMMERCIAL / INDUSTRIAL FLOOD DAMAGES

Design Flood Event (%AEP)	No. of Properties		Total Damages ($ Million)
	Flood Affected	Flooded Above Floor Level	
20% AEP	0	0	0
10% AEP	0	0	0
5% AEP	0	0	0
2% AEP	0	0	0
1% AEP	0	0	0
0.5% AEP	0	0	0
0.2% AEP	0	0	0
PMF	1	1	0.1

I6. DAMAGES TO PUBLIC BUILDINGS

I6.1 Damage Functions

The procedures identified in DPE, 2023 allow for the preparation of a depth versus damage relationship for public buildings. The damage costs include the indirect costs associated with post-flood clean-up for public buildings.

As part of the FRM tool DT01, depth versus damage relationship for public buildings have been classified for three categories which are schools, hospitals and other buildings, the latter of which comprises the following uses:

- Health (e.g. aged care, nursing home);
- Emergency Services (e.g. police station, fire station, ambulance station, NSE SES facilities etc.); and
- Government Buildings (e.g. courthouse, government administration buildings, diplomatic facilities, consulate facilities, major defence facilities, correctional facilities etc).

I6.2 Total Damages – Public Buildings

Table I6.1 over summarises the estimated public damages in the study area

While no public buildings would be impacted during floods up to 0.2% AEP in magnitude, a single structure would be above-floor inundated in a PMF event, resulting in total flood damages of about $0.08 Million.

TABLE I6.1
PUBLIC FLOOD DAMAGES

Design Flood Event (%AEP)	No. of Properties		Total Damages ($ Million)
	Flood Affected	Flooded Above Floor Level	
20% AEP	0	0	0
10% AEP	0	0	0
5% AEP	0	0	0
2% AEP	0	0	0
1% AEP	0	0	0
0.5% AEP	0	0	0
0.2% AEP	0	0	0
PMF	1	1	0.08

I7. DAMAGES TO INFRASTRUCTURE AND COMMUNITY ASSETS

No data are available on damages experienced to infrastructure and community assets during historic flood events. However, a qualitative matrix of the effects of flooding on important assets in the study area is presented in **Table I7.1**.

TABLE I7.1
QUALITATIVE EFFECTS OF FLOODING ON
INFRASTRUCTURE AND COMMUNITY ASSETS AT BOGAN GATE

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
Electricity	O	O	O	X	X	X	X	X
Telephone	O	O	O	O	O	O	O	O

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

I8. SUMMARY OF TANGIBLE DAMAGES

I8.1 Tangible Damages

Flood damages have been computed for a range of flood frequencies from 20% AEP up to the PMF. For the purposes of assessing damages, the 50% AEP was adopted as the "threshold" flood at which damages commence at Bogan Gate. As set out in **Table I8.1** over, about $0.03 Million of damages would be incurred at the 1% AEP level of flooding at Bogan Gate, increasing to a total of about $5.39 Million for the PMF.

I8.2 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 "*Net Present Value"* (**NPV**) 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 NPV via the discount rate.

Using the procedures outlined in DPE, 2023 and NSW Treasury Guidelines, economic analyses were carried out assuming a 30 year economic life for projects and discount rates of 5% pa. (best estimate) and 7% and 3% pa (sensitivity analyses).

I8.3 Average Annual Damages

The average annual damages for all flood events up to the PMF are shown below in **Table I8.2**. Note that values have been quoted to two decimal places to highlight the relatively small recurring damages.

I8.4 Net Present Value of Damages

The NPV of damages likely to be experienced for all flood events up to the 1% AEP and PMF, for a 30 year economic life and discount rates of 3, 5 and 7 per cent are shown in **Table I8.3**.

For a discount rate of 5% pa, the NPV of total damages for flood events up to the 1% AEP flood at Bogan Gate is effectively zero, while for the PMF event it is about $0.1 Million. Based on this finding, one or more schemes costing up to the latter amount could be economically justified if they eliminated damages at Bogan Gate for all flood events up to the PMF. 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 I8.1
TOTAL FLOOD DAMAGES
$ MILLION

Design Flood Event	Residential	Commercial/Industrial	Public	Total
20% AEP	0	0	0	0
10% AEP	0	0	0	0
5% AEP	0.01	0	0	0.01
2% AEP	0.02	0	0	0.02
1% AEP	0.03	0	0	0.03
0.5% AEP	0.03	0	0	0.03
0.2% AEP	0.05	0	0	0.05
PMF	5.21	0.1	0.08	5.39

TABLE I8.2
AVERAGE ANNUAL DAMAGES
$ MILLION

Design Flood Event	Residential	Commercial/ Industrial	Public	Total	
				Contribution to AAD(1)	Cumulative AAD(2)
20% AEP	0	0	0	0	0
10% AEP	0	0	0	0	0
5% AEP	<0.001	0	0	<0.001	<0.001
2% AEP	<0.001	0	0	<0.001	<0.001
1% AEP	<0.001	0	0	<0.001	<0.001
0.5% AEP	<0.001	0	0	<0.001	<0.001
0.2% AEP	<0.001	0	0	<0.001	0.001
PMF	0.005	<0.001	<0.001	0.005	0.006

1. Represents the contribution to the total average annual damages for the specified design flood event
2. Represents the cumulative annual average damages for all floods up to the specified design flood event in magnitude.

TABLE I8.3
PRESENT WORTH VALUE OF DAMAGES
$ MILLION

Discount Rate (%)	All Floods up to 5% AEP	All Floods up to 1% AEP	All Floods up to PMF
3	0	0	0.13
5	0	0	0.10
7	0	0	0.08

I9. REFERENCES AND BIBLIOGRAPHY

DPE (Department of Planning), 2023. ***"Flood Risk Management Guideline MM01 – Flood Risk Management Measures"***