Ballimore Floodplain Risk Management Study and Plan

Volume 1: Flood Study

Draft Report

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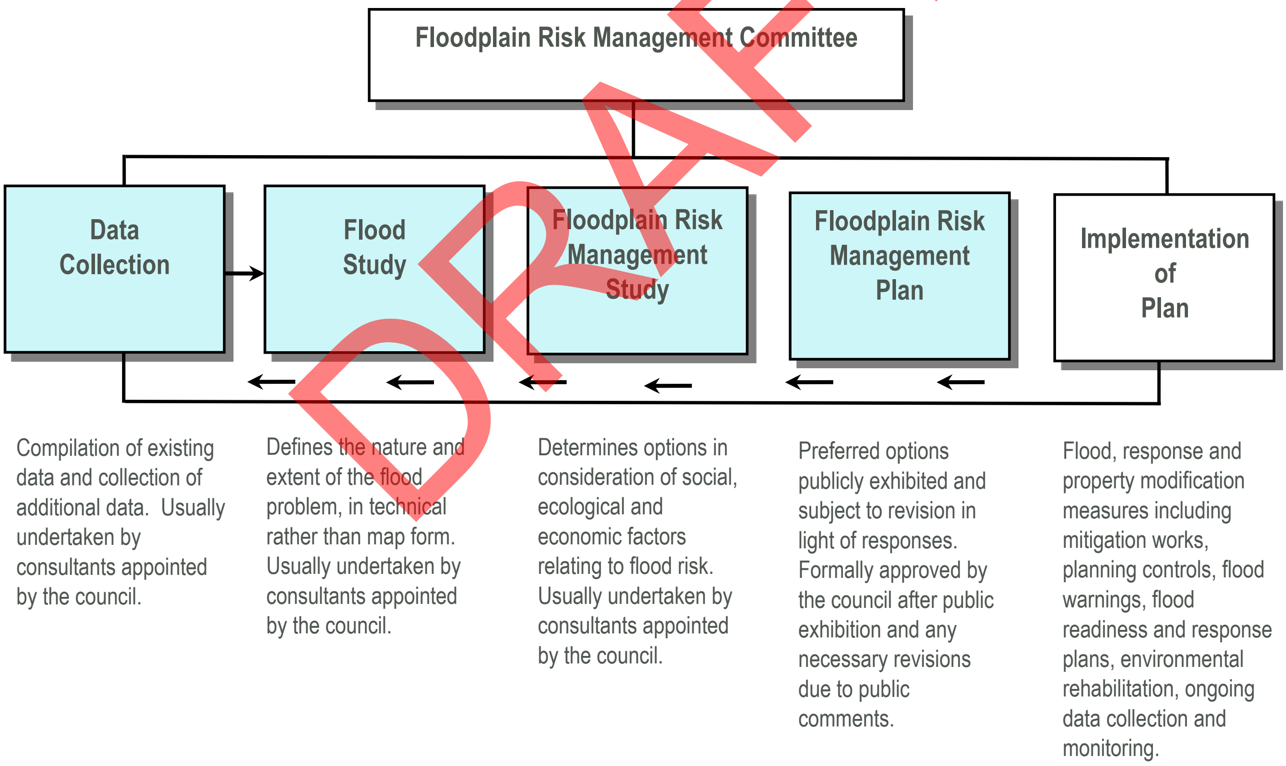
Foreword

Flooding in NSW is managed in accordance with the NSW Government's Flood Prone Land Policy. The Policy is directed towards providing solutions to existing flooding problems in developed areas, understanding potential future impacts on flood risk, and ensuring that new development is compatible with its flood risk exposure and does not create additional flooding problems in other areas.

The NSW Government's 'Floodplain Development Manual' (2005) supports the Policy by defining the responsibilities, roles and processes for the management of flood prone land in NSW. Under the Policy, the management of flood liable land is the responsibility of the local authority, in this case Dubbo Regional Council, with technical and financial support from the NSW Government. This includes the development of local flood studies and floodplain risk management studies and plans to define and manage flood risk, and the implementation of any flood risk management measures (e.g. mitigation works) proposed as outcomes of these studies. This is undertaken via the staged approach defined by the NSW Floodplain Management process shown in Figure 1.1.

The Ballimore FRMS&P represents Stages 1 to 4 of the process. It has been conducted under the NSW Floodplain Management Program and has received NSW Government financial support.



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1 Introduction

1.1 Background

The village of Ballimore is located in the Dubbo Regional Local Government Area (LGA) in the Orana region of New South Wales (NSW). Ballimore is situated in the floodplain of Talbragar River, approximately 33 km east of Dubbo and north of the Golden Highway. Ballimore Creek, a small local tributary, joins the Talbragar River at the eastern end of the village. Therefore, flooding within the village may result from regional mainstream flooding from the Talbragar River, local catchment flooding from Ballimore Creek, or overland flow flooding from local catchments within the village. These various flood mechanisms may occur either in isolation or in combination. The study area locality, catchment and floodplain topography, watercourse alignments and major transport routes are shown in Figure 1.1.

The village has experienced a number of past flood events. The 1955 flood is the largest flood on record, with other notable flood events occurring in 1870, 1920, 1926, 1971 and 1950. During the 1955 flood, the entire village was inundated to depths exceeding 1 m. The most recent flood occurred in 2010, during which low-lying properties in Ballimore were impacts by floodwaters.

Previous flood investigations undertaken within the study area include the ‘Talbragar River Flood Study’ (Rust PPK, 1995) and the ‘Ballimore Flood Study’ (Rust PPK, 1996). However, since publication of these studies, there have been advances in numerical modelling techniques and technology, updated terrain and rainfall data, and a major update to the national guideline for flood estimation (Australian Rainfall and Runoff 2019 (ARR2019)).

1.2 About this Study

BMT Commercial Australia Pty Ltd (“BMT”) was commissioned by Dubbo Regional Council (“Council”) to prepare a Floodplain Risk Management and Study and Plan (FRMS&P) for the village of Ballimore. The study focuses primarily on regional Talbragar River flood behaviour within the village, with consideration of tributary inflows, particularly Ballimore Creek, and overland flow from local catchments upstream of the village.

The FRMS&P aims to derive an appropriate mix of management measures and strategies to effectively manage flood risk in accordance with the NSW Government’s Floodplain Development Manual (NSW Government, 2005). This will provide a basis for flood risk related development control and allow for more informed planning decisions within Ballimore. However, an updated understanding of the current flood risk for Ballimore is required to inform the formulation of the FRMS&P. Therefore, a flood study based on the latest modelling methodologies, topographic data and best-practice guidance has been completed in conjunction with the FRMS&P.

The FRMS&P is primarily focussed on the impacts of regional Talbragar River mainstream and backwater flooding within Ballimore as this is the dominant flood mechanism within the village (in terms of peak flood levels and potential flood impacts). However, the study does include consideration of other flood mechanisms that may also impact the study area, such as local catchment flooding or overland flow flooding caused by local runoff during rainfall events.

The FRMS&P, including the Flood Study, is presented in three volumes:

- **Volume 1: Flood Study (this document):** Documents the data collections and review, hydrologic and hydraulic assessment, model calibration and design flood results.
- **Volume 2: Floodplain Risk Management Study and Plan:** Documents the flood risk within the study area, identification and assessment of flood mitigation measures considered for Singleton,

leading to recommendations for implementation of preferred measures as part of the Floodplain Risk Management Plan.

- **Volume 3: Mapping Compendium**: Contains all flood mapping prepared as part of this FRMS&P.

1.3 Objectives and Scope of the Flood Study

The primary objective of the Flood Study is to define the flood behaviour within the Ballimore floodplain. This has involved:

- Compilation and review of available flood-related data for the village and its catchment.
- Development of hydrologic and hydraulic models based on more detailed and contemporary topographic data, latest modelling techniques and current best-practice guidance.
- Calibration of the models to historic flood events.
- Derivation of design flows and simulation of design floods using the calibrated models.
- Simulation and mapping of design flood behaviour for the following design floods: 10%, 5%, 2%, 1%, 0.5%, 0.2%, 0.1% and 0.05% Annual Exceedance Probability (AEP) and Probable Maximum Flood (PMF) events. This includes defining flood characteristics such as extent, level and velocity.

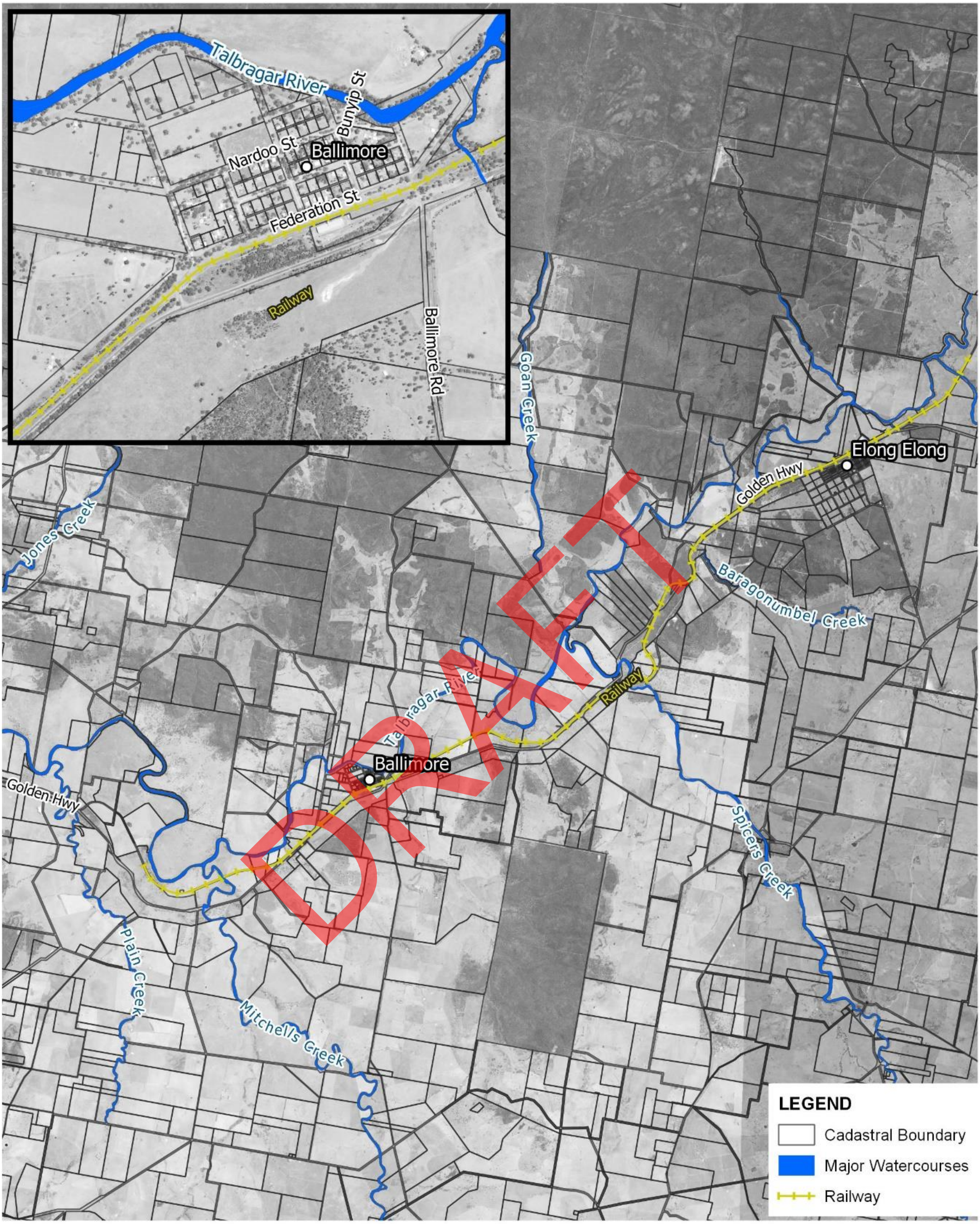
The outcomes of the Flood Study, including the design flood mapping in Map Set B in Volume 3: Mapping Compendium, will be used to inform an understanding of flood risk under existing catchment and floodplain conditions, identify flood-related issues within the study area and provide a basis for the identification and assessment of appropriate floodplain risk management activities to reduce the flood risk to both property and life (i.e. the FRMS&P documented in Volume 2).

1.4 Structure of this Report

The following report is structured into the sections below:

- Section 2 provides an overview of the study area and historic flood risk.
- Section 3 presents the details and outcomes of community consultation.
- Section 4 documents the data collection and review process.
- Section 5 describes the development of the hydrologic and hydraulic models.
- Section 6 details the hydrologic and hydraulic model calibration and validation.
- Section 7 presents the Flood Frequency Analysis.
- Section 8 summarises the design flood modelling methodology and results.
- Section 9 details the sensitivity of the modelling outputs to changes in model parameters.

[This report provides details of work completed to date. Any methodology and findings contained herein represent draft results and are not final.]



Title:

Study Locality

Figure: **1-1**

Rev: **A**

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2 Study Area and Catchment Description

2.1 Ballimore Village

Ballimore is located on the Golden Highway, approximately 30 km north-east of Dubbo in the Orana region of NSW. The village is within Wiradjuri Country and according to the 2016 Census, has a population of 197. The predominant land use within Ballimore is low density and rural residential development, with a small number of commercial (e.g. hotel), public and recreational (e.g. village hall, tennis club) properties, as well as Ballimore Public School. The village forms the extent of the study area for which flood behaviour will be defined for the Flood Study and floodplain risk management measures will be developed for the FRMS&P.

An understanding of the demographic characteristics within the village is important to inform the development of a suitable floodplain risk management plan. Social characteristics, such as population demographics, language, mobility and awareness of historic flooding may influence the community’s needs, flood response and acceptance of proposed measures. For example, the availability of the internet, primary language and access to a motor vehicle can all impact the appropriate flood awareness, warning and evacuation strategies.

The Australian Bureau of Statistics (ABS) provides a range of data collected for the village as part of the 2016 Census. A summary of the relevant demographics is provided in Table 2.1.

Table 2.1 Demographics of Ballimore (Source: 2016 Census (abs.gov.au))

Metric		Statistic
Total Population		197
Age	Median Age	44
	0 -14 years	19.4%
	15 - 54 years	40.8%
	> 55 years	39.8%
Country of Birth	Australia	79%
	Other	3%
Language	English only spoken at home	79.2%
	Speak non-English language at home	0%
Median Weekly Income	Personal	$624
	Household	$1,281
Dwelling Type	House	59
	Semi-detached, row or terrace house, townhouse	0
	Flat or apartment	0
	Other dwelling	0
Tenure	Owned (outright or with mortgage)	80.6%
	Rented	14.5%

Metric		Statistic
No. of people per dwelling	Average	2.5
No. of vehicles per dwelling	None	0%
	1 or more	95%
Internet not accessed from dwelling		22.6%

2.2 Catchment Description

As shown in Figure 1.1, Ballimore is situated on the banks of the Talbragar River. Whilst the village forms the extent of the study area for which flood behaviour will be defined for the Flood Study, the wider catchment draining to the village has been considered for determining flow rates within the Talbragar River for historic and design events.

The headwaters of the Talbragar River are formed by runoff in the Coolah Tops National Park, which is located over 150 km north-east of Ballimore. The contributing catchment area of the Talbragar River at Ballimore is about 4,000 km^2 (about 90% of the total river catchment). A major tributary of the Talbragar River is the Coolaburragundy River, which joins approximately 10 km upstream of Dunedoo. The Talbragar River discharges to the Macquarie River approximately 80 kilometres downstream of Ballimore and about 6 kilometres north of Dubbo.

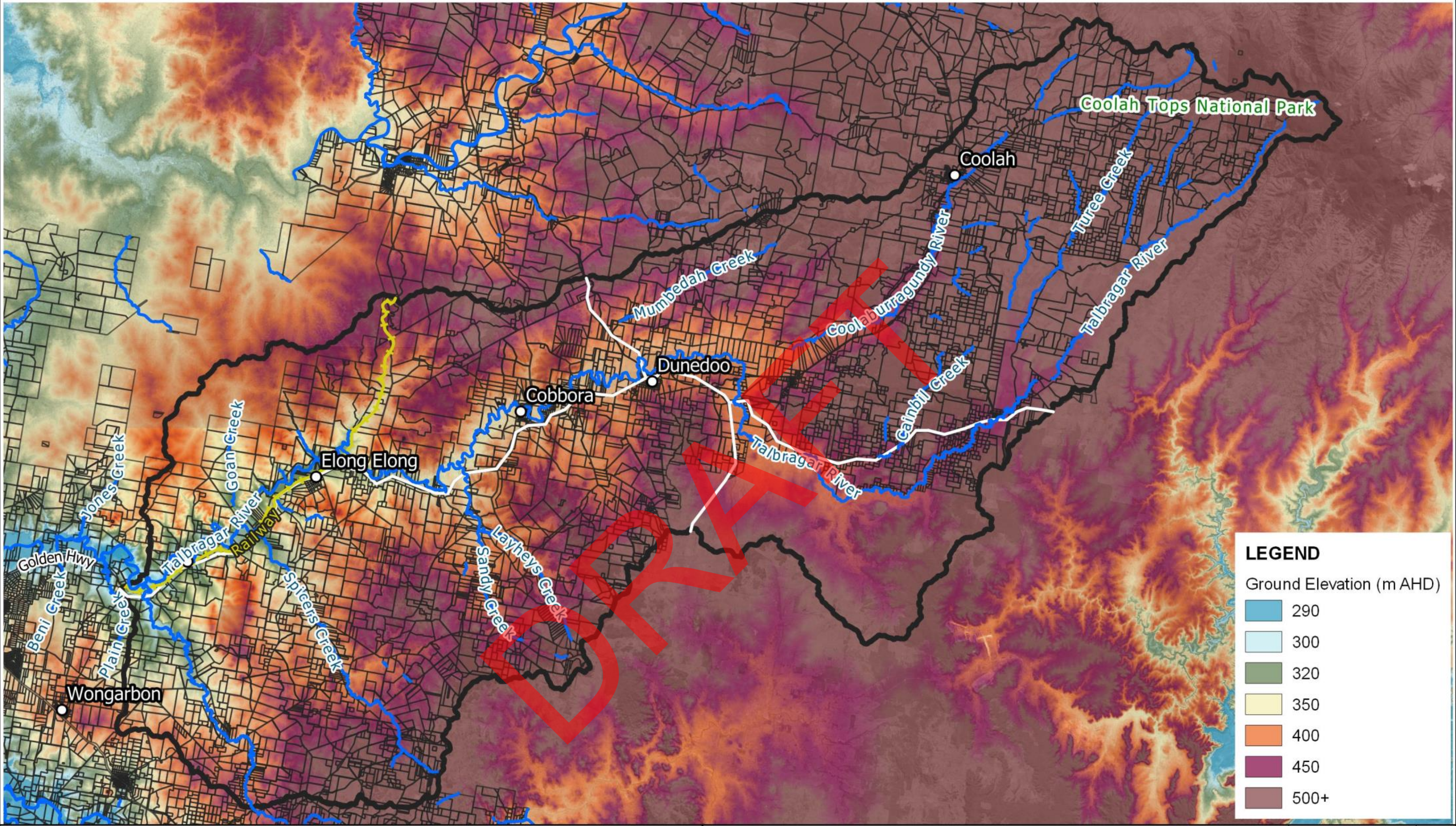
The topography of the Talbragar River catchment is shown in 0. Ground surface elevations range from about 1,100 mAHD at the catchment headwaters in Coolah Tops National Park to elevations around 300 mAHD in the lower lying and flatter floodplain areas surrounding Ballimore.

Land use within the Talbragar River catchment includes densely forested areas, particularly in the National Parks where the catchment headwaters are located. However, a significant portion of the catchment (about 85%) comprises cleared rural land with uses including agriculture and grazing.

In addition to mainstream inundation of Ballimore from the Talbragar River, the village may be subject to flooding from Ballimore Creek. This local tributary joins the river immediately east of Ballimore and has a total catchment area of approximately 30 km^2. The southern part of the catchment lays within the Yarindury and is situated at an elevation of approximately 450 mAHD, whilst the confluence with the Talbragar River is at approximately 300 mAHD.

There are several major transport routes traversing the catchment. West of Dunedoo, the Golden Highway is located on the southern floodplain of the Talbragar River and generally runs parallel to the river. The highway crosses the Talbragar River twice upstream of Dunedoo (approximately 20 km and 60 km upstream). The Dubbo to Merrygoen Railway also runs parallel to the Talbragar River for the majority of its reach within the study area, crossing the river approximately 30 km upstream of Ballimore, at Dunedoo and approximately 10 km upstream of Dunedoo. Both the Golden Highway and the Railway cross Ballimore Creek just upstream of its confluence with the Talbragar River.

Both the Golden Highway and Dubbo to Merrygoen Railway have the potential to impact flood behaviour where embankments traverse the floodplain and structures cross waterways. This infrastructure can also be impacted by mainstream flooding, causing significant transport disruption.



LEGEND

- Catchment Boundary
- Cadastral Boundary
- Watercourse
- Township
- Highway
- Railway

Title:

Catchment Topography

Drawing: 2-1

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2.3 Flood History

The village of Ballimore has experienced numerous historic flood events, with the largest flood on record occurring in 1955 (refer Figure 2.2). Table 2.2 lists the 10 largest events on record at the Elong Elong gauge, although it is noted that the 1955 flood pre-dates installation of this gauge in 1964 and therefore records do not include that event.

Table 2.2 Ten Largest Flood Levels Recorded at Elong Elong

Year	Gauge Level (m)	Water Level (mAHD)
2010	8.280	327.258
2000	7.765	326.743
1971	7.482	326.460
1998	6.987	325.965
1974	6.444	325.422
1976	6.111	325.089
2007	5.946	324.924
1990	5.783	324.761
1992	5.591	324.569
1983	5.554	324.532

During the 1955 event, intense rainfall occurred in the area over a 24-hour period commencing mid-morning on 23 February 1955 and continuing to around 12pm on 24 February 1955. More than 200 mm of rainfall was recorded during this period at all gauging stations in the Talbragar River catchment (Rust PPK, 1995). More moderate rainfall occurred within the catchment over the next 12 to 24 hours. Total rainfall depths of 300 mm to 350 mm were recorded in the Talbragar catchment during this event. The 1955 flood is generally accepted by many as equivalent to a 1% AEP event for the Talbragar River catchment (Rust PPK, 1995) and resulted in depths of inundation exceeding 1 m across the village.

Other notable floods were reported in 1870, 1920, 1926 and 1950. Whilst these floods are known to have broken the banks of the Talbragar River, floodwaters only backed up into low lying land adjacent to the river and resulted in only minor flood damage within the village.

During the most recent flood in 2010, only low-lying properties in Ballimore were impacted. The estimated flow for the 2010 event in the Talbragar River at Elong Elong station was 1,114 m^3/s (Cardno, 2019). Photographs of flooding during this event were provided during the community consultation and are shown in Figure 2.3 and Figure 2.4.

Figure 2.2 Federation Street during 1955 Flood

Figure 2.3 2010 Flood at Goan Creek Road (Source: Council)

Figure 2.4 2010 Flood at Bill Mills Bridge (Source: Council)

3 Community Consultation

3.1 Purpose

Community consultation has been an important component of this FRMS&P for Ballimore. The consultation has aimed to inform the community about the development of the floodplain risk management study and plan (including this flood study). It has provided an opportunity to collect information on the community's flood experience to be used as part of the flood study, their concerns on flooding issues, and feedback and ideas on potential floodplain management measures and other related issues. It also helps to develop and maintain community engagement with the study and any subsequent mitigation options, planning and flood emergency management.

The consultation was completed via a number of different consultation methods at various points within the FRMS&P process, as detailed in the following sections.

3.2 Community Information Letter and Questionnaire

A newsletter and community questionnaire for this study were sent to residents and businesses in Ballimore in March 2020 (refer Annex A).

The community information newsletter provided the community with an overview of the study, including:

- Background to the current study.
- Information on why flood studies and floodplain risk management studies are undertaken.
- Details on how the community can get involved.

The questionnaire sought to collect information and comments from the community on a range of items relating to the community's historic flood experiences and issues of concern, including:

- Ownership status of the property.
- Length of residency.
- Previous experience with flooding. Where previous experience with flooding had occurred, respondents were requested to provide information on the source of flooding, any financial damages incurred and any flood mitigation or response strategies employed during historic floods (e.g. sandbagging, raised equipment, etc). Photographs, observed flood depths and descriptions of flood behaviour within the catchment were also requested and, if provided, were extracted to further assist with the model calibration process.
- Potential flood management options to reduce flood risk in the study area.

In total, 12 questionnaire responses were received. The responses to the questionnaire indicate that:

- The majority (75%) of responding residents have ownership of their property. The respondents' property types is shown in Figure 3.1.
- Many respondents (58%) have resided at their property for more than 20 years. Table 3.1 summarises the length of residency for the respondents.
- A total of 7 (58%) of respondents have been impacted by flooding in the past and the source of flooding experienced is summarised in Figure 3.2.
- As shown in Figure 3.3, respondents have used several different methods for protecting their property against flooding. The most common method was lifting stock and equipment above floodwaters.
- Several historic events were identified from the consultation, however, there was no single event that was identified as the most significant event. The February 2020 and December 2010 events were reported as the most recognised events from the community consultation. Multiple respondents reported that during significant events, shallow (calf level) floodwaters inundated their property. However, limited flood marks were provided during consultation.
- Respondents provided information on a wide range of flood mitigation measures they would like Council to consider. Figure 3.4 displays the preferences for various mitigation measures, ranked by respondents from least preferred to most preferred.
- Flood mitigation measures for which respondents provide greater than 50% support include:
  - improvements in flood warning
  - increasing the frequency of maintenance works of creek channels (e.g. debris clearing, vegetation control)
  - roadside drainage works (e.g. channel widening, straightening, concrete lining, culvert enlargement).
- Other flood mitigation measures with 50% of support from respondents included:
  - improvements in emergency response procedures
  - application of firmer development controls in the floodplain for new development.

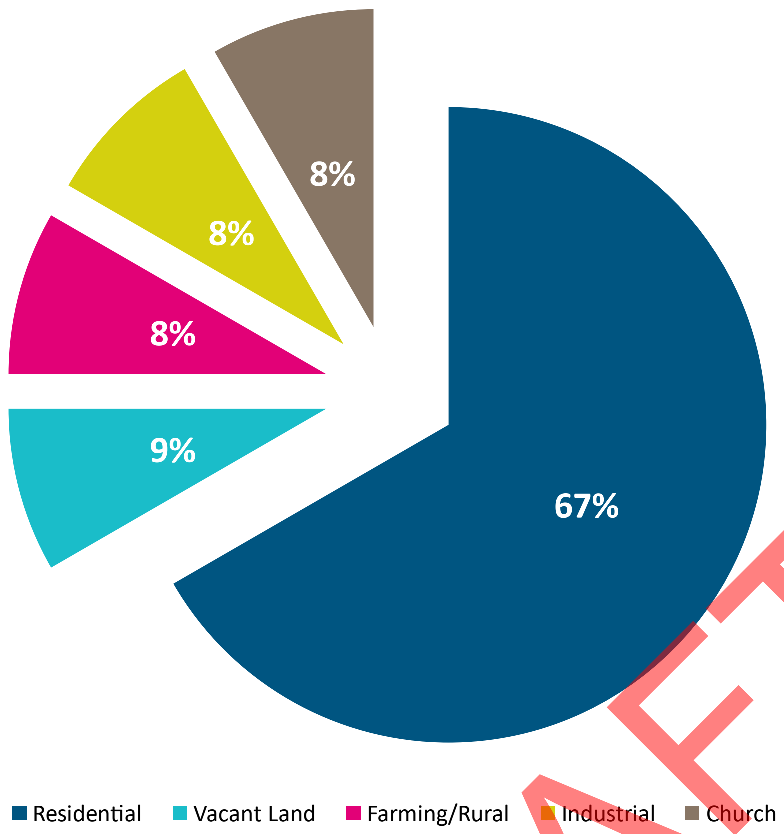


Figure 3.1 Questionnaire Responses – Property Types

Table 3.1 Respondents Length of Residency

Length of Residency	Number of Respondents	% Of Respondents
0 - 5 Years	3	25%
5 - 10 Years	0	0%
10 -20 Years	2	17%
More than 20 Years	7	58%
Not Stated	0	0%

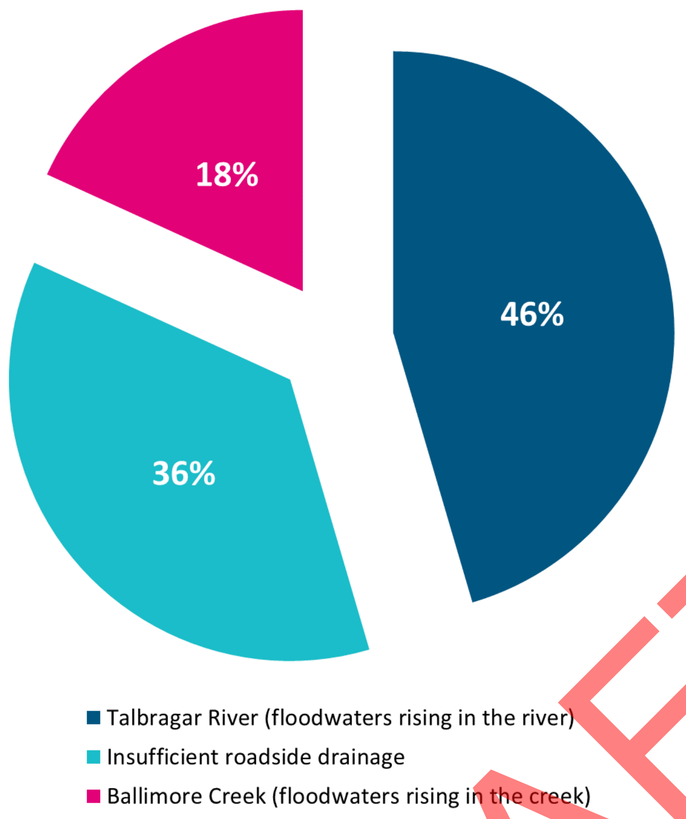


Figure 3.2 Questionnaire Response – Source of Flooding

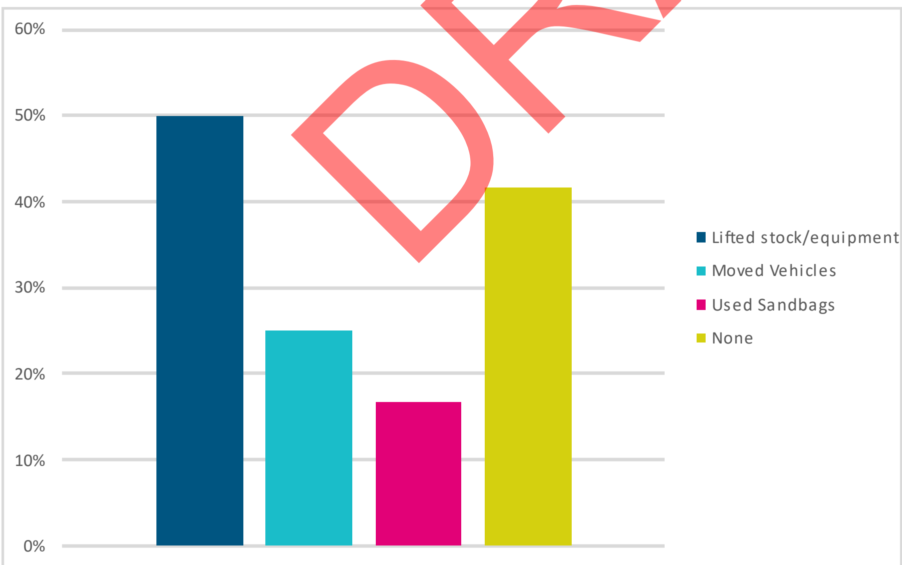


Figure 3.3 Questionnaire Responses – Actions taken to protect property against flood damage

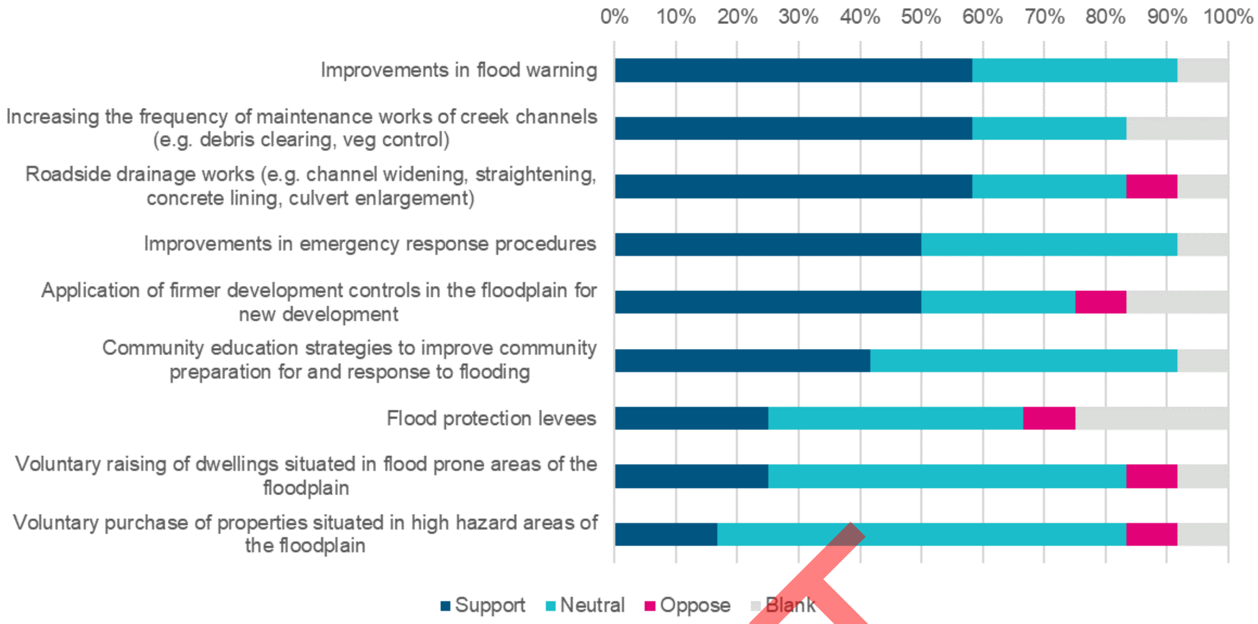


Figure 3.4 Questionnaire Responses – Support of Flood Mitigation Measures

3.3 Public Exhibition of Draft FRMS&P

[Information to be provided following completion of the public exhibition and consideration of submissions]

4 Data Collection and Review

4.1 Overview

The initial stage of the Flood Study involved the collection and review of relevant data. A description of each dataset and synopsis of its relevance to the current study below is provided as follows:

- Previous studies (Section 4.2)
- Geographic Information System (GIS) data (Section 4.3)
- Hydrologic data (Section 4.4)
- Topographic data (Section 4.5)
- Bathymetric data (Section 4.6)
- Hydraulic structure and drainage data (Section 4.7)
- Land use planning information (Section 4.8)
- Historic flood data (Section 4.9)
- Property floor level data (Section 4.10)
- Site inspections (Section 4.11)

Use of the datasets within the study for model development and calibration is documented within Sections 5 and Section 6.

4.2 Previous Studies

Past flood studies have been completed to investigate flood behaviour within Ballimore and across the Talbragar River floodplain, as discussed in the following sections.

4.2.1 Talbragar River Flood Study (Rust PPK, 1995)

In 1995, Rusk PPK completed the 'Talbragar River Flood Study' on behalf of Dubbo City Council. The flood study was undertaken to establish flood conditions along the downstream reach of Talbragar River within 10 km of the Macquarie River confluence, and therefore did not cover the floodplain at Ballimore.

The study involved the development and calibration of a RAFTS hydrologic model of the 4,950 km^2 river catchment (based on 78 sub-catchments) and MIKE-11 hydraulic model of the reach of the Talbragar River 10 km upstream of its confluence with the Macquarie River. The MIKE-11 model was based on surveyed cross-sections collected in 1995. Flood frequency analysis was also completed for the Talbragar River and Macquarie River catchments.

The RAFTS model was calibrated to the April 1990 event, which was estimated as a 20% AEP event for the Talbragar River catchment. Whilst the MIKE-11 model was calibrated to the 1955 flood, only one known flood level at the Newell Highway bridge at Dubbo was used to calibrate the model for the 1955 event. The RAFTS and MIKE-11 models were then used to simulate the 10%, 5%, 2% and 1% AEP floods, as well as an extreme event, (estimated based on flow three times the 1% AEP flow), with design flow rates being determined from the RAFTS hydrologic model.

The study estimated the flow in the Talbragar River at its confluence with the Macquarie River to be 4,250 m^3/s during the 1955 flood and 4,000 m^3/s for the 1% AEP event. The study also noted that examination of the Elong Elong gauge data indicated that for a given flood event during a period of overlapping data (1965-1974), historic flows were considerably lower than those recorded at Narranmore (located about 15 km upstream of the Elong Elong gauge) even though the Elong Elong gauge has a larger catchment area, suggesting that the rating curves generated for one (or both) of the sites may have been unreliable. However, the study was unable to identify the cause for this discrepancy between the rating curves at either or both of these gauging stations, and considering these uncertainties, the Narranmore gauge data was adopted for the flood frequency analysis (FFA) undertaken to verify the design flows produced by the RAFTS hydrologic model.

4.2.2 Ballimore Flood Study (Rust PPK, 1996)

The 'Ballimore Flood Study' was completed in 1996 by Rust PPK, on behalf of Dubbo City Council. The study focussed on flood behaviour within Ballimore village and was based on the hydrologic model from the 'Talbragar River Flood Study' (Rust PPK, 1995) and a HEC-2 hydraulic model developed specifically for this study. Surveyed cross-sections of the channel and floodplain were collected specifically for this study, however raw cross-section information is not contained within the report and the original HEC-2 model files have not been able to be located for use in the current study.

Due to the lack of available historic flood data, the HEC-2 model was not calibrated and adopted model parameters used in the MIKE-11 model for the 'Talbragar River Flood Study' (Rust PPL, 1995).

The RAFTS and HEC-2 models were used to define flood conditions for the 100%, 50%, 20%, 10%, 5%, 2%, 1% AEP floods and an extreme flood (estimated based on flow three times the 1% AEP flow). The peak 1% AEP flow at Ballimore was estimated to be approximately 3,500 m³/s from this study and the 1955 flood event was generally accepted as being equivalent to a 1% AEP event.

Key findings from the study included:

- Floodwaters are contained within the main river channel for all floods up to and including the 20% AEP event.
- All dwellings, with the exception of the tennis club house and toilet block, are above the 5% AEP flood level. 13 residences or businesses have floor levels below the 1% AEP flood level.
- Four residential properties were classified in the high hazard category, three residential properties were classified in the low hazard category and a number of businesses and depots would be inundated during the 1% AEP flood event.

Above floor flooding was assessed based on property floor levels obtained for 43 properties as part of the study, with data listed within the flood study report. These floor levels have been extracted and used as part of this FRMS&P.

The study also included the assessment of structural and on-structural flood mitigation measures, flood warning system and evacuation management planning and building and development controls. The only structural option considered was a flood protection levee, however this was not recommended due to an unfavourable cost-benefit ratio. The study recommended that Council should adopt a minimum floor height of 500 mm above the flood standard for any new dwelling within the village of Ballimore and develop a flood warning system and evacuation plan.

4.2.3 Talbragar River Supplementary Flood Study (PPK, 1999)

The Talbragar River Supplementary Flood Study was commissioned by Dubbo City Council to assist in the preparation of a Local Environmental Plan for Dubbo. The objectives of the study were to complete a supplementary flood model of the Talbragar River and integrate into the present study the findings of the Talbragar River Flood Study (Rust PPK, 1995) and the 'Review of the Macquarie River Flood Levels' (PPK, 1998).

The study was undertaken using the MIKE-11 model developed for the 'Talbragar River Flood Study' (Rust PPK, 1995) and defined updated flood levels were created for 1%, 2%, 5%, 10% and extreme flood event for the Talbragar River based on revised tailwater levels for the Macquarie River defined by flood levels established as part of the 'Review of the Macquarie River Flood Levels' (PPK, 1998). These modified tailwater conditions resulted in higher flood levels in the lower reaches of the Talbragar River (as a result of backwater flooding) when compared to the flood levels from the 'Talbragar River Flood Study' (Rust PPK, 1995). However, the flood levels in the upper reaches of the Talbragar River were largely similar to those from the previous study.

4.2.4 Macquarie River, Dubbo Compilation of Flood Studies Addendum (Cardno, 2019)

This study was completed by Cardno for Dubbo Regional Council. It included the compilation of outputs from assessments completed between 2014 and 2018 which culminated in the re-running of all historic and design floods using a TUFLOW HPC (Heavily Parameterised Computing) floodplain model based on a 6 m grid cell size and with adjusted Macquarie River inflows.

The study documents the peak flows for the Talbragar River at the Macquarie River confluence shown in 1.1.1.

Table 4.1 Peak Flows - Talbragar River at Macquarie River (Cardno, 2019)

Event	Peak Flow (m^3/s)
10% AEP	1,819
5% AEP	2,473
2% AEP	3,214
1% AEP	4,011
0.5% AEP	4,881
1955 Flood	4,185

4.3 Geographic Information System (GIS) Data

A number of digital GIS layers were either provided by Council or sourced by BMT to assist with this study, including:

- aerial photography
- cadastral lot and LGA boundaries
- roadway data (used for roadway labels)

In general, these GIS layers provide a suitable basis for preparing report figures and informing the development of hydrologic and hydraulic models.

4.4 Hydrologic Data

4.4.1 Rainfall Data

Rainfall data provides a high-quality dataset for use in the model calibration and validation process. It is used to define when historic rainfall events occurred, as well as the temporal patterns and rainfall depths for these events. There are two different rainfall gauge types that are used, these being:

- Daily rainfall data recorded over a 24-hour period to 9:00 am which provides an overview of the total amount of rainfall that occurred.

- Sub-daily rainfall data (continuous or pluviometer) recorded in small depth and time increments (less than 1 mm and usually at a 15 min/ 30 min time increment).

The Bureau of Meteorology (BoM) and Water NSW (WNSW) operate an extensive network of rainfall gauges across the east coast of NSW and within the Orana region of NSW. Comprehensive datasets of rainfall and river levels for the calibration/validation were collated as part of this study and are discussed in Section 6.

Overall, there are a large number of gauges both within the catchment and surrounding areas which provide a reasonable representation of rainfall and historical temporal patterns across the study area.

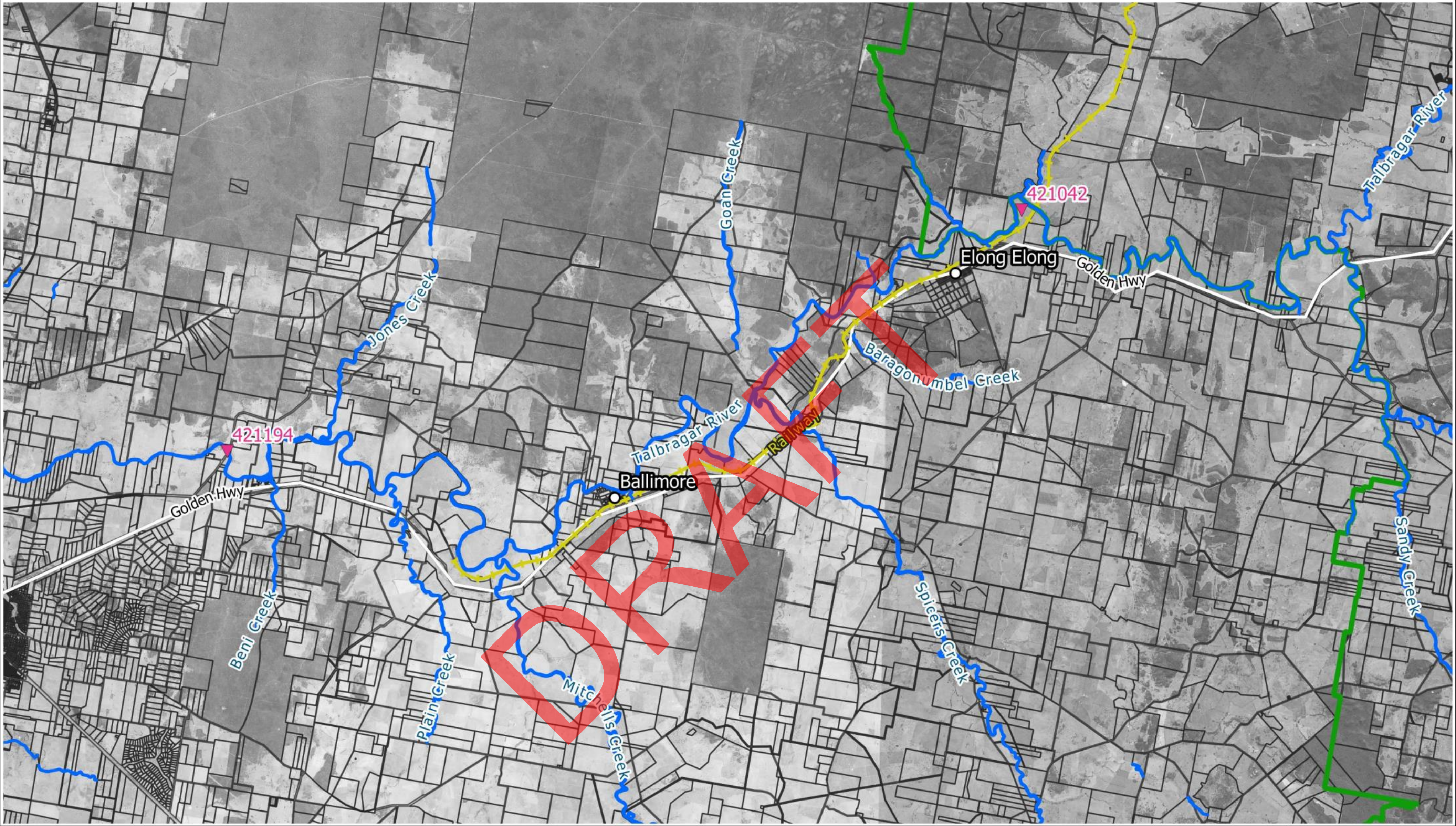
4.4.2 Water Level Gauges

There are two WaterNSW gauges within the catchment where water levels are recorded either continuously or intermittently. Currently operational continuous gauges are listed in Table 4.2, whilst the gauges used in this study are shown in Figure 4.1.

Table 4.2 Currently Operational Continuous Water Level Gauges

Gauge	Location	Commencement	Maximum Gauged (mAHD)
421042	Elong Elong	1964	5.260
421904	Dunedoo	2017	2.468

The Dunedoo gauge is approximately 62 km upstream of Ballimore but has only been in operation since 2017. The Elong Elong water level gauge is located about 20 km upstream of Ballimore, was installed in 1964 and has been in continuous operation since 1971. With 51 years of continuous record available, the Elong Elong gauge provides a suitable dataset from which to undertake a Flood Frequency Analysis (FFA), noting that it does not include the 1955 flood which is the largest historic flood experienced in recent history. Spot gauging, rating curves and channel cross-section information was obtained from the NSW Office of Water's PINNEENA database (2011) for the two gauged sites.



LEGEND

- Major Watercourses
- Dubbo Regional Council LGA Boundary
- Cadastral Boundary
- Water Level Gauge
- Highway
- Railway

Title:

Available Water Level Gauges

Drawing: **4-1**

Rev: **A**

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4.5 Topographic Data

Aerial topographic survey covering areas within the catchment was downloaded from the Elvis (Elevation Information System) Geographic Website[1] (where available) and provided by Council. This data provides extensive and detailed topographic coverage of the Talbragar River floodplain and wider catchment and is discussed below. The extent of available datasets is shown in Figure 4.2.

4.5.1 Catchment-scale Topography

The SRTM DEM-S (smoothed) dataset captured in 2000 used was at a 30 m resolution derived from the Shuttle Radar Topographic Mission (SRTM). It has been cleaned, filtered for vegetation, and smoothed by CSIRO as part of the one-second DEM for Australia project. This has been used to delineate the hydrologic model sub-catchments.

4.5.2 Floodplain Topography

The following topographic data is available to define the floodplain for the study:

- A 1 m resolution Light Detection and Ranging (LiDAR) survey provided by Council. The date of collection is unknown from the dataset provided.
- A 1m resolution LiDAR survey of the north-east portion of the hydraulic model area, flown for NSW LPI in December 2015.
- As the LiDAR did not cover the entire hydraulic model area, the remaining south-west portion was supplemented by the NSW Department of Finance Services and Innovation (DFSI) Surface Model Enhancement (SME) photogrammetry product from January 2013 at 5 m resolution.

These datasets were compiled into a Digital Elevation Model (DEM) covering the whole of the study floodplain. Where LiDAR data and photogrammetry overlapped, elevations were cross-checked to confirm the accuracy of the photogrammetry. The comparison indicated that elevations within the photogrammetry was generally comparable to those from the LiDAR data and did not exhibit a consistent under or over-estimation of elevations. Where datasets join, checks were performed to ensure there were no step changes which could result in artificial restrictions to flow. The interface of the two datasets provides for a clean transition and did not require any further modification for application as the base topography within the hydraulic model for this study.

4.6 Bathymetric Data

Cross-section data for the Talbragar River and its tributaries (including Ballimore Creek) was not available for use in this study. However, the channel geometry of these watercourses is considered to be typically well-defined within the LiDAR data. In the absence of available bathymetric data, a suitable approach to estimation of channel bed elevations within the hydraulic model for this study was developed and is discussed in Section 5.3.5.

4.7 Hydraulic Structure and Drainage Data

Design drawings for Bill Mills Bridge (Talbragar River) and the Golden Highway Bridge (Ballimore Creek) were provided by Council. Review of photographs taken during the site visit (refer Section 4.11) indicated that the Bill Mills Bridge design drawings differ from the works as executed. The Golden Highway Bridge design drawings provided were confirmed as being representative of the constructed works. Where structure design drawings are considered to be outdated or structure details were unavailable (e.g. railway bridge crossing of Ballimore Creek), structure dimensions were estimated from visual inspection, site photographs and/or desktop assessment (e.g. Google Street View). Invert, obvert

[1] https://elevation.fsdf.org.au

and desk elevations (where appropriate) were extracted from the DEM data at the inlet and outlet of the structure.

There are also numerous smaller local drainage structures located within the town, primarily providing roadside cross-drainage through road intersections and driveway crossings. All cross-drainage structures were photographed and measured during the site inspection (refer Section 4.11). The roadside channel on Bunyip Street is adequately captured by the 1 m resolution LiDAR data.

4.8 Land Use Planning Information

NSW Planning Environmental Planning Instrument (EPI) datasets were provided by the Department of Planning, Industry and Environment (DPIE). This data includes land use planning information that provides a means to distinguish between land use types across the study area and enable spatial variation of distinct hydrologic (e.g. rainfall losses) and hydraulic properties (e.g. Manning's 'n' roughness parameter).

4.9 Historic Flood Data

Historic flood data is required for model calibration and verification. Data for those historic events used for calibration (refer Section 6) was obtained from Council and provided by the community during the initial community consultation (refer Section 3.2). This includes:

- Historic flood photographs covering a range of events including: 1955, 2010, 2021 and 2016. This included 77 aerial and street-level photographs of Ballimore during the 2010 flood provided by Council. In addition to determining flood extents and depths / levels, photos with time-stamps can be used to validate the timing of the flood wave as it moves through the catchment. There were no photographs provided for the 1990 and 2000 events.

- Anecdotal data on flood conditions during historic floods. This included information indicating that rainfall at Coolah Tops normally takes approximately 3 days to increase water levels at Ballimore village.

Council do not have any surveyed flood marks for any historic events.

4.10 Property Floor Level Data

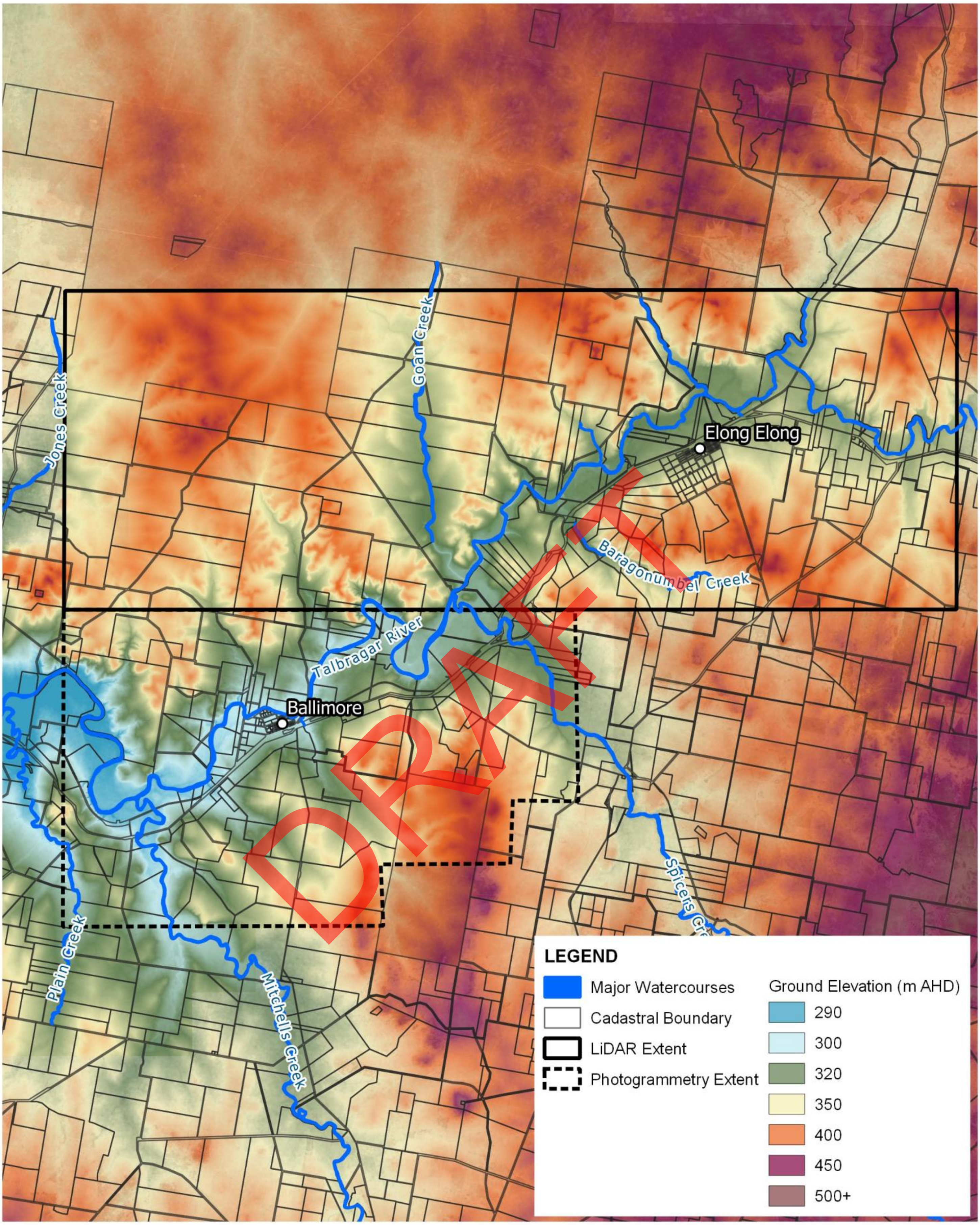
Flood level data for 43 properties in Ballimore was collected as part of the 'Ballimore Flood Study' (Rusk PPK, 1996). This data is listed in the report and has been extracted for use in this study.

4.11 Site Inspections

A site inspection was undertaken in the initial stages of the study to gain an appreciation of hydraulic features and their potential influence on the flood behaviour. Some of the key observations to be accounted for during the site inspections included:

- Presence of local structural hydraulic controls including road and railway crossings and associated embankments;
- General nature of the Talbragar River, Ballimore Creek and the associated floodplains noting river plan form, vegetation type and coverage and the presence of significant flow paths.
- Location of existing development and infrastructure on the floodplain.

This visual assessment was useful for defining hydraulic properties within the hydraulic model and ground-truthing of topographic features identified from the terrain datasets.



Title:

Extent of Topographic Datasets

Figure: **4-2**

Rev: **A**

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5 Model Development

5.1 Types of Models

Models are the most common and efficient tools for assessing flood behaviour within a catchment. The models developed for this study are broadly described as follows:

- *Hydrologic model* of the Talbragar River catchment draining to the Macquarie River (including the Ballimore Creek catchment). Hydrologic models transform rainfall into runoff and produce flow hydrographs which can then be used as input into hydraulic models.
- *Hydraulic model* extending through Ballimore and used simulate the distribution and movement of the runoff (or flow) across the floodplain and produce flood extents, levels, depths and velocities as outputs.
- *Statistical model* used to undertake Flood Frequency Analysis (FFA) for validating Talbragar River inflows derived by the hydrologic model and applied to the hydraulic model (refer Section 7).

It is recognised that the significant size of the Talbragar River catchment can introduce limitations when applying design rainfall in hydrologic models. This primarily relates to assumptions when applying a consistent design rainfall temporal pattern across the whole of the catchment. Therefore, where possible, FFA is considered to be a superior approach (relative to hydrologic modelling) when undertaken on a long and reasonably reliable record of river flows that covers the range of design magnitudes to be considered for a study.

Whilst the Elong Elong gauge has 51 years of continuous record available and is suitable in terms of both record length and data reliability, the period of record does not include the 1955 flood (i.e. the largest flood on record) which is estimated to be in the order of a 1% AEP event. Therefore, FFA cannot be used to reliably define flow hydrograph timing and shape for larger magnitude events in the order of the 1% AEP event and rarer. Accordingly, it was considered more appropriate to adopt a hydrologic modelling approach to derive design inflows for the Talbragar River, as well as inflows from tributary (e.g. Ballimore Creek, Spicers Creek, Goan Creek, etc) and floodplain sub-catchments downstream of Elong Elong and within the hydraulic model extent.

Information on the topography and characteristics of the catchments and floodplains are built into the hydrologic and hydraulic models. The models are then calibrated to recorded historical flood data (see Section 6), and subsequently used for design event simulation (see Section 8).

5.2 Hydrologic Model

5.2.1 Hydrologic Modelling Approach

The Watershed Bounded Network Model (WBNM) software was used to develop a hydrologic model covering the entire catchment area that contributes flow to the Talbragar River (i.e. from its headwaters to the outlet at the Macquarie River). Ballimore lies approximately 36 km upstream the outlet of the catchment.

WBNM is a model that is commonly used on flood studies in Australia and consists of a network of sub-catchments and sub-catchment links. Rainfall is applied within the model and a loss model used to convert the total rainfall to a net rainfall (i.e. the rainfall after losses due to factor such as vegetation interception and infiltration to the ground). Catchment lag and stream lag parameters are applied to the model to represent the responsiveness of the catchment to rainfall events. Inputs required to the WBNM model can include the following:

- catchment area (permeable and impermeable)

- rainfall depth and its spatial and temporal variation
- antecedent moisture conditions (dryness/wetness) of the catchment (i.e. initial rainfall loss) and continuing rainfall loss to represent ongoing infiltration during an event.

The model development and adopted parameters are discussed in the following sections.

5.2.2 Sub-Catchment Delineation

A single WBNM hydrologic model was developed to cover the entire catchment area that contributes flow to the Talbragar River. The SRTM digital elevation model (DEM) was used to delineate sub-catchment using an automated process in the CatchmentSIM software. Sub-catchment boundaries determined through this automated process were verified to form the final sub-catchment delineation. The study area was delineated into 115 sub-catchments as shown in 0 and listed in Table 5.1.

Table 5.1 WBNM Model Sub-catchment Properties

Catchment ID	Area (ha)	Catchment ID	Area (ha)	Catchment ID	Area (ha)
1.01	5065	3.01	5123	19.01	8188
1.02	8867	3.02	5039	20.01	5000
1.03	5253	3.03	5122	21.01	5004
1.04	5039	4.01	5450	21.02	5296
1.05	7159	5.01	7182	21.03	6034
1.06	5094	5.02	4996	21.04	5261
1.07	8548	6.01	5729	21.05	5017
1.08	5566	6.02	7056	21.06	9667
1.09	5698	7.01	5001	22.01	5324
1.10	5682	7.02	5139	23.01	5091
1.11	5427	7.03	5401	23.02	5264
1.12	5188	7.04	5100	1.24a	603
1.13	5342	7.05	5489	1.25a	2259
1.14	5122	7.06	5101	1.25b	548
1.15	1565	7.07	6622	1.26a	202
1.16	4902	7.08	5346	1.26b	4557
1.17	5496	7.09	5051	1.27a	1297
1.18	7146	8.01	5328	1.27b	1590
1.19	5401	8.02	6757	1.27c	371
1.20	5160	9.01	5012	1.28a	351
1.21	5540	10.01	5273	1.28b	3728
1.22	5074	10.02	5025	1.29a	4398
1.23	5010	11.01	5173	1.30a	542

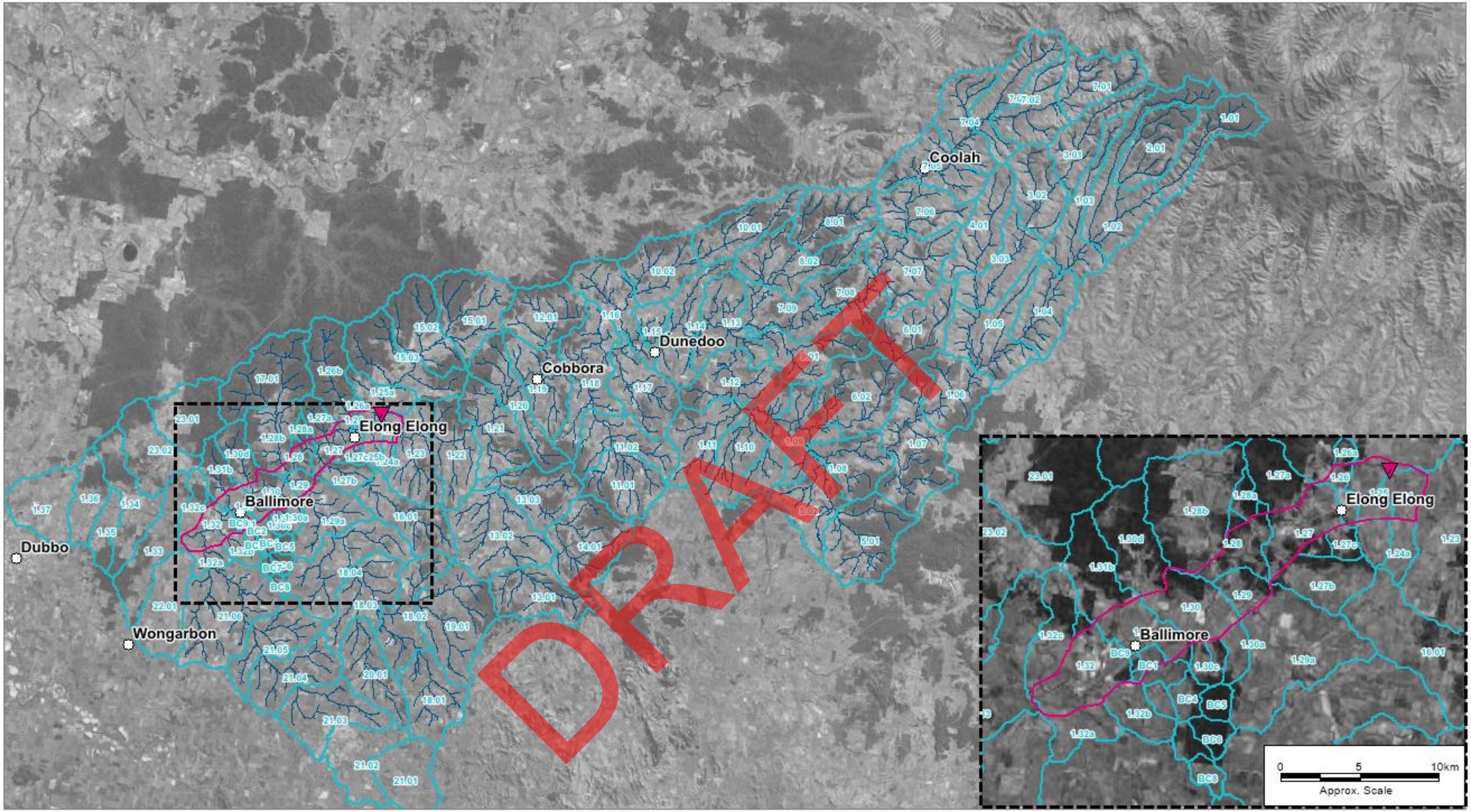
Catchment ID	Area (ha)	Catchment ID	Area (ha)	Catchment ID	Area (ha)
1.24	719	11.02	5010	1.30b	189
1.25	880	12.01	5198	1.30c	395
1.26	469	13.01	5394	1.30d	2171
1.27	1757	13.02	8356	1.31b	1736
1.28	1243	13.03	5120	1.32a	1004
1.29	693	14.01	7069	1.32b	1041
1.30	1710	15.01	6347	1.32c	1503
1.31	1379	15.02	5721	BC1	249
1.32	2200	15.03	6669	BC2	366
1.33	5532	16.01	5164	BC3	288
1.34	5265	17.01	7078	BC4	492
1.35	1963	18.01	5399	BC5	400
1.36	3315	18.02	5367	BC6	451
1.37	5005	18.03	5201	BC7	396
2.01	5324	18.04	7471	BC8	378
				BC9	68

5.2.3 Catchment Parameters

The model input parameters adopted for each sub-catchment within the WBNM model are:

- Lag factor: A lag factor (termed "C") can be used to accelerate or delay the runoff response to rainfall. This influences the shape of the hydrograph, as well as the catchment's channel routing properties that affect routing speed and attenuation. A lag factor of 1.74 was adopted during the model calibration process. This value lies within the recommended lag parameter range of 1.3 to 1.8 defined within the WBNM User guide.
- Stream Flow Routing Factor: Flow (runoff) routing is a technique used to route the sub-catchment hydrographs from the top to the bottom of the catchment system. There are different types of routing techniques in WBNM, such as stream lag, time delay and Muskingum. For the hydrologic analysis, the stream lag technique was deemed suitable as the study area predominately consists undeveloped catchments and natural streams. A stream flow routing factor of 1.0 for natural streams was adopted. This parameter is recommended to slow-down in-channel flows occurring through each sub-catchment.
- Impervious Area Lag Factor: An impervious area lag factor of 0.10.
- Impervious Percentage: As the majority of the catchment is non-urbanised, the percentage of catchment area with an impervious surface was assumed to be 0%.
- Rainfall Losses: During a typical rainfall event, not all of the rain falling on a catchment is converted to runoff. Some of the rainfall may be intercepted and stored by vegetation, some may be stored in small depressions and some may infiltrate into the underlying soils. The hydrologic model incorporates a rainfall loss model that accounts for these rainfall "losses". For this study, the "Initial-

Continuing" loss model was adopted. This loss model assumes that a specified amount of rainfall is lost during the initial saturation/wetting of the catchment (referred to as the "Initial Loss"). Further losses are applied at a constant rate to simulate infiltration/interception once the catchment is saturated (referred to as the "Continuing Loss Rate"). The initial and continuing losses are deducted from the total rainfall over the catchment, leaving the residual rainfall to be distributed across the catchment as runoff. Rainfall losses calculated as initial and continuing losses to represent infiltration. These vary for historic and design events and were determined through model calibration (see Section 6).



LEGEND

TUFLOW Model Boundary

Watercourses

1:01 Sub-catchment Boundary

Elong Elong Gauge

Title:

WBNM Model Sub-catchment Layout

Figure: 5-1

Rev: A

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Approx. Scale

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5.3 Hydraulic Model

5.3.1 Hydraulic Modelling Approach

TUFLOW was used for the hydraulic modelling for this study. TUFLOW is an industry leading hydraulic modelling software used extensively across Australia and internationally. An integrated 1D/2D TUFLOW hydraulic model was developed to simulate the dynamic interaction between in-bank flows within watercourses, overland flows in parts of the floodplain and major cross-drainage structures. The model employs the following TUFLOW features:

- Quadtree feature - Allows for the model grid resolution to be varied across the model domain. This has enabled the village of Ballimore to be modelled at a finer grid resolution whilst retaining a coarser resolution in areas that do not require a fine resolution.
- Heavily Parallelised Computation (HPC) solver – Enables 2D models to be simulated on computers' Graphical Processing Units (GPU) rather than the traditional approach of using the Central Processing Units (CPU). This allows for large catchments to be modelled at a high resolution whilst retaining practical simulation times.
- Sub-Grid-Sampling (SGS) feature - Allows the model to make maximum use of the underlying terrain data.

5.3.2 Model Extent

Consideration was given to the following in determining the extent of the TUFLOW model:

- Focus of the study outcomes on regional Talbragar River flood behaviour, with consideration of the influence of Ballimore Creek, within and around Ballimore village.
- Accuracy of model results required to meet the study's objectives.
- Topographic data coverage and resolution.
- Location of recorded data (e.g. levels/flows for calibration).
- Location of controlling features (e.g. detention basins, levees, bridges).

The model extent is shown in Figure 5.2. The model area extends about 38 km upstream of Ballimore (3.5 km upstream of the Elong Elong gauge) and 9 km downstream of Ballimore. The area modelled within the 2D domain comprises a total area of approximately 109 km^2.

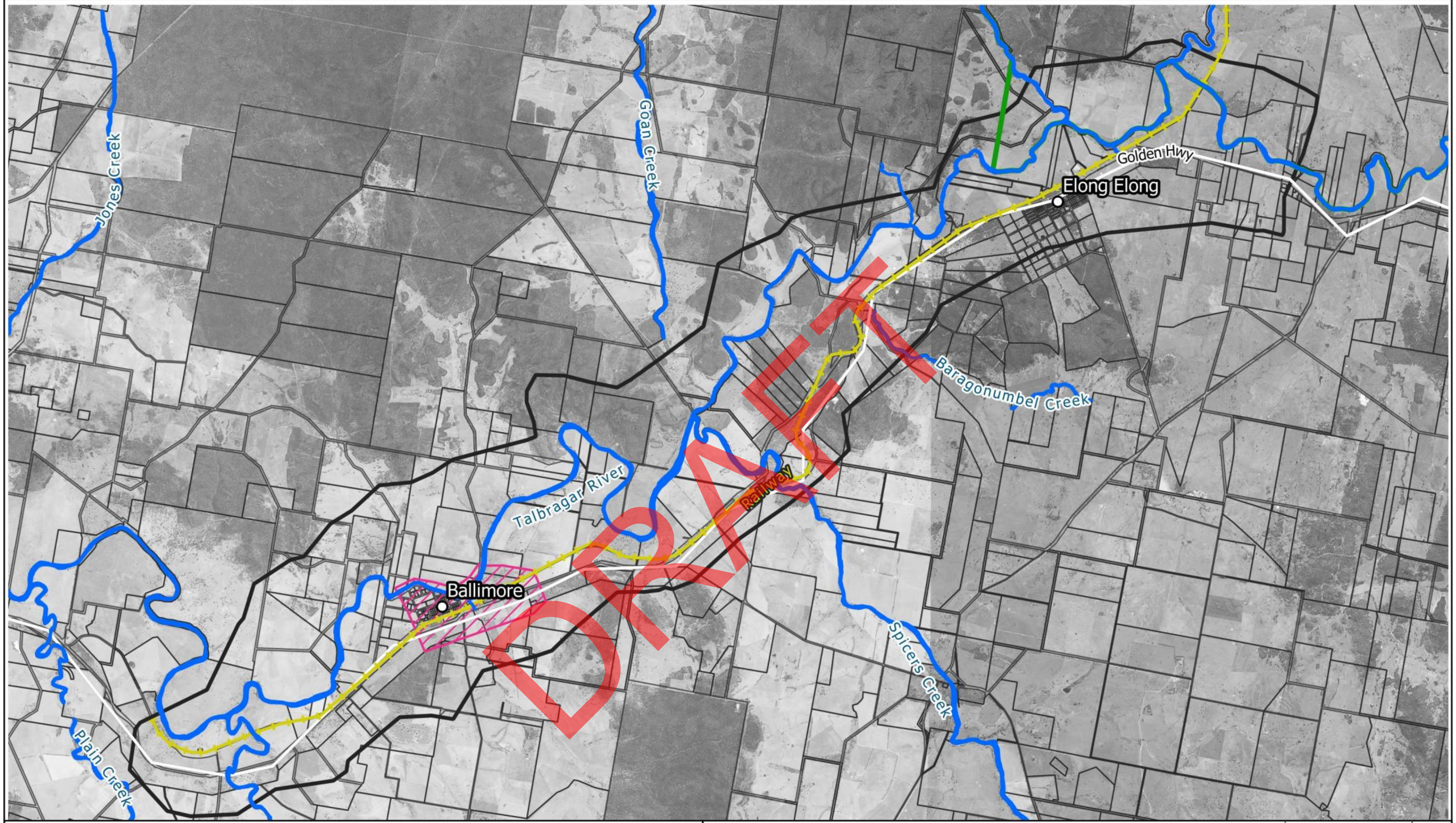
5.3.3 Model Resolution

As discussed in Section 5.3.1, TUFLOW's Quadtree feature has been used in order to vary the cell size across the model domain. The adopted cell size configuration across the model extent is shown in Figure 5.2 and is summarised as follows:

- 16 m based grid cell size across majority of modelled floodplain paired with a 1 m SGS approach.
- Three layers of refinement applied, yielding a 2 m grid cell size at Ballimore Village. This resolution was selected to give detail required for accurate representation of floodplain and channel topography and its influence on overland flows.

5.3.4 Topography

The ability of a model to provide an accurate representation of the flow distribution on the floodplain depends largely on the quality of the underlying topography. A high-resolution DEM was derived for the study area based on available LiDAR data and photogrammetry datasets (refer Section 4.5.2). This DEM was applied within the hydraulic model.



LEGEND

- Major Watercourses
- TUFLOW Model Extent
- 2m Model Extent
- Dubbo Regional Council LGA Boundary
- Cadastral Boundary
- Highway
- Railway

Title:

TUFLOW Model Extent

Drawing: 5-2

Rev: A

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5.3.5 River Bathymetry

It is noted that bathymetry data was not available for this study. To mitigate changes in elevations throughout the datasets and the lack of bathymetric data, a gully line was implemented within the TUFLOW model to represent the channel bed of the Talbragar River. This was determined based on a line of best fit between the topographic datasets listed in Section 4.5.2, with priority given to the 1 m data (refer Figure 5.3).

Figure 5.3 Adopted Talbragar River Channel Bed Invert Levels

The Talbragar River cross-section at the Elong Elong gauge was obtained from WaterNSW and compared to the river cross-section within the TUFLOW model at the gauge location. This comparison, shown in Figure 5.4, indicates that there is a good correlation between these cross-sections and that the adopted approach to modelling the river bathymetry is suitable for the purposes of this flood study.

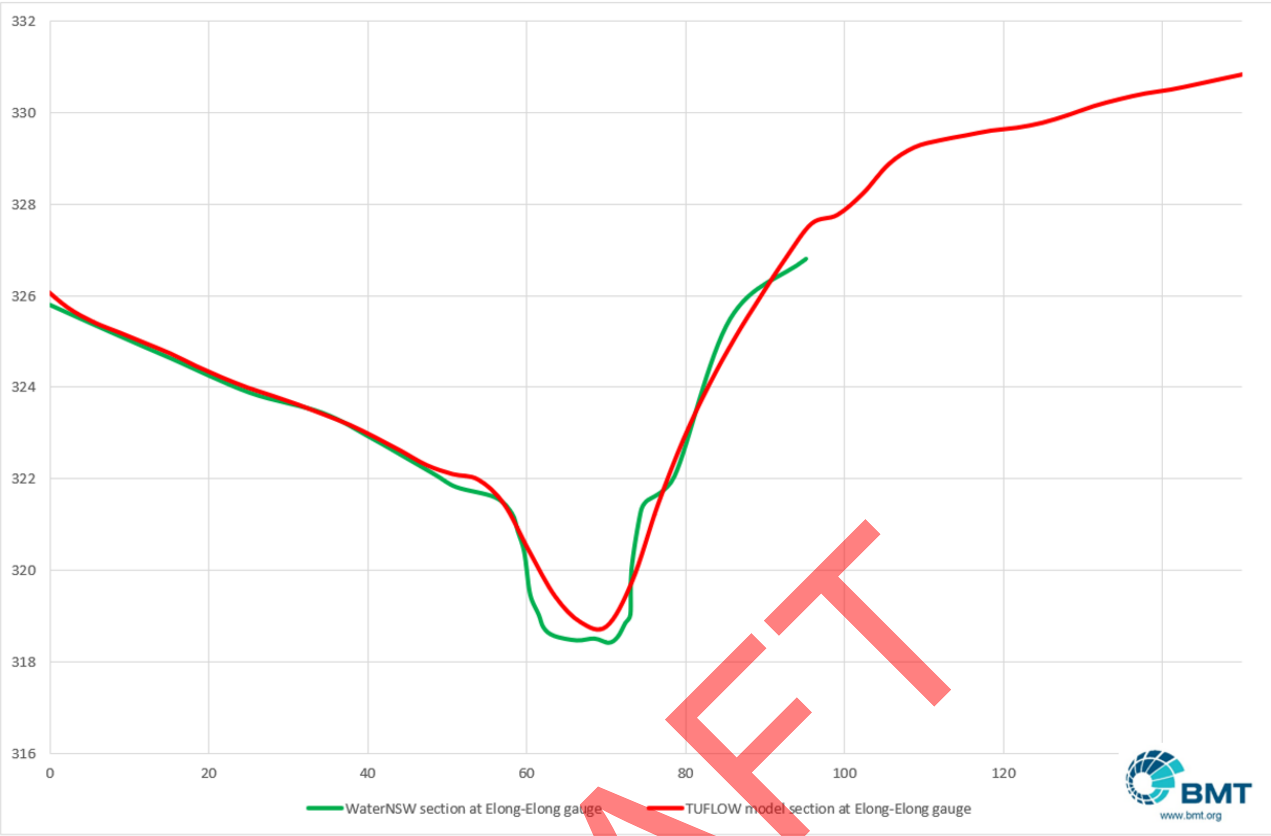


Figure 5.4 Comparison between WaterNSW and TUFLOW Model Cross-section for the Talbragar River at Elong Elong Gauge

5.3.6 Hydraulic Roughness

Manning's 'n' values are used to describe the variation in flow resistance afforded by different surface materials / land uses (e.g. trees, grass, roads, etc) within the extent of the TUFLOW model. These are specified based on land use categorisation (or roughness zones) that define the Manning's 'n' hydraulic roughness properties of each grid cell within the 2D domain.

Land use planning data, roadways and railway GIS layers, streamline GIS layers and aerial photography was used as the basis for defining the different hydraulic roughness zones within the model. Initial values of Manning's 'n' were based on a combination of industry standard values and then refined through the model calibration process (see Section 6).

Table 5.2 and Figure 5.5 shows the land use types and final Manning's 'n' values after model calibration. These values represent present day catchment conditions.

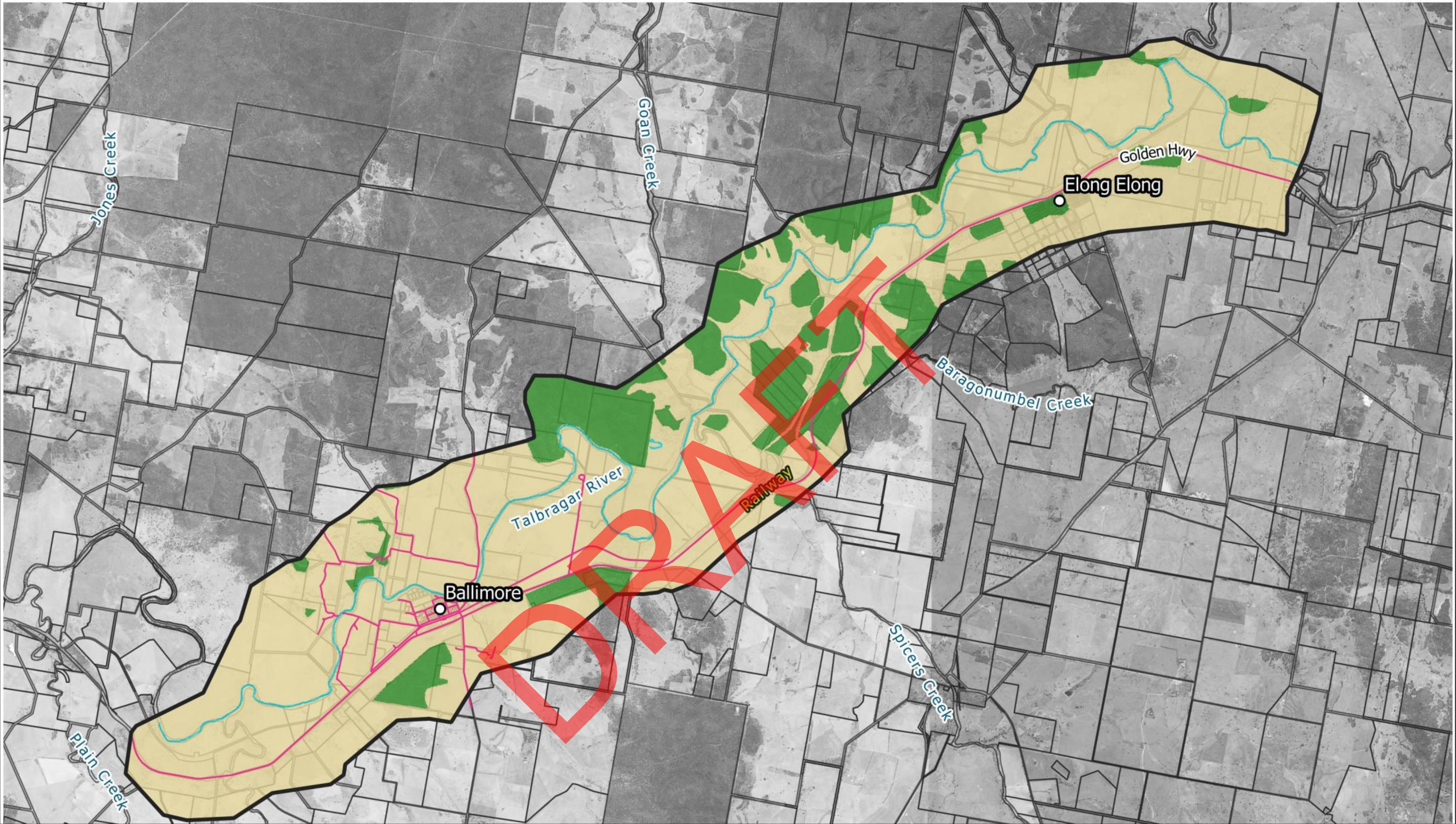
Table 5.2 Adopted Manning's 'n' Values

Land use	Manning's 'n' value
Talbragar River	0.04
Ballimore Creek	0.06
Pastureland	0.06
Forested flood areas	0.12

Land use	Manning's 'n' value
Roadways	0.02
Ballimore Village	0.06

5.3.7 Representation of Buildings

The representation of buildings is important in areas conveying significant volumes of flow or experiencing significant ponding depth. For this study, buildings are represented by removing the building footprints from the active model area. This assumption means that floodwater does not pass through and must flow around buildings, and storage effects within the building are not considered.



LEGEND

- TUFLOW Model Extent
- Cadastral Boundary

Roughness Types (Manning's n value)

- Floodplain (n=0.06)
- Forested (n=0.12)
- Roads (n=0.02)
- Creek (n=0.04)

Title:

Hydraulic Roughness Zones

Drawing: **5-5**

Rev: **A**

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5.3.8 Boundary Conditions

The specification of suitable boundary conditions that account for design flows into the system and downstream conditions at the outlet of the system is a critical component of flood simulations. Model boundary locations are shown in Figure 5.7, noting that the Elong Elong river gauge is located about 3.5 km downstream of the upstream boundary of the model on the Talbragar River.

The boundary conditions used for the TUFLOW model include:

- Upstream boundary conditions: Total flow hydrographs (i.e. flow vs time) from the WBNM model are applied at the upstream boundary of the model extent and each local tributary inflow. The hydrographs for historical and design events were derived from the results of the WBNM hydrological model developed for the study (discussed further in Section 6 and Section 8).
- Local Inflow conditions: Local or total sub-catchment runoff hydrographs derived by the WBNM model are applied as inflow hydrographs directly to the 2D model domain at the outlet of the sub-catchment.
- Downstream boundary condition: The study area is affected by mainstream flooding mechanisms. At the downstream boundary, flooding is generally contained within the banks or breakouts along the Talbragar River. The downstream model extent on the river is defined as a "HQ" type boundary. This TUFLOW boundary type automatically generates a rating curve (water level vs. flow relationship) at the model boundary based on channel and floodplain geometry, Manning's 'n' roughness values and a user specified energy slope of 0.2%.

5.3.9 Hydraulic Structures

There are numerous culvert and bridge structures located throughout the study area that enable cross-drainage under major roads and railway lines. These structures vary in terms of size and configuration, with differing degrees of influence on local hydraulic behaviour. Incorporation of structures in the TUFLOW model provides for simulation of hydraulic losses associated with these structures and their influence on flood behaviour within the study area.

Structures are included in the TUFLOW model if they have the potential to impact on regional flood behaviour, particularly around Ballimore Village. Key main river structures (bridges) and the relevant sources of data for these structures area listed in Table 5.3. Local culverts within Ballimore village (refer locations in Figure 5.6) were also incorporated into the TUFLOW model.

Bridges were modelled using TUFLOWs layered flow constriction feature. This allows for separate layers to be specified for the sub-structure, superstructure and any railings or safety barriers. 100% blockages were applied to represent the bridge deck with full/partial blockages to represent any guard rails. The sub-structure (piers) were represented through the application of a derived form loss coefficient to the model that accounted for factors such as pier type, pier skew, the obstructed flow area due to piers and abutments, skew of the structure relative to the channel. Losses were calculated based on structure design drawings (where possible) and using techniques contained in the 'Hydraulics of Bridge Waterways' (Bradley, 1978).

Culverts were modelled as 1D structures embedded within the 2D domain. Dimensions and invert elevations for circular or rectangular culverts were included directly in the TUFLOW model. An entrance loss coefficient of 0.5 and an exit loss coefficient of 1.0 were adopted for all culverts.

Table 5.3 Hydraulic Structure Details

Name	River / Creek	Source	Comment
Bill Mills Bridge	Talbragar River	Dubbo Regional Council Plan ID B375 No Date	Design drawings differed to the works as executed. Measurements were recorded during a site visit, and LiDAR data used.
Golden Highway Bridge	Ballimore Creek	Dubbo Regional Council Plan ID 206 B505 Dated 25 August 1971	Works as Executed
Remaining Bridges along Golden Highway & Railway	Multiple Watercourses	LiDAR	Approximate Representation
Local drainage culverts	N/A	BMT measurements (not surveyed) LiDAR	Approximate Representation

Figure 5.6 Location of Modelled Culverts in the Vicinity of Ballimore

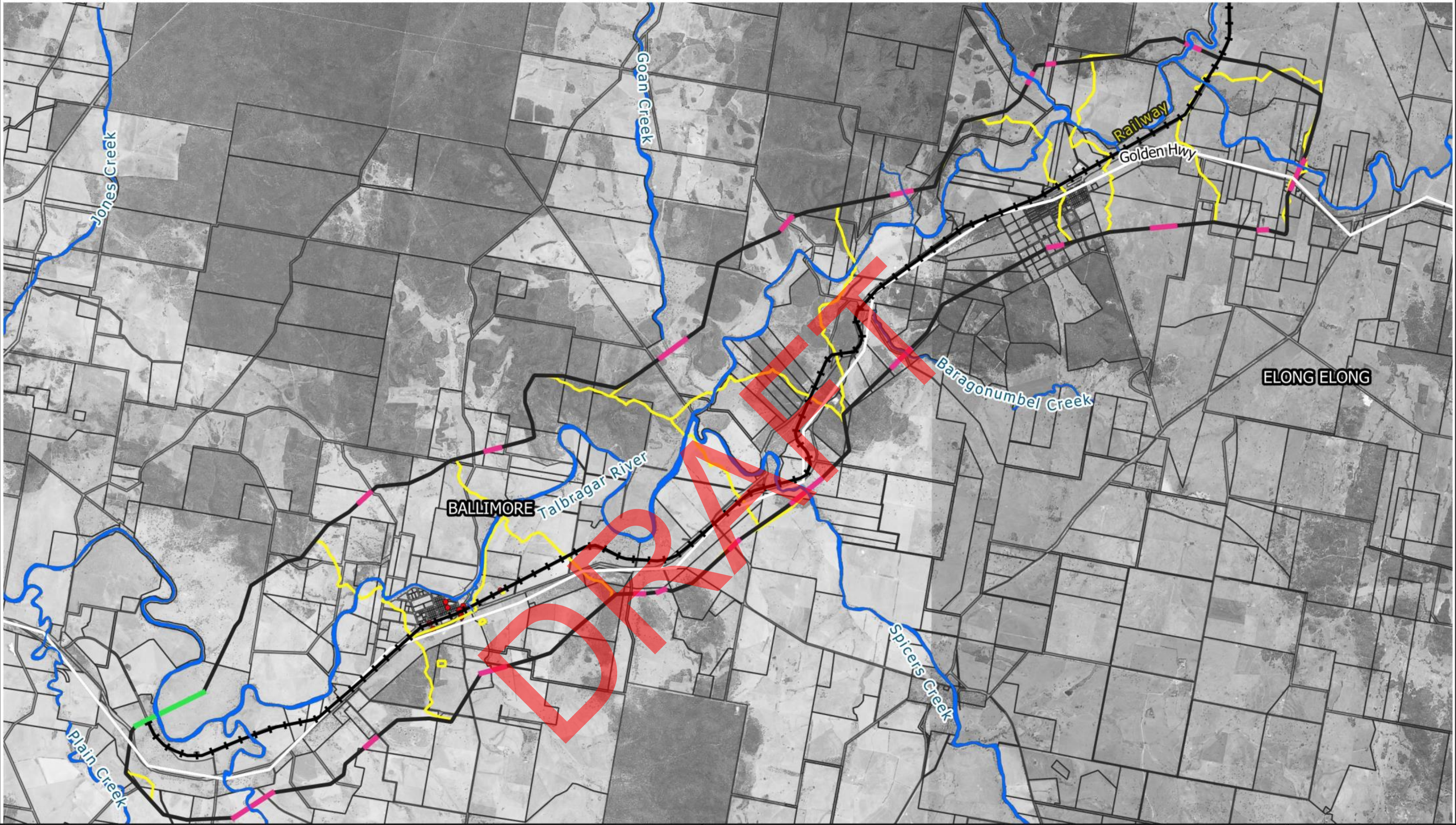
5.3.10 Structure Blockage

Following ARR2019 procedures, a blockage assessment was completed for the Golden Highway and railway bridges on the Ballimore Creek. The assessment was based on visual and desktop inspection of the area (using aerial photography) and considers brushes and tree limbs up to 10 m long as main sources of blockage. Conservatively, 10% blockage was calculated for frequencies between 5% and 0.5% AEP, whilst 20% blockage was assigned to the rarer design events. No blockage was considered for the events more frequent than the 5% AEP. An additional 5% blockage was also applied the waterway obstruction afforded by bridge piers.

For local culverts within Ballimore village (refer locations in Figure 5.6), the following blockage percentages were assumed:

- 0% blockage for all events more frequent than the 1% AEP flood.
- 50% blockage for the 1%AEP flood and for the 0.5% AEP flood.
- 100% blockage for all events rarer than the 0.5% AEP flood.

The effect of blockage assumptions was tested as part of the sensitivity analysis (refer Section 9).



LEGEND

- TUFLOW Model Extent
- Cadastral Boundary
- Sub-catchments
- Major Watercourses
- Culvert
- Sub-catchment Inflows
- Water Level Boundary
- Highway
- Railway

Title:

TUFLOW Hydraulic Structures and Model Boundaries

Drawing: 5-7

Rev: A

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6 Model Calibration

6.1 Overview

Computer flood models are approximations of very complex processes and are generally developed using parameters that may not be known with a high degree of certainty and/or are subject to natural variability. This includes catchment and floodplain roughness (i.e. Manning's n values), initial/continuing rainfall losses, and loss coefficients and blockage at culverts, bridges, pipes and stormwater pits. Accordingly, hydrologic and hydraulic models should be calibrated and/or validated against available historic flow and flood level information to establish the values of key model parameters and confirm that the models are capable of producing reliable estimates of flood behaviour.

The selection of historic events used for the purposes of model calibration and validation is generally based on whether they meet the following criteria:

- They are significant flood events.
- They are recent events which reflect existing floodplain conditions.
- They have a good amount of recorded data including rainfall and river level data.

Significant events which occurred many years ago can still be useful if recorded data is available as the model can be updated to approximate prior floodplain conditions.

It is typically necessary to have the following datasets to enable full calibration of hydrologic and hydraulic models:

- Historic rainfall data describing the temporal and spatial distribution of rainfall across each catchment for historic floods. Recorded rainfall data is typically either:
  - Daily data with depths recorded in 24-hours increments.
  - Sub-daily, pluviograph data where rainfall is usually logged in depth intervals of 0.5 mm or 1 mm and captures greater detail on the temporal variability of the rainfall.
- Stream gauge data describing the time variation in river level at gauge locations.
- Historic flood/debris marks where the peak height that water reached during historic floods has been measured.
- Anecdotal data, such as photographs and other observations of flood behaviour, noting that these may not be at the peak of the flood.

Ideally, the calibration process should cover a range of flood magnitudes to demonstrate the suitability of the model to predict flood conditions for the range of design flood magnitudes considered in the study.

6.2 Selection of Calibration Events

Initially, several calibration events were considered, including the February 1971, April 1990, November 2000 and December 2010 events. Data available for these events and calibration event selection is summarised in the following sections.

6.2.1 Rainfall Data

The availability of rainfall data is provided in Table 6.1.

Table 6.1 Summary of Available Rainfall Data for Historic Floods

Rainfall Gauge	Type	Source	Rainfall Data Available			
			1971	1990	2000	2010
51049 Trangie Research Station AWS	Pluvio	BoM	Yes	Yes	Yes	Yes
55006 Blackville Post Office	Daily	BoM	Yes	Yes	Yes	Yes
55017 Premer (Eden Moor)	Daily	BoM	Yes	Yes	Yes	Yes
55057 Willow Tree (Valais)	Daily	BoM	Yes	Yes	Yes	Yes
55061 Blackville (Welton Dale)	Daily	BoM	-	Yes	-	-
55287 Yarraman North	Daily	BoM	-	Yes	-	-
55297 Blackville (Junbarlee)	Daily	BoM	Yes	Yes	Yes	Yes
61287 Merriwa (Roscommon)	Pluvio	BoM	Yes	Yes	Yes	Yes
62005 Cassilis Post Office	Pluvio	BoM	Yes	Yes	-	Yes
62009 Cassilis (Dalkeith)	Daily	BoM	Yes	Yes	Yes	Yes
62013 Gulgong Post Office	Daily	BoM	Yes	Yes	Yes	Yes
62015 Merriwa (Merry Vale)	Daily	BoM	Yes	Yes	-	Yes
62020 Bylong (Montoro)	Pluvio	BoM	Yes	Yes	-	-
62035 Leadville (Moreton Bay)	Daily	BoM	Yes	Yes	Yes	Yes
62044 Cassilis (Manderlay)	Daily	BoM	-	Yes	-	-
62050 Borambil (Rosebud)	Daily	BoM	-	Yes	-	-
62051 Cassilis (Yarrawonga)	Daily	BoM	-	Yes	-	-
62052 Two Mile Flat Post Office	Daily	BoM	-	Yes	-	-
62053 Ulan Power Station	Pluvio	BoM	-	Yes	-	-
62076 Cassilis (Talbragar)	Daily	BoM	-	Yes	-	-
62102 Bylong (Bylong Road)	Pluvio	BoM	-	-	Yes	Yes
64009 Dunedoo Post Office	Pluvio	BoM	-	Yes	-	-
64011 Dunedoo (Martindale 2)	Daily	BoM	-	Yes	-	-
64015 Mendooran Post Office	Daily	BoM	Yes	Yes	Yes	Yes
64019 Boston (Gollan)	Daily	BoM	-	Yes	-	-
64025 Coolah (Binnia St)	Daily	BoM	Yes	Yes	Yes	Yes
64026 Cobbora (Kundiawa)	Daily	BoM	Yes	Yes	Yes	Yes
64028 Weetaliba (Weetalabah)	Daily	BoM	Yes	Yes	Yes	Yes
64033 Coonabarabran (Mirrigundi)	Pluvio	BoM	-	Yes	-	-
64046 Coonabarabran (Westmount)	Pluvio	BoM	Yes	-	Yes	Yes
64050 Weetaliba (Munna)	Daily	BoM	Yes	Yes	Yes	Yes
65000 Arthurville (Cramond)	Daily	BoM	Yes	Yes	Yes	Yes
65030 Dubbo (Mentone)	Daily	BoM	Yes	Yes	Yes	Yes

Rainfall Gauge	Type	Source	Rainfall Data Available			
			1971	1990	2000	2010
65034 Wellington (D&J Rural)	Pluvio	BoM	-	-	Yes	-
65035 Wellington Research Centre	Pluvio	BoM	Yes	Yes	-	Yes
65050 Windora	Daily	BoM	Yes	Yes	-	-
65070 Dubbo Airport Aws	Pluvio	BoM	-	-	Yes	Yes
65071 Geurie (Wooroboomi)	Daily	BoM	-	Yes	-	-
65092 Dubbo (Jaymark Road)	Pluvio	BoM	Yes	-	-	-
65107 Dubbo (Muronbung (Bridgeview))	Daily	BoM	Yes	Yes	Yes	Yes

6.2.2 Stream Gauge Data

The availability of river gauge data is provided in Table 6.2.

Table 6.2 Available River Gauge Data for Historic Floods

Gauge	Watercourse	Data Available			
		1971	1990	2000	2010
421042 Elong Elong	Talbragar River	Yes	Yes	Yes	Yes

6.2.3 Peak Flood Level Data

Council do not have any surveyed flood marks for any historic events. Therefore, peak flood levels at locations other than the gauge were not available for any of the calibration events considered for this study.

6.2.4 Anecdotal Data

As discussed in Section 4.9, anecdotal flood information was collected during the community consultation process for this study and provided by Council. This included:

- Photographs covering a range of events including: 1955, 2010, 2021, 2016. There were no photographs provided for 1990 and 2000.
- 77 aerial and street-level photographs of Ballimore during the 2010 flood provided by Council.
- Anecdotal information indicating that rainfall at Coolah Tops normally takes approximately 3 days to increase water levels at Ballimore village.

Whilst the quantity and spread of data throughout the study area is limited, the anecdotal data does provide some indication of extent and depth of inundation, and locations of some of the more severely inundated areas during historic events.

6.2.5 Selection of Calibration Events

The 1971 and 2010 events were discounted due to limited availability of rainfall data, and the 1990 and 2000 events were adopted as calibration events due to the availability of both rainfall and stream gauge data for these historic events. It is noted that the 1990 and 2000 events are the eighth largest and second largest floods on record for the Elong Elong gauge, respectively. However, it is noted that no flood photographs are available for these events.

6.3 Calibration Approach

Based on the data available, the WBNM and TUFLOW models were jointly calibrated to the April 1990 and November 2000 historic events. Calibration events were used to optimise model parameters in both models, with the overall aim of the calibration to derive suitable hydrologic and hydraulic model parameters that can be applied across a range of events, which can be used in subsequent design flood modelling.

Within the WBNM model, the total rainfall depths were calculated based on recorded rainfall and varied spatially based on analysis of a network of rainfall gauges within and around the catchment for each calibration event. As there is no pluviograph data within the catchment for both calibration events, the total rainfall depths were distributed temporally based on pluviograph data outside of the catchment, which was the main challenge of the calibration exercise. The WBNM models were calibrated by adjusting the lag parameter and rainfall losses, and spatial application of hyetographs based on a comparison of the results of the WBNM model against the shape, timing and peak flows of the hydrograph recorded at the stream gauge.

Flows from the WBNM model were then input into the TUFLOW model and routed through the channel and floodplain system, which was calibrated by adjusting the Manning's 'n' values until the modelled flow hydrograph at Elong Elong reasonably replicated the recorded flow hydrograph and peak flood level at the Elong Elong gauge.

The following sections describe the model calibration, including an overview of the considered events and the outcomes of the calibration assessment.

6.4 April 1990 Event

6.4.1 Hydrologic Modelling

Rainfall Depth and Temporal Pattern

There are two daily rainfall gauges within the catchment with recorded data for this event. The nearest pluviograph stations are situated just outside of the catchment and include:

- Jaymark Road at Dubbo (Station No. 65092) (referred to as "Dubbo")
- Wellington Research Centre (Station No. 65035)
- Bylong (Station No. 62020)

Based on the pluviograph records at Dubbo, rainfall commenced at 9pm on 18 April 1990 and continued for a period of 87 hours until 12pm on 22 April 1990.

The total rainfall depths were calculated for each sub-catchment based on analysis of the recorded rainfall from the network of daily and pluviograph gauges within and around the catchment. Figure 6.1 shows the spatial distribution of the rainfall depths for a period of 87 hours across catchment system. The temporal pattern from the Bylong pluviograph was applied to all sub-catchments upstream of the Elong Elong gauging station and the temporal pattern from the Dubbo pluviograph was applied to sub-catchments downstream of Elong Elong station. The source of temporal patterns is also shown in Figure 6.1.

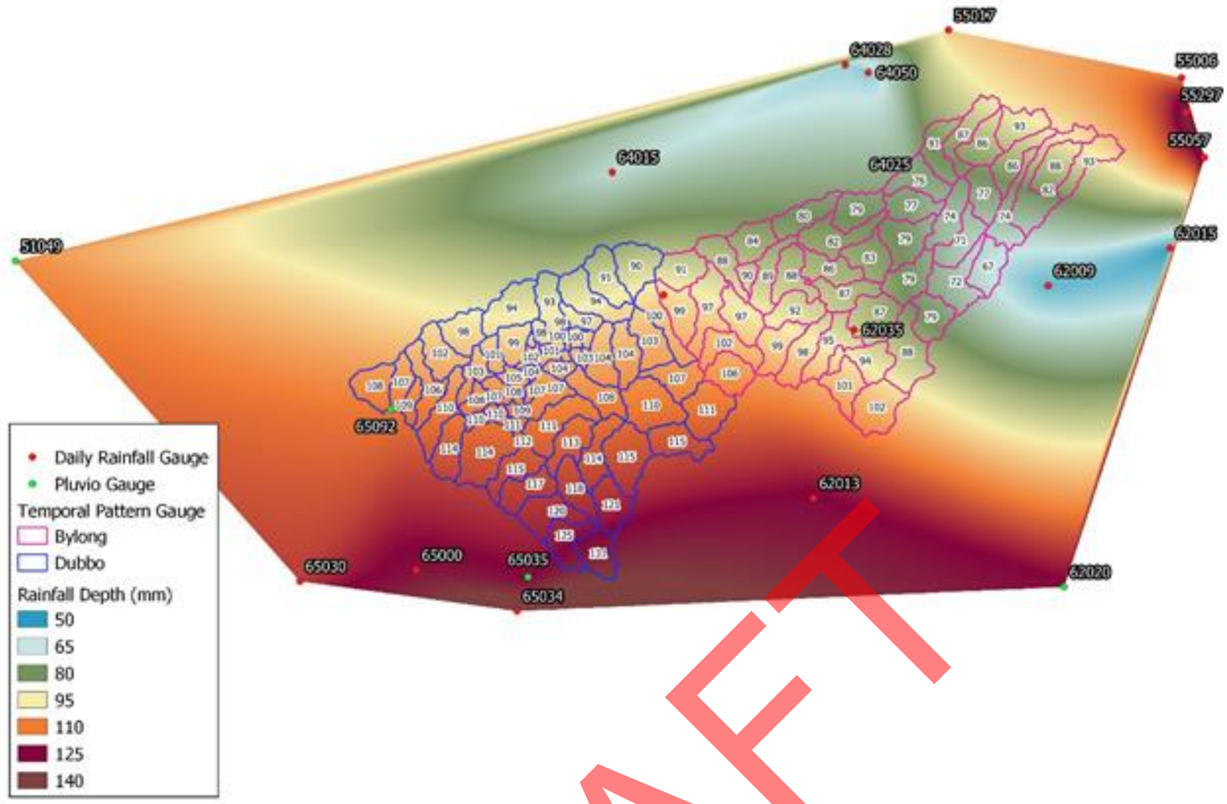


Figure 6.1 April 1990 Event Spatial Distribution of Rainfall Depth and Network of Gauges (120 hours to 9am 22 April)

Rainfall Loss

As part of the calibration, an initial loss of 20 mm and continuing loss of 2.5 mm/hr were adopted for the April 1990 event.

Calibration Results

A comparison of the modelled and recorded flow hydrographs at Elong Elong is shown in Figure 6.2. The WBNM model was able to replicate the flow magnitude of the second peak, but the peak was predicted to occur 8 hours earlier than recorded. It is noted that the lower peak flow of 243 m^3/s outputted from WBNM model was found to provide a better fit to the recorded flood level based on the joint hydraulic calibration of the WBNM and TUFLOW models (i.e. compared to the peak level flood level produced using the gauged peak flow).

It is also evident that the modelled hydrograph did not replicate the first (lower) peak well. The modelling showed that the shape of rising limb (first peak) was largely sensitive to the spatial application of the hyetographs. The modelling also showed that the lag parameter was found to influence the timing of the second peak, with a better fit (within 2-5 hours) being obtained for lag parameters greater than 1.9; but such values are outside the recommended range of 1.3-1.8.

It is noted that the Rust PPK (1995) study used the Dubbo pluviograph for the calibration of the 1990 event and appeared to replicate the double peak. To get an appreciation of the differences between the two studies, the Rust PPK (1995) study was reviewed in terms of the pluviograph and the recorded stream gauge data. The differences are summarised as follows:

- The Rust PPK (1995) study stated that the 1990 rainfall event (based on the Dubbo pluviograph) commenced at 9pm on 19 April and continued for a period of 87 hours until 12pm on 23 April. In contrast, the Dubbo pluviograph records obtained for this current study indicate that the 1990 rainfall event commenced at 9pm on 18 April 1990 and continued for a period of 87 hours until 12pm on 22 April. That is, the recorded rainfall used in the current study is ahead of the previous dataset used by Rust PPK (1995) by 24 hours.

- Based on the recorded flow hydrograph at Elong Elong, the Rust PPK (1995) study indicates that the first peak occurred at around 5am on 21 April 1990 and the second peak occurred at about 6pm on 22 April 1990. In contrast, our recorded hydrograph from the NSW Department of Water Resources shows that the first peak occurred at 10pm on 20 April 1990 and the second peak occurred at 12:45pm on 22 April 1990. That is, the recorded peak used in the current study is ahead of the previous peak used by Rust PPK (1995) by about 7 hours.

The above differences indicate that there is uncertainty around the quality of the 1990 pluviograph data. It is not known where the changes to recorded data have originated but the differences noted in the Rust PPK (1995) study result in the modelled versus recorded peaks being better aligned.

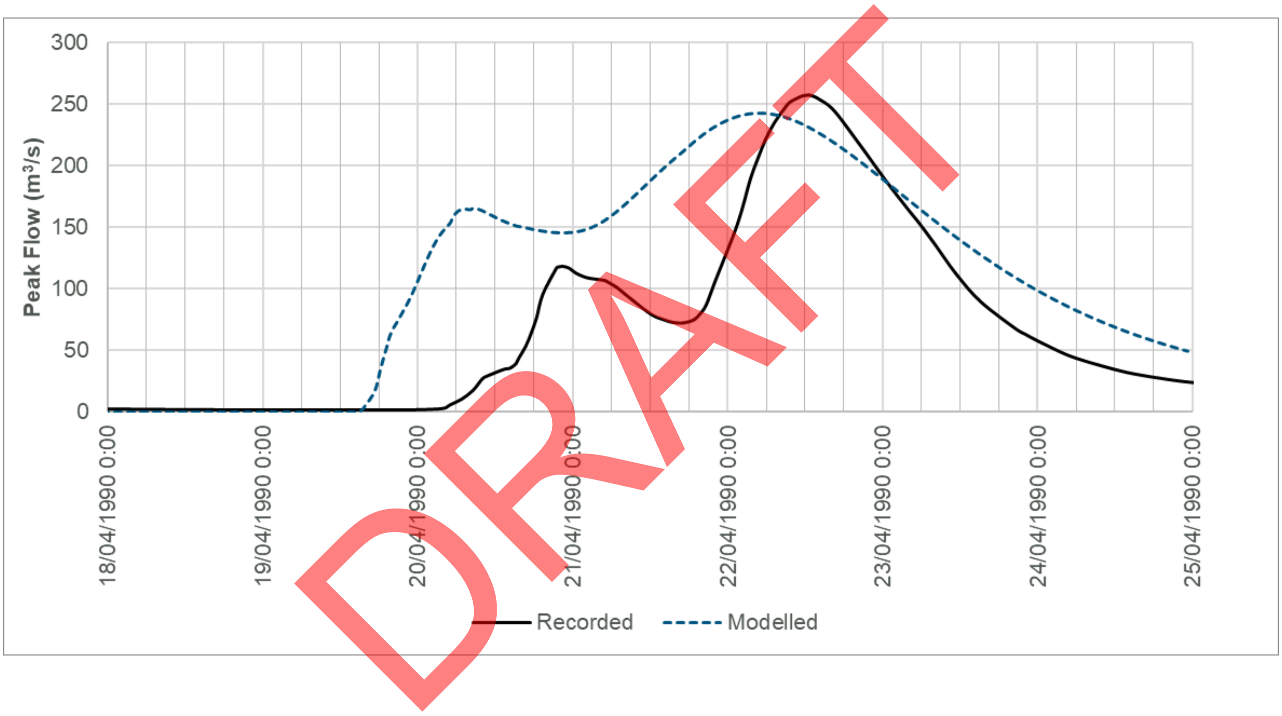


Figure 6.2 Comparison of WBNM and Recorded Flow Hydrographs at Elong Elong – April 1990 Event

6.4.2 Hydraulic Modelling

Model Parameters and Boundary Conditions

The discharge hydrographs generated by the WBNM model were used to define inflows across each TUFLOW model area for the April 1990 flood simulation. Other model parameters and boundary conditions are as per Sections 5.3.6 and 5.3.8.

Calibration Results

Figure 6.3 show a comparison of the modelled and recorded flow hydrograph at Elong Elong, which indicates that the modelled hydrograph reasonably replicates the shape of the recorded hydrograph. Table 6.3 provides a comparison of the modelled versus recorded peak flows and water levels.

Peak flood depth and level mapping produced from the results of the TUFLOW modelling of the April 1990 flood is provided in Map Set A in Volume 3: Mapping Compendium.

Table 6.3 Comparison of Modelled and Recorded Peak Flows and Water Levels at Elong Elong – 1990 Event

	Recorded	Modelled	Difference
Peak Water Level (mAHD)	324.76	324.93	+0.17
Peak Flow (m^3/s)	257	242	-15
Time of Peak	22/04/1990 12:42pm	22/04/1990 2:00am	-10hr 42min

Figure 6.3 Comparison of TUFLOW and Recorded Flow Hydrographs at Elong Elong – April 1990 Event

6.5 November 2000 Event

6.5.1 Hydrologic Modelling

Rainfall Depth and Temporal Pattern

There are four daily rainfall gauges within the catchment with recorded data for this event. The nearest pluviograph stations are situated just outside of the catchment and include:

- Jaymark Road at Dubbo (Station No. 65092) (referred to as “Dubbo”)
- Wellington Research Centre (Station No. 65035) (referred to as “Wellington”)
- Cassilis Post Office (Station No. 62005) (referred to as “Cassilis”)

Based on the pluviograph records at Wellington, rainfall commenced at 9am on 17 November and continued for a period of 60 hours until 8:30pm on 19 November (with a total depth of 94.4 mm). From 8:30pm on 19 November to 9am on 21 November, a rainfall depth of 14mm was recorded.

The total rainfall depths were calculated for each sub-catchment based on analysis of the recorded rainfall from the network of daily and pluviograph gauges within and around the catchment. Figure 6.4 shows the spatial distribution of the rainfall depths for a period of 96 hours across catchment system. It is noted that the 87% of the rainfall occurred over the first period of 60 hours. The temporal patterns from the Cassilis and Wellington were adopted for the 2000 event.

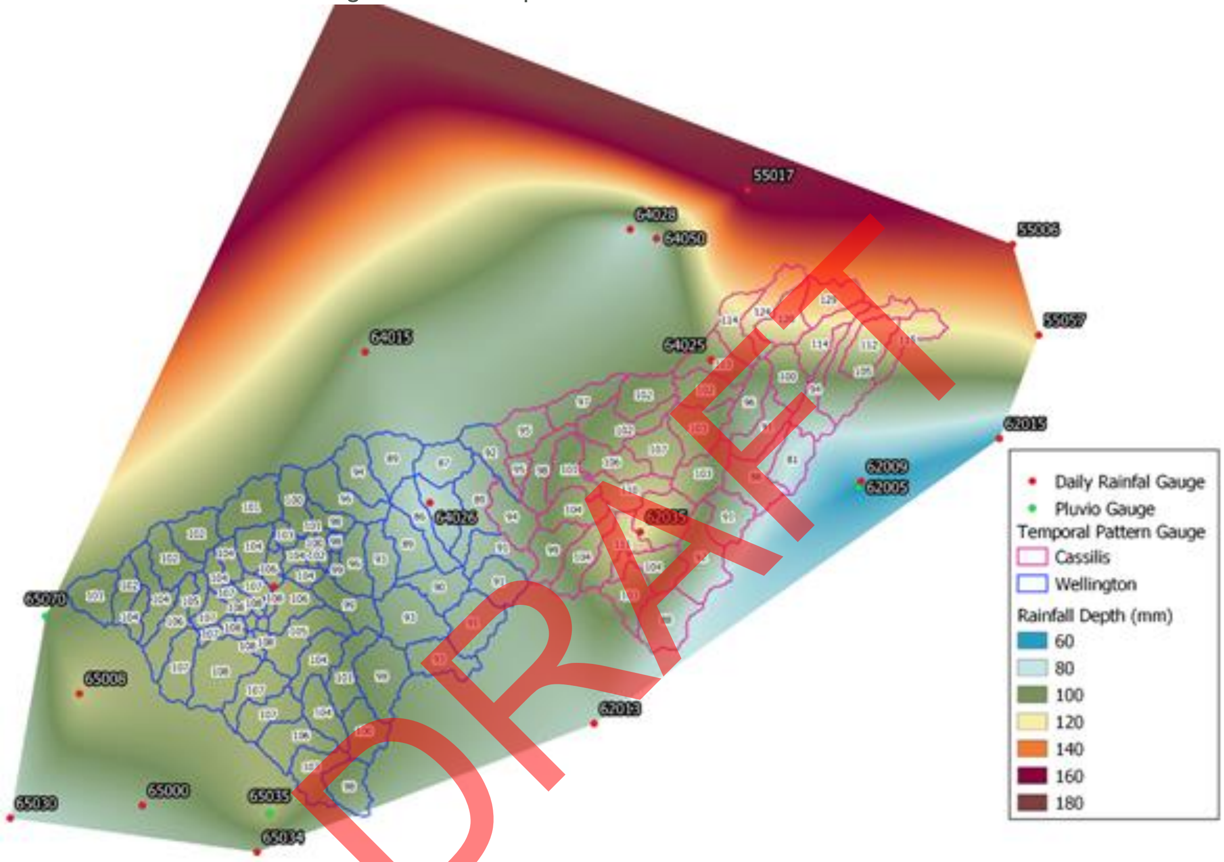


Figure 6.4 November 2000 Event Spatial Distribution of Rainfall Depth and Network of Gauges (96 hours to 9am 21 November)

Rainfall Loss

As part of the calibration, an initial loss of 15 mm and continuing loss of 3.7 mm/hr were adopted for the November 2000 event.

Calibration Results

A comparison of the modelled and recorded (derived) flow hydrographs at Elong Elong stream gauge are shown in Figure 6.5. This shows that the modelled flow hydrograph closely replicates the magnitude and timing of the peak flow and mimicked the general shape of the rising and falling limbs of the hydrograph. The modelled peak was predicted to occur 1.3 hours earlier than recorded.

However, it is evident that the recorded hydrograph did not replicate the multiple peaks along the rising limb of the hydrograph. This can be attributable to the lack of pluviograph gauges within the catchment, meaning that the actual temporal distribution of the rainfall across the catchment is highly uncertain.

Overall, given the lack of recorded pluviograph rainfall within the catchment, the calibration is deemed suitable.

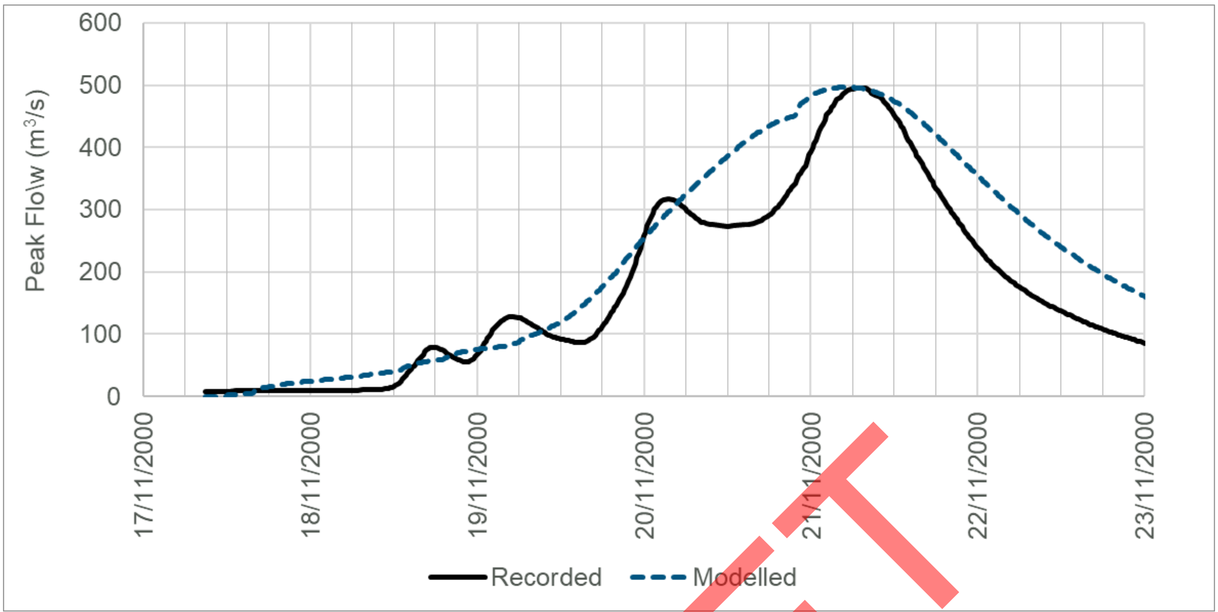


Figure 6.5 Comparison of WBNM and Recorded Flow Hydrographs at Elong Elong – 1990 Event

6.5.2 Hydraulic Modelling

Model Parameters and Boundary Conditions

The discharge hydrographs generated by the WBNM model were used to define inflows across each TUFLOW model area for the November 2000 flood simulation. Other model parameters and boundary conditions are as per Sections 5.3.6 and 5.3.8.

Calibration Results

Figure 6.6 show a comparison of the modelled and recorded flow hydrograph at Elong Elong, which indicates that the modelled hydrograph reasonably replicates the shape of the recorded hydrograph. Table 6.4 provides a comparison of the modelled versus recorded peak flows and water levels.

Peak flood depth and level mapping produced from the results of the TUFLOW modelling of the November 2000 flood is provided in Map Set A in Volume 3: Mapping Compendium.

Table 6.4 Comparison of Modelled and Recorded Peak Flows and Water Levels at Elong Elong – 2000 Event

	Recorded	Modelled	Difference
Peak Water Level (mAHD)	326.74	326.68	-0.05
Peak Flow (m^3/s)	496	508	+12
Time of Peak	21/11/2000 6:30am	21/11/2000 12:30am	-6 hr

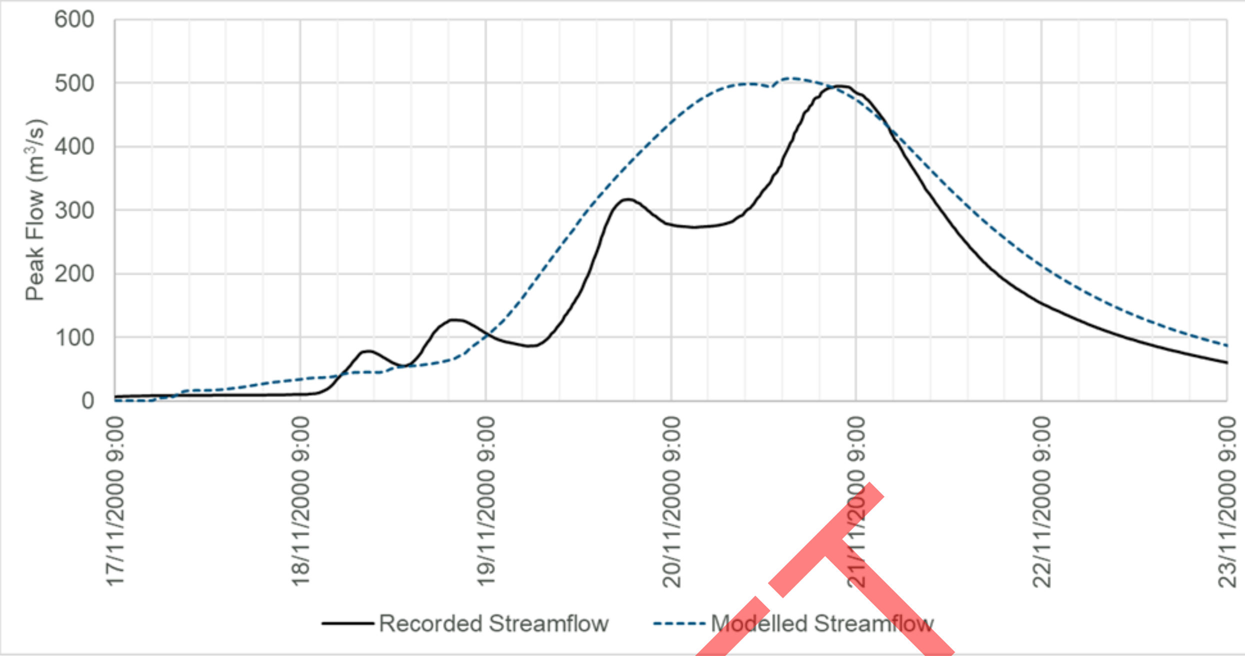


Figure 6.6 Comparison of TUFLOW and Recorded Flow Hydrographs at Elong Elong – 1990 Event

6.6 Calibration Summary

BMT has utilised a WBNM hydrologic model and a TUFLOW hydraulic model to simulate Talbragar River regional flooding behaviour in and around Ballimore Village. These models were jointly calibrated to the April 1990 and November 2000 historic events.

Based on the joint calibration results, the April 1990 calibration models replicated the peak of the hydrograph, but they failed to replicate the timing of the peak and the rising limb of the hydrograph and this is attributable to the uncertainty with the pluviograph rainfall data available and used the study. The November 2000 calibration models replicated both the magnitude and timing of the main peak of the hydrograph, but they did not replicate the multiple smaller peaks on the rising limb of the hydrograph. This is again attributable to lack of pluviograph rainfall data within the catchment

Overall, given the limited availability and quality of pluviograph data within the catchment, the WBNM and TUFLOW calibration results were deemed suitable for use in defining design flood conditions for this study.

7 Flood Frequency Analysis

7.1 Introduction

Flood frequency analysis (FFA) refers to procedures that use statistical analyses for recorded floods and related flood data to estimate flow values corresponding to selected probabilities of exceedance. Generally, these procedures are performed on peak discharges that have been converted from a recorded peak level at a gauge via use of a rating curve. FFA typically involves fitting a statistical distribution to peak flood data which are assumed to be drawn randomly from a well-behaved statistical distribution. Care should be exercised when extrapolating the data beyond the length of record.

For gauges that have a long gauge history and a reliable rating curve, peak flood estimates from FFA are generally considered the most accurate estimate of design floods for AEPs within the trusted range of extrapolation.

7.2 Selection of Gauges for FFA

The following criteria were considered when identifying gauges at which to undertake FFA:

- A reasonably long and continuous record length of historic flood levels (considered in this study to approximate 40 years or more).
- Suitability of gauge location for establishment of a reliable rating curve.
- Proximity of gauge location to study area.

The Elong Elong water level gauge was considered the most suitable gauge for use in FFA for this study when considering the above criteria. The FFA completed for this gauge is outlined in the following sections.

7.3 Elong Elong Gauge

Continuous records at the gauge extend from 1971 to 2021, allowing at least 51 years of annual maximum flows to be derived. Frequency analysis is best undertaken using an annual series of maxima flows (AMAX). To derive the AMAX at the Elong Elong gauge, the peak water level recorded in each calendar year was converted to an approximate flow rate. Initially, this conversion was undertaken using the available rating curve at the gauge; however, it was determined that the rating curve was unreliable above the level of the maximum gauged flows. Therefore, a hydraulic analysis was undertaken to derive an appropriate rating curve for the site.

The surveyed channel (and floodplain) cross-section at the Elong Elong gauge was used to calculate cross-sectional flow areas at various gauge heights. Using a range of suitable estimates of hydraulic gradient and Manning's 'n' roughness values, synthetic rating curves for the gauging site were generated. The gauged flow data (spot gaugings, independent of the continuously recorded water level) was used to calibrate an appropriate rating curve, which adopted a hydraulic gradient of 0.0015 and a Manning's 'n' roughness value of 0.04. The resultant rating curve is presented in Figure 7.1.

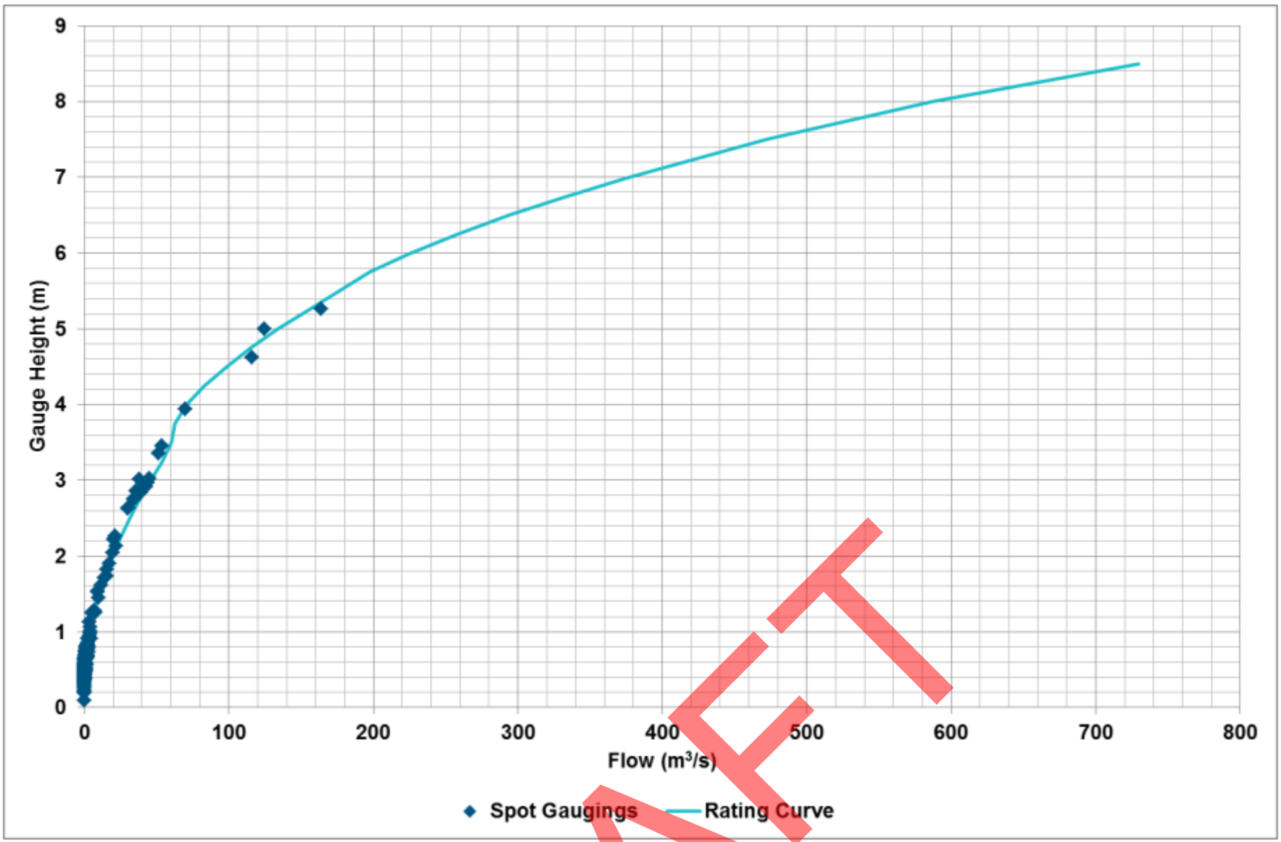


Figure 7.1 Calibrated Rating Curve for the Talbragar River at Elong Elong

The adopted rating curve for the Talbragar River at Elong Elong was then used to derive an annual maxima flow series from the recorded peak water levels, for use in the flood frequency analysis.

It was noted during the rating curve development that large flood events which occurred pre-1971 (including the large historic event in 1955 and other significant events in 1870, 1920, 1926 and 1950) were missing from the records. In order to avoid significant underestimation for rare events, estimation of the 1955 flood magnitude was undertaken, as discussed below.

7.3.2 Estimation of 1955 Flood Magnitude

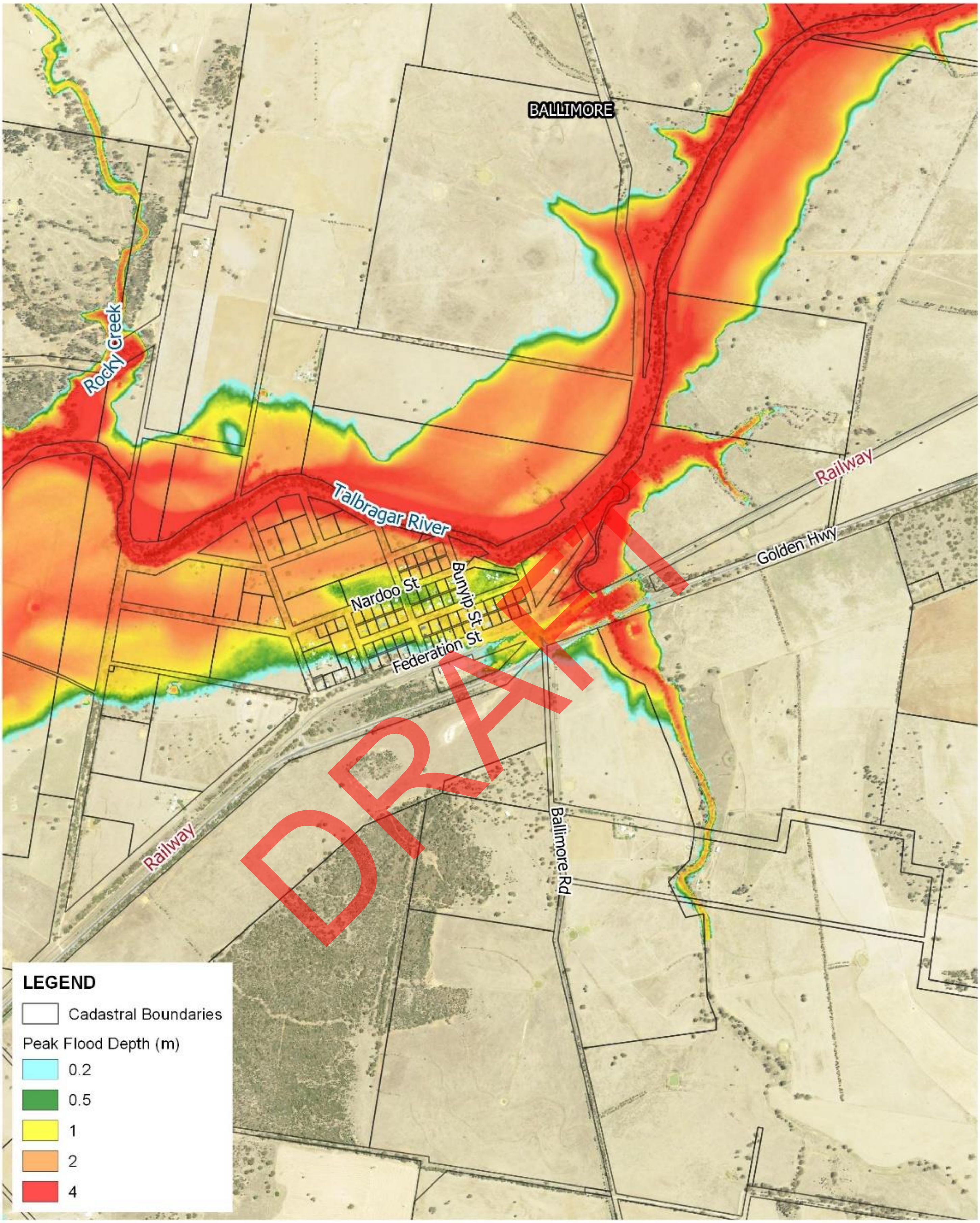
Estimation of the 1955 flood magnitude was undertaken in order to obtain a reliable input to the FFA. Whilst no gauged records exist for the 1955 event, anecdotal data describes that this historic flood resulted in floodwater depths greater than 1 m in the village of Ballimore and that the flow was considered by many as reaching a 1% AEP rarity.

The TUFLOW model developed as part of this study was used to estimate the 1955 peak flow magnitude by routing different Talbragar River inflow rates through the model. The following was noted during this process:

- With a peak flow rate of 1,000 m^3/s, floodwater is contained within the banks of the Talbragar River and fills only local tributaries and low-lying floodplain areas immediately adjacent to the river.
- With a peak flow rate of 1,700 m^3/s, shallow inundation (about 200 mm) is predicted within the Ballimore village.

- With a peak flow rate of 3,500 m^3/s, inundation of the Ballimore township is predicted with floodwater depths between 1 and 2 metres. This is consistent with the anecdotal observations of flooding at Ballimore in 1955 and indicates that the peak flow rate during the 1955 event must have been in this order of magnitude. A similar flow rate was also reported Rust PPK (1996) as being equivalent to the 1% AEP flow, consistent with the consideration that the 1955 event approximated 1% AEP rarity.

Estimated peak flood depths and extent with a 3,500 m^3/s inflow for the Talbragar River (estimated to be approximately equivalent to the 1955 event) are shown in Figure 7.2.



Title:

Predicted Peak Flood Depths at Ballimore with Estimated 1955 Talbragar River Flows

Figure: **7-2**

Rev: **A**

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7.4 Flood Frequency Analysis at Elong Elong

An annual maxima flow series consisting of 51 years of record from 1971 to 2021 was analysed using TUFLOW-FLIKE software. A Bayesian inference method was adopted with a Log Pearson III probability model. A data filtering exercise was undertaken on the AMAX to discard years with "negligible" flows (considered for the purpose of this study to be less than 20 m^3/s) and record sets whose quality was coded as *"compromised in its ability to truly represent the annual maxima flow".* This reduced the filtered data set to 37 records.

The 1955 event flow estimate of 3,570 m^3/s from Rust PPK (1996) was added to the annual maxima flow series. For the period between 1955 and 1971, it was assumed that there were no flood events of magnitude greater than 2,000 m^3/s. This information was added to the FFA analysis as censored data.

The 1870, 1920, 1926 and 1950 events were included as censored data in the FFA analysis, with an estimated flow of approximately 1,000 m^3/s. This estimation was based on the description of these historic events as creating similar flood conditions as experienced in the 2010 flood event. The 'Macquarie River Flood Study' (Cardno, 2019) reports that the Talbragar River at Elong Elong reached a peak flow of 1,114 m^3/s during the 2010 event; thus, this estimate is considered appropriate. The additional years between 1870 and 1954 (but not including 1870, 1920, 1926 and 1950) were included as censored data with estimated flows less than 1,000 m^3/s.

Table 7.1 presents the peak flow estimates from the FFA and the Log-Pearson III (LP3) fitted distribution is presented in Figure 7.3 together with the plotting positions of the annual maxima. A 1% AEP flow of 3,777 m^3/s is predicted by the FFA with the 1995 flow estimate included, which approximates the Rust PPK (1996) 1% AEP flow of 3,570 m^3/s.

Table 7.1 FFA peak flows at Elong Elong (m^3/s)

AEP (%)	FFA without 1955 flow	FFA with 1955 flow = 3,500 m^3/s
20	210	241
10	373	485
5	624	929
2	1,166	2,093
1	1,818	3,777

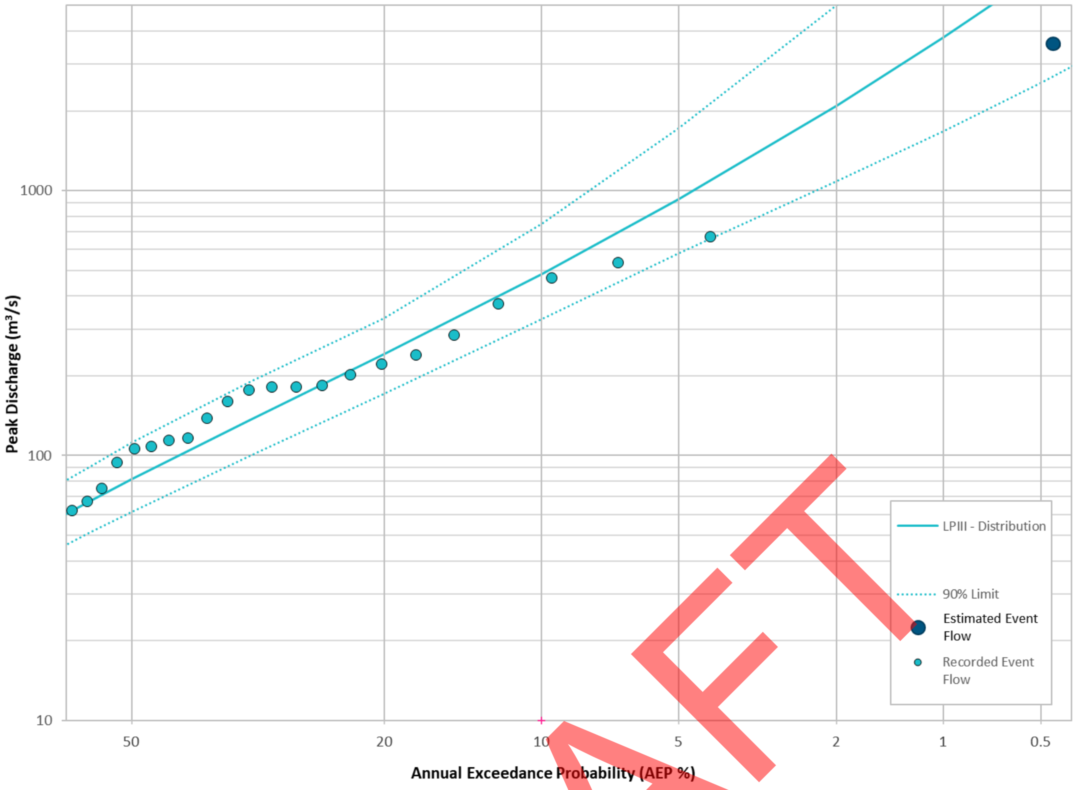
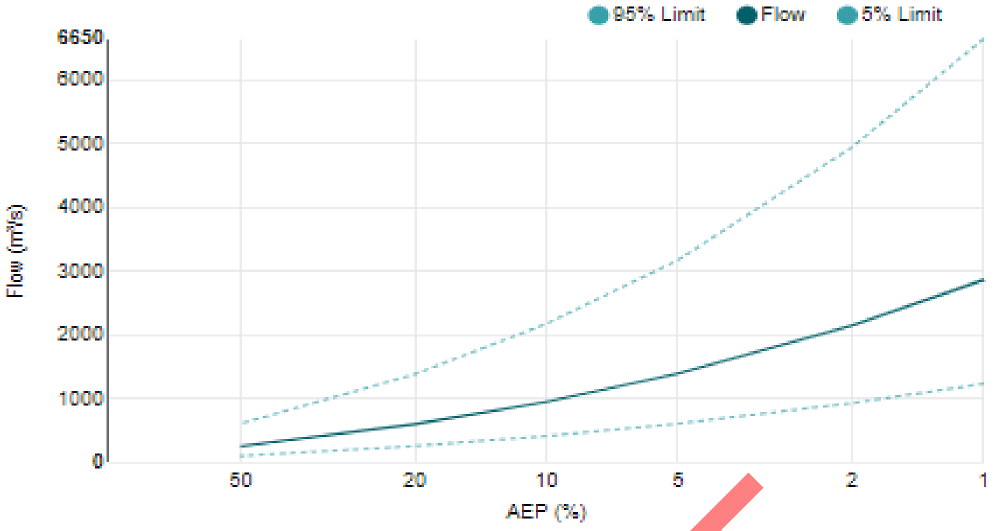


Figure 7.3 Flood Frequency Analysis at Elong Elong including the 1955 Estimated Event Flow

7.5 Regional Flood Frequency Analysis

A Regional Flood Frequency Analysis was also undertaken using the Regional Flood Frequency Estimation (RFFE) model. Accuracy of the RFFE is limited by the atypical characteristics of the Talbragar River catchment, whose area and shape factor are distinctly different from gauged catchments typically used for estimation.

The results of the FFA are presented in Figure 7.4. It can be seen that the RFFE flow estimate for the 1% AEP event is a relatively close match to the estimates from Rust PPK (1996) and the results of the FFA.



*The catchment is outside the recommended catchment size of 0.5 to 1,000 km². Results have lower accuracy and may not be directly applicable in practice.

AEP (%)	Discharge (m^3/s)	Lower Confidence Limit (5%) (m^3/s)	Upper Confidence Limit (95%) (m^3/s)
50	259	108	615
20	609	265	1390
10	958	421	2180
5	1400	616	3180
2	2150	937	4950
1	2870	1240	6650

Figure 7.4 Regional Flood Frequency Analysis Results

7.6 FFA Discussion

The FFA at Elong Elong provides design flow estimates at the upstream extent of the TUFLOW model. The results of the FFA indicate that the recorded peak flow of 535 m^3/s for the November 2000 flood corresponds to approximately the 10% AEP, whilst the recorded a peak flow of 243 m^3/s for the April 1990 event corresponds to approximately the 20% AEP.

As discussed previously, although the Elong Elong gauge has 51 years of continuous record available and is suitable in terms of both record length and data reliability, the period of record does not include the 1955 flood (i.e. the largest flood on record) which is estimated to be in the order of a 1% AEP event. Therefore, the FFA would provide the most reliable flow and hydrograph shape/timing estimates for less rare events (i.e. up to the 10% AEP flood) but cannot reliably be used to define flow hydrograph timing and shape for larger magnitude events in the order of the 1% AEP event and rarer. Accordingly, it was considered more appropriate to adopt a hydrologic modelling approach to derive design inflow hydrographs for the Talbragar River, as well as inflows from tributary (e.g. Ballimore Creek, Spicers

Creek, Goan Creek, etc) and floodplain sub-catchments downstream of Elong Elong and within the hydraulic model extent.

However, peak design flows estimated through FFA were compared against modelled peak design flow estimates in order to validate design flow outputs from the WBNM hydrologic model (refer Section 8.3.7).

8 Design Flood Modelling

8.1 Design Flood Terminology

Design flood events are hypothetical flood events with a given probability of occurrence. This probability of occurrence is the chance that the flood may occur or be exceeded in any one year and is termed the Annual Exceedance Probability (AEP). A 1% AEP flood is a flood that statistically has a 1% chance of occurring or being exceeded in any given year. This is also sometimes stated as a '1 in 100' chance of occurrence. Prior to ARR2019, design floods were typically referred to by their Average Recurrence Interval (ARI) with this terminology is being phased out in ARR2019.

Table 8.1 lists the AEPs considered in this study and their equivalent ARIs. In this report the AEP terminology, expressed as a percentage, has been used to describe probability of occurrence.

Table 8.1 Design Floods Determined in Study and Associated Terminology

AEP %	AEP 1 in Y	ARI (years)
20	5	4.5
10	10	9.5
5	20	19.5
2	50	50
1	100	100
0.5	200	200
0.2	500	500
0.1	1000	1000
0.05	2000	2000

8.2 Approach

Design flood conditions were derived for this study based on the results of TUFLOW hydraulic model simulations using the following inputs (with further details provided in the following sections):

- WBNM derived flows based on ARR2019 design flow inputs for the Talbragar River, Ballimore Creek, tributaries and floodplain.
- A downstream boundary using a normal depth condition, positioned sufficiently far downstream from the study area to avoid boundary assumptions impacting on flood levels within the study area.

The relative timing and critical durations of the Talbragar River, Ballimore Creek and local catchment inflows also required consideration, as discussed in Section 8.4.1.

8.3 Hydrologic Modelling

8.3.1 Design Rainfall

Design rainfall Intensity-Frequency-Duration (IFD) grids were obtained from the BoM website for the range of required AEP and duration combinations. The IFD grids have a grid cell spacing of 0.025 decimal spacing (approximately 2.5 km or an area of 5 km^2).

In order to consider the potential spatial variability of rainfall over the catchment, the WBNM model sub-catchments were grouped into 13 'sub-areas' of around 350 km^2 (see Figure 8.1). IFD curves for all design events were extracted at the centroid of each group and applied to the whole sub-area.

8.3.2 Temporal Patterns

Rainfall temporal patterns are used to describe how rainfall is distributed over time and were obtained from the ARR Data Hub for this study. ARR2019 sets out an ensemble approach to design hydrology whereby, for each storm duration of a given AEP, an ensemble of 10 rainfall temporal patterns is simulated. Each temporal pattern set comprises 10 ensemble patterns and covers a mix of front, mid and rear loaded storms. In accordance with ARR2019, this study uses the areal temporal pattern ensembles as the catchment area of interest is greater than 75 km^2. The adopted temporal sets were selected from the Central Slopes region.

8.3.3 Areal Reduction Factor

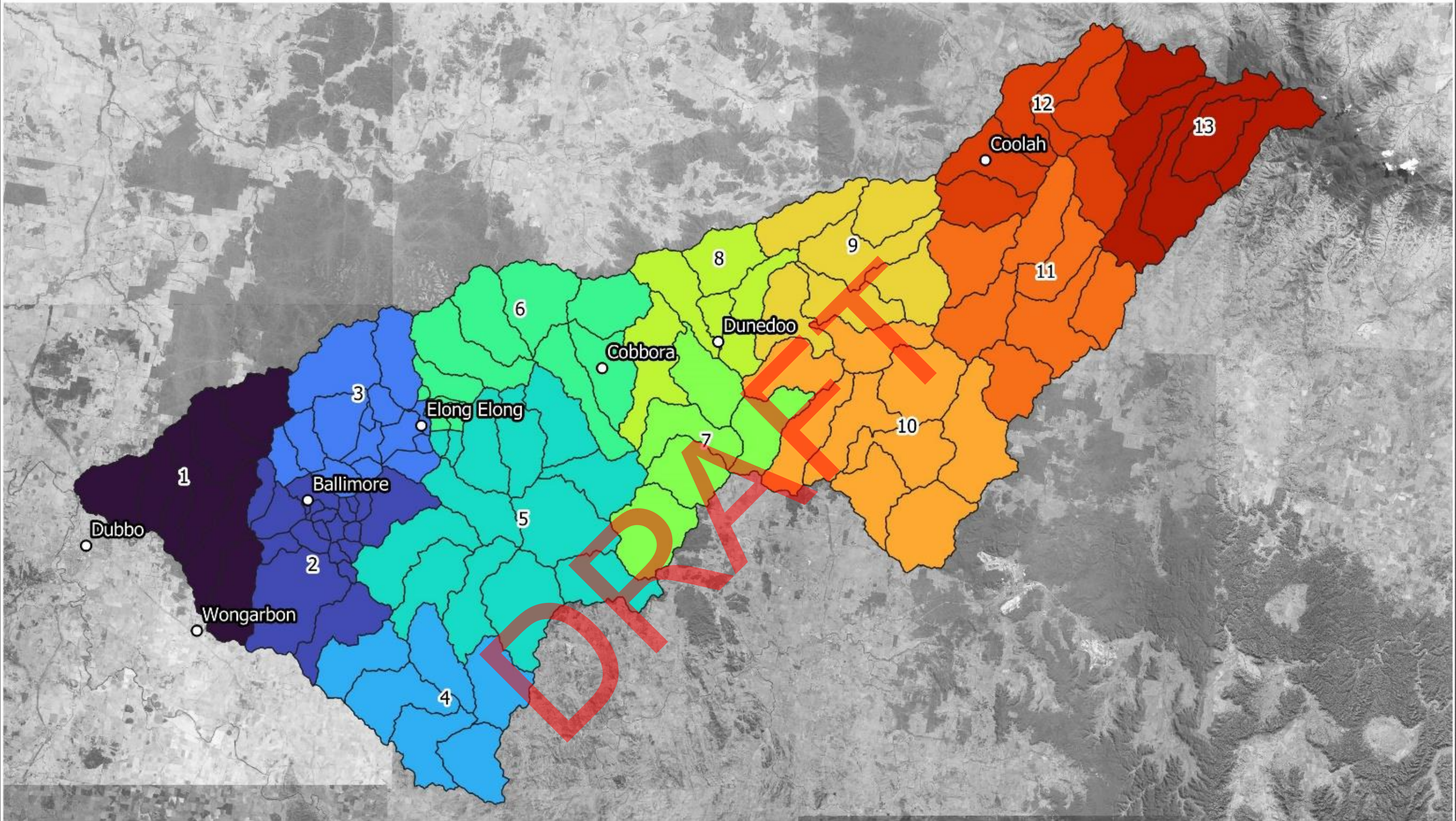
The IFD rainfall depths (see Section 8.3.1) provide rainfall at specific locations within the catchment rather than a representation of rainfall across an entire catchment area. Therefore, these are estimates at a point which need to be adjusted to an areal rainfall using an areal reduction factor (ARF). ARFs are derived from regionalised parameters available from the ARR Data Hub for the "Central NSW" region. An ARF value of 1 means no reduction in rainfall.

ARFs were not applied for events equal to and rarer than the 1% AEP as their application resulted in excessive attenuation of peak hydrographs when compared against the results of the FFA.

8.3.4 Embedded Bursts

ARR2019 requires that consideration be given to filtering out (or excluding) embedded bursts of a lower (i.e. rarer) AEP in temporal patterns. Embedded bursts occur when the rainfall accumulated over a subset (the “burst”) of a storm's temporal pattern has a depth that exceeds the IFD value for the burst's duration for the same AEP. This means that the burst has a lower (rarer) AEP than the design hyetograph and is an “embedded burst”.

Embedded bursts were detected for all AEPs and durations, and smoothing was applied to the temporal patterns to remove these embedded bursts.



LEGEND

- Townships
- Sub-catchments
- 10 Catchments Group

Title:

Sub-catchments Grouping for Spatial Rainfall Representation

Drawing: 8-1

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8.3.5 Hydrologic Losses and Parameters

Calibration of the WBNM hydrologic model was undertaken for the April 1990 and November 2000 events (refer Section 6) and was based on the use of the following losses and lag parameter:

- Initial losses: 20 mm for the 1990 event and 15 mm for the 2000 event.
- Continuing losses: 2.5 mm/hr for the 1990 event and 3.7 mm/hr for the 2000 event.
- WBNM lag parameter to 1.74.

However, application of these initial and continuing loss values when using the WBNM model to simulate the 1% AEP event resulted in a peak 1% AEP flow estimates of 1,000 m^3/s at Elong Elong. It is noted that this is significantly less than the peak 1% AEP flow estimate of 3,777 m^3/s from the FFA (i.e. more than a third of the peak flow).

Underestimation of design flows has the potential to significantly impact on the understanding of flood risk within the study area and the resultant development of appropriate flood risk management strategies. Therefore, further assessment of the suitability of calibration losses was undertaken based on consideration of the following:

- The limited quality and coverage of the rainfall data used for calibration.
- Calibration was based on pluviograph data outside of the catchment since there were no pluviograph data within the catchment system.
- Calibration unsatisfactorily reproduced the shape and timing of the historical hydrograph.
- Peak 1% AEP flows resulting from the application of calibrated losses are highly discrepant against those reported in previous studies and produced by FFA.
- Calibrated losses are based on historical flows of much higher frequency than the 1% AEP event upon which flood planning is based. That is, the November 2000 event recorded a peak flow of 535 m^3/s at Elong Elong which corresponds to approximately a 10% AEP event and the April 1990 event recorded a peak flow of 243 m^3/s at Elong Elong which corresponds to approximately a 20% AEP event.
- Consequences from underestimation of design flows (and thus design flood conditions and flood risk) could be potentially severe in terms of hazard to people and properties.

Therefore, peak 1% AEP flows produced by the WBNM model were verified against the FFA LPIII distribution curve. An iterative process was undertaken in order to achieve satisfactory correlation between peak flows outputted from the WBNM model and FFA flows for the frequent events without underestimating results in rarer events. A lag parameter of 1.6 and the recommended non-linearity parameter of 0.77 were adopted.

Continuous losses were set to 0.60 mm/hr, slightly lower than 0.68 mm/hr recommended by the ARR Datahub. A variable initial loss rate was adopted for each AEP and duration. Table 8.2 shows the adopted initial loss value, which can be numerically reproduced by combining a 70 mm initial loss value with the 90% pre-burst depths on the ARR Datahub.

Table 8.2 Initial Losses Applied to the WBNM model

Min (h)	50% AEP	20% AEP	10% AEP	5% AEP	2%AEP	1% AEP
60 (1.0)	36.7	42.9	47.1	51	43.5	37.8

Min (h)	50% AEP	20% AEP	10% AEP	5% AEP	2%AEP	1% AEP
90 (1.5)	41.6	33.1	27.4	22	29.3	34.8
120 (2.0)	33.6	30.3	28	25.9	15.8	8.3
180 (3.0)	31	29.5	28.5	27.5	21.5	17
360 (6.0)	42.1	28.7	19.9	11.4	0	0
720 (12.0)	48.3	31	19.6	8.6	0	0
1080 (18.0)	49.1	35.8	27.1	18.7	0	0
1440 (24.0)	52.7	42.4	35.5	29	14.7	4
2160 (36.0)	58	45.9	37.9	30.2	20.6	13.4
2880 (48.0)	66	59.8	55.7	51.8	35.5	23.3
4320 (72.0)	67.4	64.9	63.3	61.8	54	48.2

**Pre-burst depths and initial losses vary spatially across the catchment. The table shows results obtained at the catchment centroid*

8.3.6 Estimation of Probable Maximum Precipitation

The Probable Maximum Precipitation (PMP) is used to derive the Probable Maximum Flood (PMF) event. The definition of the PMP is the *"the theoretical maximum precipitation for a given duration under modern meteorological conditions"* (WMO, 2009). The AEP of a PMP/PMF event ranges between 10^4 and 10^7 years and is beyond the *"credible limit of extrapolation"* (Pilgrim, 1987). That is, it is not possible to use rainfall depths determined for more frequent events (1% AEP and less) to extrapolate the PMP. For this study, the PMP has been estimated using the Generalised Southeast Australia Method (GSAM) for rainfall duration between 12 and 92 hours.

Ballimore (and its catchment area) lies between the GSAM Inland Zone and the GSTMR Coastal Zone, as shown in Figure 8.2. The GSAM Inland Zone method for PMP calculation was utilised for this study since the local climate at Ballimore has characteristics more similar to inland areas of Southeast Australia rather than those associated with the typical "tropic" characteristics of the GTSMR Coastal Zone.

Additionally, the Generalised Short Duration Method (GSDM) was utilised to simulate a short duration storm (between 0.25 and 6 hours) localised on the downstream portion of the Ballimore catchment. The standard ellipses method was used to spatially vary the PMP rainfall.

Peak PMF flows at Elong Elong for durations between 0.25 and 96 hours are shown in Figure 8.3. The peak PMF flow for the critical 12-hour duration is 15,528 m^3/s.

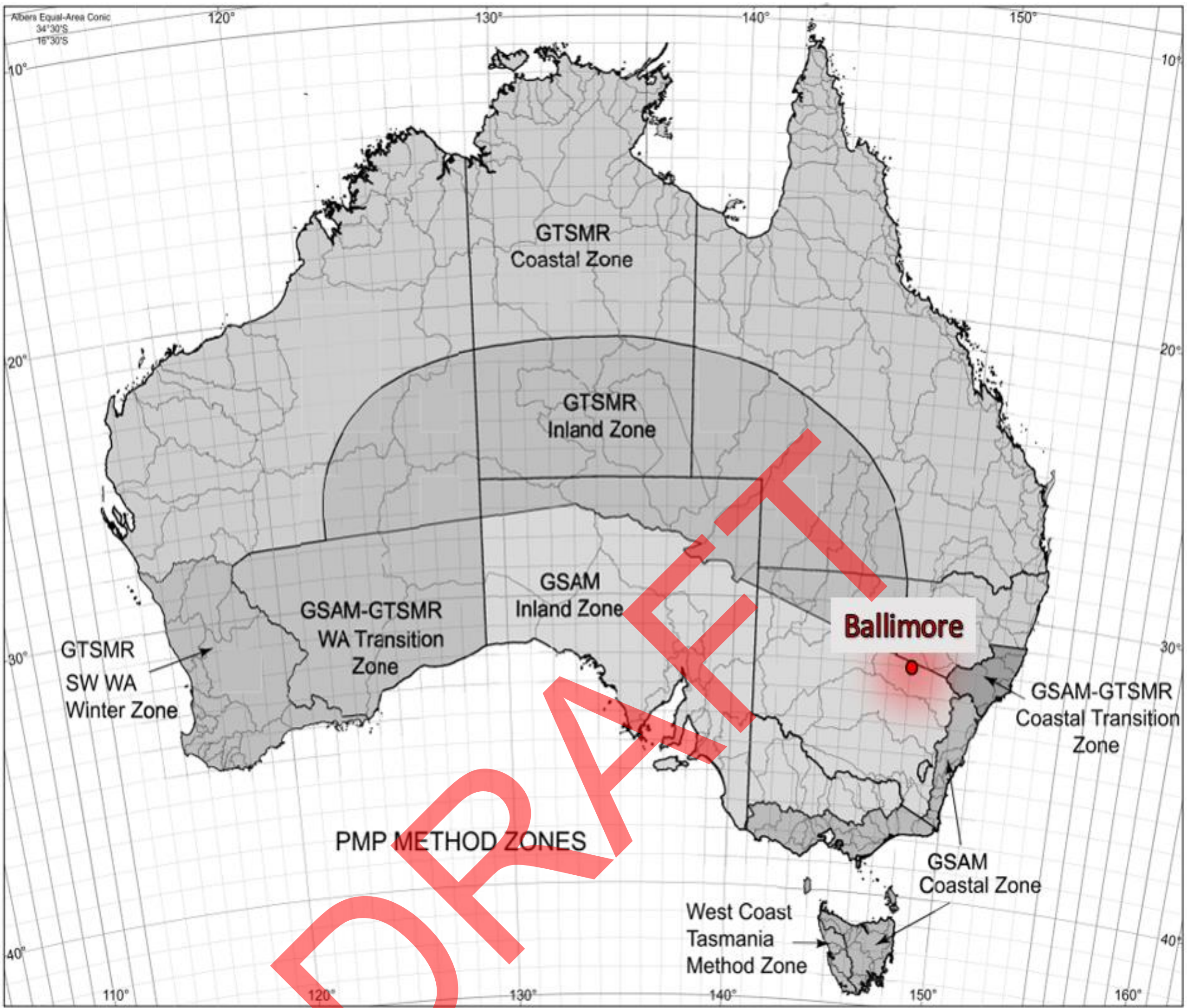

Figure 8.2 Location of Ballimore Within PMP Method Zones

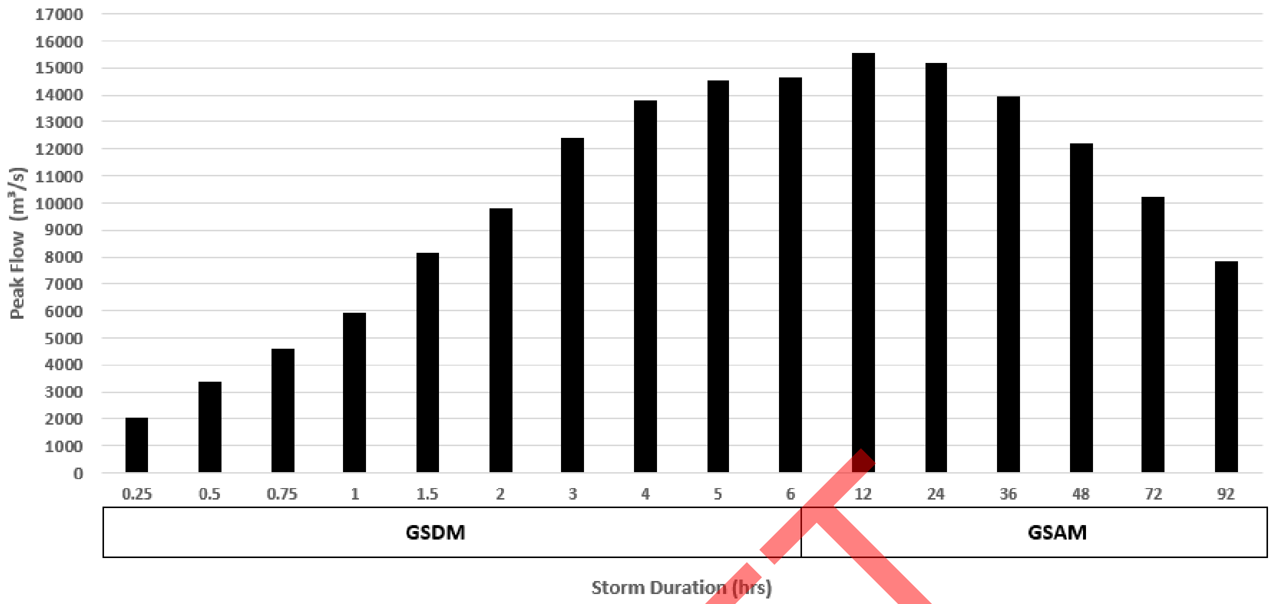

Figure 8.3 Peak PMF Flows - Talbragar River at Elong Elong

8.3.7 Verification of Hydrologic Modelling Results at Elong Elong Against FFA and Rust PPK (1996)

A critical duration assessment was undertaken for each modelled design event. The results of this assessment are presented in Annex C and peak flow rates produced by the WBNM model at Elong Elong are listed in Table 8.3, as well as a comparison against the peak flows derived through FFA (refer Section 7.4) and reported in Rust PPK (1996) at the gauge location. A plot comparing peak flows from WBNM (aqua dots) and Rust PPK (1996) (blue squares), including the FFA curves, is also shown in Figure 8.4.

Table 8.3 Comparison of Peak Flow Rates (m^3/s) at Elong Elong

AEP	WBNM	FFA	Rust PPK (1996)
50%	98	82	50
20%	511	241	400
10%	933	485	874
5%	1,441	929	1,660
2%	2,243	2,093	2,630
1%	3,912	3,777	3,570
0.5%	4,790	-	-
0.2%	5,999	-	-
0.1%	7,056	-	-
0.05%	8,235	-	-
PMF	15,528	-	10,710

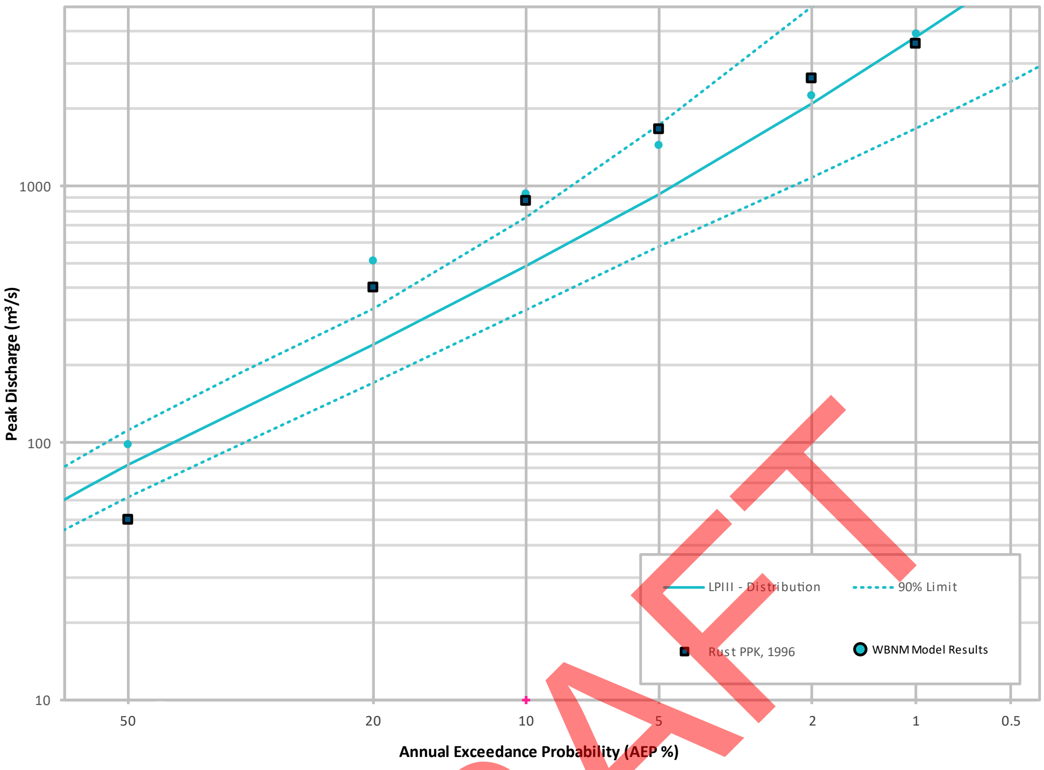

Figure 8.4 Results of WBNM model (cyan dots) against Rust PPK,1996 flows (blue squares) and Flood Frequency Analysis

From Table 8.3 and Figure 8.6, it can be seen that:

- For the 50% AEP, whilst WBNM produces a peak flow that is significantly higher than the peak flow from Rust PPK (1996), it is within the 90% confidence limits of the FFA and therefore the WBNM model results are considered appropriate for this event.
- WBNM peak flows are significantly higher than FFA results for AEPs between 20% and 5% and are outside the 90% confidence limits for the 20% and 10% AEP events. However, they are closely aligned to the results of Rust PPK (1996) for these events.
- Good correlation between peak flows from WBNM and FFA (and the FFA curve) is achieved for the 2% and 1% AEP events, with a maximum peak flow difference of only up to 7%. WBNM outputs are also closely aligned to the results of Rust PPK (1996) for these events.
- Peak PMF flows from WBNM are approximately 45% higher than those reported in Rust PPK (1996).

Please note that Rust PPK (1996) did not report peak flows for events between the 1% AEP and the 0.05% AEP, and flows for events of this magnitude cannot be reliably determined by FFA (refer previous discussion in Section 7.6).

However, given that notable flooding will not occur in the Ballimore township until rare events and that there is a good match between WBNM and FFA flows for rare events; overall, the WBNM results are considered to be suitable for use in this flood assessment, albeit somewhat conservative.

8.4 Hydraulic Modelling

8.4.1 Critical Duration Assessment

As discussed previously, Ballimore is potentially impacted by floodwaters from the following sources (shown in Figure 8.5):

- Talbragar River (approximate catchment area of 4,000 km^2);
- Ballimore Creek (approximate catchment area of 30.21 km^2); and
- Local catchment flows (approximate catchment area of 68 ha or 0.68 km^2).

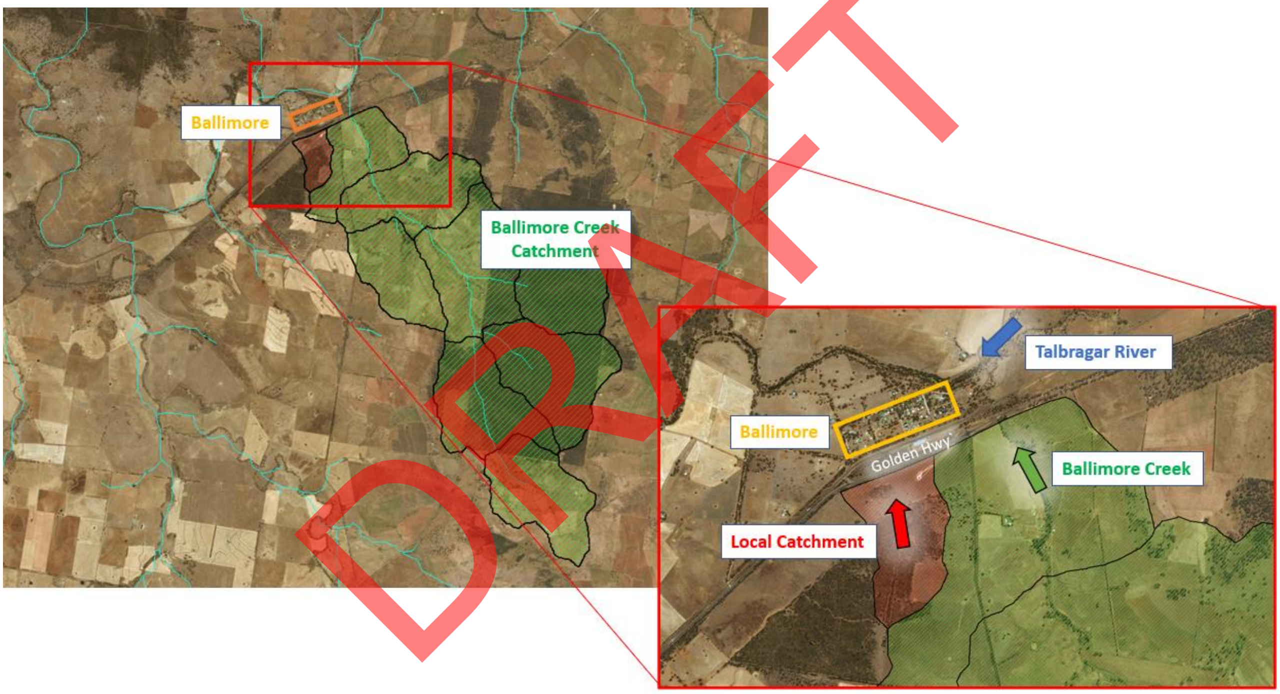

Figure 8.5 Potential Flooding Sources Impacting Ballimore

Due to the various sources of flooding and considering the significant differences in catchment areas associated with each source, critical durations varied between sources of flow. The critical durations for each potential flood source for each modelled AEP are shown in Table 8.4.

Table 8.4 Critical Temporal Patterns and Durations (hours) for Talbragar River, Ballimore Creek and Local Catchment Flows

AEP	Talbragar River	Ballimore Creek	Local Catchment
10%	36	9	3
5%	36	6	1.5
2%	36	6	2
1%	36	6	2
1 in 200	36	6	2
1 in 500	36	6	2
1 in 1000	36	6	2
1 in 2000	36	4.5	2
PMF	12		

Thus, it was necessary to consider a combination of the different critical storm durations associated with each flooding source as part of this study. This was achieved by combining the results of the design flood simulations into design flood envelopes for each modelled AEP. These enveloped results represent the maximum peak flood levels, depths and velocities across the study area (i.e. the "worst case" flood conditions in Ballimore from all sources of flooding) and were used as the basis for the design flood mapping provided in Map Set B in Volume 3: Mapping Compendium.

8.4.2 Verification of TUFLOW Results Against Historic Flood Observations and Rating Curve at Elong Elong

In terms of peak flood levels and depths, the TUFLOW model results are in good agreement with historical anecdotal observations within Ballimore, as follows:

- Peak 1% AEP floodwater depths are predicted to range from 1 to 2 m within the village, therefore reasonably replicating the observations from the 1955 event (i.e. exceeding 1 m across the village) which is considered by many as attaining 1% AEP flood magnitude.

- Peak 5% AEP flood conditions from the TUFLOW outputs predict some flooding within the low-lying properties which is consistent with the observations of the 2010 event that recorded a peak flow of approximately 1100 m^3/s (i.e. between the predicted 10% and 5% AEP event peak flows).

Furthermore, a very good alignment between the rating curve at Elong Elong and water levels produced by the TUFLOW model for a range of flows were obtained (refer to Figure 8.6). The TUFLOW rating curve shows minimal hysteresis effect which provides a substantial validation of the modelling results.

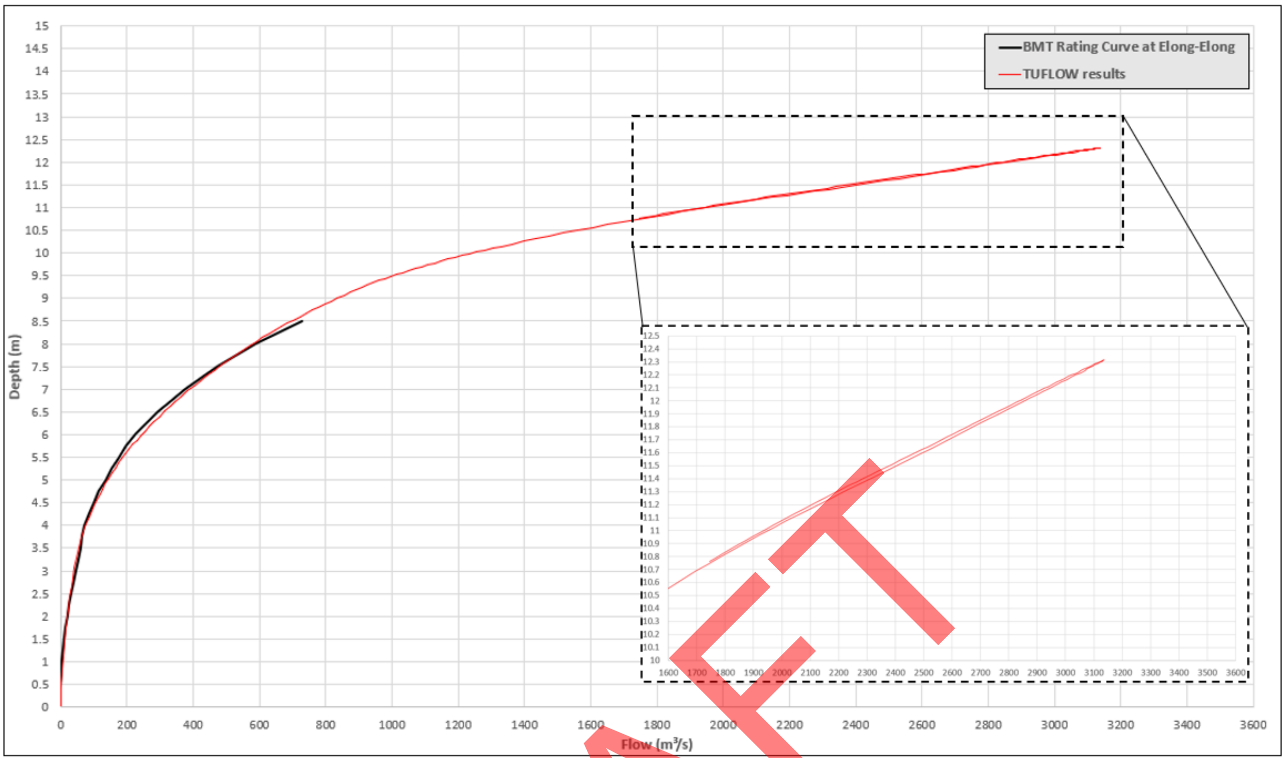

Figure 8.6 TUFLOW model results against rating curve at Elong Elong

8.5 Modelling Results

8.5.1 Peak Flood Conditions

Design flood mapping of peak flood levels, depths and velocities is provided in Map Set B in Volume 3: Mapping Compendium. Peak flows immediately upstream of Ballimore, as well as peak flood levels and depths at key locations in the village (refer location points shown on Map Set B), are listed in Table 8.5 and Table 8.6, respectively.

Table 8.5 Peak Flow Rates at Ballimore

AEP	Peak Flow (m^3/s)
10%	918
5%	1,407
2%	2,137
1%	3,563
0.5%	4,346
0.2%	5,654
0.1%	6,222
0.05%	7,261
PMF	16,749

Table 8.6 Peak Flood Levels and Depths in Ballimore

AEP	Church		School		Train Station	
	Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)	Level (mAHD)	Depth (m)
10%	N/A	N/A	N/A	N/A	N/A	N/A
5%	N/A	N/A	N/A	N/A	N/A	N/A
2%	302.29	0.09	303.41	0.04	304.74	0.06
1%	303.26	0.96	304.31	0.95	304.87	0.19
0.5%	303.74	1.44	304.74	1.37	304.89	0.21
0.2%	304.42	2.12	305.39	2.02	305.34	0.66
0.1%	304.68	2.38	305.64	2.28	305.50	0.82
0.05%	305.12	2.83	306.10	2.73	305.89	1.21
PMF	308.15	5.85	309.14	5.78	308.86	4.18

Note: N/A where location is not flooded in that design flood.

8.5.2 Discussion of Flood Behaviour

The principal flood mechanism within Ballimore is mainstream Talbragar River flooding. This flood mechanism typically occurs over longer durations and results when flow originating in the upper river catchment travels downstream along the river channel, breaches the riverbanks and inundates adjoining floodplain areas. Within Ballimore, floodwaters are predicted to initially breach the southern riverbank around Bunyip Street.

During Talbragar River events, backwater flooding also inundates the lower reaches of tributaries such as Ballimore Creek and adjacent low-lying areas. Elevated water levels in the Talbragar River and lower reaches of Ballimore Creek also inhibit the discharge of flows from Ballimore Creek into the river at its confluence upstream of Goan Creek Road. In such events, floodwaters from Ballimore Creek breach the banks and travel overland towards the village from the south.

Overland flow originating from the catchment to the south-west of the village may also inundate parts of the village. Local overland flood behaviour is generally characterised by fast-moving overland flow with a short travel time throughout the catchment.

The following provides a summary of flood behaviour across a range of design floods:

- During the 20% AEP flood and smaller magnitude events:
  Floodwaters are contained within defined watercourses and/or do not impact on property within Ballimore.
- During 10% and 5% AEP floods:
  Incipient flooding is predicted within Ballimore for events of these magnitudes. Properties within low-lying areas to the east of the township at the confluence of the Talbragar River and Ballimore Creek are predicted to be inundated by floodwater depths up to approximately 0.6 m. Flooding in these areas results when floodwaters breakout of the Ballimore Creek channel (near the bend at Goan

Creek Road) due to high downstream water levels in the Talbragar River. Properties to the north of the township are predicted to be impacted by minor inundation from the Talbragar River in such events.

- During the 2% AEP flood:
  Properties in the north and east of the Ballimore township are predicted to be inundated by depths up to 1.5 m, largely due to similar flood mechanisms described in the point above. Ballimore Public School, Ballimore Uniting Church and railway station are predicted to be marginally flood impacted despite being located on higher ground.
- During a 1% AEP flood:
  Much of Ballimore is inundations, with floodwater depths of between 1.0 and 2.5 m. It is also noted that some flooding of the area between the Golden Highway and the railway line is also caused by local catchment flows spilling across the road. Depths of up to 0.7 m are predicted within topographic low points in this area, as well as adjacent to the pipe culvert crossing of Goan Creek Road.
- During rarer floods including the 0.5%, 0.2%, 0.1 and 0.05% AEP floods and PMF:
  The majority of Ballimore and its surrounds are inundated by floodwaters. These depths scale with event intensity up to the PMF, during which Ballimore is predicted to experience floodwater depths of between 5.0 and 8.0 m.

9 Sensitivity Assessment

9.1 Overview

Computer flood models require the adoption of several modelling parameters that may not be known with a high degree of certainty or are subject to natural variation (e.g. summer vs. winter vegetation). Calibration is completed, where possible, in an attempt to ensure the adopted model parameters generate reliable estimates of flood conditions. The calibration and validation completed for this study is discussed in Section 6 .

As inputs can impact on the results generated by the models, it is important to understand how any uncertainties in key model input parameters or changes to parameters (e.g. due to climate change) may impact on the results predicted by the models. Accordingly, a sensitivity assessment was undertaken using the TUFLOW model developed by BMT for this study and for the 1% AEP flood in order to observe changes to predicted design flood behaviour in Ballimore when varying the model parameters listed in Table 9.1. In defining sensitivity tests, consideration has been given to the most appropriate parameters considering catchment properties and simulated design flood behaviour.

Table 9.1 Sensitivity Assessment Criteria

Sensitivity Assessment Scenario	Details
Coincident events for the Talbragar River and tributary/local catchment flows	Coincidence of 1% AEP Talbragar River event with 5% AEP Ballimore Creek and local catchment events
Hydraulic roughness (Manning's n)	+ 75% Manning's 'n' value applied to the Talbragar River
Downstream boundary - energy slope	Decreased Tailwater Energy Slope
Bridge blockage	Ballimore Creek Bridge – Increased Blockage Goan Creek Road Bridge – Increased Blockage
Culverts blockage	Decreased Blockage Increased Blockage

The rationalisation for each of these sensitivity tests along with adopted model parameters and results are summarised in the following sections.

Change in peak 1% AEP flood level mapping was prepared for all sensitivity assessment scenarios and is provided in Map Set C in Volume 3: Mapping Compendium. This mapping provides a visual representation of the location and magnitude of the predicted impacts of each sensitivity scenario, noting that the "difference" maps were created by subtracting the design 1% AEP flood level from the peak 1% AEP flood level for each sensitivity scenario. In general, sensitivity tests resulted in minor flood level differences when varying the model's parameters.

9.2 Coincidence of Talbragar River and Ballimore Creek/Local Catchment Events

A probability neutral approach would require, for each design AEP, the determination of flow from Ballimore Creek and from local catchments in the vicinity of Ballimore that, when combined with the flow from the Talbragar River, result in a joint probability equal to the examined design frequency. For this study, it was conservatively assumed that 1% AEP flows from the Talbragar River coincide with 1% AEP flows from Ballimore Creek and contributing local catchments, thereby defining the potential "worst-case" 1% AEP flood scenario within Ballimore.

For this study, a sensitivity test was carried to assess the impact of assuming the coincidence of 1% AEP Talbragar River flows with 5% AEP flows from Ballimore Creek and local catchment. The results of this assessment predicted no significant flood level reduction within Ballimore when compared to the design modelling results. This indicates that the dominant flood mechanism in terms of peak 1% AEP flood levels within the town is mainstream flooding from the Talbragar River.

9.3 Hydraulic Roughness

Whilst the adopted hydraulic roughness, or Manning's n values, are within typical recommended ranges, the inherent variability and uncertainty in hydraulic roughness warrants consideration of the relative impact on adopted design flood conditions. A sensitivity test on the TUFLOW modelling results to modified Manning's 'n' values was undertaken by applying a 75% increase to adopted Manning's n value for the Talbragar River, i.e. the value of 0.04 was increased to 0.07.

The output of this sensitivity assessment simulation indicates that the increased Manning's 'n' value within the extent of the Talbragar River results in a widespread increase in peak 1% AEP flood levels. At Ballimore, a water level increase of approximately 0.15 m is predicted.

9.4 Downstream Boundary - Water Surface Slope

As discussed in Section 5.3.8, a stage-discharge relationship automatically calculated based on the specified water surface slope was used to define downstream boundary conditions for the TUFLOW model. The downstream boundary is located a significant distance downstream of the study extent so as to not influence results within the specific study area of interest.

However, in order to confirm that the location of the downstream boundary is appropriate and the applied boundary condition does not influence the results within the study area, a sensitivity assessment was completed based on a scenario where the water surface slope was decreased to 0.05% (compared to the adopted downstream water surface slope of 0.2%).

The decreased slope is predicted to result in an increase in peak 1% AEP flood level extending about 3 km upstream from the downstream boundary location in the TUFLOW model and up to a maximum of 1.5 m. However, the reduced water slope results in negligible impacts on peak 1% AEP flood levels in Ballimore, with a flood level increase of less than 0.01 m predicted in the village.

9.5 Bridge Blockage

9.5.1 Ballimore Creek Bridge

The blockage assessment completed for the for the Golden Highway and railway bridge crossing of Ballimore Creek resulted in the application of 10% blockage of these structures for simulation of the 1% AEP flood. A sensitivity assessment to an increase in blockage to 50% (inclusive of the piers blockage) was completed and predicted no significant resultant flood level difference in Ballimore.

9.5.2 Goan Creek Road Bridge

For the design flood simulations, Goan Creek Road bridge on the Talbragar River is assumed as fully unblocked. A sensitivity assessment to both 50% and 90% blockage of this bridge was completed and predicted no resultant flood level difference in Ballimore.

9.6 Culvert Blockage

A sensitivity assessment of the impact of variation to adopted culvert blockage values was completed for culverts incorporated within the TUFLOW model (refer locations in Figure 5.6) based on the following two blockage scenarios:

- Fully unblocked, i.e. 0% blockage for all culverts.
- Fully blocked, i.e. 100% blockage for all culverts.

No significant flood level difference in Ballimore was predicted to result for either blockage sensitivity scenario.

10 References

Cardno. (2019), *Macquarie River, Dubbo Compilation of Flood Studies*.

Commonwealth of Australia (Geoscience Australia) (2019), *Australian Rainfall and Runoff: A guide to Flood Estimation*; edited by Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I.

Institution of Engineers (1987), *Australian Rainfall and Runoff – A Guide to Flood Estimation*; edited by DH Pilgrim, ISBN 085825 434 4.

NSW Government. (2005), *Floodplain Development Manual: the management of flood liable land*, ISBN 0 7347 5476 0.

PPK. (1999), *Talbragar River Supplementary Flood Study*.

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World Meteorological Organization (2009). *Manual for Estimation of Probable Maximum Precipitation*, 3rd edition, WMO - No. 1045, Geneva, ISBN 978-92-63-11045-9.

11 Glossary

afflux	The change in water level from existing conditions resulting from a change in the watercourse or floodplain – for example construction of a new bridge.
Annual Exceedance Probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m3/s has an AEP of 5%, it means that there is a 5% chance (that is a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year. See also average recurrence interval.
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
astronomical tide	Astronomical tide is the cyclic rising and falling of the Earth's oceans water levels resulting from gravitational forces of the Moon and the Sun acting on the Earth.
attenuation	Weakening in force or intensity.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrence of a flood as big as (or larger than) the selected event. For example, floods with a discharge as great as (or greater than) the 20 year ARI design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event (see also annual exceedance probability).
Australian Rainfall and Runoff (ARR)	National guideline document, data and software suite that can be used for the estimation of design flood characteristics in Australia.
calibration	The adjustment of model configuration and key parameters to best fit an observed data set.
catchment	The catchment at a particular point is the area of land that drains to that point.
critical duration	The critical duration is the design storm duration which provides the highest peak water levels for a given design flood (for example 1% AEP) at a given location. For example, if the following design durations were modelled - 2-hour, 6-hour, 9-hour and 12-hour – and the 9-hour duration resulted in the highest peak water level at a given location then the critical duration for that location would be 9-hours.
design flood event	A probabilistic or statistical estimate of flooding representing a specific likelihood of occurrence (for example the 100 year ARI or 1% AEP flood).
development	Existing or proposed works that may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.

discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
Extreme Flood	An extreme flood deemed to be the maximum flood likely to occur (for this study the Extreme Flood event was defined as three times the 1% AEP event).
flood	Relatively high river or creek flows, which overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
flood behaviour	The pattern / characteristics / nature of a flood.
flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage.
flood hazard	The potential risk to life and limb and potential damage to property resulting from flooding. The degree of flood hazard varies with circumstances across the full range of floods.
flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as “stage”.
flood liable land	see flood prone land.
floodplain	Land adjacent to a river or creek that is periodically inundated due to floods. The floodplain includes all land that is susceptible to inundation by the probable maximum flood (PMF) or Extreme Flood event.
floodplain management	The co-ordinated management of activities that occur on the floodplain.
floodplain risk management plan	A document outlining a range of actions aimed at improving floodplain management. The plan is the principal means of managing the risks associated with the use of the floodplain. A floodplain risk management plan needs to be developed in accordance with the principles and guidelines contained in the NSW Floodplain Management Manual. The plan usually contains both written and diagrammatic information describing how particular areas of the floodplain are to be used and managed to achieve defined objectives.

Flood Planning Levels (FPLs)	Flood Planning Levels selected for planning purposes are derived from a combination of the adopted flood level plus freeboard, as determined in floodplain management studies and incorporated in floodplain risk management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also account for the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of land use and for different flood plans. The concept of FPLs supersedes the "standard flood event". As FPLs do not necessarily extend to the limits of flood prone land, floodplain risk management plans may apply to flood prone land beyond that defined by the FPLs.
flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) or Extreme Flood event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (that is the entire floodplain).
flood source	The source of the floodwaters.
flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
floodway	A flow path (sometimes artificial) that carries significant volumes of floodwaters during a flood.
freeboard	A factor of safety usually expressed as a height above the adopted flood level thus determining the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
gauging (tidal and flood)	Measurement of flows and water levels during tides or flood events.
historical flood	A flood that has actually occurred.
hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrodynamic	Pertaining to the movement of water.
hydrograph	A graph showing how a river or creek's discharge changes with time.
hydrologic	Pertaining to rainfall-runoff processes in catchments.
hydrology	The term given to the study of the rainfall-runoff process in catchments.
hyetograph	A graph showing the depth of rainfall over time.

Intensity Frequency Duration (IFD) Curve	A statistical representation of rainfall showing the relationship between rainfall intensity, storm duration and frequency (probability) of occurrence.
LiDAR	Light Detection and Ranging –a remote sensing method used to generate ground surface elevation. Typically acquired through airborne surveys from which an aeroplane can cover large areas.
overland flow	Overland flow is surface run off before it enters a waterway. It is caused by rainfall which flows downhill along low points concentrating in gullies, channels, surface depressions and stormwater systems.
peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
pluviometer	A rainfall gauge capable of continuously measuring rainfall intensity (also called a “pluvio”).
Probable Maximum Flood (PMF)	An extreme flood deemed to be the maximum flood likely to occur.
probability	A statistical measure of the likely frequency or occurrence of flooding.
riparian	The interface between land and waterway. Literally means “along the river margins”.
runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
stage	See flood level.
stage hydrograph	A graph of water level over time.
sub-critical	Refers to flow in a channel that is relatively slow and deep.
topography	The shape of the surface features of land.
velocity	The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, that is the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, that is the average velocity across the whole river or creek section.
validation	A test of the appropriateness of the adopted model configuration and parameters (through the calibration process) for other observed events.

water level	See flood level.

Annex A Community Consultation

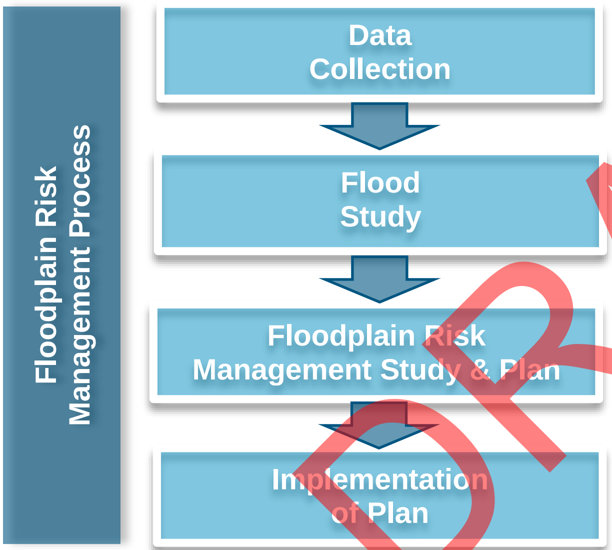
BALLIMORE VILLAGE FLOOD STUDY AND FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

INFORMATION SHEET

Introduction

Dubbo Regional Council is carrying out a Flood Study and a Floodplain Risk Management Study and Plan to understand and manage flood risks in Ballimore. This includes consideration of flooding emanating from the Talbragar River and Ballimore Creek.

The floodplain risk management process is outlined in the flow chart below.



Dubbo Regional Council will administer the project with input from the Floodplain Risk Management Committee. The Committee will oversee the study, providing regular input and feedback on key outcomes. The Committee has a broad representation including Councillors, Council staff, State Government representatives including State Emergency Services (SES), stakeholder groups and community representatives.

BMT has been commissioned to carry out the study. BMT is an independent company that specialises in water and environmental issues, including floodplain risk management.

The NSW Department of Planning, Industry & Environment is providing financial and technical assistance.

What will the Study Achieve?

The township of Ballimore has a history of major flooding, with large floods having occurred in 1955 and 2010.

In order to appropriately plan for future flood events and reduce potential impacts of flooding on the community, we need to determine the nature and extent of the existing flooding problem at Ballimore.

The main objective of the **Flood Study** is to characterise the flood behaviour in Ballimore, describing in detail the potential flood inundation extents, peak water levels, depths and velocities across the floodplain for a range of flood magnitudes.

The Flood Study will define the flood behaviour through the development of computer modelling tools which will be calibrated to known flood events. High-resolution flood maps will be produced to spatially describe the nature of flooding in Ballimore.

Ballimore during the 2010 flood event

Talbragar River at Boomley Road

The **Floodplain Risk Management Study** (FRMS) will consider the consequences of flooding on the community and aims to develop appropriate floodplain management measures to minimise and mitigate the impact of flooding. This incorporates the existing flood risk associated with current development, and future flood risk associated with future development and changes in land use.

The outcomes of the FRMS provide the basis for the **Floodplain Risk Management Plan**, containing an appropriate mix of management measures and strategies, to help direct and coordinate the responsibilities of Council, State Government and the community in undertaking immediate and future flood management works and initiatives.

Information from the study will be used by the SES during flood emergencies and will be used by Council to assist them to manage development in flood-affected areas.

Community Input

Community involvement in managing flood risks is essential to identify local concerns and values and to inform the community about the consequences of flooding and potential management options.

Your information about previous flooding, including photographs, videos and anecdotal evidence is highly valuable in understanding flooding behaviour and the potential flood risk to residents.

You can help us by passing on information about flooding you may have experienced, or by participating in community discussions about future floodplain management in Ballimore. Please:

- Complete and return the short **questionnaire** attached to this newsletter by 13th March 2020 or complete the questionnaire online by visiting https://www.surveymonkey.com/r/XPCG2G9
- Come along to the **community information session** to be held later in the year, to discuss community concerns and potential floodplain management problems and solutions.

For any general information relating to the study, please contact:

BMT

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DUBBO REGIONAL COUNCIL

Stephen Howlett

Manager Infrastructure Strategy and Design

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BALLIMORE VILLAGE FLOOD STUDY AND FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

COMMUNITY QUESTIONNAIRE

The following questionnaire should only take around 15 minutes to complete. Community involvement is essential to the success of the overall floodplain risk management process. Although voluntary, this questionnaire is your opportunity to contribute your local knowledge of flooding in the area which will help to improve the accuracy of flood models being developed as part of the study. A map of the study area has been included on page 4 for your reference.

To complete the questionnaire, please tick the appropriate boxes and provide comments where required. You may tick more than one box if applicable. Once complete, please return the questionnaire using the reply-paid envelope provided (no postage stamp required) by **13th March 2020**.

Alternatively, if you have internet access, the questionnaire can also be accessed and completed online by visiting **https://www.surveymonkey.com/r/XPCG2G9**

Your Contact Information

This information will only be used in relation to the study and will remain confidential at all times.

Name: ………

Business (if applicable): ………………………………………………………………………………………

Address: ………………………………………………………………………………………………………

……

……

Telephone: ……………………………………………

Email: ……………………………………………………

I wish to receive information for the duration of the study: □ Yes □ No

If you answered "yes", please ensure you have provided an email address.

Community Questionnaire

1. Which option best describes the property?

□ Residential □ Vacant Land □ Industrial

□ Commercial □ Farming/Rural □ Other (please specify) ………………

2. What is the status of the property?

□ Owner Occupied □ Leased to rental tenants □ Renting

3. How long have you lived, owned or operated a business at this address?

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

4. Have you ever experienced flooding within or outside your property?

□ Yes (please fill out table below) □ No (please go to question 8)

Details	Event 1	Event 2	Event 3
Date/s of flooding, if known? (Date, month, year). If more than one occasion, please list all dates.			
What **areas** were affected by flooding (select more than one if appropriate) 1 = Front yard/backyard 2 = Garage/shed 3 = Inside the building 4 = Access to or from the property 5 = Others (e.g. road, park)			
What was the **depth** of flooding (in cm) or how best could it be described? Very shallow = Below ankle Shallow = Mid-calf level Medium = Knee deep Deep = Above knee Please attach details of the location of this depth (e.g. a sketch)			
What was the **speed** of the flood waters at the peak/worst of the flooding? 1 = Stationary 2 = Walking pace 3 = Running pace			
What was the **source** of the floodwaters? 1 = Talbragar River (floodwaters rising in the river) 2 = Ballimore Creek (floodwaters rising in the creek) 3 = Ponding of water within your property 4 = Insufficient roadside drainage 5 = Other (please specify)			
What was the **duration** of the flooding? 1 = Less than 1 hour 2 = 1 – 5 hours 3 = More than 5 hours			

5. Are there any flood marks on or near your property?

(e.g. marks the mud left on the side of a building when the floodwaters went down)

☐ Yes ☐ No

If you answered "yes", do you give permission for surveyors to access your property to survey the flood marks? Please ensure you have completed the contact details above so we can contact you.

☐ Yes ☐ No

6. Do you have or know of any photographs or records of these flood events?

☐ Yes ☐ No

Please attach or email any photos or records of these flood events.

If you answered "yes", do you give permission for Council to publish your flooding photos and/or make copies of this data to contribute to the study?

☐ Yes ☐ No

7. Do you expect to undertake any further development on your land in the future?

☐ No ☐ Minor extensions ☐ New building ☐ Unsure

☐ Other (please specify) ....

8. Do you consider that flooding of your property has been made worse by works on other properties, or by the construction of roads or other structures?

☐ Yes ☐ Unsure ☐ No

If you answered "yes", please provide details / photos / sketches etc on the following page or attach to your response.

9. In previous floods, what action did you take to protect your property against flood damage?

☐ None ☐ Used sandbags ☐ Moved vehicles ☐ Lifted stock/equipment

☐ Other (please specify) ....

10. Please indicate if you support the following approaches to flood mitigation in the area. Note that the suitability of these options for use in the study area has not yet been determined and will be assessed as the study progresses.

Flood protection levees	☐ Support	☐ Neutral	☐ Oppose
Roadside drainage works (e.g. channel widening, straightening, concrete lining, culvert enlargement)	☐ Support	☐ Neutral	☐ Oppose
Increasing the frequency of maintenance works of creek channels (e.g. debris clearing, vegetation control)	☐ Support	☐ Neutral	☐ Oppose
Voluntary raising of dwellings situated in flood prone areas of the floodplain	☐ Support	☐ Neutral	☐ Oppose

Voluntary purchase of properties situated in high hazard areas of the floodplain	□ Support	□ Neutral	□ Oppose
Community education strategies to improve community preparation for and response to flooding	□ Support	□ Neutral	□ Oppose
Application of firmer development controls in the floodplain for new development	□ Support	□ Neutral	□ Oppose
Improvements in flood warning	□ Support	□ Neutral	□ Oppose
Improvements in emergency response procedures	□ Support	□ Neutral	□ Oppose

11. Do you have any suggestions for resolving the flooding or drainage problems in your area or do you have any comments you wish to make in addition to the questions in the survey?

Please attach additional pages for any further information, if needed.

……………………………………………………………………………………………………

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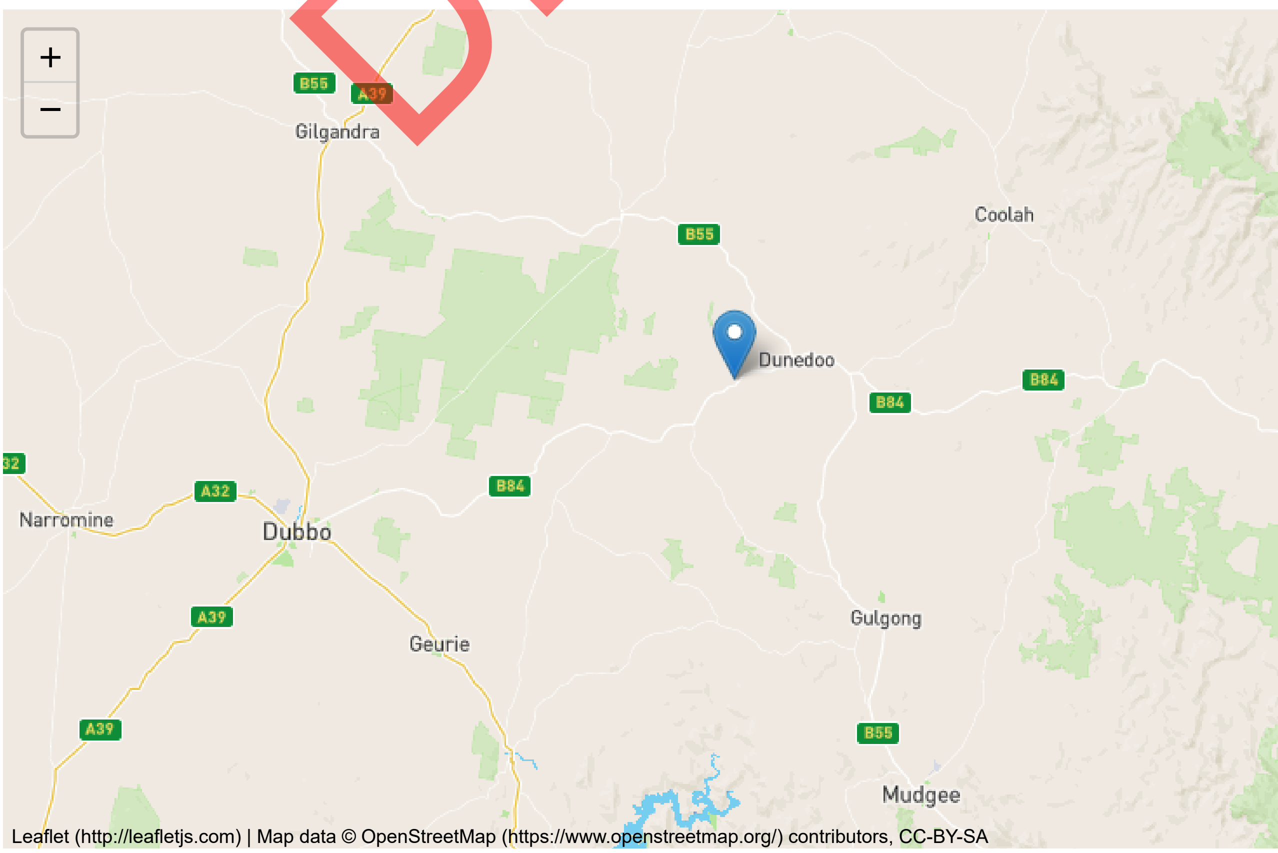
Thank you for taking the time to complete this questionnaire.

Annex B ARR Datahub – Talbragar River Catchment Centroid

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	149.294
Latitude	-32.045
Selected Regions (clear)	
River Region	show
ARF Parameters	show
Storm Losses	show
Temporal Patterns	show
Areal Temporal Patterns	show
BOM IFDs	show
Median Preburst Depths and Ratios	show
10% Preburst Depths	show
25% Preburst Depths	show
75% Preburst Depths	show
90% Preburst Depths	show
Interim Climate Change Factors	show
Probability Neutral Burst Initial Loss (./nsw_specific)	show



Data

River Region

Division	Murray-Darling Basin
River Number	22
River Name	Macquarie-Bogan Rivers

Layer Info

Time Accessed	09 February 2022 08:51AM
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
Central NSW	0.265	0.241	0.505	0.321	0.00056	0.414	-0.021	0.015	-0.00033

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	09 February 2022 08:51AM
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.

ID	19128.0
Storm Initial Losses (mm)	36.0
Storm Continuing Losses (mm/h)	1.7

Layer Info

Time Accessed	09 February 2022 08:51AM
Version	2016_v1

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

code	CS
Label	Central Slopes

Layer Info

Time Accessed	09 February 2022 08:51AM
Version	2016_v2

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

code	CS
arealabel	Central Slopes

Layer Info

Time Accessed	09 February 2022 08:51AM
Version	2016_v2

BOM IFDs

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-32.044776&longitude=149.293876&sdmin=true&sdhr=true&sdday=true&user_label=) to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	09 February 2022 08:51AM

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)	1.6 (0.071)	1.2 (0.038)	0.9 (0.024)	0.6 (0.014)	0.6 (0.012)	0.6 (0.010)
90 (1.5)	1.1 (0.041)	1.1 (0.031)	1.1 (0.027)	1.1 (0.024)	0.6 (0.010)	0.1 (0.002)
120 (2.0)	1.5 (0.052)	1.1 (0.030)	0.9 (0.020)	0.7 (0.013)	0.7 (0.012)	0.8 (0.012)
180 (3.0)	0.6 (0.019)	0.8 (0.019)	0.9 (0.018)	1.1 (0.018)	1.5 (0.022)	1.8 (0.024)
360 (6.0)	1.3 (0.033)	2.8 (0.052)	3.7 (0.060)	4.7 (0.066)	5.4 (0.065)	5.9 (0.064)
720 (12.0)	0.0 (0.001)	2.6 (0.039)	4.3 (0.055)	5.9 (0.066)	8.4 (0.081)	10.3 (0.088)
1080 (18.0)	0.0 (0.000)	0.9 (0.012)	1.5 (0.017)	2.0 (0.020)	6.5 (0.054)	9.9 (0.073)
1440 (24.0)	0.0 (0.000)	0.1 (0.001)	0.2 (0.002)	0.3 (0.002)	4.8 (0.036)	8.1 (0.054)
2160 (36.0)	0.0 (0.000)	0.1 (0.001)	0.1 (0.001)	0.2 (0.001)	2.0 (0.013)	3.3 (0.019)
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	09 February 2022 08:51AM
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	09 February 2022 08:51AM
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 (0.001)	0.0 (0.001)	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)	0.1 (0.001)	0.1 (0.001)
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	09 February 2022 08:51AM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

75% Preburst Depths

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

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	13.4 (0.581)	10.6 (0.342)	8.7 (0.238)	6.9 (0.164)	8.0 (0.161)	8.8 (0.158)
90 (1.5)	11.3 (0.433)	12.2 (0.349)	12.8 (0.311)	13.4 (0.282)	10.7 (0.191)	8.7 (0.139)
120 (2.0)	16.0 (0.567)	14.9 (0.392)	14.2 (0.316)	13.4 (0.260)	15.5 (0.256)	17.1 (0.253)
180 (3.0)	11.7 (0.367)	14.1 (0.329)	15.7 (0.311)	17.2 (0.297)	20.5 (0.302)	22.9 (0.303)
360 (6.0)	12.8 (0.324)	19.3 (0.365)	23.7 (0.381)	27.8 (0.391)	36.7 (0.441)	43.4 (0.468)
720 (12.0)	6.3 (0.129)	16.2 (0.247)	22.8 (0.295)	29.1 (0.328)	36.3 (0.347)	41.7 (0.356)
1080 (18.0)	3.5 (0.063)	10.8 (0.145)	15.6 (0.178)	20.3 (0.200)	33.0 (0.274)	42.5 (0.314)
1440 (24.0)	1.8 (0.029)	7.6 (0.093)	11.4 (0.119)	15.1 (0.136)	24.7 (0.186)	32.0 (0.213)
2160 (36.0)	0.1 (0.002)	4.4 (0.049)	7.2 (0.067)	10.0 (0.079)	11.7 (0.077)	13.1 (0.075)
2880 (48.0)	0.0 (0.000)	1.0 (0.010)	1.7 (0.014)	2.3 (0.017)	6.1 (0.037)	9.0 (0.047)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	1.8 (0.010)	3.2 (0.015)

Layer Info

Time Accessed	09 February 2022 08:51AM
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)	33.3 (1.444)	27.1 (0.873)	22.9 (0.627)	19.0 (0.449)	26.5 (0.532)	32.2 (0.576)
90 (1.5)	28.4 (1.091)	36.9 (1.055)	42.6 (1.031)	48.0 (1.008)	40.7 (0.726)	35.2 (0.562)
120 (2.0)	36.4 (1.285)	39.7 (1.045)	42.0 (0.936)	44.1 (0.855)	54.2 (0.893)	61.7 (0.912)
180 (3.0)	39.0 (1.224)	40.5 (0.947)	41.5 (0.825)	42.5 (0.734)	48.5 (0.714)	53.0 (0.700)
360 (6.0)	27.9 (0.709)	41.3 (0.781)	50.1 (0.808)	58.6 (0.825)	71.6 (0.859)	81.3 (0.876)
720 (12.0)	21.7 (0.443)	39.0 (0.593)	50.4 (0.652)	61.4 (0.693)	75.1 (0.718)	85.3 (0.729)
1080 (18.0)	20.9 (0.378)	34.2 (0.458)	42.9 (0.488)	51.3 (0.507)	70.8 (0.589)	85.4 (0.631)
1440 (24.0)	17.3 (0.289)	27.6 (0.341)	34.5 (0.359)	41.0 (0.369)	55.3 (0.417)	66.0 (0.440)
2160 (36.0)	12.0 (0.180)	24.1 (0.266)	32.1 (0.297)	39.8 (0.315)	49.4 (0.325)	56.6 (0.326)
2880 (48.0)	4.0 (0.056)	10.2 (0.105)	14.3 (0.122)	18.2 (0.132)	34.5 (0.207)	46.7 (0.244)
4320 (72.0)	2.6 (0.034)	5.1 (0.047)	6.7 (0.052)	8.2 (0.053)	16.0 (0.085)	21.8 (0.101)

Layer Info

Time Accessed	09 February 2022 08:51AM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

Interim Climate Change Factors

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

Layer Info

Time Accessed	09 February 2022 08:51AM
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)	23.0	15.5	14.3	14.9	15.5	14.1
90 (1.5)	26.0	16.3	14.2	14.2	14.3	13.0
120 (2.0)	27.1	14.9	14.0	14.5	13.6	11.0
180 (3.0)	27.6	16.1	15.0	15.4	14.3	10.7
360 (6.0)	27.6	18.1	14.8	14.0	12.1	7.6
720 (12.0)	30.1	20.7	17.4	15.7	13.7	8.6
1080 (18.0)	31.0	23.0	20.4	19.9	15.9	9.2
1440 (24.0)	32.5	24.8	23.0	23.1	19.8	12.9
2160 (36.0)	34.1	26.9	25.6	26.2	23.7	15.3
2880 (48.0)	35.9	29.8	30.2	32.2	28.2	18.4
4320 (72.0)	36.9	30.9	33.6	36.2	33.0	25.7

Layer Info

Time Accessed	09 February 2022 08:51AM
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/988ecc09-1235-4e83-a0ce-15a9615e0e95.txt)

Download JSON (downloads/4c74f0b3-4a5d-4e98-9057-b989571ed454.json)

Generating PDF... (downloads/6284c077-bba6-4ea1-80b6-287b3f7282a5.pdf)

Annex C Critical Duration and Temporal Pattern Assessment at Elong Elong

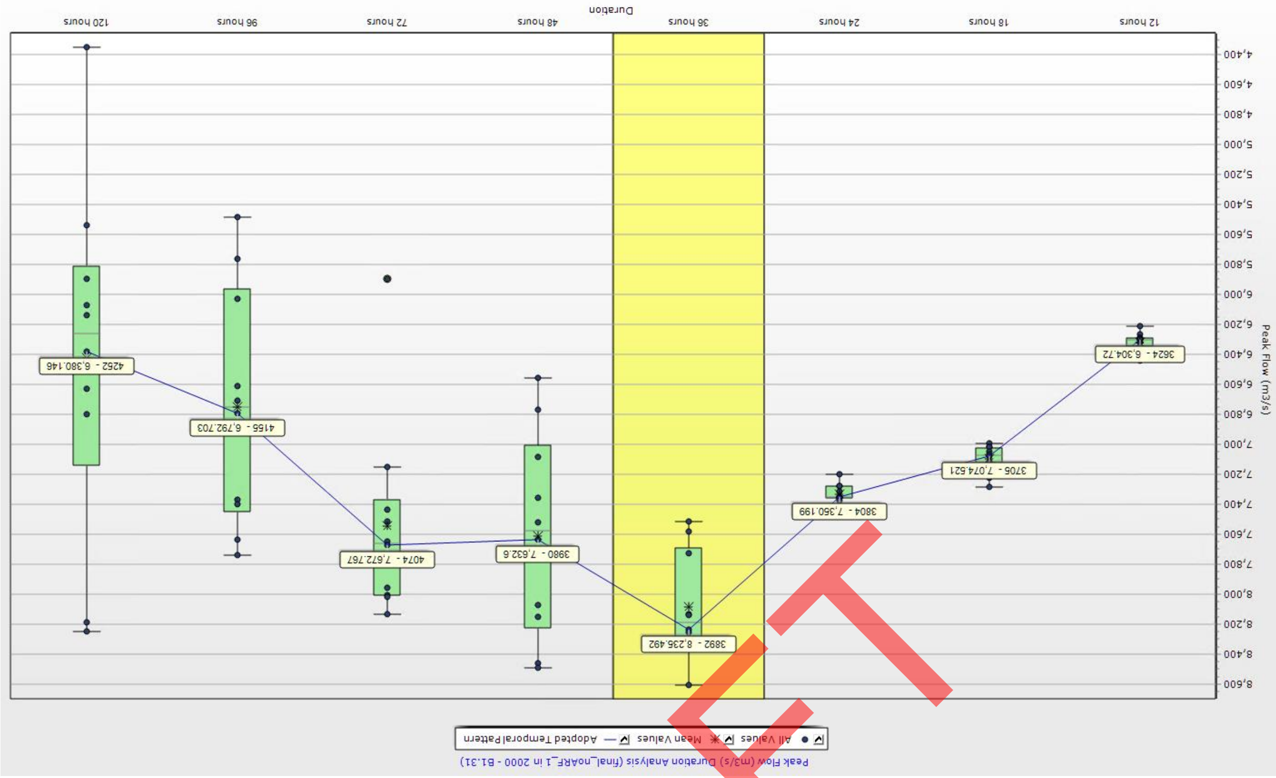


Figure C.1 Critical Temporal Pattern and Duration Assessment for 0.05% AEP Event (Critical Duration/Temporal Pattern Highlighted in Yellow)

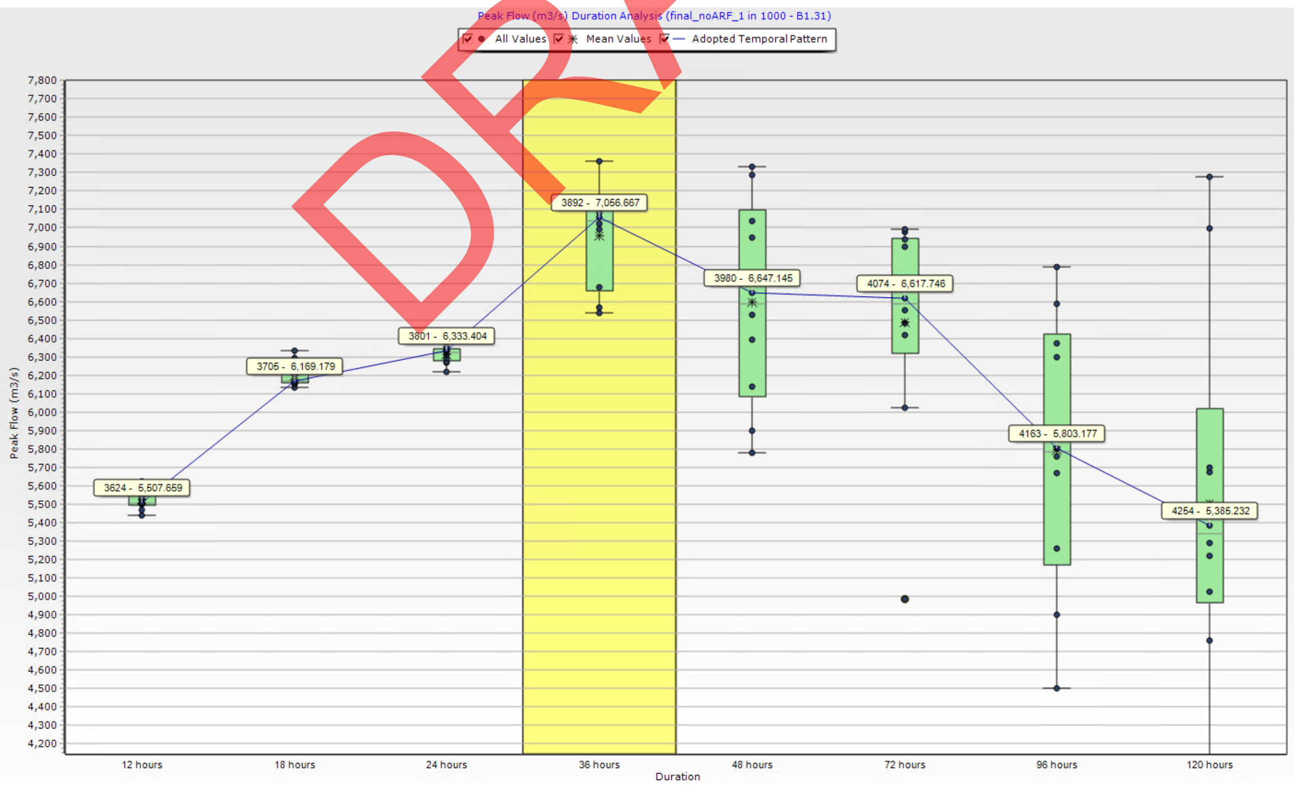


Figure C.2 Critical Temporal Pattern and Duration Assessment for 0.1% AEP Event (Critical Duration/Temporal Pattern Highlighted in Yellow)

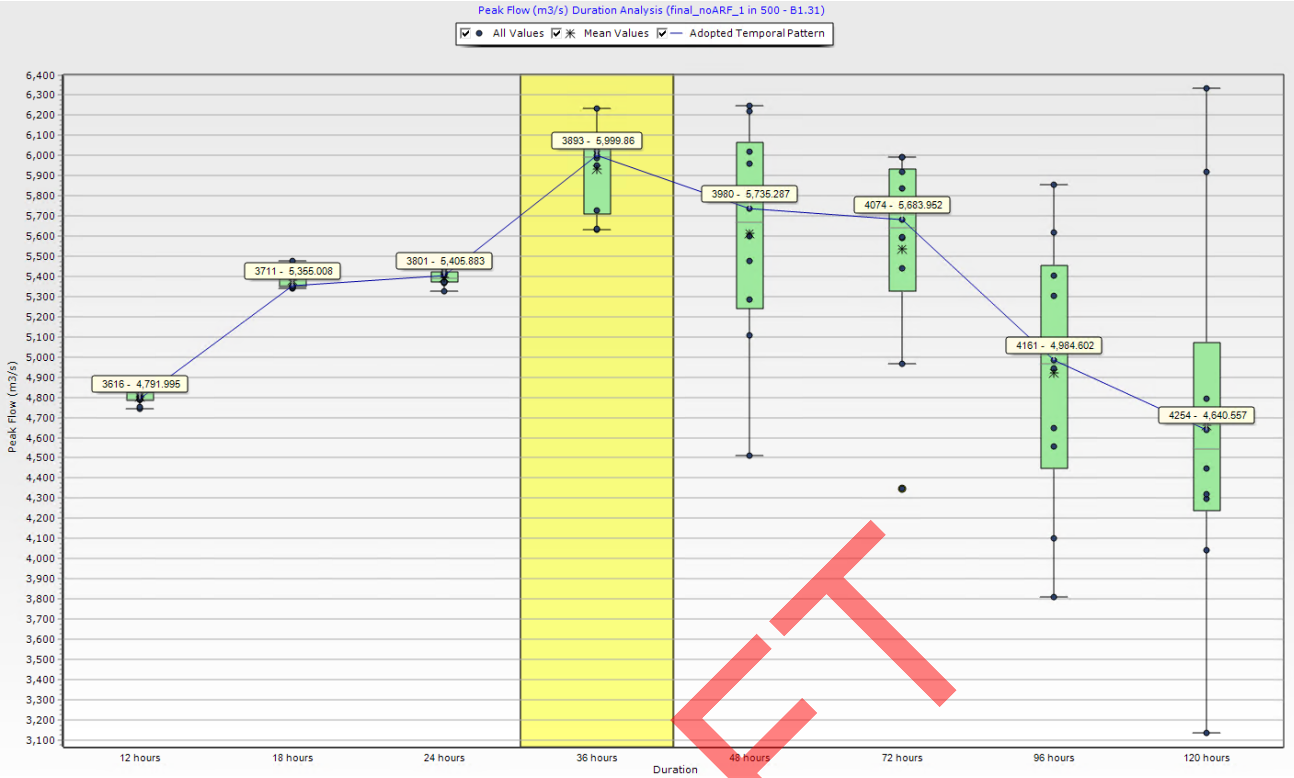


Figure C.3 Critical Temporal Pattern and Duration Assessment for 0.2% AEP Event (Critical Duration/Temporal Pattern Highlighted in Yellow)

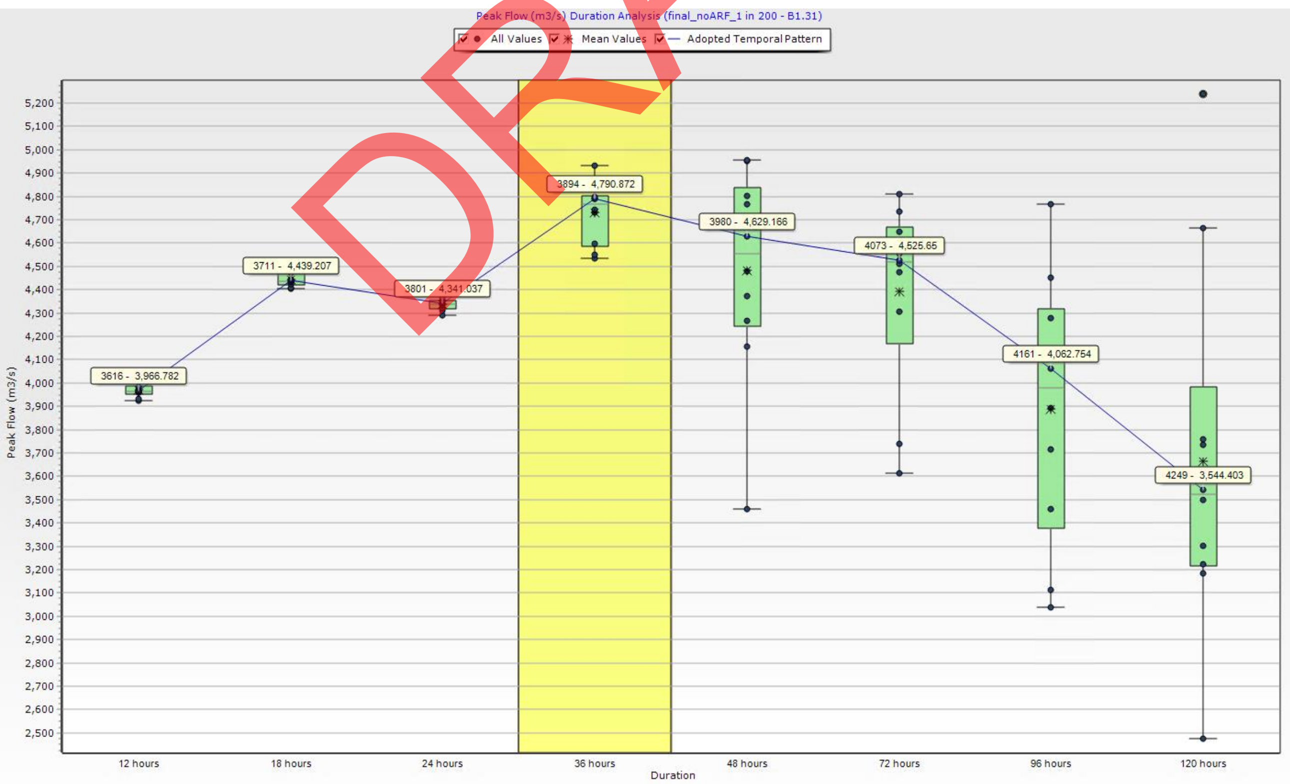


Figure C.4 Critical Temporal Pattern and Duration Assessment for 0.5% AEP Event (Critical Duration/Temporal Pattern Highlighted in Yellow)

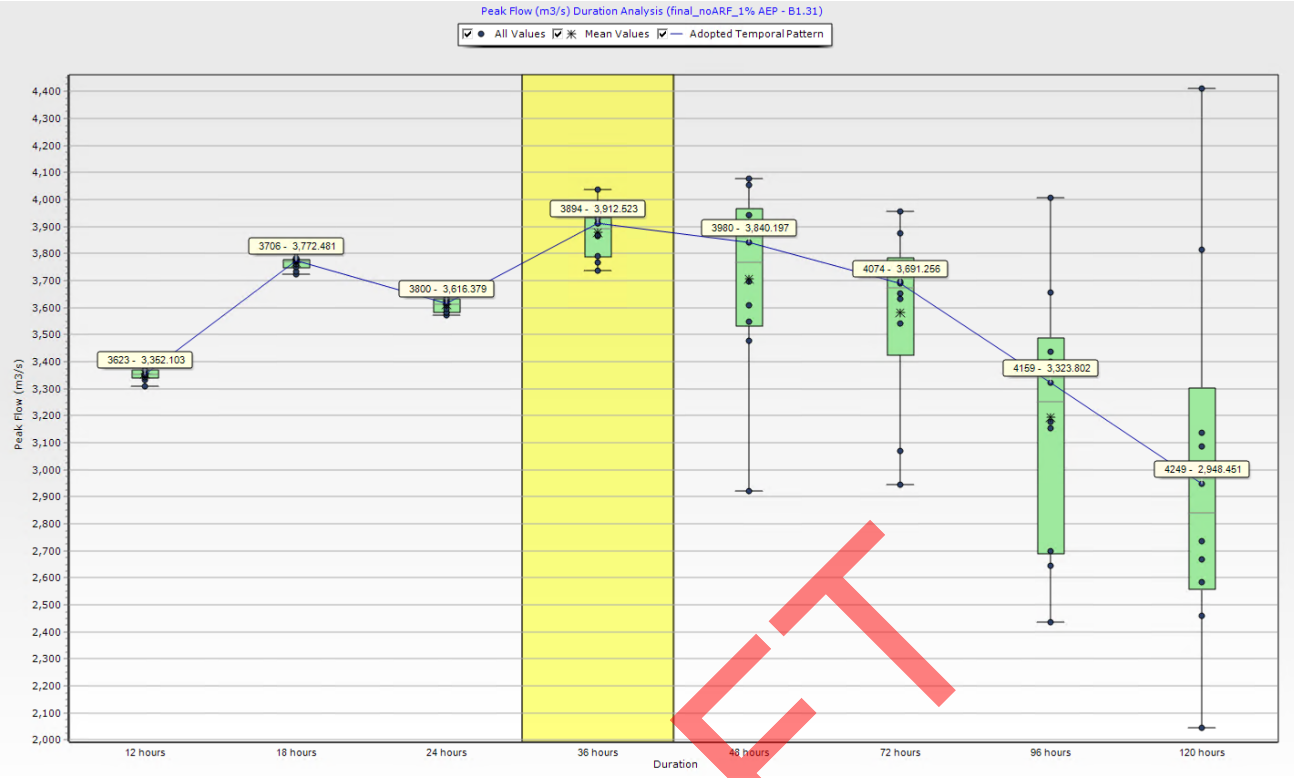


Figure C.5 Critical Temporal Pattern and Duration Assessment for 1% AEP Event (Critical Duration/Temporal Pattern Highlighted in Yellow)

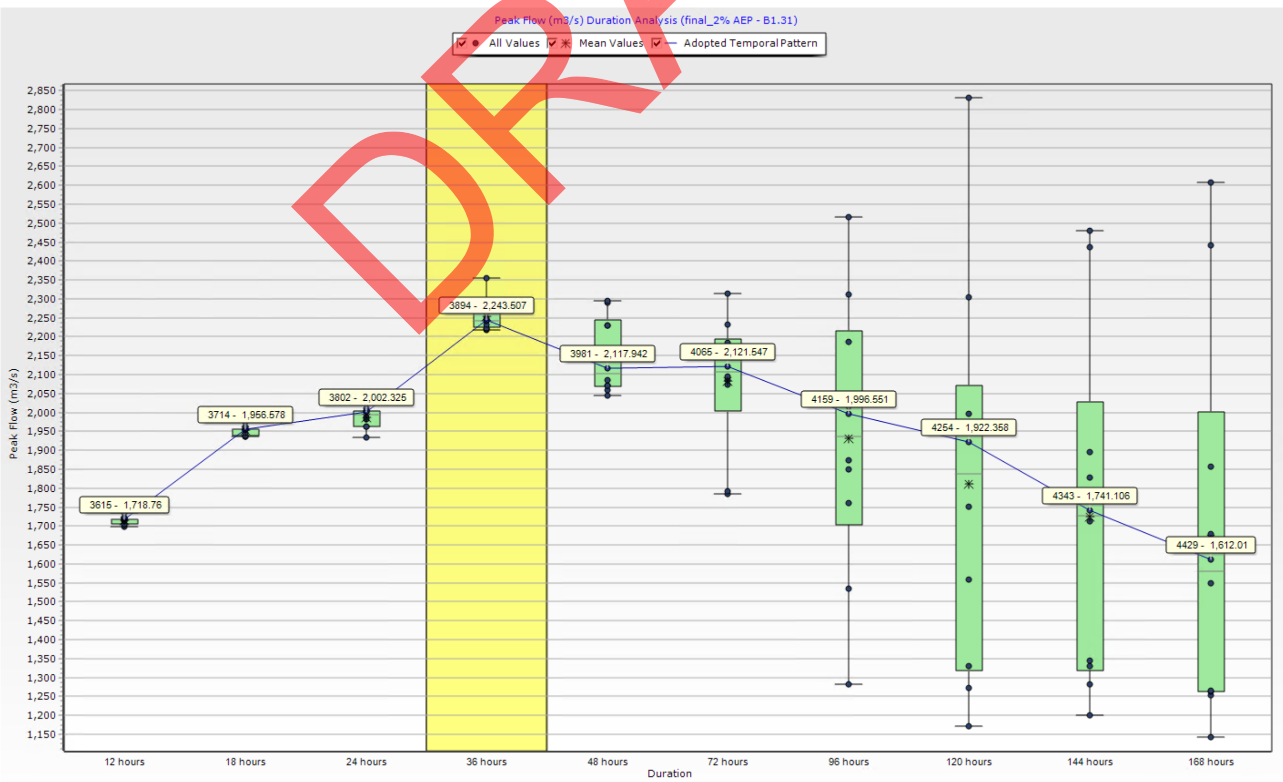


Figure C.6 Critical Temporal Pattern and Duration Assessment for 2% AEP Event (Critical Duration/Temporal Pattern Highlighted in Yellow)

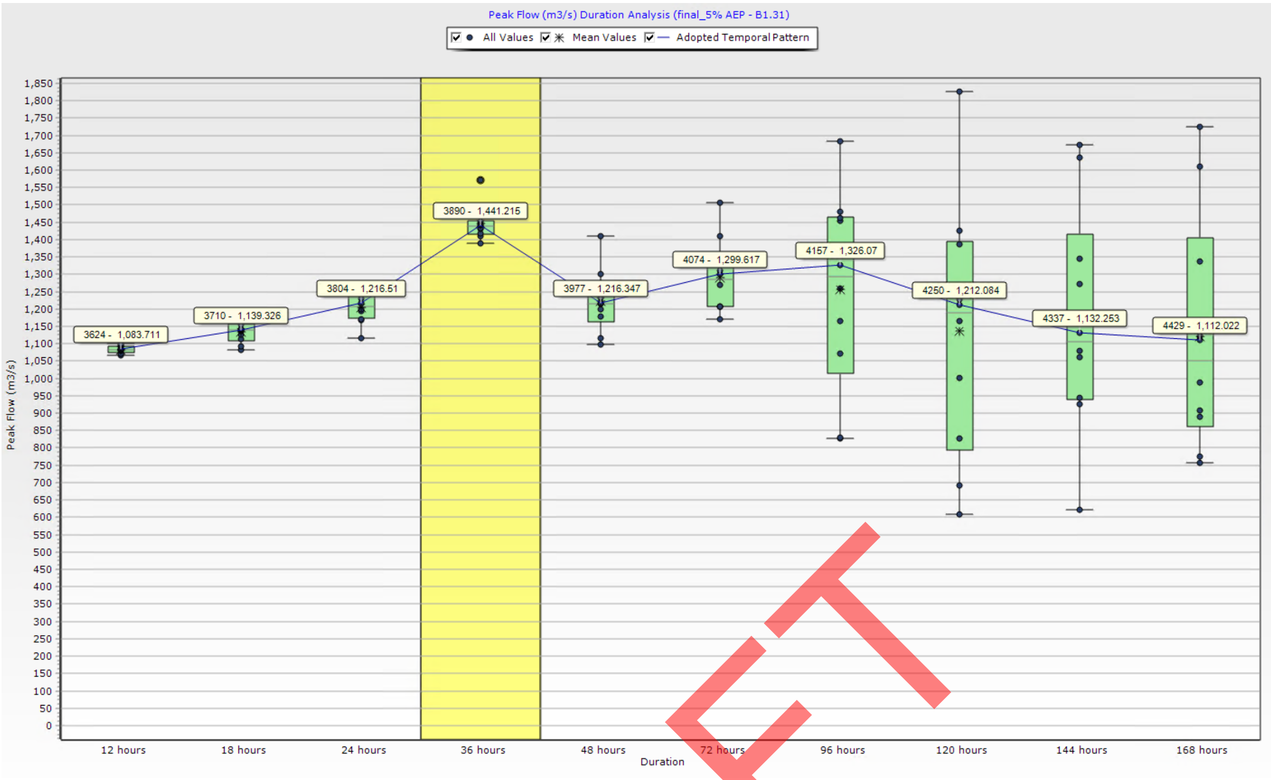


Figure C.7 Critical Temporal Pattern and Duration Assessment for 5% AEP Event (Critical Duration/Temporal Pattern Highlighted in Yellow)

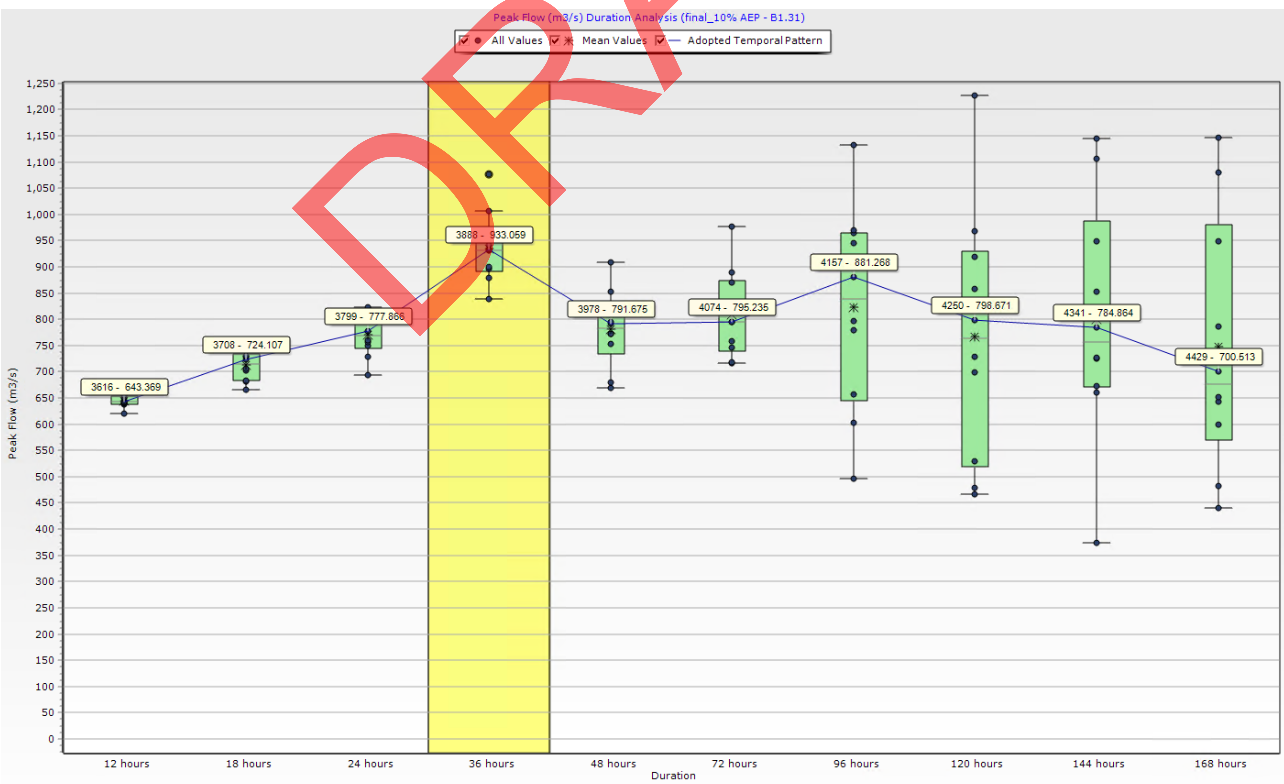


Figure C.8 Critical Temporal Pattern and Duration Assessment for 10% AEP Event (Critical Duration/Temporal Pattern Highlighted in Yellow)

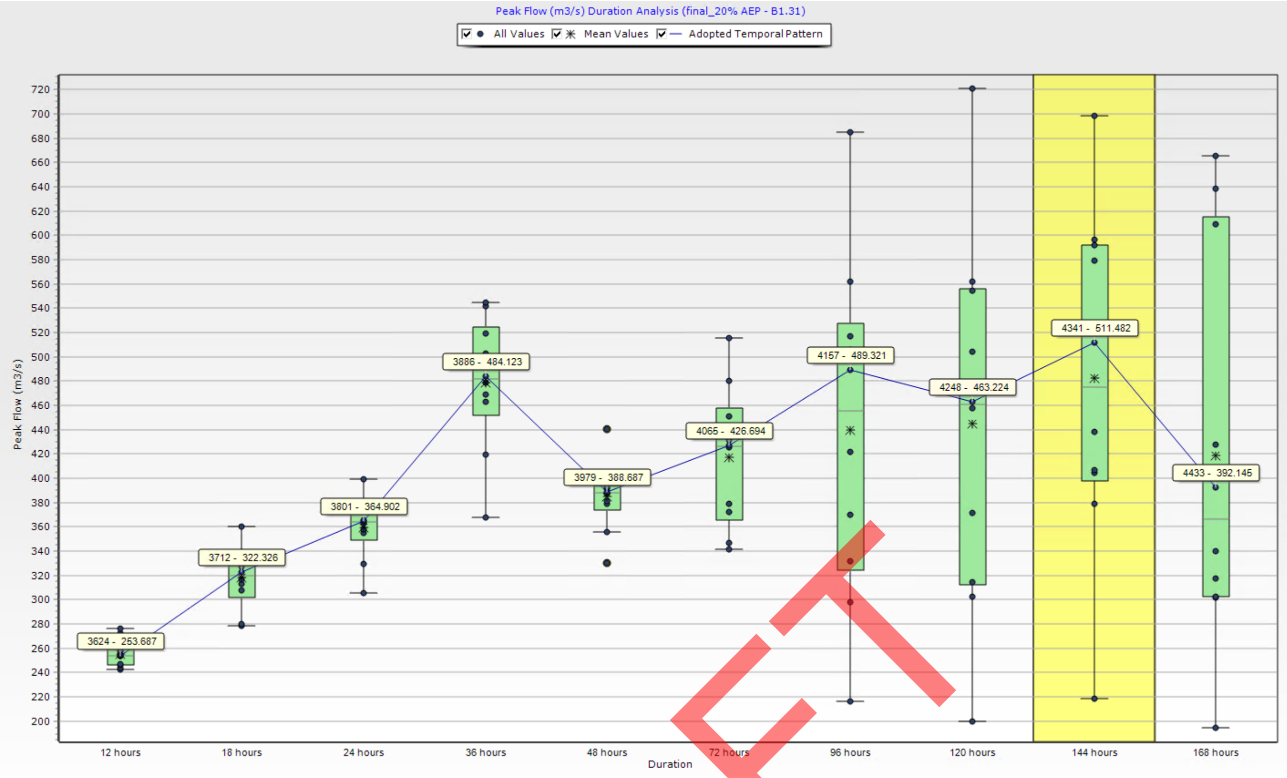


Figure C.9 Critical Temporal Pattern and Duration Assessment for 20% AEP Event (Critical Duration/Temporal Pattern Highlighted in yellow)

Annex D Blockage Assessment

BLOCKAGE ASSESMENT FORM

Australian Rainfall & Runoff

STRUCTURE : Golden Hwy and Railway Bridges at Ballimore Creek

OPENING WIDTH:..........30..........m

DEBRIS TYPE/MATERIAL/L_{10}/SOURCE AREA - ***There may be more than one material type to consider!***

Debris Type/Material	L_{10}	Source Area	How Assessed
Brush/Tree Limbs	10	Trees and Brushes along Ballimore Creek	Visual / Satellite

DEBRIS AVAILABILITY (HML) – ***for the selected debris type/size and its source area***

Availability	Typical Source Area Characteristics	Notes
High	• *Dense forest, thick vegetation, extensive canopy, difficult to walk through with considerable fallen limbs, leaves and high levels of floor litter.* • *Streams with boulder/cobble beds and steep bed slopes and banks showing signs of substantial past bed/bank movements.* • *Arid areas, where loose vegetation and exposed loose soils occur and vegetation is sparse.* • *Urban areas that are not well maintained and/or old paling fences, sheds, cars and/or stored loose material etc., are present on the floodplain close to the water course.*	
Medium	• *State forest areas with clear understory, grazing land with stands of trees* • *Source areas generally falling between the High and Low categories.*	Well Maintained rural land but several trees along the creek
Low	• *Well maintained rural lands and paddocks, with minimal outbuildings* • *Streams with moderate to flat slopes and stable beds and banks.* • *Arid areas where vegetation is deep rooted and soils resistant to scour* • *Urban areas that are well maintained with limited debris present in the source area.*	

DEBRIS MOBILITY (HML) - ***for the selected debris type/size and its source area***

Mobility	Typical Source Area Characteristics	Notes
High	• *Steep source area with fast response times and high annual rainfall and/or storm intensities and/or source areas subject to high rainfall intensities with sparse vegetation cover.* • *Receiving streams that frequently overtop their banks.* • *Main debris source areas close to streams*	
Medium	• *Source areas generally falling between the High and Low categories.*	Medium Debris Mobility
Low	• *Low rainfall intensities and large, flat source areas.* • *Receiving streams that infrequently overtop their banks.* • *Main source areas well away from streams*	

DEBRIS TRANSPORTABILITY (HML) - ***for the selected debris type/size and stream characteristics***

Transportability	Typical Transporting Stream Characteristics	Notes
High	• *Steep bed slopes (> 3%).and/or high stream velocity (V>2.5m/sec)* • *Deep stream relative to vertical debris dimension ($D>0.5L_{10}$)* • *Wide streams relative to horizontal debris dimension. ($W>L_{10}$)* • *Streams relatively straight and free of constrictions/snag points.* • *High temporal variability in maximum stream flows*	
Medium	• *Streams generally falling between High and Low categories*	Medium Transportability
Low	• *Flat bed slopes (< 1%).and/or low stream velocity (V<1m/sec)* • *Shallow stream relative to vertical debris dimension ($D<0.5L_{10}$)* • *Narrow streams relative to horizontal debris dimension.($W<L_{10}$)* • *Streams meander with frequent constrictions/snag points.* • *Low temporal variability in maximum stream flows*	

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BLOCKAGE ASSESMENT FORM

Australian Rainfall & Runoff

SITE BASED DEBRIS POTENTIAL 1%AEP (HML) - *for the selected debris type/size arriving at the site*

Debris Potential	Combinations of the Above (any order)	Notes
DP_{High}	HHH or HHM	
DP_{Medium}	MMM or HML or HMM or HLL	MMM
DP_{Low}	LLL or MML or MLL	Eg. MML, therefore DP_{Low} selected

AEP ADJUSTED SITE DEBRIS POTENTIAL (HML) - *for the selected debris type/size*

Event AEP	At Site 1% AEP Debris Potential			AEP Adjusted At Site Debris potential
	DP_{High}	DP_{Medium}	DP_{Low}	
AEP > 5% *(frequent)*	Medium	Low	Low	Eg. Low
AEP 5% - AEP 0.5%	High	Medium	Low	Eg. Low
AEP < 0.5% *(rare)*	High	High	Medium	Eg. Medium

Debris Blockage

MOST LIKELY DESIGN <u>INLET</u> BLOCKAGE LEVEL (B_{DES}%) *for the selected debris type/size*

Control Dimension Inlet Width W (m)	At-Site Debris Potential (Generally)		
	High	Medium	Low
$W < L_{10}$	100%	50%	25%
$W \geq L_{10} \leq 3^*L_{10}$	20%	10%	0%
$W > 3^*L_{10}$	10%	0%	0%

Event AEP	Bdes %
AEP > 5% *(frequent)*	Eg. Low – 0%
AEP 5% - AEP 0.5%	Eg. Low – 0%
AEP < 0.5% *(rare)*	Eg. Medium – 10%

Refer Guideline if opening H<0.33W

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Figure D.1 Golden Highway Bridge on Ballimore Creek (view from downstream)

Figure D.2 Railway Bridge on Ballimore Creek (view from upstream)

Figure D.3 Railway Bridge on Ballimore Creek (view from left bank)

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