

**KEMPSEY SHIRE COUNCIL**

# UPPER MACLEAY FLOOD STUDY

## PUBLIC EXHIBITION REPORT





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### PUBLIC EXHIBITION REPORT

JUNE 2026

|                                             |                                           |
|---------------------------------------------|-------------------------------------------|
| <b>Project</b><br>Upper Macleay Flood Study | <b>Project Number</b><br>123041           |
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#### Revision History

| Revision | Description              | Distribution | Authors     | Reviewed by | Verified by | Date   |
|----------|--------------------------|--------------|-------------|-------------|-------------|--------|
| 0        | Draft Report             | KSC          | M.Retallick |             |             | JUL 24 |
| 1        | Final Report             | KSC          | M.Retallick |             |             | MAR 25 |
| 2        | Public Exhibition Report | KSC          | M.Retallick | M.Babister  | M.Babister  | JUN 26 |

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## LIST OF ACRONYMS

|        |                                                                                                    |
|--------|----------------------------------------------------------------------------------------------------|
| AEP    | Annual Exceedance Probability                                                                      |
| ARI    | Average Recurrence Interval                                                                        |
| ALS    | Airborne Laser Scanning                                                                            |
| ARR    | Australian Rainfall and Runoff                                                                     |
| BOM    | Bureau of Meteorology                                                                              |
| DCCEEW | Department of Climate Change, Energy, the Environment and Water (DCCEEW)                           |
| DRM    | Direct Rainfall Method                                                                             |
| DTM    | Digital Terrain Model                                                                              |
| GIS    | Geographic Information System                                                                      |
| GPS    | Global Positioning System                                                                          |
| IFD    | Intensity, Frequency and Duration (Rainfall)                                                       |
| mAHD   | meters above Australian Height Datum                                                               |
| OEH    | Office of Environment and Heritage (now DCCEEW)                                                    |
| PMF    | Probable Maximum Flood                                                                             |
| SRMT   | Shuttle Radar Mission Topography                                                                   |
| TUFLOW | one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software (hydraulic model) |
| WBNM   | Watershed Bounded Network Model (hydrologic model)                                                 |

## ADOPTED TERMINOLOGY

Australian Rainfall and Runoff (ARR, ed Ball et al, 2019) recommends terminology that is not misleading to the public and stakeholders. Therefore the use of terms such as “recurrence interval” and “return period” are no longer recommended as they imply that a given event magnitude is only exceeded at regular intervals such as every 100 years. However, rare events may occur in clusters. For example there are several instances of an event with a 1% chance of occurring within a short period, for example the 1949 and 1950 events at Kempsey. Historically the term Average Recurrence Interval (ARI) has been used.

ARR 2019 recommends the use of Annual Exceedance Probability (AEP). Annual Exceedance Probability (AEP) is the probability of an event being equalled or exceeded within a year. AEP may be expressed as either a percentage (%) or 1 in X. Floodplain management typically uses the percentage form of terminology. Therefore a 1% AEP event or 1 in 100 AEP has a 1% chance of being equalled or exceeded in any year.

ARI and AEP are often mistaken as being interchangeable for events equal to or more frequent than 10% AEP. The table below describes how they are subtly different.

For events more frequent than 50% AEP, expressing frequency in terms of Annual Exceedance Probability is not meaningful and misleading particularly in areas with strong seasonality.

Therefore the term Exceedances per Year (EY) is recommended. Statistically a 0.5 EY event is not the same as a 50% AEP event, and likewise an event with a 20% AEP is not the same as a 0.2 EY event. For example an event of 0.5 EY is an event which would, on average, occur every two years. A 2 EY event is equivalent to a design event with a 6 month Average Recurrence Interval where there is no seasonality, or an event that is likely to occur twice in one year.

The Probable Maximum Flood is the largest flood that could possibly occur on a catchment. It is related to the Probable Maximum Precipitation (PMP). The PMP has an approximate probability. Due to the conservativeness applied to other factors influencing flooding a PMP does not translate to a PMF of the same AEP. Therefore an AEP is not assigned to the PMF.

This report has adopted the approach recommended by ARR and uses % AEP for all events rarer than the 50 % AEP and EY for all events more frequent than this.

| Frequency Descriptor | EY     | AEP (%) | AEP               | ARI    |
|----------------------|--------|---------|-------------------|--------|
|                      |        |         | (1 in x)          |        |
| Very Frequent        | 12     |         |                   |        |
|                      | 6      | 99.75   | 1.002             | 0.17   |
|                      | 4      | 98.17   | 1.02              | 0.25   |
|                      | 3      | 95.02   | 1.05              | 0.33   |
|                      | 2      | 86.47   | 1.16              | 0.5    |
|                      | 1      | 63.21   | 1.58              | 1      |
| Frequent             | 0.69   | 50      | 2                 | 1.44   |
|                      | 0.5    | 39.35   | 2.54              | 2      |
|                      | 0.22   | 20      | 5                 | 4.48   |
|                      | 0.2    | 18.13   | 5.52              | 5      |
|                      | 0.11   | 10      | 10                | 9.49   |
| Rare                 | 0.05   | 5       | 20                | 19.5   |
|                      | 0.02   | 2       | 50                | 49.5   |
|                      | 0.01   | 1       | 100               | 99.5   |
| Very Rare            | 0.005  | 0.5     | 200               | 199.5  |
|                      | 0.002  | 0.2     | 500               | 499.5  |
|                      | 0.001  | 0.1     | 1000              | 999.5  |
|                      | 0.0005 | 0.05    | 2000              | 1999.5 |
|                      | 0.0002 | 0.02    | 5000              | 4999.5 |
| Extreme              |        |         | ↓                 |        |
|                      |        |         | PMP/<br>PMP Flood |        |

## FOREWORD

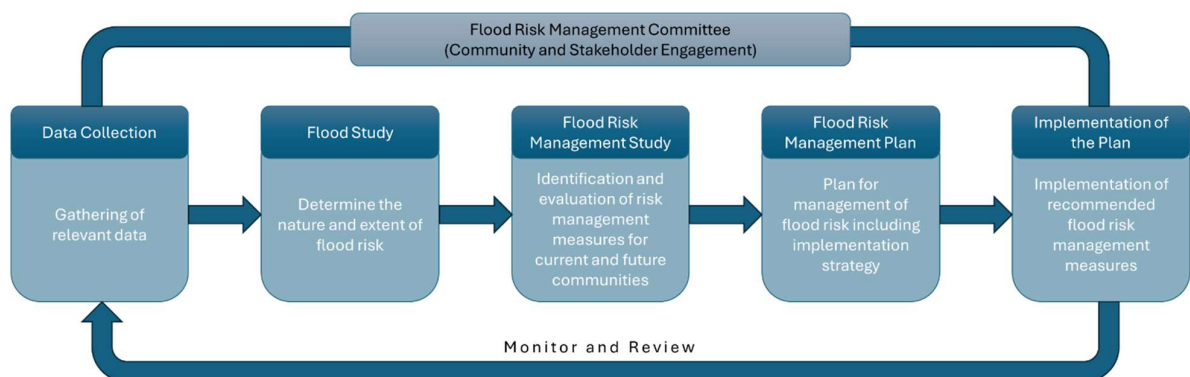
The NSW State Government's Flood Prone Land Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

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

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

1. ***Flood Study***
  - Determine the nature and extent of the flood problem.
2. ***Floodplain Risk Management***
  - Evaluates management options for the floodplain in respect of both existing and proposed development.
3. ***Floodplain Risk Management Plan***
  - Involves formal adoption by Council of a plan of management for the floodplain.
4. ***Implementation of the Plan***
  - Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

Kempsey Shire Council has prepared this document with financial assistance from the NSW Government through its Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Department of Climate Change, Energy and the Environment. The current stage is highlighted on the diagram of the floodplain management process below.



## EXECUTIVE SUMMARY

Kempsey Shire Council has embarked on the Flood Risk Management Process to understand the flood behaviour in the Upper Macleay.

### STUDY AREA

The Macleay River catchment covers an area of approximately 11,500 km<sup>2</sup>; the upper reaches of which are located within the New England Tablelands. The main tributaries including the Apsley, Muddy and Chandler Rivers rise in the Great Dividing Range and flow eastwards across the New England Tableland before falling into rugged gorge country. The Macleay River itself emerges from the gorges some 35 km upstream of Kempsey. Below Kempsey the river meanders through a wide expanse of low-lying floodplain which is subject to frequent and persistent flooding.

This study is constrained within Kempsey Shire Council's Local Government Area bordering Armidale regional Council. The project area covers approximately 2,000km<sup>2</sup>. The study area is defined as the land area that drains to the Macleay River with the hydraulic model extent defined as:

- Upstream to 800m upstream of Armidale Rd/ Five Day Creek intersection in Comara on the Macleay River,
- Includes local tributaries draining into the Macleay River in this extent, and
- Downstream to upstream of the railway bridge at Kempsey (and the overflow points into Kempsey CBD in rare events).

### PREVIOUS STUDIES

This study presents the first comprehensive flood study for the catchment. Previous studies were available including data collection studies and assessments for the highway.

### MODELLING

A WBNM hydrologic model was developed of the catchment. A TUFLOW hydraulic model of the catchment has been developed using detailed survey of ground levels, culverts and bridge structures. The WBNM model provided inflows to the hydraulic model. The TUFLOW hydraulic model has been used to reproduce the historical flood behaviour from events in 2001 and 2011 and to define flood behaviour for a range of design events.

The 2001 and 2011 events were used for calibration and validation of the hydraulic model. The model calibrated reasonably well to observed flood levels, with a better match to the 2011 event for which more information throughout the Upper Macleay was available.

While the Macleay River and the immediate backwater areas are dominated by Macleay River flooding which is typically a result of 1 to 3 days of rainfall, the upper reaches of the tributaries are dominated by shorter duration storms of 1 to 6 hours. While it does not happen in every event, it is not uncommon for a multi-day storm to have embedded thunderstorms that cause concurrent flooding on the river and the tributaries though in most cases the tributaries peak well before the Macleay River. To account for this joint probability problem two sets of scenarios were run (for example for 1% AEP flood surface):

- a 1% AEP long duration event on the Macleay River and its tributaries,
- 1% AEP short duration scenario based on the worst-case short duration for each tributary in combination with a 5% AEP event on the main river.

## DESIGN EVENT RESULTS

Flood behaviour (flood levels, depths and velocities) within the Upper Macleay catchment has been quantified for the 20, 5, 1, 0.2, 0.05% AEP and Probable Maximum Flood. Table 1 summarises the flood levels at key locations.

Flooding in the Upper Macleay River is generally confined to areas near the river and its tributaries. The upper catchment is deeply incised, but downstream of Hickey's Creek, the floodplain widens as the terrain becomes less steep. Breakout flows occur in the 1% AEP, inundating rural properties, particularly in Aldavilla, and Dondingalong. Aldavilla becomes isolated as Sherwood Road is cut off in both directions, and the Kempsey Airport is surrounded by floodwaters. In Bellbrook, a small community near Nulla Nulla Creek is isolated. During the Probable Maximum Flood (PMF), the flood extent expands, significantly inundating properties in Bellbrook, Willawarrin, Aldavilla, and many rural areas with depths exceeding 5m. Flood velocity is higher in the upper catchment where the topography is steeper. In events up to the 1% the peak flood velocity is relatively low (< 1m/s) outside the main river and tributaries.

Table 1: Design Flood Levels at Key Locations

| ID | Location                             | Flood Level (mAHD) |      |      |       |       |       |
|----|--------------------------------------|--------------------|------|------|-------|-------|-------|
|    |                                      | 20%                | 5%   | 1%   | 0.2%  | 0.05% | PMF   |
| 1  | Toose Road                           | -                  | 93.9 | 98.3 | 100.4 | 102.3 | 116.5 |
| 2  | Armidale road at Pee Dee Creek       | 77.1               | 81.5 | 86.5 | 88.9  | 91.1  | 107.6 |
| 3  | Thungutti Drive                      | -                  | -    | 74.4 | 76.6  | 78.5  | 93.6  |
| 4  | Armidale Road at Nulla Nulla Creek   | -                  | 70.0 | 74.4 | 76.6  | 78.5  | 93.6  |
| 5  | Dowlings Falls Road                  | 40.6               | 44.3 | 48.4 | 50.3  | 52.0  | 62.7  |
| 6  | Armidale Road US Hickeys Creek       | -                  | 43.9 | 46.2 | 48.4  | 50.0  | 60.4  |
| 7  | Armidale Road crossing Hickeys Creek | 38.2               | 41.9 | 46.2 | 48.3  | 50.0  | 60.1  |
| 8  | Temagog Bridge                       | 29.7               | 33.8 | 38.2 | 40.3  | 42.1  | 51.6  |
| 9  | Armidale Road at Mungay Creek        | 36.7               | 37.7 | 40.1 | 42.1  | 43.7  | 53.4  |
| 10 | Armidale Road at Deep Creek          | 24.0               | 25.6 | 29.9 | 31.6  | 33.0  | 41.4  |
| 11 | Turners Flat Road                    | -                  | -    | -    | -     | -     | 127.0 |
| 12 | Armidale Road in Skillion Flat       | -                  | -    | -    | 28.4  | 29.5  | 39.8  |
| 13 | Turners Flat Road Bridge             | 20.1               | 24.0 | 28.0 | 29.6  | 30.8  | 39.7  |
| 14 | Bellbrook Bridge                     | 67.1               | 71.4 | 75.9 | 78.0  | 79.9  | 94.7  |

## CONCLUSIONS

This study provides the first comprehensive flood study for the Upper Macleay River catchment. A detailed hydraulic model (TUFLOW) has been developed to quantify the flood behaviour of the Upper Macleay River and its tributaries, making best use of the data currently available. The flood behaviour for a range of design events (20, 5, 1, 0.2, 0.05% AEP and Probable Maximum Flood) has been determined using a calibrated hydraulic model. The study provides Kempsey Shire

Council with a suitable platform for undertaking the subsequent stages of the Floodplain Management Process, flood planning, development of flood risk management strategies and for use in setting planning levels within the study area.

## 1. INTRODUCTION

Kempsey Shire Council has embarked on the Flood Risk Management Process to understand the flood behaviour in the Upper Macleay.

The study area is defined as the land area that drains to the Macleay River with the hydraulic model extent defined as:

- Upstream to 800m upstream of Armidale Rd/ Five Day Creek intersection in Comara on the Macleay River,
- Includes local tributaries draining into the Macleay River in this extent, and
- Downstream to upstream of the railway bridge at Kempsey (and the overflow points into Kempsey CBD in rare events).

This report details the investigations, results and findings of the flood study for the Upper Macleay River. Flood study elements undertaken as part of this study include:

- a summary of available data,
- review of rating curves and flood frequency analysis,
- hydraulic model development,
- calibration of the hydraulic model, and
- definition of the design flood behaviour through the analysis and interpretation of model results.
- Evacuation routes and length of inundation and
- Flood planning level.

The study area is characterised by sparse settlement with some larger settlements. In all floods events the closure of low lying bridges in the area and associated isolation for a number of days is the main concern.

A glossary of flood related terms is provided in Appendix A.

### 1.1. Report Outline

The report structure is as follows:

- *Section 2 - Background* – background information on the catchment and previous studies,
- *Section 3 - Available data* – data used and collected as part of the study,
- *Section 4 – Adopted Modelling Approach*
- *Section 5 - Hydrologic Model* – summary of the hydrologic model developed as part of the study,
- *Section 6 - Hydraulic Model* - Hydraulic modelling of the Corindi River including model development, calibration, and verification,
- *Section 7 - Design Flood Behaviour* – description of design flood behaviour and sensitivity results,
- *Section 8 – Information to Inform Decisions on Activities in the Floodplain*

- *Section 9 – Information to Assist Emergency Response* – outputs of the study relating to emergency response
- *Section 10 – Conclusions*
- *Section 11 – Acknowledgements*
- *Section 12 – References*

## 2. BACKGROUND

### 2.1. Catchment Description

The Macleay River catchment covers an area of approximately 11,500 km<sup>2</sup>; the upper reaches of which are located within the New England Tablelands. The main tributaries including the Apsley, Muddy and Chandler Rivers rise in the Great Dividing Range and flow eastwards across the New England Tableland before falling into rugged gorge country. The Macleay River itself emerges from the gorges some 35 km upstream of Kempsey. Below Kempsey the river meanders through a wide expanse of low-lying floodplain which is subject to frequent and persistent flooding.

### 2.2. Study Area

The upper Macleay River extends well beyond Kempsey Shire Council's border and covers a vast area. The Macleay River itself forms at the confluence (junction) of Salisbury Waters and the Gara River and emerges from the gorge country approximately 25kms upstream of Belgrave Falls.

This study is constrained within Kempsey Shire Council's Local Government Area bordering Armidale regional Council. The project area covers approximately 2,000km<sup>2</sup>. The dominant water courses within the floodplain are:

- Macleay River,
- Mungay Creek,
- Dungay Creek,
- Hickeys Creek,
- Warbro Brook Creek,
- Mackenzies Creek,
- Nulla Nulla Creek,
- Pee Dee Creek,
- Five Day Creek,
- Stockyard Creek.

Flooding in the study area can occur from local creek flooding, which has typically passed by the time the Macleay River peaks.

Within the floodplain a number of small urban centres (Willawarrin and Bellbrook) are located primarily on the banks of the Macleay River. The Upper Macleay study area is a productive farming district. The primary land use within the study area is rural agriculture.

The study area is shown Figure 1 and is defined as the land that drains to the Macleay River with the hydraulic model extent defined as:

- Upstream to 800m upstream of Armidale Rd/ Five Day Creek intersection in Comara on the Macleay River,
- Includes local tributaries draining into the Macleay River in this extent, and
- Downstream to upstream of the railway bridge at Kempsey (and the overflow points into Kempsey CBD in rare events).

## 2.3. Previous Studies

While numerous studies have been undertaken in the Macleay Valley, limited studies include the Upper Macleay. A summary of previous studies relevant to the current investigation are provided below.

### **Macleay Valley ARR 2019 update (Reference 10)**

The hydrological model (WBNM) was updated to the latest ARR 2019 methodology. As part of the study, a comparison of the design flood estimates derived from the ARR 2019 methodology with the previous ARR 1987 estimates and flood frequency analysis was undertaken. Additionally, a definitive list of historic flood levels was developed for use in flood frequency analysis. The hydrology developed as part of the study forms the basis for the current study's hydrological assessment.

### **Lower Macleay River Post Flood Event Data Collection and Intelligence Review -June 2011 Flood (Reference 12)**

The NSW State Emergency Service engaged WMAwater to undertake the Lower Macleay Post Flood Intelligence Review Project. This included revision of the Flood Intelligence Cards (FIC), collection of data in relation to the June 2011 flood, and other events where new information had come to light, along with recommendations. The aim of the study was to inform future NSW SES operations in the area and to fill gaps in knowledge of flooding in the lower Macleay region. As part of the study, data on the 2011 event was collected for the Georges Creek and Bellbrook Sector. This included questionnaire responses by 93 people. During the study, the 2013 event occurred, and additional information was collected on the February 2013 event. The study surveyed the gauge zeros of all gauges in the valley. Information from this report was used in the model calibration and validation.

### **Macleay River March 2001 Flood Damages Data Collection (Reference 11)**

This report was prepared to document information pertaining to the extensive flooding of the Lower Macleay that occurred on the 10-11th of March 2001. This event was noted as being the largest to occur in the valley since 1963 and caused significant damage in several areas including the Kempsey CBD and Frederickton. In addition to documenting the available data, the report also provided an analysis of the performance of the flood mitigation scheme in the context of other published studies and reports.

### **Second Crossing Macleay River at Kempsey Flood Impacts of a Proposed Second Bridge Crossing of the Macleay River at Kempsey (Reference 13).**

Transport for NSW were investigating a second crossing of the Macleay River, upstream of the existing railway bridge. This report was prepared to document the modelling of the flood impacts for two strategic design options. An existing TUFLOW model developed by WMAwater in 2017 was utilised. The model was revised to ensure the South Kempsey Drain, Gills Bridge Creek, and the Macleay River in the vicinity of the new bridge accurately represented the existing catchment. This included the incorporation of survey of the culverts and channels and hydro survey in the vicinity of the proposed bridge.

The downstream boundary conditions used in this model were adopted for the current study's model.

**Kempsey Hydraulic Modelling Study (Reference 14)**

The study area for the 2009 Hydraulic Modelling Study (WMAwater, 2009a) included the Kempsey CBD and extended from the Kempsey Railway bridge to Frederickton. The CBD area of Kempsey was represented in detail within the SOBEK model with a 2D grid of 10 m by 10 m cells within a broader grid with 40 m cells. A broader RUBICON (1D) hydraulic model of the Lower Macleay River floodplain, extending from Belgrave Falls to the river entrance was also used as part of this study. The RUBICON model was established previously as part of the Lower Macleay valley Floodplain management Study (Webb McKeown and Associates, 1997). Inflows to this RUBICON model had previously been established in a hydrologic WBNM model of the catchment. The Kempsey Hydraulic Modelling Report (WMAwater, 2009a) details the methodology and outcomes of the hydraulic modelling undertaken to satisfy flood study objectives. Key elements of this report include:

- A summary of available data;
- Description of the hydraulic approach adopted;
- Details of the calibration and verification of the hydraulic models; and
- An analysis and interpretation of model results to quantify the design flood behaviour for the CBD under existing conditions.

The WBNM, RUBICON and SOBEK models were calibrated to the March 2001 flood event and verified against several other historical floods including the 1949, 1963 and 1980 events.

Hydrology for the 2001 event was adapted from this model for the current model.

### **3. AVAILABLE DATA**

#### **3.1. Rainfall Information**

##### **3.1.1. Historic Rainfall Data**

Historical rainfall data was obtained at several locations within the study area and surrounds. Daily rainfall and pluviograph data was obtained for a number of gauges within the region from several sources including the Bureau of Meteorology (BoM) and Manly Hydraulics Laboratory (MHL). Pluviographs are available within the study area at Bellbrook and Kempsey.

Historical rainfall was available for the 2001, and 2011 events from Reference 14 and 12. Resident rainfall totals collected as part of the post flood data collection for the 2011 and 2013 event are documented in Reference 12.

Daily read and pluviograph data was available for the 2001 and 2011 event.

##### **3.1.2. Design Rainfall Data**

To determine the design flood behaviour within the catchment, it is necessary to obtain design rainfall data. Design rainfall is based on statistical analysis of historical rainfall events to determine rainfall that has a certain probability of occurring; often identified as an ARI or AEP. The design rainfall IFD data was obtained from the BOM online design rainfall tool (<http://www.bom.gov.au/water/designRainfalls/revised-ifd/>). This is discussed more in Section 5.4.

#### **3.2. Water Level Data**

##### **3.2.1. Time Series Water Level Data**

Water NSW and BoM operate a number of water level recorders in the catchment. These being:

- Bellbrook
- Turners Flat
- Toorooka
- Euroka
- Aldavilla
- Kempsey Traffic Bridge (downstream of the catchment)

Stage hydrograph data was obtained from the Water NSW operated water level stations. The recorded time-series of water levels was used for model calibration purposes. Flow recordings were available at Turners Flat and Kempsey.

No flow readings are available at the other gauges. The opportunity for the water level record to be translated into a corresponding flow hydrograph is therefore limited. However, the recorders do provide a valuable record of flood level behaviour during an actual flood.

Stage vs time records were available for all gauges for the 2001 event. Complete stage records for the 2011 event were only available for Bellbrook, Turners Flat and Toorooka. However, at Bellbrook, the shape of the hydrograph is suspect, with the gauge levels oscillating at the peak level for the entire event. This is inconsistent with other gauges on the river and the rainfall pattern. Additionally, the gauge at Euroka was omitted because it only recorded the beginning of the hydrograph for the 2011 event.

### 3.2.2. Peak Flood Heights

The Macleay Valley has a long history of flooding. Flood records for Kempsey (Lower Macleay) date back to 1838. In comparison there is less information available for Turners Flat and Bellbrook. A summary of significant events which have occurred in the area is presented in Table 2. The more recent events for which significant data is available for calibration and validation purposes occurred in 2001 and 2011. Majority of the data collection post flood events has focused on the Lower Macleay.

Table 2: Significant Peak Flood Levels at Bellbrook and Turners Flat

| Year   | Bellbrook Gauge Height (mAHD) | Turners Flat Gauge Height (mAHD) |
|--------|-------------------------------|----------------------------------|
| 1950   | 76.15                         | -                                |
| 1949   | 75.62                         | 30.09                            |
| 1963   | 73.95                         | 25.59                            |
| 1952   | 71.43                         | -                                |
| 2001   | 71.2                          | 23.9                             |
| 1954   | 69.63                         | 22.21                            |
| 2009   | 69.2                          | 22.33                            |
| 2011   | 69.05                         | 21.69                            |
| 1967   | 68.64                         | 21.58                            |
| 1959   | 68.15                         | -                                |
| 1962   | 66.15                         | -                                |
| Jan-74 | 66.07                         | 19.25                            |
| 1976   | 65.95                         | -                                |
| 1980   | 65.6                          | -                                |
| Mar-74 | 65.51                         | 20.29                            |
| 1972   | 65.5                          | 19.01                            |
| 1977   | 65.18                         | 18.89                            |
| 1978   | 65.18                         | 17.98                            |
| 1968   | 65.1                          | -                                |
| 2013   | 65.0                          | 22.13                            |
| 1989   | 64.74                         | -                                |
| 1975   | 64.18                         | 18.16                            |

### 3.3. Topographic Information

There is a considerable amount of topographic data available for the study area. However, the accuracy and suitability of these existing datasets for use in the present study varies. This includes contours, hydro-survey, cross sections and Airborne Laser Scanning.

Airbourne Laser Scanning (ALS) ground levels were provided for the study area. The ALS collection was undertaken in 2009 to 2018. The following ALS Digital Elevation Model (DEM) datasets were obtained from Elevation and Depth Foundation Spatial Data Portal (ELVIS):

- 2m DEM acquired in April to May 2018 covering all tributaries upstream of Bellbrook.
- 2m DEM acquired in July 2017 covering all remaining areas excluding the area from the confluence of Macleay River and Deep Creek to the model outlet.
- 1m LiDAR acquired in October to November 2009 was used to supplement the missing areas.

Spatial accuracy of the ALS in the horizontal and vertical directions was reported as 0.3m and 0.8m respectively. The extent of each LiDAR data is shown in Figure 2.

Council provided detailed survey and cross section data for several bridges in the study area. Cross section details for Turners Flat were acquired from PINNEENA (Reference 9). The locations are shown in Figure 2. The cross sections and aerial imagery were used to inform the development of bathymetry.

A DEM (Digital Elevation Model) at a 2m grid resolution was used in order to:

- confirm sub-catchment and catchment watershed boundaries; and
- inform the 2D model used in the study.

### **3.4. Culvert and Structure Data**

Details of culverts and structures within the study area were available from the bridge replacement program undertaken by Council as executed plans and culvert database. Where culvert details were not available a reasonable estimate was made based on upstream culverts. Survey of Toorooka Bridge was undertaken to help confirm levels.

### **3.5. Community Consultation**

One of the central objectives of the Flood Study process is to provide the local community with a community accepted resource that can be utilised for all flood related issues including development, flood warning, response and management/remediation.

**TBC**

### **3.6. Site Visit**

A site visit was undertaken in October 2023 with Council. Tasks during the field trip included:

- Photographs and measurements of selected structures in the catchments including culvert sizes and bridges.
- General photographs capturing catchment characteristics



Photo 1: Sherwood Bridge



Photo 2: Toorooka Bridge



Photo 3: Upstream Dungay Bridge



Photo 4: D/S Dungay Bridge



Photo 5: Turners Flat Bridge



Photo 6: Bellbrook Bridge

## 4. ADOPTED MODELLING APPROACH

The primary objective of this study is to define the flood behaviour under historical and existing floodplain conditions in the Study Area.

The approach adopted for this study has been influenced by the study objectives, accepted practice and the quality and quantity of available data. There are two basic approaches to determining design flood levels namely:

- a *flood frequency approach* based upon a statistical analysis of the flood record, and
- using a *rainfall/runoff routing* approach (hydrologic modelling) to obtain flows, and then inputting these flows into a hydraulic model of the floodplain.

The rainfall runoff approach was undertaken.

A hydrologic (WBNM, Watershed Bounded Network Model, Reference 5) model was established for the catchment to determine inflows into the hydrodynamic model. A two-dimensional hydrodynamic (TUFLOW) model (Reference 6) was used to define the flood behaviour using ALS and river sections.

The TUFLOW models were calibrated and verified to two historical events namely 2001 and 2011.

The calibrated hydraulic model was then used to assess the flood levels and flood behaviour for the 20%, 5%, 1%, 0.2%, 0.05% AEP and Probable Maximum Flood (PMF) design events.

## 5. HYDROLOGIC MODELLING

### 5.1. Overview

A hydrologic model of the Macleay River catchment using the Watershed Bounded Network Model (WBNM) (Reference 5) was developed by Webb McKeown Associates (WMA). The model was updated to ARR 2019 for Council in 2020 (Reference 10). This model was adapted for the current study.

WBNM is widely used throughout Australia and particularly NSW. WBNM simulates a catchment and its tributaries as a series of sub-catchment areas linked together to replicate the rainfall and runoff process through the natural stream network. Input data includes the definition of physical catchment characteristics including surface area of sub-catchments, proportion of impervious surfaces, stream length adjustments, initial and continuing losses, temporal and spatial patterns over the catchment.

Key parameters for WBNM represent the physical characteristics of the catchment. Typical model parameters include;

- Rainfall Losses: two values, initial and continuing loss, modify the amount of rainfall excess to be routed through the model sub-catchments;
- Lag Parameter: this affects the timing of the runoff response to the rainfall and is subject to catchment size, shape and slope; and
- Non Linearity Exponent: adjustment of the non-linearity of catchment response.

The parameters adopted for this study were based on those recommended in ARR 2019 (Reference 2), Updated flows for the catchment in 2020 (Reference 10), previous experience and calibration.

A total of 66 sub-catchments were established in the original model to represent the catchment. Refinements were made to the sub-catchments to provide inflows to the study model (refer to Figure 4) and the sub catchments increased to 81.

### 5.2. Frequency Analysis

ARR 2019 (V4.2) recommends that flood frequency analysis should be applied to peak flows or discharges. Complications can arise when assessing flood frequency based on flood level rather than flow, as this assumes that the response of the river to flow is consistent over time. This is often not the case.

The reliability of the flood frequency approach depends largely upon the length and quality of the observed record and accuracy of the rating curve. In addition, flood frequency inherently accounts for many assumptions which are required in rainfall runoff routing for determining the magnitude of flow for average recurrence intervals.

These assumptions include:

- Rainfall pattern and depth,

- Joint probability of rainfalls of the various contributing tributaries,
- Areal reduction factors, and
- Loss rates.

The flood frequency approach does however have some limitations. These are:

- Accuracy of high flow gaugings is in the order of  $\pm 15\%$  (Reference 2) as it is difficult to obtain reliable estimates for significant overbank events where the width of flooding can be many kilometres,
- Changes to the local topography such as levee banks, hydraulic controls and the construction of dams can affect the homogeneity of the data set, and
- Short to medium term climatic changes may influence the flood record.

While some of these factors can affect the quality of the flood frequency analysis, for the purpose of assessment of flooding on the rural floodplain they are considered reasonable.

At site Flood Frequency Analysis (FFA) uses statistical analysis to determine the likely recurrence interval of natural events. The results of the FFA can be compared to design flows at each location to ensure the flows are of a magnitude that is representative of historical records. An existing at site FFA exists for Kempsey, although this is downstream of the catchment. Kempsey is on the main river and was the location of the main settlement and shipping limit. This means a detailed long term record is available. Upstream of Kempsey, Bellbrook and Toorooka are on the main river but are small settlements. Willawarrin is located off the main river. At Turners Flat and Bellbrook, there is insufficient information to do an at site FFA as only large floods have been recorded and there is only a short continuous record available. Additionally, whilst there are gauged flows at Turners Flat some of the flood levels are missing. While there is no reliable rating at Bellbrook, a more detailed flood record is available.

Whilst these data limitations make a conventional at site FFA unreliable, it is possible to approximate the FFA relationship using a growth curve and limits at Kempsey. This can be used to compare the rainfall-runoff modelling results along with the stage frequency results.

The catchment areas are shown in Table 3 and the frequency curves at each at site gauge location is provided in Figure 13 and Figure 14.

Table 3: Frequency Analysis

| Gauge location | Catchment Area (km <sup>2</sup> ) | % of Area to Kempsey Traffic Bridge | Fitted Ln(Mean) |
|----------------|-----------------------------------|-------------------------------------|-----------------|
| Bellbrook      | 8,859                             | 85.8                                | 7.03            |
| Turners Flat   | 9,940                             | 96.3                                | 7.09            |
| Kempsey        | 10,325                            | 100.0                               | 7.22            |

A stage frequency analysis was also undertaken based on available historical gauge levels. There are fewer gauged levels available at Turners Flat than Bellbrook and Kempsey. To infill the missing years at Turners Flat, namely peak levels in 1950 and 1952, the relationship between

Bellbrook and Turners Flat and Kempsey and Turners Flat were derived. The correlations are shown in Figure 9 to Figure 11. The estimated level was based on the Kempsey to Turners Flat Correlation to 90% and the remaining 10% based on the Bellbrook to Turners Flat correlation. This specific combination resulted in the best representation of peak flood levels and is presented in Figure 12.

The ranks for the plotting positions for the stage frequency analysis are based on the available dataset of 62 years from 1949 to 2011 at Turners Flat (including infilled years) and Bellbrook. However, the ranking of two events were adjusted using the Kempsey FFA, which is based on a much larger dataset dating back to 1883 up until 2019. Based on the Kempsey FFA, the 1949 and 1950 events are rarer than the 1% AEP based on the two largest events since settlement. The remaining plotting positions remain the same as the AEP is calculated based on the smaller dataset.

The stage frequency at Bellbrook and Turners Flat is shown in Figure 13 and Figure 14, respectively. The annual maximum flood levels are tabulated in APPENDIX B. A summary of the frequency analysis is provided in Table 4 and Table 5 for Bellbrook and Turners Flat respectively.

While Kempsey has a very long flood record, the records at Turners Flat and Bellbrook are less reliable as they are shorter, missing key events and questions exist over the high flow rating. While they could be used for traditional standalone flood frequency analysis it is more appropriate to fit a distribution incorporating the known information at Kempsey. This is particularly the case as the catchment area to Bellbrook and Turners Flat are 85% and 96% respectively of the catchment to the Kempsey gauge. While it is possible to use the statistics of the Kempsey flood frequency analysis fit as a regional prior in combination with the limited data set, it was felt this would be placing too much emphasis on the limited local data to influence the slope (standard deviation) and curvature (skew) of the fit, when these parameters could be reliably assumed to be near identical to the best fit at Kempsey. This is because using Kempsey for these parameters incorporates our understanding of all the large events that have occurred in recorded history and their influence on the overall shape of the fit. This also allows for regionally consistent estimates along the river.

The overall fit used is based on the best fit to the local data using the Kempsey Standard deviation and Skew with the mean parameter being allowed to vary. The mean was selected by minimising the RMSE of the fit. This is akin to a maximum likelihood approach.

| Parameter (log space) | Kempsey                     | Turners Flat            | Bellbrook               |
|-----------------------|-----------------------------|-------------------------|-------------------------|
| Mean                  | Traditional FFA using Flike | Best fit to local data  | Best fit to local data  |
| Standard deviation    | Traditional FFA using Flike | Assumed same as Kempsey | Assumed same as Kempsey |
| Skew                  | Traditional FFA using Flike | Assumed same as Kempsey | Assumed same as Kempsey |

Table 4: Frequency Analysis – Peak Flows and Levels at Bellbrook

| <b>AEP</b> | <b>Flow (m<sup>3</sup>/s)</b> | <b>Level (mAHD)</b> |
|------------|-------------------------------|---------------------|
| 20%        | 2,943                         | 67.39               |
| 5%         | 6,404                         | 71.46               |
| 1%         | 11,719                        | 75.49               |
| 0.2%       | 18,448                        | 79.56               |
| 0.05%      | 25,380                        | 83.71               |

Table 5: Frequency Analysis – Peak Flows and Levels at Turners Flat

| <b>AEP</b> | <b>Flow (m<sup>3</sup>/s)</b> | <b>Level (mAHD)</b> |
|------------|-------------------------------|---------------------|
| 20%        | 3,109                         | 19.85               |
| 5%         | 6,765                         | 23.35               |
| 1%         | 12,381                        | 26.86               |
| 0.2%       | 19,490                        | 29.92               |
| 0.05%      | 26,812                        | 32.92               |

### 5.3. Calibration and Validation

The WBNM models were calibrated to historical events for which sufficient rainfall and observed hydrograph data existed. Adopted calibration events were those determined as follows:

- Exclusion of events for which there was insufficient pluviograph data to represent the pattern of rainfall over the catchment and therefore to confidently model the event,
- Modelling of the 2001 event which resulted in significant flooding in the valley and is the largest recent event, and
- Modelling the 2011 event rather than the slightly larger 2013 event (at Kempsey) as there was more observed flood levels in the upper catchment. The 2011 event was rarer in the historic record at Bellbrook than at Turners Flat. While the 2013 was rarer at Turners flat than at Bellbrook.

#### 5.3.1. 2001 Event

Given the magnitude and relatively recent timing of this event, there is a considerable amount of flood-related information available for the March 2001 event. The March 2001 event, approximately a 1 in 24 AEP event, was the first to overtop both the Eden Street and First Lane levees since they were constructed (Webb McKeown and Associates, 2004a). There is some variation in the reported times of levee overtopping at the Eden Street and First Lane levees during this event, although data generally suggests the Eden Street levee overtopped first by approximately one or two hours (Reference 14). This flood event caused serious flooding and major disruption to the CBD with Belgrave Street and Forth Street becoming impassable for approximately 24 hours. The 2001 event is the 5<sup>th</sup> highest recorded at Bellbrook.

The BoM daily read records for stations in proximity to the Macleay River catchment were analysed to determine total rainfall depths across the area. Totals were calculated for the period extending from 9:00am 6/3/01 through to 9:00 12/3/01. A corresponding map of rainfall depth was then drawn up for the catchment and corresponding rainfall depths were estimated for each sub-

area. The stations used and the corresponding distribution of rainfall across the catchment as applied in WBNM is shown in Figure 16.

Temporal patterns for the WBNM model were based on data sourced from the BoM Flood Alert network of pluviometers. The relative weighting developed for each sub-area was then based on geographical and orographic considerations.

Table 6: Rainfall recorded by different guages during 2001 storm event

| Number             | Gauge Name                         | Gauge number | Source | Rainfall (mm)<br>9am 6 Mar –<br>9am 12 Mar |
|--------------------|------------------------------------|--------------|--------|--------------------------------------------|
| <b>Pluviograph</b> |                                    |              |        |                                            |
| 1                  | Woolbrook                          | 55136        | BoM    | 17.2                                       |
| 2                  | Gowrie North                       | 55194        | BoM    | 24.2                                       |
| 3                  | Nundle (Chaffey Dam)               | 55302        | BoM    | 23.2                                       |
| 4                  | Tamworth                           | 55327        | BoM    | 6.8                                        |
| 5                  | Legume                             | 56022        | BoM    | 69.8                                       |
| 6                  | Uralla                             | 57091        | BoM    | 155.6                                      |
| 7                  | Yarrowitch                         | 57104        | BoM    | 242.6                                      |
| 8                  | Bellbrook                          | 59000        | BoM    | 324.8                                      |
| 9                  | Coffs Harbour                      | 59040        | BoM    | 297.6                                      |
| 10                 | Yarras                             | 60085        | BoM    | 388.2                                      |
| 11                 | Tabulam                            | 57095        | BoM    | 159.2                                      |
| <b>Daily</b>       |                                    |              |        |                                            |
| 12                 | Armidale Airport                   | 56238        | BoM    | 32.0                                       |
| 13                 | Armidale (Belhaven)                | 56068        | BoM    | 100.8                                      |
| 14                 | Armidale (Loch Abba)               | 57106        | BoM    | 66.8                                       |
| 15                 | Armidale (Tree Group Nursery)      | 56037        | BoM    | 40.6                                       |
| 16                 | Ben Lomond (Koala)                 | 56139        | BoM    | 140.8                                      |
| 17                 | Brackendale (The Lake)             | 57050        | BoM    | 157.0                                      |
| 18                 | Collombatti (Benbullen)            | 59068        | BoM    | 310.5                                      |
| 19                 | Crescent Head                      | 59047        | BoM    | 190.8                                      |
| 20                 | Ebor (Glenowen)                    | 57001        | BoM    | 281.0                                      |
| 21                 | Ebor (Maplewood)                   | 57102        | BoM    | 794.0                                      |
| 22                 | Ebor (Pleasant View)               | 57125        | BoM    | 473.0                                      |
| 23                 | Ebor (The Racecourse)              | 59019        | BoM    | 577.4                                      |
| 24                 | Ebor (Wongwibinda)                 | 57023        | BoM    | 176.2                                      |
| 25                 | Eungai (Searles Rd)                | 59109        | BoM    | 391.6                                      |
| 26                 | Euroka (Aldavilla (Macleay River)) | 59135        | BoM    | 287.0                                      |
| 27                 | Forbes River (Birdwood)            | 60130        | BoM    | 371.8                                      |
| 28                 | Georges Creek (Murrungi)           | 57117        | BoM    | 355.4                                      |
| 29                 | Girralong                          | 59107        | BoM    | 595.8                                      |
| 30                 | Guy Fawkes (Kangaroo Creek)        | 57126        | BoM    | 514.6                                      |
| 31                 | Guyra (Lyndhurst)                  | 57049        | BoM    | 123.7                                      |
| 32                 | Guyra (Box Point)                  | 56240        | BoM    | 83.0                                       |
| 33                 | Guyra (Myloe)                      | 57046        | BoM    | 138.0                                      |
| 34                 | Guyra Hospital                     | 56229        | BoM    | 111.8                                      |

| Number | Gauge Name                         | Gauge number | Source | Rainfall (mm)<br>9am 6 Mar –<br>9am 12 Mar |
|--------|------------------------------------|--------------|--------|--------------------------------------------|
| 35     | Hillgrove (Hillview)               | 57028        | BoM    | 104.2                                      |
| 36     | Jeogla Station                     | 57011        | BoM    | 273.0                                      |
| 37     | Kempsey Airport                    | 59007        | BoM    | 294.0                                      |
| 38     | Kempsey (Wide Street)              | 59017        | BoM    | 225.2                                      |
| 39     | Lower Creek (Cedar Park)           | 57052        | BoM    | 367.0                                      |
| 40     | Millbank                           | 59131        | BoM    | 438.0                                      |
| 41     | Mount Mitchell (Tirranna)          | 56163        | BoM    | 239.6                                      |
| 42     | Nowendoc (Emu Tops)                | 60140        | BoM    | 346.8                                      |
| 43     | Point Lookout                      | 57124        | BoM    | 264.6                                      |
| 44     | South West Rocks                   | 59030        | BoM    | 184.2                                      |
| 45     | Taylors Arm                        | 59032        | BoM    | 221.0                                      |
| 46     | Thumb Creek (Figtree)              | 59120        | BoM    | 562.4                                      |
| 47     | Tia (Highrent)                     | 57045        | BoM    | 238.4                                      |
| 48     | Tia (Rambrah)                      | 57037        | BoM    | 143.8                                      |
| 49     | Toorooka (Moparrabah)              | 59055        | BoM    | 468.6                                      |
| 50     | Upper Pappinbarra (Hillcrest)      | 60067        | BoM    | 413.0                                      |
| 51     | Upper Rollands Plains (Greenacres) | 60052        | BoM    | 418.4                                      |
| 52     | Uralla (Blue Nobby)                | 57091        | BoM    | 158.4                                      |
| 53     | Uralla (Dumaresq St)               | 56034        | BoM    | 32.8                                       |
| 54     | Uralla (Mihi)                      | 56065        | BoM    | 66.4                                       |
| 55     | Uralla (Salisbury Court)           | 56028        | BoM    | 34.6                                       |
| 56     | Walcha (Craigdarroch)              | 56077        | BoM    | 44.2                                       |
| 57     | Walcha (Emu Creek)                 | 56010        | BoM    | 66.4                                       |
| 58     | Walcha (Falls View)                | 57109        | BoM    | 135.8                                      |
| 59     | Walcha (Inglewood)                 | 56236        | BoM    | 38.6                                       |
| 60     | Walcha (Karori)                    | 57119        | BoM    | 164.4                                      |
| 61     | Walcha (Pindari)                   | 57053        | BoM    | 100.0                                      |
| 62     | Walcha (Rowleys Creek)             | 57107        | BoM    | 172.2                                      |
| 63     | Walcha (Thee St)                   | 56234        | BoM    | 41.0                                       |
| 64     | Walcha Road (Boxley)               | 56075        | BoM    | 27.6                                       |
| 65     | Wandsworth (Strabanne)             | 56036        | BoM    | 70.6                                       |
| 66     | Willawarrin (Denleigh)             | 59052        | BoM    | 426.5                                      |
| 67     | Wittitrin                          | 59060        | BoM    | 346.0                                      |
| 68     | Wollomombi (Wallamumbi)            | 57022        | BoM    | 250.0                                      |
| 69     | Wollomombi (Wollomombi River)      | 57079        | BoM    | 146.0                                      |
| 70     | Woolbrook (Woolbrook Road)         | 55136        | BoM    | 16.1                                       |
| 71     | Yarras (Mount Seaview)             | 60085        | BoM    | 494.8                                      |
| 72     | Yarrowitch (Benditi)               | 57035        | BoM    | 260.6                                      |
| 73     | Yarrowitch (Maretto)               | 57104        | BoM    | 336.0                                      |

Comparison of modelled and estimated hydrograph at Turners Flat was undertaken (Figure 17). The estimated flow hydrograph at Turners Flat was based on time-series flow estimates direct from Pinneena, (i.e. the recorded water levels were translated to corresponding streamflow estimates based on the Pinneena rating relationship at Turners Flat).

When interpreting the Turners Flat flows based on the recorded levels it is worth noting that the highest gauged flow for the Turners Flat site is about 2,020 m<sup>3</sup>/s (corresponds to around 5.5 m Gauge Height (G.H)). This is well below the March 2001 peak flow estimate of around 8,096 m<sup>3</sup>/s (corresponding to 11.9 m G.H.). The accuracy of the rating is difficult to quantify without further detailed analysis. However, the accuracy of flood discharge estimates in general would be  $\pm 15\%$  at best and could be worse than this (as has found to be the case on other gauged catchments throughout Australia) (Reference 2).

The middle portion of the catchment is characterised by steep rugged terrain. The limited amount of daily rainfall data indicates that a significant rainfall gradient occurred in the northern part of this region during the March 2001 event. The lack of local temporal information in combination with the steep rainfall gradients limits the ability of WBNM model to better reproduce the observed timing at Turners Flat. The observed hydrograph timing at Turners Flat was best reproduced by assigning the temporal pattern recorded in the lower Macleay River floodplain to the middle part of the catchment. More detailed discussion of the event can be found in Reference 14.

### 5.3.2. Parameters and Loss Inputs

To best replicate the observed hydrographs (in terms of hydrograph shape, time to peak and peak discharge) a number of key parameters were varied. These were:

- Pluviograph Allocation,
- Initial Losses, and
- Continuing Losses.

A lag parameter value of  $C = 1.4$  was adopted for the catchment.

A rating curve was available at Turners Flat from PINNEENA. Calibration of the hydrologic model flows to the observed flows (converted using the rating relationship) was undertaken. This was then compared to the hydraulic model rating curve at the same location.

Rainfall losses are used to represent rainfall that is not converted into runoff. Losses are used to account for rainfall that infiltrates into the ground, enters the groundwater system, or is intercepted by vegetation. Losses are removed from the rainfall depth within the hydrologic model to produce the rainfall excess that results in runoff. Due to the small portion of the overall catchment that was impervious, the whole catchment was assumed pervious. Table 7 summarises the loss values adopted for the calibration events.

Table 7: Losses for Calibration Events

| Event | Losses            |                         |
|-------|-------------------|-------------------------|
|       | Initial Loss (mm) | Continuing Loss (mm/hr) |
| 2001  | 30                | 0.5                     |
| 2011  | 40                | 0.6                     |

### 5.3.3. 2011 Event

Between the 12<sup>th</sup> of June to the 16<sup>th</sup> of June 2011 the North Coast experienced an East Coast Low (BoM, 2011). This caused significant rainfall in the region and the Local Government Area was declared a Natural Disaster. Diagram 1 below provides a time series of the synoptic charts between the 10<sup>th</sup> of June and the 18<sup>th</sup> of June 2011.

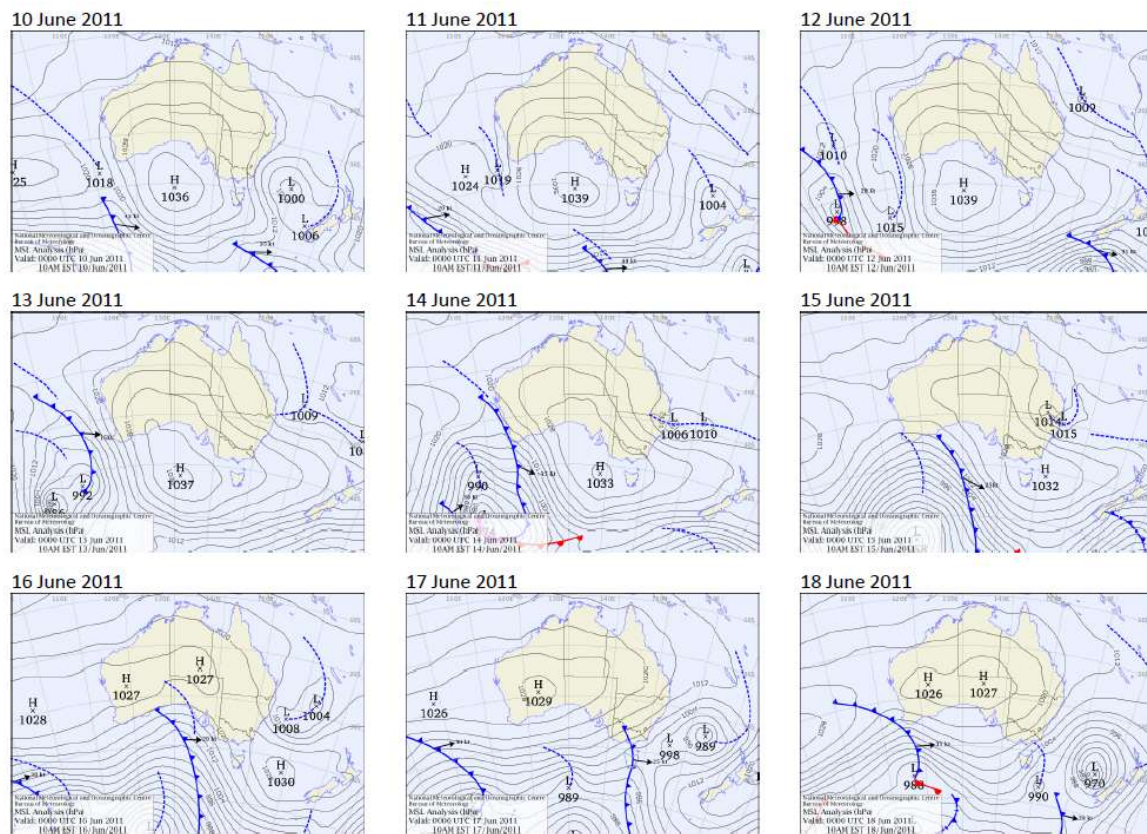


Diagram 1: National Synoptic Maps 10-18 June 2011

A significant amount of rainfall fell in the catchment not just during the event but also in the lead up to the event making the catchment soils wet and causing significant runoff. June 2011 was the wettest June since records began in 1939 at South West Rocks. Kempsey and Bellbrook recorded the highest rainfall for the month since 1967. Euroka recorded highest monthly total on record though its record has only been operating since 2001.

The highest daily rainfall in a number of years was recorded at three locations: South West Rocks, Bellbrook and Kempsey. This is summarised in Table 8.

Table 8: Highest Rainfall Records

| Station          | Number | Rain (mm) | Date (June) | Rank | Highest since |
|------------------|--------|-----------|-------------|------|---------------|
| South West Rocks | 59030  | 130.8     | 14          | 4    | 4 June 1974   |
| Bellbrook        | 59000  | 122       | 14          | 11   | 4 June 2008   |

|         |       |     |    |    |              |
|---------|-------|-----|----|----|--------------|
| Kempsey | 59017 | 112 | 14 | 13 | 11 June 1961 |
|---------|-------|-----|----|----|--------------|

During the event a high concentration of rainfall fell over the north east of the state. Diagram 2 shows the daily radar information for the 11<sup>th</sup> to the 20<sup>th</sup> of June 2011 obtained from BoM records. This series of images shows how the storm progressed over time. The peak, as shown, occurred on the 14<sup>th</sup> or 15<sup>th</sup> of June depending on the location. While the general peak of the rainfall occurred on the Tuesday the 14<sup>th</sup> of June, significant rainfall continued for two more days.

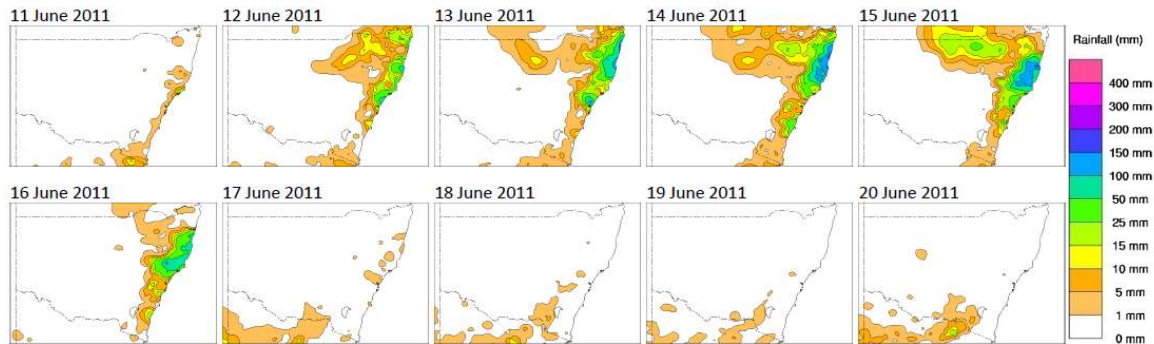


Diagram 2: Daily Rainfall Totals from 11<sup>th</sup> to 20<sup>th</sup> of June Source: BoM

There are five official BoM rainfall gauges within the Macleay River Catchment and a number of unofficial rainfall gauges (Figure 4) relevant to the data collection review. The official gauges are:

- Turners Flat (206011) – 30 Minute
- Euroka (Aldavilla) (059135) – 30 Minute
- Bellbrook (206019) – Hourly
- Kempsey (059017) – 30 Minute
- South West Rocks (059030) - Daily
- Maria River (207406) - Pluvio

The daily rainfall for these stations can be seen in Table 9.

The peak of the rainfall fell on the 14<sup>th</sup> of June 2011 at all locations (except Bellbrook), according to BoM records. Significant rainfall continued to fall on the 15<sup>th</sup> and 16<sup>th</sup>, contributing to the total volume of rainfall in the event. Higher rainfall was recorded at the most coastal gauges, including Maria River and South West Rocks.

Table 9: Daily Rainfall Totals over the Macleay Valley

| Gauge            | Daily Rainfall Totals (mm) |            |            |            |            |            |
|------------------|----------------------------|------------|------------|------------|------------|------------|
|                  | 12/06/2011                 | 13/06/2011 | 14/06/2011 | 15/06/2011 | 16/06/2011 | 17/06/2011 |
| Maria River      | 29.5                       | 52         | 165.5      | 79.5       | 73.5       | 5          |
| South West Rocks | 105                        | 90.4       | 130.8      | 96         | 85.8       | 6          |
| Kempsey          | 50                         | 67         | 110        | 68         | 54         | 0          |
| Turners Flat     | 57                         | 84         | 95         | 54         | 61         | 0          |

|           |      |    |     |     |    |   |
|-----------|------|----|-----|-----|----|---|
| Euroka    | 49.5 | 67 | 110 | 67  | 51 | 0 |
| Bellbrook | 43   | 71 | 83  | 122 | 47 | 0 |

Resident rainfall was also collected through the questionnaires (Reference 12). Figure 6 in Reference 12 presents this information based upon the sector the property is located in. This information along with the official gauges was combined to produce a temporal and spatial pattern of the total rainfall event. The rainfall distribution (Figure 18) shows a strong trend with higher rainfall on the coast. Inland from the coast the rainfall total drops from over 600mm to just over 100mm. Higher totals were also recorded north and south of Smithtown and Gladstone than at the towns.

An Intensity-Frequency-Duration (IFD) analysis was carried out at each rainfall station (Reference 12). This highlights a general trend in the rainfall over the catchment. The rainfall turned into a more significant event as time progressed and the burst duration increased. For all locations other than Maria River the intensity did not exceed a 5-year ARI for all durations up to 72hrs. The event was not a flash flood event but a build-up of continual rainfall over a number of days.

The distribution of rainfall across the catchment as applied in WBNM is shown in Figure 18. Temporal patterns were assigned based on Thiessen polygons. However, adjustments were made at the catchment boundary to use temporal patterns from the same watershed, rather than from an adjacent catchment, especially where there was a significant elevation difference.

Comparison of modelled and estimated hydrograph at Turners Flat was undertaken (Figure 19).

Table 10: Daily rainfall recorded by different gauges during 2011 storm event

| Number | Gauge Name                                  | Gauge number | Source | Rainfall (mm)<br>9am 12 Jun – 9am<br>17 Jun |
|--------|---------------------------------------------|--------------|--------|---------------------------------------------|
| 1      | Armidale (Tree Group Nursery)               | 56037        | BoM    | 69.2                                        |
| 2      | Armidale Airport Aws                        | 56238        | BoM    | 58.0                                        |
| 3      | Barraba (Neranghi)                          | 54023        | BoM    | 30.0                                        |
| 4      | Bellbrook (East Street)                     | 59000        | BoM    | 432.2                                       |
| 5      | Bellbrook (Macleay River)                   | 59122        | BoM    | 366.0                                       |
| 6      | Bellwood (Nambucca Heads<br>(Nambucca Resor | 59150        | BoM    | 424.0                                       |
| 7      | Bendemeer (Banalasta)                       | 55296        | BoM    | 11.4                                        |
| 8      | Bendemeer (Caroline St)                     | 55004        | BoM    | 18.5                                        |
| 9      | Bundarra (Glendale)                         | 56176        | BoM    | 36.2                                        |
| 10     | Bundarra Post Office                        | 56006        | BoM    | 33.0                                        |
| 11     | Dundee (Karinga)                            | 56098        | BoM    | 66.2                                        |
| 12     | Dungowan (Glendower Mountain<br>(Leconfield | 55309        | BoM    | 25.6                                        |
| 13     | Ebor (Glenowen)                             | 57001        | BoM    | 150.0                                       |
| 14     | Ebor (Pleasant View)                        | 57125        | BoM    | 322.4                                       |
| 15     | Ebor (The Racecourse)                       | 59019        | BoM    | 384.0                                       |
| 16     | Elsmore (Paradise Creek)                    | 56121        | BoM    | 17.0                                        |
| 17     | Eungai Creek (Southbank Road)               | 59075        | BoM    | 553.6                                       |

| Number | Gauge Name                                | Gauge number | Source | Rainfall (mm)<br>9am 12 Jun – 9am<br>17 Jun |
|--------|-------------------------------------------|--------------|--------|---------------------------------------------|
| 18     | Euroka (Aldavilla (Macleay River))        | 59135        | BoM    | 768.5                                       |
| 19     | Fishermans Reach                          | 59143        | BoM    | 645.2                                       |
| 20     | Forbes River (Birdwood)                   | 60130        | BoM    | 328.0                                       |
| 21     | Georges Creek (Murrungi)                  | 57117        | BoM    | 269.8                                       |
| 22     | Girralong                                 | 59107        | BoM    | 364.6                                       |
| 23     | Glen Innes (Mt Mitchell Forest)           | 57082        | BoM    | 86.4                                        |
| 24     | Glen Innes Ag Research Stn                | 56013        | BoM    | 45.5                                        |
| 25     | Glen Innes Post Office                    | 56011        | BoM    | 53.4                                        |
| 26     | Glen Morrison (Millbank)                  | 56080        | BoM    | 55.0                                        |
| 27     | Guyra (Box Point)                         | 56240        | BoM    | 30.0                                        |
| 28     | Guyra (Gowan Brae)                        | 56161        | BoM    | 67.2                                        |
| 29     | Guyra Hospital                            | 56229        | BoM    | 69.3                                        |
| 30     | Kempsey (Wide Street)                     | 59017        | BoM    | 421.0                                       |
| 31     | Kempsey Airport Aws                       | 59007        | BoM    | 344.4                                       |
| 32     | Kentucky (Vale View)                      | 56073        | BoM    | 23.0                                        |
| 33     | Kingstown Post Office                     | 56228        | BoM    | 33.0                                        |
| 34     | Kookabookra                               | 57103        | BoM    | 102.8                                       |
| 35     | Kundabung (Smith Creek Rd)                | 60018        | BoM    | 379.0                                       |
| 36     | Lower Creek (Cedar Park)                  | 57052        | BoM    | 299.8                                       |
| 37     | Majors Creek (Moparrabah (Parrabel Creek) | 59128        | BoM    | 261.0                                       |
| 38     | Meldrum (Coolawarra)                      | 59045        | BoM    | 427.2                                       |
| 39     | Millbank                                  | 59131        | BoM    | 392.0                                       |
| 40     | Mount Mitchell (Tirranna)                 | 56163        | BoM    | 78.0                                        |
| 41     | Niangala (Kentucky Blue)                  | 60142        | BoM    | 182.0                                       |
| 42     | Niangala (Mount Sandon)                   | 55322        | BoM    | 124.2                                       |
| 43     | Nowendoc (Beaufort)                       | 60082        | BoM    | 221.6                                       |
| 44     | Nowendoc (Emu Tops)                       | 60140        | BoM    | 258.8                                       |
| 45     | Nowendoc (Green Hills)                    | 60104        | BoM    | 211.2                                       |
| 46     | Number One (Murrays Creek)                | 60106        | BoM    | 318.6                                       |
| 47     | Ogunbil (Amaroo)                          | 55262        | BoM    | 62.6                                        |
| 48     | Pinkett (Benbookra)                       | 56205        | BoM    | 89.0                                        |
| 49     | Point Lookout                             | 57124        | BoM    | 264.6                                       |
| 50     | South West Rocks (Smoky Cape Lighthouse)  | 59030        | BoM    | 514.0                                       |
| 51     | Swan Vale (Numeralla)                     | 56128        | BoM    | 36.0                                        |
| 52     | Taylors Arm                               | 59032        | BoM    | 407.0                                       |
| 53     | Telegraph Point (Farrawells Road)         | 60031        | BoM    | 276.6                                       |
| 54     | Tenterden (Balook)                        | 56057        | BoM    | 35.1                                        |
| 55     | Thumb Creek (Figtree)                     | 59120        | BoM    | 434.0                                       |
| 56     | Tia (Highrent)                            | 57045        | BoM    | 159.0                                       |
| 57     | Tia (Rambrah)                             | 57037        | BoM    | 114.0                                       |
| 58     | Tingha (Crystal Hill)                     | 56007        | BoM    | 38.2                                        |
| 59     | Toorooka (Moparrabah)                     | 59055        | BoM    | 250.8                                       |
| 60     | Upper Darkwood                            | 59070        | BoM    | 304.0                                       |

| Number | Gauge Name                         | Gauge number | Source | Rainfall (mm)<br>9am 12 Jun – 9am<br>17 Jun |
|--------|------------------------------------|--------------|--------|---------------------------------------------|
| 61     | Upper Pappinbarra (Hillcrest)      | 60067        | BoM    | 351.2                                       |
| 62     | Upper Rollands Plains (Greenacres) | 60052        | BoM    | 283.2                                       |
| 63     | Uralla (Blue Nobby)                | 57091        | BoM    | 155.4                                       |
| 64     | Uralla (Church Ave)                | 56232        | BoM    | 37.8                                        |
| 65     | Uralla (Mihi)                      | 56065        | BoM    | 83.8                                        |
| 66     | Uralla (Salisbury Court)           | 56028        | BoM    | 31.4                                        |
| 67     | Walcha (Emu Creek)                 | 56010        | BoM    | 61.4                                        |
| 68     | Walcha (Inglewood)                 | 56236        | BoM    | 54.6                                        |
| 69     | Walcha (Karori)                    | 57119        | BoM    | 114.2                                       |
| 70     | Walcha (Thee St)                   | 56234        | BoM    | 44.4                                        |
| 71     | Walcha Road ( Boxley)              | 56075        | BoM    | 21.8                                        |
| 72     | Watsons Creek (Tilmunda)           | 55103        | BoM    | 22.6                                        |
| 73     | Willawarrin (Denleigh)             | 59052        | BoM    | 455.0                                       |
| 74     | Wittittrin                         | 59060        | BoM    | 250.0                                       |
| 75     | Wollomombi (Wollomombi River)      | 57079        | BoM    | 186.0                                       |
| 76     | Wollomombi Post Office             | 57033        | BoM    | 197.0                                       |
| 77     | Woolbrook (Woolbrook Road)         | 55136        | BoM    | 16.9                                        |
| 78     | Yarras (Mount Seaview)             | 60085        | BoM    | 444.6                                       |
| 79     | Yarrowitch (Benditi)               | 57035        | BoM    | 231.0                                       |
| 80     | Yarrowitch (Maretto)               | 57104        | BoM    | 268.6                                       |

## 5.4. Design Flood Events

In 2016, the 4th Edition of Australian Rainfall and Runoff (ARR 2016) was released. A minor update mainly to Book 9 Runoff in Urban Areas was released in 2019. While ARR 1987 (Pilgrim, 1987) has been considered industry best practice for many years, there have been developments in knowledge of hydrologic and hydraulic mechanisms and computational processing capabilities since its release. This drove the need for the industry guideline to be updated to the ARR 2016 version. The release of the updated version of ARR in 2016 (Reference 2) incorporated new design inputs including: rainfalls, losses, areal reduction factors, temporal patterns, pre-burst rainfalls and spatial patterns.

The updated design inputs (losses, areal reduction factors and temporal patterns) for the Upper Macleay River catchment were accessed through the ARR Data Hub (Reference 3, accessed 2021). New IFD information was available from the BOM website (<http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016>). The ARR Data Hub website allows sampling of the inputs by either a region shape file or as coordinates in the latitude and longitude projection. A region shape file was used and spatially varied IFD sampled.

The ARR Data Hub outputs including recommended losses and pre-burst values are included in APPENDIX C.

### 5.4.1. Rainfall

Intensity-Frequency-Duration (IFD) data indicates how often rainfall events of various sizes can be expected to occur at a given location in Australia. The dataset is developed using methods identified in Australian Rainfall & Runoff (Reference 2). For example, at Kempsey, the IFD information specifies that for a given year, there is a 10% chance of more than 211 mm falling within the heaviest 24-hour rain period, and a 1% chance of more than 329 mm. These numbers are referred to as “design rainfalls”, because they are often used as the standard for designing infrastructure or development.

Design rainfalls estimates were recently updated by the BoM in 2016. These IFD data were developed from regional data recorded by thousands of rainfall gauges. This dataset supersedes the previous estimates developed in 1987 and has the advantage that it includes more than 25 years of rainfall records particularly for the sub-daily rainfall gauges which became much more prevalent in the 1970s. Only a short record of sub-daily data was available for the 1987 IFD estimates.

The 2016 IFD estimates are also more likely to account for localised influences on rainfall such as orographic effects from steep terrain. This is due to the increased density of rainfall gauges and the updated regional methodology which accounted for elevation impact on IFD estimates.

Table 11 provides a comparison of the catchment average design rainfall depth between the 1987 and 2016 IFD. The catchment average rainfall depth to Bellbrook is similar between both IFD estimates. The catchment average rainfall depth to Kempsey is approximately 5% lower in the 2016 IFD.

Table 11 Comparison of IFD - 1% AEP – 24hr

| Catchment Average to | Design Rainfall Depth (mm) |          |
|----------------------|----------------------------|----------|
|                      | 2016 IFD                   | 1987 IFD |
| Kempsey              | 221.8                      | 231.6    |
| Bellbrook            | 200.5                      | 203.0    |

Diagram 3 presents a comparison of the historic catchment average rainfall to the IFD. There is a good match at 1 and 2 days but not at longer durations. This suggests the BoM IFD overestimates, but this could also be a result of most gauges being in valleys and the BoM IFD pooling information from mainly coastal gauges. Given the critical duration is 1 day this was pursued no further.

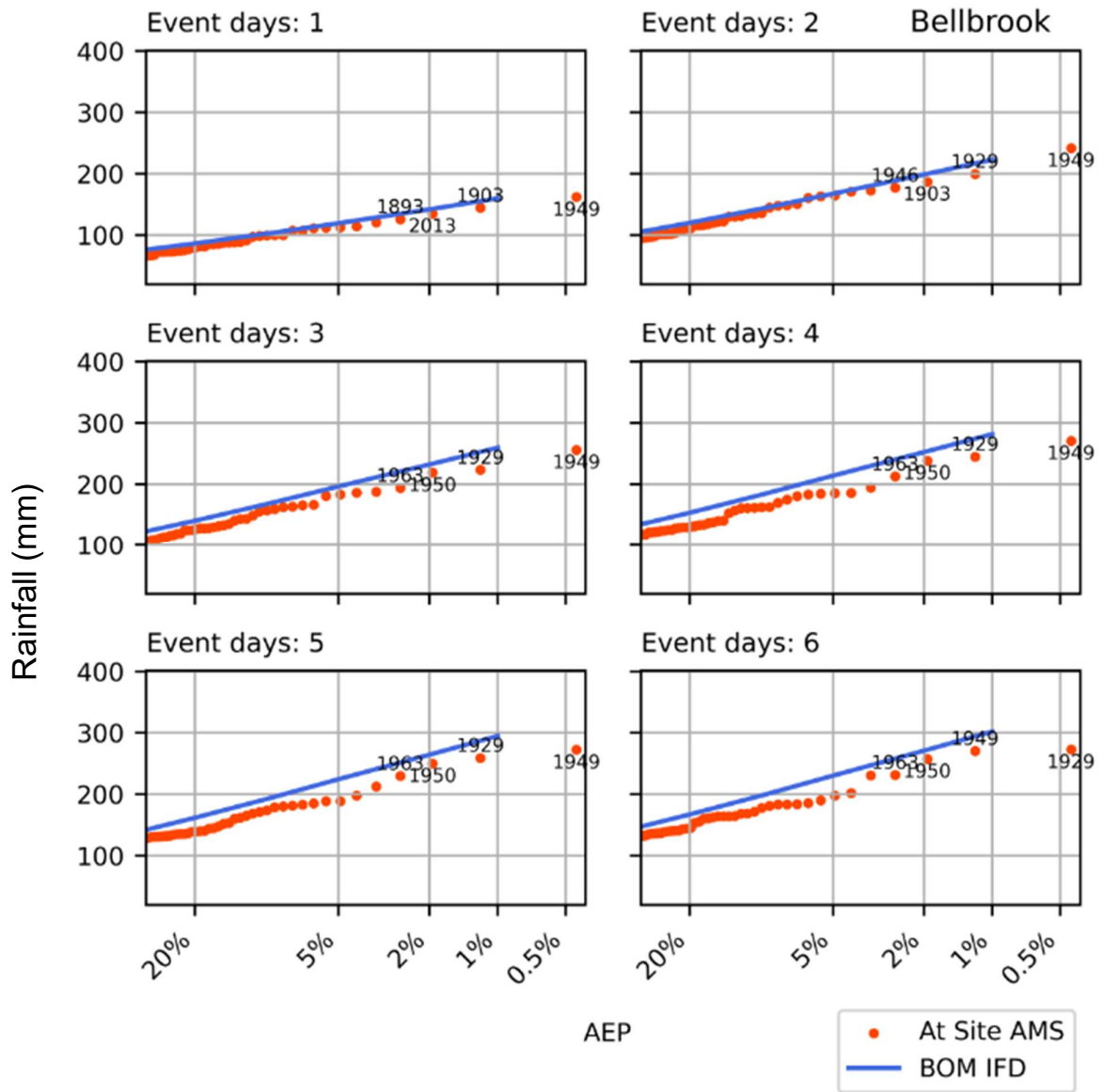


Diagram 3: Catchment average rainfall analysis to Bellbrook

### 5.4.2. Areal Reduction Factor

The Areal Reduction Factor was calculated for the area to Bellbrook (0.79) and Kempsey (0.78) (using the methodology described in ARR2016, Book 2 Ch 4 Section 3.1). Given the small change in catchment area and the minimal difference in resultant flood levels, the Bellbrook run was adopted for all design runs.

For local catchment dominated flows, areal reduction factors were calculated for three catchment areas: 50 km<sup>2</sup>, 100 km<sup>2</sup>, and 250 km<sup>2</sup>. The catchment areas of all main creeks were calculated, and the ARF for each creek was assigned based on the nearest corresponding area. The creeks included:

- Deep Creek
- Dungay Creek
- Euroka Creek
- Fattorini Creek
- Five-day creek
- Gap Creek

- Hickeys Creek
- Mackenzies Creek
- Mungay Creek
- Nulla Nulla Creek
- Oaky Creek
- Parrabel Creek
- Pee Dee Creek
- Running Creek
- Stockyard Creek
- Stony Creek
- Temagog Creek
- Warbro Creek

### 5.4.3. Temporal Patterns

Temporal patterns are a representation of how the rainfall fell over time. The temporal patterns of real storms can vary significantly, and catchments can respond very differently to the shape of the temporal pattern. For example, some rainfall events can have a significant portion of the rainfall occurring at the start of the storm burst (front loaded), and the catchment response will vary from that to a storm where a large portion of the rainfall occurs towards the end of the rainfall burst (back loaded).

ARR 2019 (Reference 2) provides ensembles of temporal patterns, i.e. 10 temporal patterns for each rainfall duration across three AEP groups. The application of the AEP groups is shown in Table 12.

Table 12: Temporal Pattern Bins

| AEP Group Name | Design AEP's Applied to |
|----------------|-------------------------|
| Rare           | 2% and 1%               |
| Intermediate   | 10% and 5%              |
| Frequent       | 50% and 20%             |

Temporal patterns for the East Coast South region were downloaded from the ARR Data Hub website (Reference 3) and input into the hydrological model. Ensembles of 10 patterns were run for the design events as per recommendations in ARR 2019 (Book 2 Chapter 5, in Reference 2).

### 5.4.4. Losses and Pre burst

ARR 2019 developed 'rural' loss values as a gridded dataset, and thus vary based on location. The losses sampled from the ARR data hub were similar to the average calibration losses. Table 14 summarises the design losses adopted.

The pre-burst rainfall depth has been sourced from the ARR Data Hub (see APPENDIX C). Pre burst rainfall depths are provided for the median, 10%, 25%, 75% and 90%.

Burst initial loss (for rural catchments) was taken from the ARR Data Hub by applying the formula:

$$\begin{aligned}
 \text{Burst Initial Loss} &= \text{Storm Initial Loss} - \text{Pre-burst} \\
 \text{E.g. Burst Initial Loss}_{1\% \text{ AEP}, 1440\text{min}} &= 45.0 - 8.9 \\
 &= 36.1 \text{ mm}
 \end{aligned}$$

Burst initial loss varied for each duration, AEP.

The Valley ARR update (Reference 10) utilised the revised NSW advice with regards to loss application which recommends the initial and continuing loss rates. The ARR data hub values for initial loss and continuing loss for the catchment area upstream of Kempsey were 26mm and 4.2mm/hr respectively. An investigation of the historic events found that some of the pre 2000 historic events were most likely modelled as the main burst only with some of the storm not included, while the post 2000 events were modelled as complete storms. The losses adopted for the calibration of historic events is shown in Table 13.

Table 13: WBNM Parameters – Historical Events (reproduced from Reference 10)

| Event   | Initial Loss (mm) | Continuing Loss (mm/hr) | Report Reference                                                 |
|---------|-------------------|-------------------------|------------------------------------------------------------------|
| 1949    | 0                 | 1.5                     | 1989 FS (Public Works)                                           |
| 1963    | 0                 | 2.5                     | 1989 FS (Public Works)                                           |
| 1977    | 0                 | 1.5                     | 1989 FS (Public Works)                                           |
| 1980    | 25                | 3                       | 1989 FS (Public Works)                                           |
| 2001    | 70                | 0.7                     | Kempsey Flood Study Hydraulic Modelling Report – 2009 (WMAwater) |
| 2013    | 50                | 0.5                     | 2013 Event Memo (WMAwater)                                       |
| Average | 24.2              | 1.6                     |                                                                  |

WMAwater undertook a Review of ARR Design Inputs for NSW study for the then Office of Environment and Heritage. This study undertook to review and advise on addressing under-estimation bias being experienced when using standard ARR 2019 design event methods with default data from the ARR data hub. The outcomes of this study indicated that there is significant bias in the standard ARR 2019 design event method with default ARR data hub losses and pre-burst.

It identified that default continuing losses from the ARR data hub over-estimated losses and therefore were not fit for purpose and should only be used where better information was not available. Based on an inspection of the results of losses adopted by this study for catchments within or near the Macleay catchment an initial loss of 26mm and a varied continuing loss with AEP was adopted for the current study (refer to <https://data.arr-software.org/catchmentlosses/map>). The parameters adopted for design events in the updated model are listed in Section 5.4.4.

Where the pre-burst depth is greater than the initial loss, a temporal pattern was applied to the pre-burst depth based on the March 2001 storm. The adopted pre-burst depth was varied to reconcile with the frequency analysis as per Section 5.4.5.

### 5.4.5. Reconciling flood frequency and rainfall runoff results

Difficulty was encountered when trying to match the flood frequency and rainfall runoff model peak flow estimates. While reconciliation of the flood frequency analysis and rainfall runoff model could

have been achieved using higher losses it was decided that high losses would result in a hydrograph low in volume, which would cause problems in the hydraulic model.

For the 20% AEP, the 75% pre-burst depths were adopted, and the 90% pre-burst depths were adopted for all other design events. The Pre-burst and continuing loss was varied in order to reconcile design flows with those from the frequency analysis. A small change was made to those adopted in the Valley ARR update (Reference 10) to better fit the record at Turners Flat.

Table 14 provides a summary of the adopted losses and pre-burst depths compared to the Valley ARR Update project (Reference 10).

Table 14: Summary of losses and pre-burst

| AEP   | Adopted Values Current Study |                         |               | Valley ARR Updated Values (Reference 10) |                         |               |
|-------|------------------------------|-------------------------|---------------|------------------------------------------|-------------------------|---------------|
|       | Initial Loss (mm)            | Continuing Loss (mm/hr) | Pre-burst (%) | Initial Loss (mm)                        | Continuing Loss (mm/hr) | Pre-burst (%) |
| 20%   | 26                           | 1.4                     | 75            | 26                                       | 1.4                     | 90            |
| 5%    | 26                           | 1.2                     | 90            | 26                                       | 1.2                     | 90            |
| 1%    | 26                           | 0.5                     | 90            | 26                                       | 0.5                     | 90            |
| 0.2%  | 26                           | 0.5                     | 90            | 26                                       | 0                       | 90            |
| 0.05% | 26                           | 0.5                     | 90            | 26                                       | 0                       | 90            |

## 5.5. Probable Maximum Precipitation

The PMP produces the PMF which is the largest probable flood that can occur on a catchment and is used to define the extent of flood prone land. PMP estimates were derived according to BOM guidelines, namely the Revised Generalised Tropical Storm Method GTSMR suitable for estimating long durations (i.e. 12– ~120 hours). Table 15 provides the catchment average PMP depth for the critical duration.

Table 15: PMP Depths

| Catchment Average To | Critical Duration (hr) | Rainfall Depth (mm) |
|----------------------|------------------------|---------------------|
| Bellbrook            | 36                     | 756                 |
| Kempsey              | 36                     | 780                 |

## 6. HYDRAULIC MODELLING

A model of the study area was developed in the hydrodynamic modelling package (TUFLOW). TUFLOW (Reference 6) is widely used in Australia and internationally for assessing flood behaviour and hydraulic hazard. The TUFLOW model version used in this study was 2023-03-AB iSP GPU (using the finite volume HPC solver). The TUFLOW Heavily Parallelised Compute (HPC) solver has the ability to run on a Graphics Processor Unit (GPU). The new HPC GPU models are significantly faster than TUFLOW Classic models, which rely on a Central Processing Unit (CPU).

The model extent for the catchment was determined in conjunction with the Kempsey Shire Council.

### 6.1. Model Configuration

The model consists of a 2D 10m grid defining the overbank and channel. The extent of the TUFLOW model is shown in Figure 5.

The model extends a sufficient distance upstream and downstream of the study area such that the imposed boundary conditions do not influence the model results in the region of interest. The TUFLOW model limits were:

- Upstream to 800m upstream of Armidale Rd/ Five Day Creek intersection in Comara on the Macleay River,
- Includes local tributaries draining into the Macleay River in this extent, and
- Downstream to upstream of the railway bridge at Kempsey (and the overflow points into Kempsey CBD in rare events).

Quadtree has also been utilised, which allows for refinement in urban centres while using a coarser grid in areas in between. A 2m grid was used for the Quadtree areas. The quadtree locations include:

- Bellbrook, north of the Bellbrook Bridge
- Willawarrin, 1km north of the Macleay River
- Small settlement located south of the Tanagog Bridge, approximately 560 m along Temagog Road.

A digital terrain model (DTM) was created using the topographic data outlined in Section 3. Culverts and bridges under a number of roads were incorporated into the model.

### 6.2. Boundary Conditions

Inflows and boundary conditions for the TUFLOW model consist of a number of time varying flow hydrographs developed using the WBNM model. In the headwater reaches, inflows were applied as Flow versus Time (QT) boundaries representing the total flow from the upstream catchment. For internal sub-catchments, local inflows were applied as 2D- surface-area (SA) polygons into the creeks and main river.

At the downstream boundary of the model, a rating curve (height vs flow) were adopted based on the results of the latest Kempsey CBD model (Reference 13). Boundaries were applied as per Table 16 (shown in Figure 5). The different rating curves are shown in Diagram 4.

Table 16: Boundary conditions

| Downstream Boundary | Type                | Comment                                                                                                                                |
|---------------------|---------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| West Kempsey        | Water level vs Time | Based on PMF level in Sea Street in Reference 13. Water overtops River Street between North and Broughton Streets in a PMF only        |
| Main River          | Water Level vs Flow | Based on Level vs flow in PMF in Reference 13. Boundary condition for Macleay River immediately upstream of the rail bridge at Kempsey |
| Overflow 1 to 4     | Water Level vs Flow | Based on Level vs flow in PMF in Reference 13. Boundary conditions cover the overflow areas to the west of the main river.             |

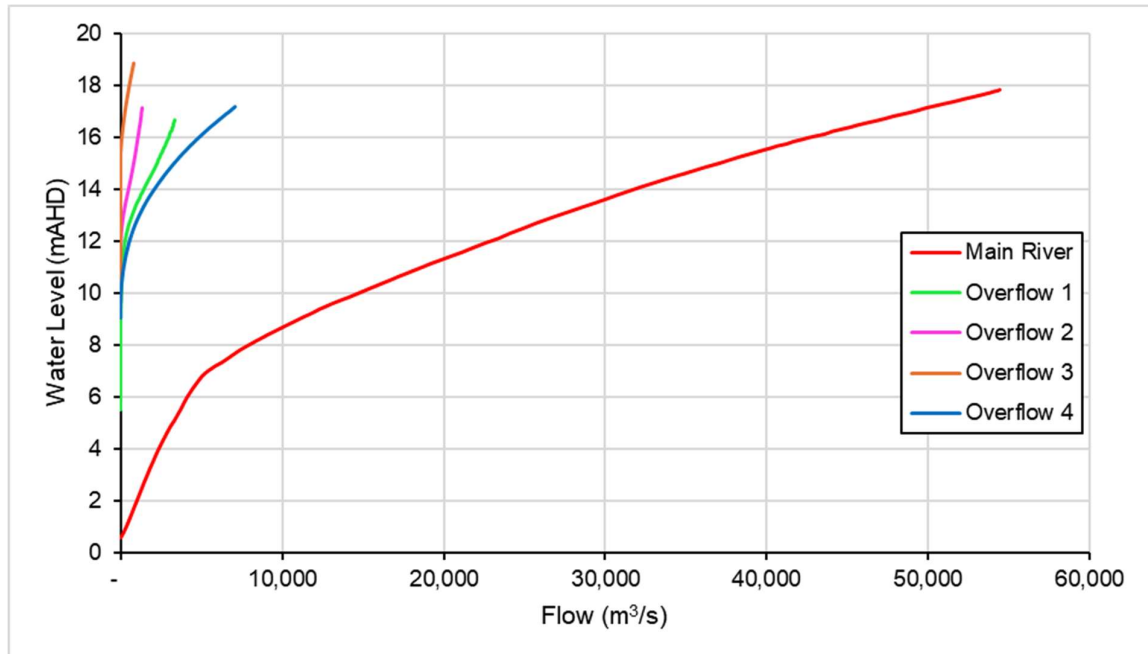


Diagram 4: Downstream Water Level vs Flow Boundary Conditions

### 6.3. Model Calibration

Model calibration was undertaken using historical data for the 2001 flood event. These events were adopted as a reasonable amount of observed data exists within the catchment. Time varying water level data is also available for these events. Previous studies on the Macleay River have used this event for calibration and been able to reproduce observed flood behaviour.

Inflows to the hydraulic model for these events were developed as described in Section 5.3.

The hydraulic efficiency of the creeks is represented (in part) within the TUFLOW model by the

roughness or friction factor, Manning's " $n$ " value. Manning's " $n$ " is used to describe the influence of the following factors on flow behaviour:

- channel roughness,
- channel sinuosity,
- vegetation and other debris/obstructions in the channel, and
- bed forms and shapes.

As part of the calibration process the Manning's " $n$ " roughness value was adjusted within reasonable limits to best match the recorded flood heights along the river system. Adopted values were selected based on an assessment of the ground cover types and vegetation density within the floodplain. The adopted values (Refer to Table 17 and Figure 6) were then used for the hydraulic modelling of the design events.

Table 17: Adopted Manning's " $n$ " Values

| Description                                     | Manning's " $n$ " Value |
|-------------------------------------------------|-------------------------|
| Hard surfaces, concrete, bitumen                | 0.02                    |
| Straight channel with no pools                  | 0.025                   |
| Winding channel with pools                      | 0.037                   |
| Default floodplain                              | 0.04                    |
| Overbank                                        | 0.042                   |
| Urbanised areas, overbank with dense vegetation | 0.06                    |
| Buildings                                       | 0.1                     |
| Dense forest                                    | 0.8                     |

## 6.4. Calibration Results and Discussion

The hydraulic model was calibrated to the 2001 event. This event was adopted for calibration as it had been used by previous studies which achieved a good calibration to observed values. The 2001 was the largest flood in recent memory.

Time varying water level data was available at:

- Bellbrook
- Turners Flat
- Toorooka
- Euroka
- Alladvilla

Comparison of modelled and observed time varying water levels at these sites are shown in Figure 20 to Figure 24. The early part of the hydrograph plus a manually read peak is available for Bellbrook. The modelled peak is lower and earlier than the observed peak. At Turners Flat the peak level is similar with the hydrograph shape slightly fatter. The modelled peak occurs 2.5hrs later than the observed peak. The modelled hydrograph at Aldavilla and Euroka has a flatter peak and more volume than the observed hydrograph. The model is high at Aldavilla and low at Euroka and Toorooka.

Observed water levels were based on data collected and documented Reference 14 for near the peak of the event. Unfortunately data collection for the event focused on Kempsey CBD due to the widespread damage. Limited information is available in the Upper Macleay other than timeseries information required for model calibration. A comparison the modelled and observed flood levels at calibration locations are provided in Table 18 for the 2001 event. The model calibrated reasonably well to observed flood levels given the uncertainty in the model inputs and the limited number of calibration points in the upper river. Most modelled flood levels were within 0.6m of the observed values. Peak flood levels for the 2001 are shown in Figure 25.

Table 18: Calibration – Modelled versus Observed Flood Levels – 2001

| ID                            | Location                          | Observed Level (mAHD) | Modelled Level (mAHD) | Difference (m) |
|-------------------------------|-----------------------------------|-----------------------|-----------------------|----------------|
| <b>Gauge Locations</b>        |                                   |                       |                       |                |
| 1                             | Macleay River at Bellbrook        | 45.3                  | 44.7                  | -0.7           |
| 2                             | Macleay River at Toorooka         | 7.4                   | 7.8                   | 0.4            |
| 3                             | Macleay River at Turners Flat     | 71.2                  | 71.1                  | -0.1           |
| 4                             | Macleay River at Aldavilla        | 12.3                  | 12.9                  | 0.6            |
| 5                             | Macleay River at Euroka           | 11.8                  | 11.3                  | -0.5           |
| <b>Debris Marks Locations</b> |                                   |                       |                       |                |
| 1                             | Sherwood Rd at Sherwood Bridge    | 14.2                  | 15.8                  | 1.6            |
| 6                             | Old Greenhill Ferry Rd, Greenhill | 9.4                   | 10.3                  | 0.9            |
| 7                             | Euroka Rd, Lot B DP58121          | 8.8                   | 8.2                   | -0.6           |
| 8                             | End of Cooks Lane, West Kempsey   | 8.5                   | 8.7                   | 0.2            |
| 9                             | Elbow St/ River St, West Kempsey  | 8.2                   | 8.4                   | 0.2            |

## 6.5. Model Verification

Model verification was conducted, using the calibrated model and parameters (as discussed in Section 6.4). The 2011 events were used for model verification.

The flooding at in the Upper Macleay is mainly driven by the river and creek systems in the area. This event was regarded by most residents as a slowest rising flood event they recall. The peak and receding flood waters were drawn out compared to other similar events. This event was similar in height to other recent events such as the March 2001 and May 2009 floods in the area. The June 2011 flood had a lower peak (for example at Bellbrook the 2011 event was 0.15m lower than 2009) and a slightly slower rate of rise. However, at Turners Flat the 2011 event was 0.64m lower than 2009. This is apparent on the hydrographs for Bellbrook, Toorooka Bridge, Turners Flat gauges (Appendix B). The falling arm of the hydrograph experiences a second burst and both the Toorooka and Turners Flat hydrographs match up with the 2009 event. The fact that the 2011 event reached a lower peak does not then translate to the total length of the event being shorter. This had a great impact on communities all around the area as most struggle with isolation more

that inundation in floods. There was a wide variance in how long properties were inundated with a range from less than a day to a number of weeks.

Observed levels and rainfall data was available for this event (as described in Section 3 and Reference 12). A number of water level gauges are located throughout the catchment and operated by BoM and KSC although most are located in the Lower Macleay. Time varying water level data was also available for Bellbrook, Toorooka and Turners Flat. Plots of the water level data vs time, including observed levels and modelled levels are provided Figure 26 to Figure 28. A good fit to the overall shape and peak was achieved at Toorooka and Turners Flat.

A total of 13hrs warning time occurred between the peak at Georges Creek and the peak at Kempsey. Confusion was caused throughout the event due to the Kempsey Traffic Bridge gauge reading being 200mm above the actual water height as read from the manual gauge boards located nearby.

Peak flood levels for the 2011 are shown in Figure 29. A comparison the modelled and observed flood levels at calibration locations are provided in Table 19 for the 2011 event. The modelled and observed levels are generally within 0.4m.

Table 19: Calibration – Modelled versus Observed Flood Levels – 2011

| ID                            | Location                          | Observed Level (mAHD) | Modelled Level (mAHD) | Difference (m) |
|-------------------------------|-----------------------------------|-----------------------|-----------------------|----------------|
| <b>Gauge Locations</b>        |                                   |                       |                       |                |
| 1                             | Macleay River at Bellbrook        | 69.1                  | 69.5                  | 0.4            |
| 2                             | Macleay River at Toorooka         | 43.2                  | 43.2                  | 0.0            |
| 3                             | Macleay River at Turners Flat     | 21.7                  | 21.9                  | 0.2            |
| 4                             | Macleay River at Aldavilla        | -                     | -                     | -              |
| 5                             | Macleay River at Euroka           | -                     | -                     | -              |
| <b>Debris Marks Locations</b> |                                   |                       |                       |                |
| 2                             | 167 Clarkes Rd, Yessabah          | 33.5                  | 33.5                  | 0.0            |
| 3                             | 98 Battles Outlet Rd, Dodingalong | 12.2                  | 12.3                  | 0.1            |
| 4                             | 681 Gowings Hill Rd, Dodingalong  | 10.6                  | 11.3                  | 0.7            |
| 5                             | 50 Nelsons Wharf Rd, Aldavilla    | 10.8                  | 10.4                  | -0.3           |

Photo 7 shows Turners Flat Bridge at an unknown time before the peak was reached. Turners Flat Bridge is a prime example of the many low lying bridges in the area. This bridge and other low lying bridges in the area were closed due to the rising flood waters, isolating many properties in the area.



Photo 7: Flooding of Turners Flat Bridge (Time and date unknown, 2011 event)

Table 20 and Diagram 5 show closure and opening times of the low lying bridges and roads within the study area, during the 2011 event. Opening times are often long after the flood has receded due to the time for access to the site to be regained, inspection times and potentially repair of the road or structure.

Table 20: Road closures- 2011

| Street Closed                                                             | Time Closed on KSC website |        | Time Open on KSC website |        | Gauge Height closed at Toorooka m AHD |
|---------------------------------------------------------------------------|----------------------------|--------|--------------------------|--------|---------------------------------------|
|                                                                           | Date                       | Time   | Date                     | Time   |                                       |
| Bellbrook Bridge                                                          |                            |        | 19/6/11                  | 4:15pm |                                       |
| Dungay Creek Road                                                         | 15/6/11                    | 9:30am |                          |        | 43.14                                 |
| Gowings Hill Road                                                         | 15/6/11                    | 9:30am | 16/6/11                  | 9:30pm | 43.14                                 |
| Marys Bay Road                                                            | 15/6/11                    | 2:50pm | 17/6/11                  | 9:35am | 43.93                                 |
| Moparrabah Road                                                           | 15/6/11                    | 9:30am |                          |        | 43.14                                 |
| Sherwood Bridge                                                           |                            |        | 19/6/11                  | 1:25pm |                                       |
| Temagog and Turners Flat                                                  |                            |        | 19/6/11                  | 4:15pm |                                       |
| Toorooka Bridge is damaged and will remain closed for an extended period. |                            |        | 3/7/11                   |        |                                       |
| Willi Willi Road                                                          | 15/6/11                    | 9:30am | 17/6/11                  | 9:35am | 43.14                                 |

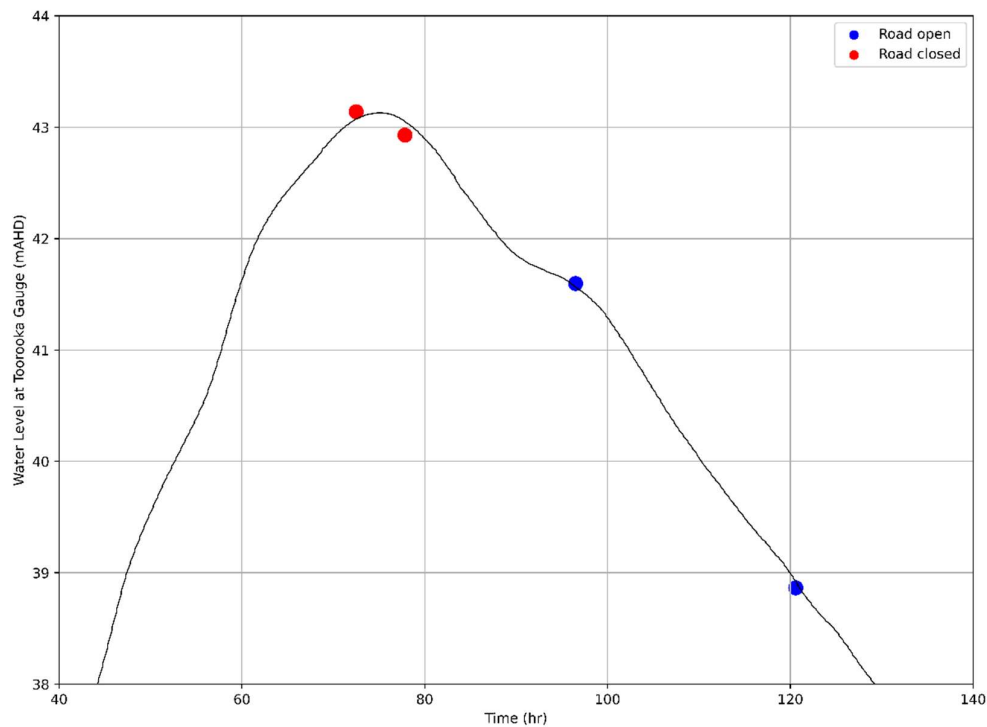


Diagram 5: Road Closure times vs Toorooka modelled flow

Reference 12 found that a total of 93 questionnaires were returned in the Georges Creek and Bellbrook sector, out of these 24 respondents were affected by the flood. No properties were reported to have flooding in their main building, with only 2 properties with flood waters in other buildings on the property. 23 properties responded with flooding on nearby roads (25%) and 10 properties responded with yard inundation (11%). Only 2 respondents evacuated with one stating it was affected by the flood and the other stating the property was affected (though nearby roads were cut). The modelling of the 2011 event found that 16 properties were potentially inundated in the event (this may include inundation of the surrounding ground but not above floor level of a structure). Figure 29 shows the locations where the model and survey align in terms of flooding behaviour at/or near the property.

## 7. DESIGN FLOOD BEHAVIOUR

### 7.1. Design Event Surfaces

While the Macleay River and the immediate backwater areas are dominated by Macleay River flooding which is typically a result of 1 to 3 days of rainfall, the upper reaches of the tributaries are dominated by shorter duration storms of 1 to 6 hours. While it does not happen in every event, it is not uncommon for a multi-day storm to have embedded thunderstorms that cause concurrent flooding on the river and the tributaries though in most cases the tributaries peak well before the Macleay River. To account for this joint probability problem two sets of scenarios were run (for example for 1% AEP flood surface):

- a 1% AEP long duration event on the Macleay River and its tributaries,
- 1% AEP short duration scenario based on the worst-case short duration for each tributary in combination with a 5% AEP event on the main river.

The design event surfaces were created using an enveloped approach. The model was run for two scenarios; river dominated, and local catchment /creek dominated. The peak water level grid was derived by taking the maximum envelope of the two scenarios.

The river dominated runs have an ARF based on the catchment average to Bellbrook. By way of example, for the 1% AEP 1440min duration event (critical), the ARF is 0.79. The ARF to Bellbrook was found to be critical vs the ARF to Kempsey. For the local catchment /creek dominated run, the ARF was calculated for the different creeks (refer Section 5.4.2) and modelled with a lower coincident river flow.

The Macleay River dominated events are generally critically 1-2 km up the tributaries above which local catchment flows dominate. This trend is consistent across all events, although the rarer the event, the greater the river event dominated up to the tributaries. An example of the river and creek dominated events for the 1% AEP are shown in Figure 32.

The design event scenarios are summarised in Table 21. The selection of temporal patterns and durations is detailed in Section 7.3. The same flow vs height downstream boundary conditions were applied to river and creek dominated runs.

Table 21: Design event scenarios

| Design Event AEP | River Dominated AEP | Creek Dominated |                      |
|------------------|---------------------|-----------------|----------------------|
|                  |                     | Creek AEP       | Coincident River AEP |
| 20%              | 20%                 | 20%             | 50%                  |
| 5%               | 5%                  | 5%              | 20%                  |
| 1%               | 1%                  | 1%              | 5%                   |
| 0.2%             | 0.2%                | 0.2%            | 5%                   |
| 0.05%            | 0.05%               | 0.05%           | 5%                   |
| PMF              | PMF                 | N/A             | N/A                  |

## 7.2. Boundary Conditions

### 7.2.1. Design Inflows

As with the historical events the TUFLOW inflows for the 20, 5, 1, 0.2, 0.05% AEP and Probable Maximum Flood (PMF) design events were obtained from a number of time varying flow hydrographs taken from the WBNM model (refer to Section 5). These inflow hydrographs were then applied to the calibrated TUFLOW hydraulic model to produce design flood levels.

## 7.3. Temporal Patterns and Durations

All temporal patterns and durations were run through the hydrologic model. Durations close to the critical duration were run in the hydraulic model. Box plots of the hydrologic modelling results are contained in APPENDIX D. The pattern above the median was chosen. The adopted patterns are described in Table 22.

Table 22: Critical Durations and chosen temporal patterns

| Event (AEP) | Duration and Temporal pattern |                   |                   |                   |                   |
|-------------|-------------------------------|-------------------|-------------------|-------------------|-------------------|
|             | River Dominated               | Creek Dominated 1 | Creek Dominated 2 | Creek Dominated 3 | Creek Dominated 4 |
| 20%         | TP4936<br>2160 min            | TP4712<br>270 min | TP4805<br>720 min | -                 | -                 |
| 5%          | TP4872<br>1440 min            | TP4591<br>360 min | TP4757<br>540 min | -                 | -                 |
| 1%          | TP4728<br>1440 min            | TP4617<br>120 min | TP4469<br>180 min | TP4529<br>360 min | TP4654<br>720 min |
| 0.2%        | TP4755<br>1440 min            | TP4618<br>120 min | TP4722<br>360 min | TP4751<br>720 min | -                 |
| 0.05%       | TP4755<br>1440 min            | TP4751<br>720 min | -                 | -                 | -                 |

## 7.4. Design Event Results

Peak flood level results for the 20%, 5%, 1%, 0.2%, 0.05% AEP and Probable Maximum Flood (PMF) design events are presented in Figure 33 to Figure 92. Peak velocities within the study area for the design events are presented in Figure 93 to Figure 98. Table 23 documents design flood levels at key locations.

Table 23: Design Flood Levels at Key Locations

| ID | Location                       | Flood Level (mAHD) |      |      |       |       |       |
|----|--------------------------------|--------------------|------|------|-------|-------|-------|
|    |                                | 20%                | 5%   | 1%   | 0.2%  | 0.05% | PMF   |
| 1  | Toose Road                     | -                  | 93.9 | 98.3 | 100.4 | 102.3 | 116.5 |
| 2  | Armidale road at Pee Dee Creek | 77.1               | 81.5 | 86.5 | 88.9  | 91.1  | 107.6 |
| 3  | Thungutti Drive                | -                  | -    | 74.4 | 76.6  | 78.5  | 93.6  |

|    |                                      |      |      |      |      |      |       |
|----|--------------------------------------|------|------|------|------|------|-------|
| 4  | Armidale Road at Nulla Nulla Creek   | -    | 70.0 | 74.4 | 76.6 | 78.5 | 93.6  |
| 5  | Dowlings Falls Road                  | 40.6 | 44.3 | 48.4 | 50.3 | 52.0 | 62.7  |
| 6  | Armidale Road US Hickeys Creek       | -    | 43.9 | 46.2 | 48.4 | 50.0 | 60.4  |
| 7  | Armidale Road crossing Hickeys Creek | 38.2 | 41.9 | 46.2 | 48.3 | 50.0 | 60.1  |
| 8  | Temagog Bridge                       | 29.7 | 33.8 | 38.2 | 40.3 | 42.1 | 51.6  |
| 9  | Armidale Road at Mungay Creek        | 36.7 | 37.7 | 40.1 | 42.1 | 43.7 | 53.4  |
| 10 | Armidale Road at Deep Creek          | 24.0 | 25.6 | 29.9 | 31.6 | 33.0 | 41.4  |
| 11 | Turners Flat Road                    | -    | -    | -    | -    | -    | 127.0 |
| 12 | Armidale Road in Skillion Flat       | -    | -    | -    | 28.4 | 29.5 | 39.8  |
| 13 | Turners Flat Road Bridge             | 20.1 | 24.0 | 28.0 | 29.6 | 30.8 | 39.7  |
| 14 | Bellbrook Bridge                     | 67.1 | 71.4 | 75.9 | 78.0 | 79.9 | 94.7  |

Flooding in the Upper Macleay River is generally confined to areas near the river and its tributaries. The upper catchment is deeply incised, but downstream of Hickey's Creek, the floodplain widens as the terrain becomes less steep.

In the 20% AEP, flooding is mostly contained within the river and its tributaries, but key bridges across the Upper Macleay River Valley are flooded. In the 5% AEP, additional properties along the river's edge are affected, and access to rural properties in Euroka is cut off due to flooding of Marys Bay Road with depths exceeding 2m. The Nulla Nulla Creek–Armidale Road Bridge is also inundated, isolating Bellbrook from the east.

Breakout flows occur in the 1% AEP, inundating rural properties, particularly in Aldavilla, and Dondingalong. Aldavilla becomes isolated as Sherwood Road is cut off in both directions, and the Kempsey Airport is surrounded by floodwaters. In Bellbrook, a small community near Nulla Nulla Creek is isolated as Bellbrook Aboriginal Station Road is flooded.

In the 0.2% AEP, the Kempsey Airport runway and buildings are inundated by depths up to 1m, and Willawarrin becomes a flood island as the bridge over Hickeys Creek is cut. Additional properties near the river and its tributaries are flooded in Willawarrin, Temagog, Mooneba, Sherwood, and Aldavilla.

In the 0.05% AEP, several properties around Bellbrook, adjacent to Nulla Nulla Creek, are inundated by depths up to 1.2m. Floodwaters are no longer contained within creeks and rivers, especially downstream of Hickeys Creek, exacerbating flooding in areas adjacent to the river and its tributaries.

During the Probable Maximum Flood (PMF), the flood extent expands, significantly inundating properties in Bellbrook, Willawarrin, Aldavilla, and many rural areas with depths exceeding 5m. Bellbrook experiences bifurcating flows from the Macleay River and backwater from Nulla Nulla Creek, isolating the town.

Flood velocity is higher in the upper catchment where the topography is steeper. In events up to

the 1% the peak flood velocity is relatively low ( $< 1\text{m/s}$ ) outside the main river and tributaries. Peak velocity increases with rarer events especially outside the riverbanks and in floodplain areas.

## 7.5. Sensitivity Analysis

### 7.5.1. Parameter Sensitivity

The model established for this study relies on a number of assumed parameters, the values of which are considered to be the most appropriate for the study area. A range of sensitivity analysis was undertaken on different key parameters in order to quantify potential variations corresponding to different modelling assumptions.

The following scenarios were considered to represent the envelope of likely parameter values:

- $\pm 20\%$  change in Manning's "n" value,
- Blockage of hydraulic structures,
- Change in continuing loss,
- $\pm 20\%$  change in the C storage routing parameter in the WBNM hydrologic model, and
- Change in the bathymetry by 1m.

For the Manning's n and blockage scenarios listed above, the hydraulic models were run for the 1% AEP design storm and the results are provided in Table 24.

A 20% increase and decrease in Manning's n value resulted in changes in flood levels the order of 1m. This is due to the steep terrain and confined floodplain. Without detailed survey within the river the Manning's n values are partially compensating for the uncertainty in the river bathymetry.

All bridges with spans less than 6m and all culverts were assessed using the ARR blockage procedure. A simplified blockage approach was applied:

- less than 1 or 2 m diameter - 50% blockage
- 2 to 6 m diameter - 10% blockage

The impacts of blockage are localised to the structures and minimal. Most of the roads are significantly overtopped during a large flood event.

As limited bathymetry was available the bathymetry was lowered by 1m. Lowering the bathymetry by 1m resulted in lower flood levels by 0.2m. Overall, the model is relatively sensitive to changes in Manning's n but insensitive to other parameter values.

Table 24: Hydraulic Parameter Sensitivity Results

| ID | Location                          | 1% AEP<br>Flood<br>Level<br>(mAHD) | Flood Level (mAHD) |                  |          |                        |
|----|-----------------------------------|------------------------------------|--------------------|------------------|----------|------------------------|
|    |                                   |                                    | +20%<br>Mannings   | -20%<br>Mannings | Blockage | Bathymetry<br>shift 1m |
| 1  | Toose Road                        | 98.3                               | 99.4               | 97.1             | 98.3     | 98.2                   |
| 2  | Armidale road at<br>Pee Dee Creek | 86.5                               | 87.5               | 85.6             | 86.5     | 86.3                   |

|    |                                      |      |      |      |      |      |
|----|--------------------------------------|------|------|------|------|------|
| 3  | Thungutti Drive                      | 74.4 | 75.5 | -    | 74.4 | -    |
| 4  | Armidale Road at Nulla Nulla Creek   | 74.4 | 75.5 | 73.5 | 74.4 | 74.2 |
| 5  | Dowlings Falls Road                  | 48.4 | 49.3 | 47.3 | 48.4 | 48.2 |
| 6  | Armidale Road US Hickeys Creek       | 46.2 | 47.2 | 45.2 | 46.2 | 46   |
| 7  | Armidale Road crossing Hickeys Creek | 46.2 | 47.2 | 45.1 | 46.2 | 45.9 |
| 8  | Temagog Bridge                       | 38.2 | 39.2 | 36.9 | 38.2 | 38.0 |
| 9  | Armidale Road at Mungay Creek        | 40.1 | 41   | 39   | 40.1 | 39.9 |
| 10 | Armidale Road at Deep Creek          | 29.9 | 30.7 | 28.9 | 29.9 | 29.7 |
| 11 | Turners Flat Road                    | -    | -    | -    | -    | -    |
| 12 | Armidale Road in Skillion Flat       | -    | 27.7 | -    | -    | -    |
| 13 | Turners Flat Road Bridge             | 28.0 | 28.9 | 27   | 28   | 27.9 |
| 14 | Bellbrook Bridge                     | 75.9 | 76.9 | 74.8 | 75.9 | 75.7 |

A sensitivity scenario was undertaken by varying the C storage routing parameter in the WBNM hydrologic model for the 5% and 1% AEP. Increasing the C storage routing parameter to 1.74 resulted in 19% and 17% decreases in the outflow of the catchment in the 5% and 1% AEP events, respectively. Decreasing the C storage routing parameter resulted in an increase in flow of 26% and 23% for the 5% and 1% AEP respectively.

Table 25: Hydrologic Model C Storage Routing Sensitivity

| Event | Scenario     | C    | Outflow (m <sup>3</sup> /s) |
|-------|--------------|------|-----------------------------|
| 5%    | Design Event | 1.4  | 9,611                       |
|       | Increased C  | 1.74 | 7,786                       |
|       | Decreased C  | 1.06 | 12,164                      |
| 1%    | Design Event | 1.4  | 16,187                      |
|       | Increased C  | 1.74 | 13,505                      |
|       | Decreased C  | 1.06 | 19,856                      |

A sensitivity scenario with no continuing loss in the WBNM hydrologic model was modelled for the 5% and 1% AEP. The outflow of the catchment was compared. Reducing the continuing loss to 0 mm/hr resulted in 29% and 11% increase in the outflow of the catchment in the 5% AEP and 1% AEP events, respectively.

Table 26: Hydrologic Model Loss Sensitivity Results

| Event | Scenario         | Initial Loss (mm) | Continuing Loss (mm/hr) | Outflow (m <sup>3</sup> /s) |
|-------|------------------|-------------------|-------------------------|-----------------------------|
| 5%    | Design Event     | 26                | 1.2                     | 9,611                       |
|       | Decreased losses | 26                | 0                       | 12,361                      |
| 1%    | Design Event     | 26                | 0.5                     | 16,187                      |
|       | Decreased losses | 26                | 0                       | 17,953                      |

## **8. INFORMATION TO INFORM DECISIONS ON ACTIVITIES IN THE FLOODPLAIN**

### **8.1. Flood Planning Area**

The flood planning level (FPL) is used to define land subject to flood related development controls and is generally adopted as the minimum level to which floor levels in the flood affected areas must be built. The FPL includes a freeboard above the design flood level. It is common practice to set minimum floor levels for residential buildings, garages, driveways and even commercial floors as this reduces the frequency and extent of flood damages. Freeboards provide reasonable certainty that the reduced level of risk exposure selected (by deciding upon a particular event to provide flood protection for) is actually provided.

To align with the Lower Macleay Study the 1% AEP with 20% climate change 2090 was estimated. The probability of a 1% AEP with 20% climate change 2090 in baseline conditions was estimated to be approximately a 1 in 450 AEP event. A 1 in 450 AEP event design flood level was interpolated from the 1% (1 in 100) AEP and a 0.2% (1 in 500) AEP design event flood levels.

The Flood Planning Area is defined as the envelope (highest) of:

- 1% AEP event plus a freeboard
- 1% AEP with 20% climate change 2090 (1 in 450 AEP)

Figure 106 to Figure 108 shows the proposed Flood Planning Area. The 1% AEP plus 20% Climate change was higher on the main river.

### **8.2. Hydraulic and Hazard Classification**

#### **8.2.1. Hazard Classification**

Hazard classification plays an important role in informing flood risk management. It reflects the likely impact of flooding on development and people, providing a measure of potential risk to life and property damage, from a flood event. Hydraulic hazard is typically determined by considering the depth and velocity of floodwaters. In recent years, there have been a number of developments in the classification of hazards. Research has been undertaken to assess the hazard to people, vehicles and buildings based on flood depth, velocity and velocity depth product.

Hydraulic hazard categories have been determined for the study area in accordance with the NSW Flood Risk Management Manual (Reference 15) and its accompanying guideline FB03 – Flood Hazard (Reference 16).

The accompanying guideline FB03 (Reference 16) contains information relating to the categorisation of flood hazard. A summary of this categorisation is provided in Diagram 6.

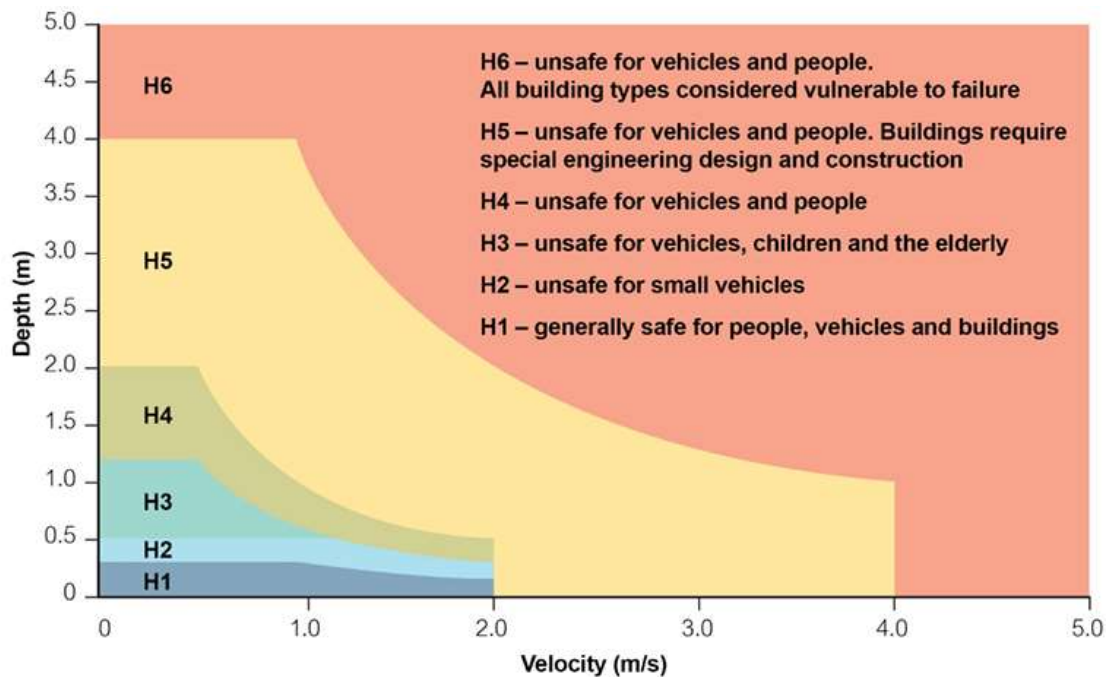


Diagram 6: General flood hazard vulnerability curves

This classification provides a more detailed distinction of the practical vulnerabilities of hazard categories, identifying the following 6 classes of hazard:

- H1 – No constraints, generally safe for vehicles, people and buildings;
- H2 – Unsafe for small vehicles;
- H3 – Unsafe for all vehicles, children and the elderly;
- H4 – Unsafe for all people and all vehicles;
- H5 – Unsafe for all people and all vehicles. Buildings require special engineering design and construction; and
- H6 – Unsafe for all people and all vehicles. All building types considered vulnerable to failure.

It should be noted that these classifications are based on the physical flood behaviour in design flood events and do not account for other hazards that may exist (such as, road surface failure) or the variability in real storm events.

Due to the confined nature of the floodplain much of the floodplain is suggest to high hazard flow even in frequent events. Creeks such as Parrabel and Temagog with braided flow paths and a broader upper floodplain are subject to lower hazards. A high hazard flow path breaks out on the bend near Turners Flat in events larger than a 1% AEP. The majority of Bellbrook and Willawarrin are subject to H6 (Unsafe for all people and all vehicles. All building types considered vulnerable to failure) hazards in a PMF while not affected in smaller events.

## 8.2.2. Hydraulic Categorisation

Hydraulic categorisation of the floodplain is used in the Flood Risk Management process to assist in the assessment of the suitability of future types of land use and development, and the

formulation of flood risk management plans.

Hydraulic categorisation involves mapping the floodplain to indicate which areas are most important for the conveyance of floodwaters, and the temporary storage of floodwaters. The Flood Risk Management Manual (Reference 15) defines land inundated in a particular event as falling into one of the three hydraulic categories listed in Table 27 based on their function during a flood event. The flood function of an area may change with the magnitude of the event, the most extreme example being areas which are flood free during a smaller more frequent flood event, forming part of a floodway in larger less frequent events. Typically, development within floodway or flood storage areas would be likely to cause water to flow into other areas redistributing the flood risk, unless the development is carefully designed to avoid these impacts. Understanding these categories can inform land use planning strategies for the appropriate management of flood risk.

Table 27: Hydraulic Categorisation Definitions

| Category             | Definition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Floodway</b>      | <ul style="list-style-type: none"> <li>Those areas where a significant volume of water flows during floods.</li> <li>Often aligned with obvious natural channels.</li> <li>Areas that, even if only partially blocked, would cause a significant increase in flood levels and/or a significant redistribution of flood flow, which may adversely affect other areas; and</li> <li>Often, but not necessarily, areas with deeper flow or areas where higher velocities occur.</li> </ul>                                                    |
| <b>Flood Storage</b> | <ul style="list-style-type: none"> <li>Parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood.</li> <li>If the capacity of a flood storage area is substantially reduced, for example by the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased; and</li> <li>Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.</li> </ul> |
| <b>Flood Fringe</b>  | <ul style="list-style-type: none"> <li>Remaining area of land affected by flooding after floodway and flood storage areas have been defined.</li> <li>Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.</li> </ul>                                                                                                                                                                                                                                                |

There are no discrete criteria or parameters which explicitly break down the floodplain into the three categories of flood function that would be suitable for all catchments. Different approaches and techniques are used in practice and by different authorities, based on the specific features of the catchment in question. The encroachment approach was tested on the catchment but due to the confined nature of the floodplain, the Howells method was implemented.

The use of velocity and depth to delineate areas of different hydraulic category follows the approach proposed by Howells et al. in their 2004 paper (Reference 18). At each grid cell, the peak velocity ( $v$ ), peak depth ( $d$ ) and their product ( $v \cdot d$ ) is considered, and the cell is categorised based on the following criteria.

- If both  $v \cdot d > 0.25$  and  $v > 0.25$ , then 'floodway'
- If both  $v > 1$  and  $d > 0.10$ , then 'floodway'
- If neither of the above apply and  $d > 0.2$ , then 'flood storage'
- Otherwise, 'flood fringe'.

The areas were expanded by first changing any 'islands' of non-floodway to floodway, that is, areas that are surrounded by floodway. Then flood runners were manually added to the floodway area, and their width was increased until they were sufficiently wide. Lowering the thresholds of  $v$ ,  $d$  and  $v \cdot d$  may also be used to select more area.

Figure 105 presents the hydraulic categories for the 1% AEP event. The majority of the floodplain is classified as floodway. Due the steep nature of the river and the confined floodplain there are limited areas of flood storage and an even smaller area of flood fringe.

### 8.3. Flood Planning Constraint Classification

Guideline 7-5 of the Australian Disaster Resilience Handbook Collection (Reference 7 recommends using Flood Planning Constraint Categories (FPCCs) to better inform land use planning activities. These categories condense the wealth of flood information produced in a flood study and classify the floodplain into areas with similar degrees of constraint. These FPCCs can be used in high level assessments of land use planning to inform and support decisions for strategic planning.

For detailed land use planning activities, it is recommended that the flood behaviour across the range of flood events be considered, depending on the level of constraint.

The Flood Risk Management Manual and its supporting guideline, Understanding and Managing Flood Risk (FB01) recommends the use of four constraint categories. It is recommended that isolation potential also be considered for the high constraint category. This could include areas classified as Low flood island (or 'Submerged' (FIS)) or high flood island (or 'Elevated' (FIE)) (Refer Section 9.1). In the study area, the isolation potential is relatively high.

The main river channel and the upper reaches of the creeks and tributaries is defined as FPCC 1. Majority of developments and uses have adverse impacts on flood behaviour in these areas. Most of the edges of the floodplain are categorised as FPCC 4. Small pockets of FPCC 2 and 3 exist.

Table 28: Flood Planning Constraint Categories for the Study Area

|        |   | Constraints <sup>1</sup>                                          | Implications                                                                                                                                                                                                                                                                                                                                | Considerations                                                                                                                                                                                                                                                                                                                                                                       |
|--------|---|-------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| FPCC 1 | a | Floodway and flood storage areas in the DFE event.                | Any development is likely to affect flood behaviour in the 0.2% AEP event and cause impacts elsewhere.                                                                                                                                                                                                                                      | Majority of developments and uses have adverse impacts on flood behaviour or are vulnerable. Consider limiting uses and developments to those that are compatible with flood function and hazard.                                                                                                                                                                                    |
|        | b | H6 hazard in the DFE event                                        | Hazardous conditions considered unsafe for vehicles and people, all types of buildings considered vulnerable to structural failure.                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                      |
| FPCC 2 | a | Floodway in the 0.2% AEP event                                    | People and buildings in these areas may be affected by dangerous floodwaters in rarer events.                                                                                                                                                                                                                                               | Many uses and developments will be more vulnerable in these areas. Consider limiting new uses to those compatible with flood function and hazard (including rarer flood flows) or consider treatments to reduce the hazard (such as filling). Consider the need for additional development control conditions to reduce the effect of flooding on the development and its occupants. |
|        | b | H5 flood hazard in the 1% AEP event                               | Hazardous conditions considered unsafe for vehicles and people, and all buildings vulnerable to structural damage.                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                      |
|        | c | Low Flood Island                                                  | Area becomes isolated by floodwater or impassable terrain, with loss of evacuation route to the community evacuation location. The area will become fully submerged with no flood-free land in an extreme event, with ramifications for those who have not evacuated and are unable to be rescued                                           |                                                                                                                                                                                                                                                                                                                                                                                      |
|        | d | High Flood Island                                                 | Area becomes isolated by floodwater or impassable terrain, with loss of an evacuation route to a community evacuation location. The area has some land elevated above the extreme flood level. Those not evacuated may be isolated with limited or no services, and will need rescue or resupply until floods recede and roads are passable |                                                                                                                                                                                                                                                                                                                                                                                      |
|        | e | H6 flood hazard in the 0.2% AEP event                             | Hazardous conditions develop in rare events which may have implications for the development and its occupants.                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                      |
| FPCC 3 |   | Within the FPA (1% AEP + 0.5m and 1% AEP Plus 20% Climate change) | Hazardous conditions may exist creating issues for vehicles and people. Structural damage to buildings is unlikely.                                                                                                                                                                                                                         | Standard land use and development controls aimed at reducing damage and the exposure of the development to flooding are likely to be suitable. Consider additional conditions for critical utilities, vulnerable facilities                                                                                                                                                          |

| Constraints <sup>1</sup> |                                                                                                             | Implications                                                                                                                                                                                                                                                               | Considerations                                                                                                                        |
|--------------------------|-------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
|                          |                                                                                                             |                                                                                                                                                                                                                                                                            | and key community infrastructure.                                                                                                     |
|                          | Note: Areas classified as FPCC 3 that are surrounded by FPCC2 and/or FPCC1 have been reclassified as FPCC2. | Even if elevated, hazard may arise from the area being isolated and cut off by deep or fast flowing water. Without a safe evacuation route, risk to life exists even if the building itself is not threatened. Such areas are reclassified as FPCC2 (see above)            | See FPCC 2                                                                                                                            |
| FPCC 4                   | Within the PMF extent                                                                                       | Emergency response may rely on key community facilities such as emergency hospitals, emergency management headquarters and evacuation centres operating during an event. Recovery may rely on key utility services being able to be readily re-established after an event. | Consider the need for conditions for emergency response facilities, key community infrastructure and land uses with vulnerable users. |
|                          | Note: Areas classified as FPCC 4 that are surrounded by FPCC2 and/or FPCC1 have been reclassified as FPCC2. | Even if elevated, hazard may arise from the area being isolated and cut off by deep or fast flowing water. Without a safe evacuation route, risk to life exists even if the building itself is not threatened. Such areas are reclassified as FPCC2 (see above)            | See FPCC 2                                                                                                                            |

## 9. INFORMATION TO ASSIST EMERGENCY RESPONSE

Isolation is an important concern during events in the catchment. At least 18 properties are isolated in Elsinore and McKenzie Creek/Scrubby Creek areas when the Bellbrook Bridge closes (this is at approximately 2.70m on the local gauge, not even a minor flood event). Toorooka Bridge also provides access for at least 45 properties, and these properties are potentially isolated if other local roads are closed. Figure 112 to Figure 121 present the design event at which properties are first flooded within the study area.

Time of inundation in a 1% AEP event shown on Figure 111 for all grid cells within the model for depths greater than 0.01m. The majority of areas are inundated for less than 60 hrs. Some low-lying areas are inundated for greater than 70 hours. Some extremely low-lying areas may experience inundation for longer.

Table 29 and Table 30 provides the levels of bridges and low points in key evacuation routes and bus routes within the catchment and the flood levels at these locations for a range of events. These low point levels (Figure 1) were derived from the ALS. This gives an indication of during what size event these roads are likely to be first cut.

Table 29: Design flood levels at low points in roads

| ID | Road Name                                      | Level of low point in road (mAHD) | Design Flood Levels at Low Point (mAHD) |        |        |          |            |       |
|----|------------------------------------------------|-----------------------------------|-----------------------------------------|--------|--------|----------|------------|-------|
|    |                                                |                                   | 20% AEP                                 | 5% AEP | 1% AEP | 0.2% AEP | 0.05 % AEP | PMF   |
| 1  | Armidale Road between Kempsey & Willawarrin    | 24.5                              | -                                       | -      | 26.9   | 28.4     | 29.5       | 39.8  |
| 2  | Armidale Road between Bellbrook & Comara       | 83.8                              | -                                       | -      | 86.7   | 89.1     | 91.3       | 107.8 |
| 3  | Toorooka Road                                  | 46.2                              | -                                       | -      | 49.1   | 51.0     | 52.8       | 63.0  |
| 4  | Sherwood Road                                  | 12.5                              | -                                       | 15.8   | 19.5   | 20.9     | 22.0       | 30.8  |
| 5  | Dungay Creek Road to Wittittrin                | 52.4                              | 52.3                                    | 52.6   | 52.9   | 53.3     | 53.6       | 54.6  |
| 6  | Mooneba Road                                   | 13.5                              | 13.5                                    | 17.3   | 20.9   | 22.4     | 23.6       | 32.9  |
| 7  | Mines Road                                     | 29.7                              | 30.3                                    | 31.2   | 31.4   | 31.6     | 33.0       | 41.4  |
| 8  | Willi Willi Road between Temagog & Willi Willi | 78.9                              | -                                       | 79.0   | 79.1   | 79.5     | 79.7       | 80.1  |
| 9  | Mungay Creek Road                              | 46.3                              | 47.7                                    | 48.8   | 49.2   | 49.4     | 49.8       | 53.4  |
| 10 | Armidale Road between Willawarrin & Bellbrook  | 42.8                              | 42.7                                    | 43.9   | 46.2   | 48.4     | 50.0       | 60.4  |
| 11 | Warbro Brook Road halfway to Willi Willi       | 69.2                              | 69.7                                    | 70.9   | 71.3   | 71.7     | 72.1       | 73.5  |

|    |                                    |      |      |      |      |      |      |      |
|----|------------------------------------|------|------|------|------|------|------|------|
| 12 | Hickeys Creek Road                 | 65.0 | 66.5 | 67.5 | 68.1 | 68.5 | 68.7 | 69.4 |
| 13 | Aboriginal Station Road, Bellbrook | 72.4 | -    | -    | 74.6 | 76.7 | 78.6 | 93.6 |

(- indicates not flooded)

Table 30: Design flood levels at bridges

| ID | Bridge Name                      | Bridge Deck Level (mAHD) | Design Flood Levels at Bridge (mAHD) |        |        |          |            |      |
|----|----------------------------------|--------------------------|--------------------------------------|--------|--------|----------|------------|------|
|    |                                  |                          | 20% AEP                              | 5% AEP | 1% AEP | 0.2% AEP | 0.05 % AEP | PMF  |
| 1  | Bellbrook Bridge                 | 61.0                     | 67.1                                 | 71.4   | 76.0   | 78.1     | 80.0       | 94.7 |
| 2  | Nulla Nulla Creek – Armidale Rd  | 69.2                     | 66.0                                 | 70.1   | 74.4   | 76.6     | 78.5       | 93.6 |
| 3  | Hickeys Creek – Billybyang Rd DS | 76.0                     | 77.8                                 | 81.0   | 81.4   | 81.7     | 82.1       | 82.0 |
| 4  | Toorooka Rd Bridge               | 33.0                     | 41.5                                 | 45.1   | 49.2   | 51.2     | 52.8       | 63.7 |
| 5  | Temagog Bridge                   | 23.5                     | 29.8                                 | 33.9   | 38.3   | 40.4     | 42.2       | 51.7 |
| 6  | Turners Flat Rd Bridge           | 18.1                     | 20.2                                 | 24.1   | 28.2   | 29.7     | 30.9       | 39.9 |
| 7  | Sherwood Bridge                  | 7.0                      | 12.1                                 | 16.0   | 19.5   | 20.8     | 21.9       | 30.4 |
| 8  | Commong Creek Bridge             | 8.0                      | 11.7                                 | 15.6   | 19.1   | 20.5     | 21.7       | 30.3 |
| 9  | Dungay Creek – Davy Ln           | 12.0                     | 14.7                                 | 15.6   | 17.0   | 18.0     | 18.9       | 25.9 |
| 10 | Dungay Creek – Gowings Hill Rd   | 15.0                     | 10.1                                 | 13.8   | 17.0   | 18.0     | 18.9       | 25.9 |

(- indicates not flooded)

Diagram 7 and Diagram 8 depict graphically when the roads and bridges are first cut compared to the nearby gauges. Table 31 shows the time until roads are cut during a 1% AEP event and the expected duration of the disruption, while Table 32 provides the same information for bridges. In less than three hours after the peak at Bellbrook gauge, Turners Flat gauge peaks.

Table 31: Inundation times of road low points

| ID | Road Name                                   | Level of low point in road (mAHD) | Hours before inundated in 1% AEP Event <sup>#</sup> | Total Time of inundation (hrs)* |
|----|---------------------------------------------|-----------------------------------|-----------------------------------------------------|---------------------------------|
| 1  | Armidale Road between Kempsey & Willawarrin | 24.5                              | 93.1                                                | 63.7                            |
| 2  | Armidale Road between Bellbrook & Comara    | 83.8                              | 90.9                                                | 21.5                            |
| 3  | Toorooka Road                               | 46.2                              | 89.7                                                | 33.2                            |
| 4  | Sherwood Road                               | 12.5                              | 81.8                                                | 57.6                            |

|    |                                                |      |      |       |
|----|------------------------------------------------|------|------|-------|
| 5  | Dungay Creek Road to Wittittrin                | 52.4 | 72.4 | 25.7  |
| 6  | Mooneba Road                                   | 13.5 | 79.9 | 76.9  |
| 7  | Mines Road                                     | 29.7 | 25.9 | 134.6 |
| 8  | Willi Willi Road between Temagog & Willi Willi | 78.9 | 86.6 | 70.7  |
| 9  | Mungay Creek Road                              | 46.3 | 24.7 | 137.1 |
| 10 | Armidale Road between Willawarrin & Bellbrook  | 42.8 | 79.1 | 44.6  |
| 11 | Warbro Brook Road halfway to Willi Willi       | 69.2 | 73.5 | 35.6  |
| 12 | Hickeys Creek Road                             | 65.0 | 22.6 | 147.5 |
| 13 | Aboriginal Station Road, Bellbrook             | 72.4 | 90.1 | 21.4  |

\*Inundation is defined as a depth of greater than 0.01m

# Time during pre-burst not included. Value indicates length of time after the beginning of the 1% AEP event.

Note: inundation times are based on the 1% AEP, 1440 min, TP4728 event, which is the critical river dominated event for the catchment. For tributaries a local catchment duration event may produce higher flood levels but shorter durations of inundation

Table 32: Inundation times at bridges

| ID | Bridge Name                      | Level of low point in road (mAHD) | Hours before inundated in 1% AEP Event <sup>#</sup> | Total Time of inundation (hrs)* |
|----|----------------------------------|-----------------------------------|-----------------------------------------------------|---------------------------------|
| 1  | Bellbrook Bridge                 | 61.0                              | 10.5                                                | 23.5                            |
| 2  | Nulla Nulla Creek – Armidale Rd  | 69.2                              | 17.3                                                | 6.6                             |
| 3  | Hickeys Creek – Billybyang Rd DS | 76.0                              | 14.6                                                | 5.0                             |
| 4  | Toorooka Rd Bridge               | 33.0                              | 5.5                                                 | 28.5                            |
| 5  | Temagog Bridge                   | 23.5                              | 12.5                                                | 21.5                            |
| 6  | Turners Flat Rd Bridge           | 18.1                              | 15.3                                                | 13.6                            |
| 7  | Sherwood Bridge                  | 7.0                               | 13.6                                                | 20.3                            |
| 8  | Common Creek Bridge              | 8.0                               | 14.8                                                | 16.2                            |
| 9  | Dungay Creek – Davy Ln           | 12.0                              | 6.1                                                 | 19.9                            |
| 10 | Dungay Creek – Gowings Hill Rd   | 15.0                              | 18.7                                                | 5.3                             |

\*Inundation is defined as a depth of greater than 0.01m

# Time during pre-burst not included. Value indicates length of time after the beginning of the 1% AEP event.

Note: inundation times are based on the 1% AEP, 1440 min, TP4728 event, which is the critical river dominated event for the catchment. For tributaries a local catchment duration event may produce higher flood levels but shorter durations of inundation

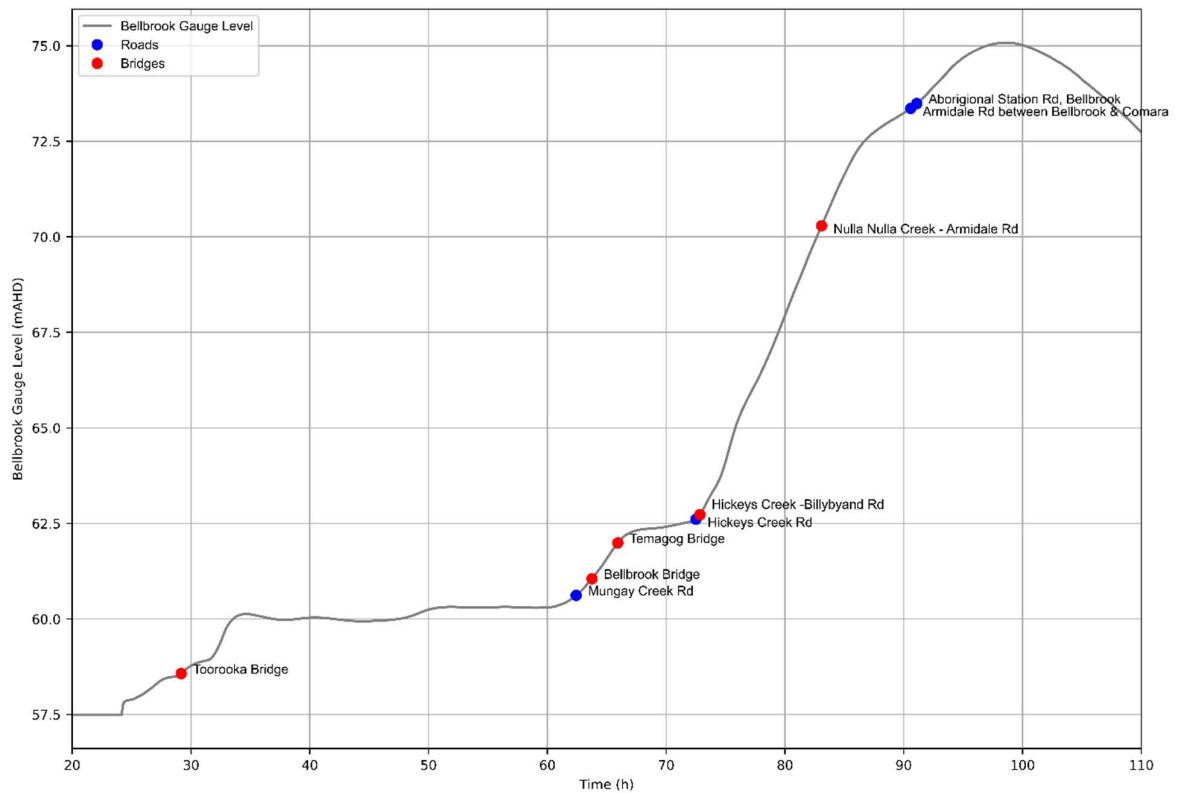


Diagram 7: Bellbrook Gauge – Road Low Point Cut Off at Gauge

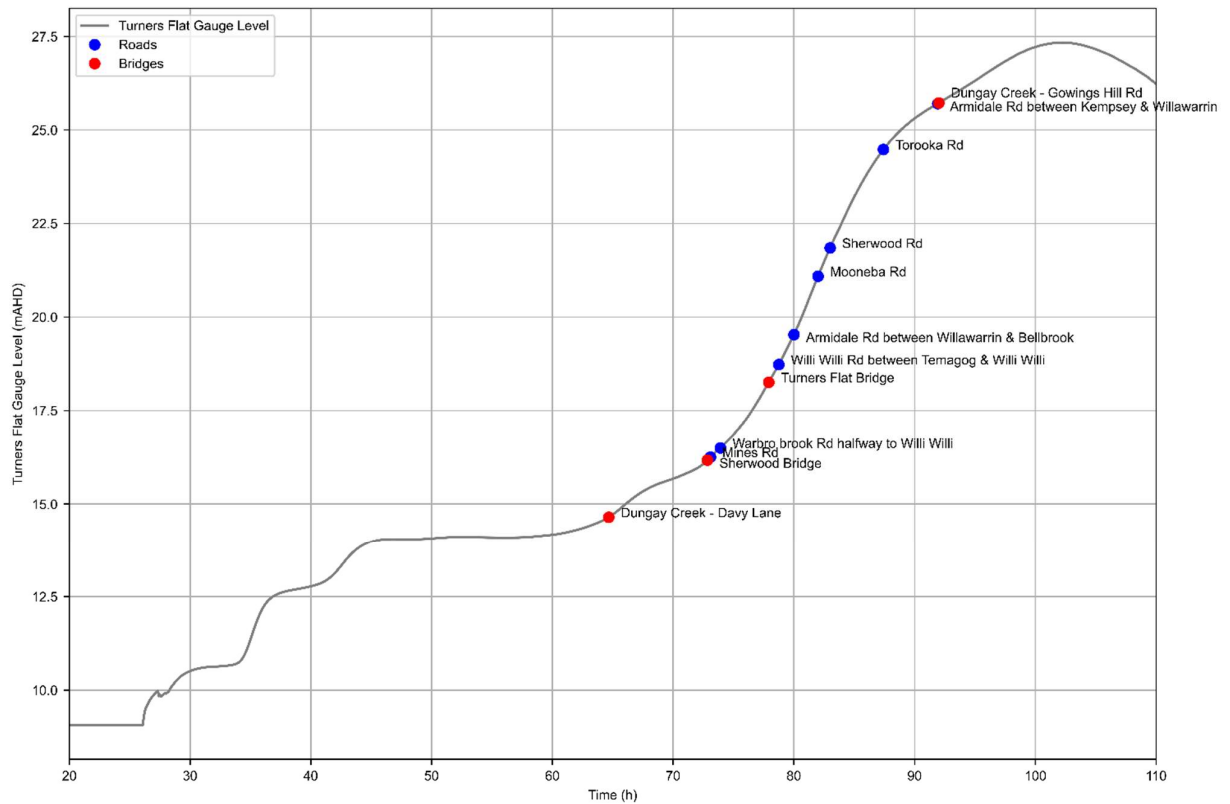


Diagram 8: Turners Flat Gauge – Road Low Point Cut Off at Gauge

## 9.1.Flood Emergency Response Classification

Flooding can result in obstruction of evacuation routes and the subsequent isolation of areas of the floodplain. The Flood Emergency Response Classification (FERC) provides a basis for understanding the varying nature, seriousness, and scale of these issues, with a particular emphasis on isolation, across the floodplain. The FERC for the study area was developed in accordance with the NSW Flood Risk Management Manual (Reference 15) and its accompanying guideline, EM01 – Support for Emergency Management Planning (Reference 17). The methodology (refer to Diagram 9) was applied for events to the PMF design event, and the classification results are presented in Figure 110. This information will be provided to the NSW State Emergency Services (NSW SES) upon completion of this project.

It is important to note that the FERC classification has been prepared based on existing development within the study area. It does not consider the classification that may pertain to new development on currently vacant land.

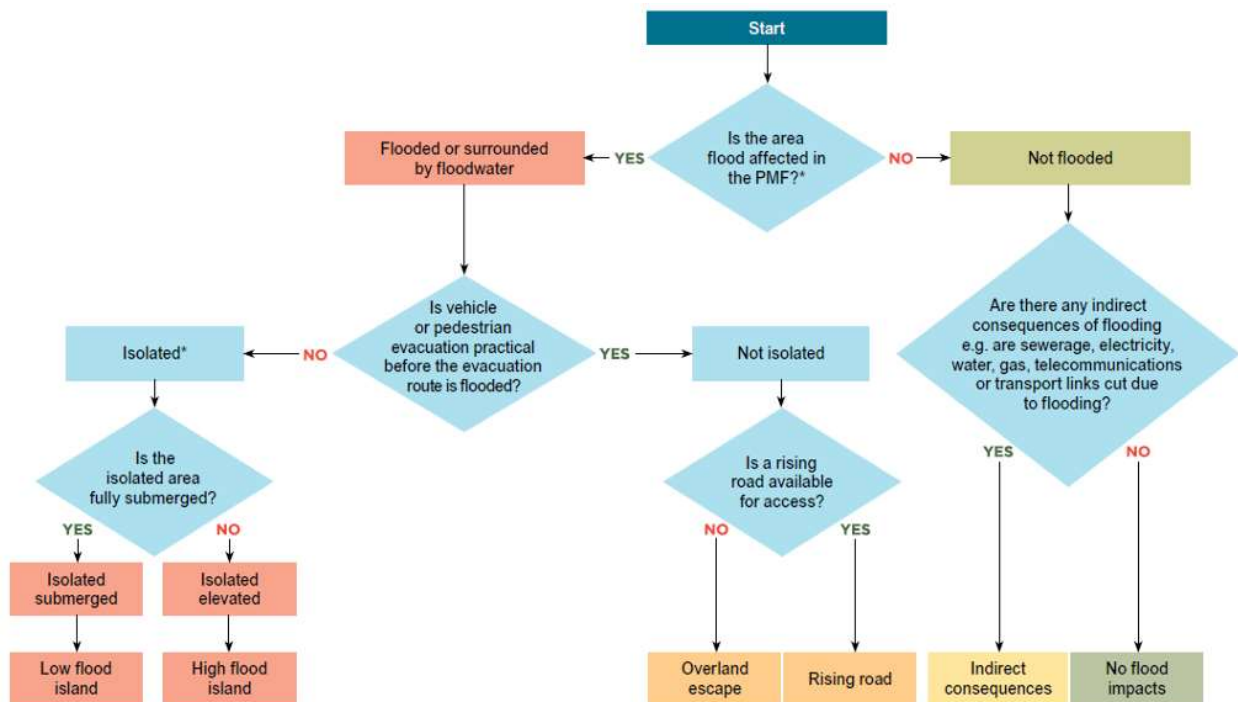


Diagram 9: Flow Chart for Determining Flood Emergency Response Classifications (Reference 17)

The classifications used are described below, taken directly from the Flood Risk Management Guideline (EM01).

- High Flood Island.** The flood island has land higher than the limit of flooding for the event being considered. During a flood these high islands are isolated from other areas of the community by floodwater, terrain, development, or infrastructure. However, there is an

opportunity for people to retreat to higher ground within the island, and therefore, the direct risk to life is reduced. The area may require resupply by boat or air if not evacuated before the road is cut. If it is not possible to provide adequate support (such as community and medical facilities) during the period of isolation, evacuation will have to take place before isolation occurs. Isolation without these services is more likely to result in fatal decisions to cross floodwaters.

- **Low Flood Island.** The flood island is lower than the limit of flooding for the event being considered. During a flood event the area initially becomes isolated by floodwater, terrain, development or infrastructure. If floodwater continues to rise after it is isolated, the land on the island will eventually be completely inundated by floodwaters. Evacuation of the community will be required prior to evacuation routes being closed as people left stranded on the island may drown.
- **Areas with Rising Road Access.** Areas where access roads rise steadily uphill and away from the rising floodwaters. The community will not be completely isolated before inundation reaches its maximum extent, even in the PMF. Evacuation can take place by vehicle or on foot along the road as floodwater advances. People should not be trapped unless they delay their evacuation from their homes, for example, people living in 2-storey homes may initially decide to stay but reconsider after water surrounds them. These communities contain low-lying areas from which people will be progressively evacuated to higher ground as the level of inundation increases. This inundation could be caused either by direct flooding from the river system or by localised flooding from creeks.
- **Area with Overland Escape Route.** Areas where escape from rising floodwater is possible by traversing overland to higher ground. The area may also have access roads to flood-free land that cross lower-lying flood prone land. Evacuation can take place by road only until access roads are closed by floodwater. Escape from rising floodwater after roads are cut is possible but involves traversing overland to higher ground. Anyone not able to walk out before access roads are cut must be reached by using boats and aircraft. If people cannot get out before inundation, rescue will most likely be from rooftops.
- **Not Flooded and Indirect Consequences.** These are areas which are outside the limit of flooding and therefore will not be inundated nor will they lose road access. However, they may be indirectly affected as a result of flood damaged infrastructure or due to the loss of transport links, electricity supply, water supply, sewage or telecommunications services and they may therefore require resupply or in the worst case, evacuation.

Figure 110 depicts the flood emergency response classifications for the Upper Macleay River catchment. Large areas of the study area are classified as Not Flooded or Indirect Consequences. The main issue faced in the region during an event is isolation. Residents are typically used to being cut off for multiple days. Isolated pockets of High flood island occur on large bends in the river. The majority of the floodplain is classified as low flood island.

## **10. CONCLUSIONS**

A detailed hydraulic model (TUFLOW) has been developed to quantify the flood behaviour of the upper Macleay River and its tributaries, making best use of the data currently available.

This model has been used to reproduce the historical flood behaviour from events in 2001 and 2011. The TUFLOW model has been used to define flood behaviour for a range of design events (20, 5, 1, 0.2, 0.05% AEP and Probable Maximum Flood).

Information to assist emergency response and flood planning constraint classification were undertaken. The model developed for the current study is suitable for further floodplain planning and use in setting planning levels within the study area.

It is recommended that data collection in future events target Upper Macleay River.

## **11. ACKNOWLEDGEMENTS**

This study was carried out by WMAwater and funded by Kempsey Shire Council and the NSW State Government. The assistance of the following in providing data and guidance to the study is gratefully acknowledged:

- Kempsey Shire Council
- NSW Department of Climate Change Energy, the Environment and Water
- The residents of the upper Macleay valley.

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Figures



## APPENDIX A. GLOSSARY

Taken from the Flood Risk Management Manual (2023)

|                                             |                                                                                                                                                                              |
|---------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Afflux</b>                               | Rise in water level in a waterway or flowpath caused by a structure, obstruction or impediment to flow.                                                                      |
| <b>Annual exceedance probability (AEP)</b>  | The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage                                                                 |
| <b>Astronomical tide</b>                    | The variation in sea level caused by the gravitational effects of (principally) the moon and sun.                                                                            |
| <b>Australian height datum (AHD)</b>        | A common national surface level datum often used as a referenced level for ground, flood and flood levels                                                                    |
| <b>Australian Rainfall and Runoff (ARR)</b> | A national guideline document, data and software suite that can be used for the estimation of design flood characteristics in Australia.                                     |
| <b>Average annual damage (AAD)</b>          | The average damage per year due to flooding that would occur in a nominated scenario in an area over a very long period of time.                                             |
| <b>Average recurrence interval (ARI)</b>    | The long-term average number of years between the occurrence of a flood equal to or larger in size than the selected event                                                   |
| <b>Catchment</b>                            | The area of land draining to a specific location                                                                                                                             |
| <b>Backwater flooding</b>                   | A mechanism by which upstream flooding is influenced by downstream conditions or controls.                                                                                   |
| <b>Catchment flooding</b>                   | Flooding due to prolonged or intense rainfall (e.g. severe thunderstorms, monsoonal rains in the tropics, tropical cyclones)                                                 |
| <b>Chance</b>                               | The likelihood of something happening that will have adverse or beneficial consequences                                                                                      |
| <b>Coastal inundation</b>                   | Inundation due to tidal or storm-driven coastal events, including storm surges in lower coastal waterways. This can be exacerbated by wind-wave generation from storm events |
| <b>Consent authority</b>                    | The authority or agency with the legislative power to determine the outcome of development and building applications                                                         |
| <b>Consequence</b>                          | The outcomes of an event or situation affecting objectives, expressed qualitatively or quantitatively                                                                        |
| <b>Continuing flood risk</b>                | Risk to existing and future development that may be reduced by EM measures                                                                                                   |
| <b>Defined flood event (DFE)</b>            | The flood event selected as a general standard for the management of flooding to development                                                                                 |
| <b>Design flood</b>                         | The flood selected as part of the FRM process that forms the basis for physical works to modify the impacts of flooding                                                      |
| <b>Development</b>                          | May be treated differently depending on the following categorisation:                                                                                                        |

|                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
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|                                                                      | <ul style="list-style-type: none"> <li>• <b>infill development:</b> the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under current land zoning</li> <li>• <b>new development:</b> development of a completely different nature to that associated with the former land-use (e.g. the urban subdivision of a previously rural area)</li> <li>• <b>redevelopment:</b> rebuilding in an area (e.g. as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale)</li> </ul>                                                                                                                                                                                                                                                                                                                                                |
| <b>Development control plan (DCP)</b>                                | See Environmental Planning and Assessment Act 1979                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Ecologically sustainable development (ESD)</b>                    | As outlined in the Local Government Act 1993.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Emergency management (EM)</b>                                     | A comprehensive approach to dealing with risks to the community arising from hazards. It is a systematic method for identifying, analysing, evaluating and managing these risks                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Emergency management plan (EMPLAN)</b>                            | The overarching EM arrangements for New South Wales, including the agreed roles and functions of various agencies. All NSW Government agencies with responsibilities and functions in disaster response and recovery contribute to this plan.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Emergency management response strategy (EM response strategy)</b> | A strategy identified by the combat agency typically used to plan, prepare for and respond to a hazard.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Events per year (EY)</b>                                          | Number of events per year.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Existing flood risk</b>                                           | The risk an existing community is exposed to as a result of its location on the floodplain                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Flash flood</b>                                                   | Flood that is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding that peaks within 6 hours of the causative rain.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Flood</b>                                                         | A natural phenomenon that occurs when water covers land that is normally dry. It may result from coastal inundation (excluding tsunamis) or catchment flooding, or a combination of both                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Flood classifications (used in flood warnings)</b>                | <ul style="list-style-type: none"> <li>• <b>Minor flooding</b> – Causes inconvenience. Low-lying areas next to watercourses are inundated. Minor roads may be closed and low-level bridges submerged. Flooding is usually below the floor level of dwellings and may require removal of stock and equipment from low-lying areas.</li> <li>• <b>Moderate flooding</b> – In addition to the above, the area of inundation is more substantial. Main traffic routes may be affected. Some buildings may be affected above the floor level. Evacuation may be required.</li> <li>• <b>Major flooding</b> – In addition to the above, extensive rural areas and/or urban areas are inundated. Many buildings may be affected above the floor level. Properties and towns are likely to be isolated and major rail and traffic routes closed. Evacuation of flood affected areas may be required. Utility services may be impacted.</li> </ul> |
| <b>Flood affected land</b>                                           | Equivalent to flood prone land                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

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| <b>Flood awareness</b>                                                | An appreciation of the likely effects of flooding, and a knowledge of the relevant flood warning, response and evacuation procedures facilitating prompt and effective community response to a flood threat      |
| <b>Flood constraints</b>                                              | Key constraints that flooding place on land                                                                                                                                                                      |
| <b>Flood damage</b>                                                   | The tangible (direct and indirect) and intangible costs (financial, opportunity costs, clean-up) of flooding                                                                                                     |
| <b>Flood education</b>                                                | Seeks to provide information to raise community awareness of flooding so as to enable individuals to understand how to manage themselves and their property in response to flood warnings                        |
| <b>Flood emergency response classification of communities (FERCC)</b> | Classification of the floodplain in consideration of the EM constraints and consequences.                                                                                                                        |
| <b>Flood evacuation</b>                                               | The movement of people from a place of danger to a place of relative safety, and their eventual return                                                                                                           |
| <b>Flood evacuation capability</b>                                    | The ability to safely evacuate to an area of relative safety within the effective warning time, having regard to the suitability and capacity of the route and the possible prevailing environmental conditions. |
| <b>Flood fringe areas</b>                                             | That part of the flood extents for the event remaining after the flood function areas of floodway and flood storage areas have been defined                                                                      |
| <b>Flood function</b>                                                 | The flood related functions of floodways, flood storage and flood fringe within the floodplain                                                                                                                   |
| <b>Flood hazard</b>                                                   | A flood that has the potential to cause harm or conditions with the potential to result in loss of life, injury and economic loss                                                                                |
| <b>Flood hazard categorisation</b>                                    | Categorisation of flood affected areas based on the degree of hazard that the flood conditions may present to people, vehicles and structures.                                                                   |
| <b>Flood impact and risk assessment (FIRA)</b>                        | A study to assess flood behaviour, constraints and risk, understand offsite flood impacts on property and the community resulting from the development, and flood risk to the development and its users          |
| <b>Flood liable land</b>                                              | Equivalent to flood prone land                                                                                                                                                                                   |
| <b>Flood mitigation standard</b>                                      | The design flood selected as part of the FRM process that forms the basis for physical works to modify the impacts of flooding.                                                                                  |
| <b>Flood (hydrologic and hydraulic) modelling</b>                     | Hydrologic and hydraulic computer models to simulate catchment processes of rainfall, run-off, stream flow and distribution of flows across the floodplain or similar                                            |
| <b>Flood plan (local or state)</b>                                    | A sub-plan of an EM plan that deals specifically with flooding; they can exist at state, zone and local levels                                                                                                   |
| <b>Flood planning area (FPA)</b>                                      | The area of land below the FPL                                                                                                                                                                                   |
| <b>Flood planning constraint categories (FPCCs)</b>                   | Categorisation of the floodplain into areas of different degrees and types of flood related constraints.                                                                                                         |

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| <b>Flood planning level (FPL)</b>  | The combination of the flood level from the DFE and freeboard selected for FRM purposes                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Flood prone land</b>            | Land susceptible to flooding by the PMF event                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Flood proofing</b>              | Measures incorporated in the design, construction or alteration of individual buildings or structures that are subject to flooding, to reduce structural damage and potentially, in some cases, reduce contents damage.                                                                                                                                                                                                                                                              |
| <b>Flood risk</b>                  | Risk is based on the consideration of the consequences of the full range of flood behaviour on communities and their social settings, and the natural and built environment                                                                                                                                                                                                                                                                                                          |
| <b>Flood risk management (FRM)</b> | The management of flood risk to communities                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Flood storage areas</b>         | Areas of the floodplain that are outside floodways which generally provide for temporary storage of floodwaters during the passage of a flood and where flood behaviour is sensitive to changes that impact on temporary storage of water during a flood                                                                                                                                                                                                                             |
| <b>Flood study</b>                 | <p>A comprehensive technical investigation of flood behaviour undertaken in accordance with the principles in this manual and consistent with associated guidelines</p> <p>A flood study defines the nature of flood behaviour and hazard across the floodplain by providing information on the extent, level and velocity of floodwaters, and on the distribution of flood flows considering the full range of flood events up to and including extreme events, such as the PMF</p> |
| <b>Flood warnings</b>              | Warnings issued when there is more certainty that flooding is expected, are more targeted and are issued for specific catchments                                                                                                                                                                                                                                                                                                                                                     |
| <b>Flood watches</b>               | Provide the community with early advice of a developing situation that may lead to flooding.                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Floodplain</b>                  | Equivalent to flood prone land                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Floodways</b>                   | Areas of the floodplain which generally convey a significant discharge of water during floods and are sensitive to changes that impact flow conveyance. They often align with naturally defined channels or form elsewhere in the floodplain                                                                                                                                                                                                                                         |
| <b>Flow</b>                        | The rate of flow of water measured in volume per unit time, for example, cubic metres per second ( $\text{m}^3/\text{s}$ )                                                                                                                                                                                                                                                                                                                                                           |
| <b>Freeboard</b>                   | A factor of safety typically used in relation to the setting of minimum floor levels or levee crest levels                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Frequency</b>                   | The measure of likelihood expressed as the number of occurrences of a specified event in a given time                                                                                                                                                                                                                                                                                                                                                                                |
| <b>FRM measures</b>                | Measures that can reduce flood risk                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>FRM options</b>                 | The FRM measures that might be feasible for the management of a particular area of the floodplain                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>FRM plan</b>                    | A management plan developed in accordance with the principles in this manual and its supporting guidelines                                                                                                                                                                                                                                                                                                                                                                           |

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| <b>FRM study</b>                                                        | A management study developed in accordance with the principles in this manual and its supporting guidelines                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Future flood risk</b>                                                | The risk future development and its users are exposed to as a result of its location on the floodplain                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Gauge height</b>                                                     | The height of a flood level at a particular water level gauge site related to a specified datum                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Habitable room</b>                                                   | <p>In a residential development – a room used for normal domestic activities that:</p> <ul style="list-style-type: none"><li>• includes a bedroom, living room, lounge room, music room, television room, kitchen, dining room, sewing room, study, playroom, family room, home theatre and sunroom</li><li>• includes a bedroom, living room, lounge room, music room, television room, kitchen, dining room, sewing room, study, playroom, family room, home theatre and sunroom</li></ul> <p>In an industrial or commercial situation – an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.</p> |
| <b>Hazard</b>                                                           | A source of potential harm or conditions that may result in loss of life, injury and economic loss due to flooding                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Hydraulics</b>                                                       | The study of water flow in waterways and flowpaths; in particular, the evaluation of flow parameters such as water level and velocity                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Hydrograph</b>                                                       | A graph that shows how the discharge or stage/flood level at any location varies with time during a flood.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Hydrology</b>                                                        | The study of the rainfall and run-off process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Integrated planning and reporting framework (IP&amp;R framework)</b> | The IP&R framework includes a suite of integrated plans that set out a vision and goals and strategic actions to achieve them. It involves a reporting structure to communicate progress to council and the community as well as a structured timeline for review to ensure the goals and actions are still relevant                                                                                                                                                                                                                                                                                                                                          |
| <b>Lifecycle costing</b>                                                | All of the costs associated with the project. This usually includes investigation, design, construction, operation, monitoring, maintenance, asset and performance management and, in some cases, renewal, upgrade, decommissioning and disposal of a management measure.                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Likelihood</b>                                                       | A qualitative description of probability and frequency                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Likelihood of occurrence</b>                                         | The likelihood that a specified event will occur                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Local environmental plan (LEP)</b>                                   | See Environmental Planning and Assessment Act 1979                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Local government area (LGA)</b>                                      | The area serviced by the local government council                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Local overland flooding (LOF)</b>                                    | Inundation by local run-off on its way to a waterway, rather than overbank flow from a waterway                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Local strategic planning statement (LSPS)</b>                        | Local strategic planning statements assist councils to implement the priorities set out in their community strategic plan and actions in regional and district plans                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |

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| <b>Loss</b>                                                   | Any negative consequence or adverse effect, financial or otherwise                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Mainstream flooding</b>                                    | Inundation resulting from overbank flow from a waterway rather than by local run-off.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Merit-based approach</b>                                   | Weights social, economic, ecological and cultural impacts of land-use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and wellbeing of the state's rivers and floodplains                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>NSW Floodplain Management Program</b>                      | The NSW Government's program of technical support and financial assistance to local councils to enable them to understand and manage their flood risk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>NSW Flood prone land policy</b>                            | The NSW Flood prone land policy included in the NSW Flood Risk Management Manual (2023)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Peak flow</b>                                              | The maximum flow occurring during a flood of a given annual exceedance probability.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Prevention, preparedness, response and recovery (PPRR)</b> | <p>Involves:</p> <ul style="list-style-type: none"> <li>• <b>prevention:</b> to eliminate or reduce the level of the risk or severity of emergencies</li> <li>• <b>preparedness:</b> enhances the capacity of agencies and communities to cope with the consequences of emergencies</li> <li>• <b>response:</b> to ensure the immediate consequences of emergencies to communities are minimized</li> <li>• <b>recovery:</b> measures that support individuals and communities affected by emergencies in the reconstruction of physical infrastructure and restoration of physical, emotional, environmental and economic wellbeing</li> </ul> |
| <b>Probability</b>                                            | A statistical measure of the expected chance of a flood                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Probable maximum flood (PMF)</b>                           | The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation (PMP), and where applicable, snow melt, coupled with the worst flood-producing catchment conditions                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Probable maximum precipitation (PMP)</b>                   | The greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long- term climatic trends (World Meteorological Organization 1986)                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Rainfall intensity</b>                                     | The rate at which rain falls, typically measured in millimetres per hour (mm/h)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Residual flood risk</b>                                    | The risk to the existing and future community that remains with FRM, EM and land-use planning measures in place to address flood risk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Risk</b>                                                   | 'The effect of uncertainty on objectives' (ISO 2018)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Risk analysis</b>                                          | The systematic use of available information to determine how often specified (flood) events occur and the magnitude of their likely consequences                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Run-off</b>                                                | The amount of rainfall that ends up as streamflow, also known as rainfall excess                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

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|----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Severe thunderstorm warnings</b>          | Warnings provided to communities of the threat of dangerous thunderstorms. They are issued when a severe thunderstorm is occurring or likely to occur.                                                                                                                                                        |
| <b>Severe weather warnings</b>               | Warnings provided for potentially hazardous or dangerous weather that is not solely related to severe thunderstorms, tropical cyclones or bushfires. They are issued whenever severe weather is occurring in an area or is expected to develop or move into an area.                                          |
| <b>State environmental planning policy</b>   | See Environmental Planning and Assessment Act 1979                                                                                                                                                                                                                                                            |
| <b>Scenario</b>                              | A scenario may relate to current, historical or assumed future floodplain, catchment and climate conditions                                                                                                                                                                                                   |
| <b>Stage</b>                                 | Equivalent to water level; measured with reference to a specified datum                                                                                                                                                                                                                                       |
| <b>Stage hydrograph</b>                      | A graph that shows how the water levels at a particular location change with time during a flood. It must be referenced to a particular datum.                                                                                                                                                                |
| <b>Storm surge</b>                           | The increases in coastal water levels above predicted astronomical tide level (i.e. tidal anomaly) resulting from a range of location-dependent factors                                                                                                                                                       |
| <b>Survey plan</b>                           | A plan prepared by a registered surveyor.                                                                                                                                                                                                                                                                     |
| <b>Temporal pattern</b>                      | The variation of rainfall intensity with time during a rainfall event.                                                                                                                                                                                                                                        |
| <b>Tidal anomaly</b>                         | The difference between recorded storm surge levels and predicted astronomical tide level.                                                                                                                                                                                                                     |
| <b>Tipping point</b>                         | The critical point in a situation, process or system beyond which a significant and often unstoppable effect or change takes place.                                                                                                                                                                           |
| <b>Total warning system (TWS)</b>            | A total warning system describes a means of collecting information about an impending emergency, understanding the nature of the threat, communicating that information to those likely to be affected by it, and facilitating protective action and timely response.                                         |
| <b>Total warning system for flood (TWSF)</b> | An integrated system defining the level of flooding at which a warning will be initiated, the physical means by which it will be relayed, and the persons to whom it will be given. The system includes all necessary hardware such as water level actuators, and radio transmitting and receiving equipment. |
| <b>Velocity</b>                              | The speed of floodwaters, measured in metres per second (m/s)                                                                                                                                                                                                                                                 |
| <b>Vulnerability</b>                         | The degree of susceptibility and resilience of a community, its social setting, and the built environment to flooding                                                                                                                                                                                         |
| <b>Water surface profile</b>                 | A graph showing the flood stage at any given location along a watercourse at a particular time.                                                                                                                                                                                                               |
| <b>Wave set-up</b>                           | The increase in water levels in coastal waters (within the breaker zone) caused by waves transporting water shoreward. The zone of wave set-up against the shore is balanced by a zone of wave 'set-down' (i.e. reduced water levels) seawards of the breaker zone.                                           |

**Wind fetch**

The horizontal distance in the direction of wind over which wind waves are generated.

**Wind set-up**

The increase in water levels in coastal and inland waterways caused by the wind driving the water shoreward and 'piling it up' against the shore.



## APPENDIX B. ANNUAL MAXIMUM SERIES

| Year | Level at Bellbrook |
|------|--------------------|
| 1949 | 75.62              |
| 1950 | 76.15              |
| 1952 | 71.43              |
| 1954 | 69.63              |
| 1959 | 68.15              |
| 1962 | 66.55              |
| 1963 | 73.95              |
| 1967 | 68.64              |
| 1968 | 65.1               |
| 1972 | 65.05              |
| 1974 | 66.07              |
| 1974 | 65.51              |
| 1975 | 64.18              |
| 1976 | 65.95              |
| 1977 | 65.18              |
| 1978 | 63.65              |
| 1980 | 65.6               |
| 1989 | 64.74              |
| 2001 | 71.2               |
| 2009 | 69.2               |
| 2011 | 69.05              |

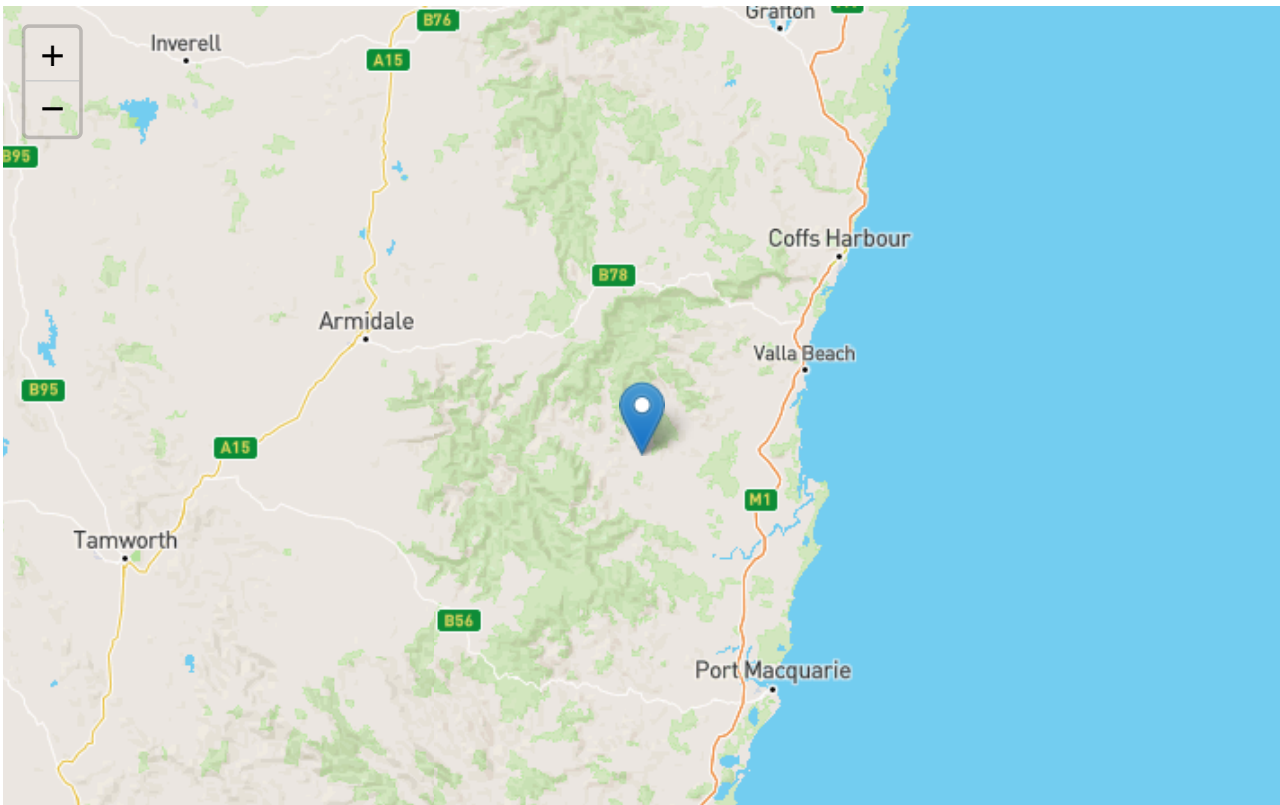
| year | Level at Turners Flat |
|------|-----------------------|
| 1949 | 30.09                 |
| 1963 | 25.59                 |
| 1967 | 21.58                 |
| 1972 | 19.01                 |
| 1974 | 19.248                |
| 1974 | 20.29                 |
| 1975 | 18.16                 |
| 1977 | 18.89                 |
| 1978 | 17.98                 |
| 2001 | 23.9                  |
| 2009 | 22.33                 |
| 2011 | 21.69                 |



# Australian Rainfall & Runoff Data Hub - Results

## Input Data

|                                                         |         |
|---------------------------------------------------------|---------|
| Longitude                                               | 152.507 |
| Latitude                                                | -30.819 |
| 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     | South East Coast (NSW) |
| River Number | 6                      |
| River Name   | Macleay River          |

Layer Info

|               |                        |
|---------------|------------------------|
| Time Accessed | 19 August 2024 04:43PM |
| Version       | 2016_v1                |

ARF Parameters

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

| Zone             | a     | b     | c     | d    | e       | f    | g     | h     | i       |
|------------------|-------|-------|-------|------|---------|------|-------|-------|---------|
| East Coast North | 0.327 | 0.241 | 0.448 | 0.36 | 0.00096 | 0.48 | -0.21 | 0.012 | -0.0013 |

Short Duration ARF

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

Layer Info

|               |                        |
|---------------|------------------------|
| Time Accessed | 19 August 2024 04:43PM |
| 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                             | 10461.0 |
| Storm Initial Losses (mm)      | 45.0    |
| Storm Continuing Losses (mm/h) | 4.4     |

## Layer Info

|               |                        |
|---------------|------------------------|
| Time Accessed | 19 August 2024 04:43PM |
| Version       | 2016_v1                |

## Temporal Patterns | Download (.zip) (static/temporal\_patterns/TP/ECsouth.zip)

|       |                  |
|-------|------------------|
| code  | ECsouth          |
| Label | East Coast South |

## Layer Info

|               |                        |
|---------------|------------------------|
| Time Accessed | 19 August 2024 04:43PM |
| Version       | 2016_v2                |

## Areal Temporal Patterns | Download (.zip) (./static/temporal\_patterns/Areal/Areal\_ECsouth.zip)

|           |                  |
|-----------|------------------|
| code      | ECsouth          |
| arealabel | East Coast South |

## Layer Info

|               |                        |
|---------------|------------------------|
| Time Accessed | 19 August 2024 04:43PM |
| Version       | 2016_v2                |

## BOM IFDs

Click here ([http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate\\_type=dd&latitude=-30.81919&longitude=152.5072&sdmin=true&sdhr=true&sdday=true&user\\_label=](http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-30.81919&longitude=152.5072&sdmin=true&sdhr=true&sdday=true&user_label=)) to obtain the IFD depths for catchment centroid from the BoM website

## Layer Info

|               |                        |
|---------------|------------------------|
| Time Accessed | 19 August 2024 04:43PM |
|---------------|------------------------|

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)       | 1.4<br>(0.043)  | 1.6<br>(0.037)  | 1.8<br>(0.034)  | 1.9<br>(0.032)  | 2.2<br>(0.032)  | 2.5<br>(0.032)  |
| 90 (1.5)       | 0.8<br>(0.023)  | 1.4<br>(0.029)  | 1.8<br>(0.031)  | 2.2<br>(0.032)  | 6.6<br>(0.081)  | 10.0<br>(0.108) |
| 120 (2.0)      | 1.8<br>(0.045)  | 2.5<br>(0.045)  | 2.9<br>(0.045)  | 3.4<br>(0.044)  | 12.1<br>(0.132) | 18.5<br>(0.178) |
| 180 (3.0)      | 2.4<br>(0.052)  | 7.3<br>(0.115)  | 10.6<br>(0.139) | 13.7<br>(0.153) | 26.5<br>(0.245) | 36.1<br>(0.292) |
| 360 (6.0)      | 12.0<br>(0.195) | 24.5<br>(0.285) | 32.9<br>(0.316) | 40.8<br>(0.332) | 48.2<br>(0.323) | 53.8<br>(0.315) |
| 720 (12.0)     | 14.5<br>(0.171) | 27.8<br>(0.228) | 36.5<br>(0.246) | 45.0<br>(0.255) | 55.9<br>(0.262) | 64.1<br>(0.264) |
| 1080 (18.0)    | 12.1<br>(0.117) | 22.5<br>(0.149) | 29.3<br>(0.159) | 35.9<br>(0.164) | 47.3<br>(0.180) | 55.9<br>(0.188) |
| 1440 (24.0)    | 4.2<br>(0.036)  | 13.7<br>(0.079) | 19.9<br>(0.093) | 25.9<br>(0.102) | 31.8<br>(0.105) | 36.1<br>(0.105) |
| 2160 (36.0)    | 4.4<br>(0.031)  | 12.2<br>(0.058) | 17.3<br>(0.067) | 22.3<br>(0.073) | 29.7<br>(0.081) | 35.3<br>(0.086) |
| 2880 (48.0)    | 0.2<br>(0.001)  | 4.7<br>(0.020)  | 7.7<br>(0.026)  | 10.5<br>(0.030) | 17.3<br>(0.042) | 22.4<br>(0.049) |
| 4320 (72.0)    | 0.0<br>(0.000)  | 0.2<br>(0.001)  | 0.3<br>(0.001)  | 0.5<br>(0.001)  | 6.6<br>(0.014)  | 11.2<br>(0.022) |

Layer Info

|               |                                                                                                                      |
|---------------|----------------------------------------------------------------------------------------------------------------------|
| Time Accessed | 19 August 2024 04:43PM                                                                                               |
| 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<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |
| 90 (1.5)       | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |
| 120 (2.0)      | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |
| 180 (3.0)      | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |
| 360 (6.0)      | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |
| 720 (12.0)     | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |
| 1080 (18.0)    | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |
| 1440 (24.0)    | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |
| 2160 (36.0)    | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |
| 2880 (48.0)    | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |
| 4320 (72.0)    | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |

Layer Info

|               |                                                                                                                      |
|---------------|----------------------------------------------------------------------------------------------------------------------|
| Time Accessed | 19 August 2024 04:43PM                                                                                               |
| 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<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |
| 90 (1.5)       | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |
| 120 (2.0)      | 0.0<br>(0.000) | 0.1<br>(0.001) | 0.1<br>(0.002) | 0.2<br>(0.002) | 0.4<br>(0.004) | 0.5<br>(0.005) |
| 180 (3.0)      | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 1.1<br>(0.010) | 1.8<br>(0.015) |
| 360 (6.0)      | 0.0<br>(0.000) | 2.9<br>(0.033) | 4.7<br>(0.046) | 6.6<br>(0.053) | 7.4<br>(0.049) | 8.0<br>(0.047) |
| 720 (12.0)     | 0.2<br>(0.002) | 3.3<br>(0.027) | 5.4<br>(0.036) | 7.3<br>(0.042) | 5.6<br>(0.026) | 4.3<br>(0.018) |
| 1080 (18.0)    | 0.0<br>(0.000) | 3.0<br>(0.020) | 5.1<br>(0.027) | 7.0<br>(0.032) | 7.7<br>(0.029) | 8.3<br>(0.028) |
| 1440 (24.0)    | 0.0<br>(0.000) | 0.3<br>(0.002) | 0.5<br>(0.002) | 0.7<br>(0.003) | 4.3<br>(0.014) | 7.1<br>(0.021) |
| 2160 (36.0)    | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.1<br>(0.000) | 0.1<br>(0.000) | 1.4<br>(0.004) | 2.3<br>(0.006) |
| 2880 (48.0)    | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.8<br>(0.002) | 1.5<br>(0.003) |
| 4320 (72.0)    | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) | 0.0<br>(0.000) |

Layer Info

|               |                                                                                                                      |
|---------------|----------------------------------------------------------------------------------------------------------------------|
| Time Accessed | 19 August 2024 04:43PM                                                                                               |
| 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)       | 19.4<br>(0.594) | 20.2<br>(0.461) | 20.7<br>(0.401) | 21.2<br>(0.356)  | 24.5<br>(0.348)  | 27.0<br>(0.341)  |
| 90 (1.5)       | 17.9<br>(0.483) | 24.1<br>(0.484) | 28.3<br>(0.479) | 32.3<br>(0.471)  | 50.7<br>(0.620)  | 64.6<br>(0.697)  |
| 120 (2.0)      | 21.5<br>(0.531) | 32.7<br>(0.596) | 40.1<br>(0.614) | 47.2<br>(0.620)  | 74.6<br>(0.815)  | 95.1<br>(0.914)  |
| 180 (3.0)      | 46.4<br>(0.996) | 48.6<br>(0.762) | 50.1<br>(0.656) | 51.5<br>(0.576)  | 91.7<br>(0.848)  | 121.8<br>(0.986) |
| 360 (6.0)      | 57.0<br>(0.929) | 76.6<br>(0.891) | 89.6<br>(0.860) | 102.0<br>(0.830) | 124.9<br>(0.836) | 142.0<br>(0.831) |
| 720 (12.0)     | 43.1<br>(0.508) | 67.0<br>(0.551) | 82.9<br>(0.558) | 98.2<br>(0.557)  | 117.6<br>(0.551) | 132.2<br>(0.544) |
| 1080 (18.0)    | 47.2<br>(0.456) | 72.9<br>(0.485) | 90.0<br>(0.489) | 106.4<br>(0.487) | 113.1<br>(0.430) | 118.2<br>(0.397) |
| 1440 (24.0)    | 30.3<br>(0.255) | 53.0<br>(0.305) | 68.0<br>(0.319) | 82.5<br>(0.326)  | 91.6<br>(0.302)  | 98.4<br>(0.287)  |
| 2160 (36.0)    | 26.4<br>(0.185) | 42.5<br>(0.202) | 53.2<br>(0.206) | 63.5<br>(0.207)  | 85.3<br>(0.234)  | 101.6<br>(0.248) |
| 2880 (48.0)    | 15.8<br>(0.098) | 32.8<br>(0.138) | 44.0<br>(0.151) | 54.8<br>(0.159)  | 71.8<br>(0.175)  | 84.6<br>(0.185)  |
| 4320 (72.0)    | 1.5<br>(0.008)  | 12.7<br>(0.047) | 20.1<br>(0.060) | 27.1<br>(0.069)  | 49.4<br>(0.106)  | 66.1<br>(0.127)  |

Layer Info

|               |                                                                                                                      |
|---------------|----------------------------------------------------------------------------------------------------------------------|
| Time Accessed | 19 August 2024 04:43PM                                                                                               |
| 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)       | 82.7<br>(2.533)  | 64.5<br>(1.473)  | 52.4<br>(1.016)  | 40.9<br>(0.686)  | 99.6<br>(1.413)  | 143.7<br>(1.813) |
| 90 (1.5)       | 68.6<br>(1.856)  | 70.3<br>(1.410)  | 71.4<br>(1.208)  | 72.4<br>(1.057)  | 107.6<br>(1.314) | 134.0<br>(1.446) |
| 120 (2.0)      | 79.3<br>(1.956)  | 107.8<br>(1.963) | 126.7<br>(1.939) | 144.9<br>(1.903) | 209.3<br>(2.289) | 257.7<br>(2.479) |
| 180 (3.0)      | 124.6<br>(2.676) | 136.8<br>(2.145) | 144.9<br>(1.897) | 152.7<br>(1.707) | 216.7<br>(2.004) | 264.7<br>(2.143) |
| 360 (6.0)      | 103.9<br>(1.692) | 127.0<br>(1.477) | 142.3<br>(1.367) | 157.0<br>(1.277) | 206.7<br>(1.384) | 243.8<br>(1.427) |
| 720 (12.0)     | 94.0<br>(1.109)  | 134.0<br>(1.101) | 160.5<br>(1.081) | 185.9<br>(1.055) | 202.7<br>(0.950) | 215.4<br>(0.887) |
| 1080 (18.0)    | 87.3<br>(0.844)  | 128.0<br>(0.852) | 154.9<br>(0.842) | 180.8<br>(0.827) | 191.7<br>(0.728) | 199.8<br>(0.670) |
| 1440 (24.0)    | 90.6<br>(0.762)  | 119.4<br>(0.686) | 138.5<br>(0.649) | 156.8<br>(0.619) | 180.7<br>(0.595) | 198.7<br>(0.580) |
| 2160 (36.0)    | 80.7<br>(0.564)  | 99.9<br>(0.474)  | 112.7<br>(0.436) | 124.9<br>(0.408) | 156.2<br>(0.428) | 179.7<br>(0.439) |
| 2880 (48.0)    | 47.1<br>(0.293)  | 71.4<br>(0.301)  | 87.4<br>(0.300)  | 102.8<br>(0.298) | 133.2<br>(0.325) | 156.0<br>(0.341) |
| 4320 (72.0)    | 41.0<br>(0.222)  | 47.5<br>(0.175)  | 51.9<br>(0.156)  | 56.0<br>(0.142)  | 87.1<br>(0.187)  | 110.4<br>(0.212) |

Layer Info

|               |                                                                                                                      |
|---------------|----------------------------------------------------------------------------------------------------------------------|
| Time Accessed | 19 August 2024 04:43PM                                                                                               |
| 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 | 0.869 (4.3%) | 0.783 (3.9%)  | 0.983 (4.9%)  |
| 2040 | 1.057 (5.3%) | 1.014 (5.1%)  | 1.349 (6.8%)  |
| 2050 | 1.272 (6.4%) | 1.236 (6.2%)  | 1.773 (9.0%)  |
| 2060 | 1.488 (7.5%) | 1.458 (7.4%)  | 2.237 (11.5%) |
| 2070 | 1.676 (8.5%) | 1.691 (8.6%)  | 2.722 (14.2%) |
| 2080 | 1.810 (9.2%) | 1.944 (9.9%)  | 3.209 (16.9%) |
| 2090 | 1.862 (9.5%) | 2.227 (11.5%) | 3.679 (19.7%) |

Layer Info

|               |                                                                                                                                                          |
|---------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Time Accessed | 19 August 2024 04:43PM                                                                                                                                   |
| 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)       | 31.3 | 15.8 | 15.1 | 16.1 | 15.8 | 11.6 |
| 90 (1.5)       | 31.8 | 17.0 | 15.7 | 15.2 | 13.9 | 8.4  |
| 120 (2.0)      | 29.6 | 16.2 | 14.3 | 13.5 | 11.6 | 7.4  |
| 180 (3.0)      | 23.7 | 15.0 | 14.5 | 13.5 | 10.4 | 4.5  |
| 360 (6.0)      | 20.8 | 14.1 | 13.1 | 10.8 | 10.5 | 3.7  |
| 720 (12.0)     | 23.8 | 17.2 | 15.7 | 14.1 | 14.6 | 3.9  |
| 1080 (18.0)    | 25.6 | 19.1 | 18.5 | 15.2 | 16.7 | 4.5  |
| 1440 (24.0)    | 30.6 | 23.4 | 22.9 | 18.5 | 20.1 | 6.8  |
| 2160 (36.0)    | 33.2 | 27.2 | 25.9 | 21.8 | 23.0 | 9.6  |
| 2880 (48.0)    | 39.2 | 31.3 | 29.7 | 25.8 | 26.6 | 10.4 |
| 4320 (72.0)    | 42.8 | 37.2 | 36.1 | 40.0 | 28.6 | 11.6 |

Layer Info

|               |                        |
|---------------|------------------------|
| Time Accessed | 19 August 2024 04:43PM |
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|                |         |
|----------------|---------|
| <b>Version</b> | 2018_v1 |
|----------------|---------|

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|             |                                                                                                                                                                                                                                                                                                                                                                                                                          |
|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Note</b> | 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 \(downloads/cae790ce-07e2-4b49-ba70-6d4717ccee89.txt\)](#)

[Download JSON \(downloads/2905abf1-4bc1-4a5a-9988-d32728fd3d5a.json\)](#)

[Generating PDF... \(downloads/39fe7fa2-d4d8-45e5-85ec-2c63147e1493.pdf\)](#)

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Figure D1  
Hydrological Modelling Results  
Box Plots  
20% AEP Event - Bellbrook

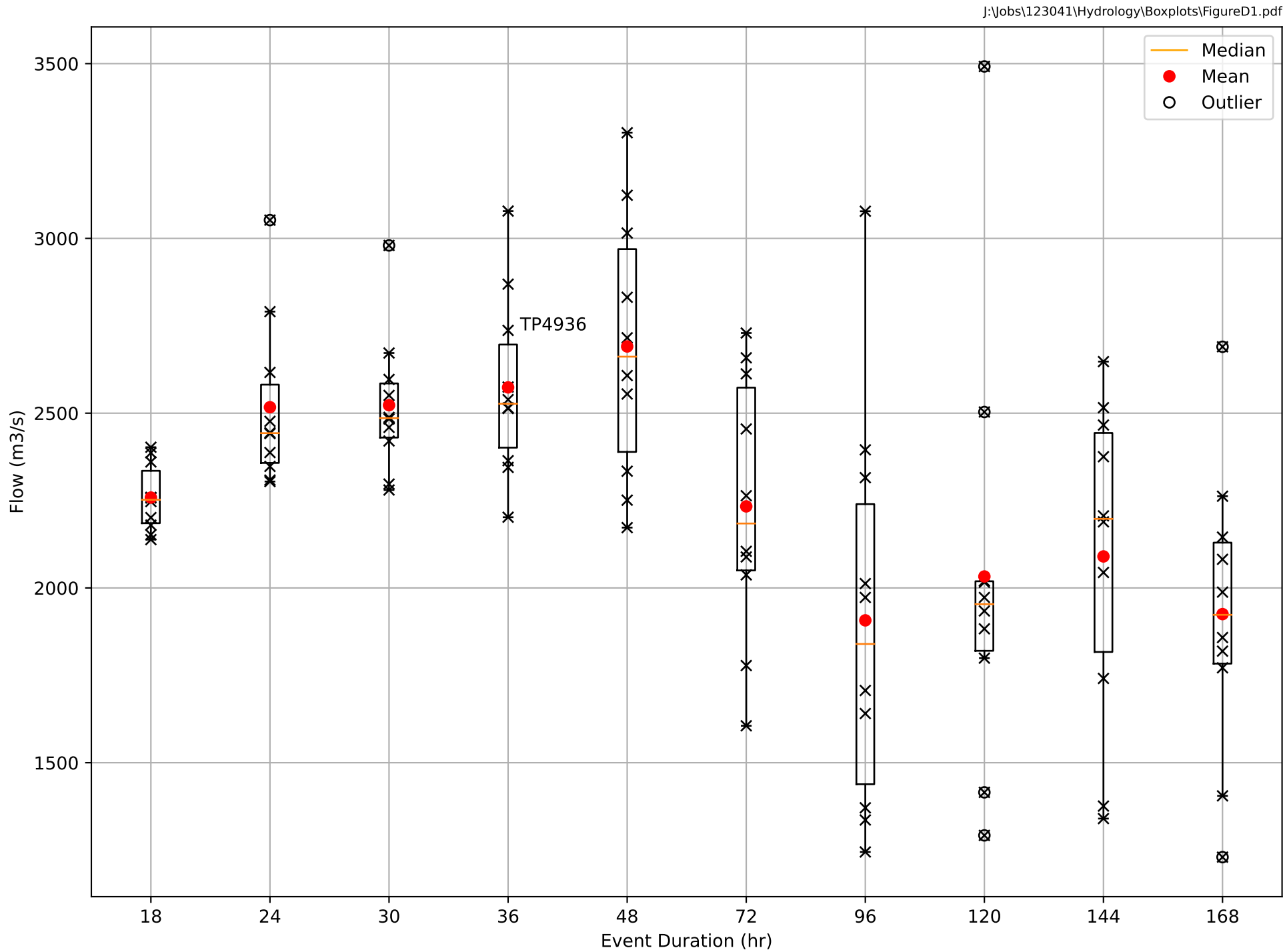


Figure D2  
Hydrological Modelling Results  
Box Plots  
5% AEP Event - Bellbrook

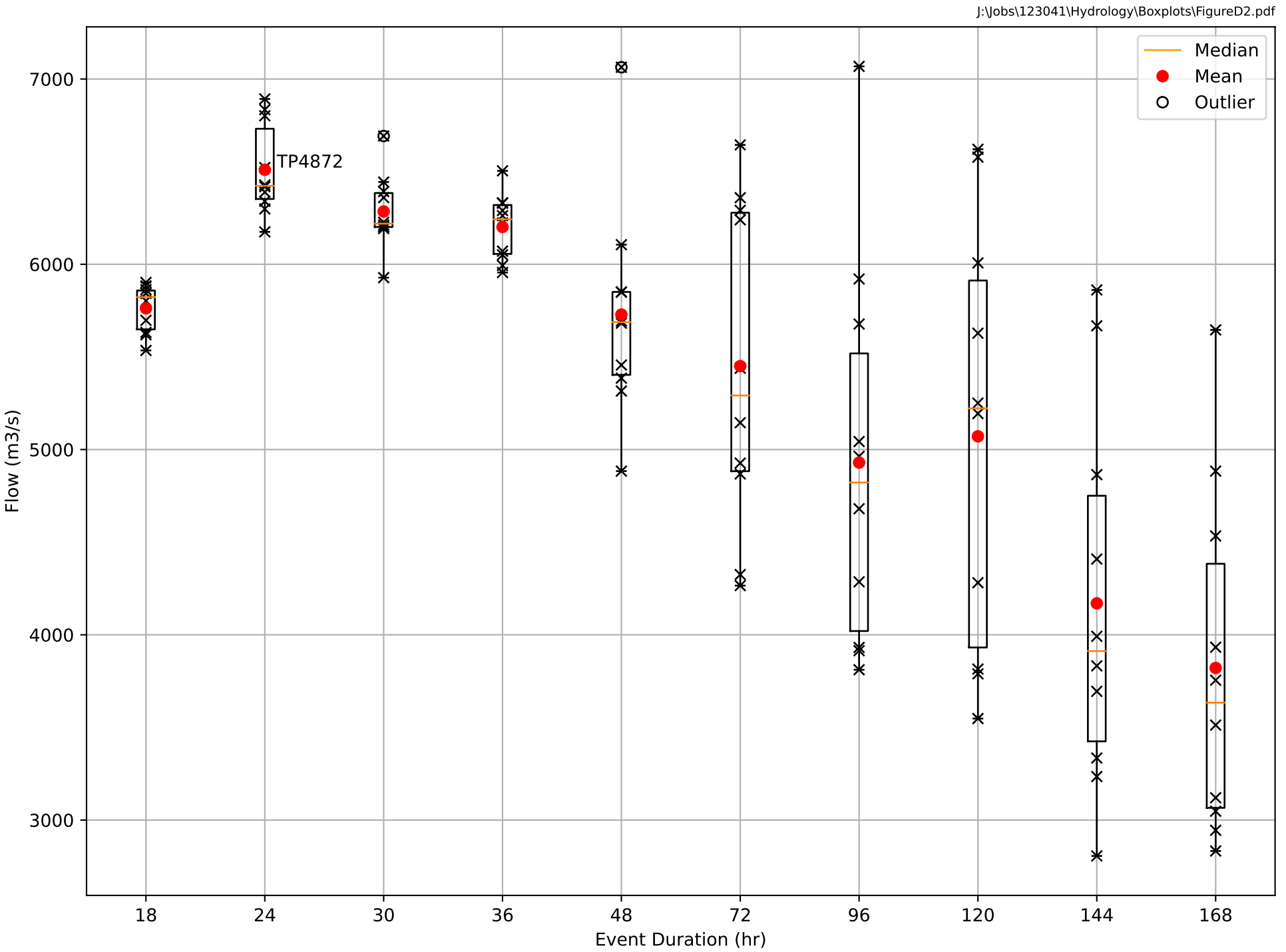


Figure D3  
Hydrological Modelling Results  
Box Plots  
1% AEP Event - Bellbrook

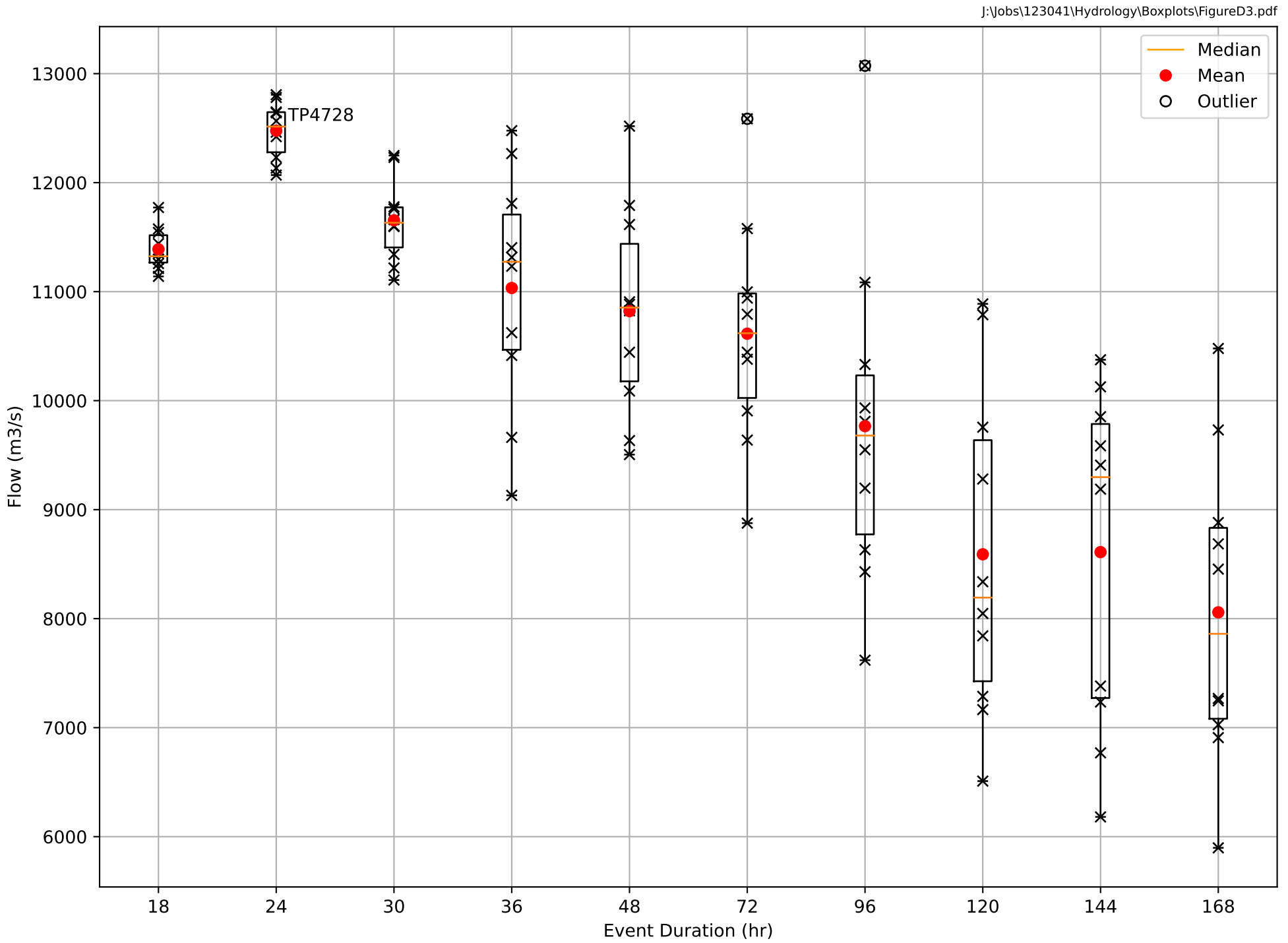
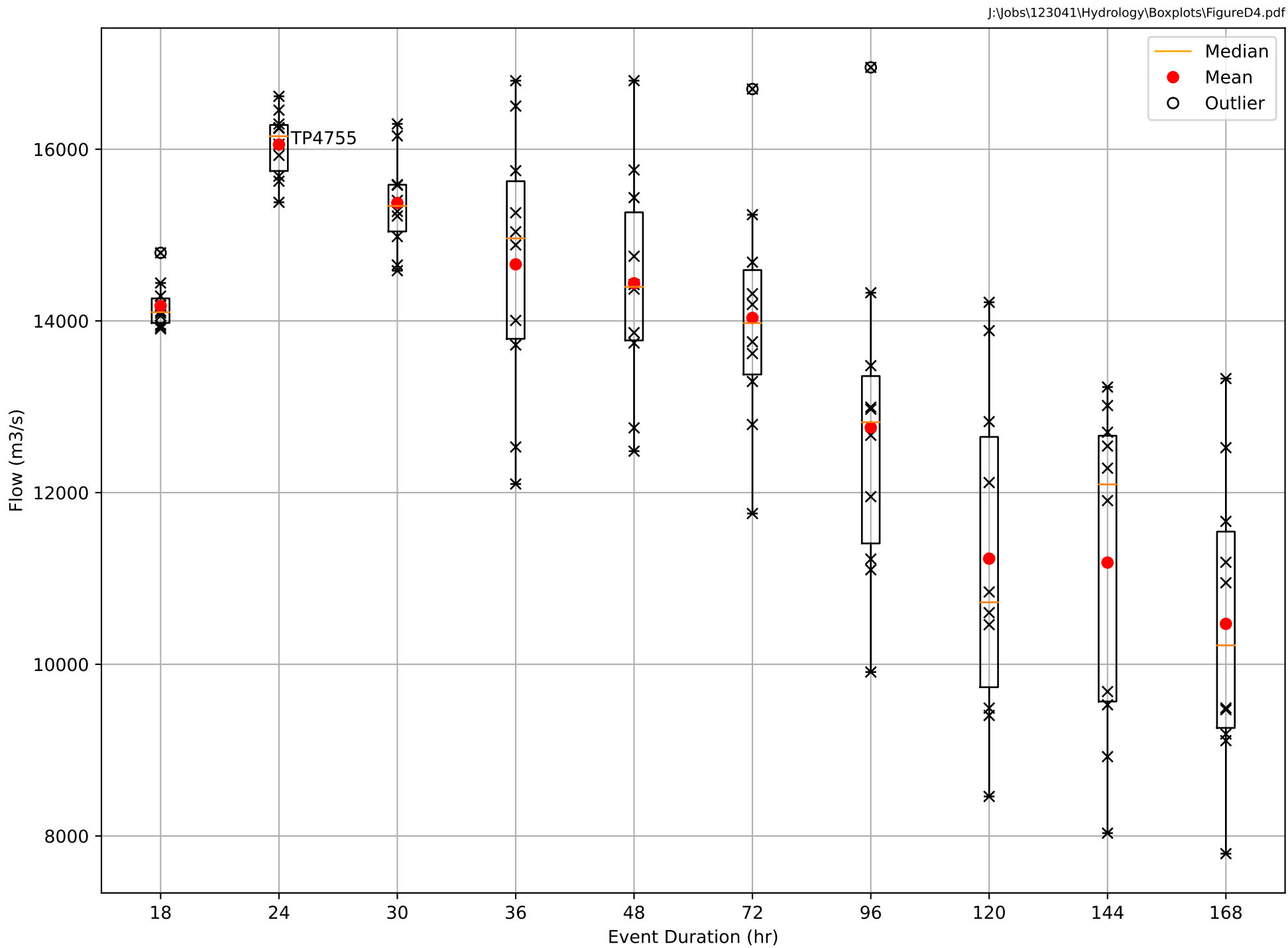


Figure D4  
Hydrological Modelling Results  
Box Plots  
1 in 500AEP Event - Bellbrook



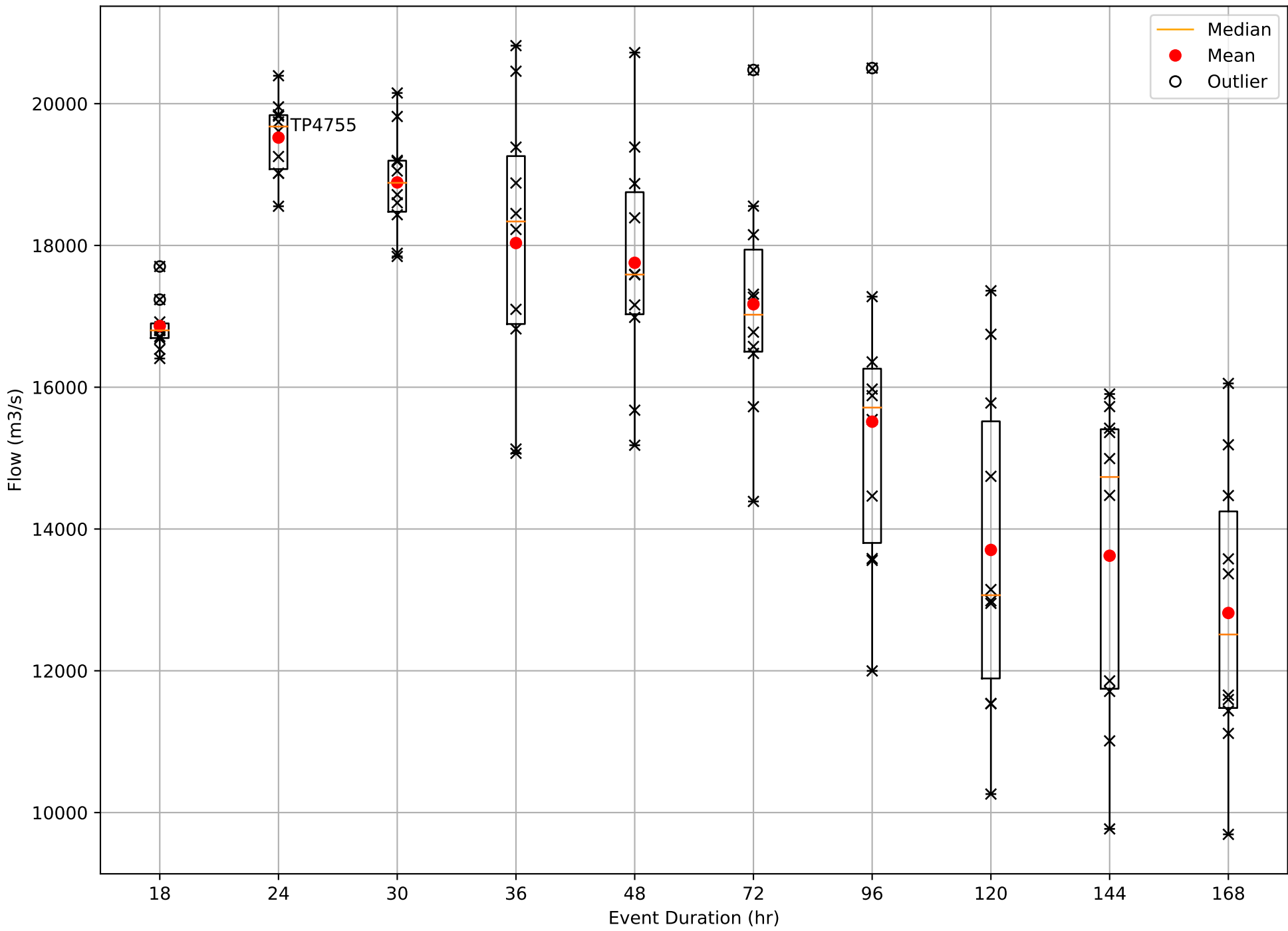


Figure D5  
Hydrological Modelling Results  
Box Plots  
1 in 2000AEP Event - Bellbrook