Marong Flood Study

Final Report - November 2018

North Central CMA has produced this study in response to an action identified in the:

Regional Floodplain Management Strategy
Everyone has a role to play in preparing for floods

NORTH CENTRAL
Catchment Management Authority
Connecting Rivers, Landscapes, People

Acknowledgement of Country

The North Central Catchment Management Authority acknowledges Aboriginal Traditional Owners within the region, their rich culture and spiritual connection to Country. We also recognise and acknowledge the contribution and interest of Aboriginal people and organisations in land and natural resource management.

Project Details

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Front cover photo: Bullock Creek at Salis Road on the 28 November 2010 (Bronwyn and Mike Perry)

North Central Catchment Management Authority acknowledges the City of Greater Bendigo and VicRoads for providing information regarding the hydraulic structures for this report.

Glossary of Terms

Annual Exceedance Probability (AEP)	The likelihood of occurrence of a flood of a given size or greater occurring in any one year, usually expressed as a percentage. For example, if a peak flood flow of 500m^3/s has an AEP of 5%, it means that there is a 5% (one-in-20) chance of a flow of 500m^3/s or greater occurring in any given year.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Australian Rainfall and Runoff (ARR)	ARR is a national guideline for the estimation of design flood characteristics in Australia published by Engineers Australia. ARR aims to provide reliable estimates of flood risk to ensure that development does not occur in high risk areas and that infrastructure is appropriately designed. The edition is currently being revised.
Average Recurrence Interval (ARI)	A statistical estimate of the average number of years between floods of a given size or larger than a selected event. For example, floods with a flow as great as or greater than the 20-year ARI (5% AEP) flood event will occur, on average, once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. See also Annual Exceedance Probability.
Catchment	The area of land draining to a particular site. It is related to a specific location and includes the catchment of the main waterway as well as any tributary streams.
DEM	Digital Elevation Model – a three-dimensional computer representation of terrain.
Design Flood	A hypothetical flood representing a given probability generally based on some form of statistical analysis. An average recurrence interval (ARI) or exceedance probability (AEP) is attributed to the estimate.
Flood	A natural phenomenon that occurs when water covers land that is normally dry. It may result from coastal or catchment flooding, or a combination of both.
Flood Frequency Analysis (FFA)	A statistical analysis of observed flood magnitudes to determine the probability of a given flood magnitude.
Flood Hazard	Describes the potential of flooding to cause harm or damage. Flood hazard is computed by multiplying flood depth by flood velocity.
Floodplain	An area of land that is subject to inundation by floods up to, and including, the largest probable flood event.
Flow	The volume of water which passes per unit time. Flow or discharge is measured in volume per unit time, for example, megalitres per day (ML/day) or cubic metres per second (m3/sec). Flow is different from the

	velocity of flow, which is a measure of how fast the water is moving, for example, metres per second (m/s).
Hydraulics	The study of water flow in waterways, channels or pipes; in particular, the evaluation of flow parameters such as water level, extent and velocity.
Hydrograph	A graph that shows how the discharge changes with time at a particular location.
Hydrology	The study of the rainfall and runoff process, including the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
Intensity Frequency Duration (IFD)	Statistical analysis of rainfall describing the rainfall intensity (mm/hr), frequency (probability measured by the AEP) and duration (hours). This analysis is used to generate design rainfall estimates.
LiDAR	Light Detection and Ranging – Ground survey taken from an aeroplane typically using a laser. LiDAR is used to generate a DEM.
Land Subject to Inundation Overlay (LSIO)	A Planning Scheme overlay to identify flood affected land. The overlay extent is based on the 1% AEP design flood event.
Manning's n	A measure of the hydraulic roughness, or resistance to flow, due to surface conditions, typically averaged over an area of relative homogeneity. For example, there is greater resistance to flow through an area of heavy brush and trees than over maintained grass.
Peak Flow	The maximum flow occurring during a flood event past a given point in the river system.
Pluviograph	A rain gauge measuring the depth of rainfall over a small period of time, typically much less than a day.
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location.
Rating Curve	The relationship defining discharge for a given water level at a particular recording location.
RORB	The hydrological modelling program used in this study to calculate the runoff generated from historic and design rainfall events.
Runoff	The amount of rainfall that becomes stream flow; also known as rainfall excess.
TUFLOW	The hydraulic modelling program used in this study to simulate the flow of flood water through the floodplain. The model uses numerical equations to describe the movement of water.

Executive Summary

The North Central Regional Floodplain Management Strategy (RFMS), 2018-28 was developed by North Central CMA in partnership with local councils, water corporations, Victorian State Emergency Service (VicSES), Traditional Owners, the Department of Environment, Land, Water and Planning (DELWP), Parks Victoria, VicRoads, Bureau of Meteorology and local communities. A regional priority outlined in the RFMS is to address gaps in flood knowledge through flood mapping projects. Currently, the available flood information for Marong is limited and flood extents have been estimated from historical and anecdotal evidence. In order to address the lack of good quality information, one of the specific actions identified in the RFMS is to undertake a detailed flood study of Bullock Creek for Marong.

The purpose of this study was to update flood information available for the township of Marong. The information produced by this study may be used to:

- **Assess the flood risk to existing and proposed development.** The vision of the City of Greater Bendigo for Marong is a satellite township that supports a population of 8,000 people, which is approximately 5 times greater than the current population. Therefore, there is a need to improve the flood information currently available for Marong in order to facilitate appropriate future development.
- **Define flood related controls in the Greater Bendigo Planning Scheme.** Marong does not currently have a Land Subject to Inundation Overlay (LSIO). An Environmental Significance Overlay (ESO) covers 50 metres either side of Bullock Creek but does not fully cover the 1% AEP flood extent. This study will enable the flood related planning overlays to be incorporate for Marong into the Greater Bendigo Planning Scheme.
- **Develop flood intelligence products and inform emergency response planning.** The flood data will assist in identifying the flood risk to existing buildings and infrastructure. This data will also facilitate a damage assessment to be undertaken for the township based on a floor level survey of potentially impacted properties.
- **Assist in the preparation of community flood awareness and education products.**
- **Support the assessment of flood risk for insurance purposes.**

It should be noted that the scope of this study excludes the assessment of any mitigation options.

This report details the methodology and assumptions used to develop the design flood information. This included the creation of a hydrologic rainfall-runoff model using RORB which was calibrated to the September 2016 flood event. The hydrologic model was then used to derive design flood hydrographs for 20%-0.5% annual exceedance probability (AEP) flood events. The design flows were compared to other peak flow estimation techniques for verification and then used as inputs into a hydraulic model developed using TUFLOW.

Once calibrated, the TUFLOW model was used to produce flood mapping of the 20%-0.5% AEP design flood events. The outputs included gridded data of the water surface elevation, depth and velocity for the range of design events modelled. Flood intelligence was then produced from this mapping by assessing the flood impacts on buildings, properties and roads.

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1 Introduction

This study has been undertaken to update the flood information for the township of Marong. The outputs of this study may be used to:

- Assess the flood risk to existing and proposed development;
- Define flood related controls in the Greater Bendigo Planning Scheme;
- Develop flood intelligence products and inform emergency response planning;
- Assist in the preparation of community flood awareness and education products;
- Support the assessment of flood risk for insurance purposes.

This study focuses on riverine flooding from Bullock Creek and Fletchers Creek within the proposed growth boundary for Marong. This study will improve knowledge in the region by the provision of detailed flood information for a range of flood events, in particular the 1% AEP flood event.

This study involved detailed hydrologic and hydraulic modelling of Bullock Creek and Fletchers Creek through Marong. This report details the methodology and assumptions uses to develop the design flood information. Through this study, a hydrologic rainfall-runoff model was developed using RORB which was calibrated to the September 2016 flood event. This model was then used to derive design flood hydrographs for 20%-0.5% annual exceedance probability (AEP) flood events. The design flows were compared to other peak flow estimation techniques for verification and then used as inputs into the hydraulic model created using TUFLOW.

Once calibrated, the TUFLOW model was used to produce flood mapping of the 20%-0.5% AEP design flood events. The outputs included gridded data of the water surface elevation, depth and velocity for the range of design events modelled.

The water surface elevations estimated for the 1%AEP were compared with the information collated on the flood survey undertaken for the January 2011 event. This comparison was possible as it was determined that the January 2011 flood event was slightly higher than the 1% AEP event.

1.1 Study Area

Marong is a fast-growing town. In 2011 it was reported to have 311 residents and according to the census in 2016 it has reached a population of 1,416. It is located 17 kilometers to the west of Bendigo.

It has been identified by the City of Greater Bendigo (CoGB) as a future satellite township of Bendigo with an expected population of 8,000 people.

The town is built around an existing town centre and public space network featuring Bullock Creek and Malone Park. Bullock Creek flows south to north, bisecting the township and is visualized as a prominent feature for future developments. The planned development of the town requires careful consideration of the flooding risk to minimise effects on the population and infrastructure.

Bullock Creek catchment is bounded upstream by Jonathon Lane and Johansens Road, Walmer and downstream by Sheldons Road, Nerring. It has a catchment area of 199 km^2 with mostly bushland. The township of Marong is located close to the downstream end of the catchment. Fletchers Creek flows contribute to Bullock Creek and the confluence is located at the north-western side of Marong.

The 1% AEP flood event is mostly contained within the low-lying areas adjacent to the waterway and breaks mostly around the Malone Park Reserve, at the Eastern side of the Calder Alternative Highway between the railway and the Calder Highway. It also affects the northern part of the town where it approaches the forest that surrounds Bullock Creek. Some flooding is observed over the Calder Highway and the Marong-Serpentine Road.

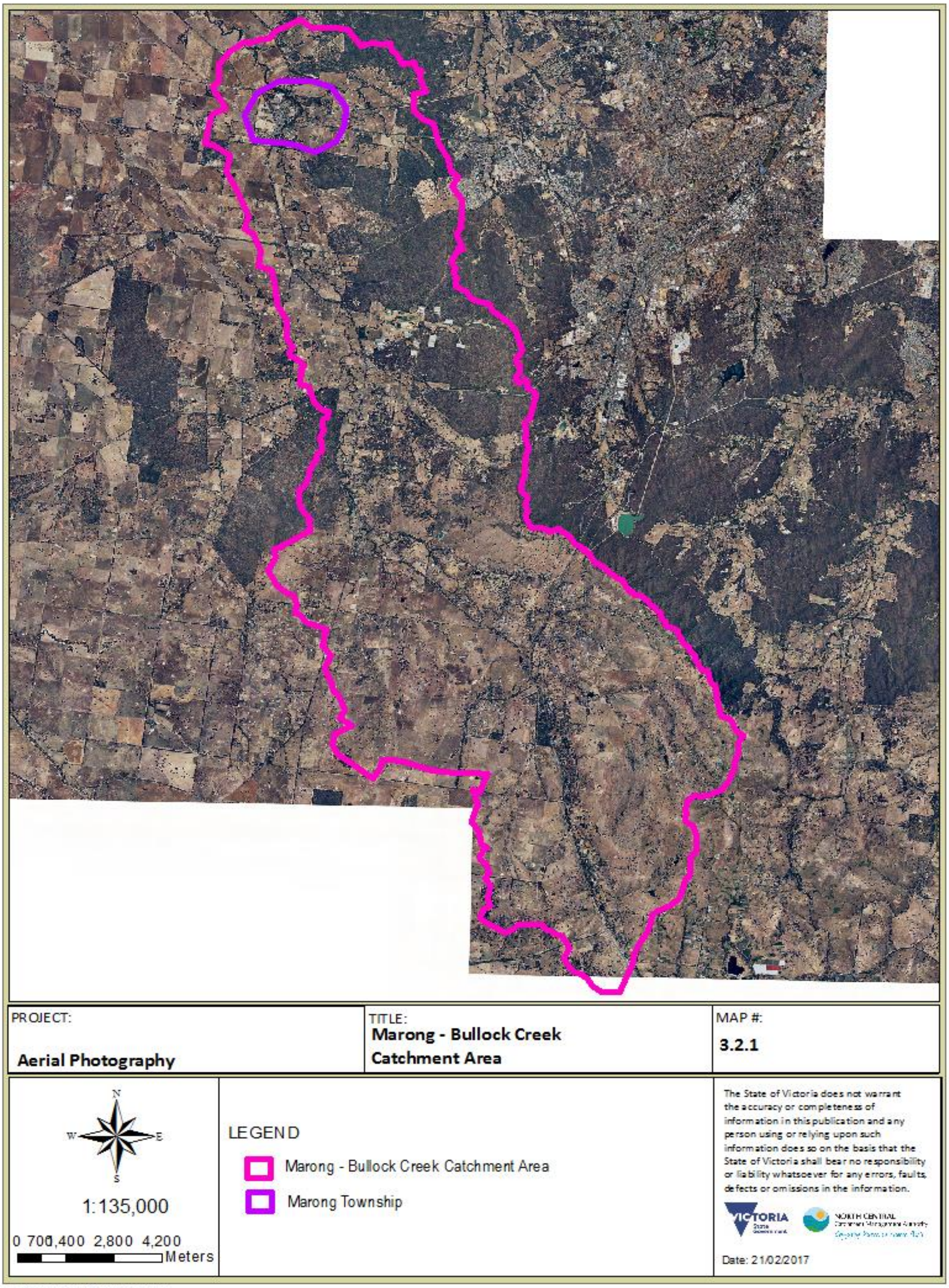

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Figure 1.1 Aerial view of Lockwood to Marong catchment

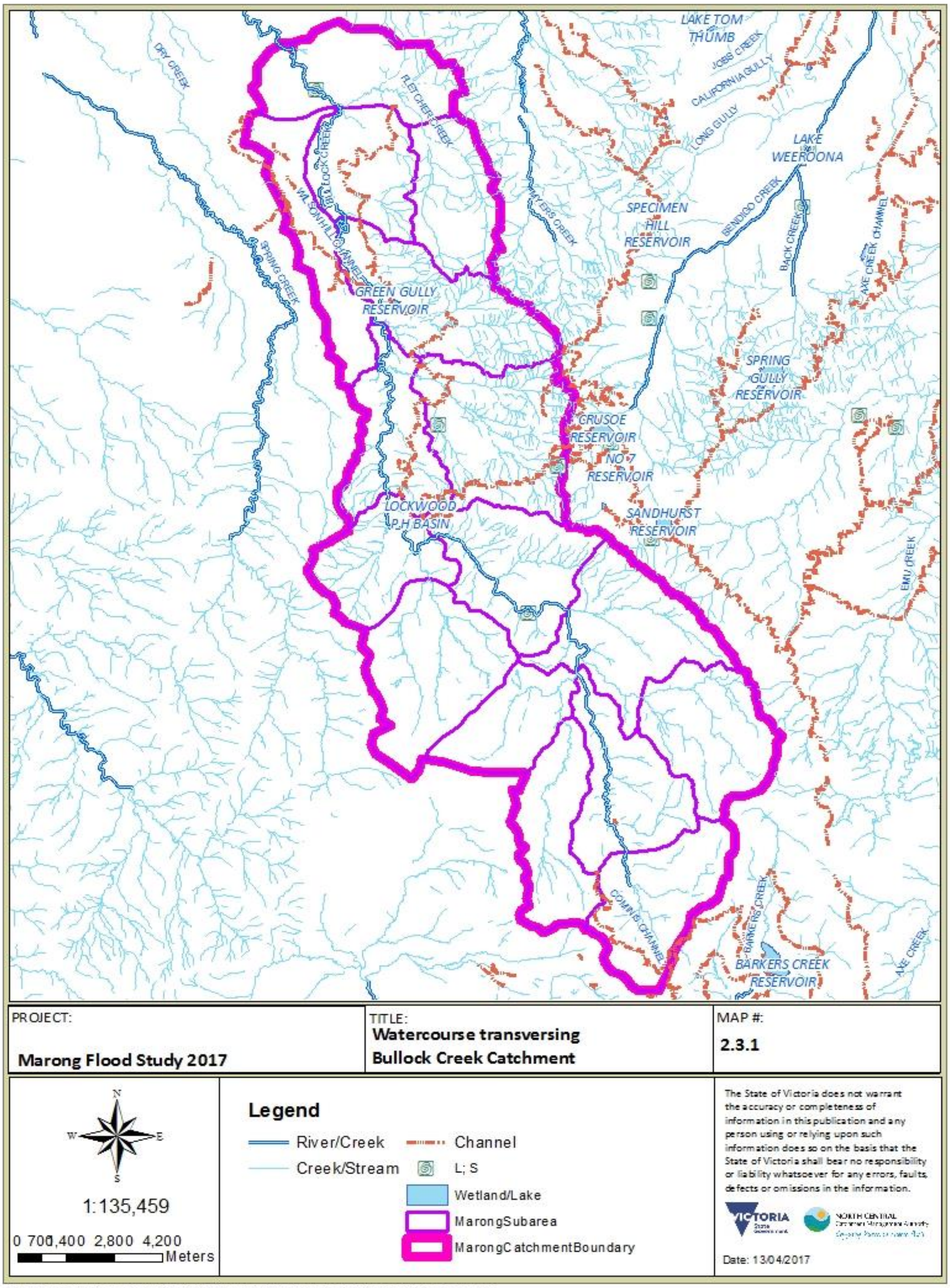

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Figure 1.2 Watercourses within the Bullock Creek (Lockwood to Marong) catchment

1.2 Historical Flood Investigations

No previous detailed flood studies have been undertaken for Marong.

The existing Land Subject to Inundation Overlay (LSIO) is limited to the area south of the Malone Park reserve. There is no existing Land Subject to Inundation Overlay (LSIO) through the existing urban area of Marong. There is however an existing Environmental Significance Overlay (ESO) which applies to a defined 100 metres centrally located over the centerline of both Bullock Creek and Fletchers Creek. The primary purpose of this overlay is to ensure waterway protection but an objective of this overlay is also:

"to ensure development does not occur on land liable to flooding and minimise the potential damage to human life, buildings and property caused by flood events".

Whilst the ESO is an effective tool it does not cover the full width of the floodplain, leaving areas currently subject to inundation without any overlays.

The lack of previous flooding investigations and limited information is currently an issue for planning of the future development of the town, therefore, this study is being undertaken to provide clarity in terms of areas subject to inundation and depths to identify potential expansion of the town and its limitations to reduce risk to infrastructure and human health.

Figure 1.3 Land Subject to Inundation and Environmental Significance Overlays (Vicplan)

1.3 Historical Flood Records

Table 1.1 displays the largest floods that have been recorded at the Bullock Creek at Marong streamflow gauge which has continuous instantaneous flow records dating back to 1973.

The streamflow gauge for Bullock Creek at Marong has a reasonable length of data, however, recent flood events such as those in 2010 and 2011 exceeded the capability of the gauge so no reliable measurements are available for these events.

Table 1.1 Historical flood events

Rank	Year	Peak Flow Rate (m^3/s) (Bullock Creek @ Marong gauge)
6	May 1974	52.3
3	September 1983	61.6
8	September 2016	79.4

A flood survey was undertaken for the January 2011 event in Marong and several flood depths were reported across the township (See Table 1.2). These measurements have been used in this study to calibrate the hydraulic model.

Figure 1.4 shows the location of the flood depth markers measured for the 2011 flood event. Given that there is no stream flow data for this event, the rainfall data was used to calculate the cumulative rainfall for the 2011 event, and it was determined that this event was slightly higher than the 1% AEP event (See section 3.4.3).

Table 1.2 Survey flood depths for the January 2011 event

Survey Point	Flood Level (m AHD)
BULF001	186.24
BULF002	187.87
BULF003	184.99
BULF004	185.57
BULF005	186.07
BULF006	186.43
BULF007	186.01
BULF008	186.57
BULF009	186.55
BULF010	187.52
BULF011	187.55
BULF012	188.03
BULF013	185.6
BULF014	185.24

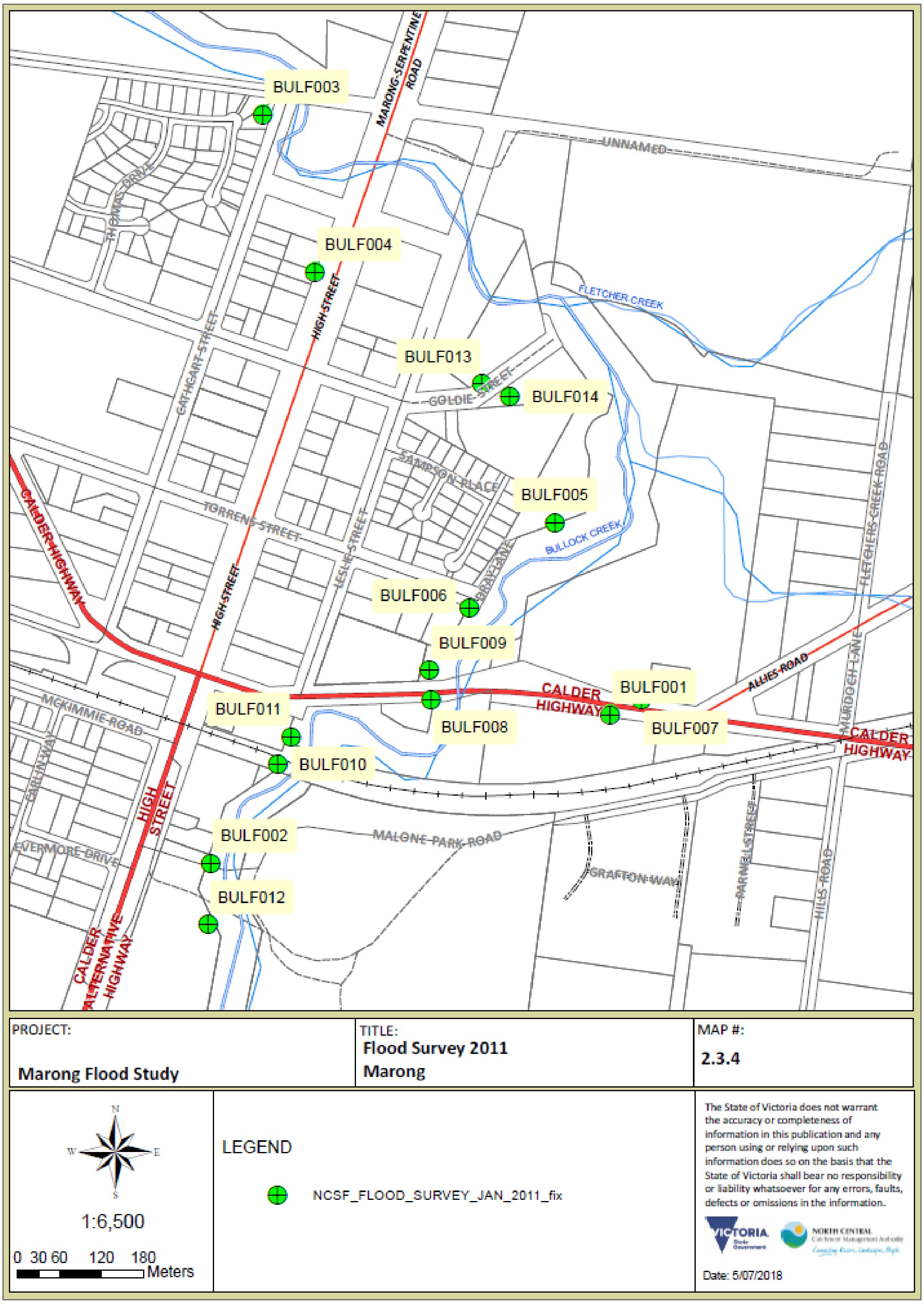

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Figure 1.4 Location of flood survey points for 2011 flood event

1.4 Site Visit

A site inspection was undertaken the 18 June 2018 to identify any infrastructure that could have impacts on the flow and to confirm the information available was adequate and to better understand the flood behaviour around the township.

Furthermore, a second site visit was undertaken on 30 July 2018 with some local community members. This inspection was focused on the flow constriction created by the bridge in Serpentine Road. The local community members indicated the extents of flooding observed in the January 2011 flood event and made suggestions on how to improve flooding conditions in the surrounding area to Bullock Creek along Serpentine Road.

Additional anecdotal information was also obtained from local community members during the process of community consultation organised by the City of Greater Bendigo.

2 Data Review and Assessment

This section documents the data that was collated by North Central CMA for the Flood Study. The information was sourced from government agencies and independent sources including:

- North Central Catchment Management Authority (NCCMA);
- Department of Environment, Land, Water and Planning (DELWP);
- Bureau of Meteorology (BoM);
- City of Greater Bendigo;
- VicTrack;
- VicRoads; and
- Members of the local Marong community.

The data has been compared to pre-existing data throughout the process and calibrated to provide the most accurate representation of the catchment.

2.1 Topographic and Physical Data

The hydrological and hydraulic models require the input of both topographic and physical data. As described below, this study has utilised Light Detection and Ranging (LiDAR) data and information of existing hydraulic structures obtained from VicRoads and the City of Greater Bendigo Shire Council.

2.1.1 LiDAR Data

The Aerial LiDAR (Light Detection and Ranging) survey is available for the Bullock Creek Catchment from two (2) separate sources:

- **Statewide_DEM** – covers Victoria at a grid resolution of 25 metres. Due to the low resolution, this LiDAR data was only used to define the subcatchment areas for the hydrological model where other LiDAR was not available.
- **MD_CoGB** – produced by the photomapping Services Pty Ltd as part of the Bendigo Urban Flood Study. The Bendigo Region area was captured using Optech Gemini LiDAR system (Airbone Laser Scanning) from the 9th to the 11th of December of 2012.
  The LiDAR has a quoted horizontal accuracy of ±18cm and a vertical accuracy of ±10cm. As this dataset has a grid resolution of 1 metre and covers the City of Greater Bendigo and the associated floodplain it was deemed suitable for the hydraulic model.

It should be noted that the method used to collect LiDAR data does not penetrate the surface of water and therefore the data generated does not represent the natural surface level of the bed of the waterway. No bathymetric survey has been undertaken for Bullock Creek Creek, and funding was not available for this study to obtain this information. However, the MD_CoGB data was collected during a period when there was no flow within the river. Consequently, the water level was very low at the time the data was gathered and therefore it provides a reasonable approximation of the topography of the waterway.

These LiDAR sets are currently utilised by the North Central CMA and are considered suitable for this study. The 25 metre State-wide DEM dataset is sufficient in determining catchment delineation. The

MD_CoGB LIDAR set provides sufficient detail within the study area to undertake the hydraulic modelling. Figure 2.1 shows the LiDAR data used for the study.

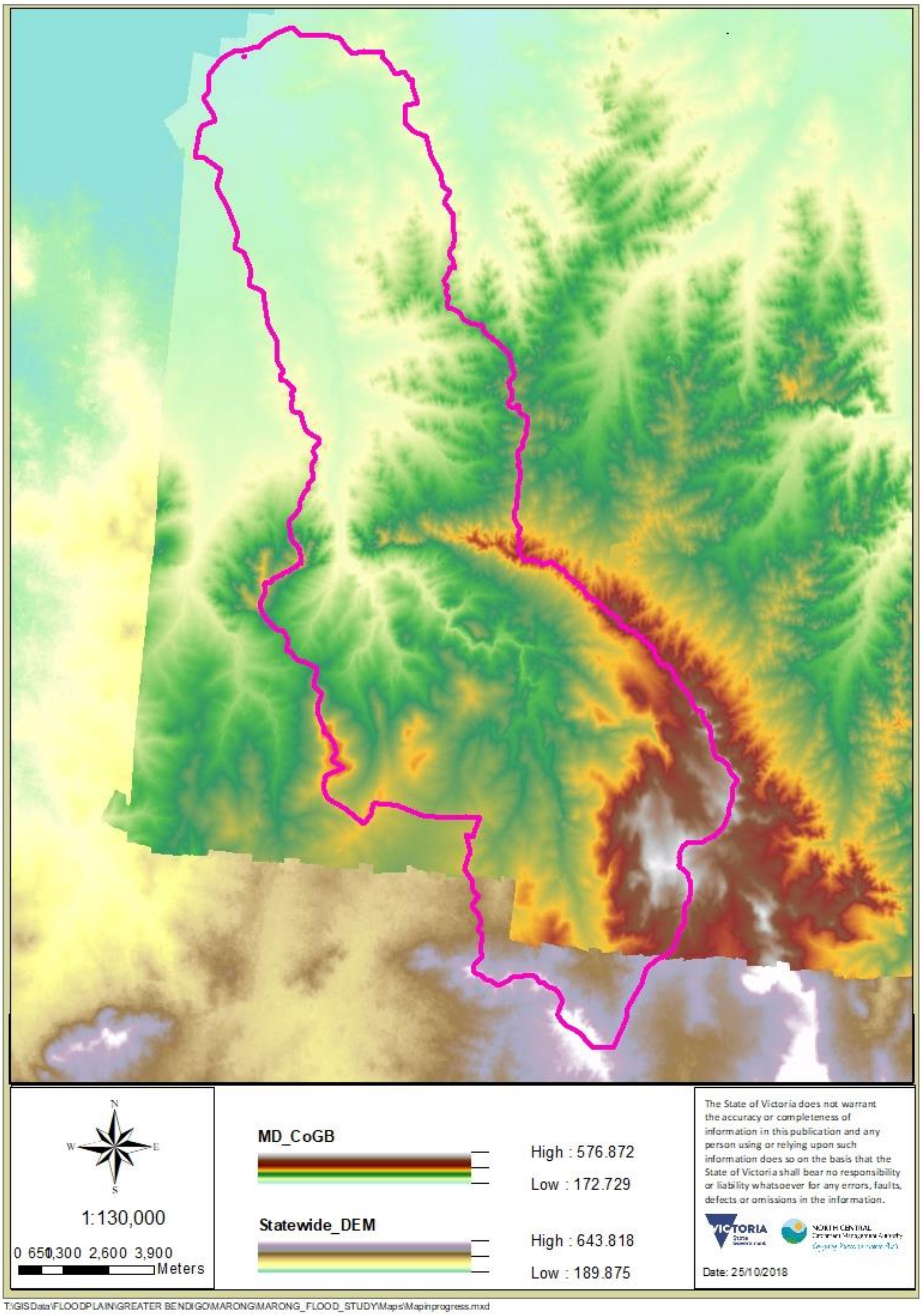

Figure 2.1 LiDAR data available for the Bullock Creek (Lockwood to Marong) catchment area

2.1.2 Culverts and Bridges

The hydraulic model included existing hydraulic structures that are known to have a significant impact on the flow of flood water within the township. These are listed in Table 2.1 and their location is shown in Figure 2.2.

A site inspection was undertaken the 18 June 2018 to identify any other infrastructure that could have impacts on the flow and to confirm the information available was adequate. In the inspection it was noticed the existence of a box culvert under the Calder Highway (Culvert01) of which there was no record, so measurements were taken to include it in the model. The invert levels and top of the structures have been determined with the LiDAR and was considered to be sufficient with no requirements for further survey. Figure 2.3**,**

Figure 2.4 and Figure 2.5 have images and details of existing infrastructure.

Table 2.1 Hydraulic structures included in the model

Waterway	Structure Name	Managing Authority	Structure Details	Reference Number
Bullock Creek	Bridge01 – Calder Highway	VicRoads	6-span bridge Width = 32.3 m	SN0218
	Bridge02 – Serpentine Road	Local Council	3span bridge Width = 27.5 m	
	Rail Bridge	V/Line	11-span bridge Width = 54 m	
	Culvert01 – Calder Highway	Local Council	3 RCP 1.25 m diameter	

Figure 2.2 Location of hydraulic structures

	
Top	Side
	
Under – Original	Under – right widening

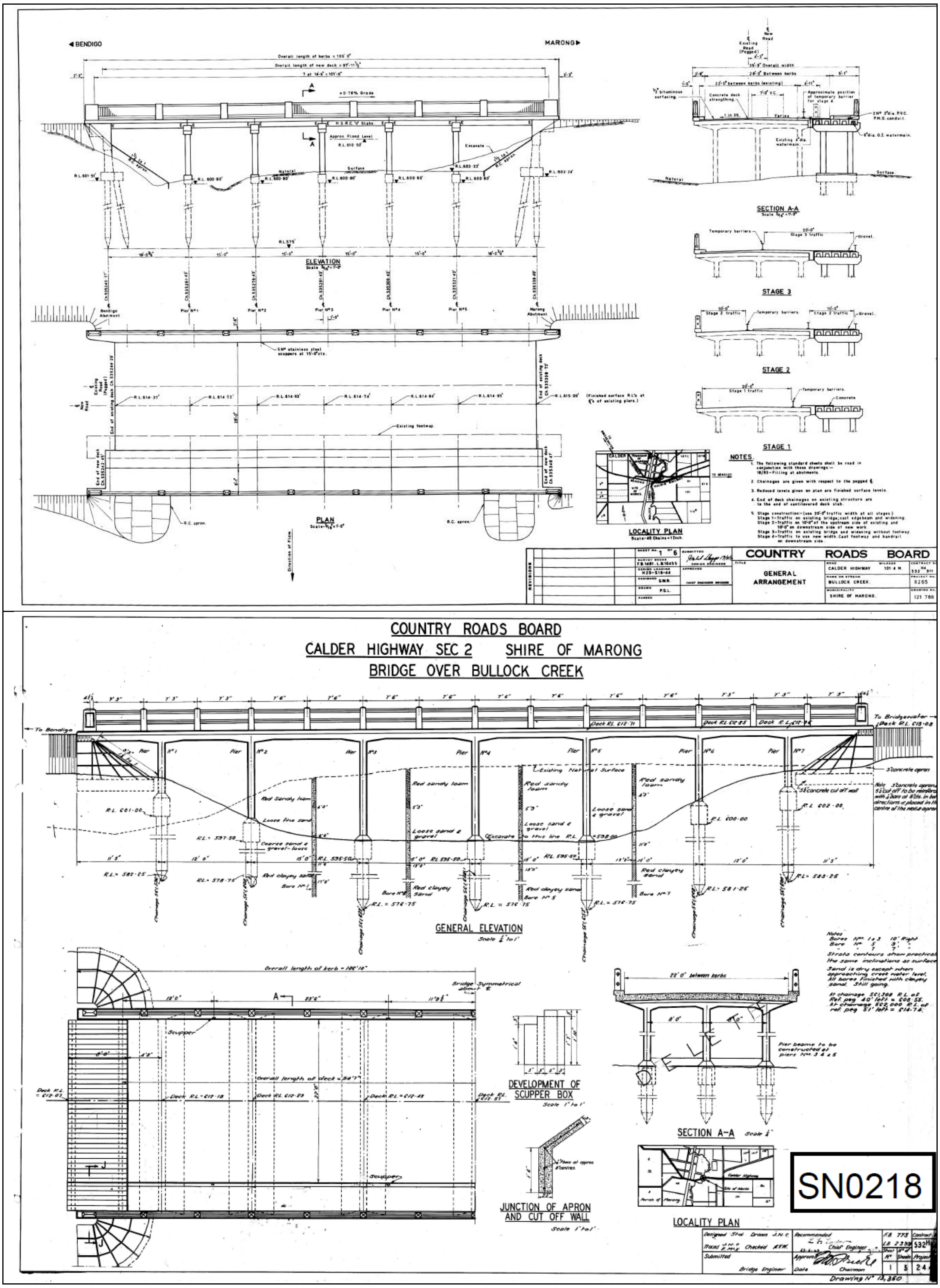

Figure 2.3 Bridge SN0218 (Bridge01) on Calder Highway over Bullock Creek. Images provided by VicRoads

	
Historic Wooden Rail Bridge	Historic Wooden Rail Bridge
	
Marong - Serpentine Road Bridge over Bullock Creek. Bridge02	

Figure 2.4 Historic Wooden Rail Bridge

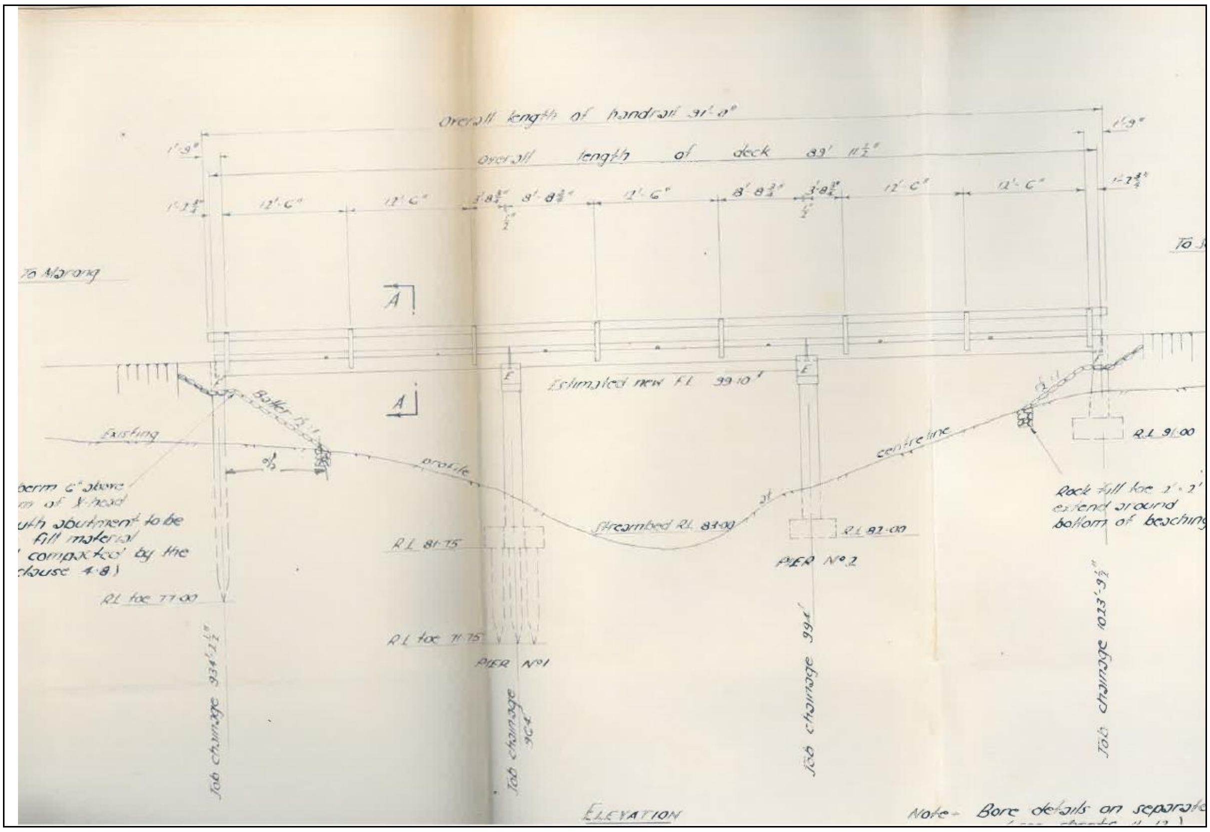

Figure 2.5 Road Bridge on the Marong- Serpentine Road (Bridge02) - Data supplied by City of Greater Bendigo

2.1.3 Marong Drainage Network

The underground drainage network was not included in this hydraulic model. The purpose of this study is to investigate how large flood events are conveyed through the Township of Marong by the Bullock Creek. Hence, this study does not consider the stormwater system which would have a negligible impact on the riverine flood behaviour.

2.2 Streamflow Data

Streamflow data was utilised throughout this investigation providing historic data in which to calibrate and verify the hydrologic and hydraulic models. The gauge of most relevance to this report is the Bullock Creek @ Marong (gauge 407246). Instantaneous streamflow data for the September 2016 flood event was sourced from the Water Measurement Information System managed by the Department of Environment, Land, Water and Planning (DELWP) – www.data.water.vic.gov.au

Gauge 407235 located at Bullock Creek @ Lockwood has a limited timeframe of data therefore made it suitable to calibrate to, see Table 2.2.

Table 2.2 Streamflow gauge details

Station Name	Station No.	Easting/ Northing	Status	Data type	Period of record
Bullock Creek @ Marong	407246	244244 / 5931358	Active	Instantaneous Flow; Water level and Discharge	February 1973 – Present
Bullock Creek @ Lockwood	407235	250414 / 5915873	Non-active	Instantaneous Flow; Discharge	May 1966 – April 1975

Table 2.3 Quality and gap summary

Parameter Name	Unit	Time series type	Start date	End date	Quality Code	Total years	Percent (%)
Watercourse discharge	cumec	Daily mean	04/02/1973	15/01/2017	Quality A	38.68	87.95
					Quality B	0.25	0.57
					Quality C	4.67	10.61
					Quality E	0.24	0.54
					Quality F	0.00	0.00
					Missing	0.15	0.34
Watercourse level	m	Daily mean	04/02/1973	15/01/2017	Quality A	43.16	98.14
					Quality B	0.27	0.60
					Quality C	0.41	0.93
					Quality E	0.00	0.00
					Quality F	0.00	0.00
					Missing	0.15	0.33

(www.bom.gov.au/waterdata/)

There are 41 years (1973 – 2017) of instantaneous flow and level for gauge 407246 located approximately 400 metres downstream of the Township. The quality and gap summary data suggest that there is a medium-high level of confidence on the recordings from the 407246 gauge just north of Marong. The confidence level was analysed by determining whether the quality data exceeds 30 years with a majority located within Quality A, which is at 38.68 years and 87.95%, shown in Table 2.3.

Although the quality of data recorded is acceptable through further analysis the maximum flood discharge is not recorded for the 2010 and 2011 flood events. This is due to the flows exceeding the capability of the gauge.

Figure 2.6 presents the recorded hydrograph for the September 2016 event at gauge 407246.

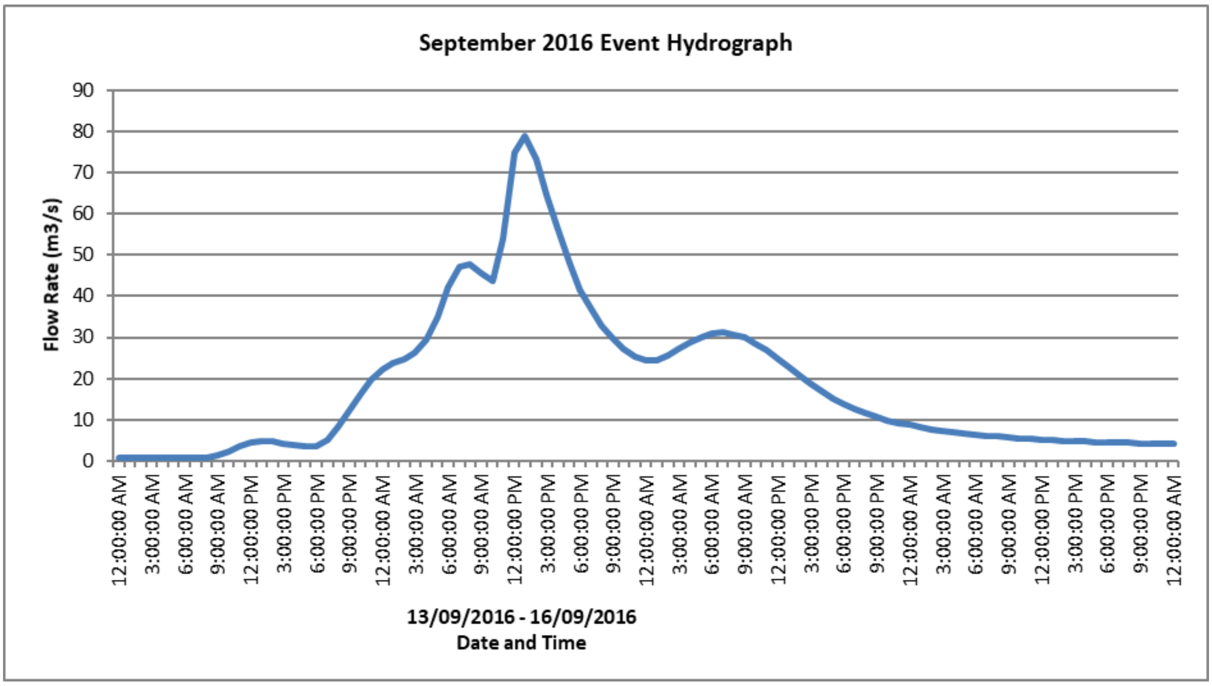

Figure 2.6 Recorded hydrograph for the September 2016 Flood event at gauge 407246

2.3 Rainfall data

The rainfall data required both pluviograph and daily records for the calibration of the RORB model; see Figure 2.7 for the location of all gauges. Hourly rainfall data is required to understand the temporal distribution of rainfall during the recent flood events (i.e. 2010, 2011 and 2016) while the daily rainfall provides the spatial variation and rainfall depths.

Through analysis of the data available from the Bureau of Meteorology, several rainfall gauges were identified near the Bullock Creek catchment.

Table 2.4 presents the 13 rainfall gauges used in this study, taking into account their proximity, the length of records and quality of the data.

Table 2.4 Daily rainfall gauges within and surrounding the Bullock Creek catchment

Gauge Number	Station Name	Period of Record
081100	Woodstock-On-Loddon (Alexandra Park)	1970 – Present
081092	Eastville (Bonnie Banks)	1969 – 2016
081058	Bridgewater (Post Office)	1894 – Present
081047	Tarnagulla	1888 – Present
081128	Tarnagulla (Llanelly)	2011 – Present
081121	Sandhurst Reservoir	1986 – 2012
081123	Bendigo Airport	1991 – Present
081020	Inglewood (Post Office)	1880 – Present
088009	Cairn Curran Reservoir	1949 – Present
081041	Raywood	1898 – Present
088118	Harcourt	1968 – Present
088032	Joyce Creek	1907 – Present
088132	Baringhup (Blue Hills) – CLOSED	1972 – 2013

Due to the location of the Bullock Creek Catchment there were no rain gauges within the boundary to provide pluviograph rainfall data. There are three (3) available locations surrounding the catchment which were superimposed onto the closest sub catchments, they were:

- Axe Creek @ Sedgewick (406216)
- Axe Creek @ Strathfieldsaye (406262)
- Muckleford Creek @ Muckleford North (407300)

Using ArcGIS the three abovementioned rain gauges were plotted where the proximity to each sub-catchment was assessed and the closest to each was utilised.

Table 2.5 Daily total rainfall gauges within and surrounding the Bullock Creek Catchment

Gauge Number	Station Name	Period of Record
406216	Axe Creek @ Sedgewick	16/11/1988 – 24/05/2017
406262	Axe Creek @ Strathfieldsaye	26/05/1989 – 21/04/2017
407300	Muckleford Creek @ Muckleford North	19/09/1996 – 24/05/2017

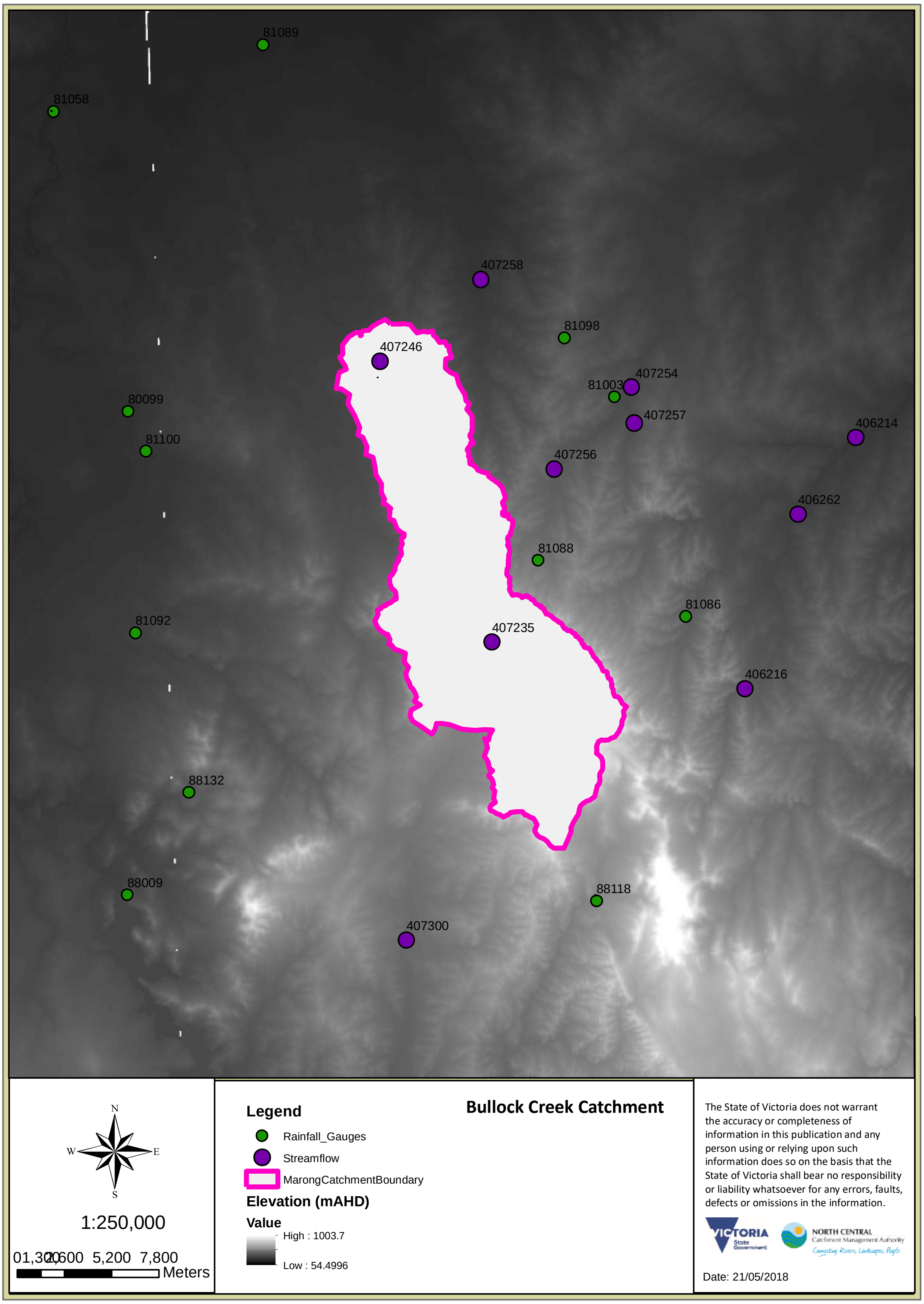

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Figure 2.7 Locations of rainfall and streamflow gauges in the vicinity of the Bullock Creek catchment

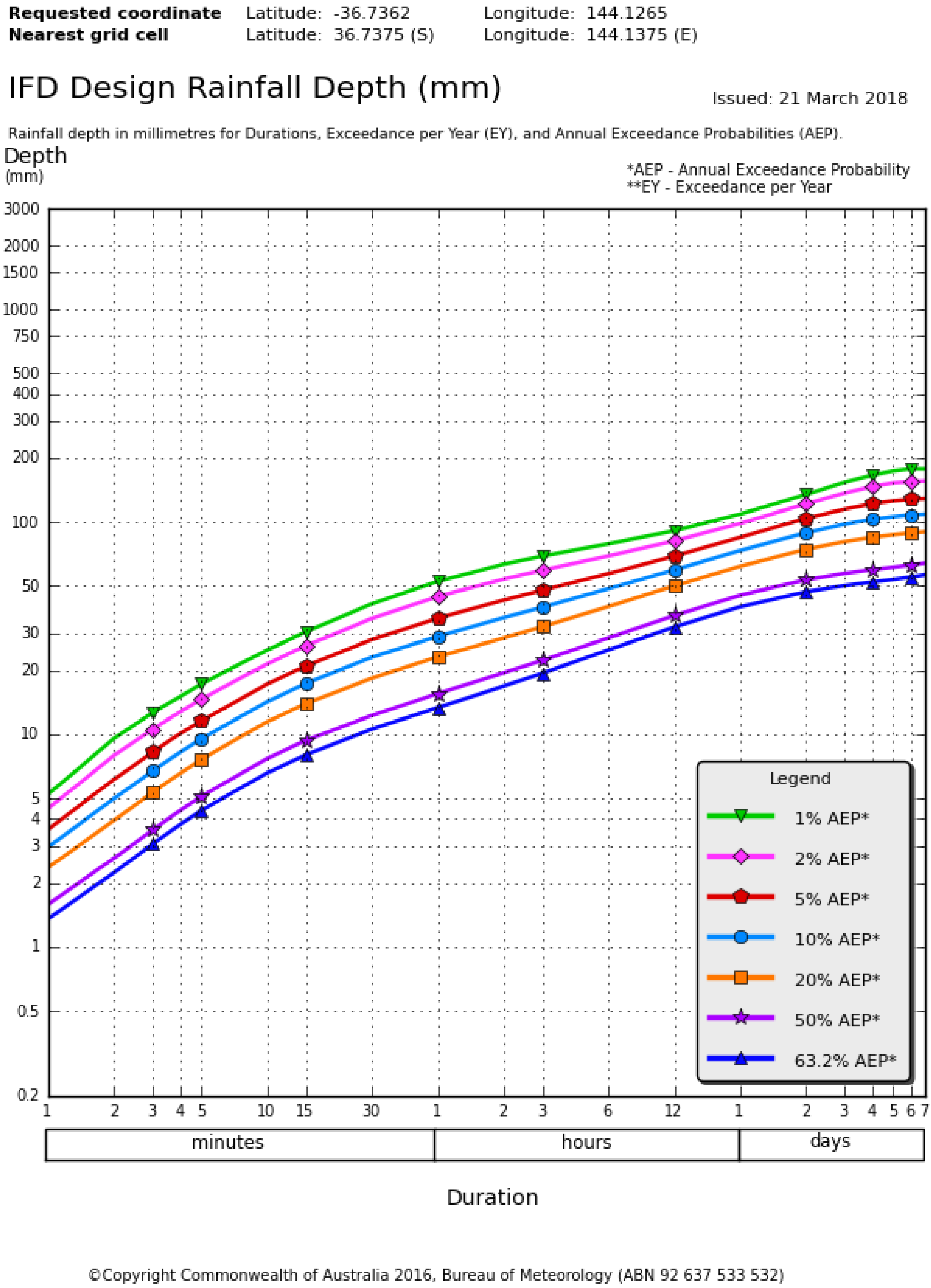


Figure 2.8 IFD plot for Marong Township

2.4 Storage data

There are no significant storages that will contribute to the Bullock Creek catchment area.

3 Hydrologic Analysis

3.1 Overview

The hydrologic model of the catchment for Bullock Creek was developed using the rainfall-runoff program RORB (version 6.32). The calculated flows were extracted to use as boundary conditions within a hydraulic model (TUFLOW).

The hydrologic modelling process for the Marong Flood Study required a verification process whereby an initial RORB study using the September 2016 event for calibration was eventually verified after the hydraulic modelling phase as lack of data restricted further calibration.

RORB is a non-linear runoff and streamflow routing program used to calculate flood hydrographs from rainfall and other channel inputs. The catchment is delineated into subareas which are connected by reach storages. Specific losses are subtracted from the rainfall on each subarea to produce rainfall-excess. The rainfall-excess is then routed through the catchment storage to generate hydrographs at any location.

The following methodology was applied for the RORB modelling of the Bullock Creek catchment up to the Marong gauge:

- 16 catchment subareas were delineated using the available LiDAR data.
- Nodes were placed throughout the sub-catchments at points of interest (i.e. streamflow gauges at Lockwood and Marong), at junctions between any two reaches and at centroids to the sub-catchments.
- Reaches and slopes were extracted from GIS data.
- Subarea fraction impervious values were estimated using the Land Use Zoning classification and aerial photography.
- Storm files for the November 2016 events were created using pluviography data from gauges 406216, 406262 and 407300; and the hydrograph measured by gauge 407246. These storm files were used to calibrate the RORB model.
- The RORB model parameter k_c was calibrated to the observed flood hydrographs for the September 2016 events at the Marong – Bullock Creek gauge.
- A Monte Carlo analysis was undertaken on the RORB model to determine appropriate design losses by fitting it to the Bullock Creek at Marong gauge flood frequency curve.
- Using the design losses and the calibrated parameter, k_c, a second RORB Monte Carlo analysis was run using the applicable design inputs for the Marong catchment to determine the flood frequency curve for the critical storm duration at the township.
- Individual runs from the Monte Carlo analysis which produced peak flows approximately equal to the required design flood AEPs were then selected.
- The inputs of the selected runs (including rainfall depth, loss factors and temporal patterns) were then used to produce complete hydrographs for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP design events. These were then used as inflow boundary conditions for the hydraulic model.

3.2 Flood Frequency Analysis

Flood Frequency Analysis (FFA) refers that use recorded and related flood event data in identifying the probability model of flood peaks at a particular location in the catchment, i.e. Marong. These analyses were used to perform risk-based design and flood risk assessment. Theses set of analysis are generally considered more reliable, however, depending on streamflow gauge missing large peaks like the September 2010, January 2011 and February 2011 in this flood study it may not be the best source of reliability and rather used as a validity exercise.

3.2.1 Data Analysis

A flood frequency analysis was conducted on the Bullock Creek at Marong gauge to assist with the RORB model calibration and generation of design hydrographs. Flood frequency analysis (FFA) involves the fitting of a probability model to an annual series of maximum recorded flows to relate the magnitude of extreme events to their frequency of occurrence. This statistical analysis allows the estimation of design flood flows.

The annual maximum flood series for the Bullock Creek at the Marong gauge was extracted from the available 41 years of instantaneous streamflow data, from 1973 to 2017.

The quality and gap summary data suggest that there is a medium-high level of confidence on the recordings from the 407246 gauge just north of the Marong Township. The confidence level is analysed by determining whether the quality data exceeds 30 years with a majority located within Quality A, which is has at 38.68 years and 87.95 %.

Although the quality of data recorded is acceptable through further analysis the maximum flood discharge is not recorded for the 2010 and 2011 flood events. This is likely due to loss of gauge or exceeding the capability.

This data was evaluated to ensure that the annual maximum flows were independent and homogenous. During the gauge streamflow record no significant storages have been constructed upstream of the gauge and there has not been a significant increase in urbanisation of the gauge catchment. Hence, the annual maximum series derived from the gauge satisfies the criterion of homogeneity. Additionally, all annual maximum flows were produced from separate storm events; therefore, the independence criterion is also achieved.

3.2.2 FLIKE

The program FLIKE was used to undertake a flood frequency analysis of the annual maximum series of flows at the Bullock Creek at Marong gauge.

For the FLIKE analysis a Gumbel distribution was used given the LPIII proved to be unsatisfactory for this catchment, whilst the Gumbel distribution show good correlation between the expected quantile and the gauged data (see Figure 3.22). Furthermore, the Gumbel Distribution has good performance when the sample size is less than 50, which is this case we have only 36 years of gauged data.

No prior information from the Regional Flood Frequency Estimation method was incorporated into the analysis. An initial analysis was undertaken using the regional parameters and it was determined that they were not consistent with the gauge data. This is in accordance with ARR, Book 3, Section 2.3.10 and 2.6.3.5, which states that regional prior information should be used unless there is evidence that it is not applicable to the catchment of interest.

As recommended in ARR, Book 3, Section 2.8.6, the multiple Grubbs-Beck test was used to identify potentially influential low flows. These low flows are not representative of the population of floods and it is important that they are censored so that they do not unduly influence the distribution fit. The multiple Grubbs-Beck test identified 23 low flows which were censored to achieve an improved distribution fit.

Table 3.1 and

Figure 3.1 present the AEP quantile estimates and their 90% confidence limits. The results of the FLIKE flood frequency analysis indicate that the September 2016 (77.8 m^3/s) flood event was approximately 5% AEP flood event.

Table 3.1 Bullock Creek at Marong FFA results

AEP (%)	5% Confidence Limit (m^3/s)	Quantile Estimate (m^3/s)	95% Confidence Limit (m^3/s)
50	1.3	12.7	23.5
20	28.6	41.2	59.2
10	43.4	60.1	86.1
5	56.8	78.2	112.1
2	73.6	101.6	146.3
1	86.0	119.2	172.6

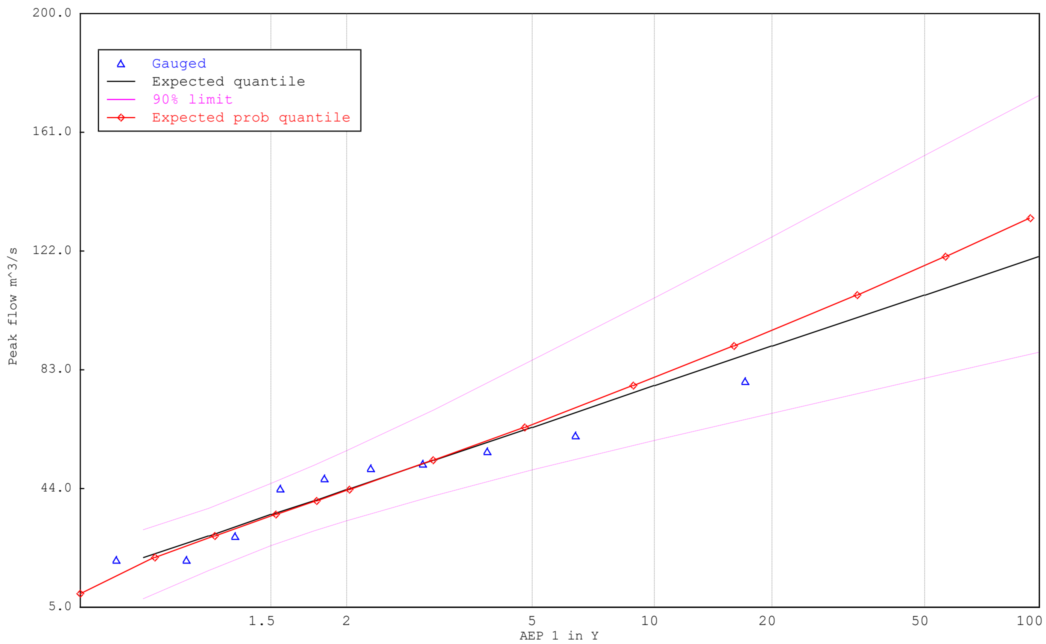


Figure 3.1 Flood frequency analysis of Bullock Creek at Marong

3.3 RORB Model Construction

3.3.1 Sub-catchments and Delineation, Reach Type and Loss Model

The RORB Study initially requires watershed delineation producing a number of sub-catchments for modelling. If the number of sub-catchments is too small the hydrographs will appear too similar to the rainfall time series outputs.

Bullock Creek has a catchment area of 199 km2. The catchment was delineated into 16 sub-catchments as shown in Figure 3.2.

Nodes were placed throughout the sub-catchments at points of interest (i.e. streamflow gauges at Lockwood and Marong), at junctions between any two reaches and at centroids to the sub-catchments. These were connected via reaches, each with an ArcGIS calculated length, slope and type.

Reach types are classified into five (5) different reach types (1 = natural, 2 = excavated & unlined, 3 = lined channel or pipe, 4 = drowned reach, 5 = dummy reach). All reaches within the Bullock Creek catchment are represented as “Natural” this is due to the open grassed areas and natural waterways present. Design hydrographs were extracted at the boundaries of the sub-catchments and the local catchment points.

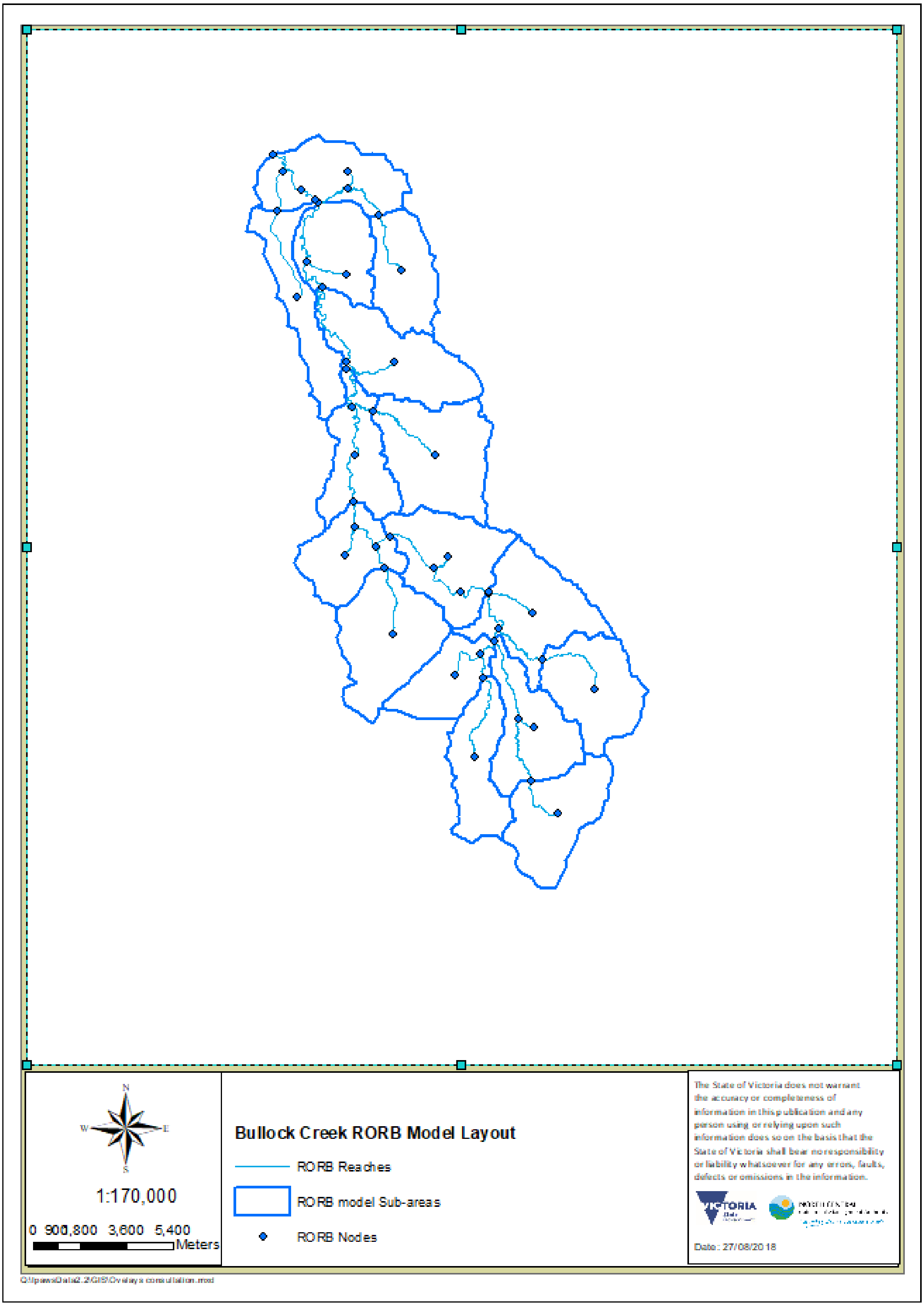


Figure 3.2 RORB sub-catchments delineation, nodes and reaches

3.3.2 Fraction Impervious

Fraction impervious values were devised in each of the sub-catchments by the approximation of land use, based on the Land Use Zoning from the planning scheme layers and aerial photography.

The zones found and adopted in this area can be seen in Table 3.2. These values were then interpolated and averaged out per sub-catchment (see Table 3.2).

Table 3.2 Land use and zoning including description and allocation of fraction impervious

Land Use Zone	Description	Fraction Impervious
Commercial Zone (B1Z & B3Z)	Commercial centres with retail, office, business and community uses	0.8
Farm Zone (FZ)	Rural areas	0.001
Industrial Zone (IN1Z, IN2Z)	Manufacturing and storage facilities	0.8
Low Density Residential (LDRZ)	0.4 Ha minimum lot size	0.2
Public Conservation & Resource Zone (PCRZ)	Natural environment w associated facilities	0
Public Park and Recreation Zone (PPRZ)	Public recreation and open space	0.01
Public Use Zone (PUZ1-7)	Public utility and community services and facilities	0.6
Residential Zone (R1Z, TZ)	Normal range of densities	0.45
Rural Conservation Zone (RCZ, RCZ1, RCZ2)	Natural environment and agricultural use	0
Road Zone (RDZ1, RDZ2)	Secondary and local roads	0.6
Rural Living Zone (RLZ1, RLZ2, RLZ5)	Rural residential and agricultural use	0
Special Use Zone (SUZ4)	Golf Courses and associated uses	0.01
Special Use Zone (SUZ6)	Caravan Park	0.45

Table 3.3 RORB Study – Sub-catchments, Areas and Fraction Impervious

SUB-CATCHMENT	AREA (km^2)	Fraction Impervious
A	12.749	0.001
B	10.518	0.001
C	12.654	0.035
D	14.002	0.010
E	16.076	0.002
F	16.918	0.008
G	15.669	0.005
H	10.143	0.041
I	10.096	0.024
J	12.233	0.075
K	8.4713	0.008
L	15.041	0.036
M	9.8761	0.031
N	10.722	0.024
O	12.863	0.040
P	10.358	0.039

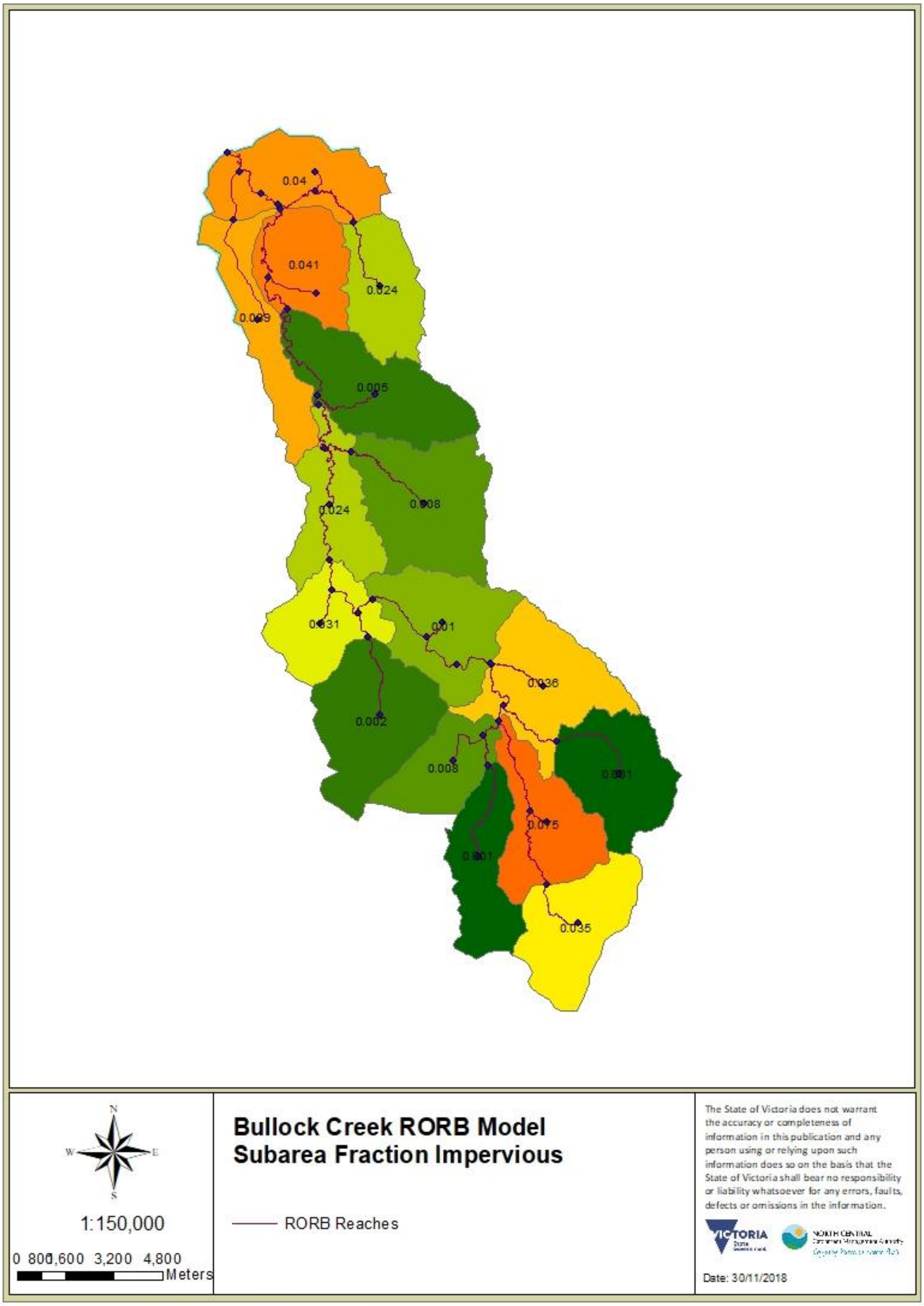


Figure 3.3 Fraction Impervious Values for the Bullock Creek Catchment

3.4 Bullock Creek RORB Model Calibration

3.4.1 Overview

Within RORB, the model parameter Kc and losses are used to fit the calculated to observed hydrograph. An initial loss/continuing loss model was found to provide a better fit of observed and modelled flood hydrographs and was therefore adopted for this study.

The RORB calibration process was undertaken by fitting the model to the observed rainfall and runoff for the recorded flood event of September 2016. The calibration was used to determine the appropriate values for kc (nonlinearity parameter), continuing and initial losses for the catchment, such that the model could replicate the output hydrograph at the Marong – Bullock Creek gauge.

The RORB model was calibrated to the Bullock Creek at Marong gauge located further downstream of Marong as this was the nearest available gauge. Recent historical events such as September 2016, September 2010 and January 2011 were analised to be used for the calibration of the hydrologic model. These are characterized by their large size and the fact that they were observed to have significant flooding in the area. However, due to errors and insufficient data for the flood events of 2010 and 2011 only the September 2016 event was used for calibration purposes.

An initial Kc value of 0.8 was adopted based on the Australian Rainfall and Runoff BOOK 5: FLOOD HYDROGRAPH ESTIMATION which recommends a kc value of between 0.6 and 1.0 to represent the non-linearity of the catchment. Initially as represented in corresponding studies in the region an m of 0.8 was adopted as the most appropriate in replicating the event.

Generally due to the rural nature of the catchment the initial losses would be higher than proposed, however, due to a wet catchment with heavy rainfall days prior to the observed flood event the assumption of a lower initial loss of 15.0 millimeters was appropriate.

The continuing losses were similar to those suggest in the RORB manual and on the Australian Rainfall and Runoff guidelines of 1.8 millimeters per hour.

A trial and error fitting procedure was used to reproduce the flood peak, volume and shape of the observed hydrograph for the 2016 event. The adopted kc value was then compared to regional estimations to assess its reasonableness.

3.4.2 RORB Model Calibration Event Data

3.4.2.1 Observed Streamflow Data

Instantaneous streamflow data for the Bullock Creek at Marong gauge was obtained from for the DELWP Water Measurement Information System for the selected calibration events. Gauged streamflow data is shown in Figure 3.4 for the September 2016 flood event.

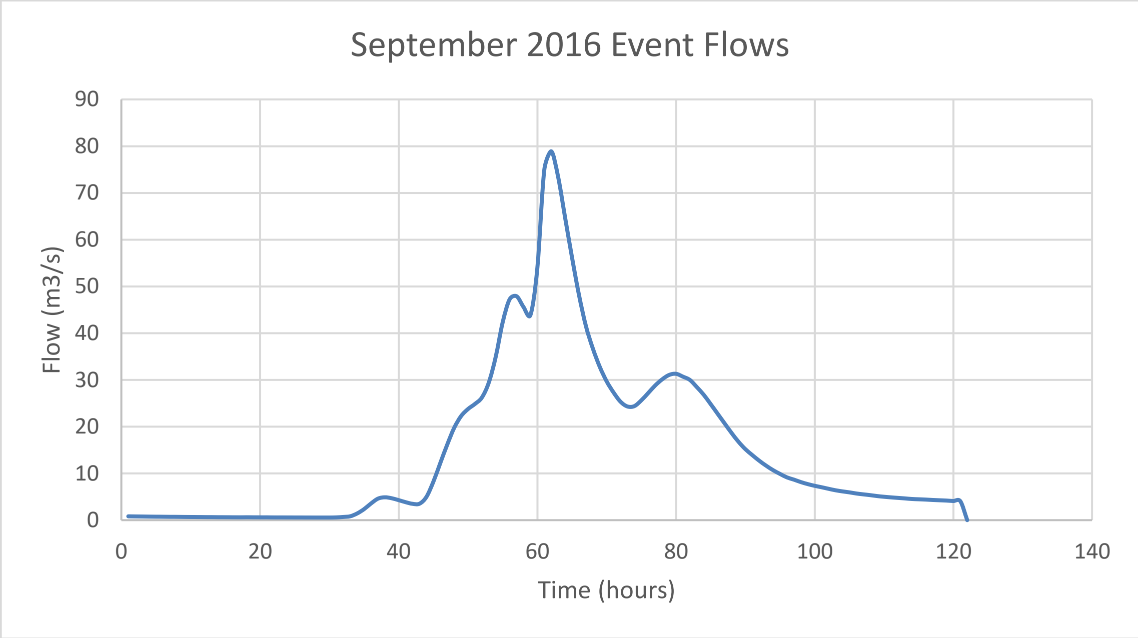


Figure 3.4 September 2016 Instantaneous Flows at station 407246

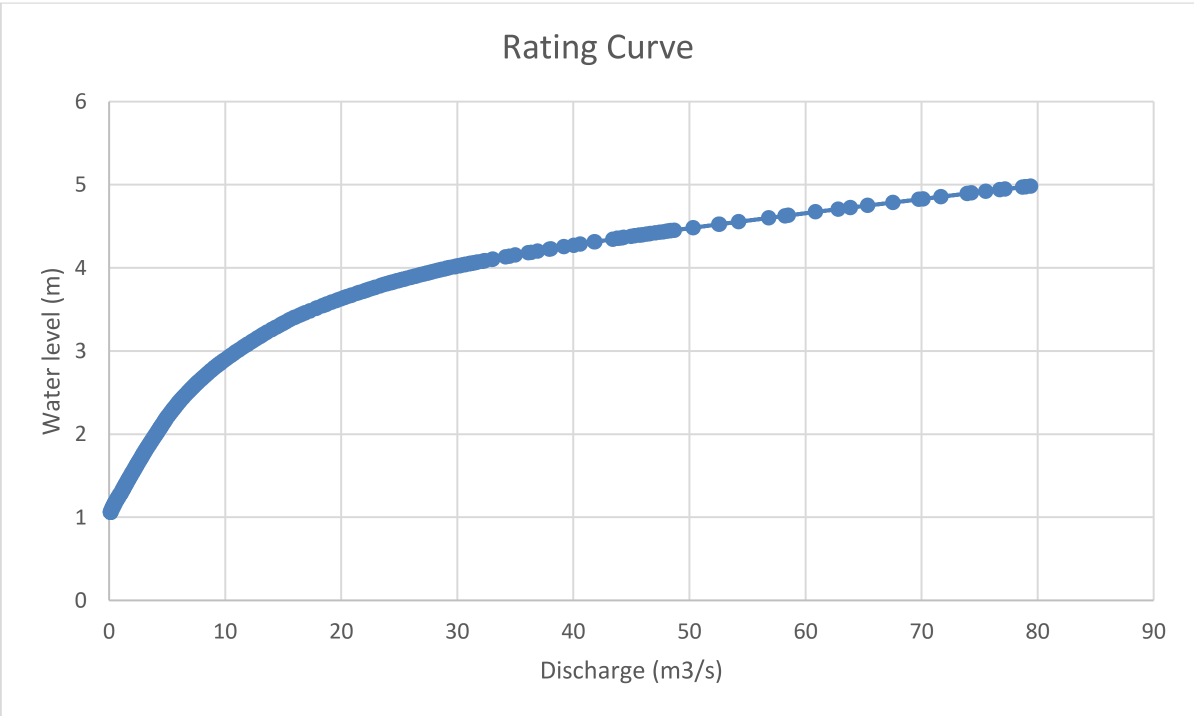


Figure 3.5 Rating Curve for Station 407246

3.4.2.2 Baseflow Separation

Baseflow describes the portion of streamflow resulting primarily from groundwater discharge, as opposed to surface runoff. As RORB only models direct rainfall runoff, it is necessary to understand the different components and, if necessary, separate the total streamflow into surface runoff and baseflow.

ARR 2016 recommends that the following be considered in order to determine whether baseflow is likely to be a significant component of the flood hydrograph:

- **Baseflow Peak Factor**
  The Baseflow Peak Factor (BPF) is defined as the relative magnitude of baseflow compared to surface runoff for a 10% AEP event. A map of the BPF is provided in ARR, Book 5, Section 4.4, to allow identification of the appropriate factor for the catchment. According to this map, the Campaspe catchment has a factor of less than 0.05. Furthermore, the Data Hub specifies the BPF for the catchment as 0.04.
- **Streamflow data review**
  Figures 5.4.5 and 5.4.6 from ARR Book 5, Section 4.4 present estimations of BFP based on catchment characteristics. Using these estimates a BFP of less than 0.1 was determined.

Hence, baseflow is considered to have a negligible impact on the flood hydrographs in this catchment and therefore baseflow has not been explicitly removed from the recorded hydrographs.

3.4.2.3 Observed Rainfall Data

Pluviograph rainfall data provided temporal and total hourly rainfall patterns for the catchment. The three gauged pluviograph rainfall stations in proximity to the catchment were utilised to their respective sub-catchments. This is due to no single station being able to represent the majority of catchment and therefore it was deemed most appropriate to consider them separately as seen in Table 3.4.

The pluviograph gauges utilised for this study are: Axe Creek @ Sedgewick (406216), Axe Creek @ Strathfieldsaye (406262) and Muckleford Creek @ Muckleford North (407300). Hourly total rainfall gauges were present throughout the catchment.

The pluviograph data was used to define the temporal distribution of rainfall at each of the storm events.

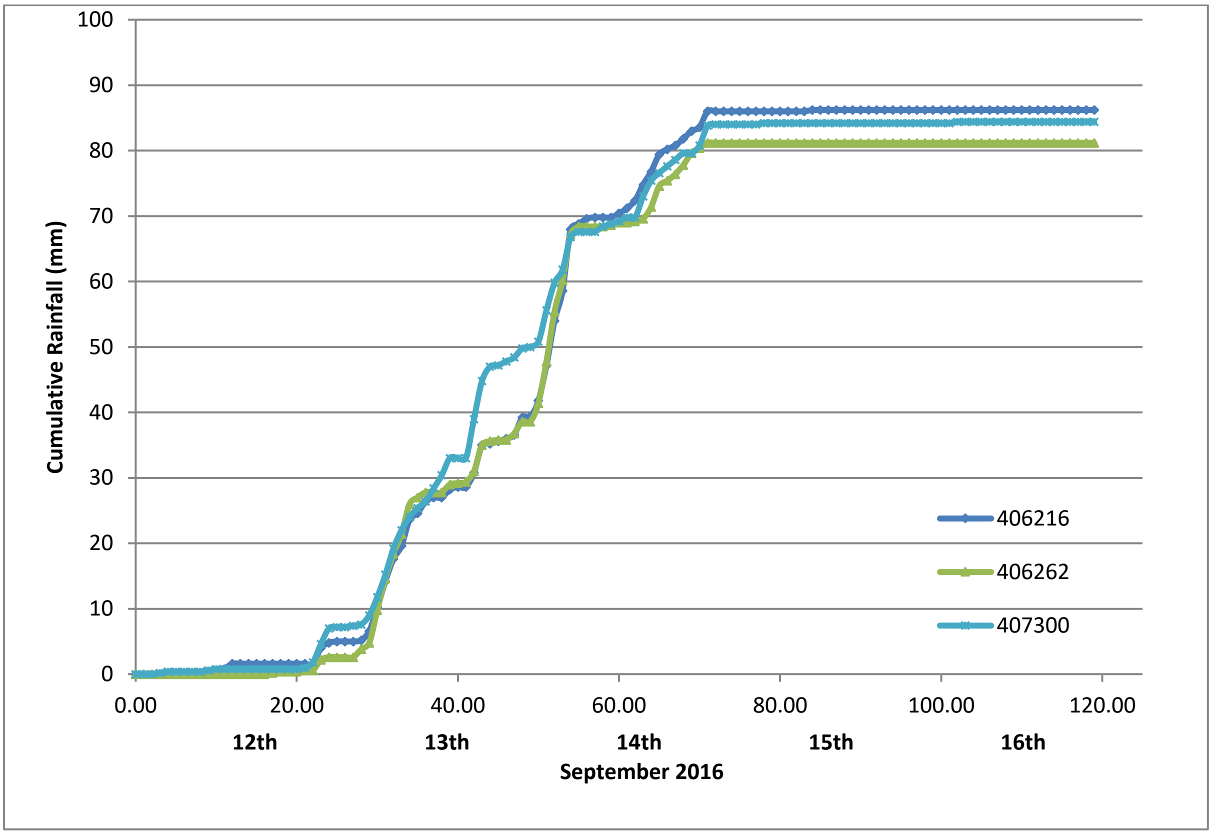
Table 3.4 Pluviograph stations projected to their corresponding sub-catchments

SUB-CATCHMENT	Pluviograph Gauge	RORB Allocation
A	406216	1
B	407300	3
C	406216	1
D	406216	1

SUB-CATCHMENT	Pluviograph Gauge	RORB Allocation
E	407300	3
F	406216	1
G	406262	2
H	406262	2
I	406262	2
J	406216	1
K	406216	1
L	406216	1
M	407300	3
N	406216	1
O	406262	2
P	406262	2

Rainfall data for each temporal gauge was analysed to determine the comparisons in variability across the catchment. This is important as though these datasets are not within the catchment area the gauges followed similar trends in the September 2016 event, as seen in Figure 3.6 below.

Figure 3.6 Cumulative rainfall at pluviography stations 406216, 406262 and 407300 during the September 2016 event



Though there is a lack of significant difference between the temporal patterns timing, the distances from each sub-catchment indicates it is more appropriate to utilise the different pluviographs. The gauges 40612 and 406262 are located outside the eastern catchment boundary whilst the 407300 is located outside the western catchment boundary. This may attribute to the slight increase in differential in burst concentration on the 13th of September.

The temporal rainfall distributions for each RORB subarea were sourced from the closest available pluviograph stations for the September 2016 storm event as shown in Figure 3.7.

The total storm rainfall depth is also required at each available daily rainfall gauge for the calibration events. This data is used to produce rainfall isohyets for each event to estimate the rainfall depth for each model subarea for the total storm duration.

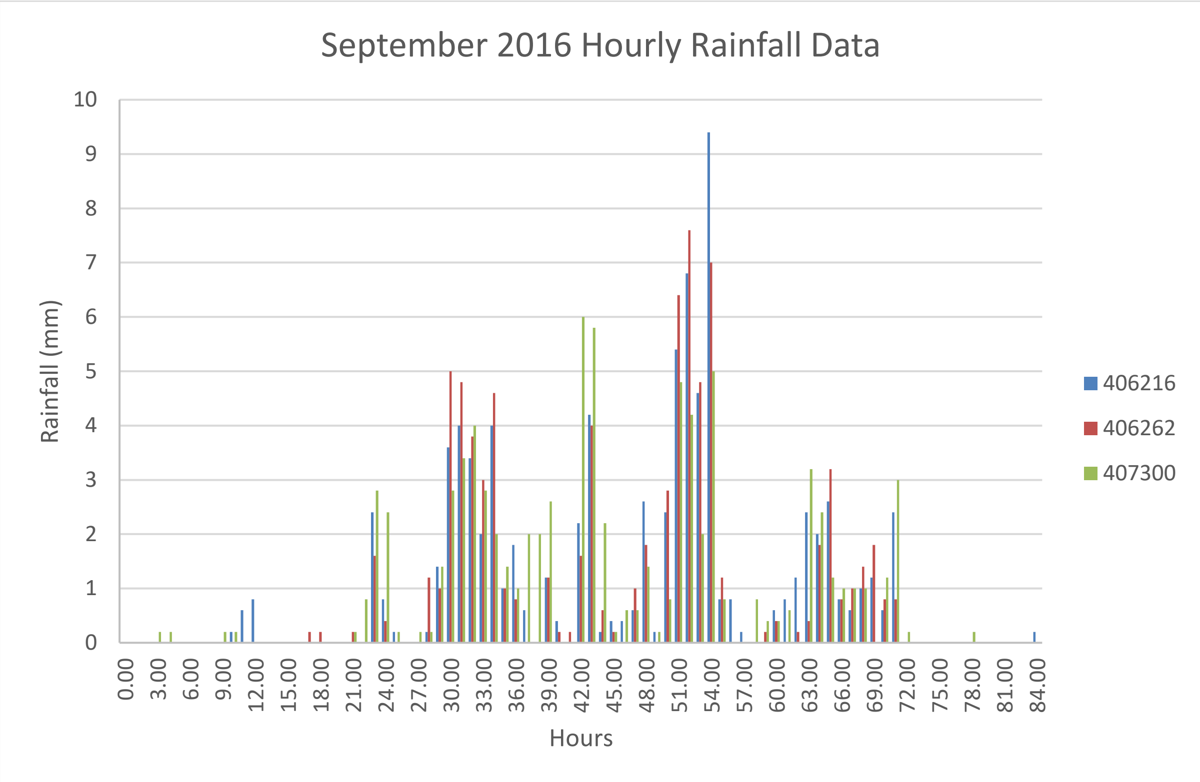


Figure 3.7 Pluviograph records for the September 2016 Event

3.4.2.4 Losses

An initial loss/continuing loss model was adopted for the RORB model and calibration was achieved using the FIT option in RORB. The initial loss parameter was determined by trial and error to reasonably reproduce the observed rising limb of the hydrograph. Depending on the initial loss chosen, the FIT option enabled RORB to automatically select the continuing loss value that minimises the error between the calculated and observed hydrograph volume. In addition to ensuring a good model fit, the adopted calibration losses were also reviewed against those adopted in the Rochester Flood Management Plan as well as whether the values were realistic in general.

3.4.2.5 Hydrologic parameters

For the September 2016 flood event, the kc, m, initial losses and continuing losses were adjusted until the measured hydrograph at the Bullock Creek @ Marong gauge (407246) match with the calculated hydrograph in peak timing and volume. The modelled hydrograph at Marong, Figure 3.8, replicated the peak flow, timing and volume of discharge well, though the timing of the second burst was unable to be replicated.

The peak timing for the calibration was delayed by approximately 5 hours from that of the September 2016 event, this occurred over the 168 hour time period and is considered negligible. The peak discharge and volume differentials were 0.0% and 3.0% respectively and again were considered appropriate.

The Kc value adopted, after an iterative process, was 24.80 with a m value of 0.8, initial loss of 15 millimetres and a continuing loss of 1.8 millimetres per hour.

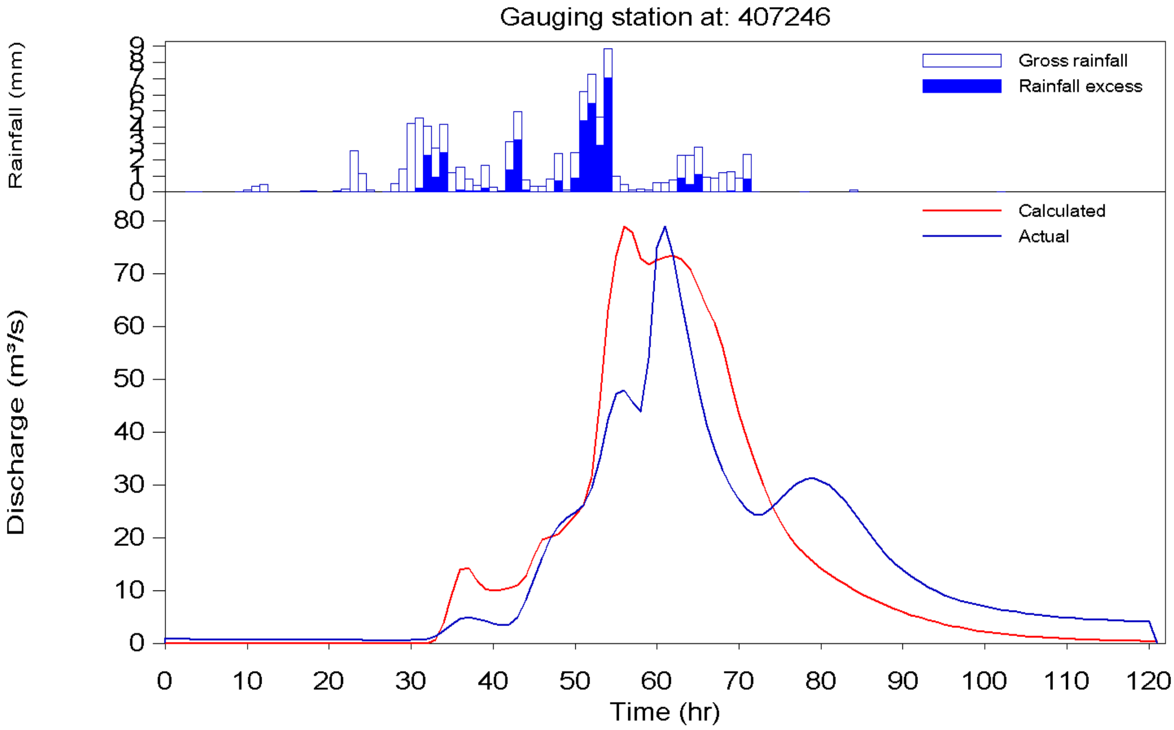


Figure 3.8 Calculated and actual hydrographs associated with the Bullock Creek @ Marong gauge including the parameters Kc=24.80 and m=0.8

The RORB model was able to replicate the September 2016 storm event peak discharge, volume and timing within reasonable accuracy. The adopted values for kc, m, initial loss (IL) and continuing loss (CL) for the calibration are summarised in Table 3.5. As shown, the difference between the observed and modelled peak flow and volume are acceptable.

Table 3.5 RORB calibration parameters and results for September 2016 event

Model Parameters	Kc	24.8
	m	0.8
	IL	15.0
	CL	1.8
Peak Flow (m3/s)	Observed	78.9
	Calculated	78.9

	Relative difference (%)	0
Volume (ML)	Observed	6.76E6
	Calculated	6.54E6
	Relative difference (%)	3.0

Due to the lack of viable data for the September 1983, September 2010, January 2011 and February 2011 events confidence of a single calibration event may be low. In order to address uncertainty associated with the hydrologic model the hydraulic model was developed to verify the RORB calibration.

3.4.2.6 Total Spatial Rainfall Patterns

Total hourly rainfall spatial distribution was utilised in order to determine the closest total rainfall gauges to each catchment. Datasets were interpolated to determine spatial mapping for the catchment and the gauges surrounding. This data was then calculated into a zonal format in order to determine the total rainfalls within each of the sub-catchments.

The accumulated total rainfall for the entire storm duration was determined for each rainfall station. These values were then mapped spatially and interpolated to create a raster surface as shown in Figure 3.9.

The distribution of rainfall was heaviest to the north-western and south-eastern sides of the catchment, with rainfall totals becoming weaker downstream of the catchment. A differential of 40 millimetres is observed over the catchment area.

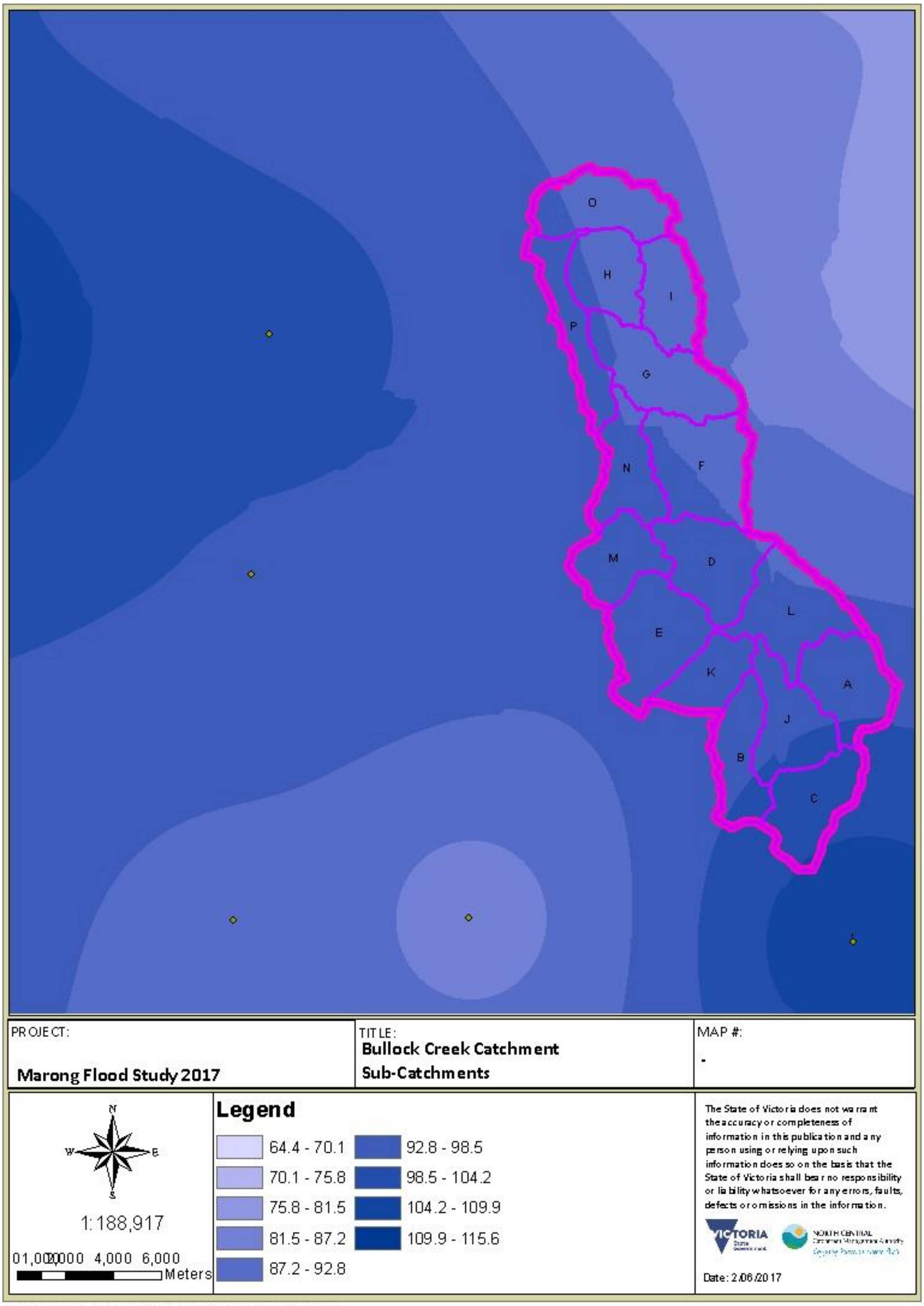


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Figure 3.9 Total rainfall distribution (in mm) through interpolation of the September 2016 flood event

3.4.3 January 2011 Flood Event Calibration

Given that there were no reliable streamflow measurements for the January 2011 event, this was not used in the hydraulic model calibration. However, using the rainfall recorded for the event it was possible to identify the intensity of the event and use it for calibration of the hydraulic model.

The peak total cumulative rainfall and the peak rainfall intensity recorded at gauge 406216 at 83.4 millimeters and 9.4 millimetres per hour (mm/hr) respectively as represented below in Figure 3.10 and Figure 3.11

For the 2011 event at gauge 406216, the cumulative rainfall shows the 2011 to be slightly higher than the 1% event. Given that the streamflow data is missing for this flood event, the rainfall data has allowed for comparison of the flood depths observed in the 2011 flood event with the hydraulic model.

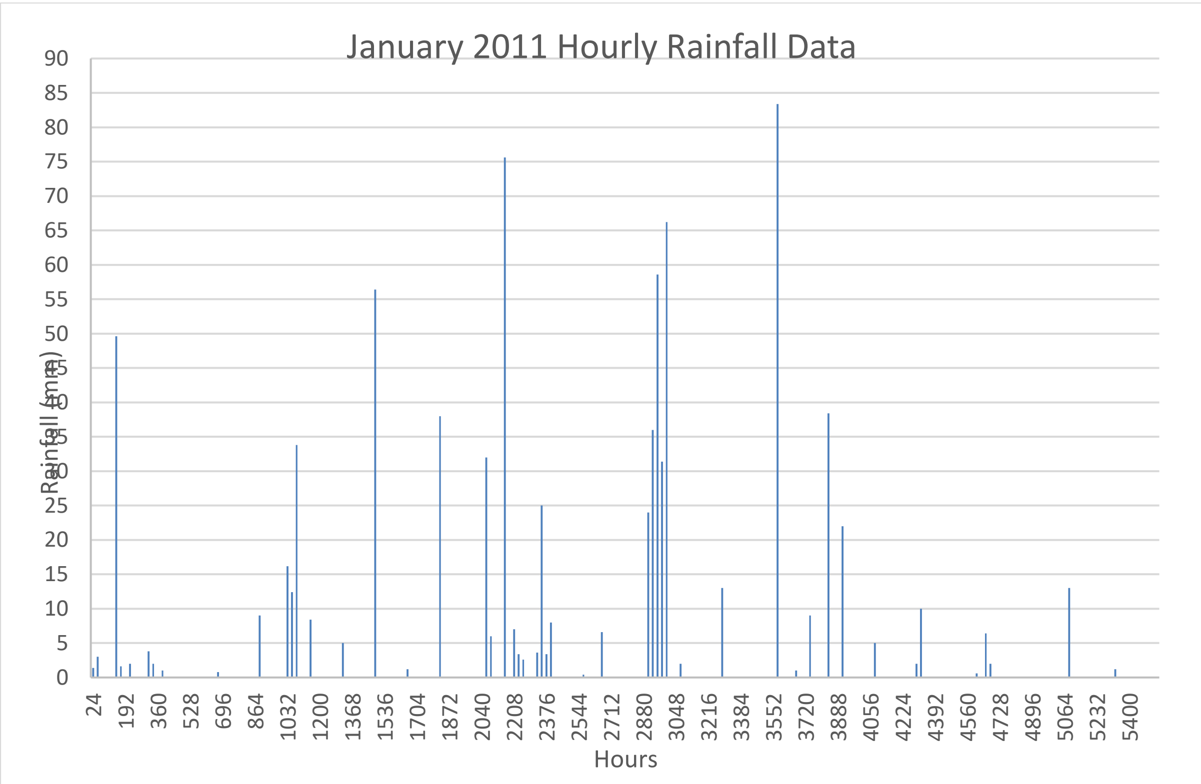

Figure 3.10 Rainfall for the 2011 flood event at gauge 406216

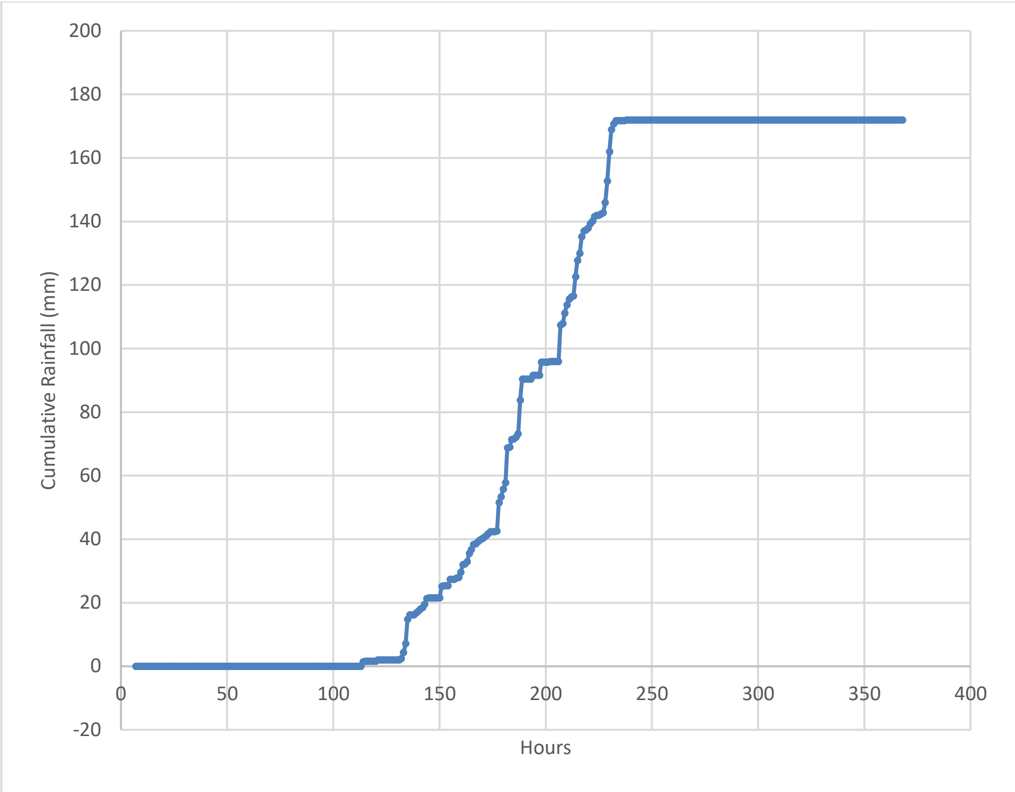

Figure 3.11 Cumulative rainfall at gauge 406216 for the January 2011 event

In Figure 3.11 the rainfall intensity for the 2011 flood event can be calculated with the grade of the curve, giving a rainfall intensity over 4 days of about 2mm/hr. When this intensity is compared with the IFD curve for Marong (see **Error! Reference source not found.**), it can be noted the rainfall intensity for the January 2011 event is slightly larger than the 1% AEP. This information was used to calibrate the hydraulic model as there is available the flood survey pegs as shown in Table 1.2.

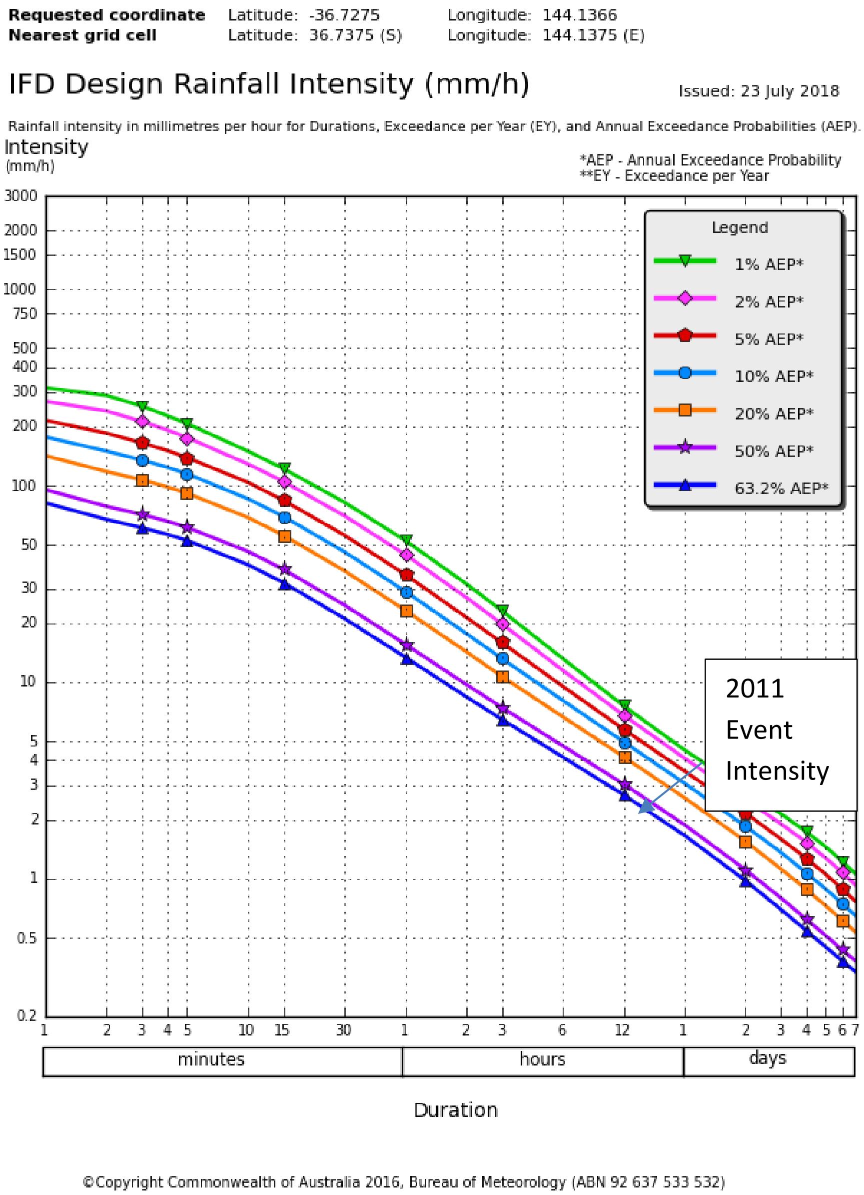

Figure 3.12 IFD curve for Marong in mm/hr

3.4.4 Discussion

3.4.4.1 Routing Parameter

All events were calibrated with a nonlinearity parameter, *m,* set to 0.8, which is the value commonly adopted for RORB models, this value was also adopted for the design runs.

The September 2016 event was calibrated to determine the most appropriate routing parameter, k_c.

The calibrated value of k_c was compared to a range of recommended prediction equations as shown in **Table 3.6**. This included the regional equations for Victoria as recommended in ARR 2016. Note that the catchment area (A) referred to in the estimation equations is 199km^2.

Furthermore, d_{av} provides an indication of the travel distance to the outlet of the RORB model and is given by the weighted average flow distance from all nodes to the catchment outlet. The value of d_{av} obtained for the Bullock Creek RORB model was 27.42km.

Table 3.6 Predicted Kc values for calibration of the September 2016 event

Method	Applicable Region	Equation	Predicted k_c
RORB Default Equation	Australia wide	$k_c = 2.2*A^{0.5}*(Q_p/2)^{0.8-m}$	30.99
Regional Equation	For areas where annual rainfall <800mm	$k_c = 0.49*A^{0.65}$	15.26
Regional Equation	For areas where annual rainfall >800mm	$k_c = 2.57*A^{0.45}$	27.79
Pearse et al. (2002) after Dyer (1994)	Australia wide	$k_c = 1.14*d_{av}$	31.25
Pearse et al. (2002) after Yu (1989)	Australia wide	$k_c = 0.96*d_{av}$	26.32

A review of the routing parameter estimates determined from alternative methods indicated that the parameters used in calibration were reasonable (Table 3.7). Therefore, the k_c value determined from the calibration was considered to be suitable for the design runs.

Table 3.7 Adopted RORB model parameters

k_c	m
24.8	0.8

3.4.4.2 Losses

The losses used in the calibration are shown in Table 3.8. The initial loss (IL) parameter was determined by trial and error to reasonably reproduce the observed rising limb of the hydrograph. Then, using the FIT option in RORB, a corresponding continuing loss (CL) was automatically determined in RORB to minimise the error between the calculated and observed hydrograph volume.

It should be noted that the design losses are not derived from the losses used for calibration. This is because the losses applied to these historical events depended on the antecedent conditions of the catchment.

Table 3.8 RORB calibration loss parameters September 2016 Event

IL (mm)	CL (mm/hr)
15	1.8

3.5 Design Event Modelling for Bullock Creek

For this study the 63.20%, 50%, 20%, 10%, 5%, 2%, 1% and 0.5% AEP events were determined. The inputs for design flood estimation are described throughout the following sections.

3.5.1 Design Model Parameters

Initially, a Monte Carlo analysis was run for Bullock Creek RORB model to determine the applicable design losses. The parameters used included the Intensity-Frequency-Duration (IFD) design rainfalls, temporal patterns, spatial patterns and Areal Reduction Factors (ARF). These values were used to calibrate the design losses by fitting the Monte Carlo peak flow estimates for the 50-1% AEP events at Bullock Creek at the Marong gauge to the values determined in the flood frequency analysis for this same gauge. The relevant inputs are described below.

3.5.1.1 Fraction Impervious

The fraction impervious values for the RORB subareas were based on the planning zones as described in Section 3.3.2. Unlike the calibration, these values were not refined using aerial photography as it represents the runoff potential based on future development in accordance with the planning scheme.

3.5.1.2 IFD

The relevant IFD was obtained from the Bureau of Meteorology website. Rainfall depth units were selected instead of intensity for the RORB input.

Additional durations were added to the IFD table to match the durations for which temporal patterns were available. The table was also expanded by adding the rainfall depths for rare events. At the time of writing, rainfall depths for events from 1 in 200 to 1 in 2000 AEP were not available on the Bureau of Meteorology's website for durations less than 24 hours. Hence, the method recommended in ARR, Book 8, Section 3.6.3 for estimating very rare sub-daily rainfalls was used. Sub-daily rainfall depths are determined by multiplying the relevant 1% AEP design rainfall depth for each duration by specific growth curve factors. ARR 2016 notes that due to the method used to derive these growth curve factors there may be the potential for significant discontinuity when compared to the values provided for durations of 24 hours and longer. As a result, it was necessary to smooth the growth factors to ensure the depths varied in a consistent manner across storm durations and exceedance probability. The growth curve factors were applied to the shortest durations and intermediary depths were smoothed between these values and those provided on the Bureau of Meteorology's website. A log graph displaying the smoothed results is shown in Figure 3.13.

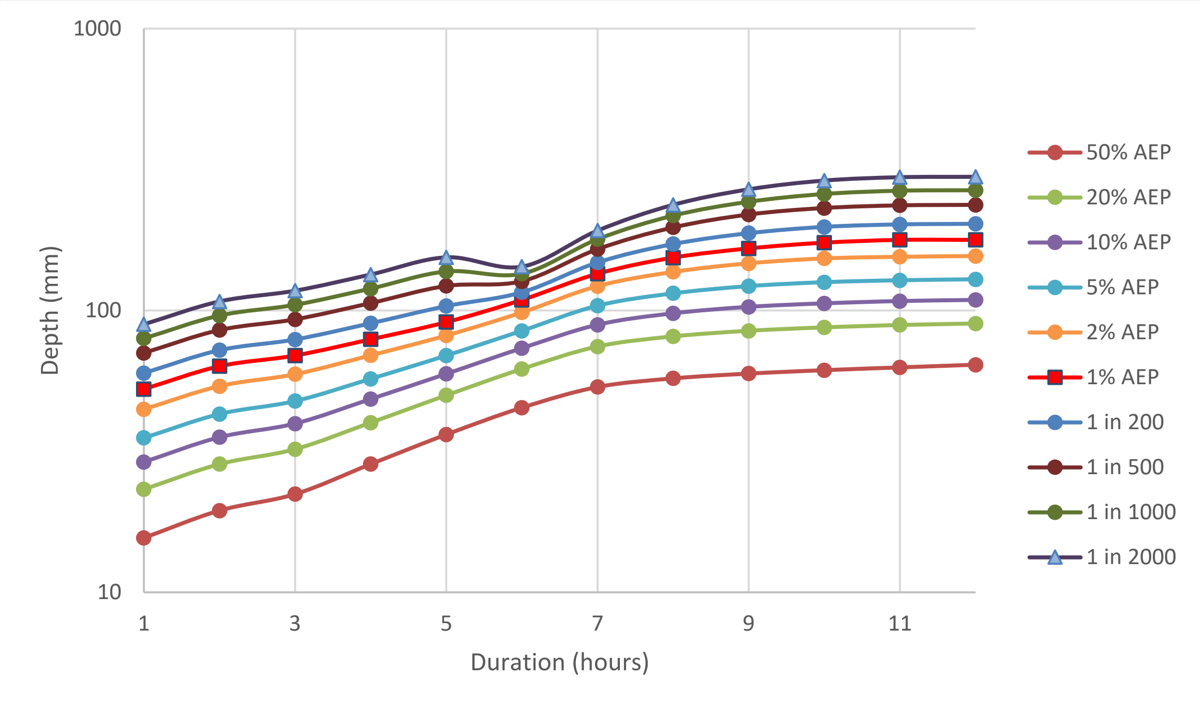

Figure 3.13 Log graph showing smoothing of depth-duration relationship for very rare rainfall events (1 in 200 to 1 in 2000)

3.5.1.3 Areal Reduction Factor

The Areal Reduction Factor (ARF) is the ratio between the design values of areal average rainfall and point rainfall. It is used to account for the fact that larger catchments are less likely than smaller catchments to experience high intensity storms simultaneously over the whole of the catchment area. The values applied were read into the RORB model from the Data Hub file.

3.5.1.4 Design Temporal Pattern

The temporal patterns have been assessed to determine if any contain outlying / erroneous embedded bursts which would cause the RORB model to overestimate the peak flows. This was done by comparing the sub-period rainfall totals of a particular temporal pattern against the IFD to determine whether it is rarer than the AEP of the entire burst.

The assessment used areal temporal patterns, as the catchment area for Bullock Creek is 199 Km^2. The temporal pattern sample is selected based on Table 2.5.9 from AR&R2016. In this case use 200km^2.

Areal temporal patterns were available for following storm durations: 12, 18, 24, 36, 48, 72, 96, 120, 144, and 168 hours. For each duration there are ten different temporal patterns, resulting in a total of 100 patterns available for modelling.

The analysis revealed that one temporal patterns contained outlying embedded bursts; pattern 3 from the 72-hour duration storm, pattern 2 and 5 from the 96-hour duration storm, and pattern 3 from the 120-hour storm. For example, pattern 5 from the 120-hour duration contained an embedded rainfall burst which was rarer than a 1 in 2000 AEP event.

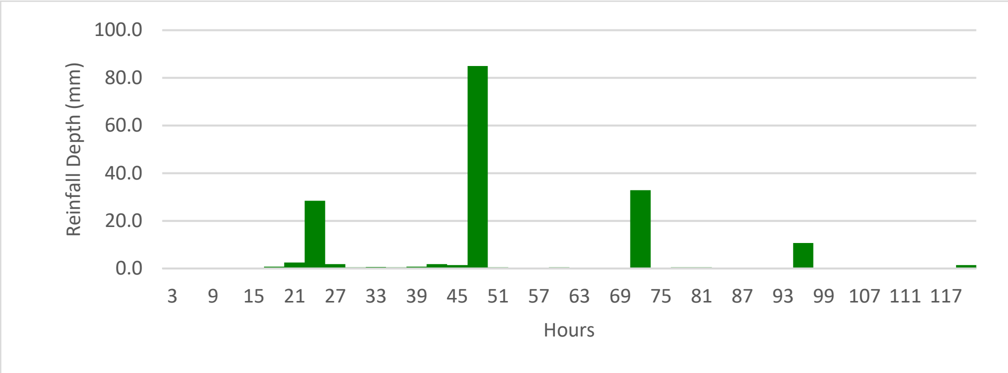

Figure 3.14 Rainfall temporal pattern 3 for the 120-hour duration, 1% AEP storm

As stated in *Addressing embedded bursts in design storms for flood hydrology* (Scorah et. al., 2016), "Censoring of temporal patterns which contain embedded bursts may be appropriate if the number of afflicted patterns is small." As the patterns with embedded bursts represent a small proportion of the total number of patterns available these embedded patterns were simply excluded from the modelling.

The figures below (Figure 3.15 and Figure 3.16) show a comparison of the calculated hydrographs when all the temporal patterns are included and those hydrographs when the temporal patterns are analysed to remove outliner or erroneous patterns.

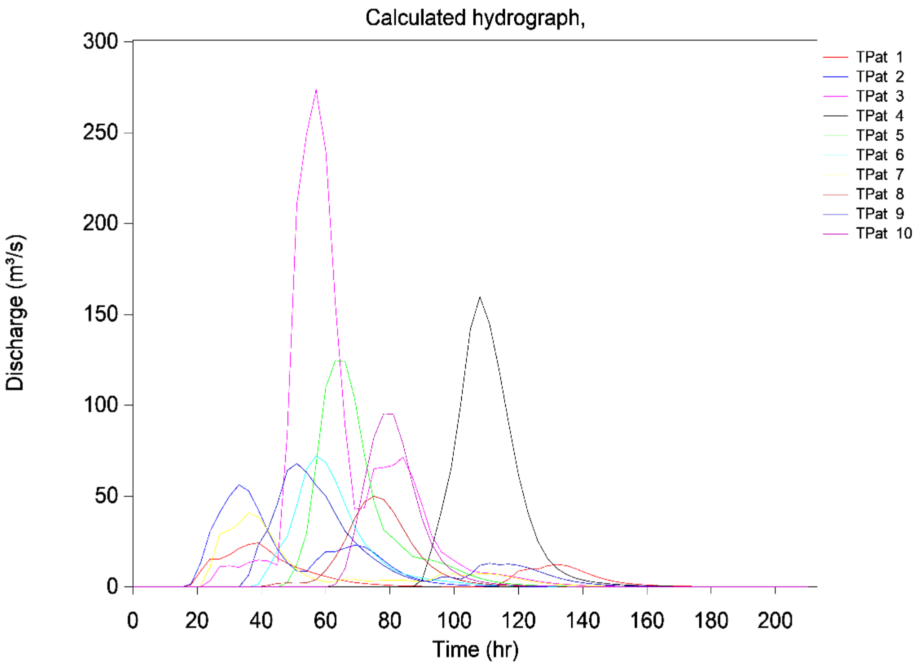

Figure 3.15 Calculated hydrograph for the 1% AEP 72-hour storm with all temporal patterns

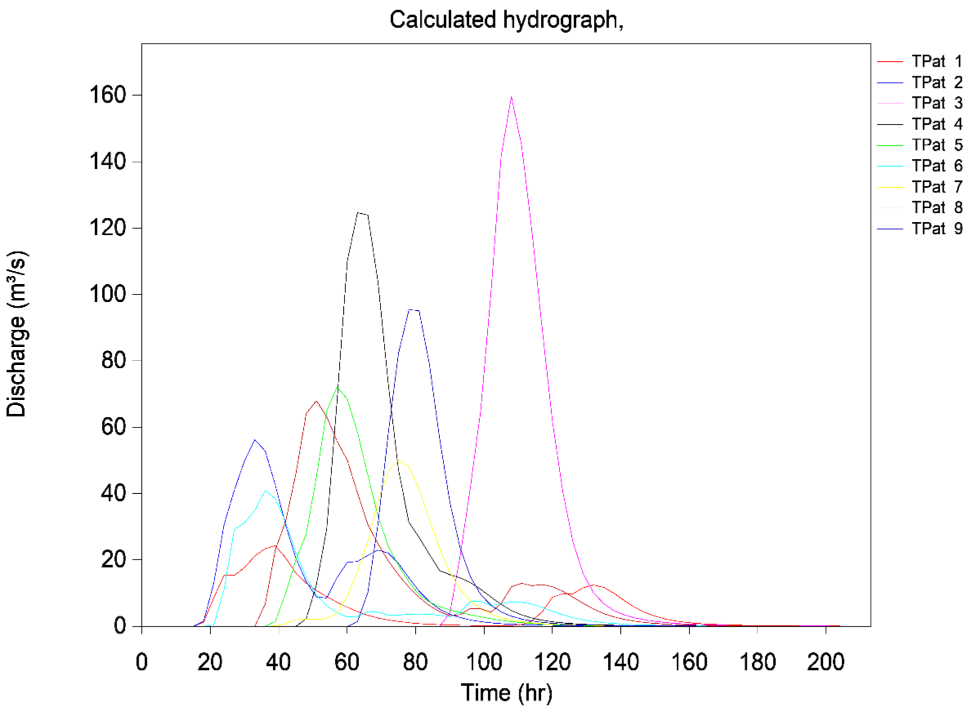

Figure 3.16 Calculated hydrograph for the 1% AEP 72-hour storm with the outliner temporal pattern removed

3.5.1.5 Design Spatial Pattern

As the catchment area was greater than 20km^2 and the AEPs modelled were not rarer than the 1% AEP event, the method recommended in ARR, Book 2, Section 6.3 was used to determine the design spatial pattern. The IFDs at each subarea centroid were extracted. Based on a preliminary model run with a uniform spatial pattern, the critical duration for the entire catchment was estimated to be 12 hours. Hence, the rainfall depth for each subarea corresponding to the 12 hour duration, 1% AEP storm was collated and used to determine the weighted average rainfall depth. The rainfall depths at each of the subareas were then divided by the weighted average rainfall depth to derive the non-dimensional spatial pattern. The spatial pattern used is shown in Table 3.9.

Table 3.9 Design spatial pattern for Bullock Creek catchment

Subarea	Area (km^2)	Rainfall (12hr, 1% AEP) (mm)	Rainfall x Area	Pattern
A	12.750	217	2766.7	114.93%
B	10.519	197	2072.2	104.34%
C	12.654	201	2543.5	106.46%
D	14.002	185	2590.4	97.98%
E	16.077	190	3054.6	100.63%
F	16.918	184	3112.9	97.45%
G	15.669	181	2836.1	95.86%
H	10.143	178	1805.5	94.27%
I	10.096	183	1847.6	96.92%
J	12.234	199	2434.6	105.40%
K	8.471	190	1609.6	100.63%
L	15.041	193	2902.9	102.22%
M	9.876	183	1807.3	96.92%
N	10.722	181	1940.8	95.86%
O	12.864	178	2289.8	94.27%
P	10.359	178	1843.9	94.27%
		Weighted Average Rainfall	**188.81**	

3.5.1.6 Simulation Parameters

In accordance with the calibration shown in Section 3.4, the model parameters used were k_c =24.8, m=0.80.

3.5.1.7 Design Losses

As recommended in ARR 2016 an Initial Loss/Continuing Loss model was applied to the RORB Monte Carlo analysis. To determine appropriate design loss values, a number of values were trialled and compared to the Bullock Creek at Marong gauge flood frequency analysis. The losses that achieved peak flow values close to the gauge flood frequency curve were selected for use in the design flow modelling.

For all trials loss factors were constant and not varied. That is, the initial loss (IL) and continuing loss (CL) were not factored depending on AEP or duration of the event. However, the initial losses were selected stochastically. The default initial loss distribution in RORB is shown in Table 3.10 and shows the initial loss factors exceeded a given proportion of the time (ARR, Book 5, Chapter 3, Table 5.3.13).

Table 3.10 Initial loss distribution

Proportion of time value is exceeded (%)	IL Factor
0	3.19
10	2.26
20	1.71
30	1.4
40	1.2
50	1
60	0.85
70	0.68
80	0.53
90	0.39
100%	0.140

The values trialled include the Data Hub recommended regional losses and losses specifically fitted to the gauge flood frequency curve. The loss values are presented in the following sections and the model results are compared in Table 3.12.

- **<u>Data Hub Loss Values</u>**

The regional loss values obtained from Data Hub are shown below:

- Storm Initial Loss = 18.0mm
- Continuing Loss = 2.4mm/hr

It should be noted that the initial loss is relative to the complete storm and not only the critical design burst that is used in the RORB model. Hence, the storm initial loss must be converted to a burst initial loss as recommended in ARR, Book 2, Section 5.9.9, using the following equation:

Burst Initial Loss = Storm Initial Loss – Preburst

The median preburst depths for different AEPs and durations were obtained from Data Hub and are shown in Table 3.11 below.

Table 3.11 Median preburst depths (mm) for various flood AEPs and durations

Duration (hrs)	AEP %					
	50	20	10	5	2	1
1	2.6	2.6	2.6	2.7	1.8	1.2
1.5	3.4	2.8	2.5	2.1	1.2	0.6
2	2.8	2.9	3.1	3.2	2.1	1.3
3	2.0	2.8	3.3	3.8	4.6	5.2
6	0.9	1.5	1.9	2.3	3.4	4.3
12	0.0	0.6	0.9	1.3	2.2	3.0
18	0.0	0.1	0.2	0.3	0.8	1.2
24	0.0	0.0	0.0	0.0	0.1	0.2
36	0.0	0.0	0.0	0.0	0.0	0.0
48	0.0	0.0	0.0	0.0	0.0	0.0
72	0.0	0.0	0.0	0.0	0.0	0.0

The expected critical duration of the catchment is 12 hours, therefore, a representative preburst depth of 3mm is selected, and the resulting applicable burst initial loss is 15mm.

<u>Loss Values Fitted to the Flood Frequency Analysis</u>

A Monte Carlo analysis was undertaken to fit the Flood Frequency Analysis. The Flood Frequency Analysis (FFA) is described in Section 3.2. A Monte Carlo run was undertaken for each combination of losses to determine the best fit. The results of the fitted losses are shown in Table 3.12.

Table 3.12 Comparison of flows at Bullock Creek @ Marong gauge for various design loss combinations

AEP (%)	Flood Frequency Analysis - Flike (m^3/s)	Fitted Design Losses IL = 15mm CL = 2.4mm/hr	Fitted Design Losses IL = 21mm CL = 2.4mm/hr	Fitted Design Losses IL = 21mm CL = 3.0mm/hr	Difference
50	12.7	13.3	18.1	14.2	4.7%
20	41.2	41.4	39.5	47.3	0.5%
10	60.1	64.4	61.0	72.7	1.6%
5	78.2	80.2	76.8	79.4	-1.7%
2	101.6	119	106.1	94.27	4.4%
1	119.2	144.53	131.9	117.7	-1.2%
0.5	136.7	176.16	174.3	150.6	10.2%

Using the results from Table 3.12 above, a final Monte Carlo analysis was run using the fitted continuing loss values with vary with AEP. The results are displayed in

Table 3.13 Comparison average flood frequency and the Monte Carlo analysis

AEP (%)	Flood Frequency Analysis - (m^3/s)	Calculated flow with Fitted Design Losses (m^3/s)	Difference
50	12.7	13.3	4.7%
20	41.2	41.4	0.5%
10	60.1	64.4	1.6%
5	78.2	80.2	-1.7%
2	101.6	94.3	4.4%
1	119.2	117.7	-1.2%

The RORB model has been calibrated to the gauge located at Marong for Bullock Creek using the September 2016 flood event. This calibration was used to determine the model parameters k_c and m. The design losses were calibrated by fitting the RORB Monte Carlo analysis results to the flood frequency analysis. Using these values, a RORB Monte Carlo analysis was rerun with parameters specific to the catchment including the applicable IFD rainfall data, spatial patterns and temporal patterns. The adopted design parameters are detailed in Table 3.14.

Table 3.14 Adopted design initial and continuing losses

AEP	Initial Loss (mm)	Continuing Loss (mm/hr)
50% - 20%	15	2.4
10% - 2%	21	2.4
1% - 0.5%	21	3.0

3.5.2 Design Flow Results

3.5.2.1 Monte Carlo Analysis

The design parameters detailed above were used to undertake a Monte Carlo simulation for the Marong catchment. The critical storm duration for the catchment was determined to be 12 hours. The results of the Monte Carlo flood frequency analysis (FFA) are shown in Table 3.15. These flows were generated at the upstream boundary of the model for the Township. The individual design runs used for the Monte Carlo analysis were then assessed to determine which provided the most similar peak flow to the FFA.

These run parameters were used to generate the complete hydrographs for the design floods ranging from the 50% - 0.5% AEP events. The design hydrographs are shown in Figure 3.17

below. It should be noted that the areal reduction factor (ARF) was not input into the individual design hydrograph runs as this factor is already incorporate into the rainfall depth parameter for each simulation run in the Monte Carlo analysis.

Table 3.15 Design runs for the Monte Carlo Analysis

AEP	Peak Flow from MC FFA (m^3/s)	Run	ARI (years)	Rainfall Depth (mm)	Temporal Pattern	Run Peak Flow (m^3/s)
50%	12.7	12hr, Div 3, Run 19	1.7	31.1	8	13.3
20%	41.2	12hr, Div 15, Run 19	4.3	43.9	5	40.7
10%	60.1	12hr, Div 21, Run 20	8.2	52.1	5	62.6
5%	78.2	12hr, Div 27 Run 16	18.1	61.7	1	77.7
2%	101.6	12hr, Div 33 Run 12	45.9	72.5	4	101.8
1%	119.2	12hr, Div 36, Run 15	80.6	79	10	119.7
0.5%	136.7	12hr, Div 40, Run 20	200.3	92.5	4	158.3

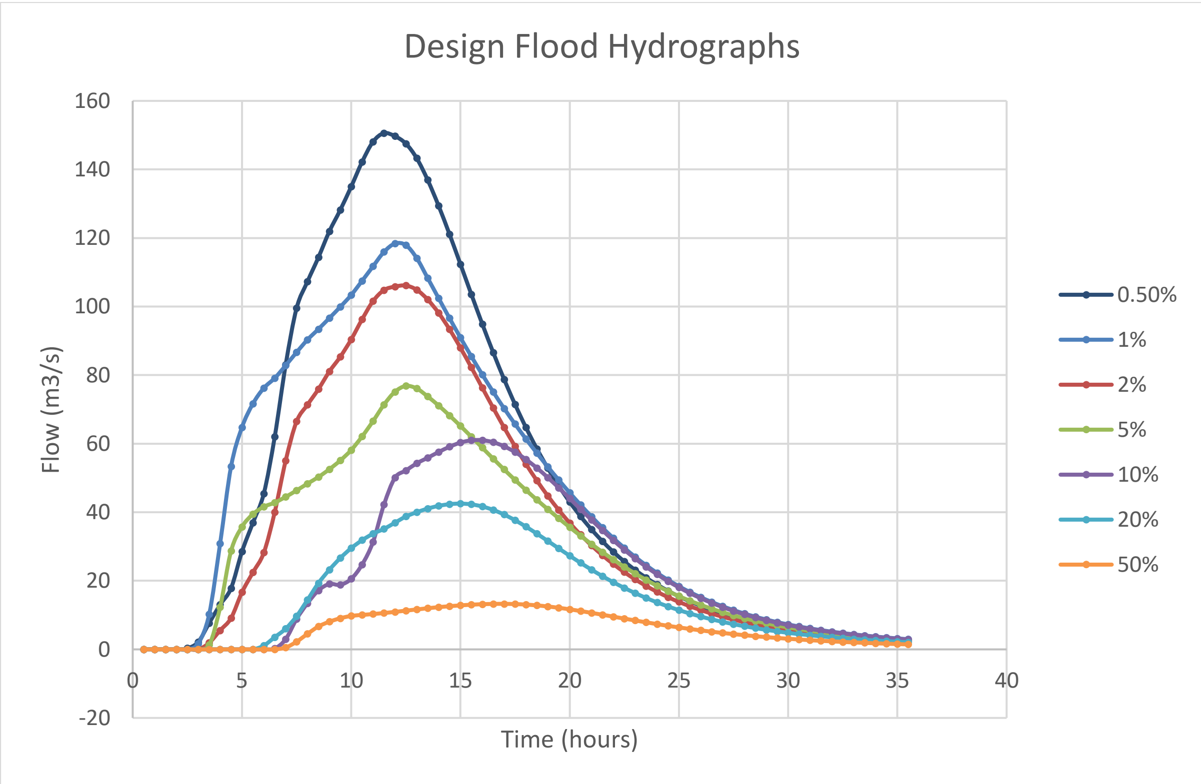

Figure 3.17 Design flood hydrographs for Marong

3.5.2.2 Ensemble Analysis

An ensemble assessment of the temporal patterns for the 1% AEP event was also undertaken for comparison with the Monte Carlo analysis. Ensemble analysis is generally used to determine the applicable temporal pattern to be applied to generate the design hydrographs. Ten areal temporal patterns for each storm duration were assessed. The results are presented in the box plot shown in Figure 3.18 . The box plot shows that the 12 hour duration is critical as it has the highest mean flow. Note that the highest peak flow for the 12 hour storm is 172.2m^3/s. However, this flow was not adopted and the flow of 119.2 m^3/s estimated with the FFA was used.

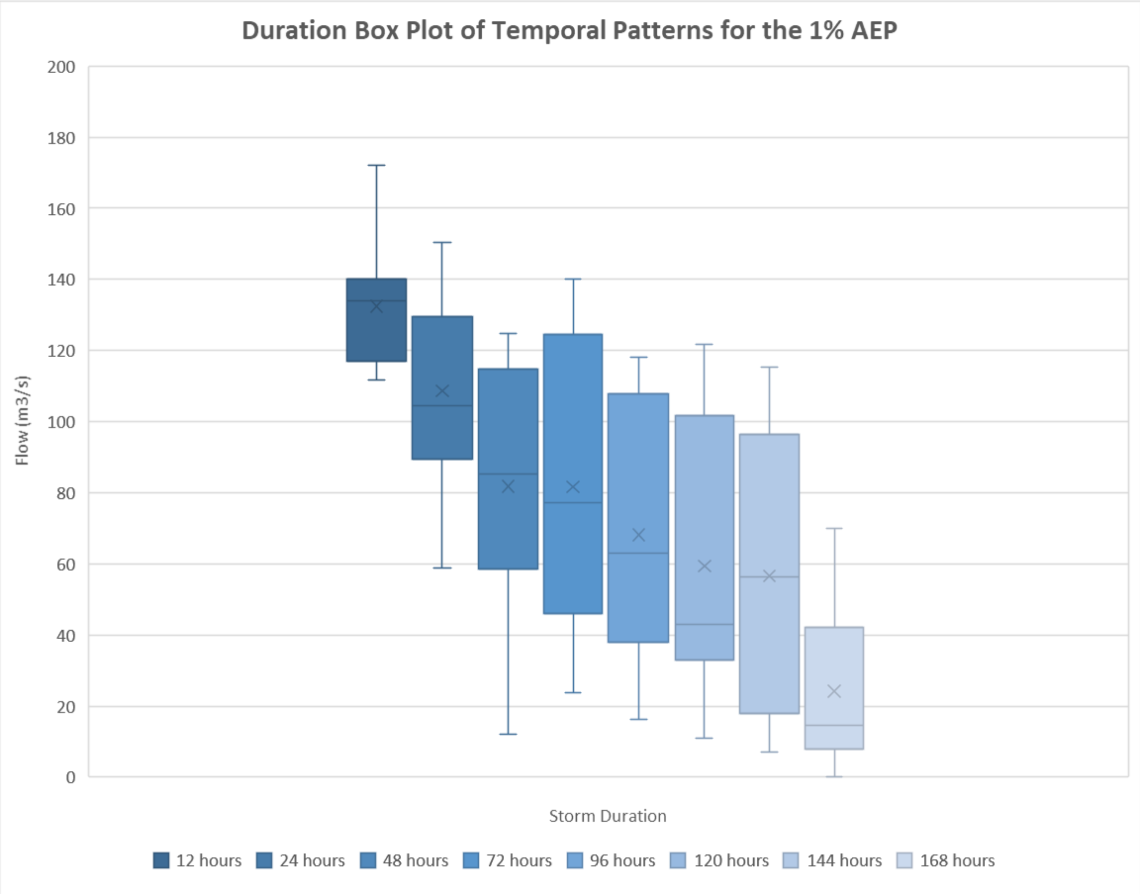

Figure 3.18 Duration box plot of temporal patterns for the 1% AEP design event.

3.5.3 Fletchers Creek Design Flows

The hydrographs for the hydraulic model required the flows from Fletchers Creek to be included as an input. Therefore, this location was obtained as an additional hydrograph print-out location.

The design parameters used to produce these hydrographs were the same as those adopted to generate the design hydrographs at Marong as this produces critical flows through township. The design hydrographs for Fletchers Creek are shown in Figure 3.19 below.

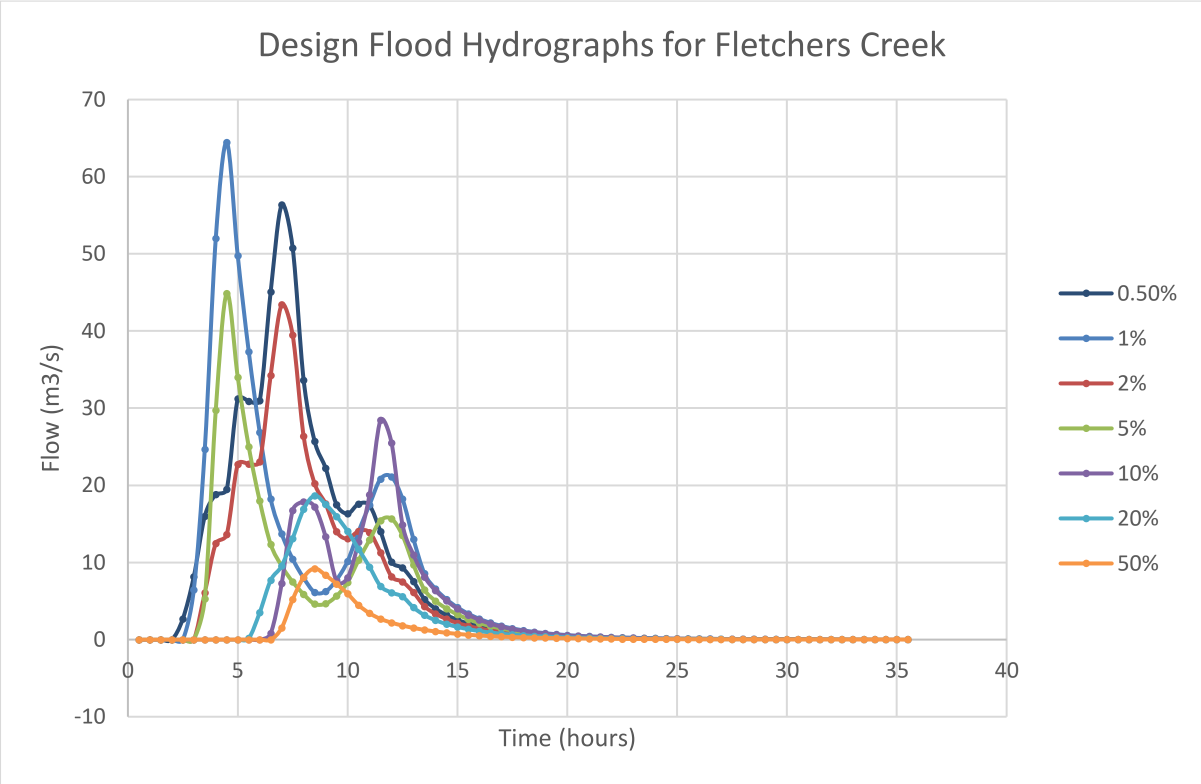

Figure 3.19 Design Hydrographs for Fletchers Creek

3.5.4 Summary

From the Monte Carlo analysis, the critical storm duration was determined to be 12 hours. The parameters used to generate the individual design hydrographs for the 50% - 0.5% AEP flood events are shown in Table 3.15. The corresponding hydrographs are shown in Figure 3.17 above.

The design hydrographs from Bullock Creek and Fletchers Creek were included in the model at the locations shown on Figure 3.20.

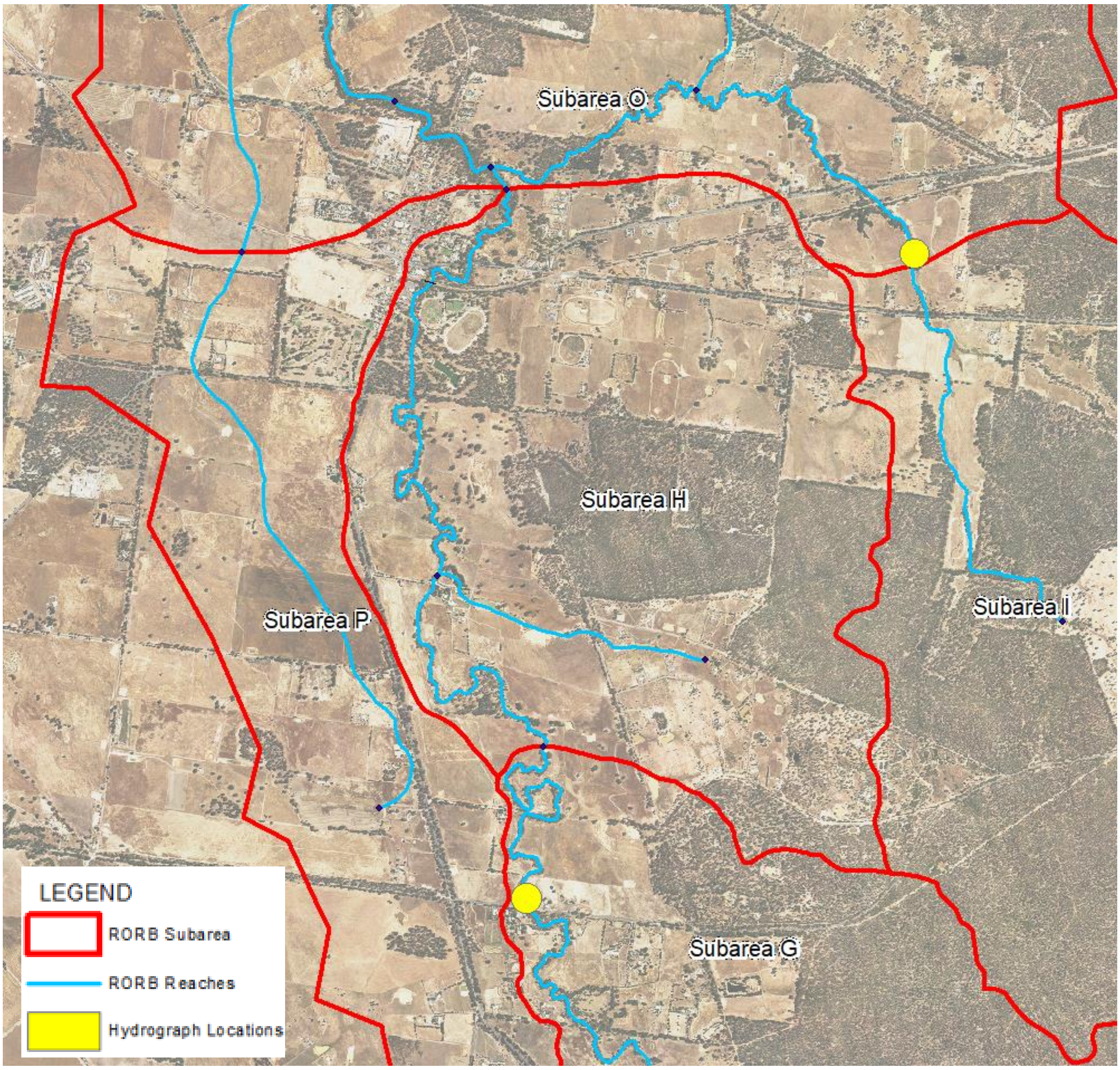

Figure 3.20 Locations of the design hydrographs in the hydraulic model

3.6 Design Flow Verification

The design flows are largely dependent on the adopted RORB model design parameters. Therefore, these flows were compared to several other peak flow estimates for verification. The methods used to verify the design flows generated from RORB included:

- Regional Flood Frequency Estimates
- BoM FFA
- Rational Method
- Generalised Extreme Value Distribution
- Gumbel (Extreme Value Type I) Distribution

- Log Pearson Type III Distribution
- Hydrological Recipes Estimate

3.6.1 Regional Flood Frequency Estimates

ARR 2016 recommends the use of the Regional Flood Frequency Estimation (RFFE) tool for estimating peak design flows. The RFFE tool was developed as part of the revision of ARR and is available on the ARR 2016 website. The tool requires the following inputs: catchment area, outlet location and catchment centroid location. Essentially, the RFFE approach transfers flood frequency characteristics from a group of gauged catchments to the location of interest. This estimation technique is limited to catchments that meet the following criteria:

- Catchment area is greater than 100km^2;
- Urban areas account for less than 10% of total catchment area;
- Catchment does not contain large storages. Small farm dams do not significantly impact on the estimate; and,
- Land use has not changed significantly.

The RFFE tool was used to estimate peak flows for the Bullock Creek Catchment 0.75 kilometers from the Marong stream gauge, see Table 3.16.

Table 3.16 Information regarding the project catchment area on RFFE

Distance of nearest gauged catchment (km)	Catchment Area (km^2)	Design rainfall intensity, 1 in 2 AEP and 6 hr duration (mm/hr)	Design rainfall intensity, 1 in 50 AEP and 6 hr duration (mm/hr)	Shape factor of ungagged catchment
0.75	199	4.79896	11.750289	0.57

The results for the AR&R RFFE Model 2017 for the reporting locations shown in Table 3.17 list the 1% AEP peak discharge as 157 m^3/s including a mean and standard deviation in Table 3.18. Due to the magnitude of this discharge it should be noted that the RFFE flows were only used as a comparison with other techniques.

Table 3.17 RFFE Results

skew	StDev	Mean	AEP (%)	0.95	Qy	0.05
0.098	0.609	3.597	50	105	36.0	12.2
			20	167	60.5	21.9
			10	224	79.9	28.6
			5	290	101	35.3
			2	396	131	43.9
			1	494	157	50.6

Table 3.18 RFFE parameters

No.	Mean	Std dev	Correlation		
1	3.597	0.653	1.000		
2	0.609	0.218	-0.330	1.000	
3	0.098	0.029	0.170	-0.280	1.000

3.6.2 Bureau of Meteorology Flood frequency

The projection exhibited by the FFA of the Bureau of Meteorology suggests that 1% AEP flow rate is approximately 93 – 94 m^3/s, as shown in Figure 3.21.

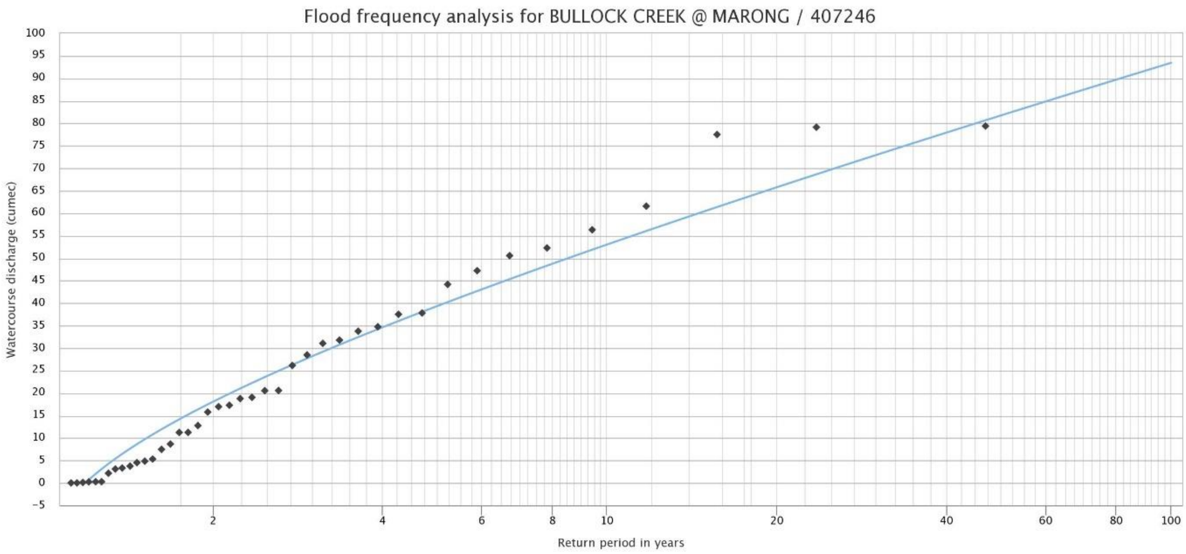

Figure 3.21 Flood Frequency Analysis associated with Water Data Online (BoM)

3.6.3 Gumbel (Extreme Value Type I) Distribution

The extreme value Type I distribution (Gumbel method) is a special case of the three-parameter GEV distribution. The following calculations were conducted using the formula below. This method produced a 1% AEP of 119.2 m3/s as can be seen in Table 3.19 and Figure 3.22.

Calculations:

$$F(x) = e^{-e^{-y}}$$

$$G(x) = 1 - F(x)$$

$$\frac{1}{T} = 1 - e^{-e^{-y}}$$

$$y = -In\,In\frac{T}{T-1}$$

The application Flike (Tuflow Flood Frequency Analysis Software) was used to undertake these calculations.

Table 3.19 Gumbel Method Flood Discharge Analysis

Return Period T (yr)	Probability P (percent)	Flood discharge Q (m^3/s)
2	50	12.7
5	20	41.2
10	10	60.1
25	4	78.2
50	2	101.6
100	1	119.2
200	0.5	136.7

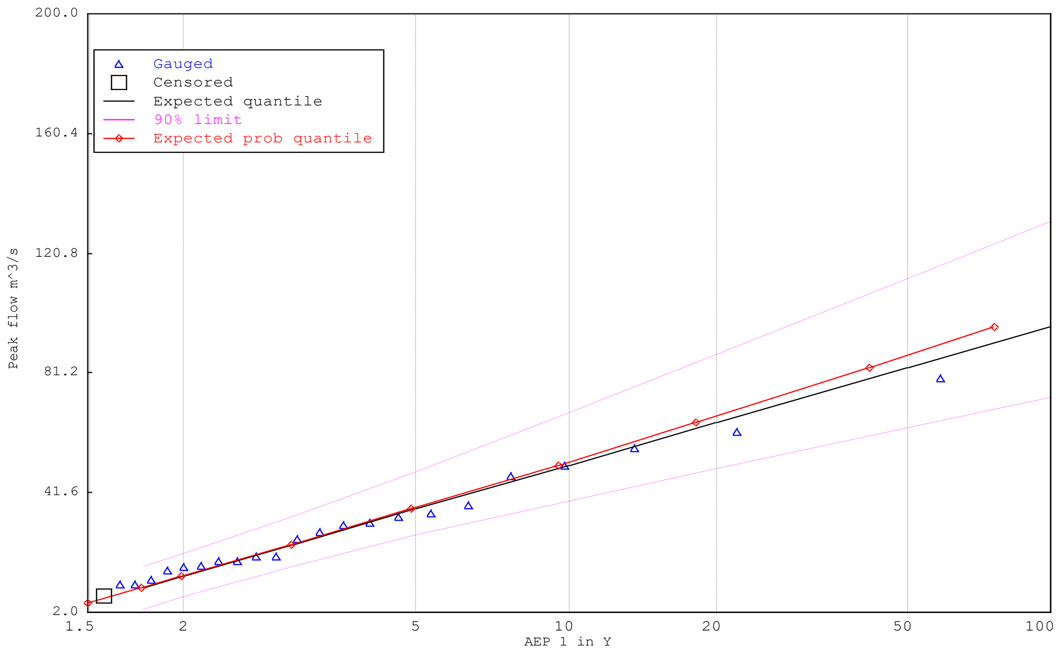

Figure 3.22 Gumbel Distribution

It is noted the 1%AEP estimated with the Log Pearson III distribution is considerable lower that the one estimated with the Gumbel distribution, however, the LPIII proved to be unsatisfactory for this catchment, whilst the Gumbel distribution show good correlation between the expected quantile and the gauged data (see Figure 3.22). Furthermore, the Gumbel Distribution has good performance when the sample size is less than 50, which is this case we have only 36 years of gauged data.

3.6.4 Log Pearson Type III Distribution

The program FLIKE was used to undertake the analysis of the Log Pearson Type III distribution.

Table 3.20 present the AEP quantile estimates and their 90% confidence limits. The results of the FLIKE flood frequency analysis indicate that the September 2016 (77.8 m^3/s) flood event was approximately 1% AEP flood event.

As discussed in section 3.2.2 this distribution was considered inadequate for the catchment and the data available. Furthermore, as shown in section 4.3.2 the hydraulic model was run with the calculated peak flow of 119 m^2/s has a good correlation with the 1% AEP flood event, therefore, the flow calculated with Log Pearson distribution was considered underestimated.

Table 3.20 Bullock Creek at Marong Log Pearson Type III results

AEP (%)	5% Confidence Limit (m^3/s)	Quantile Estimate (m^3/s)	95% Confidence Limit (m^3/s)
50	13	22	25
20	36	45	53
10	52	58	73
5	65	68	87
2	75	77	110
1	80	83	126

3.6.5 Probabilistic Rational Method (ARR87)

Although no longer recommended by ARR 2016, the probabilistic rational method was used to estimate the 1% AEP peak flows for comparison only. The calculations were undertaken in accordance with the technique described in ARR 1987, using the 1987 IFD values that apply to this method. The estimated flow was 147 m^3/s.

3.6.6 Hydrological Recipes Estimate

This method utilises a regional equation for the calculation of the 1% AEP event in rural catchments. The following equation estimated a 1% AEP of 265.1 m^3/s based on the catchment area of 199 km^2 to Marong of Bullock Creek in a rural catchment. This figure does not seem appropriate as the it is more than twice that of the other projected flood frequencies.

<u>Rural Catchment:</u>

$Q_{100} = 4.67 \times (area^{0.763})$

$Q_{100} = 4.67 \times (199^{0.763})$

$Q_{100} = 265.1$

<u>Urban Catchment</u>

$Q_{100} = 10.29 \times (area^{0.71})$

$Q_{100} = 10.29 \times (199^{0.71})$

$Q_{100} = 441.2$

3.6.7 Summary

Table 3.21 below shows the 1% AEP peak flow estimations for the catchment of Bullock Creek at Marong.

It can be seen that the RORB model results correlate well to the gauge flood frequency curve as it was calibrated to this. The RORB model results are lower that the RFFE, significantly lower that the Probabilistic Rational Method and the Regional Method for fully rural and urban catchments. However, the 1% AEP calculated flows using RORB are higher that the Log Pearson and BoM but shows very good correlation to those estimated with Gumbel distribution.

Table 3.21 Comparisons in Flood Frequency Analysis Projections

Technique	1% AEP projection (m^3/s)
RFFE	157m^3/s
Log-Pearson III Distribution	83 m^3/s
BoM FFA	93-94 m^3/s
Gumbel (Extreme Value Type I) Distribution / Flike	119.2 m^3/s
Probabilistic Rational Method	147 m^3/s
Hydrological Recipes Estimate	Rural Catchment: 265.1 m^3/s Urban Catchment 441.2 m^3/s
RORB Model	118.4 m^3/s

shows the comparison of the flow estimates undertaken by different methods. The flows from the hydrological estimates for rural and urban catchments were not included for clarity as they are considerable higher than all the other estimates. It can be noted that the design flows determined with the RORB model lie between the flood frequency analysis confidence of 5% and 95% and is in good alignment with most of the other estimates.

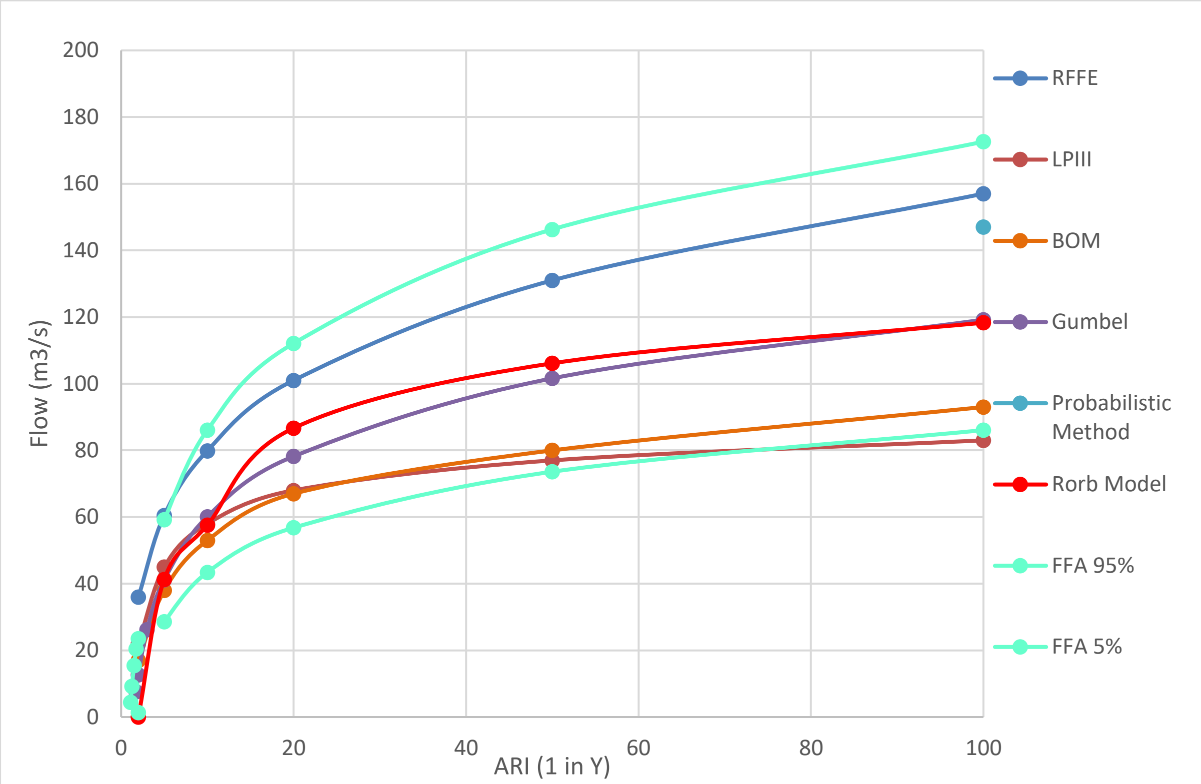

Figure 3.23 Comparison of design peak flow estimates for Bullock Creek

3.7 Climate Chanage Sensitivity Analysis

The RORB Monte Carlo analysis used to determine the design flows inherently accounts for variation in the temporal pattern, losses and rainfall depth by stochastic sampling. Hence, further sensitivity analysis on these parameters is not required.

However, ARR 2016 recommends that the potential impacts of various climate change projections be considered. This involves adjusting the IFD rainfall data to future climates by using the method recommended in ARR, Book 1, Section 6.3.5. This method is based on temperature scaling using temperature projections from the CSIRO and is preferred as climate models produce temperature estimates more reliably than individual storm events.

The Data Hub file includes the interim climate change factors to apply based on the different climate scenarios modelled and the planning horizon (shown in Table 3.22). The climate scenarios are based on Representative Concentration Pathways (RCPs) which describe the different concentrations of greenhouse gases and aerosols.

Table 3.22 Interim climate change factors for Marong

Planning Horizon	RCP4.5		RCP6		RCP8.5	
	Temp. Increase (°C)	Increase in Rainfall	Temp. Increase (°C)	Increase in Rainfall	Temp. Increase (°C)	Increase in Rainfall
2030	0.85	4.3%	0.845	4.2%	0.974	4.9%
2040	1.086	5.4%	1.05	5.3%	1.341	6.7%
2050	1.303	6.5%	1.283	6.4%	1.734	8.7%
2060	1.478	7.4%	1.539	7.7%	2.212	11.1%
2070	1.629	8.1%	1.775	8.9%	2.753	13.8%
2080	1.741	8.7%	2.036	10.2%	3.26	16.3%
2090	1.793	9.0%	2.316	11.6%	3.748	18.7%

For the sensitivity analysis, the planning horizon of 2090 was adopted. ARR, Book 1, Section 6.2 recommends the use of both RCP 4.5 and 8.5 to consider the impacts of low and high concentrations. Hence, based on these assumptions, the table above indicates 9.0% and 18.7% increase in rainfall for scenarios RCP 4.5 and 8.5 respectively.

Figure 3.24 below compares the resulting design flood hydrographs for the different climate change scenarios to the standard design hydrograph for the 10% and 1% AEP events on Bullock Creek. Table 3.23 displays the increase in peak flow for each of the climate change scenarios, which are greater than the corresponding increases in rainfall depths. For example, under scenario RCP 8.5 the rainfall is increased by 18.7% however the 1% AEP peak flow has doubled and exceeds the 0.5% AEP peak flow under current climate conditions. Similarly, the 10% AEP peak flow is increased to the equivalent of the 5% AEP peak flow under climate scenario RCP 8.5.

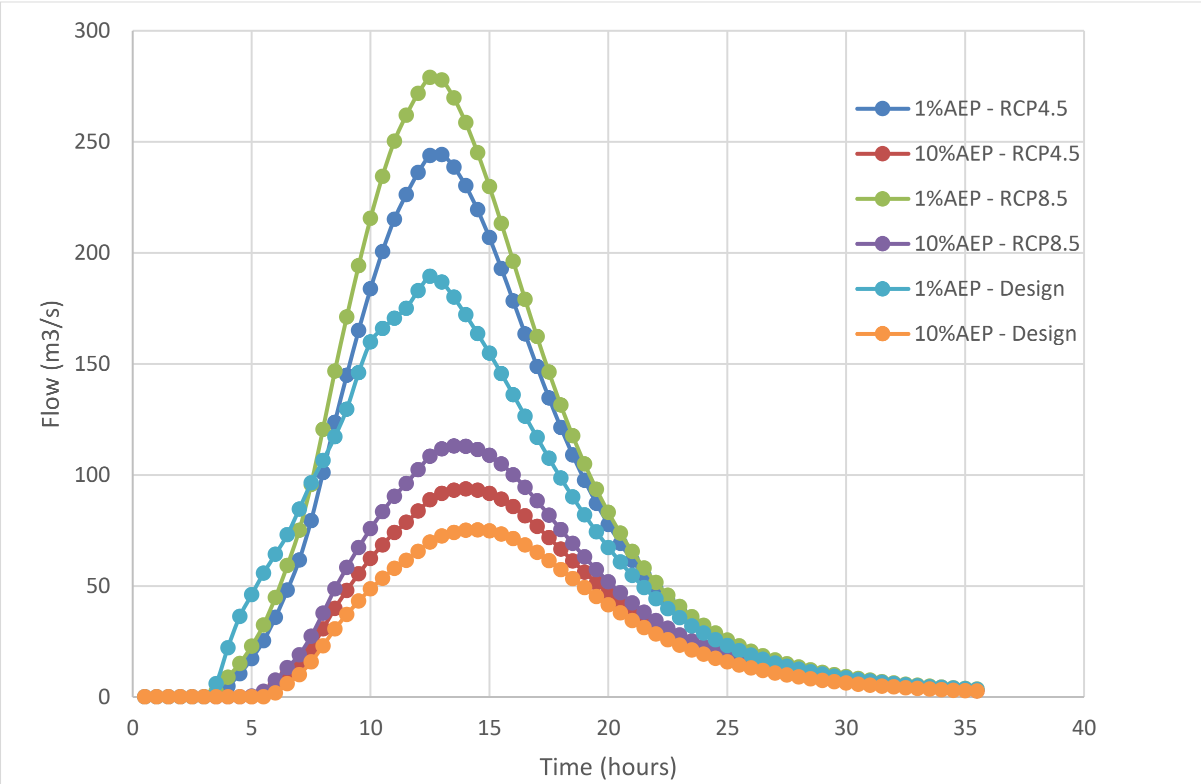

Figure 3.24 Hydrographs including climate change

Table 3.23 Comparison of climate change scenarios peak flows

	Design Peak Flow (m^3/s)	RCP4.5 Peak Flow (m^3/s)	Difference	RCP8.5 Peak Flow (m^3/s)	Difference
1% AEP Event	118.4	237.1	100%	273.1	130.6%
10% AEP Event	61.0	88.7	45.4%	108.6	78.0%

3.8 Probable Maximum Flood

Estimates of the Probable Maximum Flood (PMF) were determined using the regression equations recommended in *Hydrological Recipes* (Grayson et al., 1996). These equations allow the computation of a triangular PMF hydrograph based on the catchment area. This estimation method was derived from analysis of PMF estimates from 56 catchments in South Eastern Australia ranging in size from 1 - 10,000km^2. As Bullock Creek catchment has a catchment area within this range and do not have any significant storages, this method is directly applicable. The PMF peak flow estimate for Bullock Creek is 365 m^3/s.

Book 8 – 6.2.4 Preliminary Estimate of Rare to Extreme Events suggests applying a “quick” method when deriving approximations for the PMF design flood. As stipulated, the overall estimates should not be used for final design purposes, however, does provide an applicable location for flood extents. In this study the Regression Equations for Probable Maximum Floods in South Eastern Australia were utilised as follows.

$$Q_P = 129.1A^{0.616}$$

$$V = 497.7A^{0.984}$$

$$T_P = 1.062 \times 10^{-4} A^{-1.057} V^{1.446}$$

$$T_r = \frac{V}{1.8Q_P}$$

$Q_P = peak\ flow\ [m^3s^{-1}]$

$A = Catchment\ area\ [km^2]$

$V = hydrograph\ volume\ [ML]$

$T_P = time\ to\ peak\ of\ the\ hydrograph\ [hr]$

$T_r = length\ of\ hydrograph\ [hr] derived\ by\ mass\ balance$

The estimates for the Probable Maximum Flood peak flow is 3365 m^3/s, a hydrograph volume of 90999 ML, a time to peak of hydrograph of 5.84 hours and a length of hydrograph at 15 hours.

The PMF flow for Fletchers Creek is 536 m^3/s, a volume of 4839 ML, time to peak of 1.96 hours and a hydrograph length of 5 hours.

3.9 Summary of Design Parameters and Events

Based on the results of the calibration and validation runs of the RORB model, the parameters as detailed in Table 3.24 were adopted for estimating design flows at Marong. The design hydrographs adopted for the hydraulic model inputs are shown in Figure 3.25 below.

Table 3.24 Adopted Design Parameters and Design Peak Flow

Parameter	Value
m	0.8
kc	24.8
IL	15 for 50% - 20% AEP 21 for 10% - 0.5% AEP
CL (mm/hr)	2.4 for 50% - 2% AEP 3.0 for 1% - 0.5% AEP

AEP	Peak Flow (m^3/s)	
	Calculated at the inlet boundary of the model on Bullock Creek.	Fletchers Creek
20	42.5	18.65
10	61.02	28.4
5	76.84	44.86
2	106.12	43.41
1	118.37	64.46
0.5	150.58	56.34

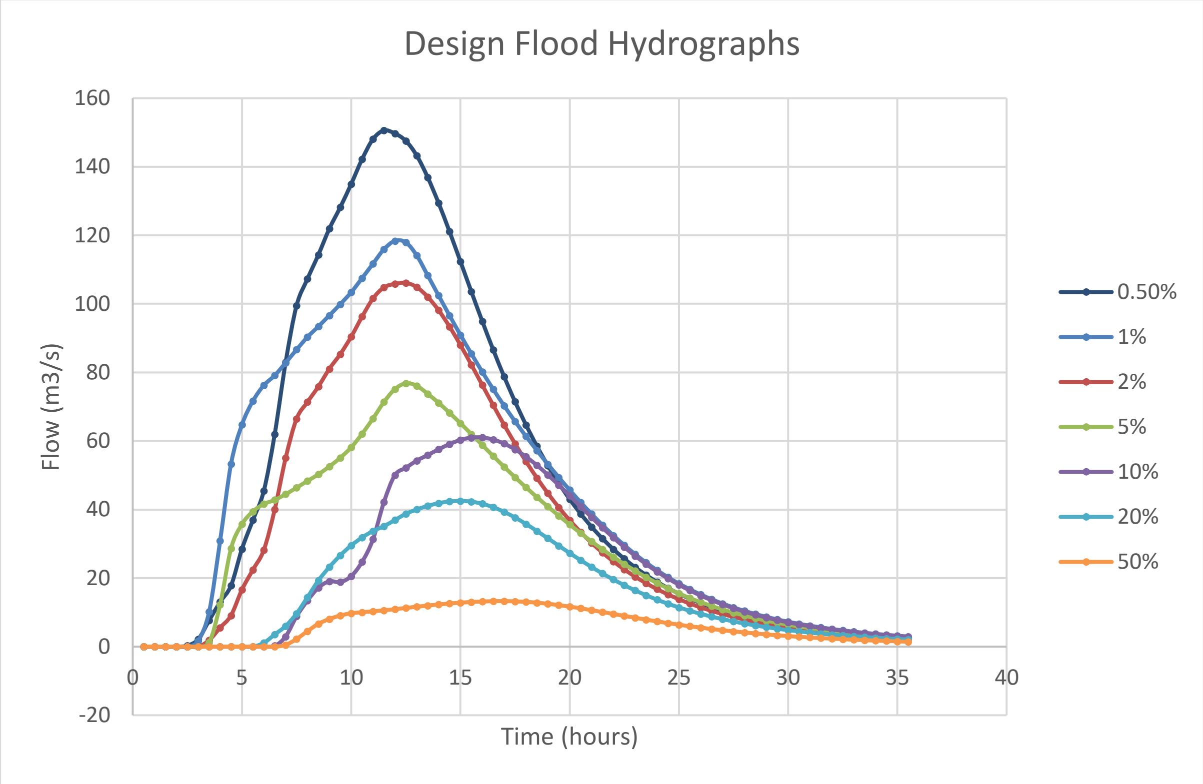

Figure 3.25 Design Hydrographs for Bullock Creek

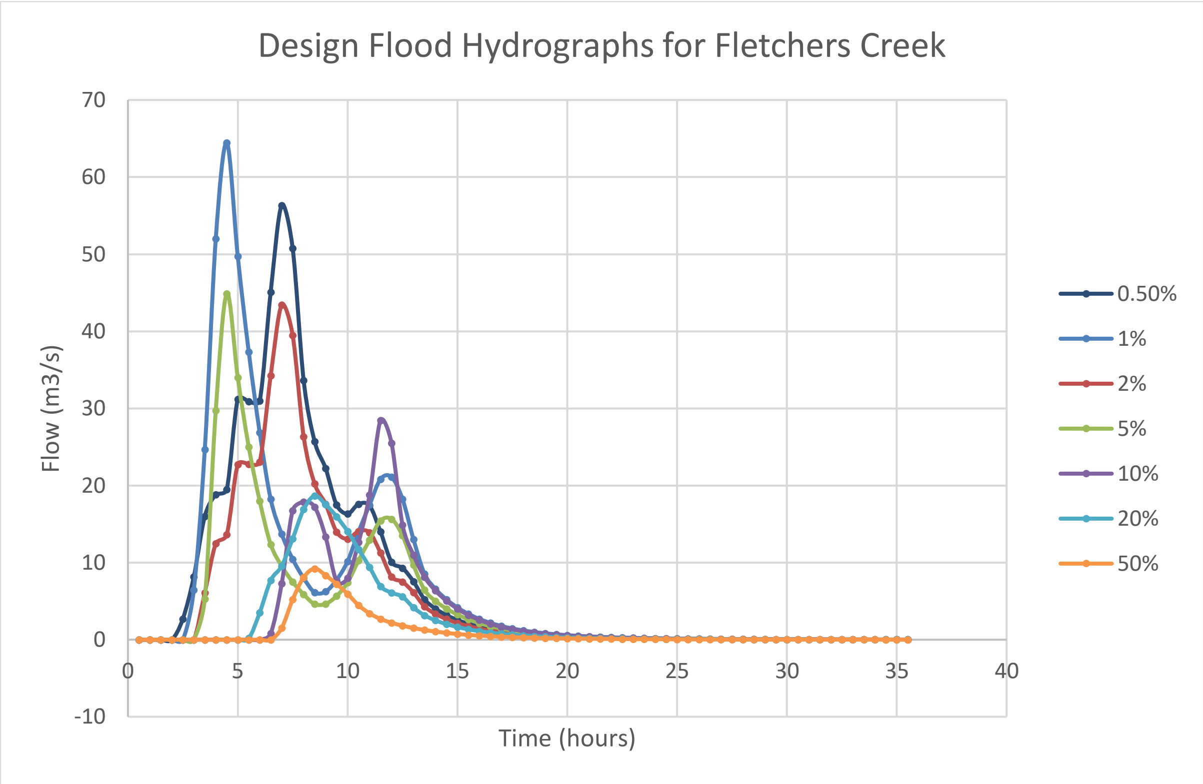

Figure 3.26 Design Hydrographs for Fletchers Creek

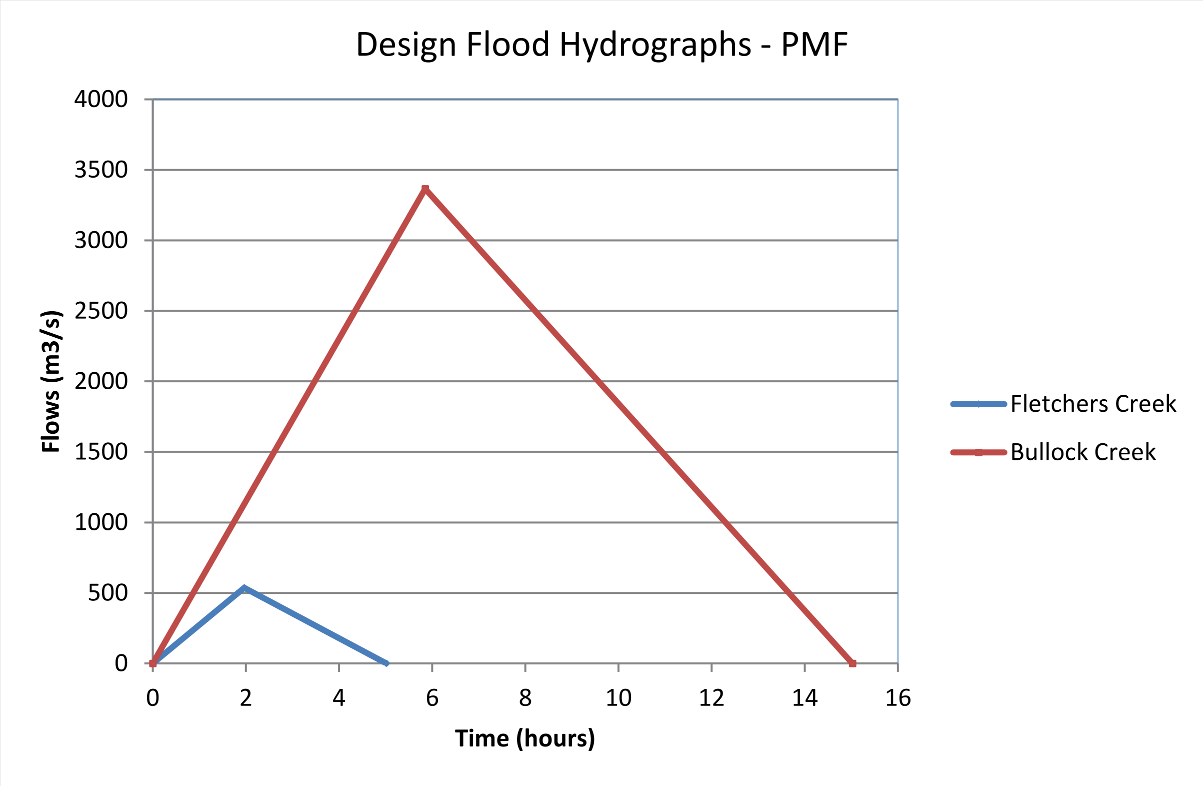

Figure 3.27 Probable Maximum Flood (PMF) hydrographs for Bullock and Fletchers Creek

4 Hydraulic Modelling

4.1 Overview

A detailed combined 1D-2D hydraulic model of Marong Township was developed to produce flood mapping for the calibration and design flood events. The calibrated hydraulic model simulates flood flow behavior of Bullock Creek and includes Fletchers Creek flows contributions. The following sections detail the hydraulic model setup, calibration and generation of design flood mapping.

4.2 TUFLOW Model Construction and Parameters

4.2.1 Model Overview

The hydraulic modelling software TUFLOW was used for this study. The model was run with the most recent TUFLOW build 2017-09-AB-iDP-w64.

TUFLOW is a floodplain modelling tool developed by BMT WBM which can model both 1D and 2D systems. The hydraulic modelling approach consisted of the following components:

- One dimensional (1D) hydraulic model of the culverts;
- Two dimensional (2D) hydraulic model of the waterways, broader floodplain and large multi-span bridges; and
- Links between the 1D and 2D hydraulic models to integrate the 1D hydraulic structures with the broader floodplain flow.

The major waterways, Bullock and Fletchers Creeks, were modelled in the 2D domain rather than as 1D elements due to the following advantages:

- Form, bend, contraction and expansion losses are explicitly accounted for.
- Velocity is calculated for each individual cell rather than averaged horizontally across the channel.

The TUFLOW model was created in GDA94/MGA Zone 55.

4.2.2 Modelling Parameters

4.2.2.1 Projection

The TUFLOW model was created in GDA94/MGA Zone 55.

4.2.2.2 Extent

The hydraulic modelling was preliminarily developed for the entire catchment, however, became filtered down to concentrated analysis around the project township of Marong. The presence of Fletchers Creek to the west of the township required a revised model extent as the backwater build up impacts may increase pressures on Marong.

The model extent comprises the township centre and local rural lots which is approximately 28.80 square kilometres in area. The town centre is 2.70 square kilometres and approximately 1.6 kilometres in length and width. Following Bullock Creek, the extent downstream reaches out approximately 4.26 kilometres and upstream approximately 7.58 kilometres.

A grid resolution of 2.5 metres was adopted as it captures the township characteristics with more detail whilst maintaining feasible run times.

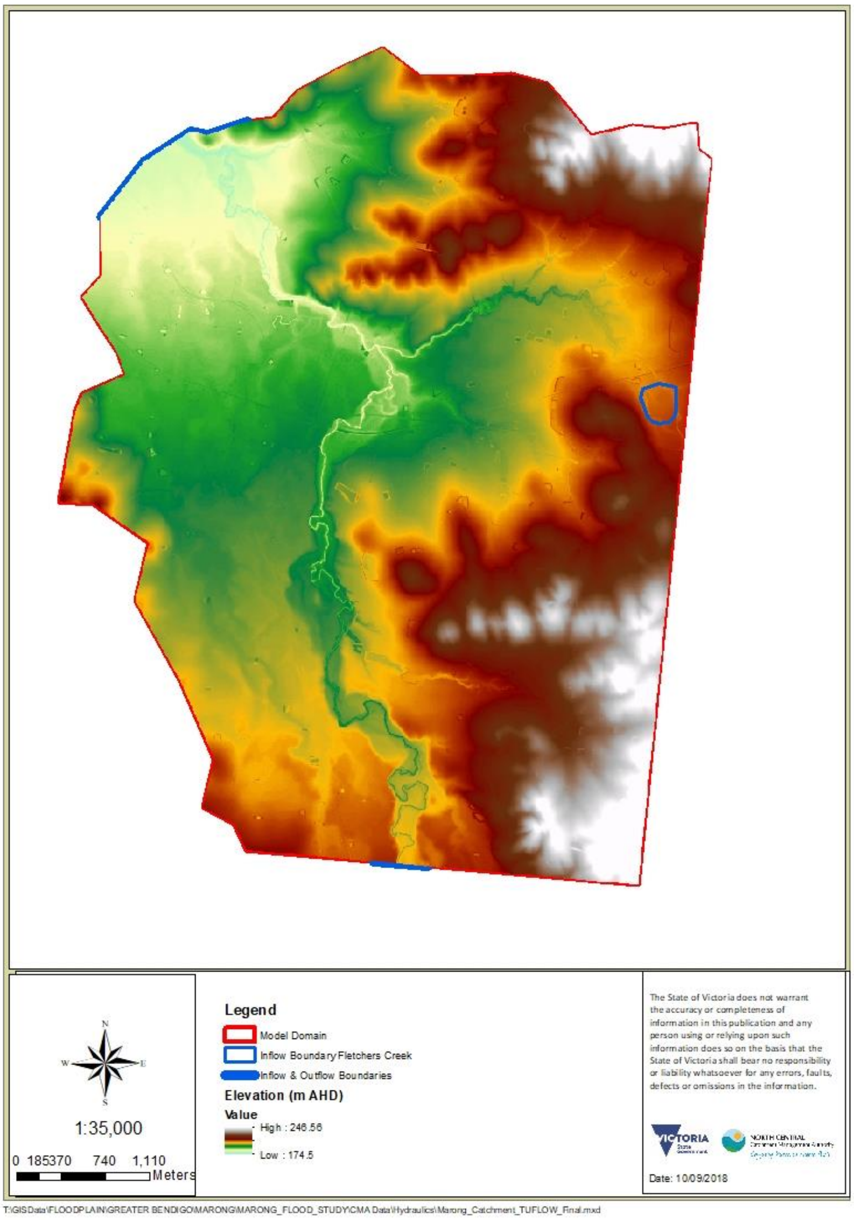

Figure 4.1 Hydraulic model extents

4.2.2.3 Topography

The topographic data available for the location was primarily LiDAR. The statewide DEM dataset was inappropriate due to the uncertainty in results and resolution. The CoGB_20m LiDAR was trimmed to cover only the area of interested and was converted to DEM resolution to comply with parameters set by TUFLOW.

Due to LiDAR's incapability of penetrating water there is no datasets for the topography within Bullock Creek. As this creek is not a large body of water the bathymetric data is not necessary and therefore the use of the LiDAR dataset was deemed acceptable.

4.2.2.4 Timestep

The timestep selected is critically important for the stability and accuracy of the model. The Courant Number is a measure of the model stability and, for a 2D square grid, is defined as:

$$C_r = \frac{\Delta t\sqrt{2gH}}{\Delta x}$$

where, *Δt = timestep (s)*
Δx = cell size (m)
g = acceleration due to gravity m/s^2
H = depth of water (m)

For most real-world applications, the Courant Number generally needs to be less than 10 and is typically around 5 for a 2D scheme. In order to achieve this criterion, the computational timestep is typically set to between one half and one quarter of the cell size (TUFLOW Manual 2010, pp. 3-8 – 3-9). For this model, a 2.5 metre cell size was chosen and the 2D timestep used was 1.5 seconds. The 1D timestep was set to half the 2D timestep as recommended in the TUFLOW Manual, that is 0.75 seconds.

4.2.2.5 Runtime

The model was run long enough for the input hydrograph to peak and for the peak to be conveyed through the model to the outlet. The entire hydrograph was not required to be completely run through the model as the primary cause of flooding for the study area is due to conveyance of the peak flow rather than due to the volume of flood water conveyed. The typical runtime for the hydraulic model was 35 hours.

4.2.2.6 Hydraulic Roughness

Hydraulic roughness's were initial assigned as a Manning's n value based on the current land use zoning. These values were further refined based on aerial photography and knowledge of the area.

Two scenarios were run, one using the current land developments and a future design model which includes the proposed developments highlighted in the “Marong Township Structure Plan” developed by City of Greater Bendigo.

The Manning’s n values adopted were based on standard industry values and are shown in Table 4.1.

The Bullock Creek catchment comprises many differing categories of vegetation density, road reserve density, water bodies (dams), agricultural and pastoral land and industrial /commercial areas. This provides a variable roadmap of Manning’s values to input into the model area, see Figure 4.2.

Table 4.1 Manning’s values for the TUFLOW hydraulic model area

Material ID	Manning's n	Description
1	0.02	Local and/or major roads - with no road reserves
2	0.03	Local and/or major roads - with low vegetated road reserves / industrial
3	0.03	Ponds and other water bodies
4	0.035	Agricultural and pastoral farming
5	0.04	Local and/or major roads - with high vegetated road reserves
6	0.05	Scattered brush
7	0.06	Light brush and trees
8	0.06	Public Park and Recreation Zone Public recreation and open space
9	0.06	Waterway with scattered vegetation
10	0.06	Low density residential
11	0.08	Waterway with moderate vegetation
12	0.085	General residential
13	0.09	Waterway with high vegetation
14	0.1	Dense Bushland
15	0.1	Rural residential

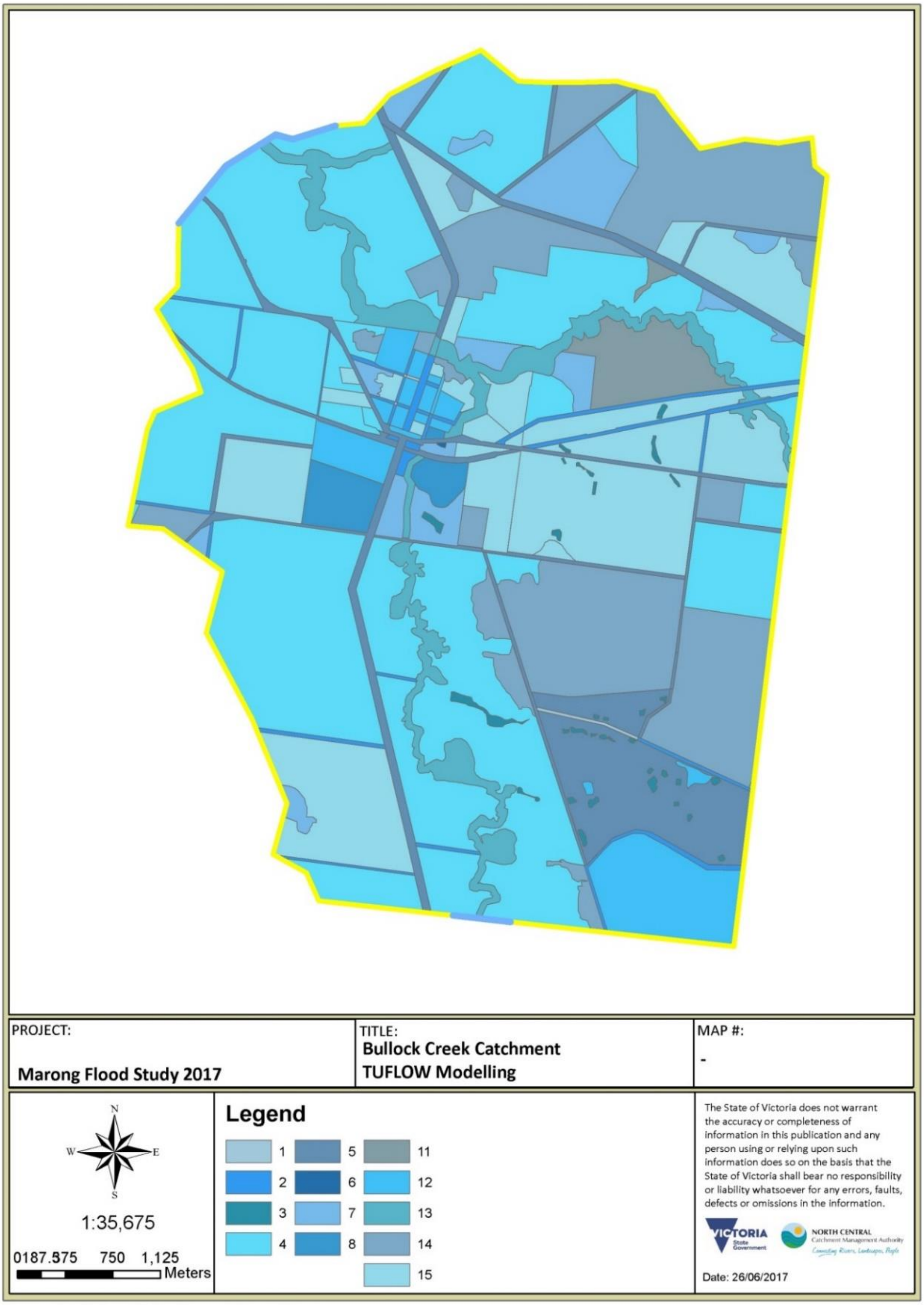

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Figure 4.2 Manning's values for the TUFLOW hydraulic model area – Existing Scenario

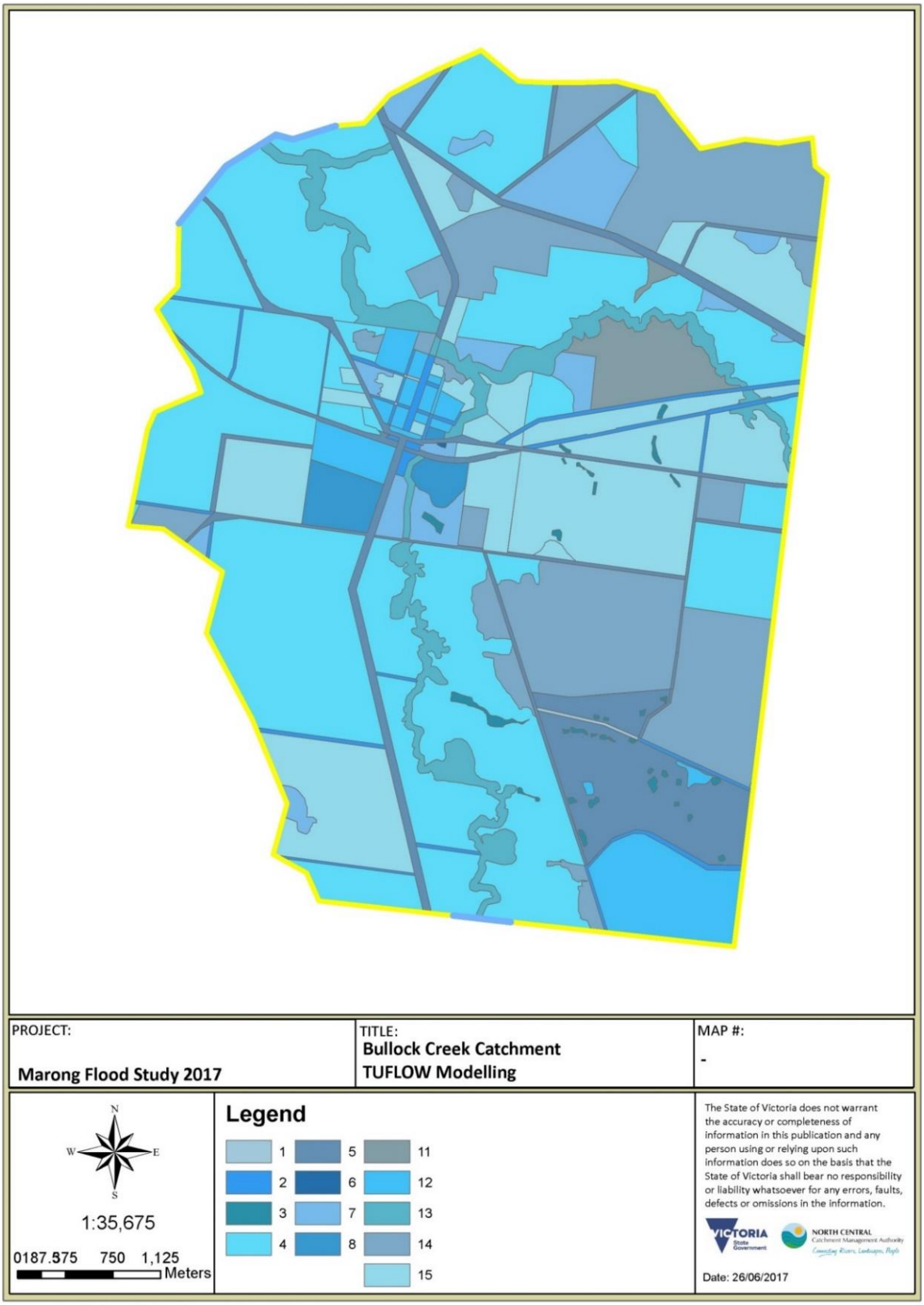

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Figure 4.3 Manning's values for the TUFLOW hydraulic model area – Development Scenario

4.2.3 Boundary Conditions

Inflow boundary conditions were placed at two locations one in the upstream edge of the model with the hydrographs associated with Bullock Creek. A second inflow boundary for Fletchers Creek. The hydrographs for Bullock Creek were determined from the hydrologic analysis of the catchment and include the Rainfall and Runoff modelling, local catchment flows, the Bullock Creek Streamflow gauge and flood frequency analysis. The inflow boundaries can be seen in Figure 4.4 below.

The outflow boundary is located directly downstream of Marong after the congruence of Bullock and Fletchers Creek.

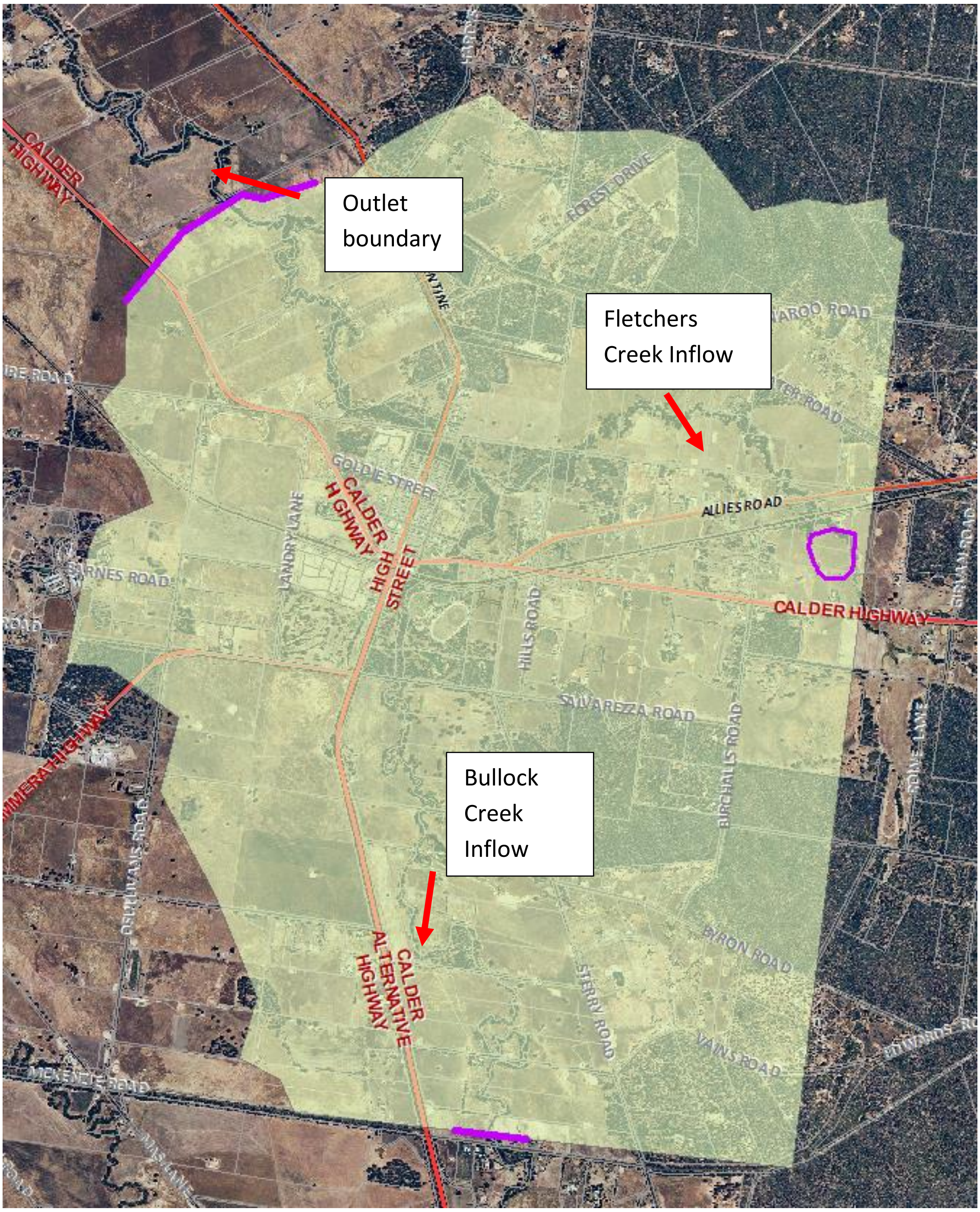

Figure 4.4 Location of Boundary conditions for the hydraulic model

4.2.4 Structures

The model included a number of hydraulic structures that impact on flood behaviour. The height of weirs was determined from the LiDAR and incorporated into the model topography using breaklines. Culverts were input as 1D elements coupled to the 2D model domain; however, flow over the top of the culverts is simulated in the 2D model domain. Plans of these structures were received from the asset owners and invert levels were estimated based on site inspections and comparisons with the LiDAR data. Large bridges were modelled as 2D layered flow constrictions with the appropriate losses adopted from *Hydraulics of Bridge Waterways (1978).*

The head loss across each of the bridges modelled in 2D was assessed to ensure the adopted loss factors were reasonable. The head losses for each bridge for both the 10% and 1% AEP design events are shown in Table 4.2 below.

Table 4.2 Head loss across structures

Structure	Head Loss in 10% AEP Event (m)	Head Loss in 1% AEP Event (m)
Bridge 01 - Bridge over Bullock Creek on Calder Highway	0.20	0.25
Bridge 02 - Bridge over Bullock Creek on Serpentine Road	0.25	0.35
Rail Bridge - Historic Rail Bridge	0.20	0.35
Culvert 01 - Culvert under Calder Highway	0.30	0.50

4.3 Hydraulic Model Calibration and Validation

4.3.1 Overview

The hydraulic model was calibrated to the January 2011 flood event as this was the largest event which there were known sufficient flood levels to calibrate the model. There is however, a level of uncertainty given there was not sufficient gauged data for this event.

The calibration was undertaken with an initial run of the 1% AEP event with the design flows calculated using RORB. This hydraulic model included the structures within Bullock Creek as described in Section 4.2.4 . The results from the TUFLOW model were compared to the to the pegging undertaken by North Central CMA team members during the 2011 flood event. Knowing that the 2011 flood event was slightly higher than the 1% AEP as discussed in Section 3.4.3 it was expected the flood levels to be slightly lower than those on the pegs. A comparison of the 2011 flood event observations and the design TUFLOW model is described below.

The input hydrographs used in the hydraulic model for each event are shown in Appendix **Error! Reference source not found.**.

Calibration and validation was based on the flood pegs for the 2011 flood event and anecdotal observations gathered from the community. A site inspection and community consultation provided valuable information regarding the flood behavior during recent flood events. The following sections describe the hydraulic calibration and validation by comparing the modelled results to the historical observations for each event.

4.3.2 Comparison of 1% AEP model and observed 2011 flood event

The RORB hydrologic model was used to generate hydrographs for different events. Given that the hydrograph for the January 2011 flood event was not available but according to the analysis as discussed in Section 3.4.3 the January 2011 is expected to be approximately the 1% AEP flood. The hydrograph calculated with the hydrologic model is shown in Figure 4.5. The hydrographs were then input into the TUFLOW hydraulic model at the corresponding inflow boundaries. The mapping outputs were compared to the historical evidence to calibrate the hydraulic model. The location of the available calibration data is shown in

Figure 1.4 and the calibration at each of these locations is detailed in Table 4.3 below.

Table 4.3 shows the comparison of the flood levels between the 2011 flood event and the design 1% AEP model. Most of the modelled water surface elevations present good correlation with the flood levels surveyed for the 2011 flood event.

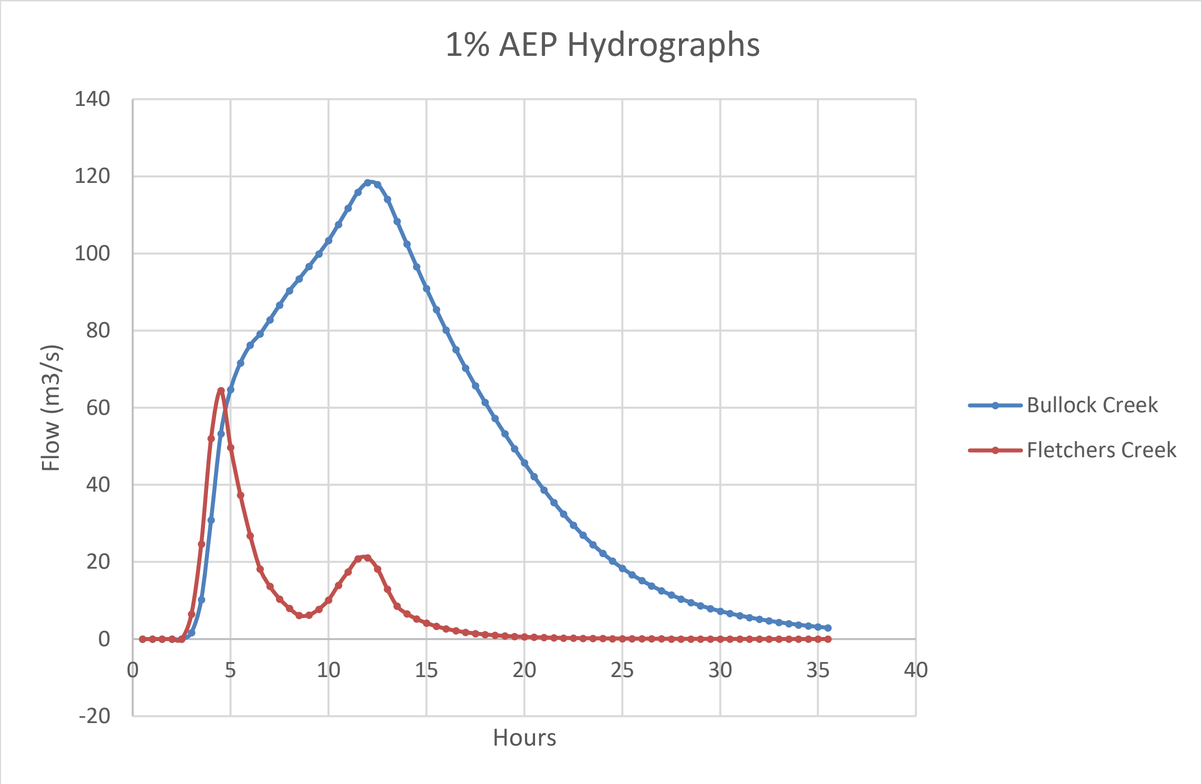

Figure 4.5 Inflow hydrographs for the 1% AEP flood event

Table 4.3 Comparison with survey flood depths for the January 2011 event

Survey Point	2011 Flood Level (m AHD)	1% AEP design Flood Level (m AHD)	Difference (%)
BULF001	186.24	186.2	0.02
BULF002	187.87	187.7	0.09
BULF003	184.99	185.1	-0.05
BULF004	185.57	185.5	0.03
BULF005	186.07	-	-
BULF006	186.43	186.3	0.06
BULF007	186.01	-	-
BULF008	186.57	186.5	0.03
BULF009	186.55	186.4	0.08
BULF010	187.52	186.2	0.07
BULF011	187.55	187.1	0.2
BULF012	188.03	-	-
BULF013	185.6	185.8	-0.1
BULF014	185.24*	185.8	-0.3

In the table above, there are three locations where there is no level as the extents of the modelled scenario didn’t reach the extents of the 2011 flood event in those locations. There are three locations (BULF003, BULF013 and BLF014) where the modelled elevations are higher than the data taken in the 2011 flood event.

The figure below shows the locations BULF013 and BULF014. A potential reason for the elevated depth from the hydraulic model might be related to the in interaction of Bullock and Fletchers Creek at their confluence given that both hydrographs were assumed had no relative lag between each other.

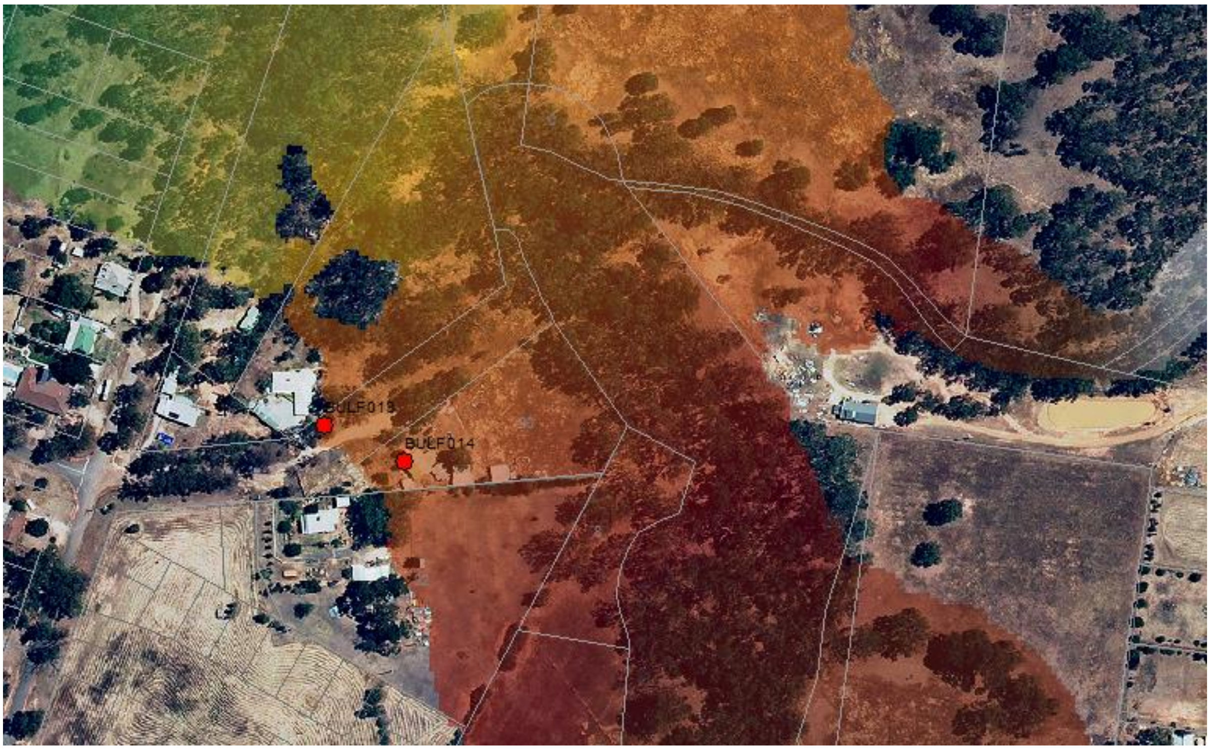

Figure 4.6 Location of BULF013 and BULF014 in the model

A community consultation was undertaken in conjunction with City of Greater Bendigo as part of the “Marong Township Structure Plan”. The consultation took place on the 23 July, 24 July, 30 July and 4 August.

Based on the residents of Marong the flood extents presented for the 1% AEP flood event were very close to those experienced during the 2011 floods. Many residents checked the extents of flooding within their property and agreed with the model results. Figure 4.7 shows the flood extents for the 1% AEP.

Figure 4.7 1% AEP Design Flood Depth for the Township of Marong

From the community consultation and some additional communications with the residents of Marong it was highlighted the flooding during the 2011 flood event overtopping the Marong - Serpentine Road that almost reaches the property with address 80 Marong-Serpentine Road as shown in the figure below:

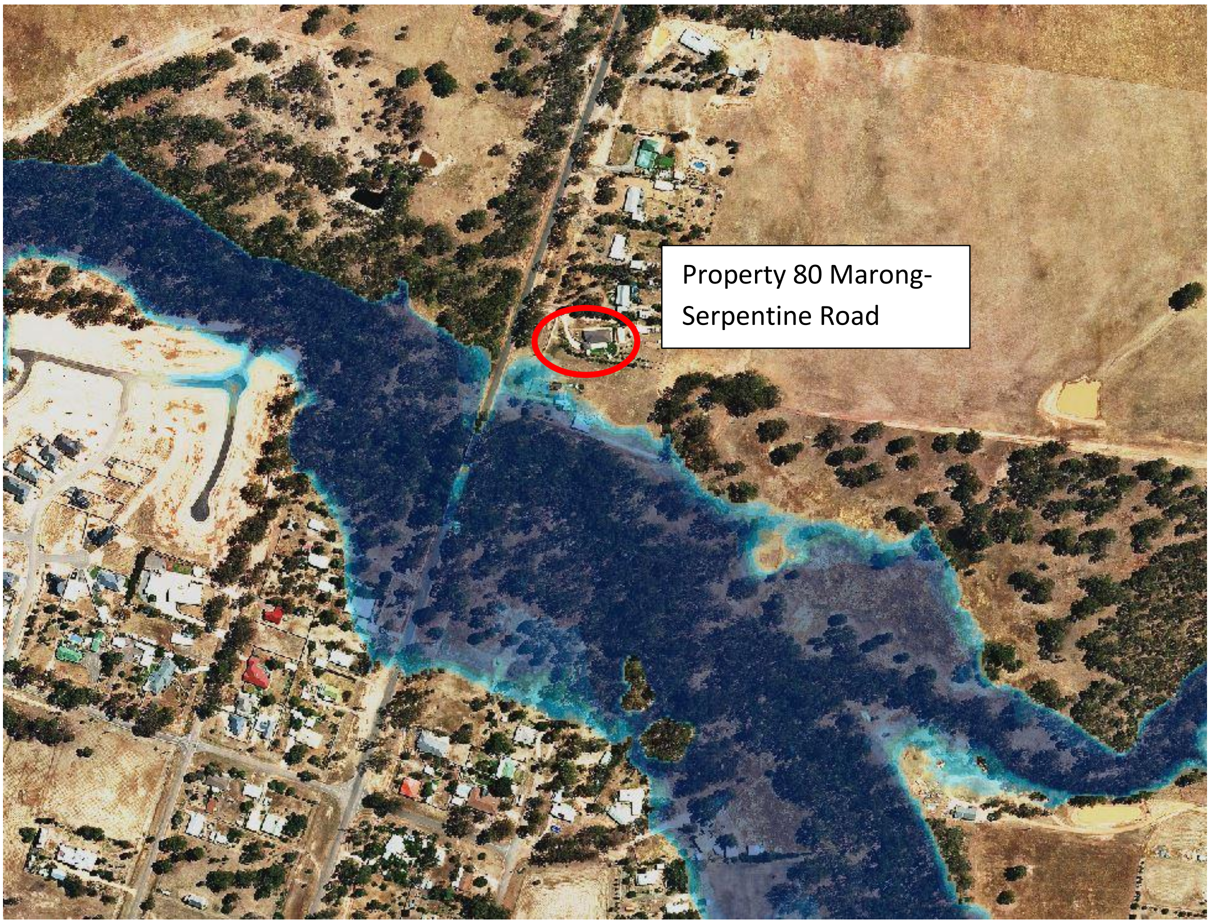

Figure 4.8 Extent of flood over the Marong – Serpentine Road

Residents of 1329 - 1339 Calder Highway commented on the flood waters during the 2011 flood event overtopping the highway and reaching their property where they used to have tomato plants and almost reaching the dwelling at 1339 Calder Highway. The modelled flood extents represent this very closely and that was expressed by the community (See Figure 4.9).

Furthermore the community in general agree with the modelled extents over the Malone Park Recreation Reserve as shown in Figure 4.9.

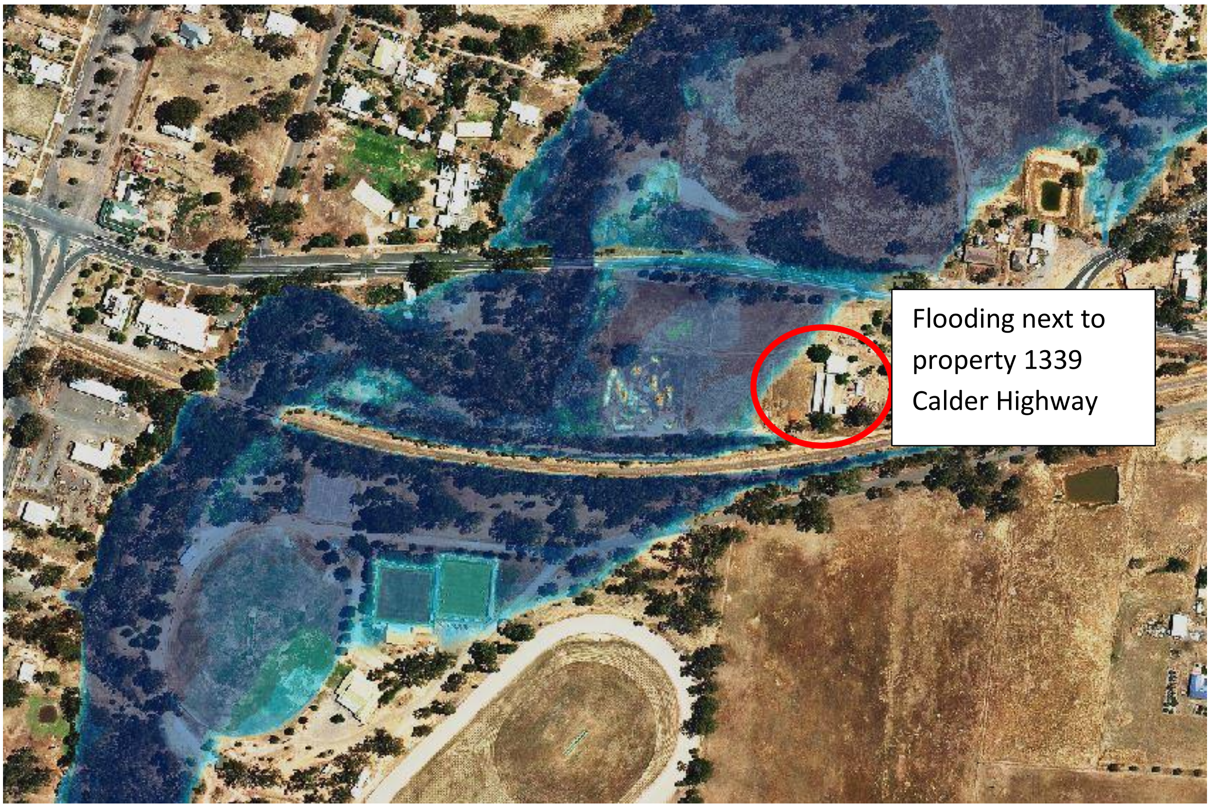

Figure 4.9 Extent of flood over Calder Highway flooding nearby the property 1339 Calder Highway

4.3.3 Summary

The model results for the 1% AEP are very close to those observed during the January 2011 flood event based on the flood pegs available and the anecdotal observations.

4.4 Sensitivity Analysis

The hydraulic model sensitivity was tested by varying the Manning's roughness values, the downstream outflow boundary condition, the model inflows and the hydrograph volumes to determine the influence of these parameters on the model results. The sensitivity analysis was undertaken based on the 1% AEP design results. These various scenarios are detailed in the following sections.

4.4.1 Roughness Sensitivity

The model sensitivity to the Manning's roughness values was analysed by varying these values by 20% and comparing the results to the base case scenario. The Manning's roughness values adopted for the base case scenario are detailed in Section 4.2.2.6. With the roughness increased by 10% the flood levels were increased by an average of 0.18m. The maximum localised increase in flood height was 0.58m. Due to the steep slopes of the catchment the flood extent for Bullock Creek was only slightly increased.

Similarly, with the Manning's values reduced by 10%, the flood levels were decreased by an average of 0.06m. The difference in extent was very minor as shown in Figure 4.10. The maximum decrease in flood height was 0.46m, the location of which is shown in the red insert in Figure 4.10. The significant difference at this site is due to the topography of the floodplain.

Overall, the model indicates there is minimal change in flood level based on the roughness selected for Bullock Creek, therefore the sensitivity to this factor is small.

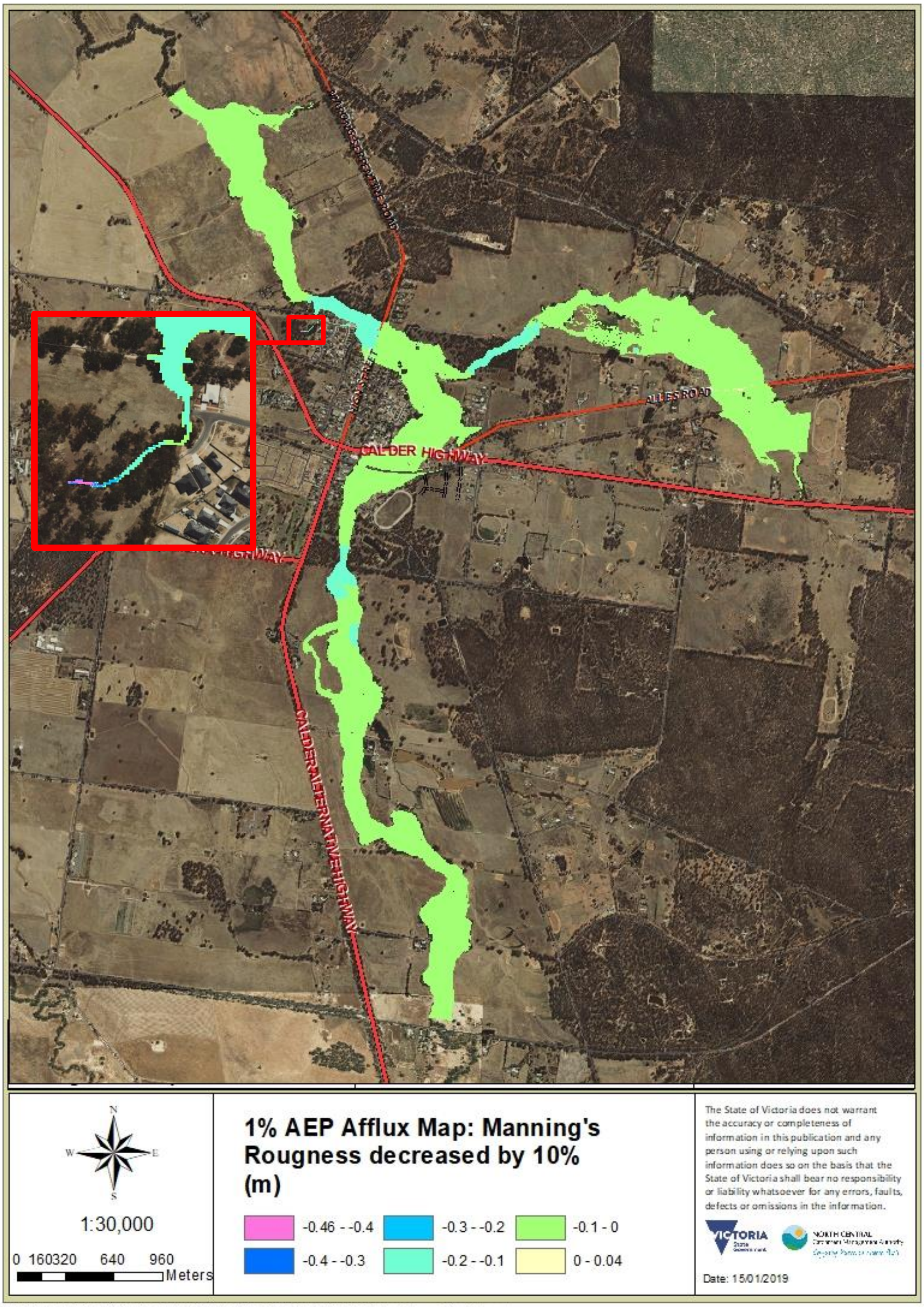

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Figure 4.10 1% AEP afflux map comparing base scenario to sensitivity scenario with Manning's roughness reduced by 10% (Sensitivity Scenario – Base Case Scenario)

4.4.2 Outflow Boundary Condition Sensitivity

The sensitivity of the hydraulic model to the outflow boundary condition was also analysed. The base case scenario applied a water surface slope of 0.01 at the outflow boundary to determine the flow rate of water leaving the model. This was compared to two sensitivity scenarios, the first of which reduced the water surface slope to 0.002, and the second where it was increased to 0.02.

As expected, the flood levels near the outflow model boundary are increased when the boundary condition slope is reduced to 0.002 as shown in Figure 4.11. The afflux immediately upstream of the model boundary is significant, with flood levels around 0.7m higher than the base case scenario. However, the impacts are quickly dissipated further upstream of the boundary to less than a 50mm increase at a distance of 500m from the boundary. Due to the steep river banks this afflux only results in a negligible increase in flood extent.

Figure 4.12 shows the results due to increasing the outflow boundary slope to 0.02. As shown the flood levels are slightly reduced as compared to the base case scenario. The maximum decrease in flood level is approximately 0.29m immediately at the outflow boundary. At a distance of 96m upstream of the outflow boundary the difference in flood level is less than 50mm. Due to the relatively small decrease in flood level there is no significant change in flood extent for this scenario.

Overall, the influence due to the outflow boundary is generally minor and the flood flows remain contained within the same extents. Therefore, it is considered that the hydraulic model is not particularly sensitive to the outflow boundary conditions and the areas of interest for the model are not impacted.

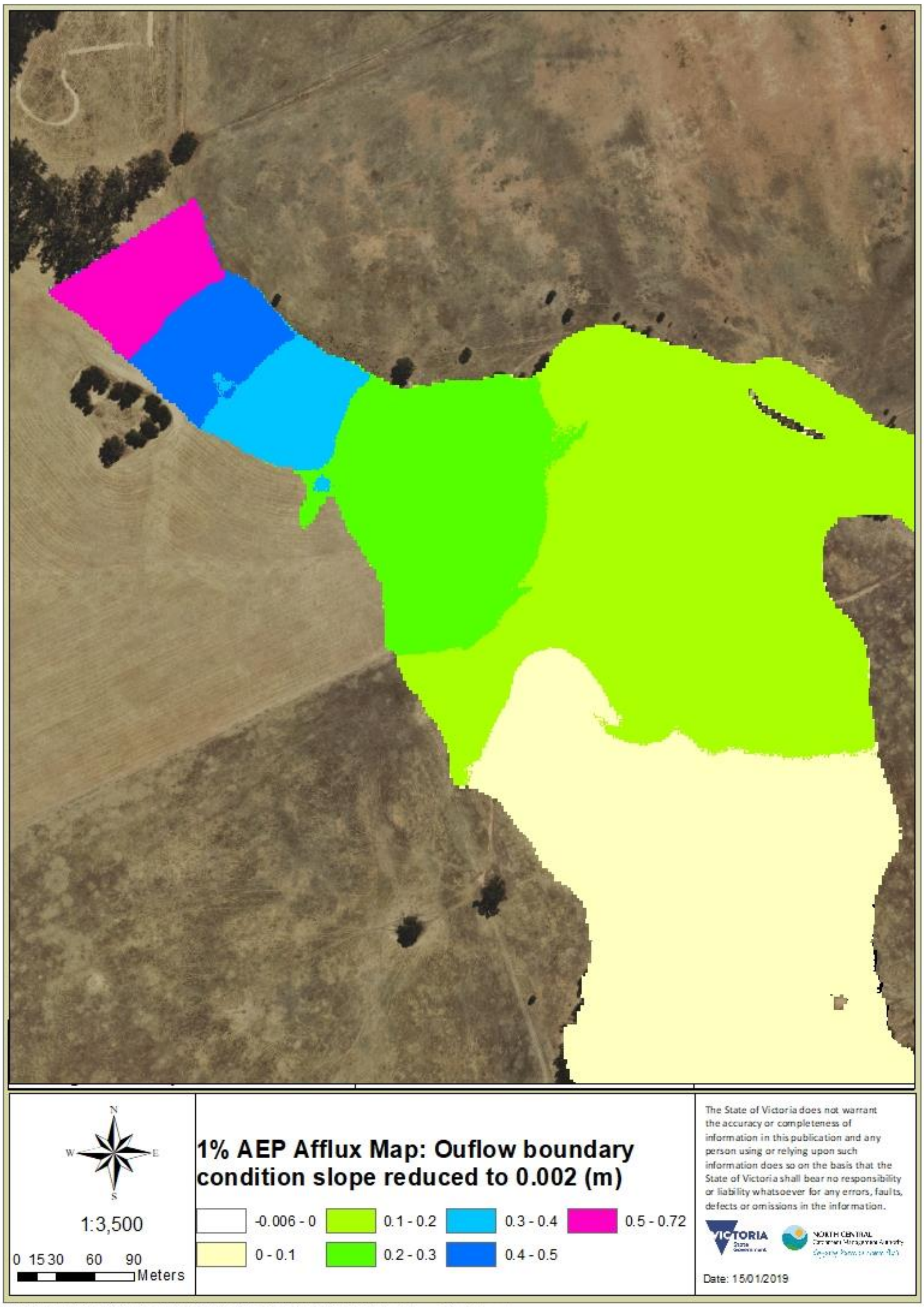

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Figure 4.11 1% AEP afflux map comparing base case scenario to sensitivity scenario with the outflow boundary slope reduced to 0.002 (Sensitivity Scenario – Base Case Scenario)

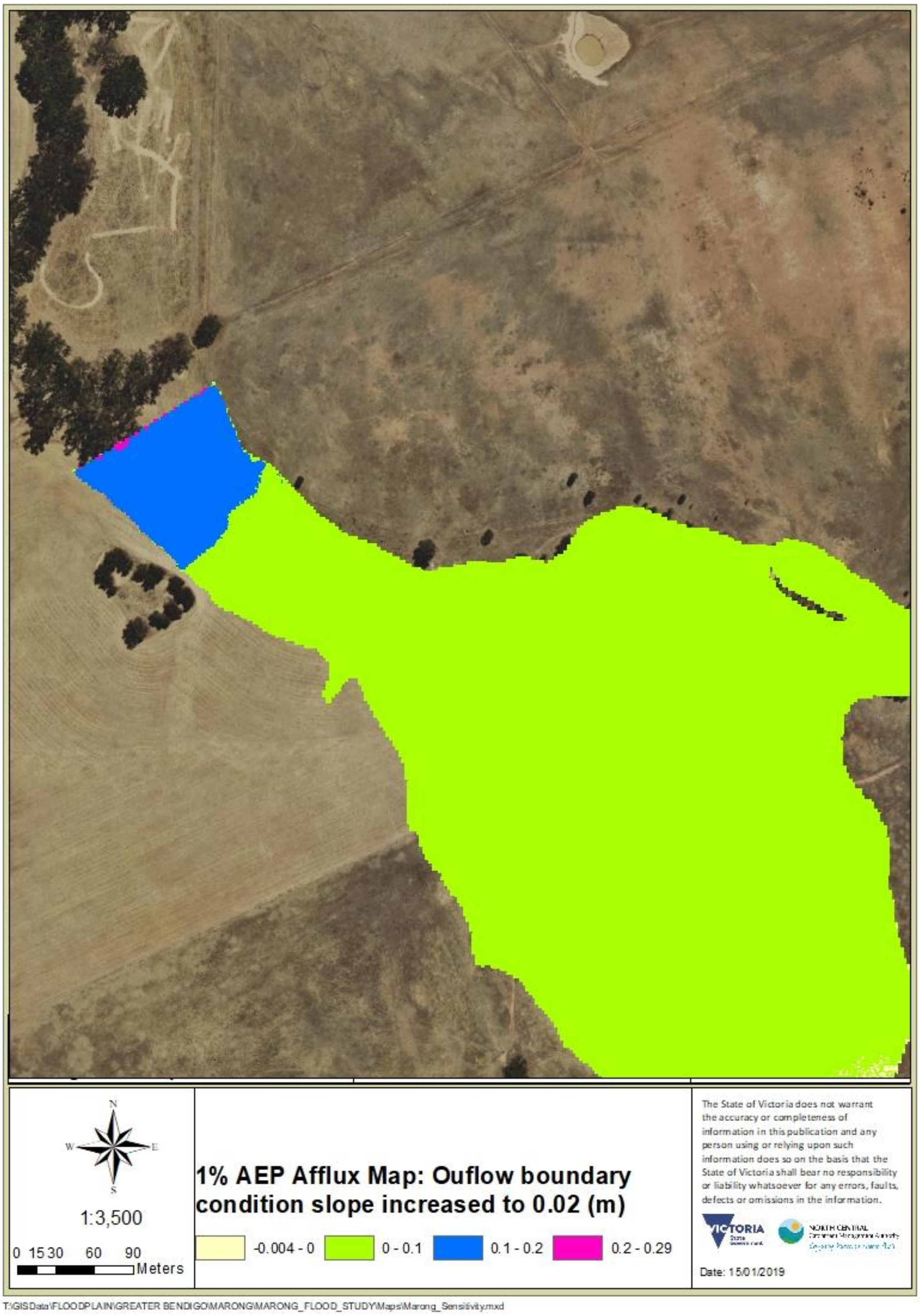

Figure 4.12 1% AEP afflux map comparing base case scenario with sensitivity scenario with the outflow boundary slope increased to 0.02 (Sensitivity Scenario – Base Case Scenario)

4.4.3 Model Inflow Sensitivity

The sensitivity of the hydraulic model to the inflows was tested by varying all inflow hydrographs by 10%. Figure 4.13 shows the afflux due to the inflow hydrographs being increased by 10%. The flood levels are only increased an average of 0.07m compared to the base case scenario, with localised increases on over 0.5m as shown in the red insert in Figure 4.13. Moreover, there is no material increase in flood extent.

The afflux results for a 10% reduction of the inflow hydrographs is shown in Figure 4.14. There is an average decrease of 0.07m in flood level and an overall minor decrease in flood extent. The areas impacted by variations in the model inflow appear to be reasonably consistent as shown by comparing Figure 4.13 and Figure 4.14. The Bullock Creek reach between Calder Highway and Serpentine Road appear to be the most sensitive to changes in flow, with levels varying by approximately 0.2m along this section due to a 10% increase or decrease in the inflow hydrographs.

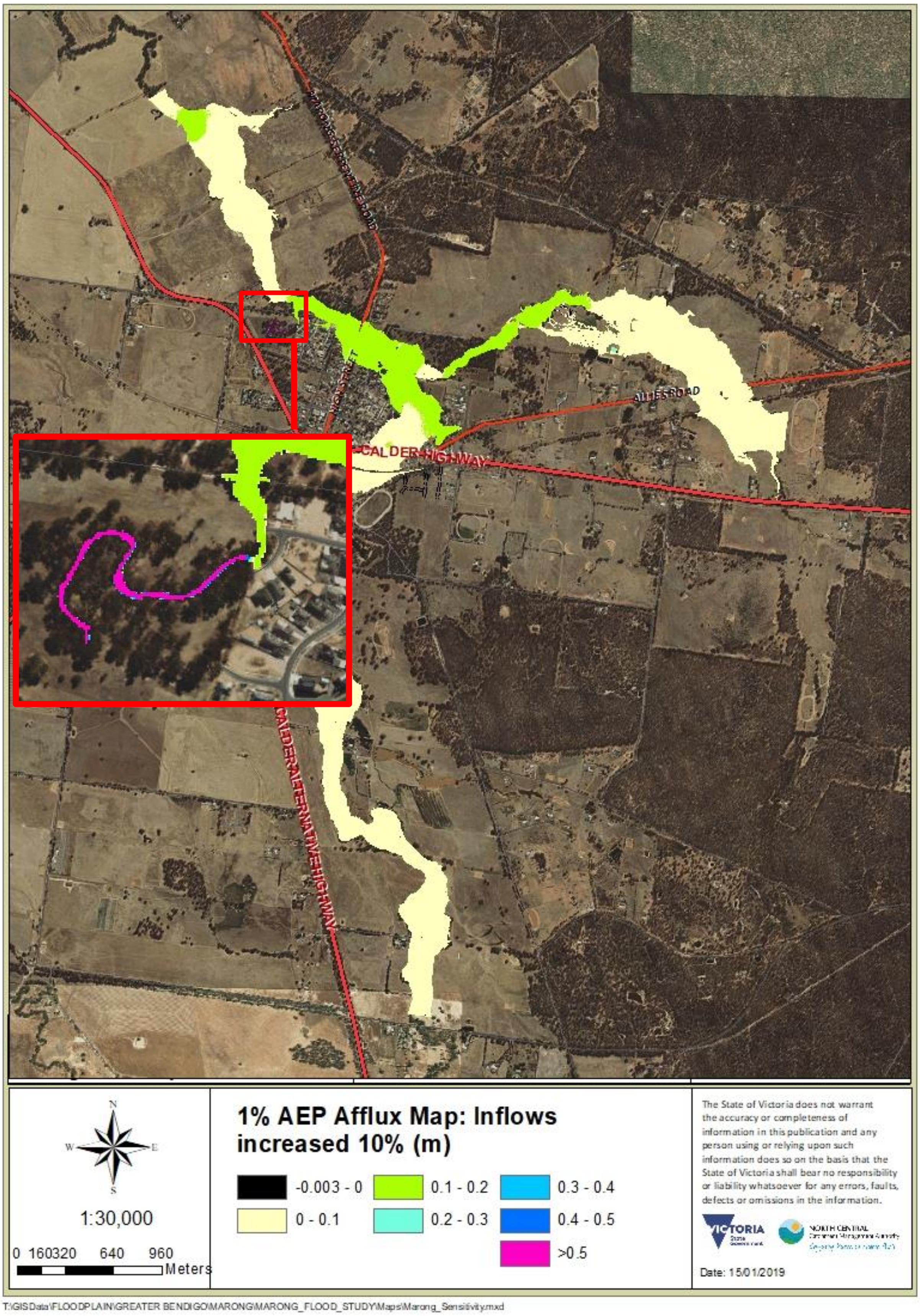

Figure 4.13 1% AEP afflux map comparing base case scenario to sensitivity scenario with flows increased by 10% (Sensitivity Scenario – Base Case Scenario)

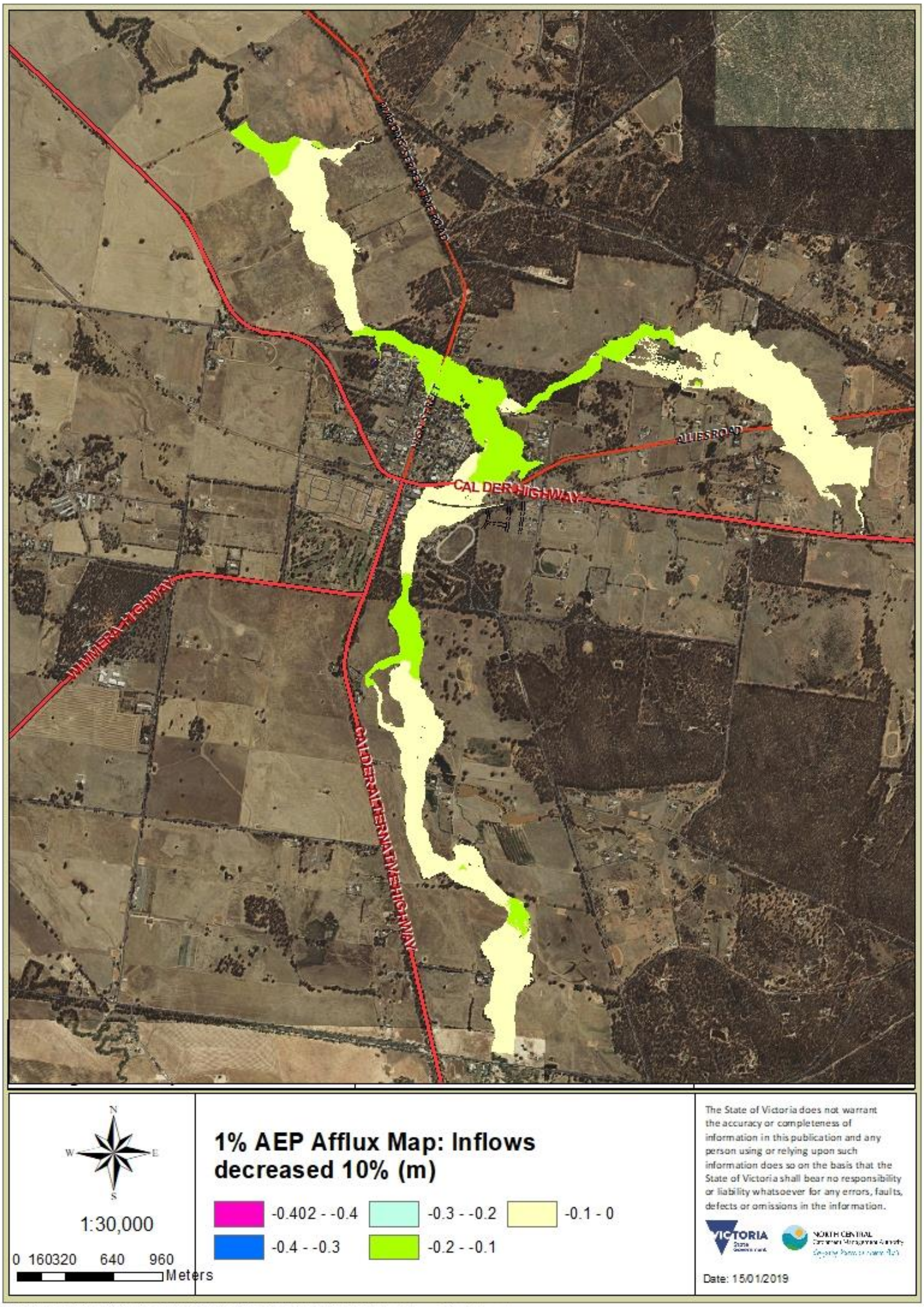

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Figure 4.14 1% AEP afflux map comparing base case scenario to sensitivity scenario with inflows decreased by 10% (Sensitivity Scenario – Base Case Scenario)

4.5 Design Flood Modelling

4.5.1 Model Quality Assurance

To ensure the modelling was fit for purpose, the TUFLOW model results were assessed. Checks were made to ensure that input data such as topography, surface roughness, and hydraulic structures were appropriately represented by the hydraulic model. Model inflow and outflow boundaries were located a sufficient distance from areas of interest to ensure that the boundary conditions did not influence model results. The absence of any negative depth warnings or significant volume fluctuations for the modelled events also indicated the stability of the hydraulic model. Furthermore, the peak cumulative mass error for the various model scenarios were less than 0.25% and therefore within acceptable limits.

4.5.2 Community Consultation

A community consultation was undertaken in conjunction with City of Greater Bendigo as part of the "Marong Township Structure Plan". The consultation took place on the 23 July, 24 July, 30 July and 4 August. Based on the residents of Marong the flood extents presented for the 1% AEP flood event were very close to those experienced during the 2011 floods. Many residents checked the extents of flooding within their property and agreed with the model results.

A common comment received was that the flooding was intensified with the construction of the bridge on Serpentine Road, as it only has 3 spans and blocks the flows, whilst the bridge upstream on Calder Highway has 6 spans. Furthermore, several residents propose to put box culverts on the side of the Serpentine bridge to increase its capacity. This mitigation option was not investigated in this study.

Additionally, it was learnt from the community that there is a flow constriction due to an old landfill located to the north of Cathcart Street, nearby a proposed outlet for stormwater from future developments is planned.

4.5.3 Design Results

The hydraulic model was used to generate water surface elevations (flood levels), depths, velocities and hazard (depth multiplied by velocity) rasters for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP flood events as well as the PMF. These outputs were then post-processed to generate flood extents, flood contours and velocity vectors for all design events. The extents produced from the raster data were smoothed using the Polynomial Approximation with Exponential Kernel (PAEK) algorithm and applying a tolerance of 20 metres. This provided a more realistic extent of flooding while still sufficiently preserving the definition of the raster data. Additionally, any small islands occurring within the flood extent with an area less than 400m^2 were removed for clarity.

Figure 4.15 and Figure 4.16 show all design flood extents overlayed on a single map for comparison. It can be seen that due to the confined floodplain along Bullock Creek at Marong there is not a substantial difference between the 20% AEP flood extent and the 0.5% AEP flood extent, although the average difference in flood level is 1 metre. The flood depth maps for each design event are shown in the Appendix 7.

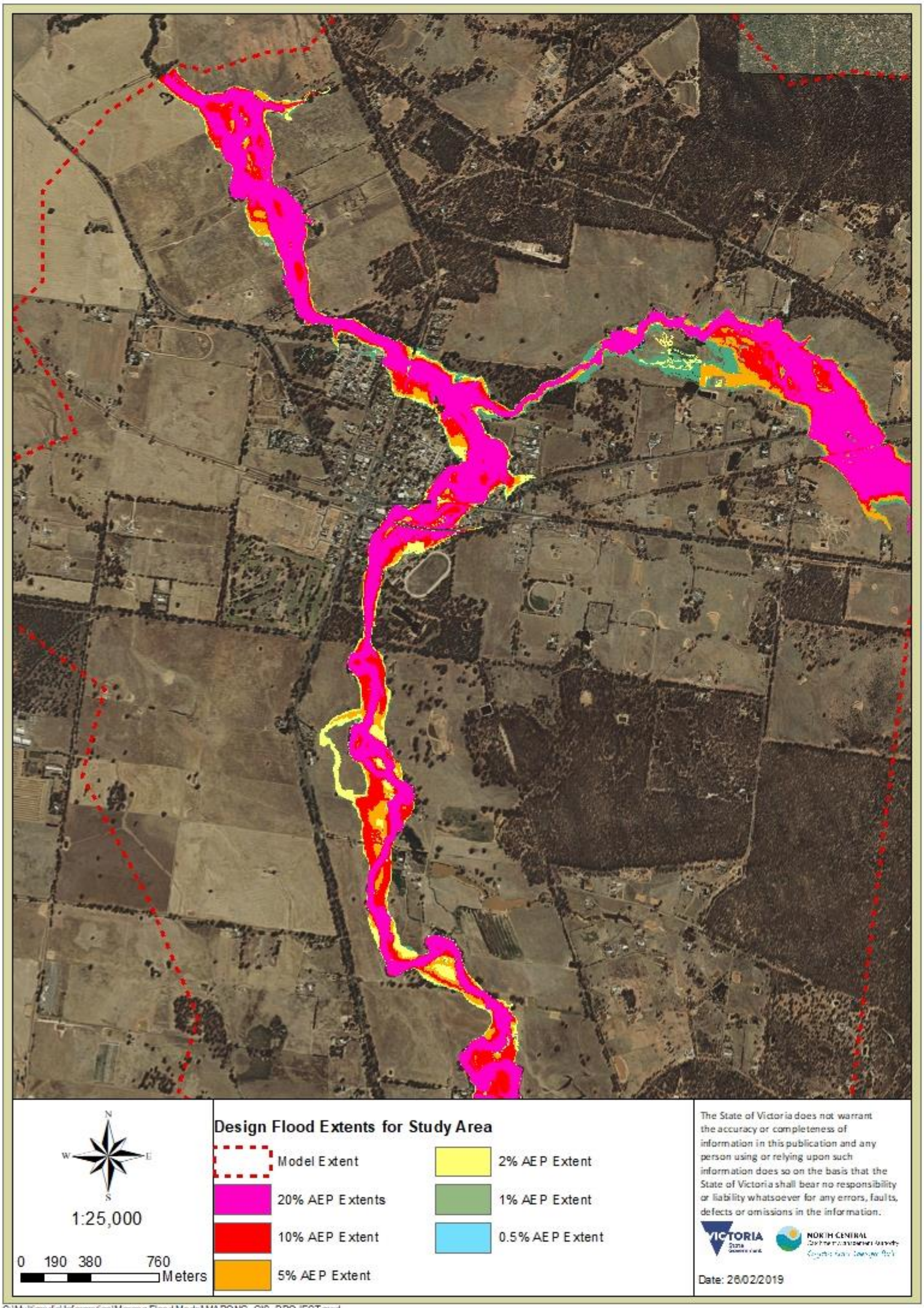

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Figure 4.15 Design flood extents for the study area

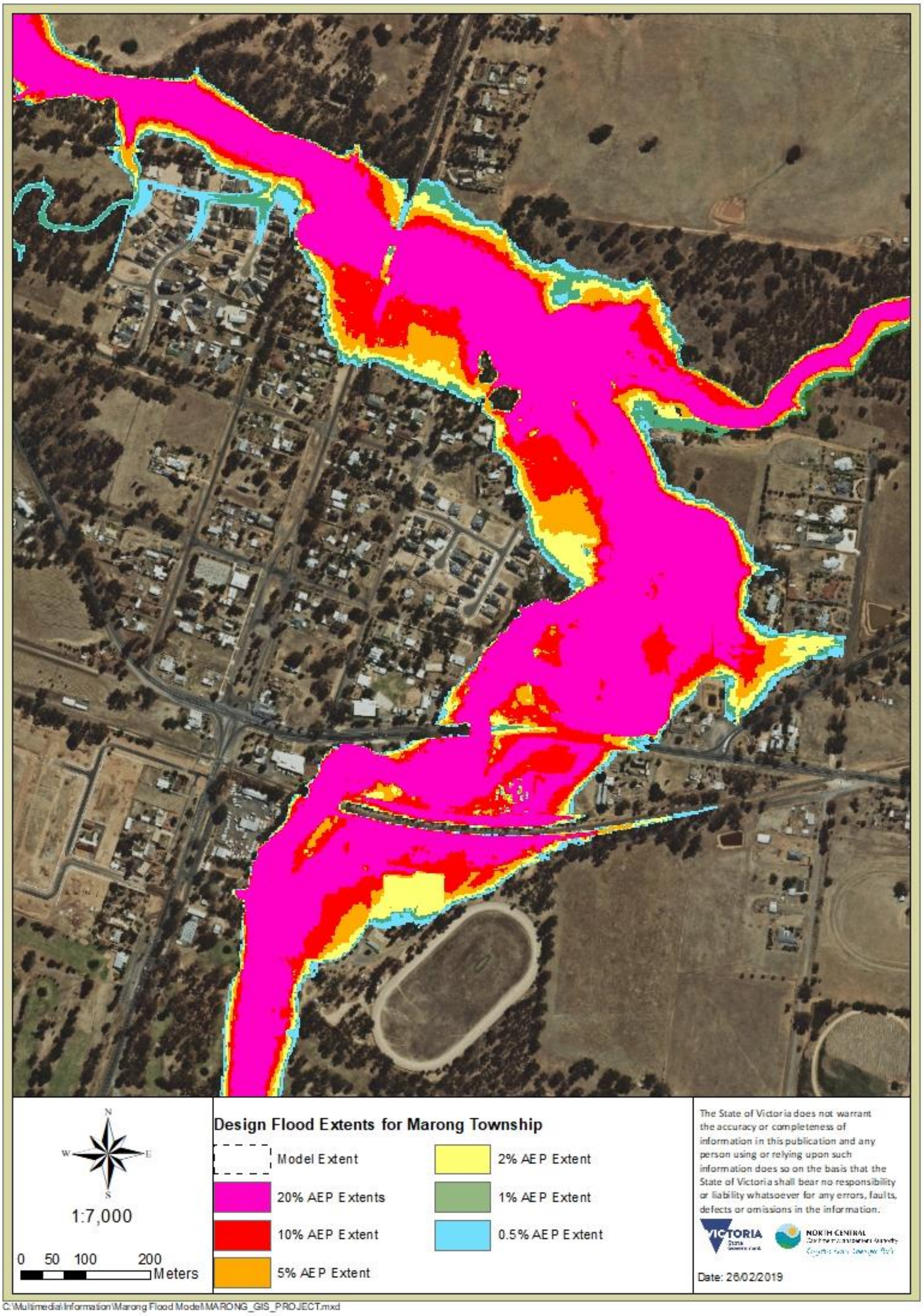

Figure 4.16 Design Flood Extents for the Township of Marong

4.6 Design Flood Behaviour

The design flood mapping shows that flooding is generally confined through the Township of Marong by the banks of Bullock Creek. In a 1% AEP flood event, flood waters are mostly contained except for the floodplain east of the township between the bridge in Calder Highway and the one in Serpentine Road. The extents for the 0.5% AEP are very similar to the 1% AEP event with differences in depth.

The following comments summarize the key flood impacts for each design event.

20% AEP Flood Event

- Most of the properties flooded are located at the Northeastern side of Goldie Street with the property 85 Goldie Street having depths up to 0.9 metres and 90 Goldie Street up to 0.7 metres depth.
- Cathcart Street near Alana Court is inundated with depths up to 0.6 metres and the northeaster section of Goldie Street with depths up to 0.5 metres.
- Allies Road at the crossing of Fletchers Creek nearby Frankels Lane (upstream section of Fletchers Creek) is likely to flood with depths under 0.3 metres.
- Some flood water backup onto the railway and some flows break to the left of the bridge crossing on Calder Highway. The highway does not get overtopped.

10% AEP Flood Event

- Most of the properties flooded are located at the Northeastern side of Goldie Street with depths higher than 1.0 metre at 85 Goldie Street and 90 Goldie Street.
- 78 High Street is mostly inundated with low depths of 0.2 metres. Whilst 81 High Street is inundated to the front of the property with depths up to 0.3 metres.
- Cathcart Street near Alana Court is inundated with depths up to 1.0 metres and the northeaster section of Goldie Street with depths up to 0.85 metres.
- Allies Road at the crossing of Fletchers Creek nearby Frankels Lane (upstream section of Fletchers Creek) is likely to flood remains with depths under 0.3 metres.
- Properties between the railway and Calder Highway are affected with depths up to 0.9 metres.
- Some flood water backup onto the railway and some flows break to the left of the bridge crossing on Calder Highway overtopping the highway just very low flow depths.
- The Marong Serpentine Road is overtopped with flow depths up to 0.16 metres.
- The sports oval at the Malone Park is partially inundated with depths up to 0.3 metres.

5% AEP Flood Event

- Several properties located along High Street are inundated with depths up to 0.5 metres at 78 High Street and 0.7metres at 81 High Street.
- The properties on Goldie Street reach depths of 1.4 metres.

- Cathcart Street near Alana Court is inundated with depths up to 1.3 metres and the northeastern section of Goldie Street with depths up to 1.2 metres.
- Allies Road at the crossing of Fletchers Creek nearby Frankels Lane (upstream section of Fletchers Creek) is likely to flood with depths up to 0.36 metres.
- Properties between the railway and Calder Highway are affected with depths up to 0.9 metres.
- Some flood water backup onto the railway and some flows break to the left of the bridge crossing on Calder Highway overtopping the highway flow depths under 0.3 metres.
- The Marong Serpentine Road is overtopped with flow depths up to 0.36 metres.
- The sports oval at the Malone Park is partially inundated with depths up to 0.5 metres.

2% AEP Flood Event

- Several properties located along High Street are inundated with depths just under one metre at 81 High Street.
- The properties on Goldie Street reach depths of 1.7 metres.
- Cathcart Street near Alana Court is inundated with depths up to 1.5 metres and the northeastern section of Goldie Street with depths up to 1.3 metres.
- Allies Road at the crossing of Fletchers Creek nearby Frankels Lane (upstream section of Fletchers Creek) is likely to flood with depths up to 0.4 metres.
- Properties between the railway and Calder Highway are affected with depths up to 1.2 metres.
- Some flood water backup onto the railway and some flows break to the left of the bridge crossing on Calder Highway overtopping the highway flow depths under 0.3 metres.
- The Marong Serpentine Road is overtopped with flow depths up to 0.5 metres.
- The sports oval at the Malone Park is partially inundated with depths up to 0.5 metres.

1% AEP Flood Event

- Several properties located along High Street are inundated with depths up to 1.2 metres at 81 High Street.
- The properties on Goldie Street reach depths of 1.9 metres.
- Cathcart Street near Alana Court is inundated with depths up to 1.5 metres and the northeastern section of Goldie Street with depths up to 1.6 metres.
- Some flood water backup onto the railway and some flows break to the left of the bridge crossing on Calder Highway overtopping the highway flow depths just over 0.3 metres.
- Malone Park is partially flooded
- Some properties along High Street north of Goldie Street are flooded or partially flooded.
- The Marong Serpentine Road is overtopped with flow depths above 0.5 metres.
- Considerable number of rural lots to the south of the township are also partially flooded.

0.5% AEP Flood Event

- Several properties located along High Street are inundated with depths just above 1.4 metres at 81 High Street.
- The properties on Goldie Street reach depths just above 2 metres.
- Cathcart Street near Alana Court is inundated with depths up to 1.9 metres and the northeastern section of Goldie Street with depths up to 1.9 metres.
- Some flood water backup onto the railway and some flows break to the left of the bridge crossing on Calder Highway overtopping the highway flow depths just over 0.5 metres.
- Malone Park is partially flooded
- Some properties along High Street north of Goldie Street are flooded or partially flooded.
- The Marong Serpentine Road is overtopped with flow depths above 1.1 metres.
- Considerable number of rural lots to the south of the township are also partially flooded.

5 Summary / Conclusions

This report has documented the methodology and results of the Marong Flood Study. Through the development and calibration of hydrologic and hydraulic models, the flood behaviour has been determined for various design flood events ranging from the 50% AEP to the 0.5% AEP. The model outputs generated for these design events include flood extents, levels, depths and velocities. These results will be used to update the available flood information for the township.

It is recommended that the current planning scheme is updated to reflect the 1% AEP design results determined by this study. Given there is no current Land Subject to Inundation Overlay (LSIO) overlay over the township, updating the LSIO is essential to ensure future developments are assessed in accordance with the new available information provided by this study.

6 References

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Appendices

Appendix 1. Datahub data

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	144.126
Latitude	-36.736
Selected Regions	
River Region	
ARF Parameters	
Temporal Patterns	
Areal Temporal Patterns	
Interim Climate Change Factors	
Baseflow Factors	

Region Information

Data Category	Region
River Region	Loddon River
ARF Parameters	Southern Temperate
Temporal Patterns	Murray Basin

Data

River Region

division	Murray-Darling Basin
rivregnum	7
River Region	Loddon River

Layer Info

Time Accessed	20 May 2018 02:07PM
Version	2016_v1

ARF Parameters

Long Duration ARF

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

Zone	Southern Temperate
a	0.158
b	0.276
c	0.372
d	0.315
e	0.000141
f	0.41
g	0.15
h	0.01
i	-0.0027

Short Duration ARF

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

Layer Info

Time Accessed	20 May 2018 02:07PM
Version	2016_v1

Storm Losses

Note: Burst Loss = Storm Loss - Preburst

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

Storm Initial Losses (mm)	18.0
Storm Continuing Losses (mm/h)	2.4

Layer Info

Time Accessed	20 May 2018 02:07PM
Version	2016_v1

Temporal Patterns

code	MB
Label	Murray Basin

Layer Info

Time Accessed	20 May 2018 02:07PM
Version	2016_v2

Areal Temporal Patterns

code	MB
arealabel	Murray Basin

Layer Info

Time Accessed	20 May 2018 02:07PM
Version	2016_v2

BOM IFD Depths

Click here to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

Time Accessed	20 May 2018 02:07PM
Version	2016_v2

Interim Climate Change Factors

Values are of the format temperature increase in degrees Celcius (% increase in rainfall)

	RCP 4.5	RCP6	RCP 8.5
2030	**0.85 (4.3%)**	0.845 (4.2%)	**0.974 (4.9%)**
2040	**1.086 (5.4%)**	1.05 (5.3%)	**1.341 (6.7%)**
2050	**1.303 (6.5%)**	1.283 (6.4%)	**1.734 (8.7%)**
2060	**1.478 (7.4%)**	1.539 (7.7%)	**2.212 (11.1%)**
2070	**1.629 (8.1%)**	1.775 (8.9%)	**2.753 (13.8%)**
2080	**1.741 (8.7%)**	2.036 (10.2%)	**3.26 (16.3%)**
2090	**1.793 (9.0%)**	2.316 (11.6%)	**3.748 (18.7%)**

Layer Info

Time Accessed	20 May 2018 02:07PM
Version	2016_v1
Note	ARR recommends the use of RCP4.5 and RCP 8.5 values

Baseflow Factors

downstream	10884
area_sqkm	1488.210688
catch_no	10898
Volume Factor	0.144688
Peak Factor	0.047259

Layer Info

Time Accessed	20 May 2018 02:07PM
Version	2016_v1

Appendix 2. Annual Maximum Series

Rank	DATE	PEAK FLOW m3/s	QC Code	
1	2016	79.405	180	Data not recorded, equipment malfunction.
2	2011	76.605	254	Rating table exceeded
3	1983	61.583	1	Unedited data
4	1992	56.325	1	Unedited data
5	1974	52.288	104	Records manually estimated.
6	1978	50.579	1	Unedited data
7	1995	47.233	1	Unedited data
8	1975	44.186	1	Unedited data
9	1973	37.820	104	Records manually estimated.
10	1990	37.527	1	Unedited data
11	1987	34.763	1	Unedited data
12	1993	33.768	1	Unedited data
13	2010	32.320	254	Rating table exceeded
14	1988	31.798	1	Unedited data
15	1981	31.067	1	Unedited data
16	1986	28.501	1	Unedited data
17	1996	26.153	104	Records manually estimated.
18	2000	20.576	76	Reliable non-linear interpolation using other data sources, not correlation.
19	1984	20.538	104	Records manually estimated.
20	2007	19.064	150	Rating extrapolated due to insufficient gaugings (see additional quality info)
21	1979	18.784	1	Unedited data
22	2015	17.308	150	Rating extrapolated due to insufficient gaugings (see additional quality info)
23	1991	16.986	1	Unedited data
24	1980	15.795	1	Unedited data
25	1989	12.792	1	Unedited data
26	1997	11.267	1	Unedited data
27	1985	8.681	104	Records manually estimated.
28	2012	7.492	150	Rating extrapolated due to insufficient gaugings (see additional quality info)
29	2004	5.343	2	Good quality data - minimal editing required. Drift correction
30	1976	4.869	1	Unedited data
31	2005	4.545	2	Good quality data - minimal editing required. Drift correction
32	2003	3.768	104	Records manually estimated.
33	1977	3.351	1	Unedited data
34	2002	3.129	2	Good quality data - minimal editing required. Drift correction
35	1999	2.184	1	Unedited data
36	2009	0.306	9	Pool dry ? no data collected
37	1998	0.302	1	Unedited data
38	2013	0.264	150	Rating extrapolated due to insufficient gaugings (see additional quality info)
39	2001	0.142	2	Good quality data - minimal editing required. Drift correction

40	1994	0.034	1	Unedited data
41	2006	0.034	9	Pool dry ? no data collected
42	1982	0.000	104	Records manually estimated.
43	2008	0.000	9	Pool dry ? no data collected
44	2014	0.000	150	Rating extrapolated due to insufficient gaugings (see additional quality info)
45	2017	0.000	150	Rating extrapolated due to insufficient gaugings (see additional quality info)

Appendix 3. Design Flood Depth Maps (20% AEP to 0.5% AEP)

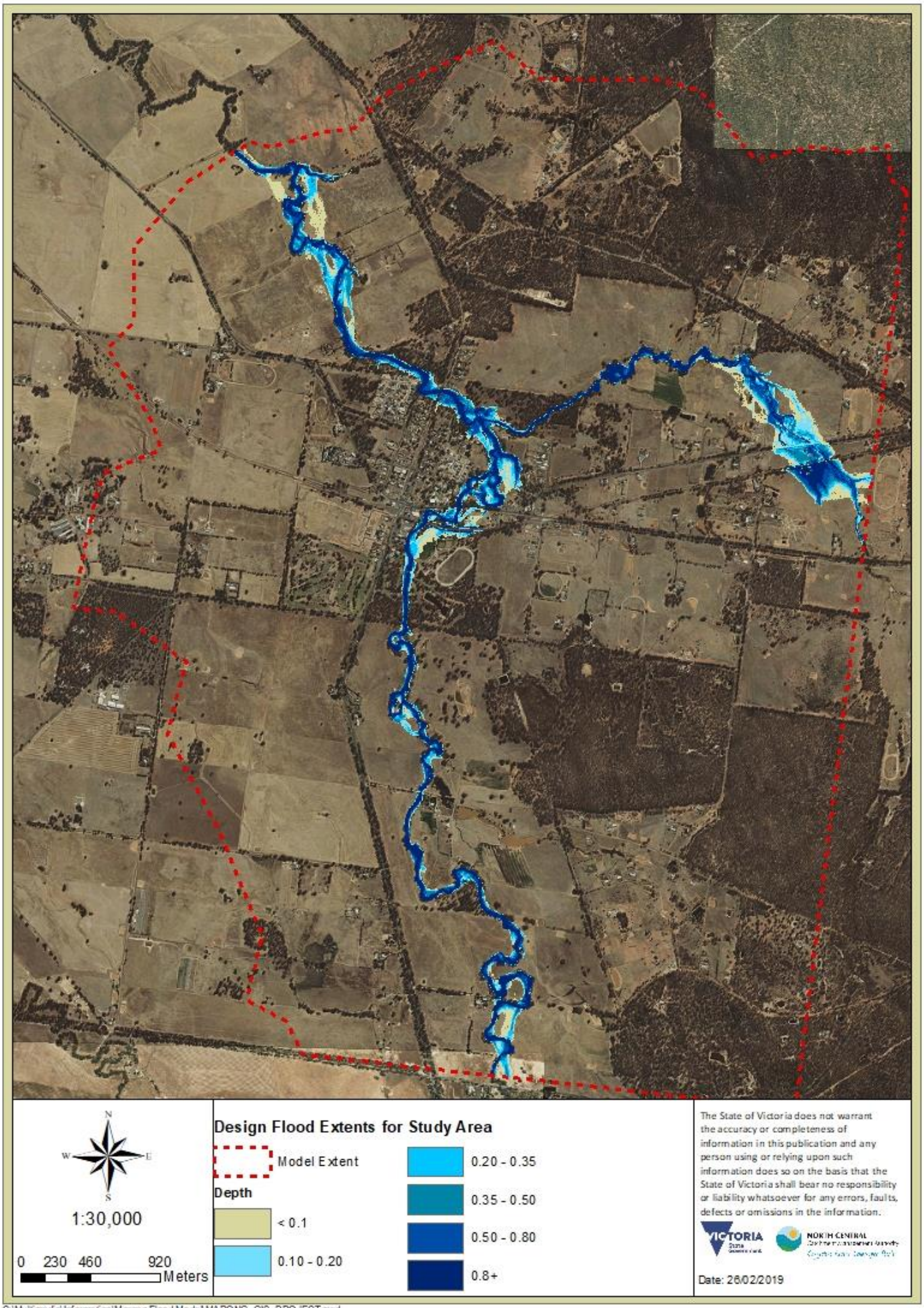

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Figure 0.1 20% AEP Design Flood Depth

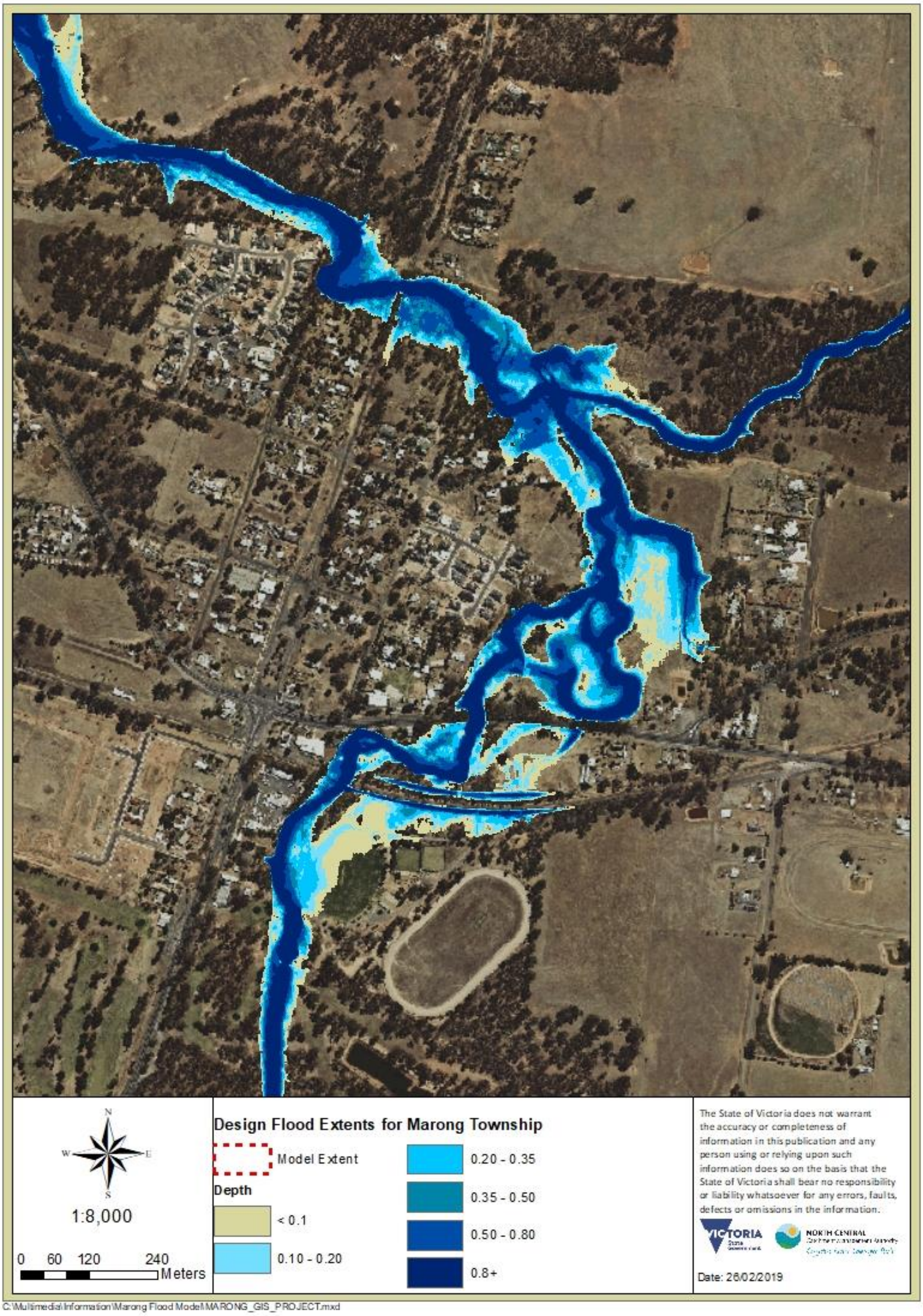

Figure 0.2 20% AEP Design Flood Depth for the Marong Township

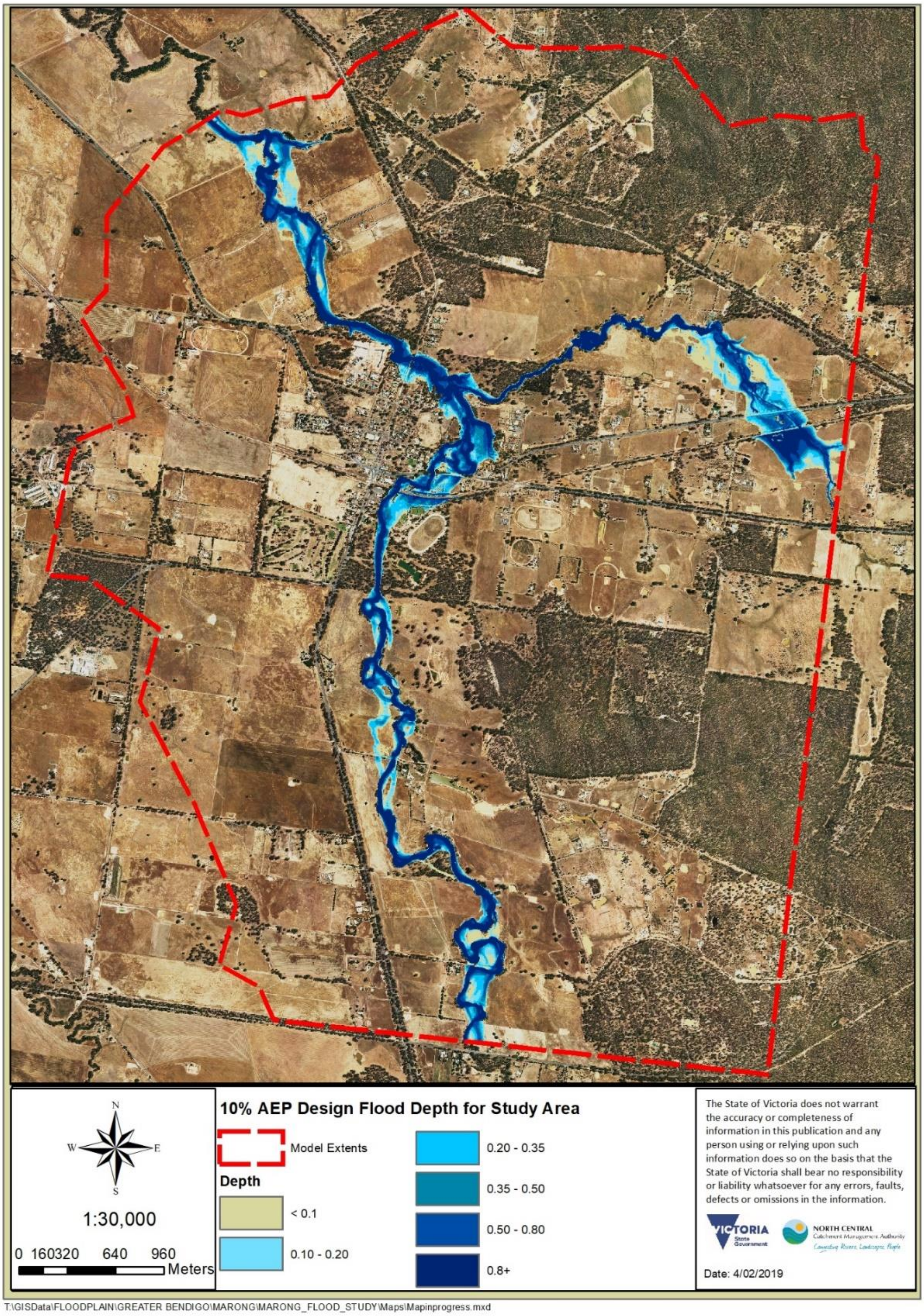

Figure 0.3 10% AEP Design Flood Depth

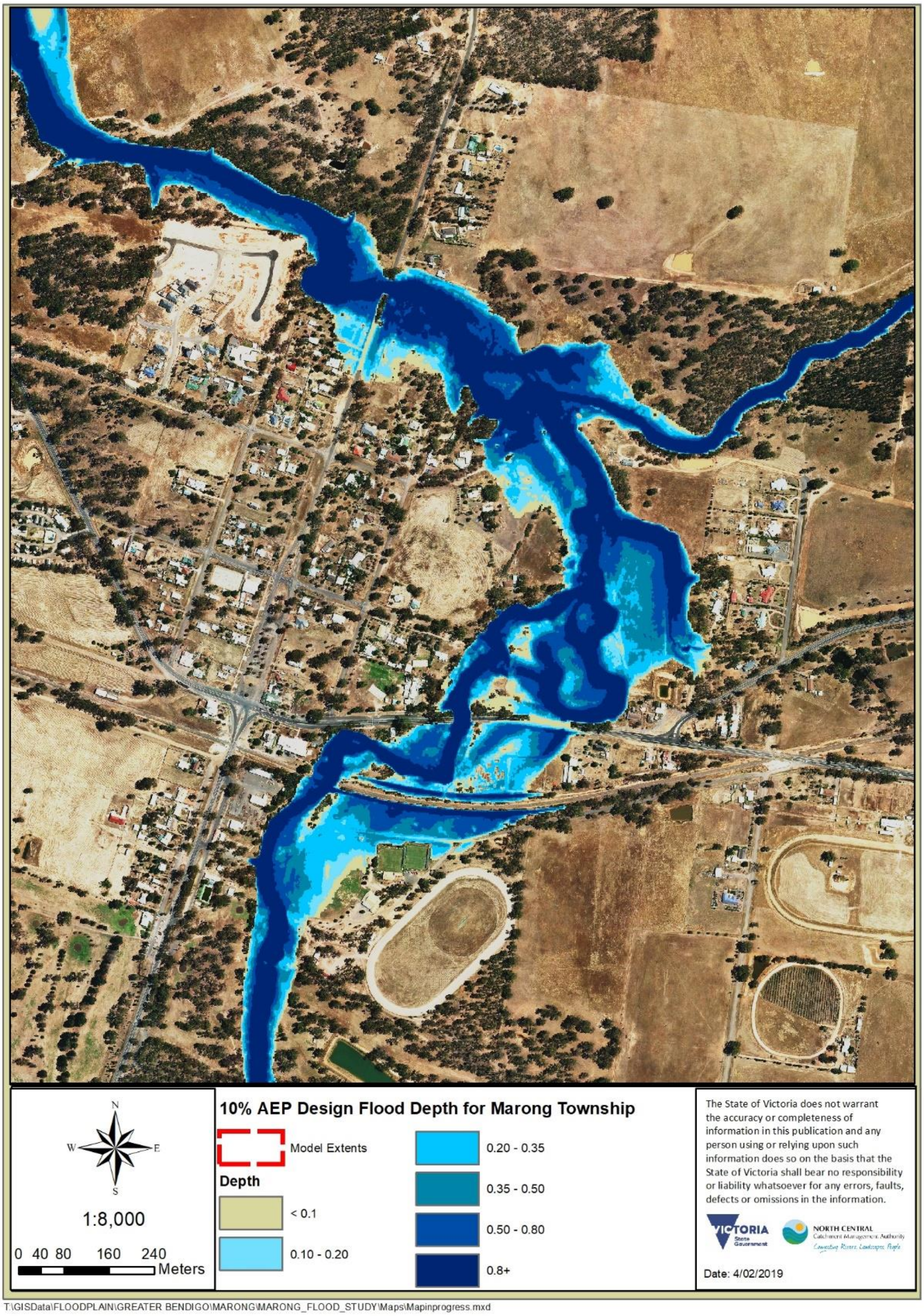

Figure 0.4 10% AEP Design Flood Depth for the Marong Township

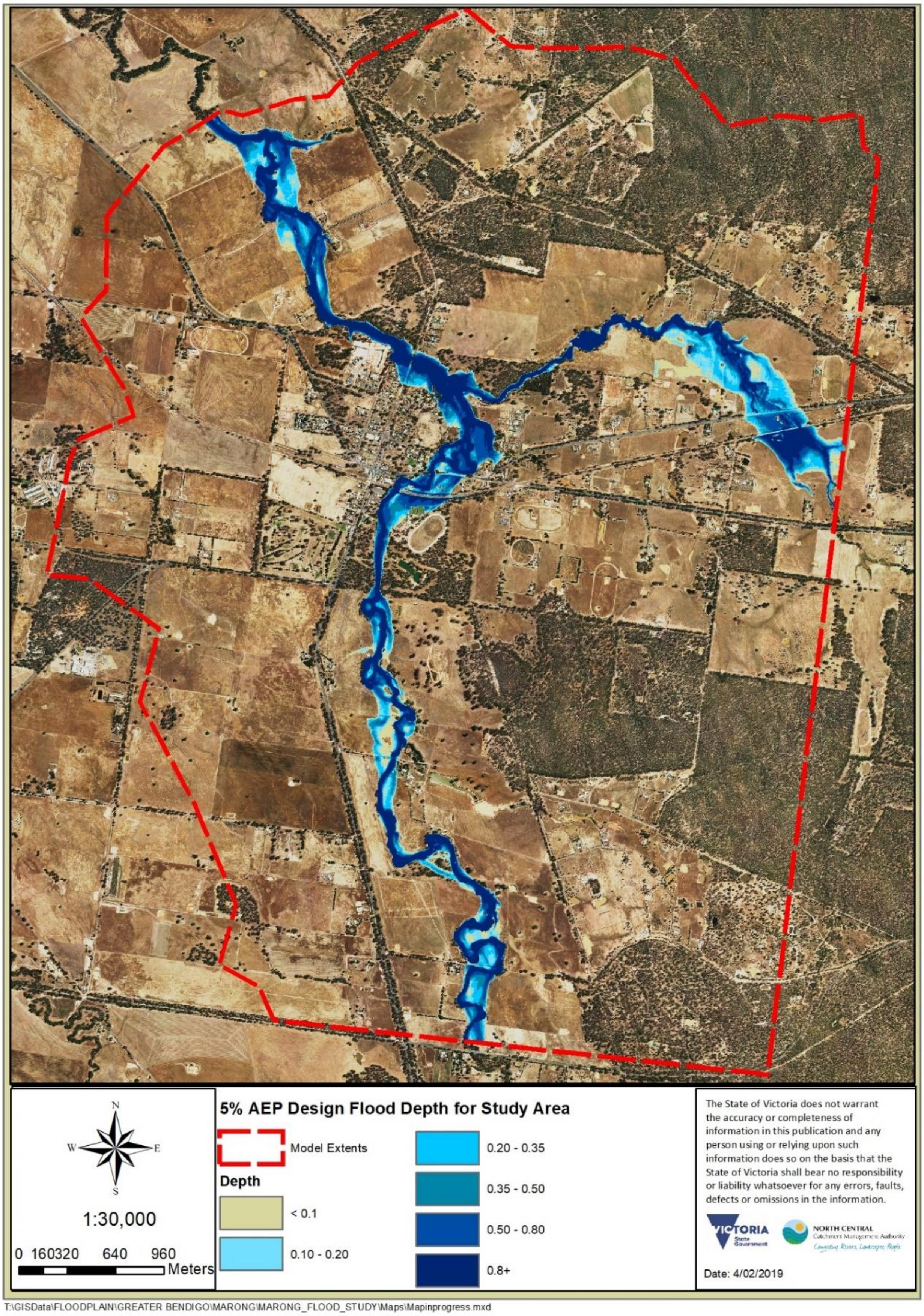

Figure 0.5 5% AEP Design Flood Depth

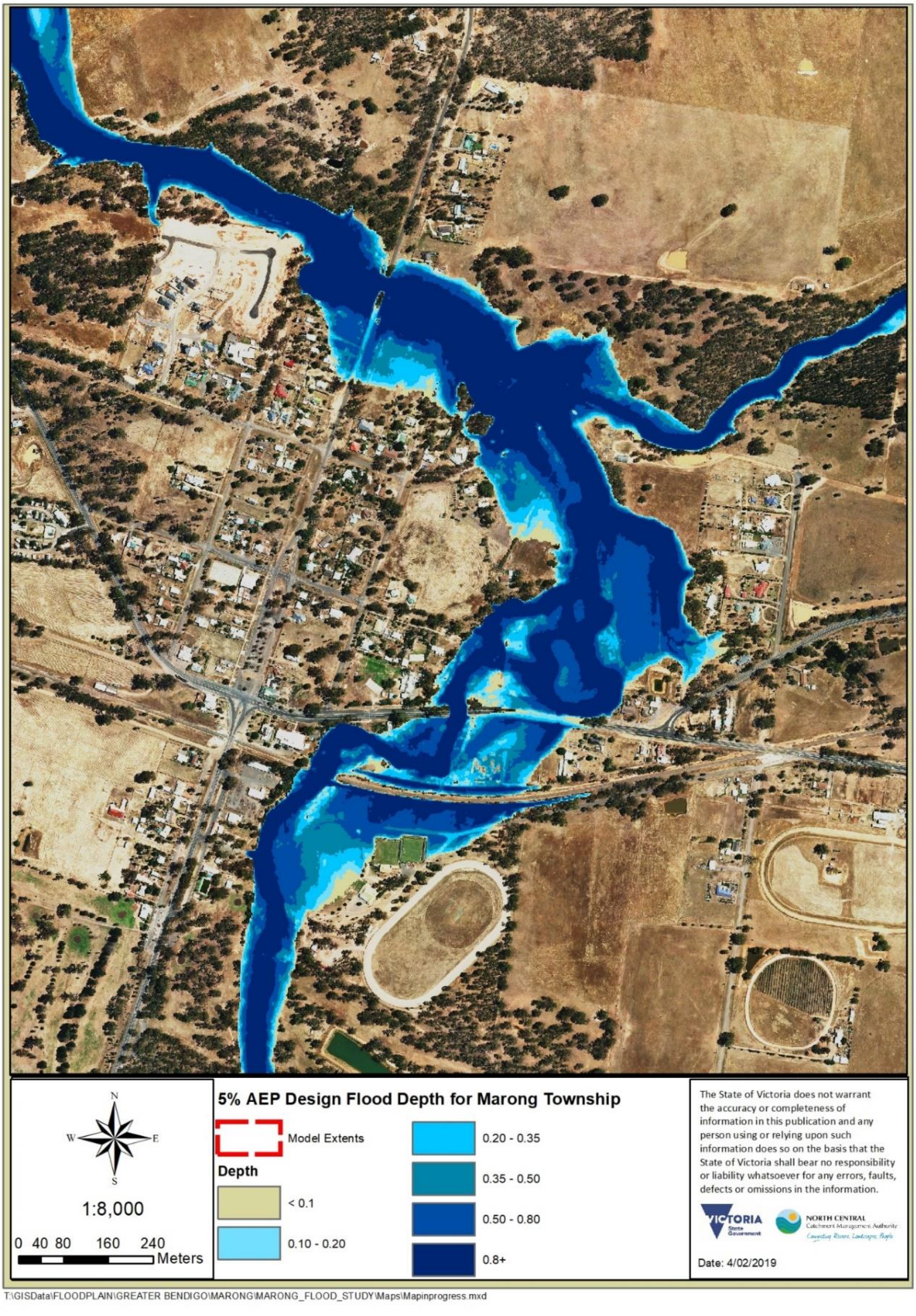

Figure 0.6 5% AEP Design Flood Depth for the Marong Township

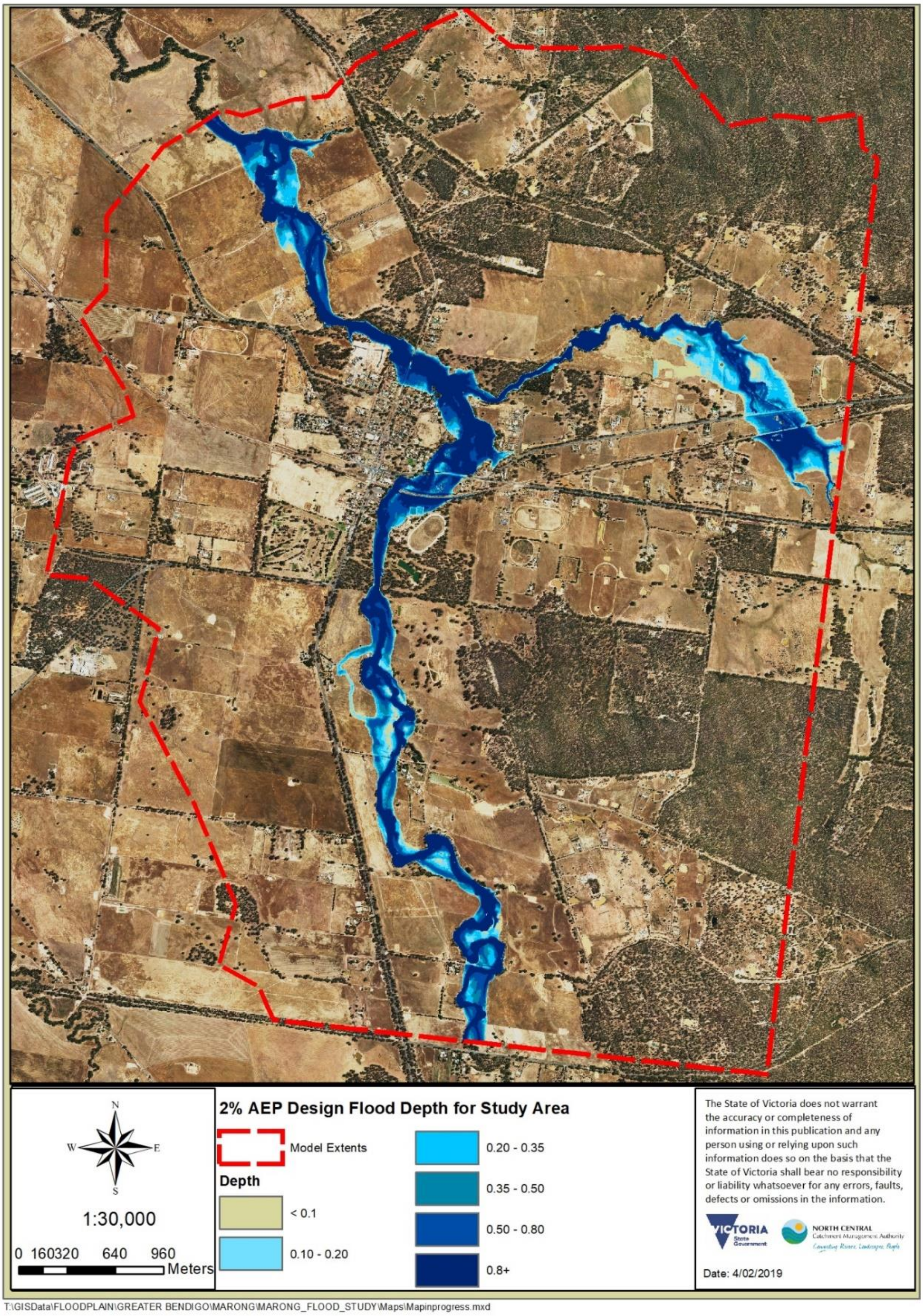

Figure 0.7 2% AEP Design Flood Depth

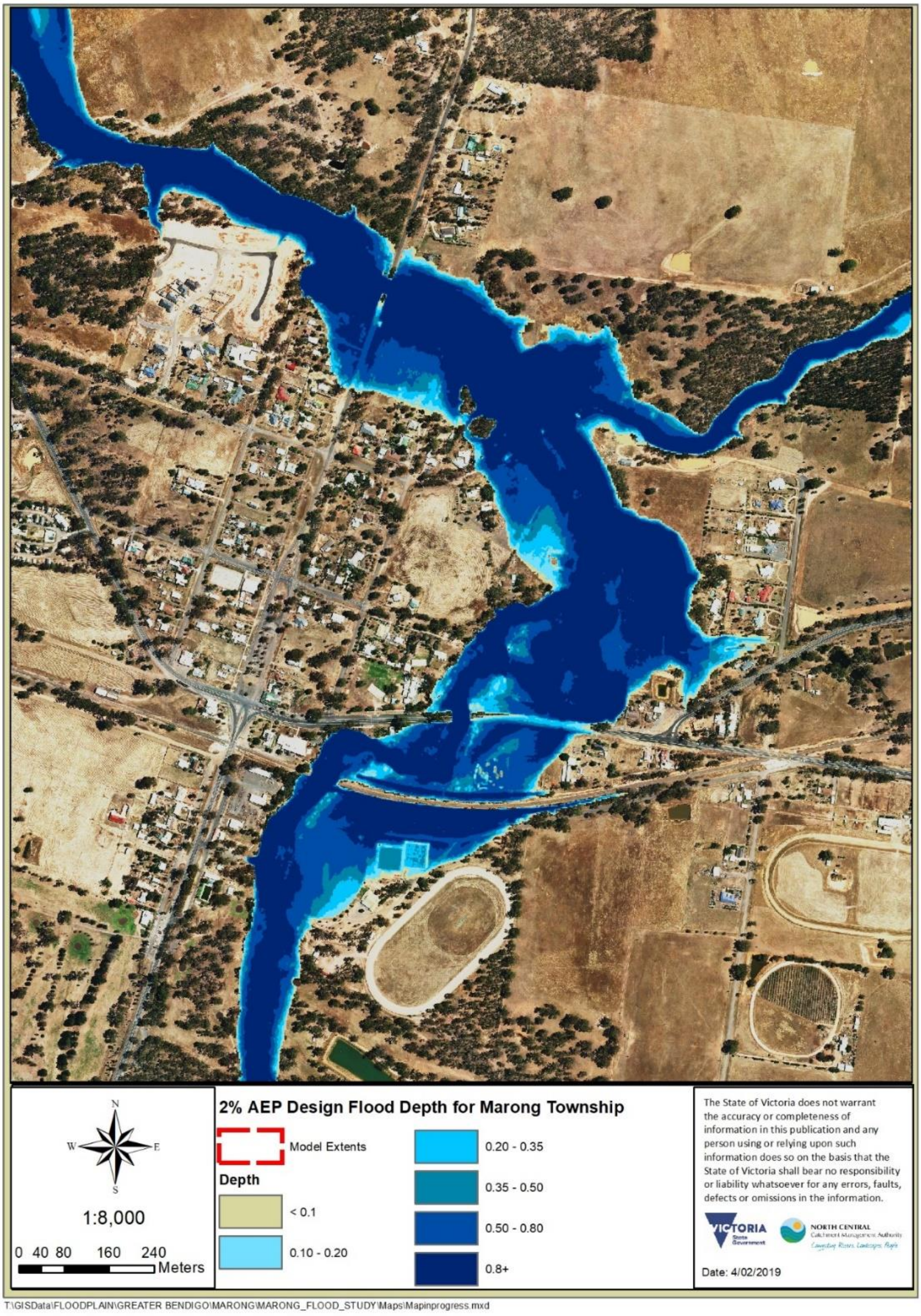

Figure 0.8 2% AEP Design Flood Depth for the Marong Township

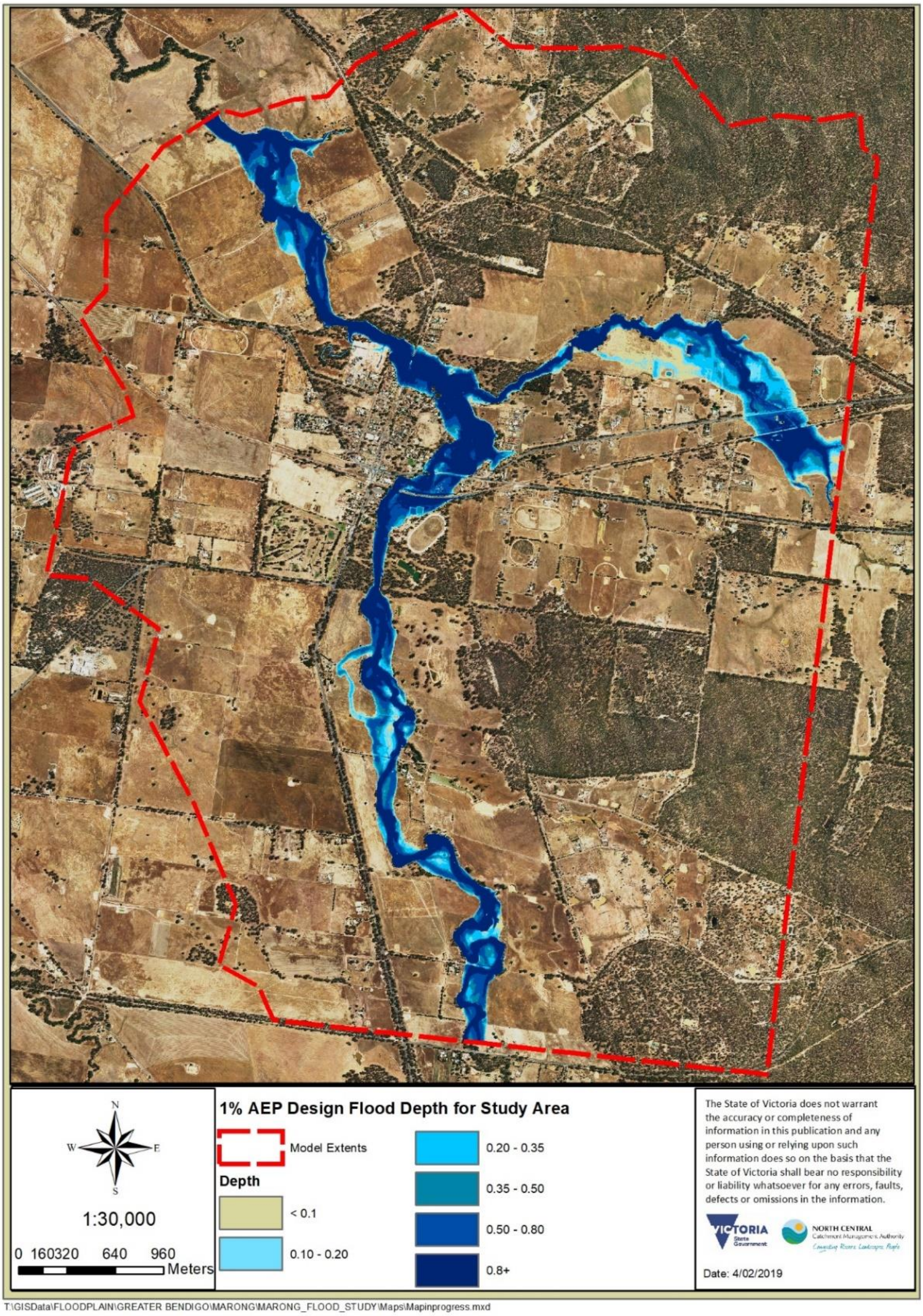

Figure 0.9 1% AEP Design Flood Depth

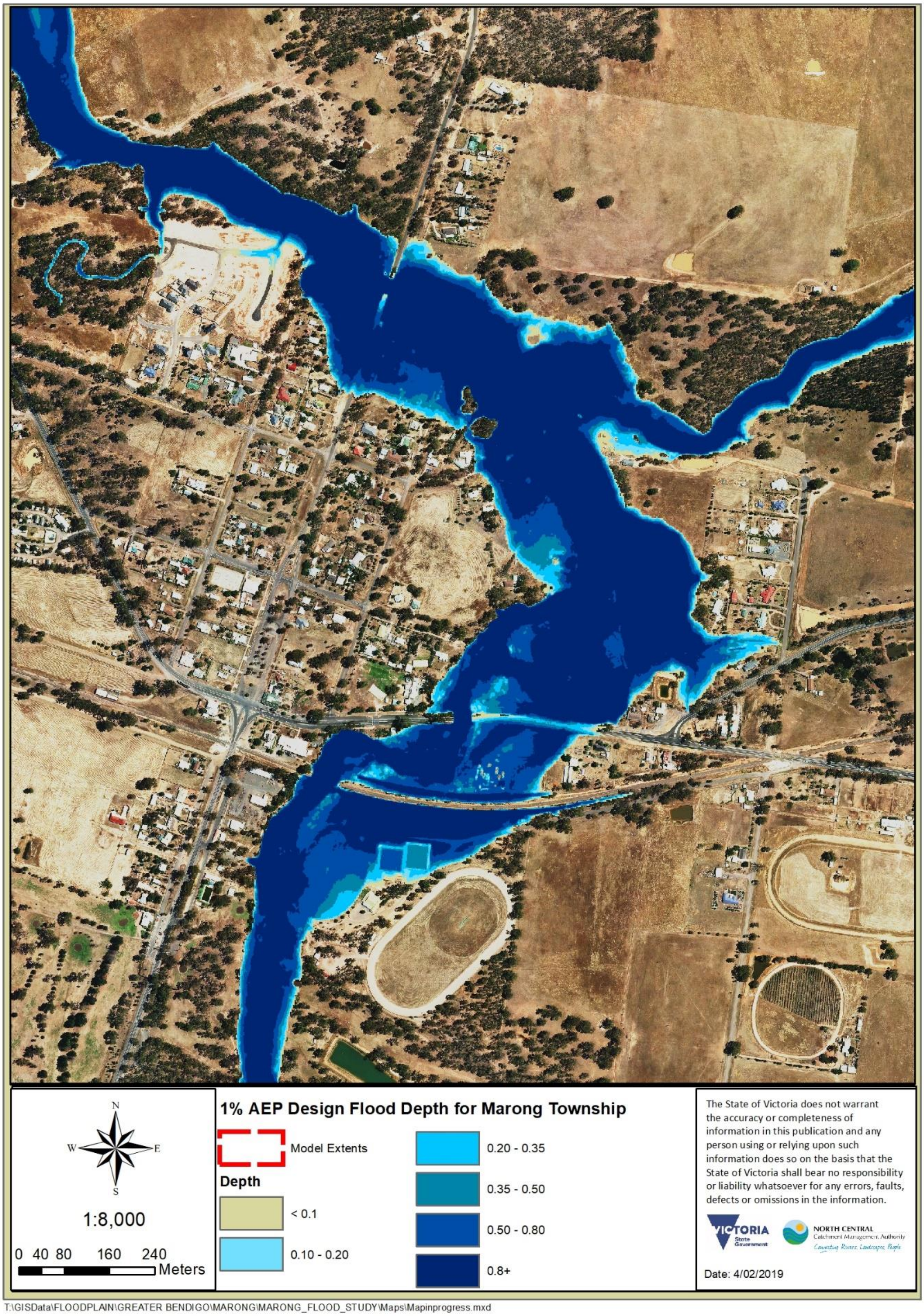

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Figure 0.10 1% AEP Design Flood Depth for the Marong Township

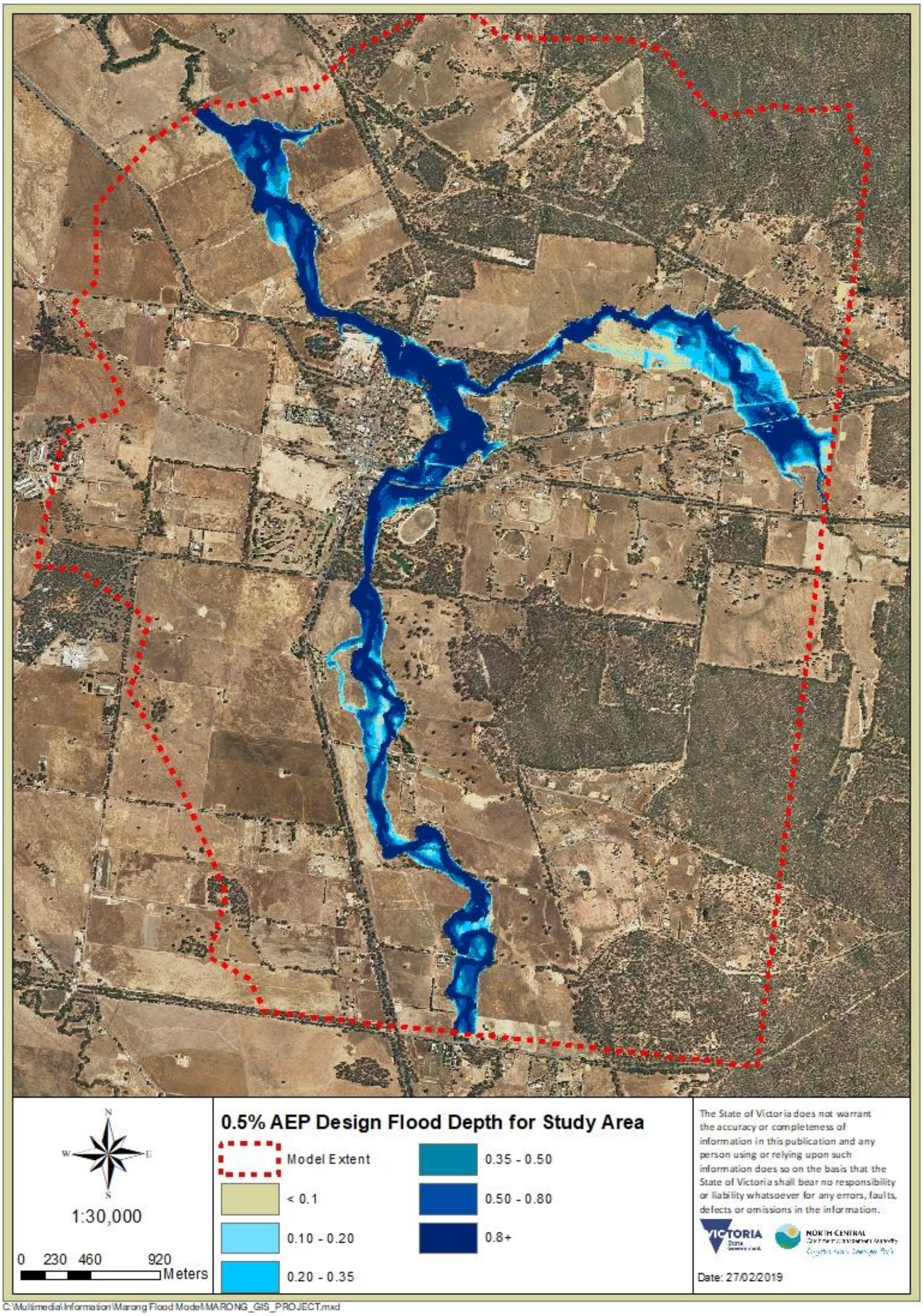

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Figure 0.11 0.5%AEP Design Flood Depth

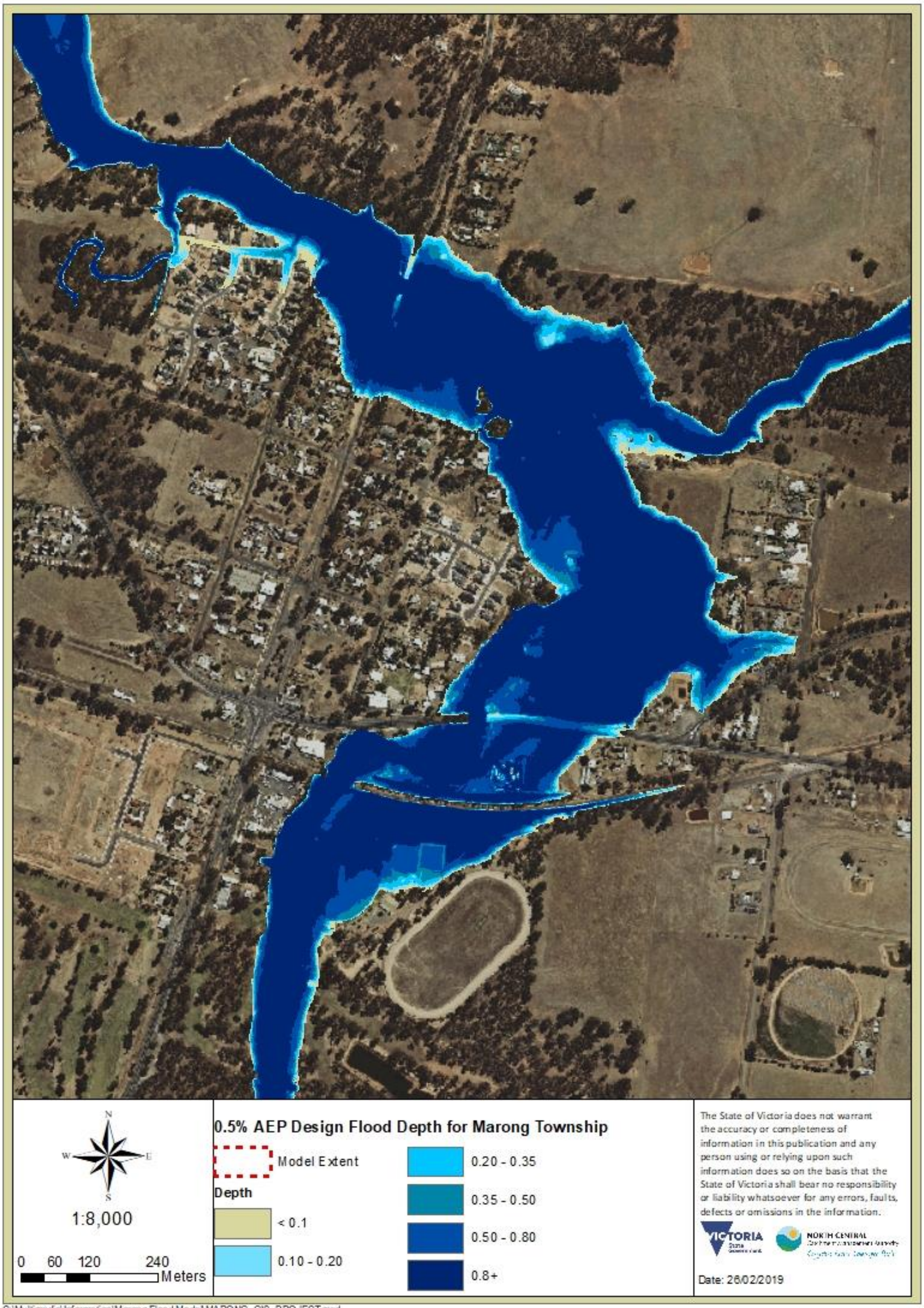

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Figure 0.12 0.5% AEP Design Flood Depth for the Marong Township