Flood Warning Report

Upper Mt. Emu Creek Flood Investigation

Glenelg Hopkins CMA

16 June 2020

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Cover Image: Mt. Emu Creek at Trawalla, Jan 2011

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16 June 2020

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Dear Tatjana

Upper Mt. Emu Creek Flood Investigation

Please see attached Flood Warning Deliverables and Summary report. This report documents the flood warning improvement outputs produced as part of the Upper Mt. Emu Creek Flood Investigation.

Additional to this report a spreadsheet was provided outlining the recommended rating curve changes, Lake Burrumbeet stage-storage relationship and Lake Burrumbeet outflow stage discharge relationship.

If you have any questions regarding this report, please do not hesitate to contact me.

Yours sincerely

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WATER TECHNOLOGY PTY LTD

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1 INTRODUCTION

1.1 Overview

Water Technology was commissioned by the Glenelg Hopkins Catchment Management Authority (Glenelg Hopkins CMA) to undertake the Upper Mt. Emu Creek Flood Investigation. The investigation area covered the upper Mt. Emu Creek catchment, extending along Mt. Emu Creek from upstream of Trawalla to Skipton, and the length of Baillie Creek from Lake Burrumbeet to the confluence with Mt. Emu Creek. Both waterways have a well-known history of flooding and some of the most significant flood events are recent and well recorded (e.g. events in 2010, 2011 and 2016). These flood events caused substantial damage to local infrastructure and agricultural assets (e.g. roads, bridges and fencing, as well as fodder, crop and stock losses). Severe impacts have also occurred within the township of Skipton and at the Lake Goldsmith Steam Preservation Society (LGSPS), damaging facilities and historical artefacts.

A previous flood investigation at Skipton was undertaken by Water Technology in 2013[1]. Since the completion of the study several physical and academic changes have occurred which impact inundation along Mt. Emu Creek and within Skipton, these include:

- Flood mitigation works have been undertaken in Skipton, altering the inundation characteristics within the township.
- Upgrade of the Western Highway, adding a significant floodplain feature at Trawalla. This is likely to increase demand for land development west of Ballarat because of the reduction in commute time between Beaufort and Ballarat.
- Australian Rainfall and Runoff 2019[2] was released outlining revised recommendations for hydrologic and hydraulic analysis (updated from Australian Rainfall and Runoff 1987[3]).

The updated analysis of flooding along Mt. Emu Creek and Baillie Creek was required to support the design and establishment of a formal flood warning service for Skipton.

This flood investigation provides a comprehensive flood analysis for several key areas of interest in the upper region of Mt. Emu Creek and up-to-date flood intelligence information. The flood intelligence information focuses on the township of Skipton but includes several other areas along the upper Mt. Emu Creek.

This report is one of a series, documenting the outcomes of the Upper Mt. Emu Creek Flood Investigation. The reporting stages of this project were as follows:

- R01 - Data Review and Validation.
- R02 – Draft Hydrology and Hydraulics Calibration Report.
- R03 – Draft Hydrology and Hydraulics Design Report.
- R04 – Final Hydraulic Report and Mapping Deliverables.
- R05 –**Flood Warning Report (this report).**
- R06 – Flood Damages and Mitigation Assessment Report.

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[1] Water Technology (2013), Skipton Flood Investigation.
[2] Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) (2019), Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia
[3] Institution of Engineers, Australia (1987), Australian Rainfall and Runoff: A Guide to Flood Estimation , Vol. 1, Editor-in-chief D.H. Pilgrim, Revised Edition 1987 (Reprinted edition 1998), Barton, ACT

- R07 – Flood Intelligence Report and Animations.
- R08 – Project Summary Report.

1.2 Previous reporting

There were several previous reporting milestones and memos prior to the production of this report. These documents include:

- Data collation report – R01 (V01 – Issued 11/06/2019, V02 – Issued 05/07/2019).
  - This report detailed the data collated and gaps in the data required to be filled. The major outcome of this report was the requirement for additional LiDAR data, which was acquired of the study area vastly improving the dataset coverage. Additional areas included floodplain areas between Lake Goldsmith and Mena Park and Lake Goldsmith.
- Survey requirements memo – M01 (V01 – Issued 05/02/2019, V02 – Issued – 21/03/2019).
  - This memo was produced as a base guideline to assist in sourcing feature survey to verify the additional LiDAR data and accurately define structures within the hydraulic model.
- Calibration update memo report – M02 (V01 – Issued 04/09/2019).
  - This report was produced to update Glenelg Hopkins CMA on the progress of the hydraulic model calibration and to enable a clean handover between changing Project Managers.
- Calibration Report – R02 (V01 – Issued 13/11/2019, V02 – Issued 31/01/2020).
  - This report detailed development of the hydrologic and hydraulic models, as well as the hydraulic model calibration process.
- Design Modelling Report – R03 (V01 – Issued 28/01/2020).
  - This report outlined the design modelling process, design flows and design draft 1% Average Exceedance Probability (AEP) mapping.
- Flood Mitigation Assessment Report – R06 (V01 – Issued 17/04/2020)
  - This report outlined several flood mitigation measures trialled during the flood investigation, focusing on the Lake Goldsmith Steam Preservation Society and Skipton.

This report (R05) describes the flood warning deliverables produced as part of the study and discusses the uncertainty in rating curve estimates and travel times between key locations. The report was written to allow flood emergency personnel (primarily the Bureau of Meteorology) to understand the limitations in the intelligence data and make appropriate decisions. This report is closely linked to the Municipality Flood Emergency Planning (MFEP) report – R07.

2 BACKGROUND

2.1 Study area

Mt. Emu Creek is located approximately 30 km west of Ballarat at its closest point, flowing from Langi Kal Kal to the Hopkins River west of Cudgee. The Upper Mt. Emu Creek Flood Investigation focuses on the area extending from upstream of Trawalla to about 4 km downstream of Skipton, whilst covering the entirety of Baillie Creek and its associated floodplain. This extends from Lake Burrumbeet to the confluence with Mt. Emu Creek. The total catchment area of the investigation is approximately 1,250 km^2 and spans three municipalities. However, the extent of the required project outputs is only relevant to the Pyrenees and Corangamite Shire Council areas. The study area is displayed in Figure 2-1.

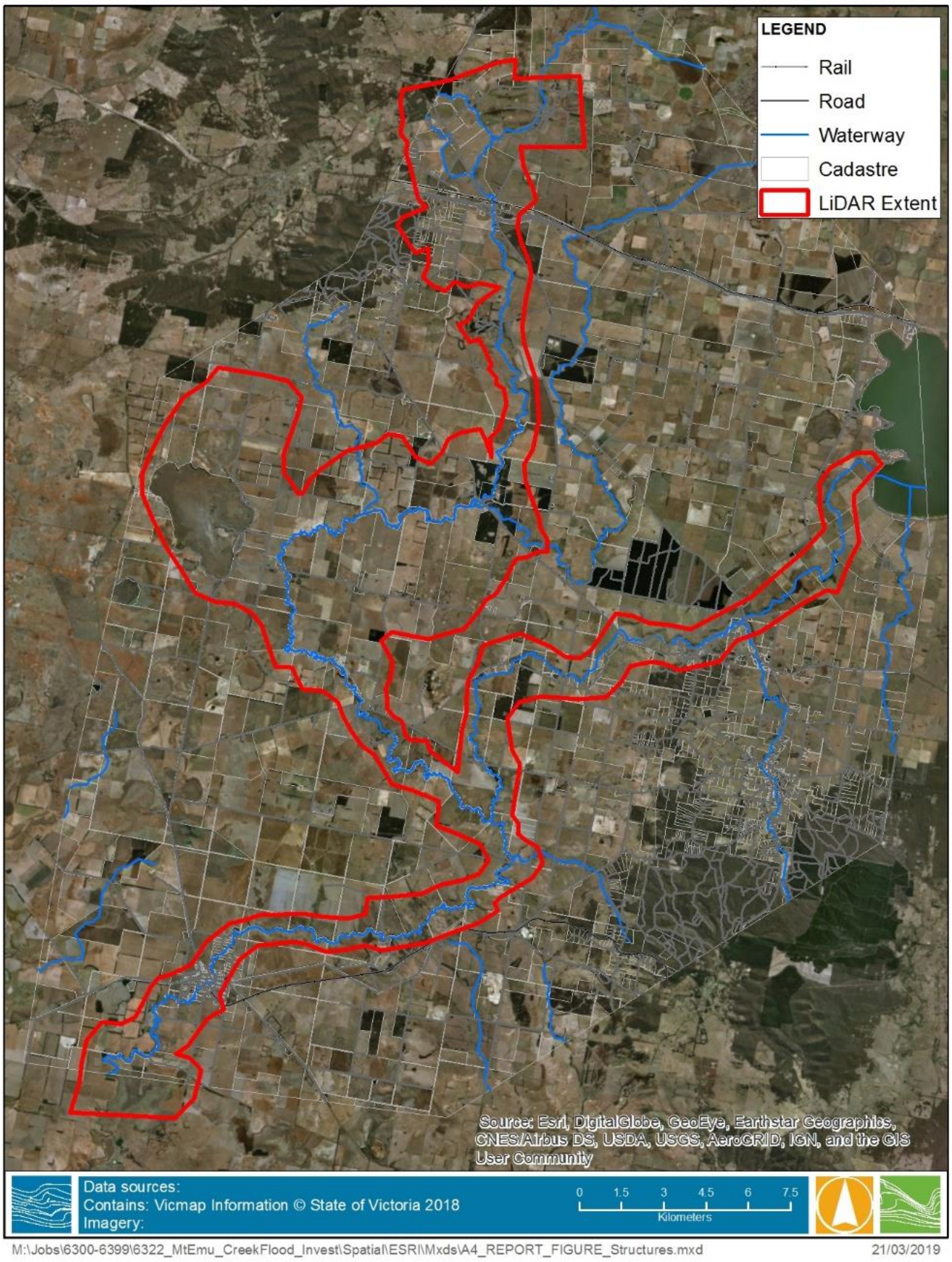

FIGURE 2-1 UPPER MT. EMU CREEK FLOOD INVESTIGATION – STUDY AREA

2.2 Flood warning improvement deliverables

The tender document sets out several specific flood improvements required to facilitate the implementation of a formal flood warning service for Skipton. The Bureau of Meteorology has highlighted the following locations as potentially useful gauging stations for Mt. Emu Creek:

- Mount Emu Creek at Guthrie's Bridge (has been used for PALS deployments).
- Mount Emu Creek at Mena Park (historic gauging station).
- Mount Emu Creek at Cameron's Bridge (new gauging station).
- Mount Emu Creek at Skipton (historic gauging station).
- Mount Emu Creek at Trawalla (potential future gauging station).
- Baillie Creek at Carngham – Streatham Road (proposed PALS site).

The hydraulic model developed as part of this project was used to produce theoretical raining curves at each of the above locations and the peak travel time estimates between each of them. The theoretical rating curves were compared to the available existing curves (where available) and historic observations. Travel time estimates are presented showing a range of potential peak travel times; however, the progression of a flood peak is highly dependent on the magnitude of an event, spatial and temporal rainfall pattern and antecedent catchment conditions.

The hydraulic model extent and the gauging locations of interest are shown in Figure 2-2.

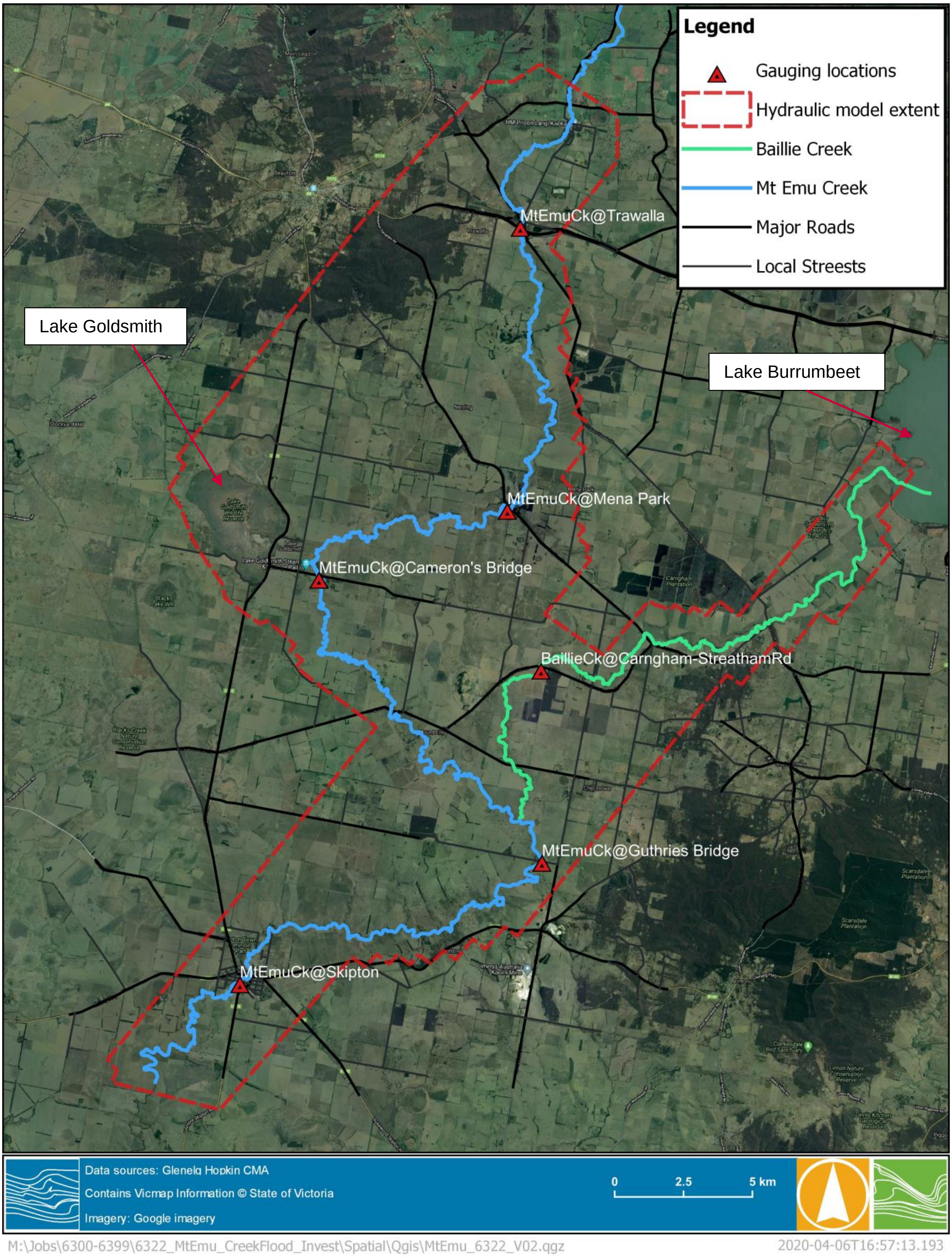

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FIGURE 2-2 HYDRUALIC MODEL EXTENT AND GAUGING STATIONS

3 CURRENT FLOOD WARNING SYSTEM

Currently, three existing gauging stations along Mt. Emu Creek form the current flood intelligence system:

- Mt. Emu Creek at Skipton (236203) – Immediately upstream of Smythe Street within Skipton, the flood level prediction gauge for Skipton.
- Mt. Emu Creek at Guthries Bridge (236238) - About 13 km upstream of Skipton, a Portable Automated Logger System (PALS) deployed supporting flood warning for Skipton. Given the limited data at this gauge, there is no rating curve available to provide reliable flood warning.
- Mt. Emu Creek at Mena Park gauge (236213) - Another 20 km further upstream, has well defined rating curve for low flows. The rating of this gauge is unreliable for water level above 2.4 m as a result of the breakout of flood flows from a tributary and very broad floodplain.

4 RATING CURVE REVIEW

4.1 Overview

The TUFLOW model developed as part of the Upper Mt. Emu Creek Flood Investigation was used to generate a theoretical rating curve at each existing and prospective gauge location. The TUFLOW model was calibrated to the 2011 and 2016 flood events with observations recorded at each gauge existing and prospective gauge location. Detailed reporting covering the development and calibration of the hydraulic model can be found in the Model Calibration Report (R02) with a brief discussion of the model calibration at each location in the following specific sections.

The model determined theoretical rating curves were compared to the recorded flow rates and heights currently used as the basis for the existing rating curves (where they exist). Typically, hydrographers can accurately measure flow within a confined channel and/or floodplain; however, once floodplain flow becomes complex with several flow paths at varying depths and interactions between numerous flow paths, this measurement becomes very difficult. Inversely, the hydraulic model used in this study focuses on producing accurate flood levels for flood events where significant out of bank flow is occurring, with limited emphasis on calibration during small flow events. As a result, the model can accurately define a theoretical flow rate and height relationship where there is complex out of bank flows but isn't expected to be able to produce and accurate relationship during low, in channel flows.

The report includes recommendations to modify the existing gauge rating curves, joining the current measurement based rating and the modelled theoretical rating. Joining the two methods enables an accurate rating at low in channel flows (based on measured data) and high out of bank flows (based on theoretical model results).

The theoretical rating curves were produced using the largest design event modelled as part of the Upper Mt. Emu Creek Flood Investigation (i.e. 0.2% AEP) but a comparison was also made to smaller events and no significant change in the rating curve was found across the events.

4.2 Mt. Emu Creek

4.2.1 Mt. Emu Creek at Skipton

The Mt. Emu Creek at Skipton gauge (236203) is located on the north side of Smythe Street at Skipton. The gauge has an existing rating, with a change to the hydraulic control in 1987. The change in control resulted in a shift in the gauge rating curve and measured data points before 1987 were removed from the rating.

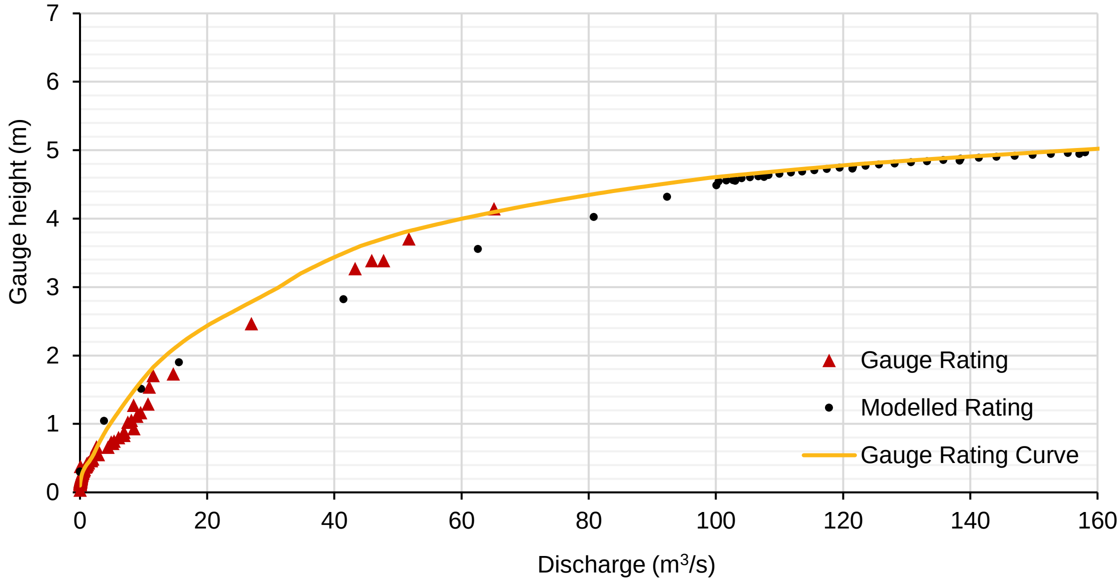
The 2011 and 2016 hydraulic model calibration showed an outstanding calibration through the Skipton township and at the Skipton gauge location, with the modelled flood level within 1cm that recorded during 2011 and 15cm (modelled lower than that observed) during 2016. This gives confidence in the modelled rating at high out of bank flows.

A modelled theoretical rating curve was developed for the Mt. Emu Creek at Skipton gauge based on the current gauge location and control. Comparison between the modelled theoretical rating curve and the measurement based gauge rating curve (i.e. post 1987). The location of the modelled rating curve extraction is shown in Figure 4-1 with the rating shown in Figure 4-2.

In general, the modelled theoretical and current rating curves match very well; however, the existing measurement based gauge rating will perform better during lower, in-channel flows. There is limited recorded data during high flows, above a gauge level of around 4.1 m and the existing rating curve is extrapolated.

The hydraulic model will provide more reliable estimates of the relationship between flowrate and height at water levels above 4.5 m. Above 5.0 m the existing gauge rating curve is likely to underestimate flow rate. The gauge rating curve indicates a water level of 6.0 m the flowrate is 400 m^3/s, whereas the modelled theoretical rating is around 450 m^3/s. These differences are considered relatively minor.

FIGURE 4-1 RATING CURVE EXTRACTION LOCATION AT THE SKIPTON GAUGE



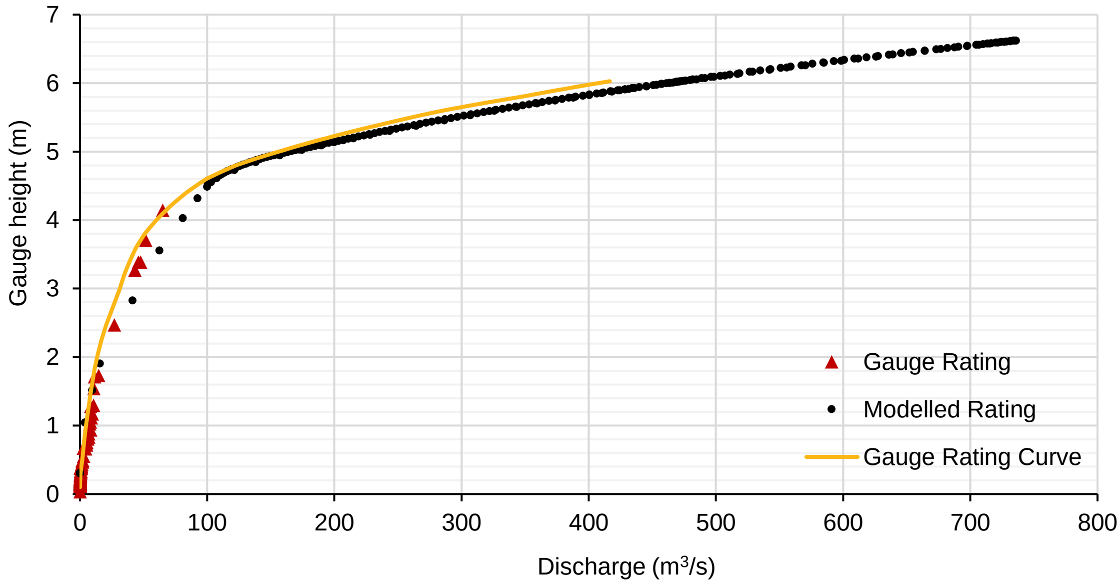


FIGURE 4-2 RATING CURVE COMPARISON AT THE SKIPTON GAUGE, TOP: LOW FLOWS; BOTTOM: HIGH FLOWS

During the Skipton Flood Investigation[1] a modelled rating curve was determined for Skipton was determined, how this rating curve compares to that determined during this project is shown below in Figure 4-3. The modelled ratings show a very close match.

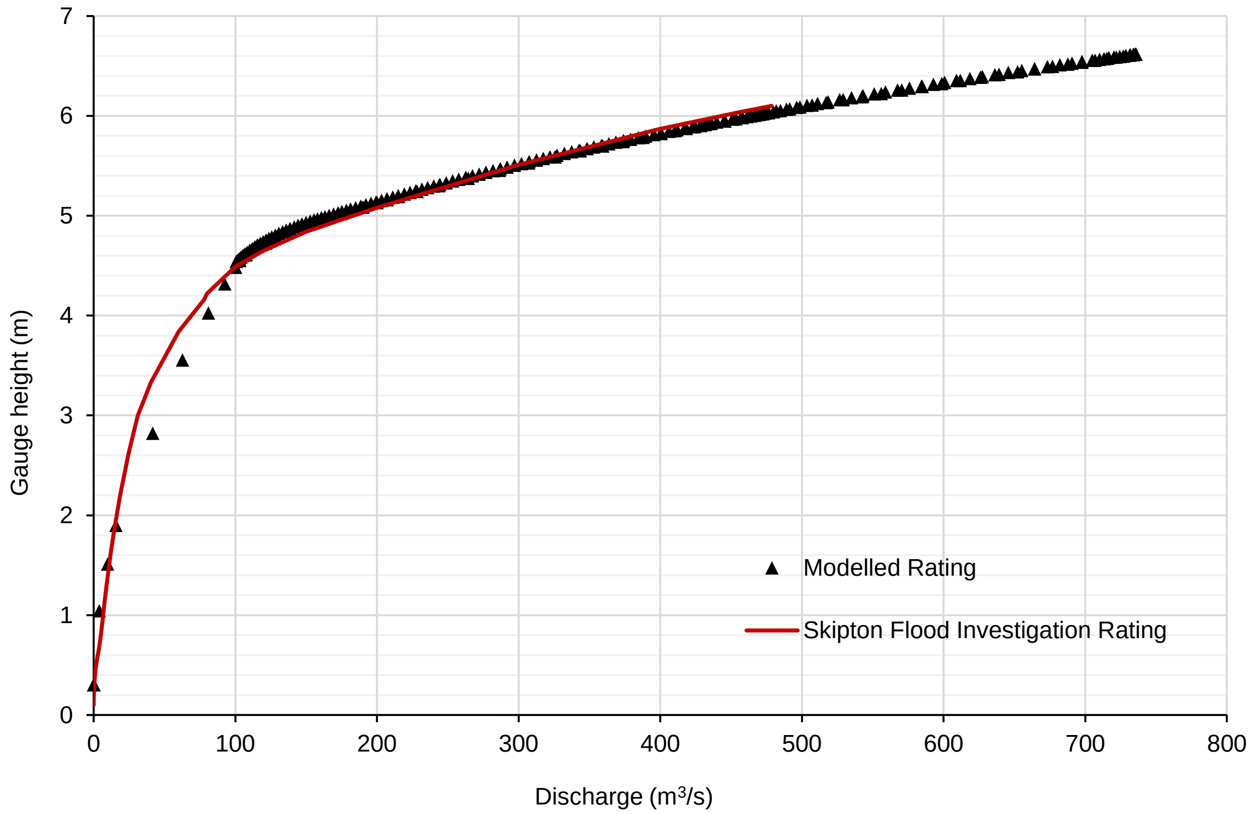


FIGURE 4-3 RATING CURVE COMPARISON BETWEEN THE RATING DETERMINED DURING THE SKIPTON FLOOD INVESTIGATION AND THIS PROJECT

A revision to the Mt. Emu Creek at Skipton gauge rating could be made at high flows at a level above 4.5 m. Table 4-1 summarises the recommendation of how the existing gauge rating curve and modelled rating curved should be linked.

TABLE 4-1 REVISED RATING AT SKIPTON GAUGE

Gauge Height (m)	Discharge	Method
0	0	Gauge rating curve
Etc.	Etc.	Gauge rating curve
4.604	9.62	Gauge rating curve
4.609	107.59	Interpolated gauge rating curve and modelled rating curve
Etc.	Etc.	Interpolated gauge rating curve and modelled rating curve
5.133	200.01	Interpolated gauge rating curve and modelled rating curve
5.162	206.95	Modelled rating curve
Etc.	Etc.	Modelled rating curve
6.619	735.89	Modelled rating curve

4.2.2 Mt. Emu Creek at Guthries Bridge

The existing Mt. Emu Creek at Guthries Bridge (236238) has been used for PALS deployments with only stream water level being recorded. No available rating table can be compared to the modelled theoretical rating.

During the September 2016 event the Skipton CFA took eater level recordings over the course of the event, relative to gauge boards installed at the proposed PALS gauge location. The peak recorded level at Guthries Bridge was 327.8 m AHD. This compared to a modelled maximum water level of 327.9 m AHD, 100mm higher than that observed. This gives good confidence in the modelled levels at Guthries Bridge.

Figure 4-4 displays the modelled theoretical rating curve. It should be noted that a surveyed zero gauge level of 324.09 m AHD was provided by Glenelg Hopkins CMA and it was adopted for the gauge rating below.

The extraction location of the theoretical rating curve is shown in Figure 4-5.

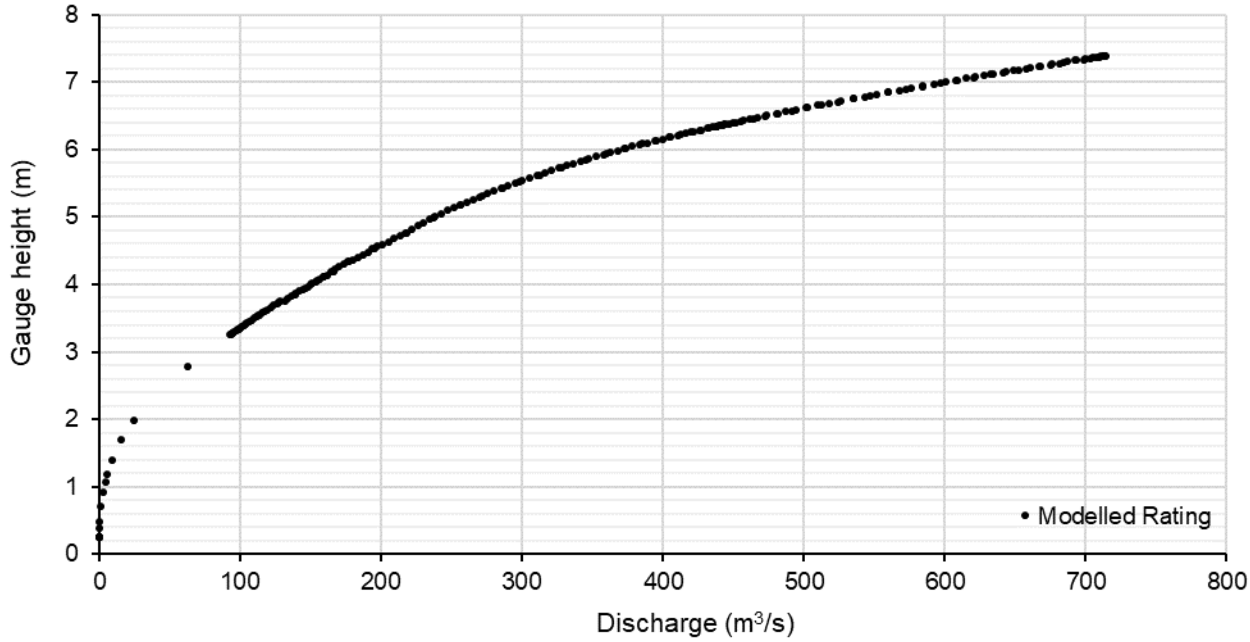


FIGURE 4-4 MODELLED RATING CURVE AT GUTHRIES BRIDGE GAUGE

FIGURE 4-5 MODELLED THEORETICAL RATING CURVE EXTRACTION LOCATION AT GUTHRIES BRIDGE GAUGE

4.2.3 Mt. Emu Creek at Cameron Bridge

Mt. Emu Creek at Cameron Bridge is a proposed new gauging station location at the Carngham – Lake Goldsmith Road, around 400 m east of the steam rally site. The gauge site is characterised by a confined section of the Mt. Emu Creek, enabling accurate physical flow rate measurements. The new gauge site is yet to be instrumented. In the short term it is intended to be set up as a PALS site. In the longer term, this site may be suitable for permanent instrumentation with the view to potential replacement of the Mena Park gauge, which is not suitable from a flood warning system perspective (discussed further in Section 4.2.4).

There were significant anecdotal comments, observations and photos were provided by Brian Smith, the Flood Information Coordinator and member of the Lake Goldsmith Steam Preservation Society (LGSPS). The model calibration showed the hydraulic model was able to closely match observations and provided confidence in the theoretical rating curve at Camerons Bridge.

Figure 4-6 shows the theoretical rating curve in m AHD with the extraction location shown in Figure 4-7.

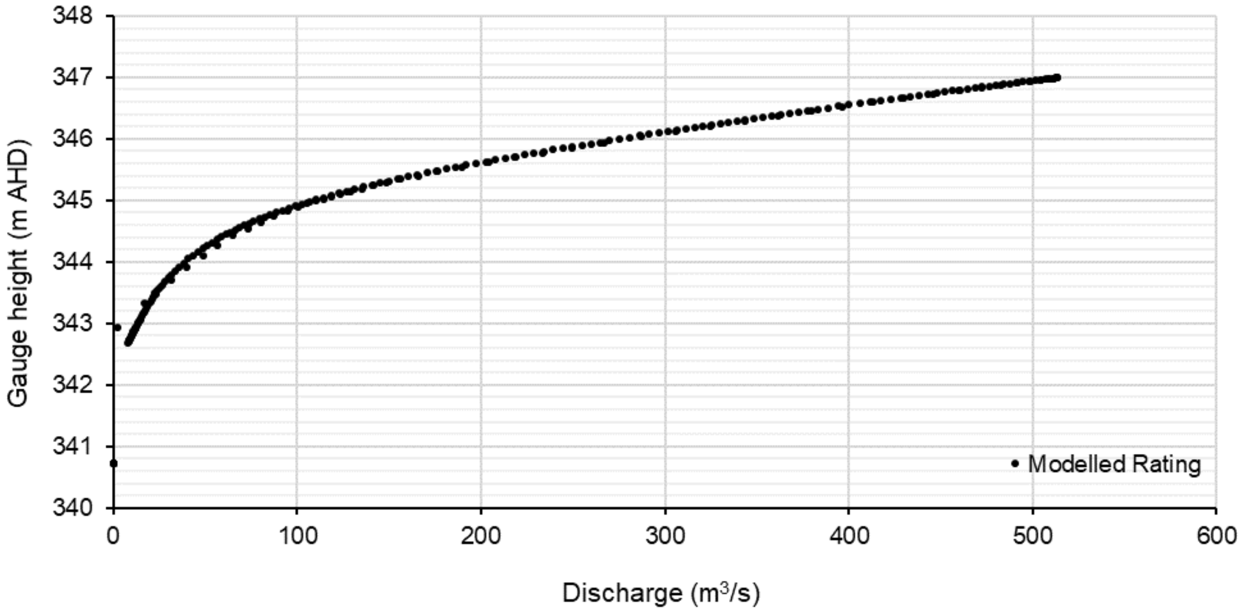


FIGURE 4-6 MODELLED THEORETICAL RATING CURVE AT CAMERON BRIDGE

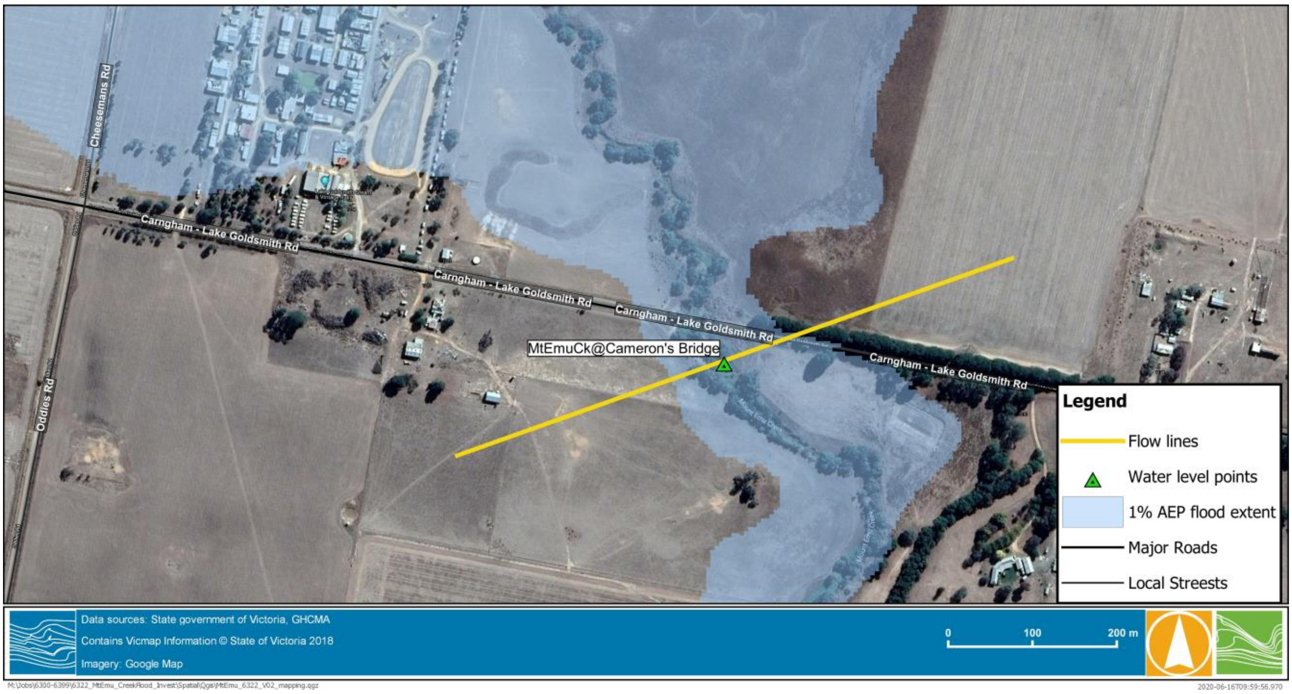


FIGURE 4-7 MODELLED THEORETICAL RATING CURVE EXTRACTION LOCATION AT CAMERON BRIDGE

4.2.4 Mt. Emu Creek at Mena Park

The Mt. Emu Creek at Mena Park gauge (236213) has been operating since 1967. It is understood that there was change of control at the Mena Park water level gauge in 1974, resulting a shift in the gauge rating curve. Comparisons made within this report only include measured data points post 1974.

The Mena Park gauge is in a poorly confined section of the Mt. Emu Creek floodplain, which results in difficulty physically measuring high flows, and large uncertainty in the flow record once water levels exceed channel capacity. When water levels exceed approximately 2.4 m, the gauge rating becomes unreliable due to the break out of flood water flowing across the broader floodplain.

During the January 2011 event there were seven peak flood heights surveyed up and downstream of the Mena Park gauge. Of these points four showed modelled flood levels were within 100mm and all seven were within 200mm. Modelling of January 2011 showed a maximum flood level 210mm lower than that recorded. Modelling of the September 2016 event showed the modelled level was within 20mm of that recorded at the gauge. These observations show the model is producing reasonable flood level estimates at the Mena Park gauge location.

Spring Creek enters Mt. Emu Creek immediately downstream of the Mena Park gauge, during hydraulic modelling of the gauge the Spring Creek inflow was added downstream of the confluence with Mt. Emu Creek. As a result, the extracted stage-discharge relationship at Mena Park is only reflective of flow in Mt. Emu Creek. This is shown in Figure 4-8.

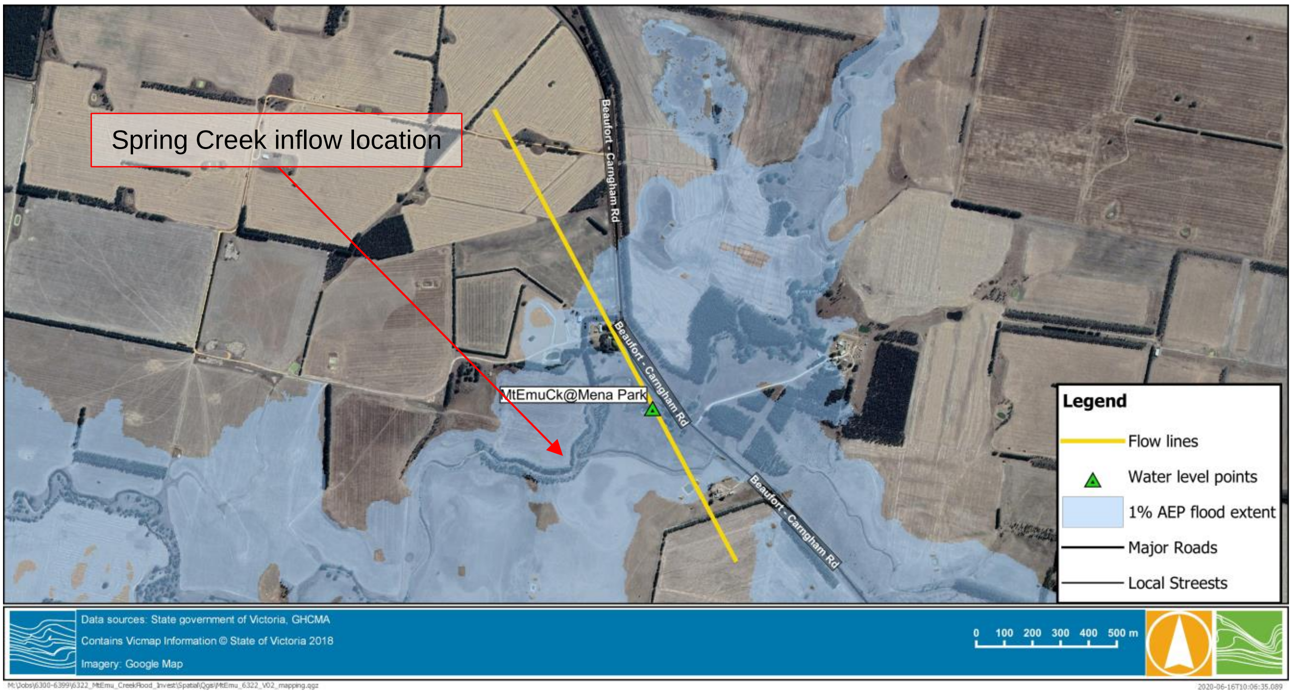


FIGURE 4-8 MENA PARK GAUGE, SPRING CREEK INFLOW AND MODELLED THEORETICAL RATING CURVE EXTRACTION LOCATION

The surveyed zero gauge level of the Mena Park gauge is 350.8 m AHD. As shown in Figure 4-9, there is a clear separation between the existing measurement based rating curve and the modelled theoretical rating curve at around a flow of 45 m^3/s or water level of 2.2 m, there is limited recorded data above this point and the existing rating curve is extrapolated. The modelled theoretical rating curve is expected to give a more realistic height and flow relationship above this point.

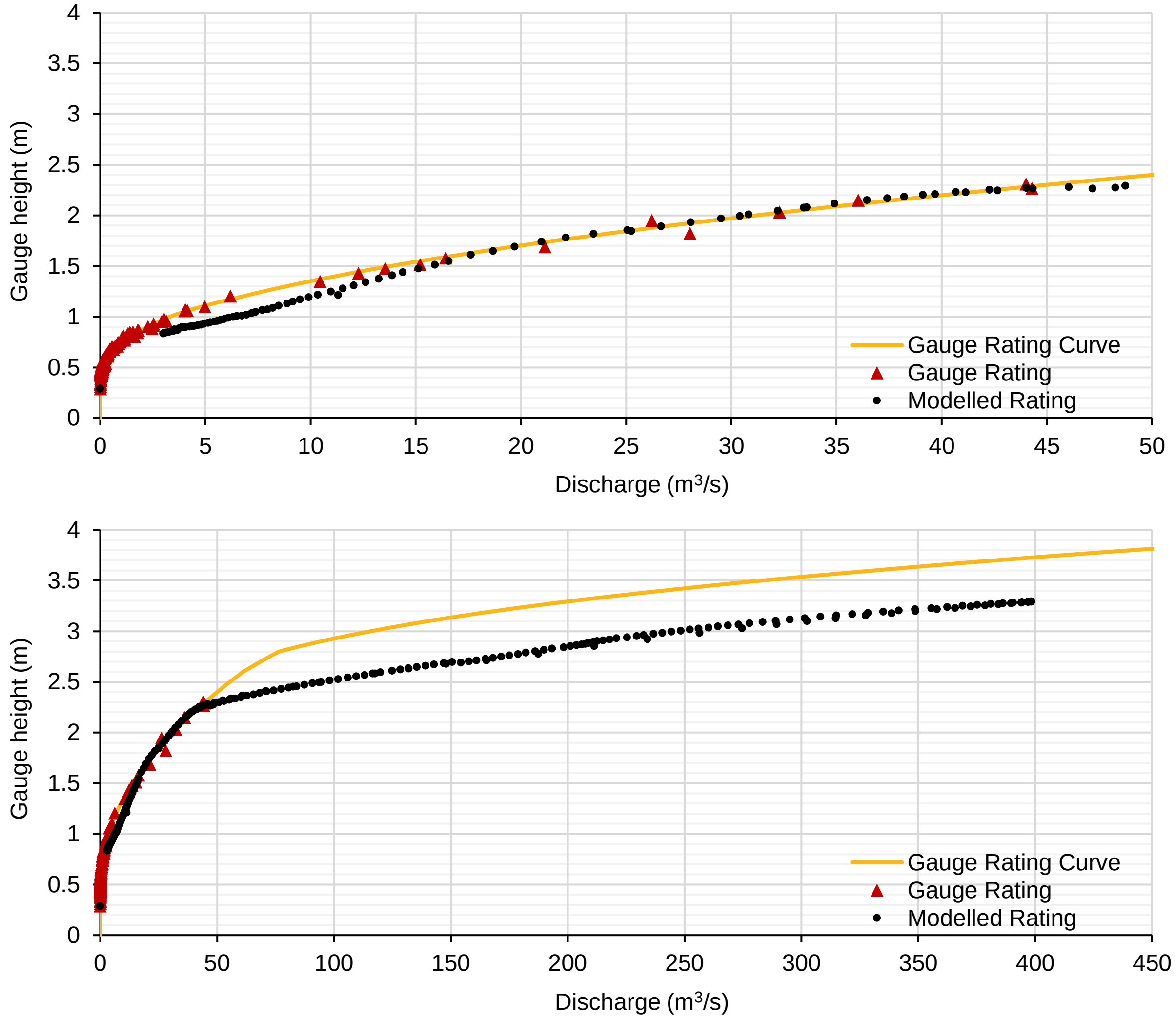


FIGURE 4-9 RATING CURVE COMPARISON AT MENA PARK, TOP: LOW FLOWS; BOTTOM: HIGH FLOWS

Table 4-2 outlines the recommended transition from the existing measured gauge rating to the theoretical modelled rating curve.

TABLE 4-2 RECOMMENDED REVISED RATING AT THE MENA PARK GAUGE

Gauge Height (m)	Discharge	Method
0	0	Gauge rating curve
Etc.	Etc.	Gauge rating curve
1.702	19.96	Gauge rating curve
1.707	20.13	Interpolated gauge rating curve and modelled rating curve
Etc.	Etc.	Interpolated gauge rating curve and modelled rating curve
2.267	43.26	Interpolated gauge rating curve and modelled rating curve
2.269	44.03	Modelled rating curve
Etc.	Etc.	Modelled rating curve
3.293	398..43	Modelled rating curve

4.2.5 Mt. Emu Creek at Trawalla

There is no existing gauge station at Trawalla. Immediately upstream of the new Western Highway at Mt. Emu Creek a modelled theoretical rating curve was extracted for a hypothetical gauging station, as displayed in Figure 4-10. A gauging station at Trawalla could give an early indication of high flows in Mt. Emu Creek before potential inundation at Mena Park and the Lake Goldsmith Stream Preservation Society. If the Mena Park gauge was moved it could give support flood intelligence for upper areas along Mt. Emu Creek which currently use the Mena Park gauge.

During January 2011 there were nine surveyed flood marks captured. Of these, the hydraulic model matched four within 100mm and 8 within 200mm, demonstrating the hydraulic model was well calibrated in proximity to the potential gauging station location.

The location of the extracted theoretical rating curve is shown in Figure 4-11.

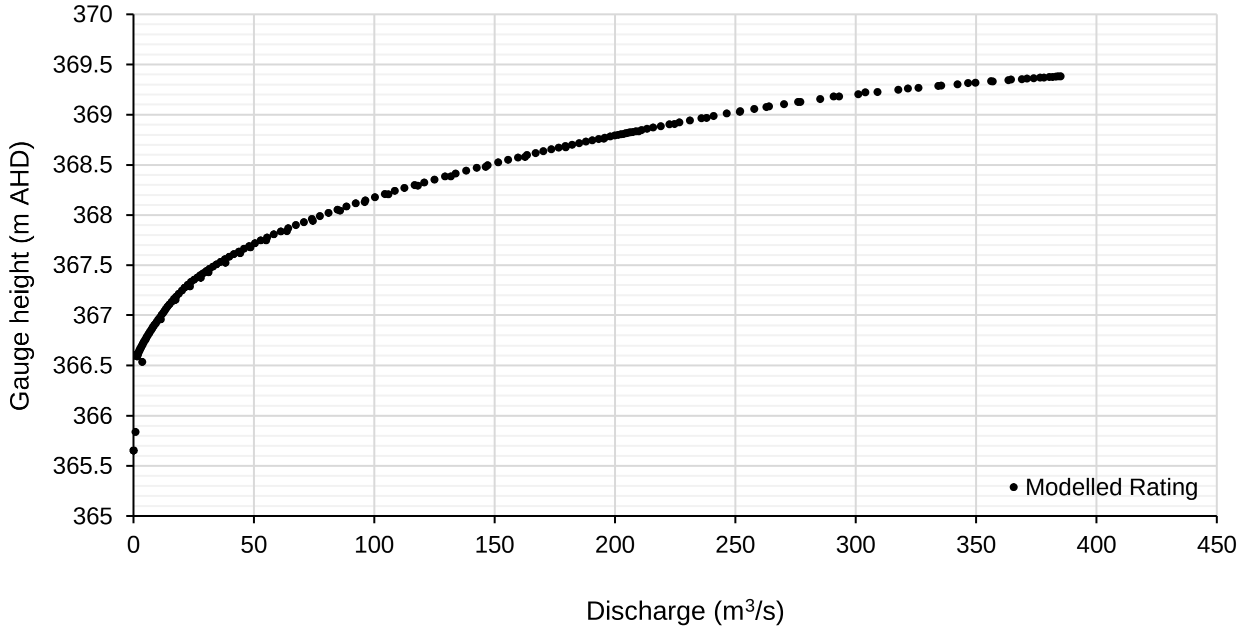


FIGURE 4-10 MODELLED THEORETICAL RATING CURVE AT TRAWALLA

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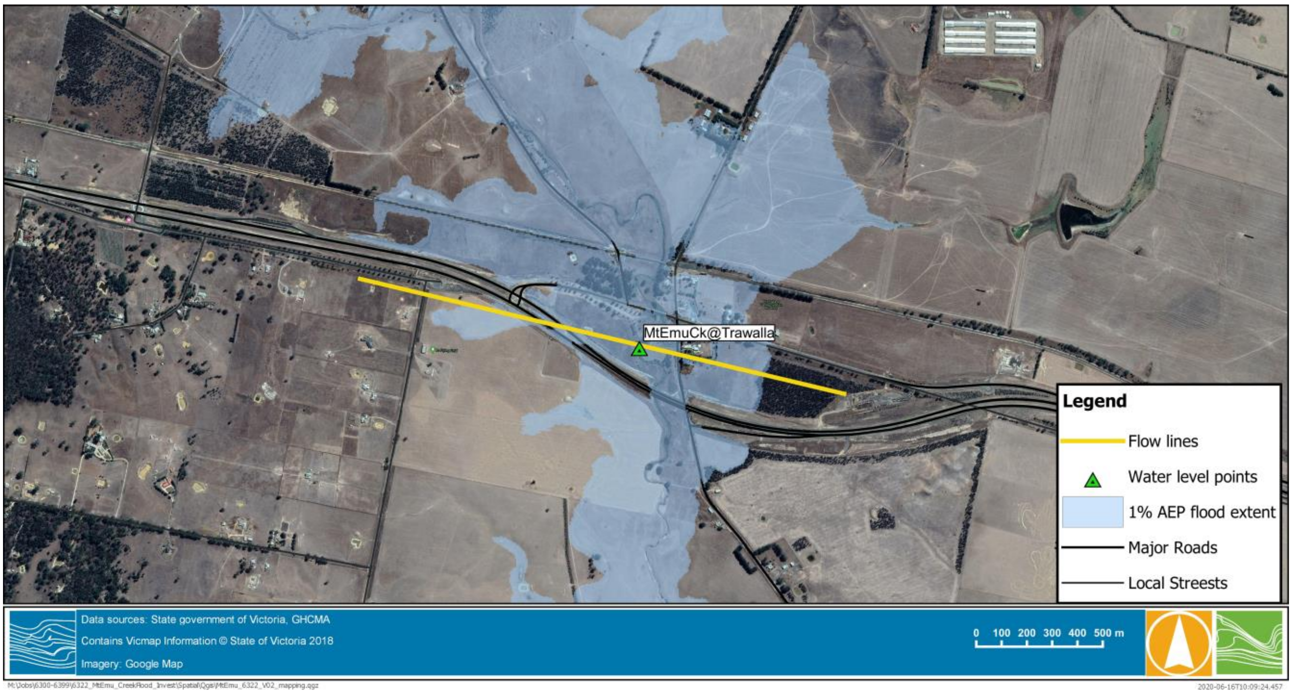

FIGURE 4-11 MODELLED THEORETOCAL RATING CURVE EXTRACTION LOCATION AT TRAWALLA

4.2.6 Lake Burrumbeet Outlet

The Lake Burrumbeet outlet structure was described in the Floodplain Management Plan for Lake Burrumbeet and Burrumbeet Creek Catchment. Report[4]. The structure was detailed as having a crest length of 30.7 metres and a crest level of 378.7 m to Australian Height Datum (AHD), and removable wooden planks to a height of 379.1 m AHD. Survey undertaken during the Burrumbeet Flood Investigation confirmed these levels; however, a spillway length of 27m was determined. During this study a flowrate height relationship for the Lake Burrumbeet Outlet was determined in RORB using the below spillway discharge equation.

$$Qs = K_W L_S (H - H_S)^{3/2}$$

Where Qs is the spillway discharge (m3/s), Kw is the weir coefficient for the spillway (1.74 for a Sharp Crested weir with a vertical face, adopted here), LS is the effective length of the spillway (m), H is the water surface elevation (m), and HS is the spillway crest elevation (m).

The determined spillway water level and height relationship determined with the weir boards removed and in place is shown in Table 4-3.

TABLE 4-3 LAKE BURRUMBEET OUTLET – FLOWRATE VS. HEIGHT RELATIONSHIP

Water Level (m)	Water Level (m AHD)	Weir Flow – Boards Removed (m^3/s)	Weir Flow – Boards in place (m^3/s)
0	378.7	0.0	0
0.1	378.8	1.5	0

[4] Lawson and Treloar (2003) Floodplain Management Plan for Lake Burrumbeet and Burrumbeet Creek Catchment. Report RM2049 Ver. 1.0 / J5350 prepared for Glenelg Hopkins Catchment Management Authority and Ballarat City Council.

Water Level (m)	Water Level (m AHD)	Weir Flow – Boards Removed (m^3/s)	Weir Flow – Boards in place (m^3/s)
0.2	378.9	4.2	0
0.3	379	7.7	0
0.4	379.1	11.9	0
0.5	379.2	16.6	1.5
0.6	379.3	21.8	4.2
0.7	379.4	27.5	7.7
0.8	379.5	33.6	11.9
0.9	379.6	40.1	16.6
1	379.7	47.0	21.8
1.1	379.8	54.2	27.5
1.2	379.9	61.8	33.6
1.3	380	69.6	40.1
1.4	380.1	77.8	47.0

4.3 Baillie Creek

4.3.1 Baillie Creek at Carngham – Streatham Road

There is no existing gauging station on Baillie Creek at Carngham – Streatham Road, and a complete absence of gauges along Baillie Creek. A PALS site is proposed immediately downstream of the Carngham – Streatham Road bridge, and this location was used to create a modelled theoretical gauge rating as shown in Figure 4-12. Baillie Creek is a major tributary of Mt. Emu Creek and a gauge at this location would provide an understanding of the contribution Baillie Creek is making to Mt. Emu Creek. It would also provide flood intelligence for potential flood warnings in Skipton.

Although the hydraulic model calibration did not focus on location, Glenelg Hopkins CMA had a discussions with local landowners at Carngham – Streatham Road who confirmed calibration modelling recollections. This gives confidence in the reliability of the modelled theoretical rating curve.

The location of the extracted theoretical rating curve is shown in

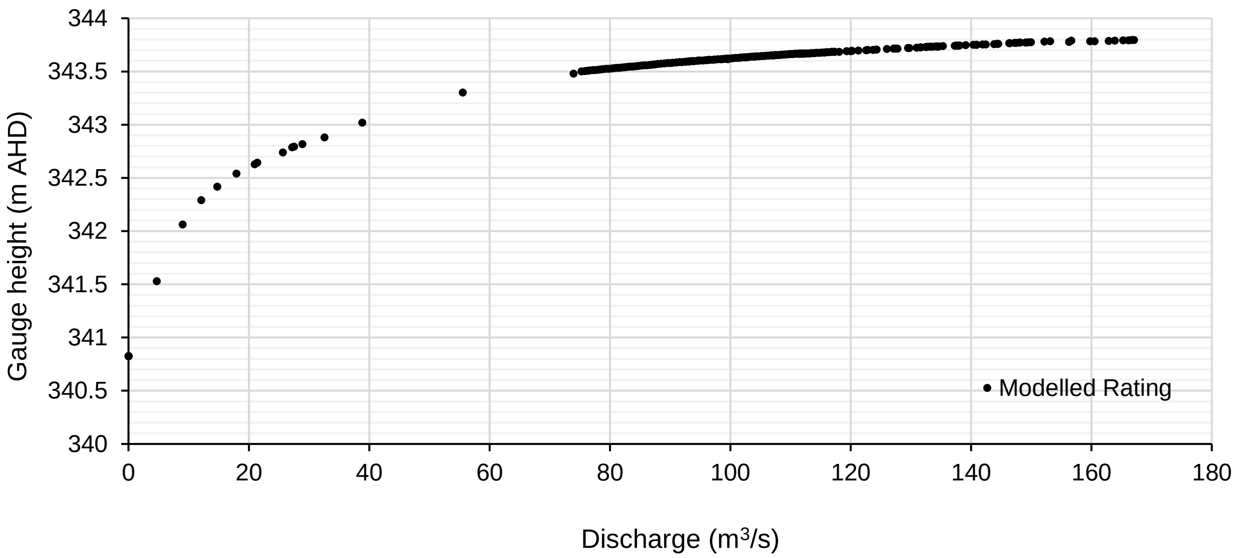

FIGURE 4-12 MODELLED THEORETICAL RATING CURVE AT CARNGHAM – STREATHAM ROAD.

FIGURE 4-13 MODELLED THEORETICAL RATING CURVE EXTRACTION LOCATION AT CARNGHAM – STREATHAM ROAD

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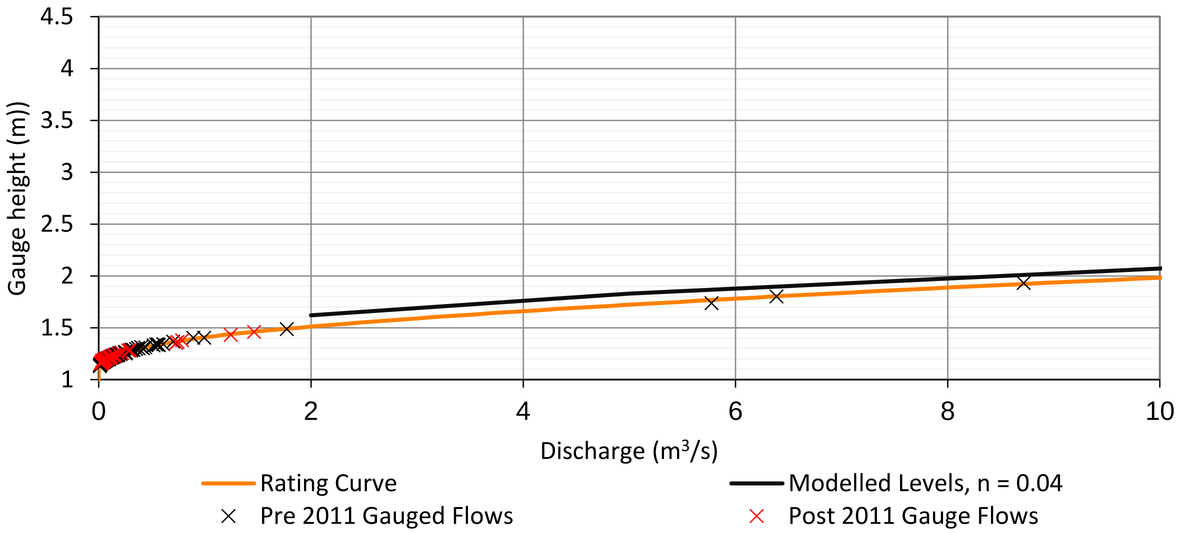
4.4 Burrumbeet Creek

4.4.1 Burrumbeet Creek at Bo Peep (Lake Burrumbeet)

The rating curve for Burrumbeet Creek at Bo Peep gauge was revised accounting for flows gauged post 2011, as shown in Figure 4-14. The addition of these flows did not influence the previously revised Thiess rating curve. Several roughness values were trialled in hydraulic modelling of the Bo Peep gauge, a Manning's 'n' roughness of 0.04 matched the observed data best and was used as the basis of the modelled theoretical rating curve.

The gauge rating curve is expected to perform better in low flows, but there is limited information for flows above 10 m³/s and the gauge rating is extrapolated from this point on. The modelled rating curve matches well to the gauge rating in flows between 20 m³/s to 25 m³/s. For flows above 25 m³/s, the gauge rating curve overestimates the gauge water level. It is recommended that the gauge rating curve be based on the existing curve for flow rates below 20 m³/s and be based on the theoretical rating curve above 20 m³/s.



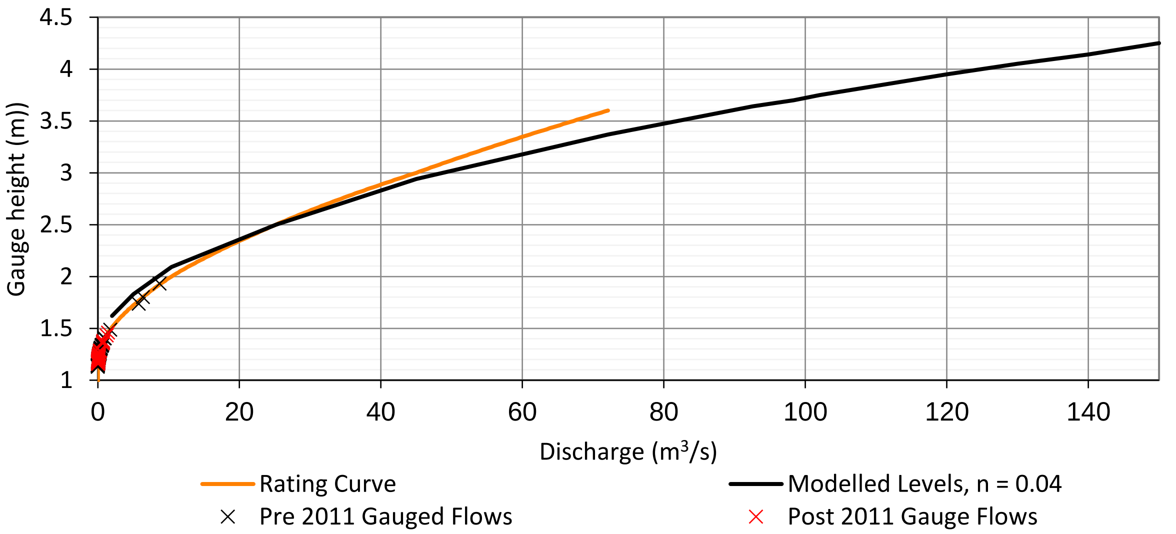


FIGURE 4-14 REVISION OF RATING CURVE FOR BURRUMBEET CREEK AT BO PEEP, TOP: LOW FLOWS; BOTTOM: HIGH FLOWS

Table 4-4 shows the recommended transition from the existing measurement based rating curve to the modelled theoretical rating curve.

TABLE 4-4 REVISED RATING AT BO PEEP GAUGE

Gauge Height (m)	Discharge	Method
0	0	Gauge rating curve
Etc.	Etc.	Gauge rating curve
2.34	19.93	Gauge rating curve
2.35	20.25	Interpolated gauge rating curve and modelled rating curve
Etc.	Etc.	Interpolated gauge rating curve and modelled rating curve
2.49	24.83	Interpolated gauge rating curve and modelled rating curve
2.5	25.17	Modelled rating curve
Etc.	Etc.	Modelled rating curve
4.25	150	Modelled rating curve

5 SENSITIVITY ANALYSIS

5.1 Lake Burrumbeet starting level

The Final Hydraulic Modelling Report (R04) documents several sensitivity analysis on various modelling assumptions. One of the sensitivity tests undertaken was the impact of the initial storage volume in Lake Burrumbeet preceding a 1% AEP flood event. During design modelling undertaken as part of this project Lake Burrumbeet started full as a conservative assumption given the lack of extensive water level record and no ability to undertake a joint concurrency analysis.

Modelling showed when Lake Burrumbeet begins a 1% AEP rainfall event empty, outflow from the lake has negligible impact the peak flow at Skipton, with a maximum outflow of around 10 m^3/s, 40 hours after the flood peak reaches Skipton. This is shown in Figure 5-1. When Lake Burrumbeet is full preceding a 1% AEP rainfall event, higher flowrates spill to Baillie Creek and result in an increase in peak flow at Skipton. In a 1% AEP event, the peak flow at Skipton was increased by about 30 m^3/s (opposed to an empty Lake Burrumbeet) which is equivalent to around a 10 cm increase in flood level.

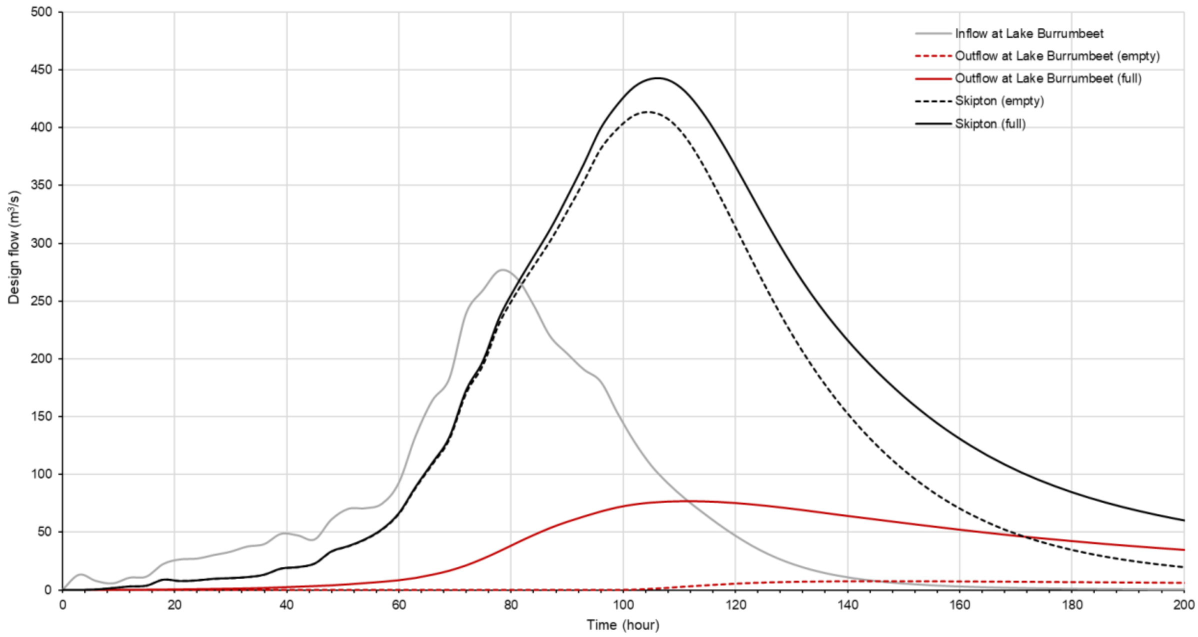


FIGURE 5-1 SENSITIVITY TEST ON INITIAL LAKE BURRUMBEET STORAGE

5.2 Roughness

During sensitivity testing the 1% AEP event was modelled increasing and decreasing the adopted global roughness values. The adopted roughness value was varied from a Manning's 'n' of 0.045 to 0.054 and 0.036. Results showed the expected shift in the rating curve, with the curve impacted most at high flows.

The change in the modelled rating for each gauge rating curve is shown in Figure 5-2 to Figure 5-7.

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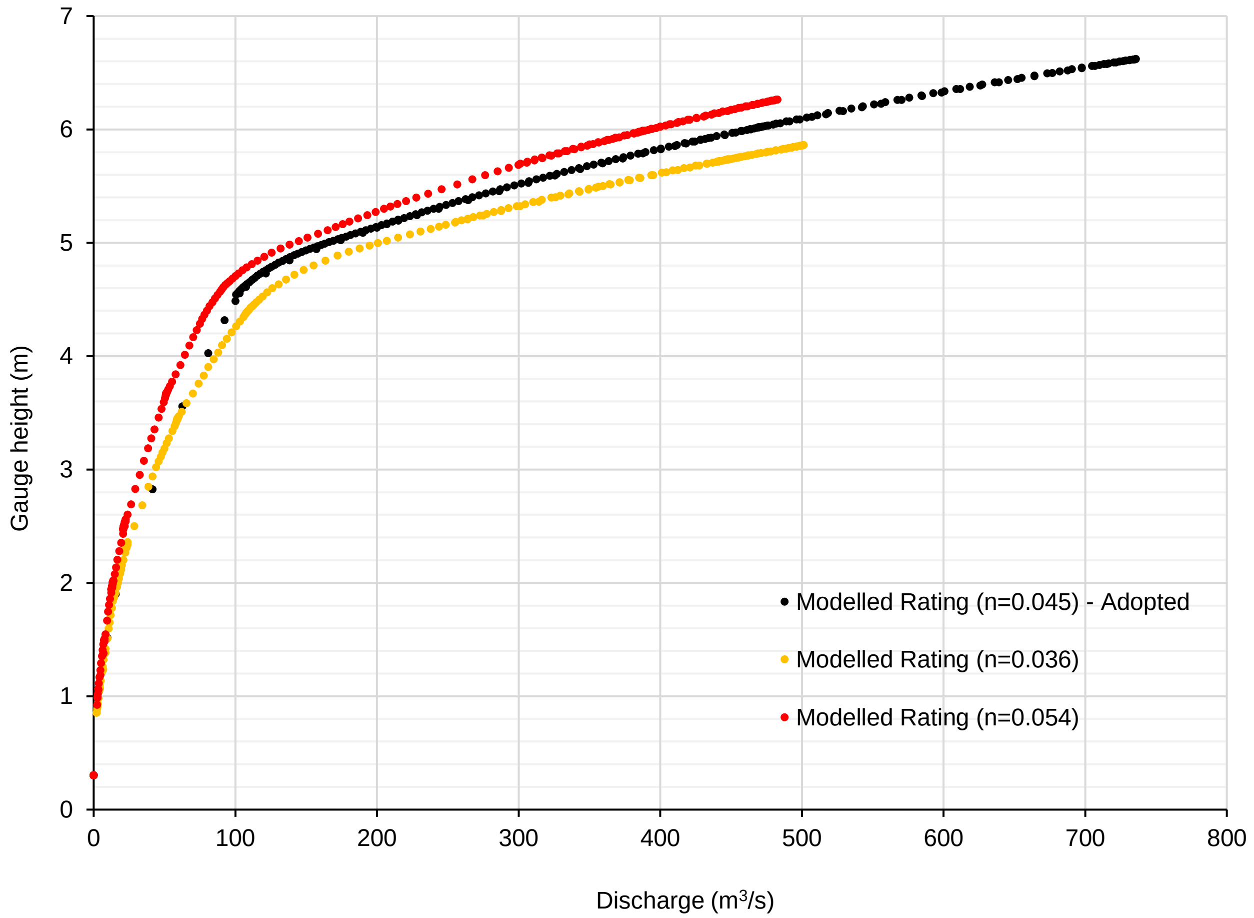

FIGURE 5-2 ROUGHNESS SENSITIVITY TESTING AT THE SKIPTON GAUGE

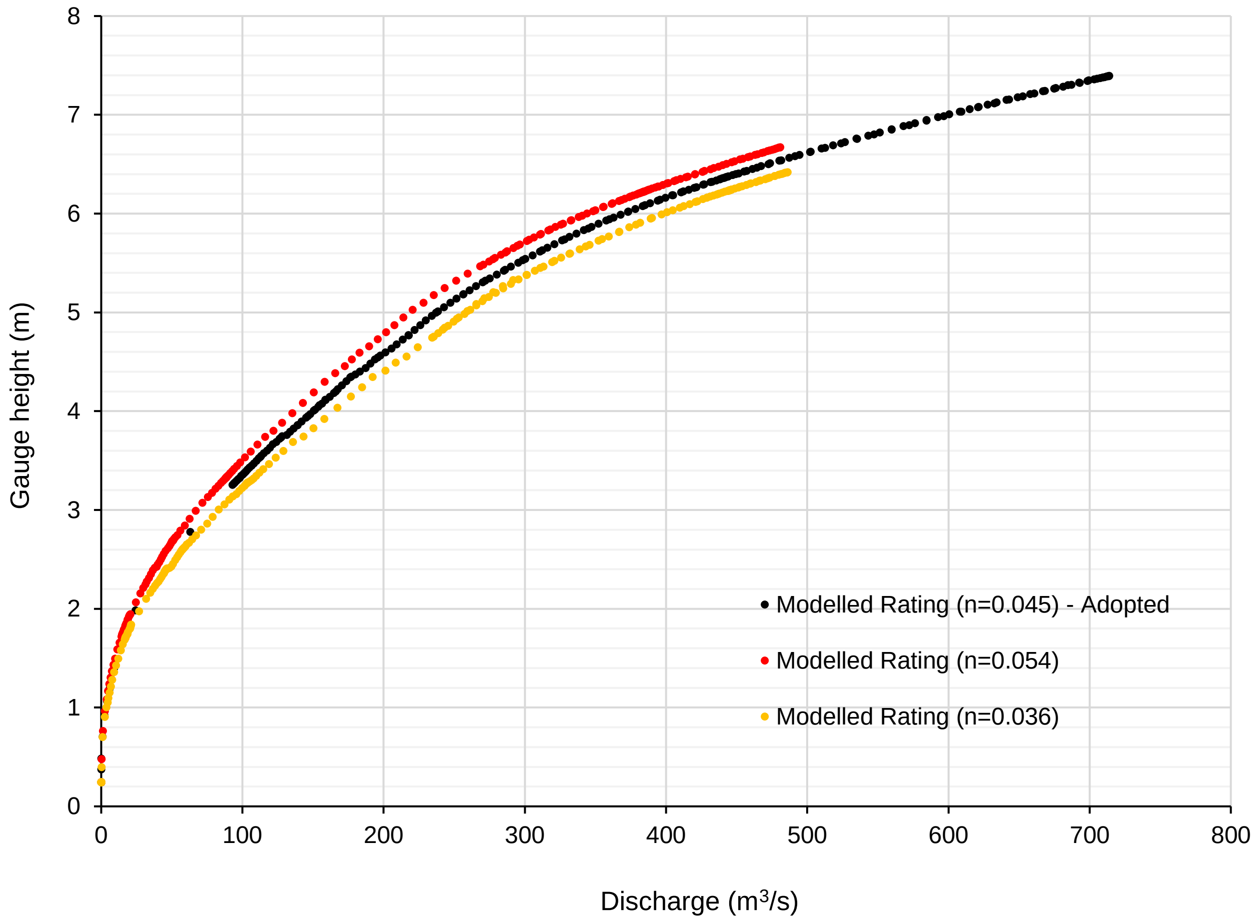

FIGURE 5-3 ROUGHNESS SENSITIVITY TESTING AT GUTHRIES BRIDGE

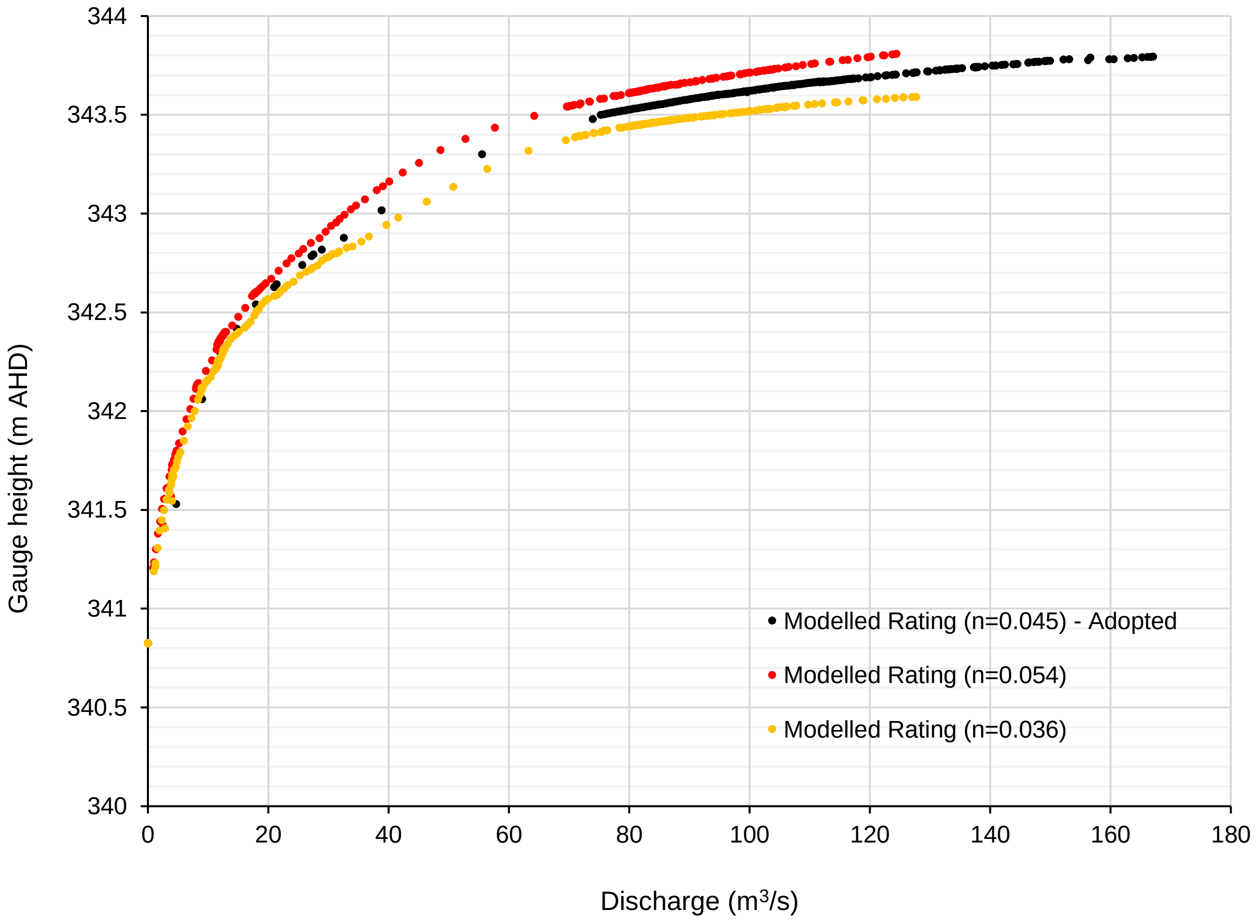

FIGURE 5-4 ROUGHNESS SENSITIVITY TESTING AT CARNGHAM STREATHAM ROAD

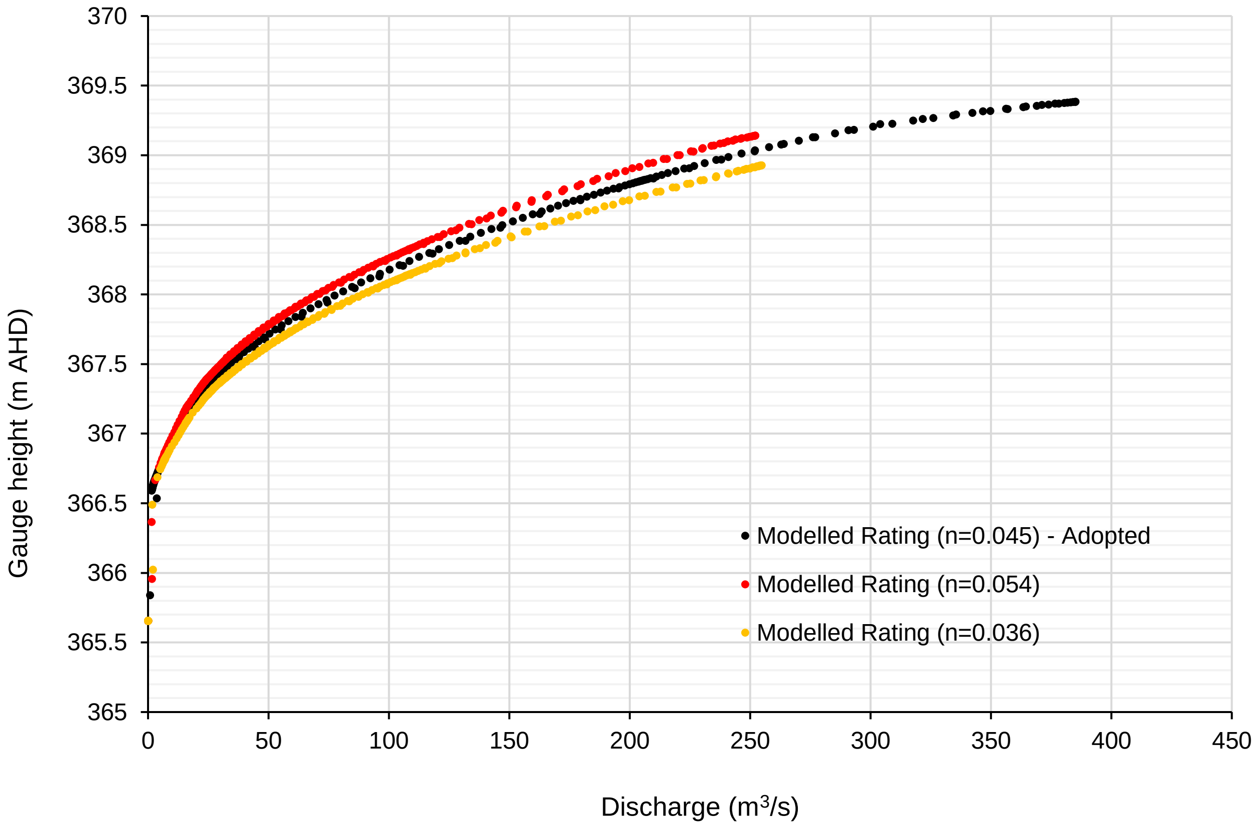

FIGURE 5-5 ROUGHNESS SENSITIVITY TESTING AT CAMERON BRIDGE

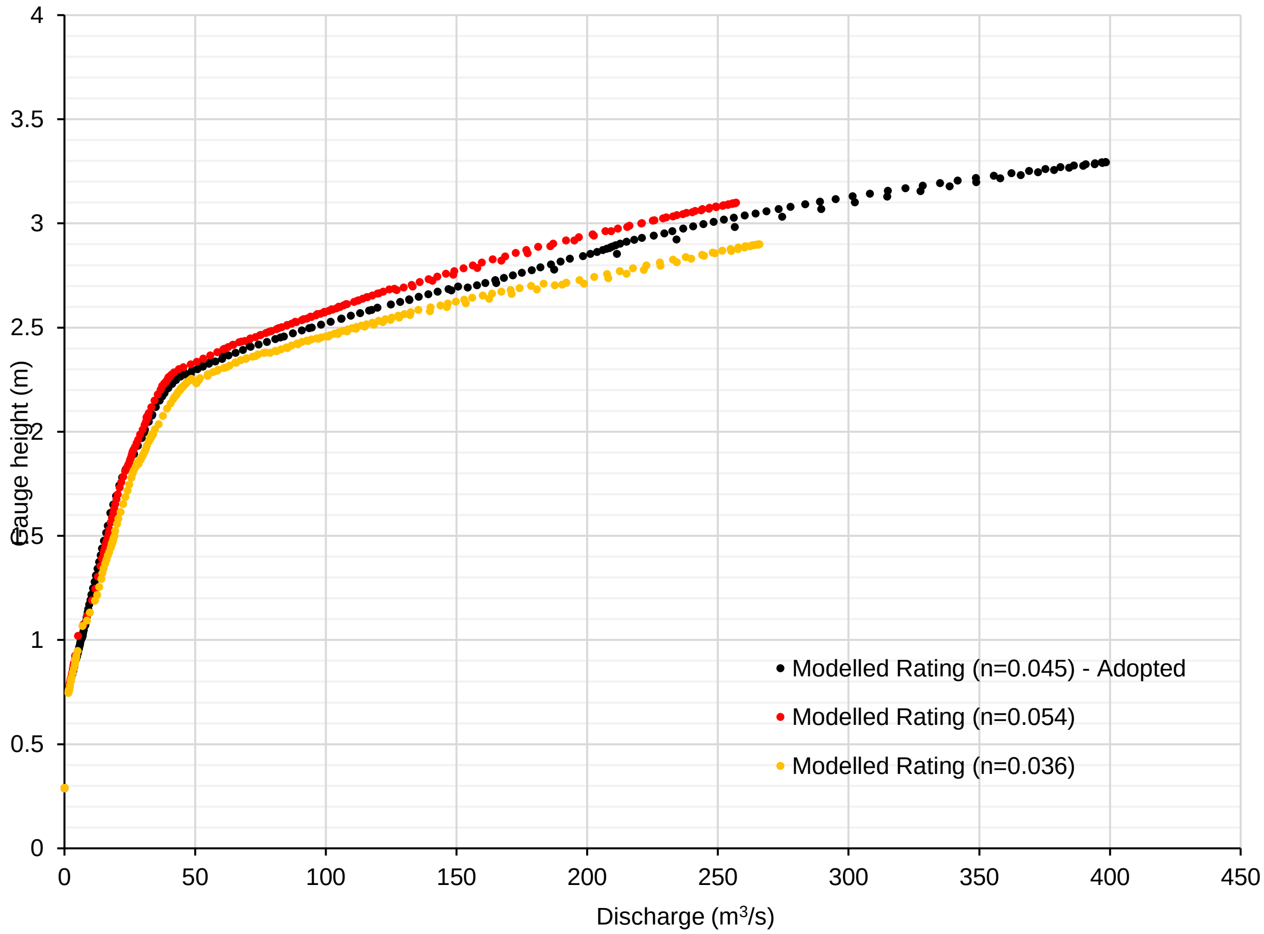

FIGURE 5-6 ROUGHNESS SENSITIVITY TESTING AT MENA PARK

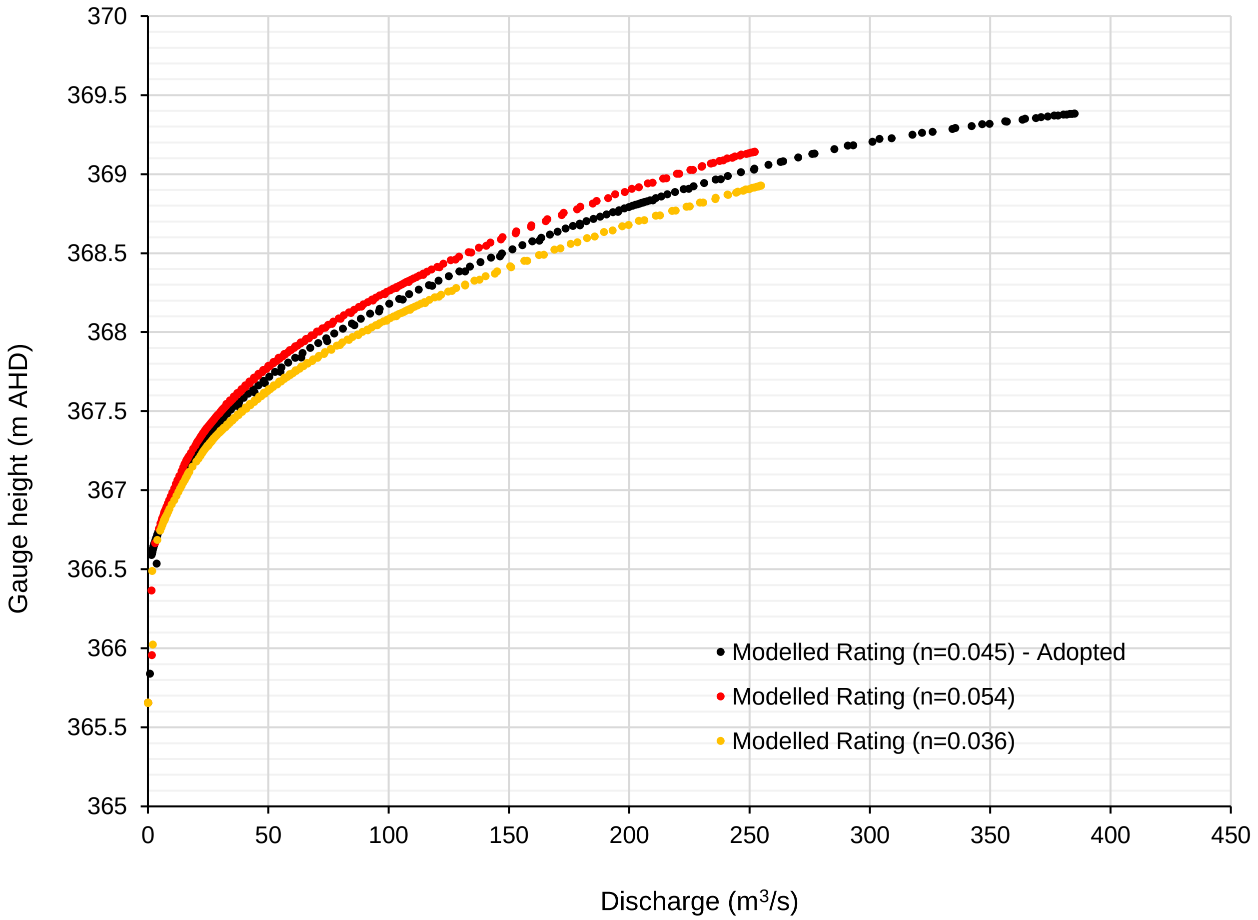

FIGURE 5-7 ROUGHNESS SENSITIVITY TESTING AT TRAWALLA

6 FLOOD PEAK TRAVEL TIME

6.1 Overview

Flood peak travel times along Mt. Emu Creek and Baillie Creek are highly sensitive to variations in rainfall temporal and spatial patterns, as well as antecedent conditions. The January 2011 and September 2016 events give an indication of historic timing while the design events give an indication of timing given specific rainfall characteristics. The lag time from the beginning of rainfall to the beginning of flooding can be used as an approximate guide, but in general peak travel time between gauges will be a more consistent way to assess flood peak travel times due to the variability in the rainfall temporal patterns.

Understanding the timing of historic events is important for future flood warning purposes because of the community and emergency agency perception of these events. It allows for a point of reference for future events as a point of comparison showing similarities or discrepancies.

Timing of flooding in Mt. Emu Creek downstream of the Baillie Creek confluence can be influenced by the concurrence of peak flows in both waterways. This is especially prevalent when a ‘double peak’ rainfall pattern occurs when two high intensity rainfall bursts occur during the one event. This can result in the timing of the first flow peak in Mt. Emu Creek occurring concurrently with the second peak in Baillie Creek. This double peak temporal pattern can occur within the Mt. Emu Creek catchment and is something emergency response agencies should be aware of during an event.

6.2 Historic events

6.2.1 Overview

The January 2011 flood event was the largest recorded in the Mt. Emu Creek catchment. The recorded peak flow at Skipton was close to a 1% AEP. A relatively minor flood occurred in September 2016, roughly equivalent to a 10% AEP event. The TUFLOW model developed as part of this study was calibrated to both the 2011 and 2016 flood event and details of the calibration results can be found in the Model Calibration Report (R02).

6.2.2 January 2011

Modelled rainfall and steam flows during the 2011 event (i.e. 12th – 14th January) are shown in Figure 6-1, showing 30-minute rainfall totals recorded at the Beaufort (Sheepwash) rain gauge and streamflow each existing and prospective gauge location. The estimated lag time between heavy rain in the upper catchment around Beaufort to a rise in the Skipton streamflow gauge was around 6.5 hours. The Skipton gauge peaked around 22 hours after the end of the rainfall. The estimated flood peak travel time between the Skipton gauge and Guthries Bridge was around 3.5 hours.

At Cameron Bridge, the modelled lag time between heavy rain to a rise at the gauge was around 8.5 hours, with a peak around 12.5 hours after the end of the rainfall. The modelled peak travel time between the Mena Park gauge and Cameron Bridge was around 5 hours.

The proposed gauging station at Carngham – Streatham Road is on Baillie Creek and its flow was dominated by rainfall in the Lake Burrumbeet catchment. There were two flow peaks during the event, the second peak was caused by spills from Lake Burrumbeet as shown in Figure 6-2. It is important to note that the initial rise and first peak at Guthries Bridge and Skipton was caused by Baillie Creek. The modelled peak travel time from Carngham – Streatham Road to Guthries Bridge was around 2.5 hours.

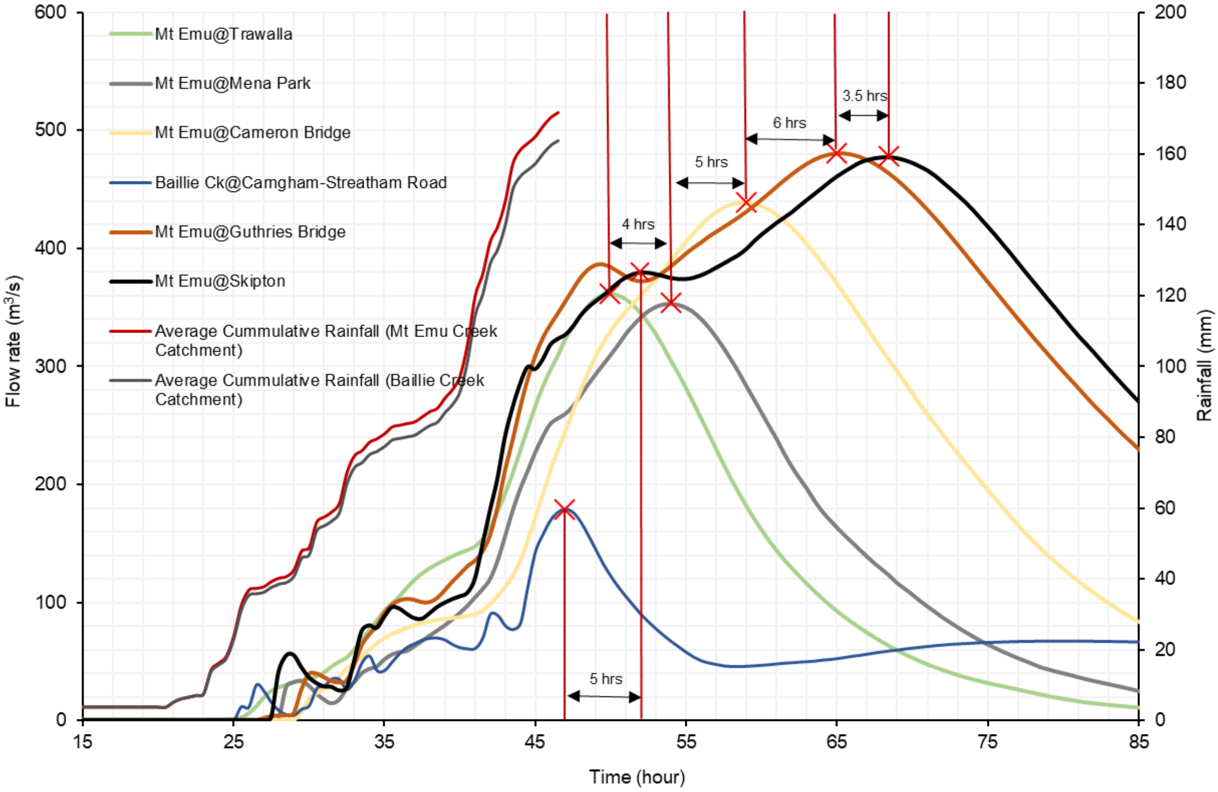

FIGURE 6-1 ESTIMATED OF TRAVEL TIME BETWEEN GAUGING STATIONS DURING JANUARY 2011

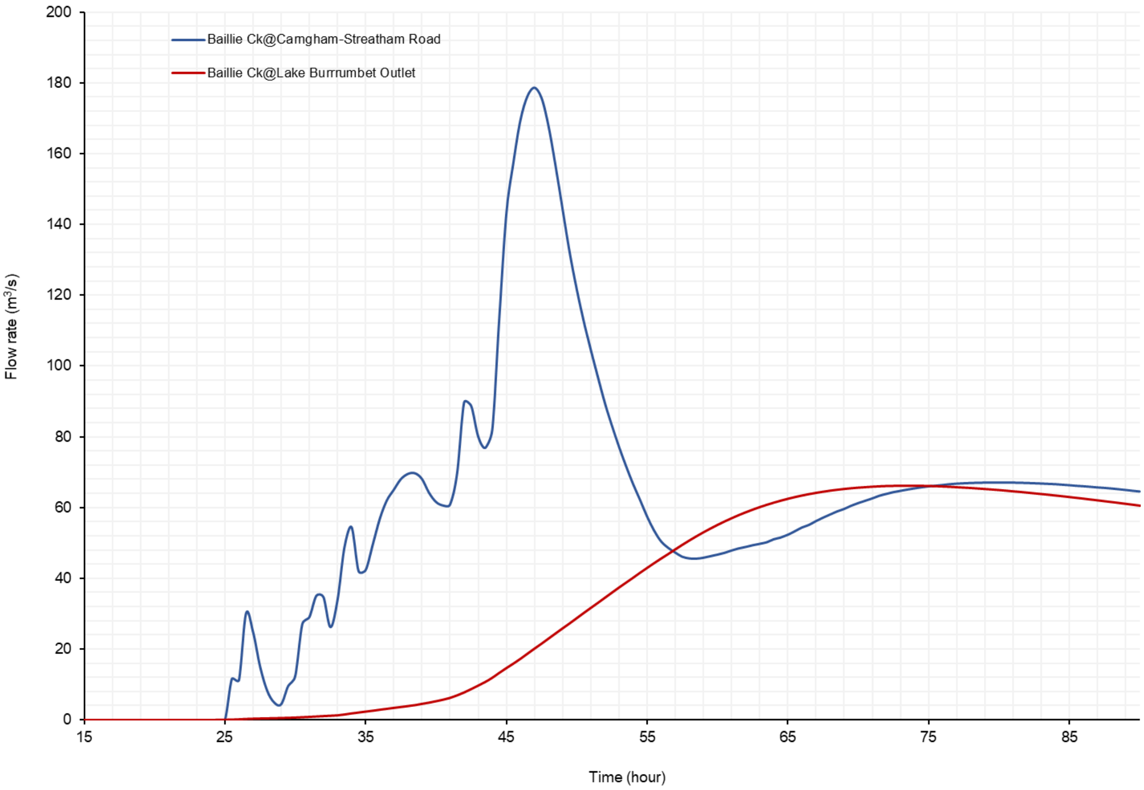

FIGURE 6-2 MODELLED HYDROGRAPH AT LAKE BURRUMBEET OUTLET

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6.2.3 September 2016

In contrast to the 2011 event, 2016 flooding was relatively minor. Figure 6-3 shows the modelled hydrograph at each streamflow gauge and the 30-mintue rainfall records at the Beaufort (Sheepwash) rain gauge over the 13th – 14th September. The modelled lag time from the start of the rainfall to a rise in the Skipton gauge was around 16 hours. The flood peak at Skipton was around 31.5 hours after the end of the rainfall. The modelled peak travel time between Guthries Bridge and the Skipton gauge was around 3 hours.

The modelled time between the start of rainfall to a rise at the proposed in Cameron Bridge gauge was estimated to be around 20 hours. The modelled flood peak at Cameron Bridge was estimated to be around 49 hours after the start of the rainfall. The modelled travel time from the Mena Park gauge to Cameron Bridge was around 7 hours.

Flow at the proposed Carngham – Streatham Road gauge were dominated by rainfall upstream of Baillie Creek. The model estimated peak travel time from this gauge to Guthries Bridge was around 6 hours, based on the first peak at Guthries Bridge gauge.

Table 6-1 below summaries the estimated lag times of rainfall to flood response and peak travel times between gauging stations along Mt. Emu Creek during January 2001 and September 2016.

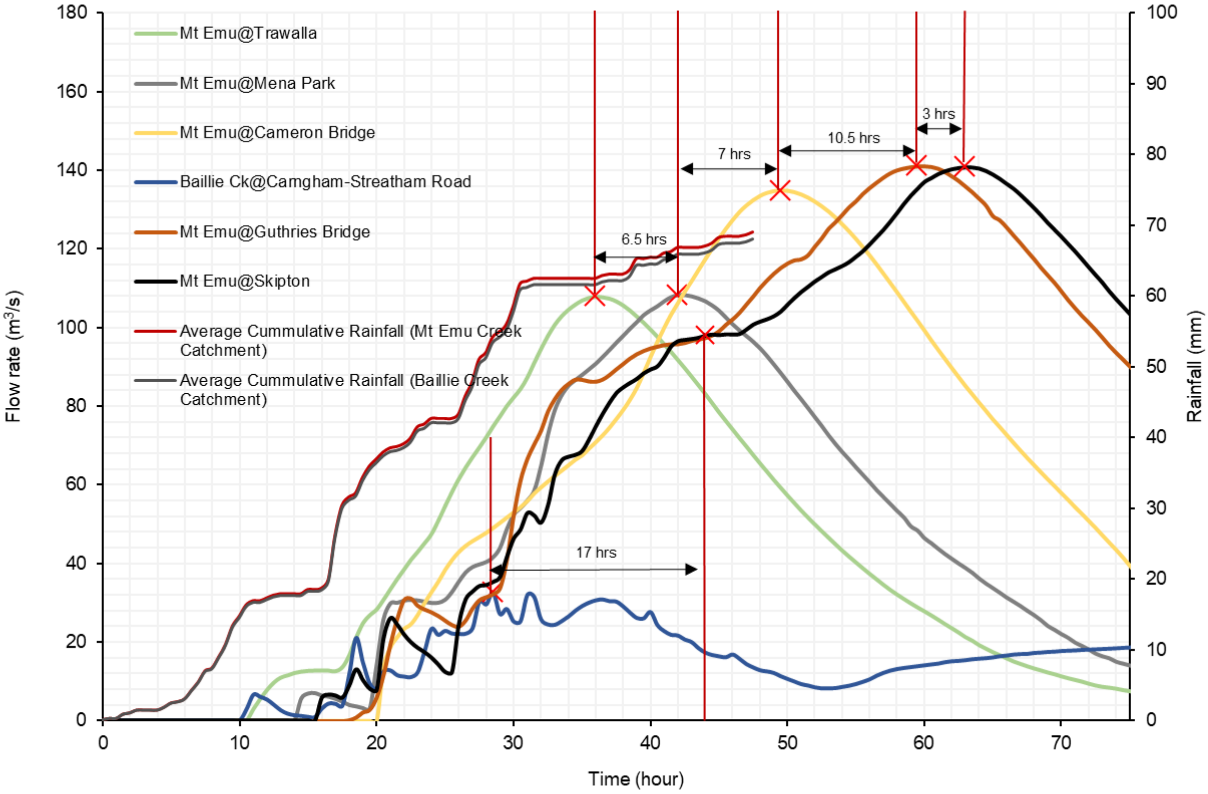

FIGURE 6-3 ESTIMATED OF TRAVEL TIME BETWEEN GAUGE STATION IN SEPTEMBER 2016 FLOOD

TABLE 6-1 FLOOD RISE AND PEAK TRAVEL TIME ALONG MT. EMU CREEK

Location from	Location to	Travel time (hours)	
		January 2011 flood	September 2016 flood
Start of rainfall at Beaufort (Sheepwash)	Mt. Emu @ Mena Park	7 (to start of rise)	14.5 (to start of rise)
End of rainfall	Mt. Emu @ Mena Park	7.5 (to peak)	11 (to peak)
Start of rainfall	Mt. Emu @ Cameron Bridge	8.5 (to start of rise)	20.5 (to start of rise)
End of rainfall	Mt. Emu @ Cameron Bridge	12.5 (to peak)	18 (to peak)
Start of rainfall	Mt. Emu @ Skipton	6.5 (to start of rise)	16 (to start of rise)
End of rainfall	Mt. Emu @ Skipton	22 (to peak)	31.5 (to peak)
Mt. Emu @ Trawalla	Mt. Emu @ Mena Park	4	6.5
Mt. Emu @ Mena Park	Mt. Emu @ Cameron Bridge	5	7
Mt. Emu @ Mena Park	Mt. Emu @ Guthries Bridge	11	17.5
Baillie Ck @ Carngham-Streatham Road*	Mt. Emu @ Guthries Bridge	2.5 (to first peak)	6 (to first peak)
Mt. Emu @ Guthries Bridge	Mt. Emu @ Skipton	3.5	3

*This gauge station is located on Baillie Creek

7 FLOOD CLASSIFICATION LEVELS

Flood classifications describe in general terms the severity and nature of flood impacts at river height stations. There are three flood classes: minor, moderate and major. A nationally-applied definition for flood classifications has been as outlined by the Bureau of Meteorology in the National Arrangements for Flood Forecasting and Warning (www.bom.gov.au/water/floods) and are listed below:

- **Minor** - Causes inconvenience. Low-lying areas next to watercourses are inundated. Minor roads may be closed and low-level bridges submerged. In urban areas inundation may affect some backyards and buildings below the floor level as well as bicycle and pedestrian paths. In rural areas removal of stock and equipment may be required.
- **Moderate** - In addition to the above, the area of inundation is more substantial. Main traffic routes may be affected. Some buildings may be affected above the floor level. Evacuation of flood affected areas may be required. In rural areas removal of stock is required.
- **Major** - In addition to the above, extensive rural areas and/or urban areas are inundated. Many buildings may be affected above the floor level. Properties and towns are likely to be isolated and major rail and traffic routes closed. Evacuation of flood affected areas may be required. Utility services may be impacted.

As part of this project the flood classification levels recommended for Skipton previously determined during the Skipton Flood Study[1] have been reviewed, specifically relating to the Skipton township. These were as follows with a description of the modelled impact of inundation show during this study:

- Minor flood level 4.00m (281.012 m AHD).
  - This level is lower than any modelled level during this study; however, the 20% AEP event reaches 4.18 m and the most prominent impact is the Smyths Street bridge overtopping. There are also minor areas of private property and rural land inundated.

The 20% AEP event impacts match well with the minor flood classification definition, and it is suggested a level of 4.18m be adopted as a minor flood class level linking to the 20% AEP event and mapping.

- Moderate flood level 4.70m (281.712 m AHD).
  - The 2016 event reached a level of 4.88m and the 10% AEP event reaches 4.89 m, the following was observed in modelling for both events:
    - Breakout of flood water from eastern bank of Mt. Emu Creek.
    - Overtopping at Wright St and Smythe St.
    - Flood water inundating significant areas of private land.
    - Buildings on Wright Street isolated.
    - Property at 1 Pett St flooded below floor and may need protection or evacuation.

The 10% AEP event impacts match well with the moderate flood classification definition, and it is It is suggested a level of 4.88m be adopted as a moderate flood class level linking to the 10% AEP event and mapping.

- Major flood level 5.10m (282.112 m AHD).
  - This level is slightly below a 5% AEP event which reaches 5.23 m. At this level, the following impacts are observed.
    - Properties in Cleveland St are flooded.
    - Glenelg Highway approaching from each side of the bridge are overtopped.

- Overtopping at Anderson St.
- Properties near Stewart Park and properties in Anderson St, south of Montgomery St are flooded.
- 28 properties are flooded above floor.
- Major disruption to traffic routes.
- Evacuation of private properties will be required.

The 5% AEP event impacts match well with the major flood classification definition, and it is It is suggested a level of 5.10m be adopted as a major flood class level linking to the 5% AEP event and mapping.

8 SUMMARY AND RECOMMENDATIONS

8.1 Gauge rating curve estimates

The hydraulic model developed as part of this study was used to produce the theoretical rating curves for the proposed and existing gauging stations along Mt. Emu Creek and Baillie Creek. Comparisons between the existing measurement based rating curves and modelled theoretical rating curves were made. Low flows or in-channel flow regimes were not the focus of the theoretical rating curve development and the model is not considered to be of sufficient definition to be used when flow is solely in channel. The model was calibrated to high flow events and the modelled theoretical rating curves should only be used in this instance, while the measurement based rating curves should be used flow low, in channel flows.

It is recommended Glenelg Hopkins CMA, BoM and DEWLP review the theoretical and measured rating curves presented in this report along with the proposed changes at high flows to allow for an improved understanding of the relationship between high flows and water level at each gauge location.

8.2 Travel time estimates

Travel time along the modelled waterways varies between flood events, depending on the storm temporal patterns, spatial patterns, magnitude and the antecedent conditions. Travel time from the Mena Park gauge to Cameron Bridge is generally between 5 to 9 hours. The travel time from upstream gauges along Mt. Emu Creek or Baillie Creek to the Skipton gauge/Mena Park gauge varies depending on which waterway dominates peak flow. From a flood warning perspective, Guthries Bridge can confirm the expected forecast at Skipton and should be used as the key site supporting flood forecasting. The travel time from Guthries Bridge gauge to Skipton gauge is between 2 and 4 hours.

8.3 Flood Class Levels

It is recommended the following flood classification level discussion and suggestions be reviewed by Glenelg Hopkins CMA and the Bureau of Meteorology:

- The 20% AEP event impacts match well with the minor flood classification definition, and it is suggested a level of 4.18m be adopted as a minor flood class level linking to the 20% AEP event and mapping.
- The 10% AEP event impacts match well with the moderate flood classification definition, and it is It is suggested a level of 4.88m be adopted as a moderate flood class level linking to the 10% AEP event and mapping.
- The 5% AEP event impacts match well with the major flood classification definition, and it is It is suggested a level of 5.10m be adopted as a major flood class level linking to the 5% AEP event and mapping.

APPENDIX A
TRAVEL TIME IN FLOOD PEAK – DESIGN EVENTS

Design events

Overview

A range of AEP design events were modelled as part of this study. Details of the design modelling scenarios can be found in the Design Modelling Report (R03). The 1% and 20% AEP coupled with their corresponding critical durations (i.e. 96 hours and 48 hours) for Skipton were used to derive estimated peak travel times between gauges. It is important to note each design event had a specific temporal pattern associated with it.

1% AEP

The progression of flood hydrographs along Mt. Emu Creek for the 1% AEP event (96 hours) are shown in Figure A-1, the time from the start of rainfall to a rise in the Skipton gauge was about 9 hours. The flood peak at Skipton was 70 hours after the end of rainfall. It is noted that this is a 96-hour duration event and the time to peak is driven by the duration as well as magnitude of the flood event. The estimated peak travel time between the Guthries Bridge gauge and Skipton gauge is estimated to be around 1.5 hours.

The estimated peak travel time between the Mena Park gauge and the proposed Cameron Bridge gauge is around 6 hours.

In a shorter duration 1% AEP event (48 hours), with a different rainfall temporal pattern, two peaks appeared in the Guthries Bridge and Skipton model results, as shown in Figure A-1. The first peaks are driven by flow in Baillie Creek. The Skipton gauge peaked 4.5 hours after Carngham – Streatham Road. The second peak at Skipton is driven by flows in Mt. Emu Creek, with estimated travel time of 8.5 hours from Cameron Bridge gauge as measured by the flood peaks.

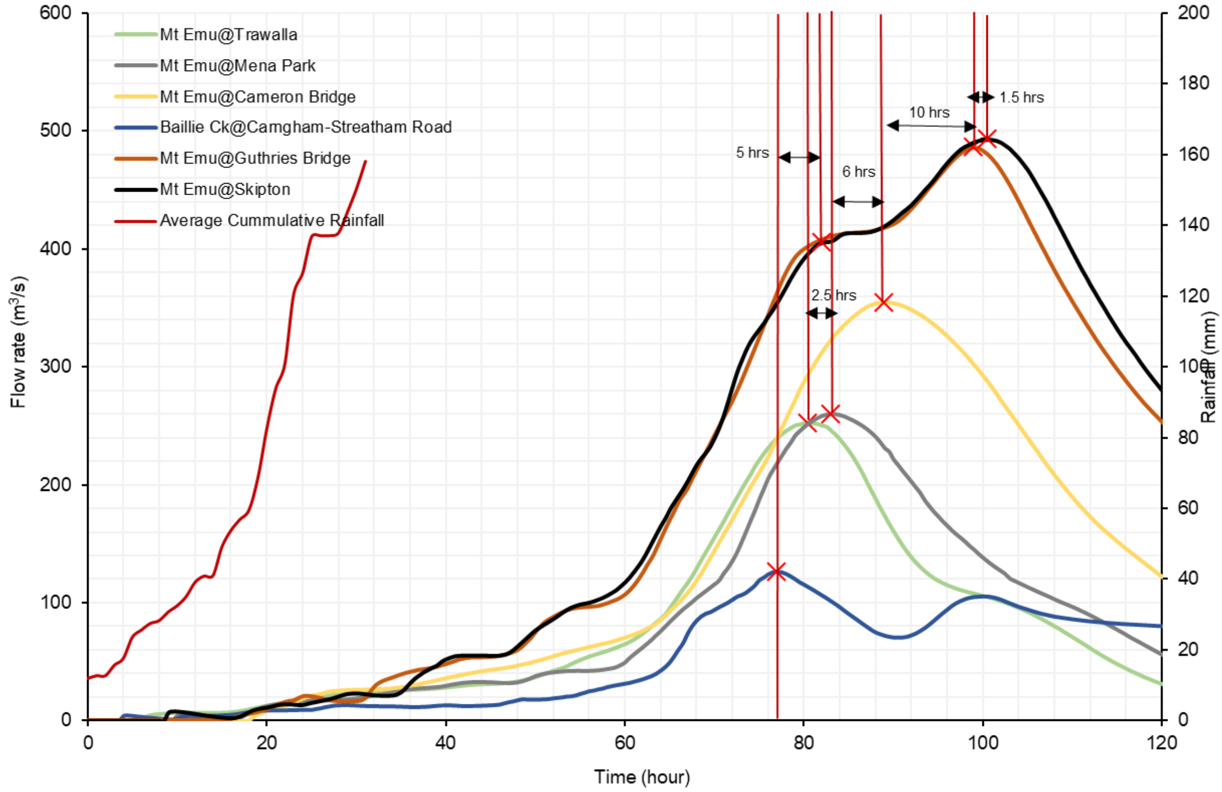

FIGURE A-1 ESTIMATED OF TRAVEL TIME BETWEEN GAUGE STATION IN A 1% AEP EVENT (96-HOUR, TP27)

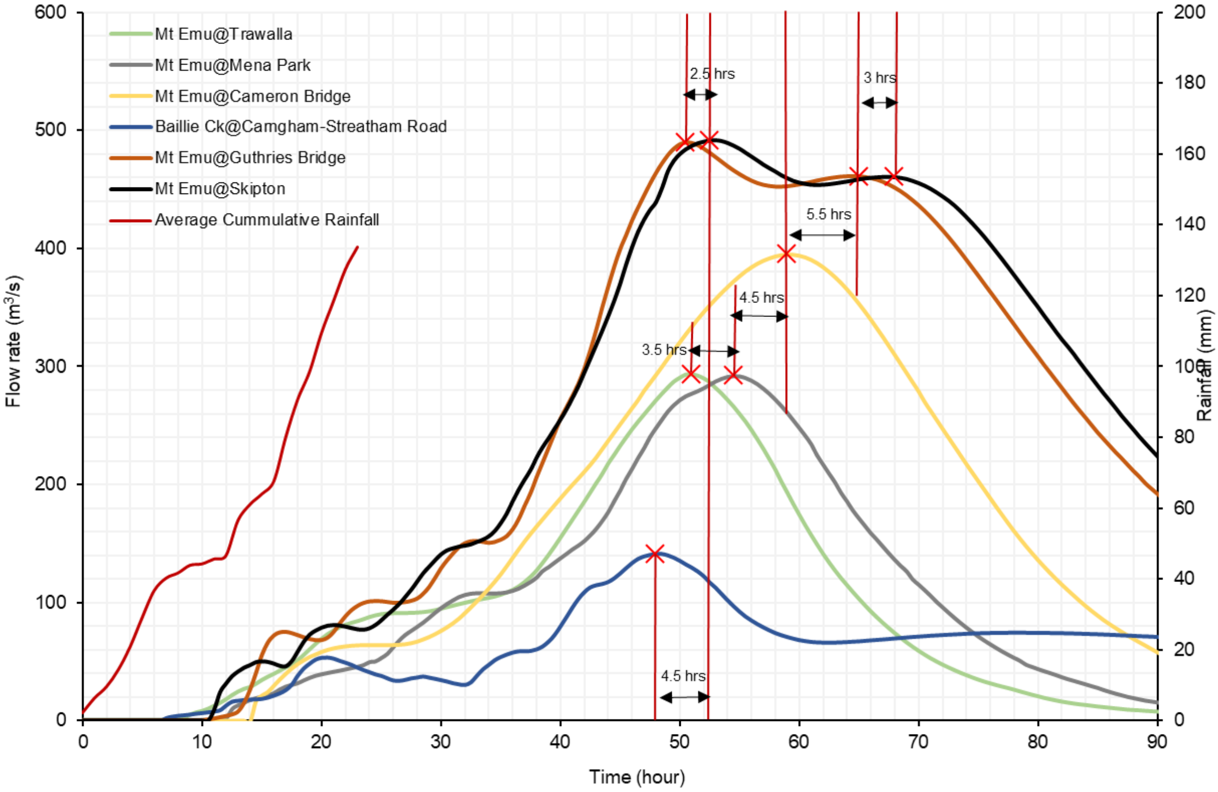

FIGURE A-2 ESTIMATED OF TRAVEL TIME BETWEEN GAUGE STATION IN A 1% AEP EVENT (48-HOUR, TP29)

20% AEP

Hydrographs for the 20% AEP (48 hours) event are displayed in Figure A-3, the time from the start of rainfall to a rise in the Skipton gauge is about 14 hours. The Skipton gauge peaked 27 hours after the end of the rainfall. As shown in Figure A-3, there were two peaks in the Skipton gauge and Guthries Bridge modelled flows. The first peak (i.e. 27 hours after the end of rainfall) was driven by a rise in Baillie Creek at Carngham – Streatham Road bridge, where was peak in 3.5 hours before that recorded at Skipton and Guthries Bridge . After the first peak, flow at Skipton and Guthries Bridge started to fall slowly, but they increased quickly and peaked again at 57.5 hours and 53.5 hours after the end of rainfall. The second peaks at these two gauges were driven by flows in the broader Mt. Emu Creek catchment, with an estimated travel time of 10 to 14 hours from Cameron Bridge.

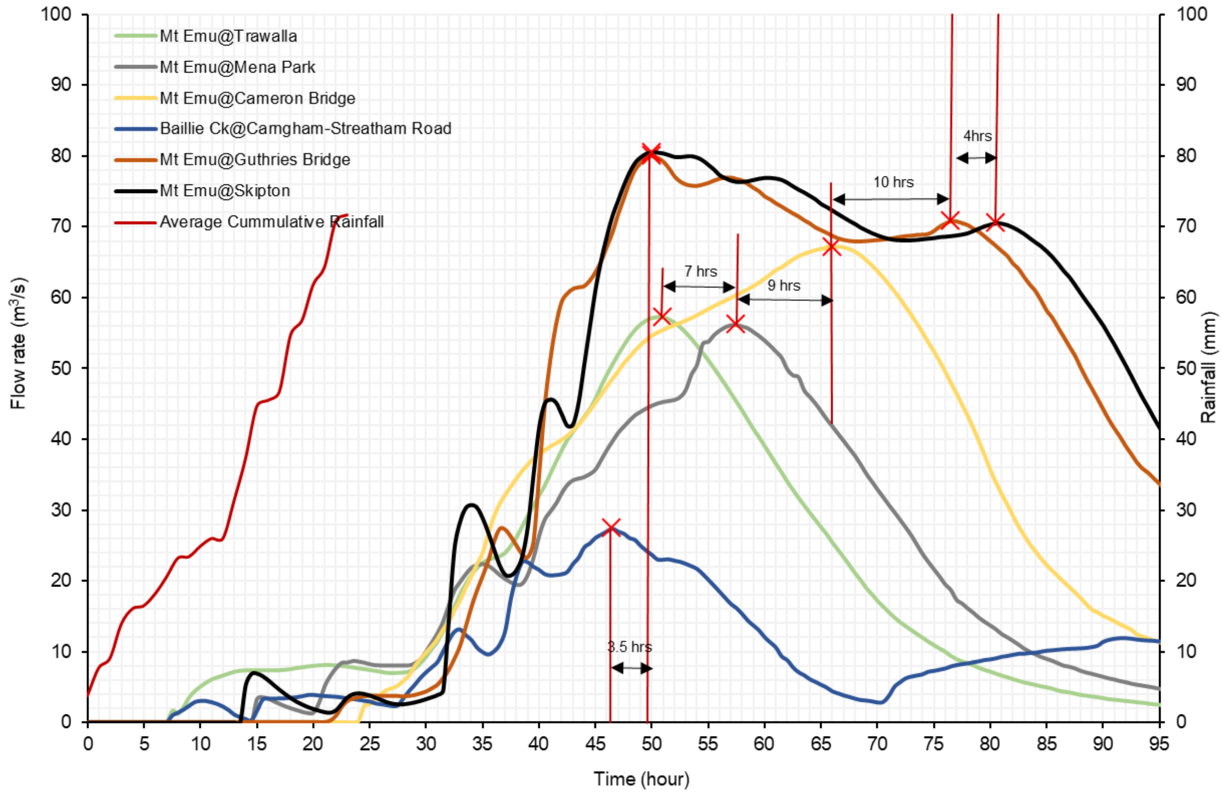

FIGURE A-3 ESTIMATED OF TRAVEL TIME BETWEEN GAUGE STATION IN A 20% AEP EVENT (48-HOUR, TP01)

TABLE A-1 FLOOD RISE AND PEAK TRAVEL TIME ALONG MT. EMU CREEK (DESIGN EVENTS)

Location from	Location to	Travel time (hours)		
		1% AEP flood (96-hour)	1% AEP flood (48-hour)	20% AEP flood
Mt. Emu @ Trawalla	Mt. Emu @ Mena Park	2.5	3.5	7
Mt. Emu @ Mena Park	Mt. Emu @ Cameron Bridge	6	4.5	9
Mt. Emu @ Mena Park	Mt. Emu @ Guthries Bridge	16	10 (2nd peak)	19 (2nd peak)
Baillie Ck @ Carngham-Streatham Road*	Mt. Emu @ Guthries Bridge	3.5 (1st peak)	2 (1st peak)	3.5 (1st peak)
Mt. Emu @ Guthries Bridge	Mt. Emu @ Skipton	1.5	2.5	4

*This gauge station is located in Baillie Creek

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Fax (03) 9558 9365

Brisbane

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South Brisbane QLD 4101
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