



Lower Thomson River Flood Study

Report

v1

08/07/2019

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1 Introduction

The West Gippsland Catchment Management Authority (WGCMA) commissioned HARC to undertake the Lower Thomson River Flood Study. The study is being undertaken in conjunction with Venant Solutions and Michael Cawood and Associates. The study area is shown in Figure 1-1.

This study included detailed hydrological and hydraulic modelling of the Lower Thomson and Latrobe River.

This project forms part of the Regional Flood Mapping Program. Outputs from the Regional Flood Mapping Program will be used by Catchment Management Authorities (CMAs), Local Government Authorities (LGAs) and VICSES to meet a range of business requirements. Outputs will be used to define flood related controls in Municipal Planning Schemes. They will be used to develop flood intelligence products, inform emergency response planning and assist in the preparation of community flood awareness and education products. Furthermore, outputs from the Program will be used to support the assessment of flood risk for insurance purposes.

The project was funded from Department Environment Land Water and Planning (DELWP) and forms part of the Regional Flood Mapping Program.

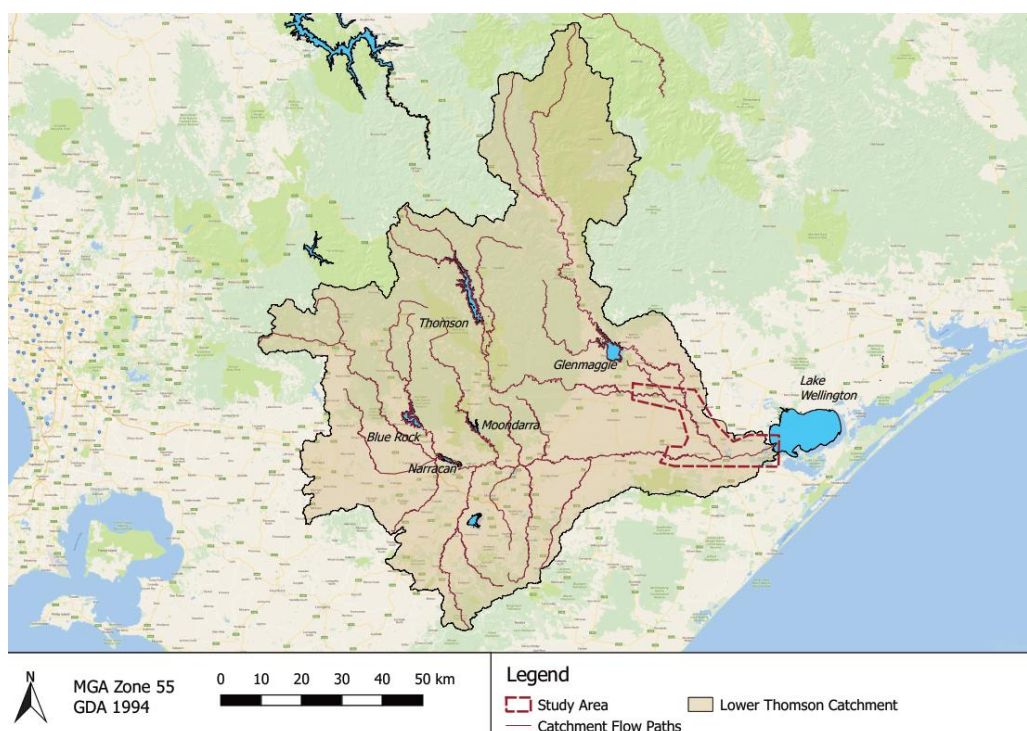


Figure 1-1 Study and Catchment Area

2 Catchment Description

The floodplain of the lower Thomson River is a complex system where the Latrobe River and the Thomson River combine to flow into Lake Wellington. The catchment area where the Latrobe River flows into Lake Wellington is approximately 8,380 km². Approximately 14 kilometres to the north of the confluence of the Thomson and the Latrobe Rivers another major river joins the Thomson River, the Macalister River. Flood levels along the Lower Latrobe River / Thomson River are influenced by levels in Lake Wellington which in turn are influenced by:

- n The inflowing hydrographs from the catchments around the Lakes;
- n Starting lake levels;
- n Coastal ocean levels; and
- n Wind.

In addition, the presence of large dams (including Lake Glenmaggie, Thomson Dam, Blue Rock, Lake Narracan and Moondarra Dam) in the upper reaches of the catchment can influence flows in the lower reaches of the catchment (particularly Lake Glenmaggie and Thomson Dam).

Also located within the catchment are three open cut mines, for three power supply companies. These open cut mines have resulted in alterations to the local catchments.

In general, the upper reaches of the catchment consist of rolling hills whilst the lower portion of the catchment is substantially flatter. For example, the catchment upstream of Lake Glenmaggie rises from a level of approximately 70 m AHD at the dam to approximately 1,640 m AHD over a distance of approximately 90 kilometres at a slope of 1 in 57. Whereas, downstream of Lake Glenmaggie the catchment falls from approximately 70 m AHD at the dam to approximately 0 m AHD at Lake Wellington over a distance of approximately 70 kilometres at a slope of 1 in 1,000.

The average annual rainfall varies from approximately 1,400 mm/year in the north, 1,000 mm/year in the south and 580 mm/year at the outlet.

The catchment area is shown in Figure 1-1.

3 Community consultation and review process

3.1 Overview

A key element in the development of the Lower Thomson Flood Study was the engagement of the community in the study. This engagement was undertaken over the course of the study through several different means including community information sessions and meetings with the Steering Committee (which had a number of community representatives). Community consultation was managed by the WGCMA. The aims of the community consultation were as follows:

- n To raise awareness of the study and to identify key community concerns.
- n Provide an opportunity for the community to contribute anecdotal information and experiences of historic flood events.
- n To provide information to the community and seek their feedback/input regarding the study including the existing flood behaviour

3.2 Steering Committee

The development of the Flood Study was supported by a Steering Committee (SC) throughout the project. The SC included two (2) community members, willing to assist WGCMA and Wellington Shire Council (WSC), who had observed or experienced first-hand recent flooding, had valuable links to the community for engagement purposes and were generally interested in improving local flood resilience. The SC also consisted of representatives from WGCMA, WSC, DELWP, VICSES, VicRoads, Bureau of Meteorology (BoM) and Ventia.

The following SC meetings were held:

- n Meeting 1 - A general overview and discussion of the project goals.
- n Meeting 2 – Presentation and discussion on the hydrological study and preliminary hydraulic modelling results.
- n Meeting 3 – Presentation and discussion on the hydraulic modelling results and flood mapping.

3.3 Community consultation

A key aspect of community engagement is to provide information to the community and then to seek feedback. For the development of the Flood Study, community engagement processes were generally supported by media releases to local newspapers, paid public meeting notices or direct mailing and contact of individuals in the community.

At all stages, the WGCMA led the public consultation activities with technical input from HARC and Venant Solutions. The following is a list of the key community consultation activities that were undertaken:

- n Public Meeting 1 - The purpose of the meeting was to seek recent or historically observed flood information from the community to enable the project team to better understand flooding behaviour within the study area. This information was critical to inform the development of calibrated flood models for use in determining design flood extents.
- n The WGCMA Project Manager contacted numerous individuals during the course of the project, seeking further flood behaviour information, information regarding flood warning services and the capacity to respond.
- n Various round-table sessions during the SC meetings to capture the knowledge from local community members, Council staff and agency representatives.
- n Public Meeting 2 - The purpose of the meeting was to provide the community the results of the hydrology and hydraulic modelling to “ground truth” the results based on their experience of flooding.

4 Hydrologic data review

This section describes the key information used in the hydrological investigation.

4.1 Streamflow Gauges

There are numerous streamflow gauges located throughout the Latrobe River catchment. At the start of the project a discussion was held with Ventia¹ to ascertain the most suitable streamflow gauges to use for this project. Suitability was determined based on the location of the streamflow gauge to the study area, quality of the rating curve, length of record and not being influenced by tidal levels.

The streamflow gauge stations used in the hydrological investigation are shown in Table 4-1. The location of the streamflow gauge stations are shown in Figure 4-1. Streamflow data was downloaded from the Department of Environment, Land, Water and Planning (DELWP) water monitoring site (<http://data.water.vic.gov.au/monitoring.htm>). Southern Rural Water (SRW) supplied some streamflow information at Lake Glenmaggie.

Table 4-1 Streamflow Gauge Data used for Calibration and Verification

Station Number	Name	Date of Available Data	Maximum Gauged Level (m)	Maximum Gauged Flow (m ³ /s)	Maximum Recorded Level (m)	Maximum Recorded Flow (m ³ /s)	Catchment Area (km ²)
226005	Latrobe River @ Thoms Bridge	24/05/1960 – current	6.21	713	6.31	826	2,657
226200	Latrobe River @ Rosedale (combined flow)	01/11/1900 – 09/03/1934	4.32	147	4.32	147	4,144
226228	Latrobe River @ Rosedale (Main Stream)	01/12/1936 - current	4.97	247	5.46	353	4,144
226224	Latrobe River @ Rosedale (Anabranh)	01/12/1936 - current	5.01	769	5.58	1,215	4,144
225231	Thomson River @ U/S	01/04/1976 - current	4.90	334	8.89	1,109	1,080

¹ Ventia are the hydrographers who currently had a contract with the Department of Environment, Land, Water and Planning to monitor and maintain numerous streamflow gauges throughout Victoria

Station Number	Name	Date of Available Data	Maximum Gauged Level (m)	Maximum Gauged Flow (m ³ /s)	Maximum Recorded Level (m)	Maximum Recorded Flow (m ³ /s)	Catchment Area (km ²)
	of Cowwarr Weir						
225212	Thomson River @ Wandocka	29/03/1963 - current	6.85	416	6.90	520	1,417
225232	Thomson River @ Bundalagah	03/11/1976 - current	7.30	341	7.72	1,580	3,538
225221	Macalister River @ Stringybark Creek	18/03/1968 - current	3.60	667	6.53	2,174	1,542
225204	Macalister River @ Lake Glenmaggie (Tail Gauge)	27/03/1919 - current	6.38	571	9.57	1,583	1,891

A brief summary of the discussion with Ventia on each of the streamflow gauges is given below. A discussion on particular events at some of the gauges is given in Section 5.2.

226005 Latrobe River @ Thoms Bridge

This site is considered reliably rated to 4.5 metres and extrapolated up to 6.6 metres.

The current upper end of the rating curve is based on gauging undertaken since 2000 with the highest gauge since 2000 being 4.97 m. Hence why the rating curve is considered reliable to 4.5 m. The highest gauging at the site of 6.21 m was in 1978.

226200 Latrobe River @ Rosedale (combined flow)

Ventia are not currently responsible for the ratings at this site. As such, the current rating is from 1928 and is suspended.

226228 Latrobe River @ Rosedale (Main Stream) and 226224 Latrobe River @ Rosedale (Anabranh)

The current rating for 226228 does not include the anabranh flow because there is an anabranh site 226224. The Latrobe River initially breaks out upstream of the 226228 site and the over bank flow is captured in the anabranh rating until the streams are fully combined. The river banks at 226228 are a fair bit higher at the site hence considerable flow bypasses the

mainstream site during a high flow event. The total flow at these sites is confined to the river floodplain area. There is a good history of levels at this site.

225231 Thomson River @ U/S of Cowwarr Weir

The site is located in a confined channel. This site is reliably rated to 3.8 metres and the rating is extrapolated up to 12.2 metres.

225212 Thomson River @ Wandocka

The rating at this site is considered reliable to 5.6m and extrapolated up to 7.0 m.

For this site there have been a number of datum changes over time. In the 1970s there was an adjustment to the gauge boards and therefore not all historical gaugings are applicable due to the datum differences. For this gauge, only gaugings done since 1980 contribute to the upper end of the rating curve. There was a high gauging level taken in 2016 therefore, it is possible that this site could be considered reliable for a level higher than currently assumed.

This site also breaks out into a number of anabranches but has been measured up to and above breakout. The site is currently in operation and a good history of level data.

225232 Thomson River @ Bundalaguah

The rating at this site is considered reliable up to 4.4m and extrapolated up to 7.8 m.

High flows are difficult to measure at this location due to break out across two main anabranches which can be inaccessible during medium flood events and in major events water can totally bypass the site across the flood plain. A good history of level data exists at this site. Ventia had a side looker at this site for a number of years to capture velocity data.

There has also been a significant change in the site between 1989 and 1996 and all gaugings done before 1989 are not considered applicable to the current rating curve. The current upper level on the rating curve is based on a measurement done in 2011 and since it displays significantly more water than any other measurement done at the site, the level where the rating curve is considered reliable was kept as it is until a confirmation gauging is undertaken.

225221 Macalister River @ Stringybark Creek

Historically this site has been very stable on the upper level rating. The rating at this site is considered reliable up to 2.8 m and extrapolated up to 4.0 m.

In the 2000s there appears to have been a major change in the hydraulic conditions at this site. Since that time there have only been two gaugings at approximately 1.84 m but this displays a significant positive deviation from gaugings done at that height previously. While the shape of the rating has been kept, it has been shifted reflect the change in hydraulic conditions.

225204 Macalister River @ Lake Glenmaggie (Tail Gauge)

This site is considered reliably rated to 4.4 metres and the rating is extrapolated up to 11 metres.

This site has had various site letters A to D and the gaugings have been done at all four sites. Those gaugings done at Site A to C cannot be related to those done at Site D. While the flow figures should be comparable, the datums are different. The current upper level of the D Site rating is based on two historic gaugings in 1985 and 1993. These are the highest level gaugings ever at the D site. Below these measurements, however, there has been some variability and a shift to the left in recent years. However, some of the 2011 gaugings are more to the right. Therefore the current rating is based on the majority of the measurements.

4.2 Pluviograph data

A pluviograph is an instrument that records the amount of rainfall that has fallen over a period of time. The pluviographs were used to determine the temporal pattern of rainfall over the catchment for each of the calibration events. The details of the pluviographs used are shown in Table 4-2. The pluviograph locations are shown in Figure 4-1. Information at each pluviograph was supplied by the Bureau of Meteorology.

Table 4-2 Pluviograph data

Station No.	Name	Latitude	Longitude	Start Date	End Date
85000	Aberfeldy	-37.70	146.37	Oct-1969	Sep-1984
85278	Aberfeldy (Lily Creek (Larommi))	-37.72	146.39	Jul-1985	Jun-2015
85263	Murrays Balook	-38.43	146.54	Jan-1974	Feb-1978
85277	Noojee (Slivar)	-37.90	145.97	Oct-1981	Dec-2011
85256	Barkly River (Glenlea)	-37.51	146.55	Apr-1974	Apr-2004
85237	Noojee English HMSD	-37.88	146.00	Mar-1959	Jul-1978
85269	Noojee Pearce	-37.88	146.02	Aug-1978	Nov-1981
85264	Novacs	-38.40	146.63	Jul-1968	Jun-1978
85106	Olsens Bridge (Morwell River Prison)	-38.49	146.32	Jan-1957	Jan-1979
85236	Callignee North	-38.32	146.56	Aug-1961	Current
86094	Powelltown DNRE	-37.86	145.74	Feb-1973	Jun-1973
83062	Tamboritha	-37.58	146.63	Jan-1965	Oct-1966
85079	Tanjil Bren	-37.80	146.20	Feb-1957	Jan-1976
85072	East Sale Airport	-38.12	147.13	May-1953	Current
85176	Tanjil Bren Post Office	-37.83	146.18	Jun-1957	Jun-1991
85227	East Tarwin (Mirboo Pastoral Company)	-38.52	146.20	Nov-1971	Current
83034	Thomson Upper	-37.63	146.13	Feb-1971	Mar-1977
85235	East Tarwin No.18	-38.53	146.26	May-1972	Jan-1977
85170	Traralgon L.V.W. & S.B.	-38.22	146.52	Aug-1961	Aug-1979

Station No.	Name	Latitude	Longitude	Start Date	End Date
85240	Ellinbank Dairy Research Inst.	-38.25	145.93	Aug-1961	Dec-2000
85026	Erica	-37.97	146.37	Apr-1959	Sep-1975
85092	Warragul (Carbethon)	-38.20	145.90	Jul-1974	Aug-1975
85058	Glencairn (Barkly River (Glenview))	-37.53	146.55	Apr-2004	Current
83033	Woods Point	-37.57	146.25	Jan-1954	Current
85034	Glenmaggie Weir	-37.91	146.80	Dec-1957	Dec-2017
85098	Yallourn	-38.20	146.40	Jan-1936	Jan-1949
85103	Yallourn SEC	-38.19	146.33	Nov-1949	Jan-1972
86325	Latrobe River (Recorder No. 3)	-37.92	145.85	May-1973	Dec-1980
86322	Latrobe River No.1	-37.90	145.77	Mar-1973	Dec-1980
86323	Latrobe River No.2	-37.85	145.85	Mar-1973	Dec-1980

4.3 Daily rainfall data

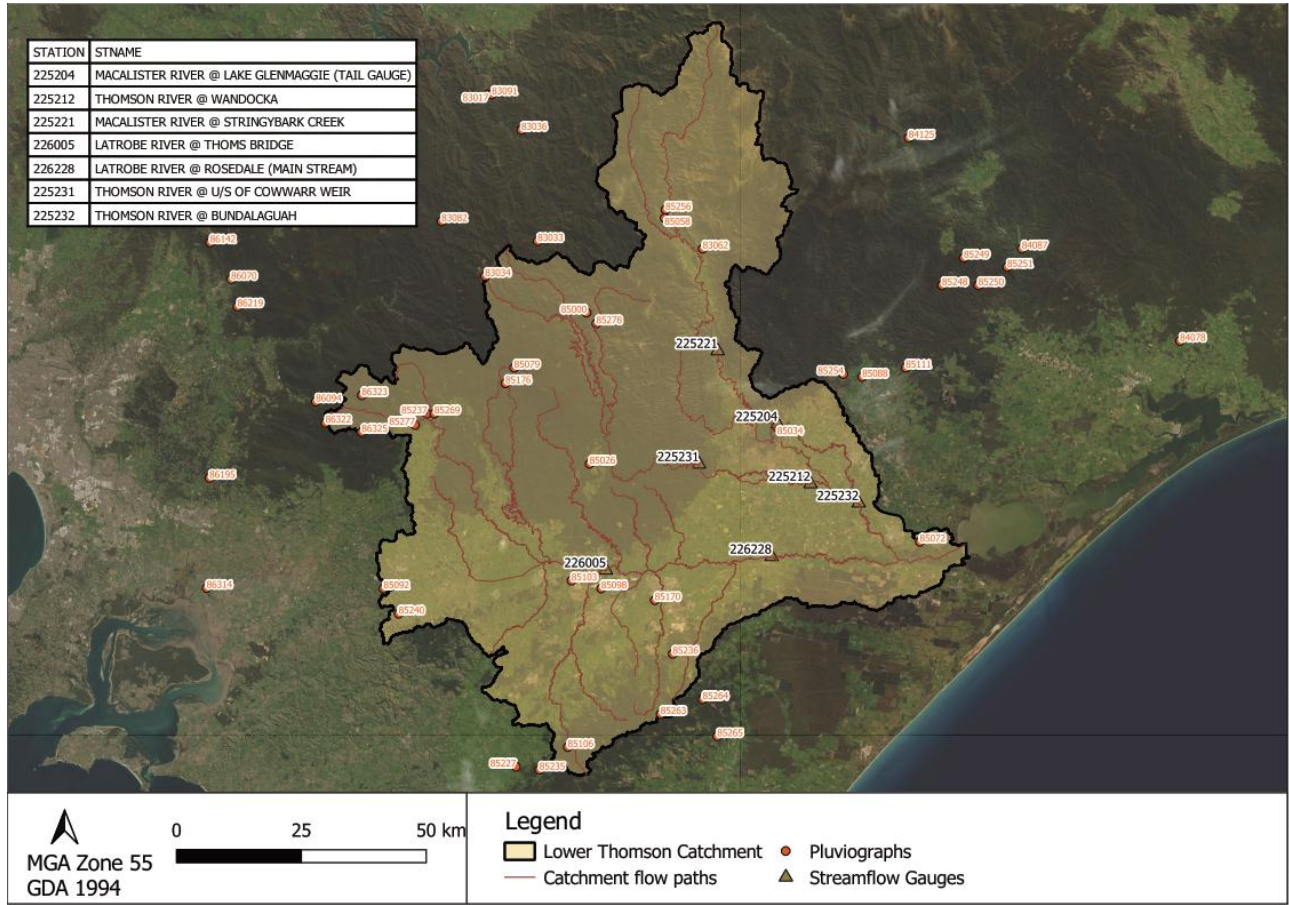
Three data sources were used to determine the amount of rainfall that fell over different parts of the catchment (spatial pattern) for each of the historical events, namely:

- n Australian Water Availability Project (AWAP) (Raupach et al., 2009);
- n daily rainfall gauges; and
- n pluviographs.

The primary source of data used to determine spatial patterns of rainfall were the daily AWAP rainfall data. The AWAP data were downloaded from the Bureau of Meteorology website. The AWAP data provide a spatial (5 kilometre resolution) distribution of daily rainfall across the Australian continent. The AWAP data use model-data fusion methods to combine both measurements and modelling to estimate rainfall.

The AWAP data were checked for consistency with the rainfall recorded at daily rainfall gauges and the sum of rainfall recorded at the pluviographs.

Lower Thomson River Flood Study



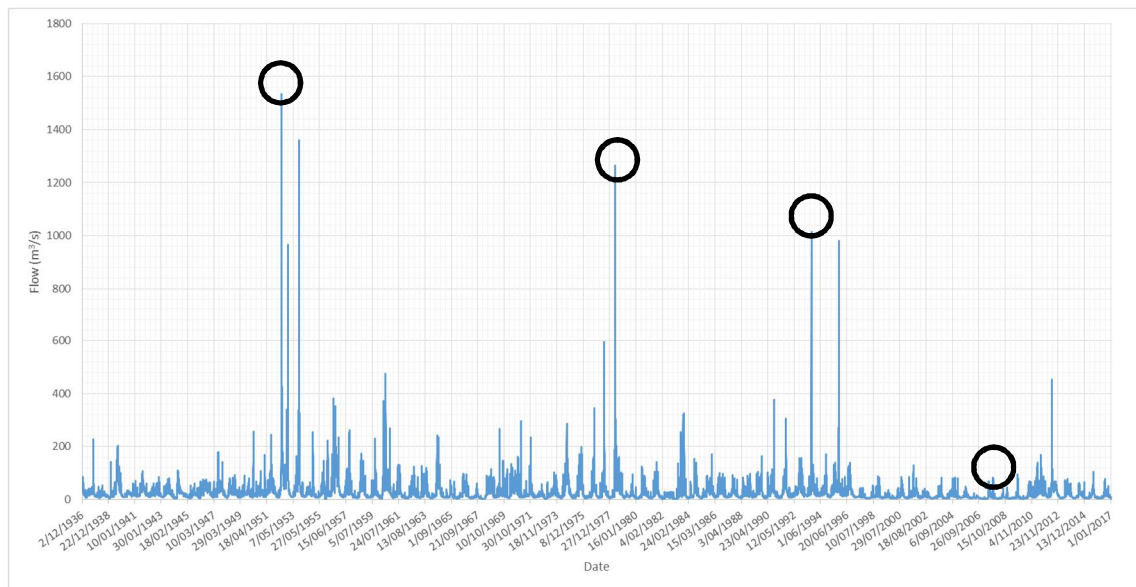
n Figure 4-1 Gauge location map for Latrobe River catchment

4.4 Events chosen for calibration

The events chosen for calibration of the hydrological model were determined by examining streamflow data in conjunction with available pluviograph information and flood level information which is to be used in the hydraulic modelling. The events chosen were:

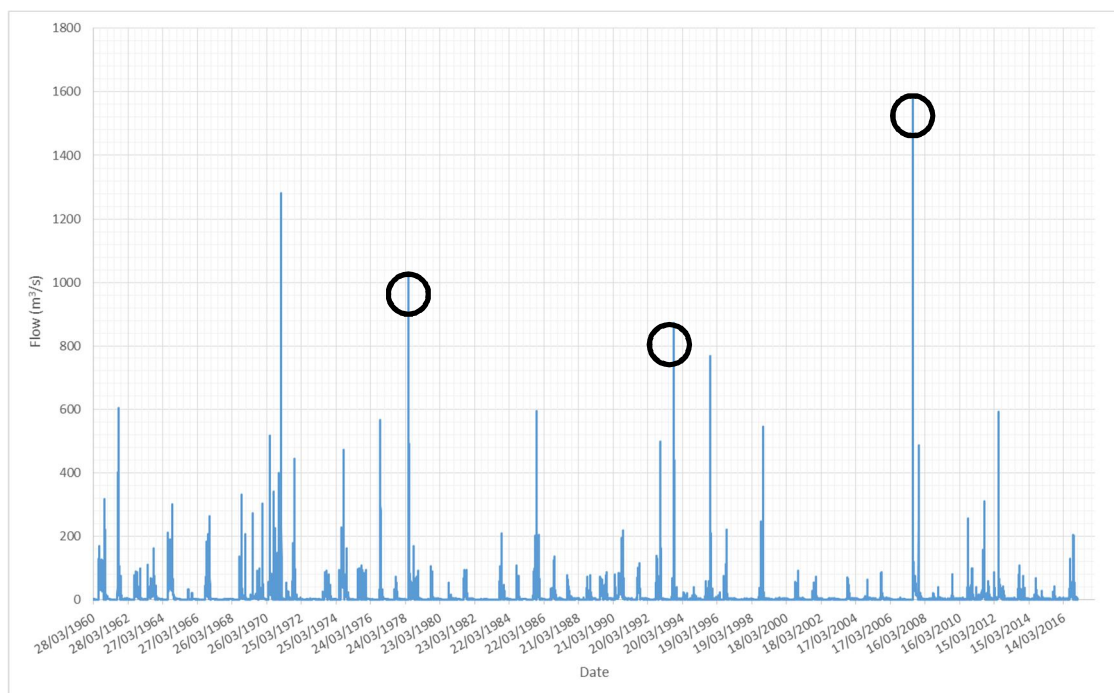
- n April 1952;
- n June 1978;
- n September 1993; and
- n June 2007.

Figure 4-2 shows the flows recorded at Rosedale Combined (226228 plus 226224) with the events chosen for calibration, each highlighted with a black circle. It is noted that the 1952 event is the largest on record, the 1978 event is the third highest event, the 1993 event is the fourth highest and the 2007 is a very low event on the Latrobe River.



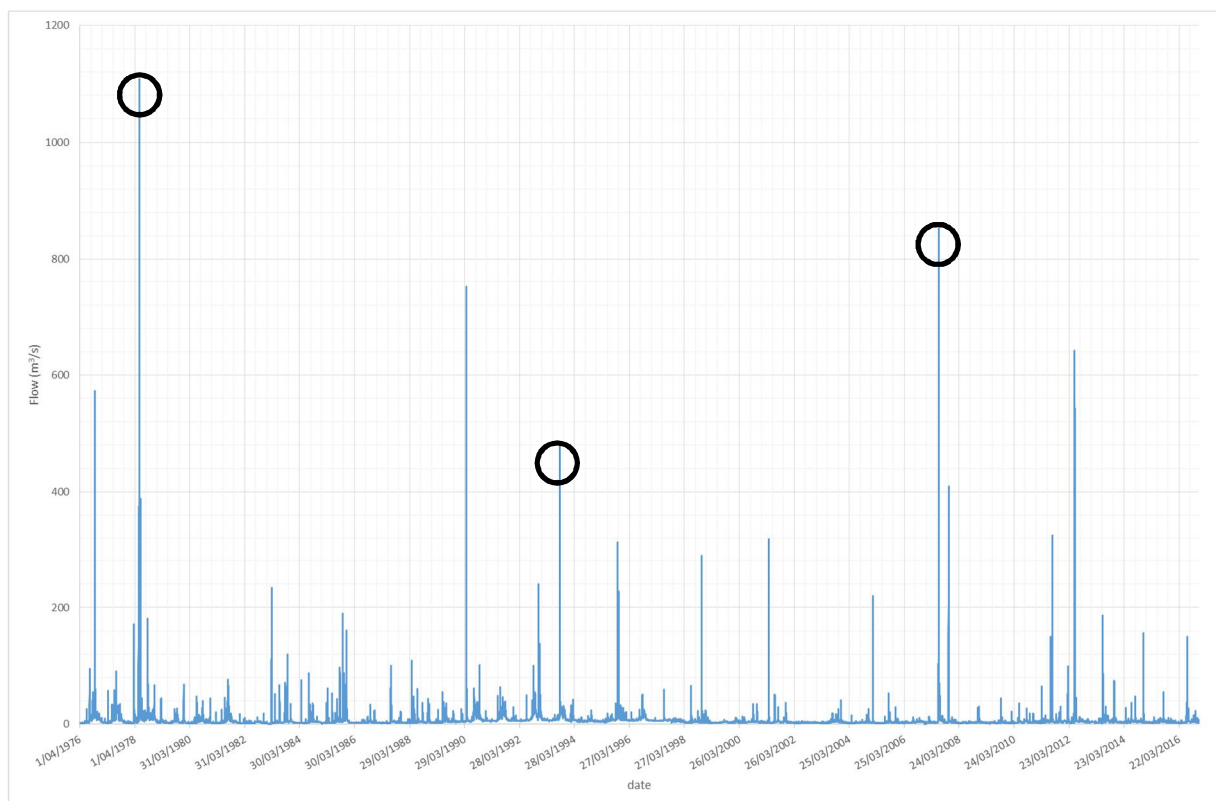
n **Figure 4-2 Streamflow information recorded at Rosedale Combined (226228 plus 226224)**

Figure 4-3 shows the flows recorded at Macalister River @ Lake Glenmaggie (Tail Gauge) (225204) with the events chosen for calibration, each highlighted with a black circle. It is noted that there is no estimate of the 1952 event at this gauge, 1978 event is the third highest event, the 1993 event is the fourth highest and the 2007 is the highest recorded event on the Macalister River.



n **Figure 4-3 Streamflow information recorded at Macalister River @ Lake Glenmaggie (Tail Gauge) (225204)**

Figure 4-4 shows the flows recorded at Thomson River @ U/S Cowwarr Weir (225231) with the events chosen for calibration, each highlighted with a black circle. It is noted that there is no estimate of the 1952 event at this gauge, 1978 event is the highest event, the 1993 event is the sixth highest and the 2007 is the second highest event on the Thomson River.



n **Figure 4-4 Streamflow information recorded at Thomson River @ U/S of Cowwarr Weir (225231)**

5 Rainfall runoff model

5.1 Model layout

A rainfall runoff model, RORB, was established for the catchment. RORB (Laurenson and Mein, 1995; Laurenson et al., 2010) is a general runoff and streamflow routing program that is used to calculate flood hydrographs from rainfall and other channel inputs. It subtracts losses from rainfall to determine rainfall excess and routes this through catchment storages to produce streamflow hydrographs at points of interest. The model is spatially distributed, non-linear, and applicable to both rural and urban catchments. It makes provision for both temporal and areal distribution of rainfall as well as losses, and can model flows at any number of points throughout a catchment (including upstream and downstream of reservoirs). In general terms, development of a RORB model entails sub-dividing the catchment into a series of subareas to suit the catchment topography and other features such as the location of gauging stations and storage locations. The catchment topography was assessed using the VicMap 10 metre Digital Elevation Model (DEM).

Four different types of reaches can be defined in RORB, each having different properties and different relative delay time. The reach types are identified as 1 for natural, 2 for excavated but unlined, 3 for lined channel or pipe and 4 for drowned reach. Drowned reaches were used within storages; natural reaches were used for all other reaches. Excavated and lined channel reaches (types 2 and 3) are normally only applied in urbanised areas and hence were not used in this study.

Impervious fractions are required for each subarea. For rural areas the impervious fraction is usually assumed to be zero. For areas that are inundated by reservoirs, an impervious fraction was calculated based on the percentage of the subarea that is inundated.

The RORB model was configured in a GIS framework using ArcRORB (Hydrology and Risk Consulting, 2016).

For each of the calibration events the rainfall depths were estimated for each subarea to account for the spatial variation of rainfall across the catchment. Rainfall depths were estimated by interpolating the AWAP rainfall data to the RORB model subarea centroids. The temporal distribution of rainfall was estimated by assigning the patterns from the available pluviographs.

The RORB model transforms the rainfall excess of a given storm event into a flood hydrograph. In order to compare the RORB model's simulated hydrograph with the recorded or observed hydrograph, it was necessary to remove the baseflow component from the recorded hydrograph. Baseflow was removed in accordance with guidance given in Book 5 Chapter 4 of Australian Rainfall and Runoff (Hill et. al., 2016).

5.2 Calibration

RORB models are based on catchment geometry and topographic data, and the two principal routing parameters are k_c and m . The parameter m describes the degree of non-linearity of the catchment's response to rainfall excess, while the parameter k_c describes the delay in the catchment's response to rainfall excess. A value of 0.8 was adopted for the non-linearity parameter, m , for this study, which is recommended by Laurenson et al. (2010) and recommended in Book 8 of Australian Rainfall and Runoff (Nathan and Weinmann, 2016) for modelling very large and extreme flood events. The routing parameter, k_c , is selected by calibrating the RORB model to historic floods. The selection of k_c is discussed in Section 5.

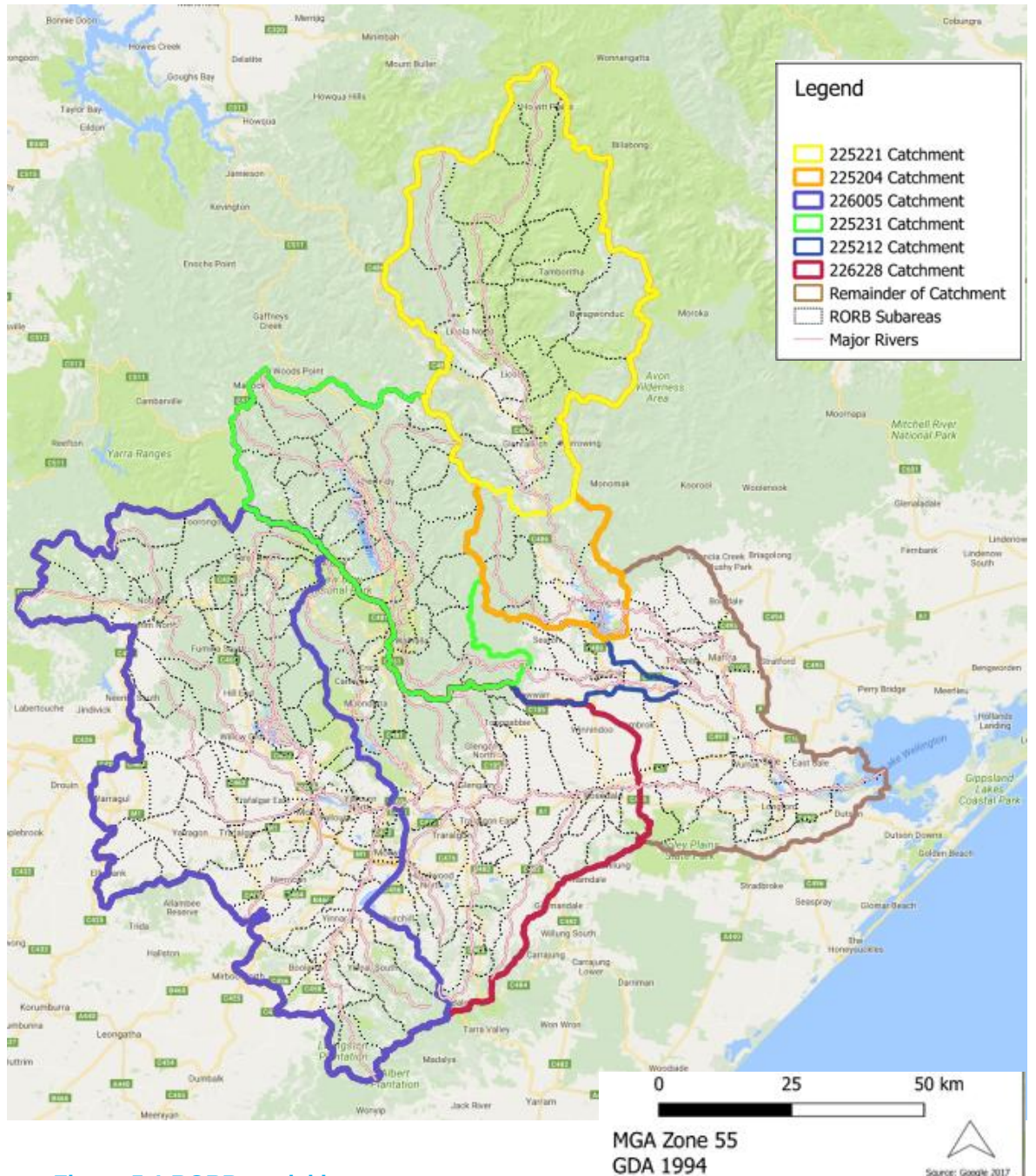
The remaining RORB model parameters represent rainfall losses, using either an initial loss/continuing loss model, or an initial loss/proportional loss (i.e. runoff coefficient) model. An initial loss/continuing loss model was adopted for this study because it is more appropriate for modelling very large and extreme floods. The selection of losses is discussed in Section 7.

In general, the calibration approach was:

- n Adjustment of the k_c to achieve a fit to the shape of the recorded hydrograph. The model was run interactively with various trial values of k_c , and the value giving best reproduction of the observed data was adopted.
- n Initial loss directly affects the start of the hydrograph rise, but also affects the time distribution of rainfall excess and hence the hydrograph peak, especially for long storms with large variations of intensity. The continuing loss generally affects the hydrograph volume. The initial and continuing loss were adjusted in conjunction to attempt to match the start of the hydrograph rise and achieve a reasonable fit between the modelled and observed hydrograph volumes.

Calibration of the RORB model was undertaken by setting up historical storm files and running the RORB model with routing parameters and losses such that a match was achieved against the recorded flood hydrographs. Details of the RORB model are shown in Figure 5-1.

The model was broken up into different sections for each of the gauges used in calibration. Therefore, a different k_c value was adopted for each section of the model.



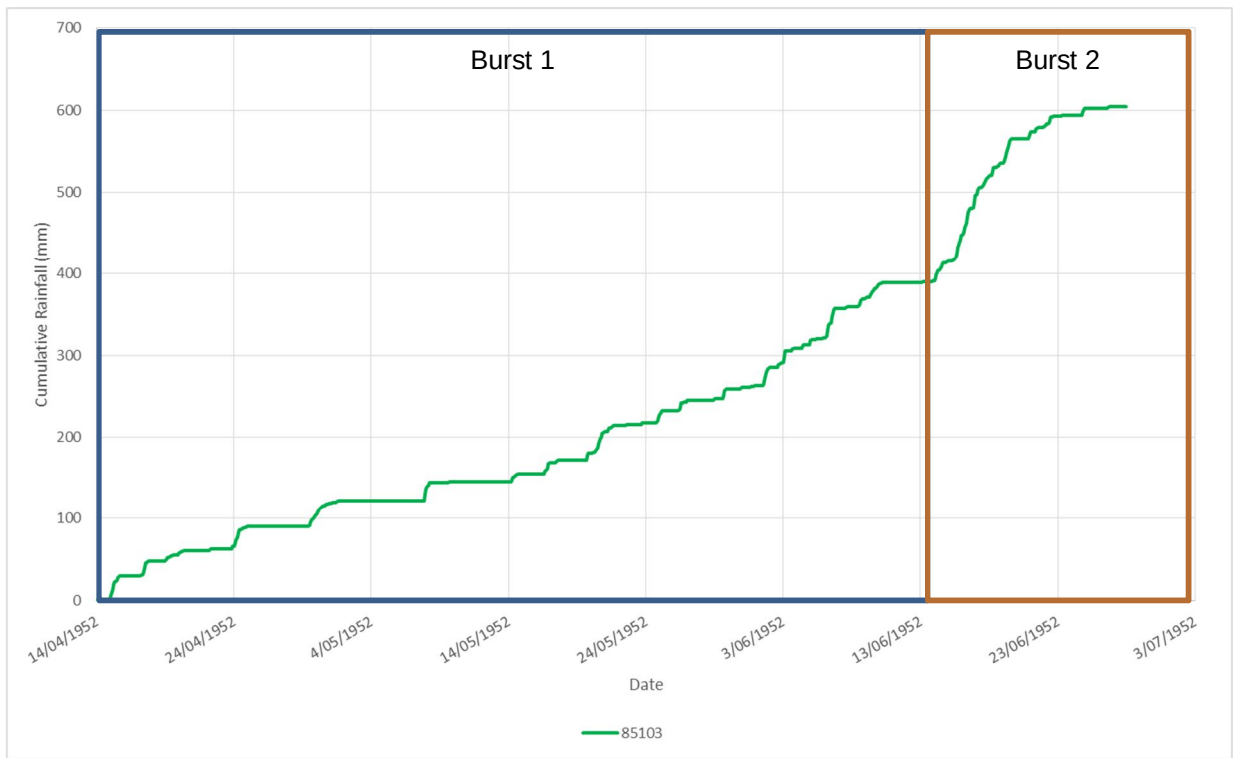
n **Figure 5-1 RORB model layout**

A brief discussion on each calibration event is given below.

5.2.1 April 1952

For the April 1952 event only data from one pluviograph was available, 85103 (Yallourn SEC) so was used as the temporal pattern of rainfall for the entire catchment (refer to Figure 4-1 for location of pluviograph). Figure 5-2 shows the pluviograph information available.

Rainfall depths were estimated by interpolating the AWAP rainfall data to the RORB model subarea centroids. Figure 5-3 shows the rainfall depths across the catchment. For the April 1952 event there was a significant amount of rain (approximately 400 mm) that fell over the two months before the main burst on the 14th June 1952. The total storm depths were divided into two bursts (burst one beginning on April 14th, and burst two on the 14th June). The preceding rainfall to the main burst was modelled to provide context, that is, the catchment was wet, for this event.



n **Figure 5-2 Temporal patterns of rainfall depths extracted from pluviographs for the April 1952 event**

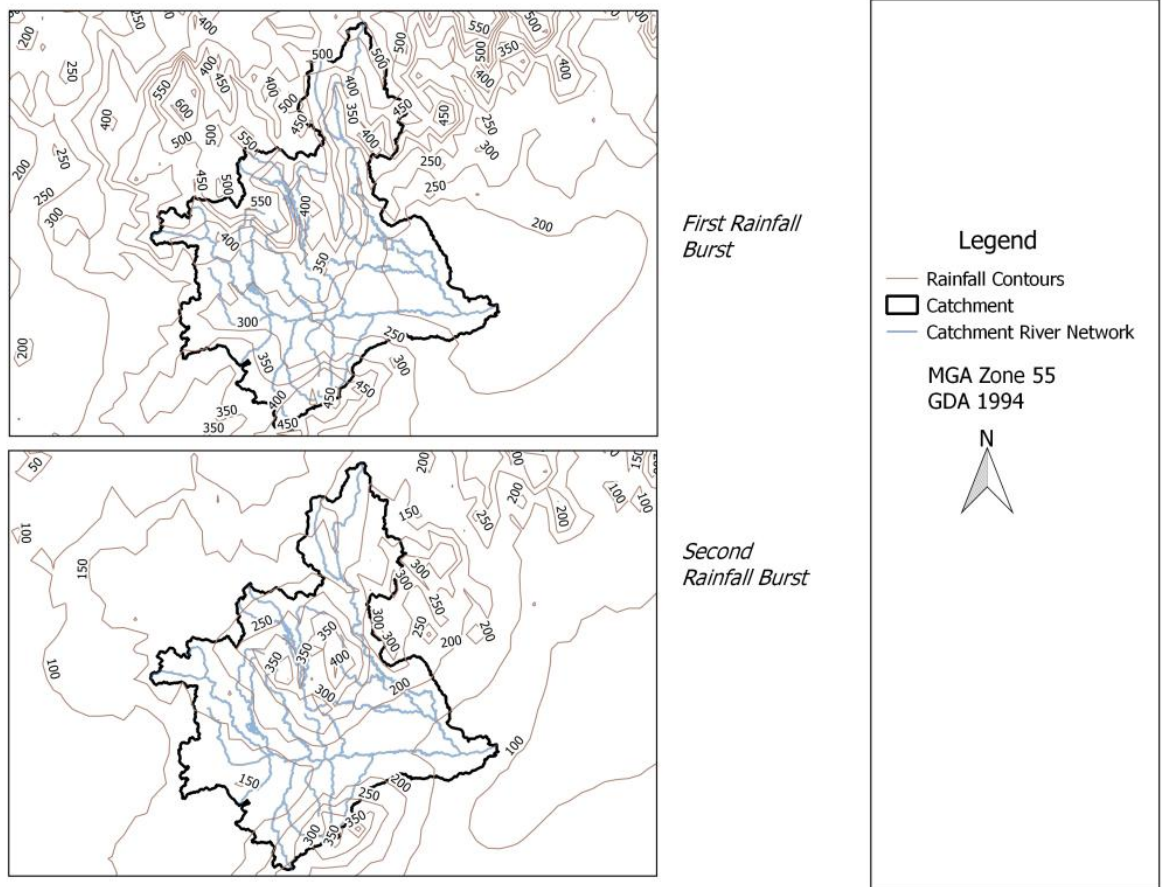


Figure 5-3 Spatial pattern of rainfall depths for the April 1952 event

For this event the only streamflow gauge information available was at Rosedale (226200 and 226228 combined). The RORB model transforms the rainfall excess of a given storm event into a flood hydrograph. In order to compare the RORB model's generated hydrograph with the recorded hydrograph, it is necessary to remove the baseflow component from the recorded hydrograph. Baseflow was manually separated from the total flow hydrograph at the streamflow gauge. Appendix A shows the baseflow that was removed.

Of the four main dams in the catchment (Blue Rock, Glenmaggie, Moondarra and Thomson) only Lake Glenmaggie had been built at the time of this event. Therefore, Lake Glenmaggie was added into the RORB model for this event. However, as there is no gauge information on the Macalister River for this event it made no difference to the calibration.

For this event only one of the three mines, Yallourn (began in approximately 1920), was included in the model. The mine was included as a storage which was assumed to be at its current size. Whilst the assumption of the mine being at its current size is conservative the impact on flows along Latrobe is minor. The calibration run was undertaken with and without the mine in place and the impact on peak flows was found to be less than 1% at Rosedale.

A summary of the calibration parameters for the April 1952 event are shown in Table 5-1. A summary of the calibration results are shown in Table 5-2 with the hydrograph shown in Figure 5-4.

Table 5-1 Summary of calibration parameter values for the event in April 1952

Gauge	k_c	m	IL (mm) Burst 1	CL (mm/h) Burst 1	IL (mm) Burst 2	CL (mm/h) Burst 2
226005 (Thoms Bridge)	80	0.8	250	0.5	5.0	0.2
226228 and 226224 (Rosedale Combined)	64	0.8	250	0.5	5.0	0.2

Table 5-2 Summary of the key model output for the event in April 1952

Gauge	Peak(m^3/s)		Time to Peak (hours)		Volume (m^3)	
	Calculated	Recorded	Calculated	Recorded	Calculated	Recorded
226005 (Thoms Bridge)	n/a	n/a	n/a	n/a	n/a	n/a
226228 and 226224 (Rosedale Combined)	1536	1534	1548	1536	8.19E+08	1.12E+09

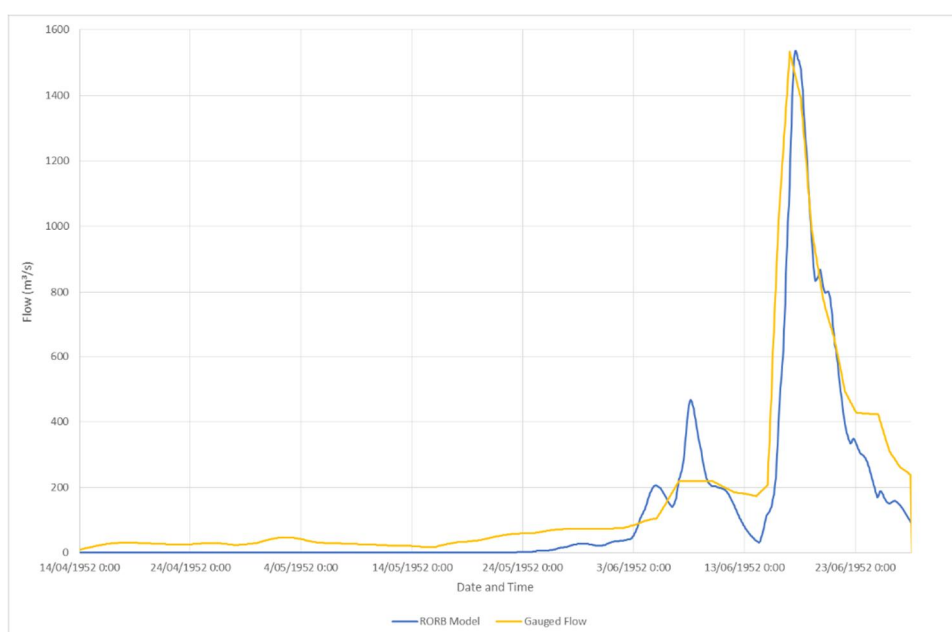


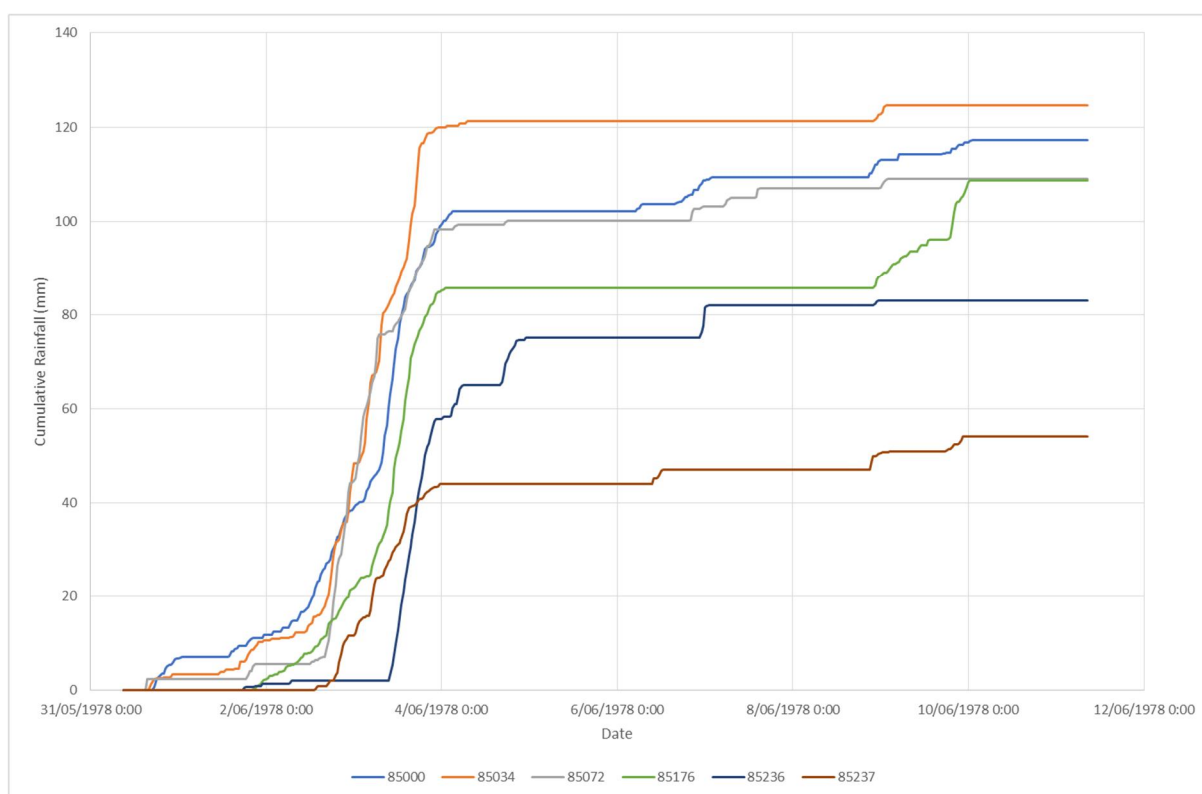
Figure 5-4 RORB calibration at Rosedale Combined (226200 and 226228) – April 1952

5.2.2 June 1978

For the June 1978 event data from nine pluviographs were available, 85000, 85034, 85072, 85176, 85236 and 85237. All of these gauges were used in the calibration process (refer to Figure 4-1 for location of pluviographs). As listed in Section 4.2 other pluviographs were in

operation during this time however not all of them had data recorded during the rainfall event. The temporal pattern of rainfall in each subarea was defined using the closest gauge. Figure 5-5 shows the pluviograph information available at each gauge. The pluviographs highlight the variability in rainfall depths over the catchment.

Rainfall depths were estimated by interpolating the AWAP rainfall data to the RORB model subarea centroids. Figure 5-6 shows the rainfall depths across the catchment.



n **Figure 5-5 Temporal patterns of rainfall depths extracted from pluviographs for the June 1978 event**

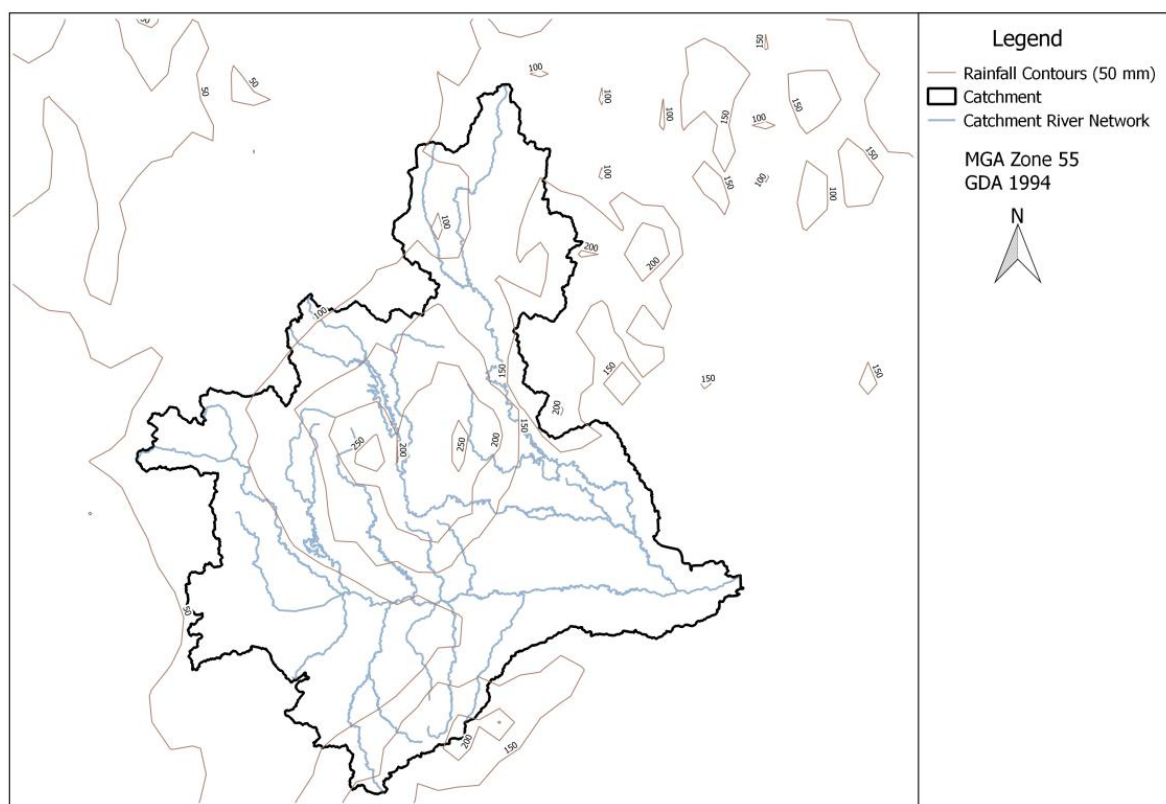


Figure 5-6 Spatial pattern of rainfall depths for the June 1978 event

For this event several streamflow gauges are available. The streamflow gauges used for this event were 226005 (Latrobe River @ Thoms Bridge), Rosedale combined (226228 and 226224), 225231 (Thomson River @ U/S of Cowwarr Weir) 225212 (Thomson River @ Wandocka), 225232 Thomson River @ Bundalaguah), 225221 (Macalister River @ Stringybark Creek) and 225204 (Macalister River @ Lake Glenmaggie – Tail Gauge). Baseflow was manually separated from the total flow hydrograph at each of the streamflow gauges. Appendix A shows the baseflow that was removed.

Of the four main dams in the catchment (Blue Rock, Glenmaggie, Moondarra and Thomson) only Lake Glenmaggie and Moondarra had been built at the time of this event. Therefore for this event those two dams were included in the RORB model. The starting reservoir levels were taken from the historical reservoir level data.

For this event two of the three mines, Yallourn and Hazelwood (began in approximately 1950), was included in the model. The mines were included as a storage which were assumed to be at their current size. Whilst the assumption of the mine being at its current size is conservative the impact on flows along Latrobe is minor. The calibration run was undertaken with and without the mine in place and the impact on peak flows was found to be less than 1% at Rosedale.

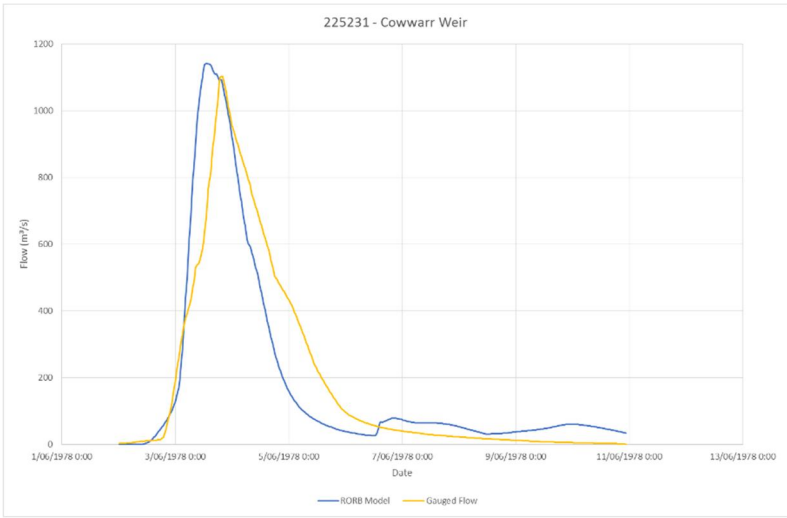
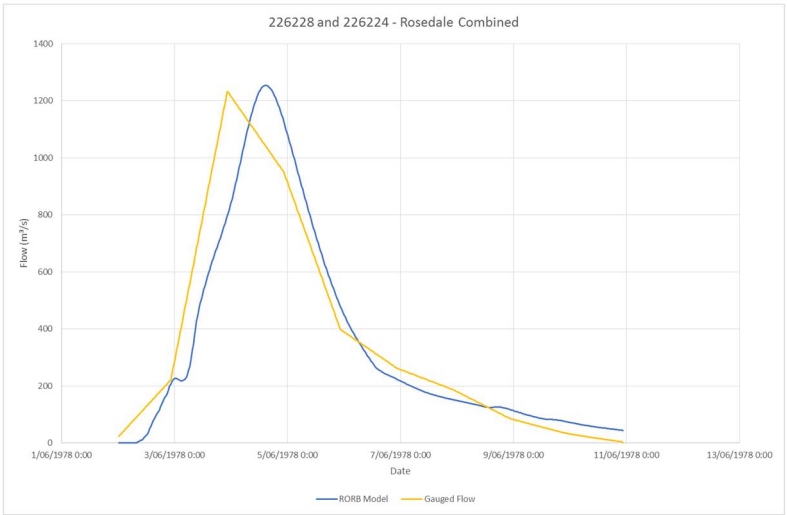
A summary of the calibration parameters for the June 1978 event are shown in Table 5-3. A summary of the calibration results are shown in Table 5-7 with the hydrograph shown in Figure 5-7.

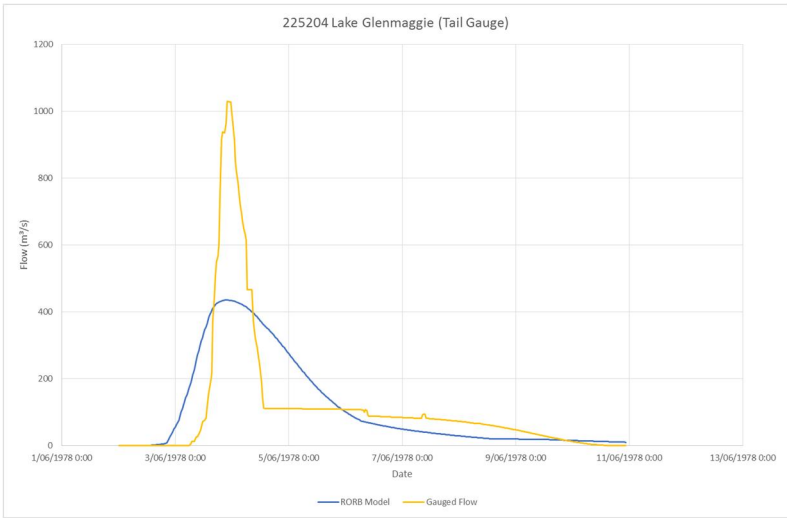
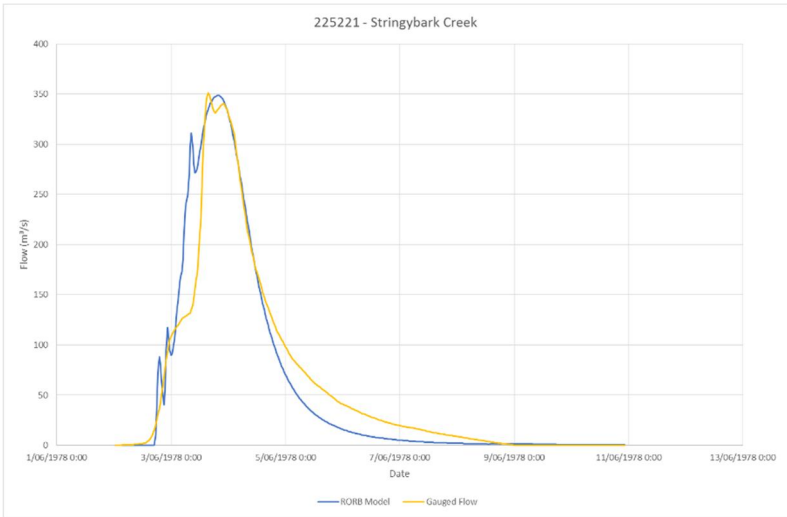
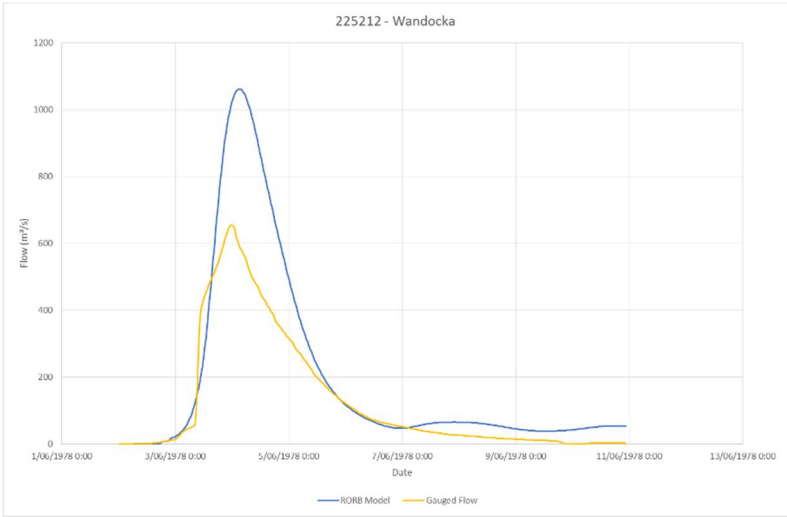
Table 5-3 Summary of calibration parameters values for the event in June 1978

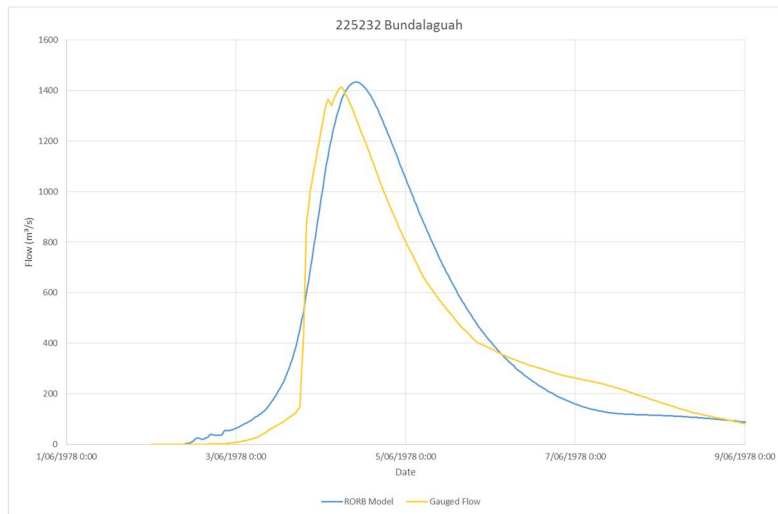
Gauge	k_c	m	IL (mm)	CL (mm/h)
226005 (Thoms Bridge)	80	0.8	10	1.2
226228 and 226224 (Rosedale Combined)	70	0.8	10	1.0
225231 (Cowwarr Weir)	70	0.8	20	0.3
225212 (Wandocka)	50	0.8	40	3.0
225221 (Stringybark Ck)	62	0.8	50	3.0
225204 (Lake Glenmaggie)	23	0.8	20	0.5
225232 (Bundalaguah)	75	0.8	20	3.0

Table 5-4 Summary of key model output for the event in June 1978

Gauge	Peak(m^3/s)		Time to Peak (hours)		Volume (m^3)	
	Calculated	Recorded	Calculated	Recorded	Calculated	Recorded
226005 (Thoms Bridge)	795	804	50.0	51.0	1.40E+08	8.45E+07
226228 and 226224 (Rosedale Combined)	1254	1233	62	46	2.75E+08	2.91E+08
225231 (Cowwarr Weir)	1141	1103	37	43	1.45E+08	1.50E+08
225212 (Wandocka)	1061	654	51	47	1.53E+08	9.94E+07
225221 (Stringybark Ck)	349	351	43	39	4.55E+07	4.77E+07
225204 (Lake Glenmaggie)	435	1028	46	46	8.71E+07	8.87E+07
225232 (Bundalaguah)	1433	1414	58	59	2.53E+08	2.65E+08







n **Figure 5-7 RORB calibration June 1978**

In general, a good calibration was achieved at each gauge with a few notable exceptions. The RORB model could not replicate the flow at 225204 (Lake Glenmaggie – Tail Gauge). As this gauge is located immediately downstream of Lake Glenmaggie it will be influenced by the gate operations at Lake Glenmaggie making it more difficult to replicate in the RORB model.

This event was discussed with Ventia to gain insight into the gauging for this event. The rating at 225221 (Macalister River @ Stringybark Creek) was discussed along with 225204 (Lake Glenmaggie – Tail Gauge). The gauge at 225221 is upstream of 225204 and captures most (82%) of the Lake Glenmaggie catchment. Historically 225221 “has been very stable on the upper level rating” (personal communication - Ventia). Ventia have a number of gaugings up to approximately 460 m³/s. The flow at 225211 for the 1978 event is 351 m³/s which gives confidence in the flow estimate at 225221.

At 225204 the highest measured flow is 585 m³/s compared to the flow of 1028 m³/s for the 1978 event. As a result the flow estimate at 225204 is extrapolated further compared to that at 225204 giving less confidence in the flow estimate at 255204. Therefore, for this event the calibration was focused on matching the hydrograph at 225221.

Also for the 1978 event the RORB model could not replicate the flow at 225212 (Thomson River @ Wandocka) if the flow at 225231 (Thomson River @ U/S of Cowwarr Weir) was replicated and vice versa. This was discussed with Ventia as well and it was noted that “The rating for 225231 is extrapolated beyond approximately 382 m³/s, which is the highest gauging conducted at the site. The rating for 225212 is extrapolated beyond approximately 434 m³/s which is the highest gauging conducted at the site. The current rating at 225212 displays that the river has broken out on to its flood plain while the rating at 225231 does not give this indication”. Given the location of the sites this variation is expected but does not explain why 225231 has much higher flows than 225212. In consultation with the WGCMA it was decided to match the flow at 225231

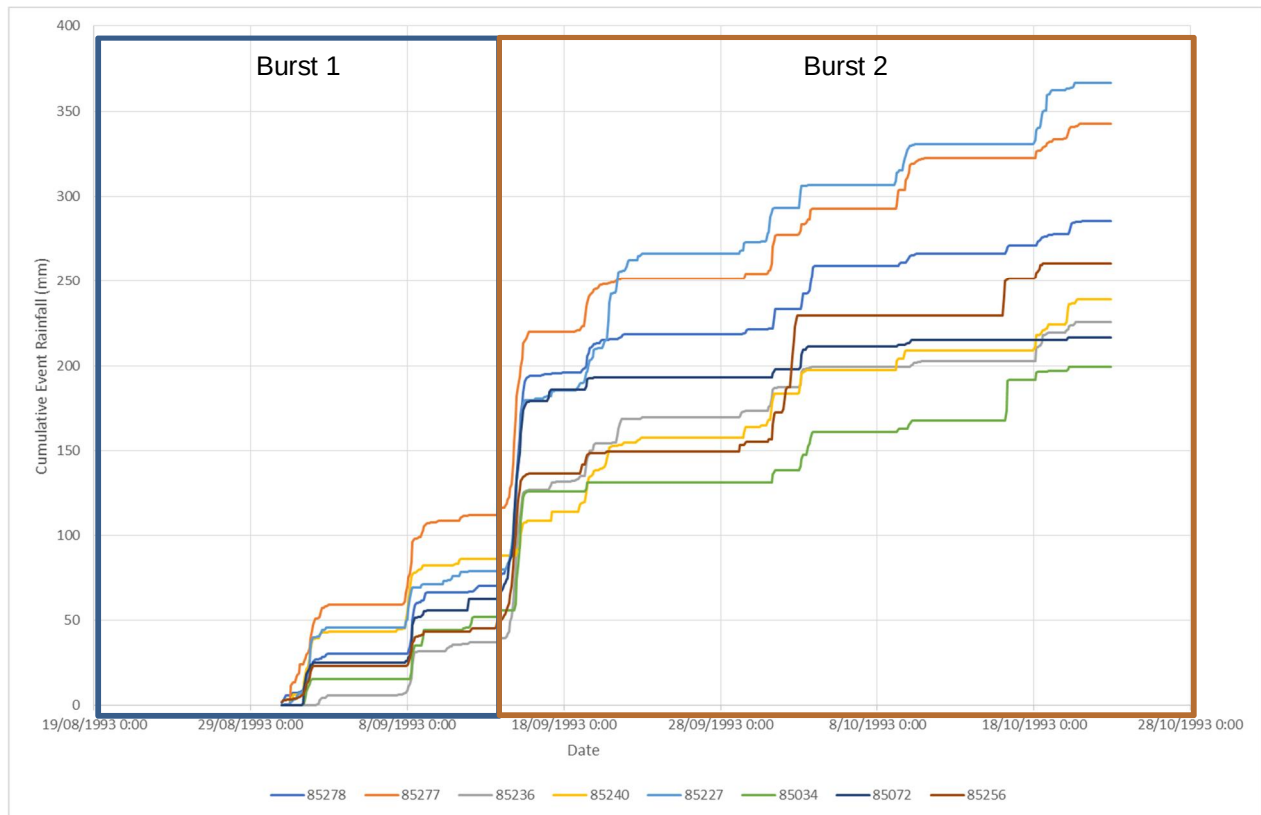
as the gauge is located in a defined cross section and therefore there is likely to be more certainty in the rating curve. In addition to the above, as the RORB model matches the flows estimate at 225232 (Thomson River @ Bundalaguah) well this adds confidence in the RORB estimates at 225231, which flows into 225232.

On the Latrobe River the volume of the hydrograph at 226005 (Thoms Bridge) is overestimated. As Thoms Bridge is well upstream of the hydraulic model boundary and the volume at Rosedale is reasonable the modelling undertaken is considered adequate for the estimation of k_c .

5.2.3 September 1993

For the September 1993 event data were available at eight pluviographs, 85278, 85277, 85236, 85240, 85227, 85034, 85072 and 85256 all of these gauges were used in the calibration process (refer to Figure 4-1 for location of pluviographs). As listed in Section 4.2 other pluviographs were in operation during this time however not all of them had data recorded during the rainfall event. The temporal pattern of rainfall in each subarea was defined using the closest gauge. Figure 5-8 shows the pluviograph information available at each gauge. The pluviographs highlight the variability in rainfall depths over the catchment.

Rainfall depths were estimated by interpolating the AWAP rainfall data to the RORB model subarea centroids. Figure 5-9 shows the rainfall depths across the catchment. For the September 1993 event the total storm depths were divided into two bursts (burst one beginning on the 31st August, burst two on the 14th September).



n **Figure 5-8 Temporal patterns of rainfall depths extracted from pluviographs for the September 1993 event**

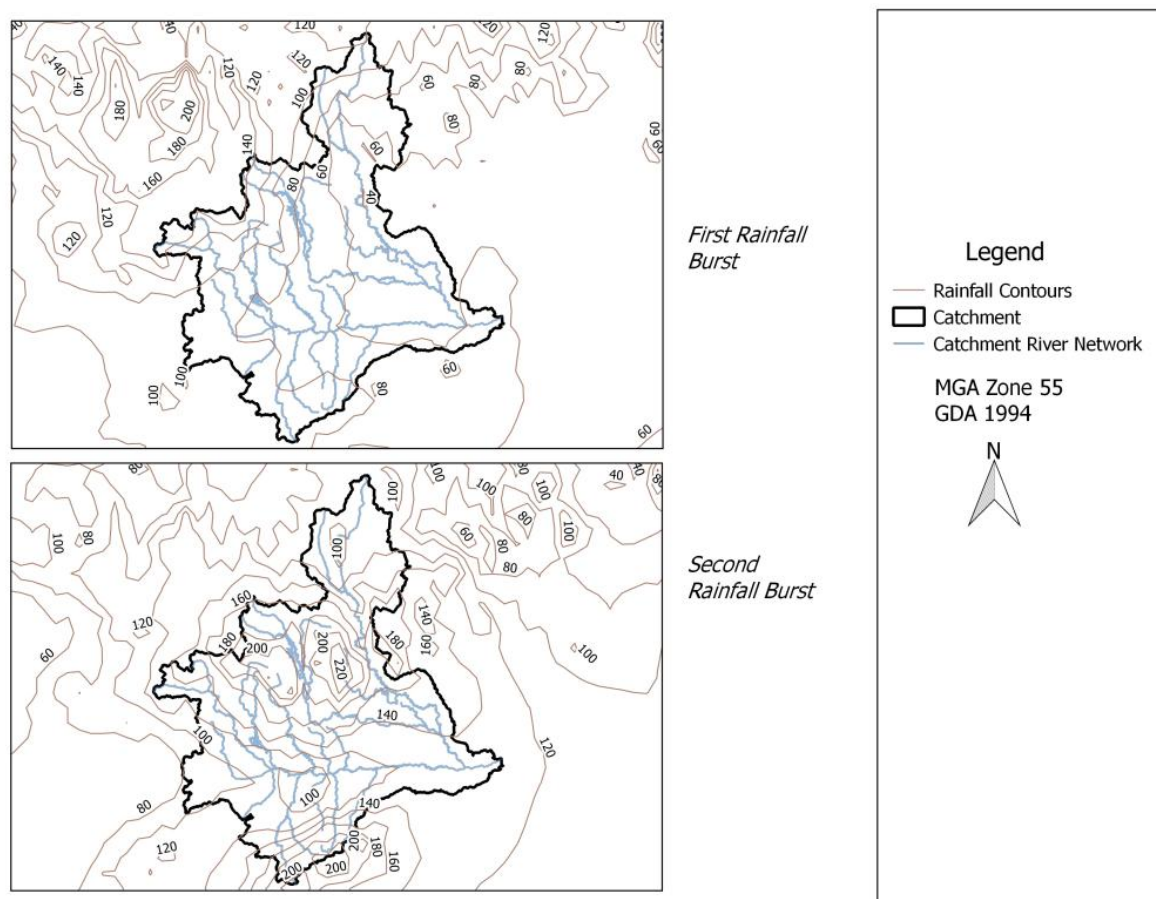


Figure 5-9 Spatial pattern of rainfall depths for the September 1993 event

For this event several streamflow gauges are available. The streamflow gauges used for this event were 226005 (Latrobe River @ Thoms Bridge), Rosedale combined (226228 and 226224), 225231 (Thomson River @ U/S of Cowwarr Weir) 225212 (Thomson River @ Wandocka), 225221 (Macalister River @ Stringybark Creek) and 225204 (Macalister River @ Lake Glenmaggie – Tail Gauge). Baseflow was manually separated from the total flow hydrograph at each of the streamflow gauges. Appendix A shows the baseflow that was removed. There was no recorded hydrograph at 225232 (Thomson River @ Bundalaguah) available for this event.

All four main dams in the catchment (Blue Rock, Glenmaggie, Moondarra and Thomson) had been built at the time of this event. Therefore for this event those all the dams were included in the RORB model. The starting reservoir levels were taken from the historical reservoir level data.

For this event each of the three mines, Yallourn, Hazelwood and Loy Yang (began in approximately 1982), was included in the model. The mines were included as a storage which were assumed to be at their current size. Whilst the assumption of the mine being at its current size is conservative the impact on flows along Latrobe is minor. The calibration run was

undertaken with and without the mine in place and the impact on peak flows was found to be less than 1% at Rosedale.

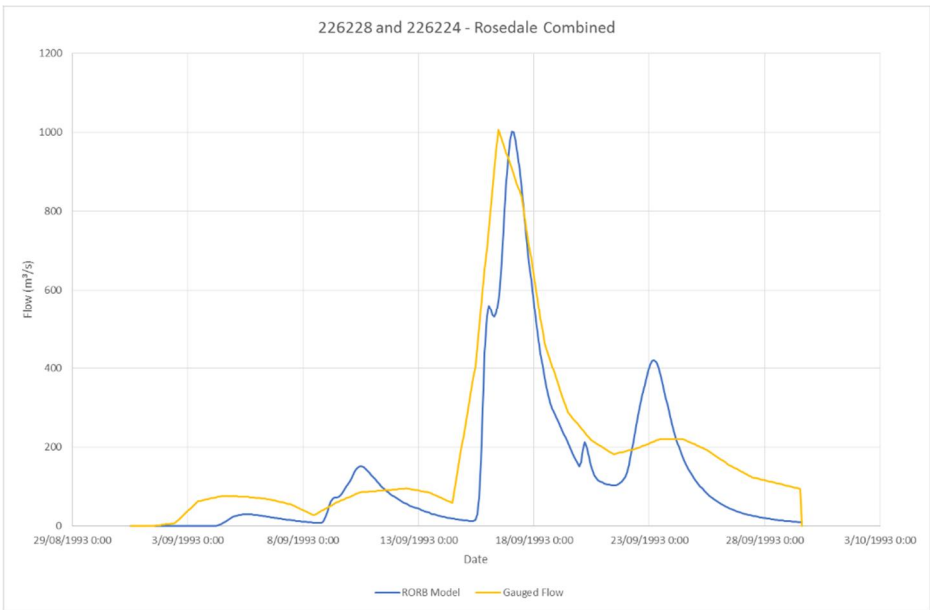
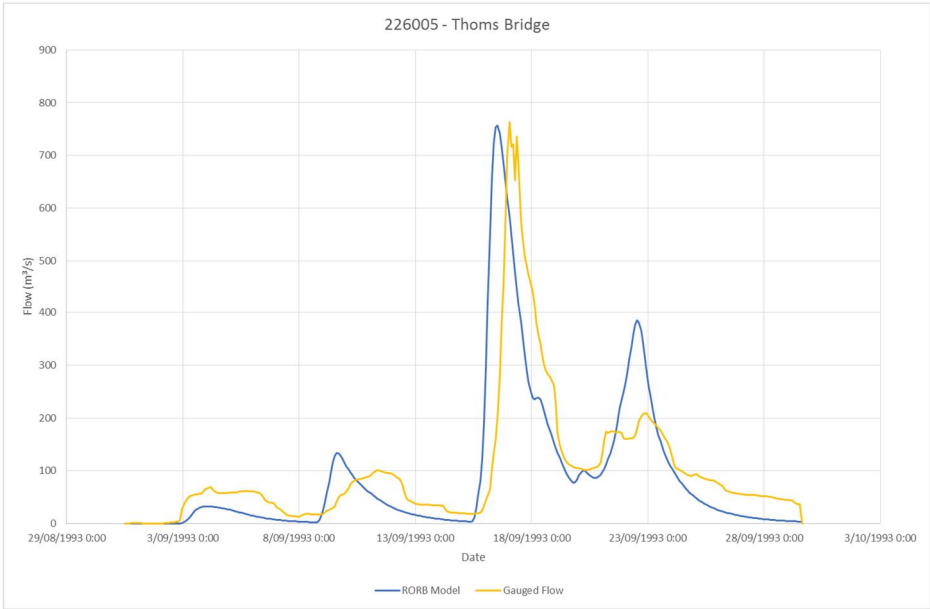
A summary of the calibration parameters for the September 1993 event are shown in Table 5-5. A summary of the calibration results are shown in Table 5-6 with the hydrographs shown in Figure 5-10.

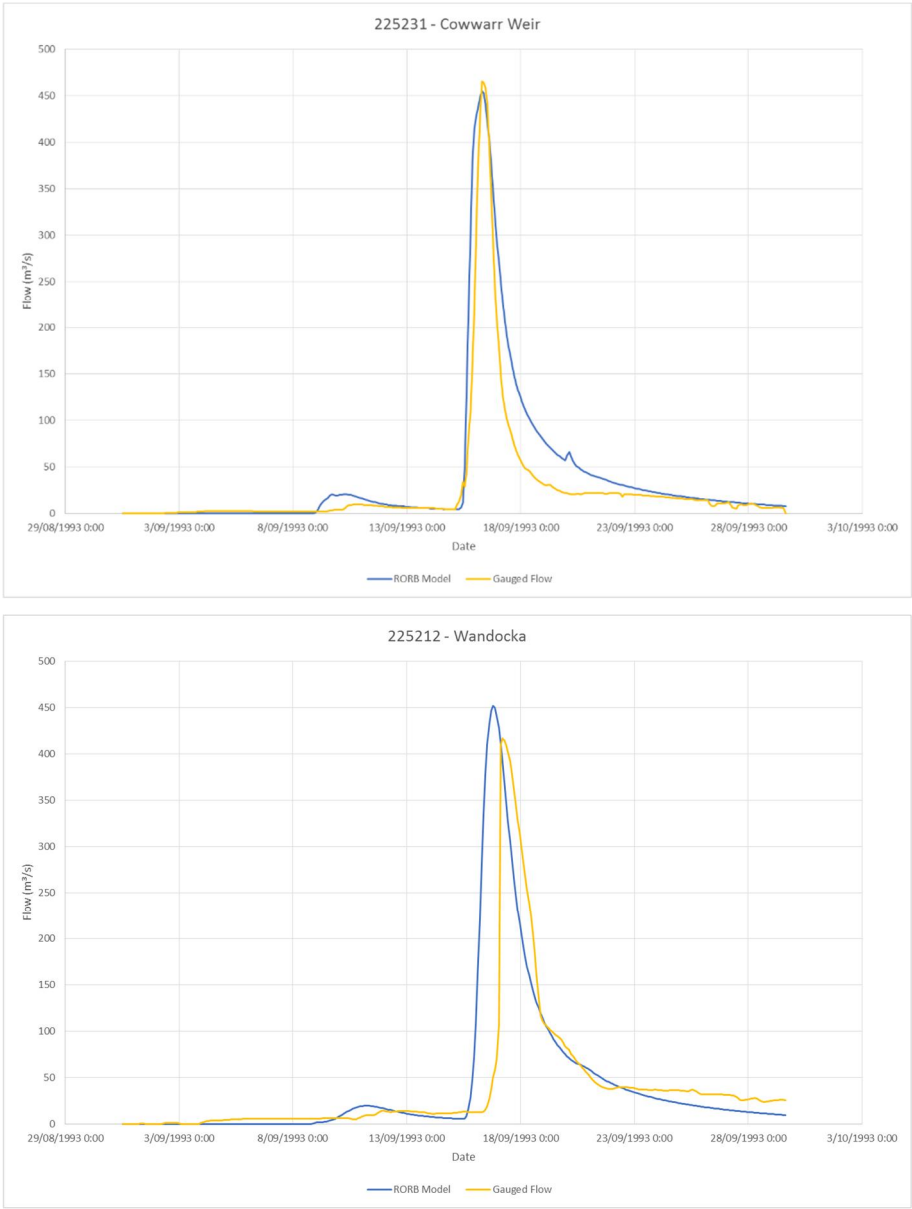
ⁿ **Table 5-5 Summary of calibration parameters values and key model output for the event in September 1993**

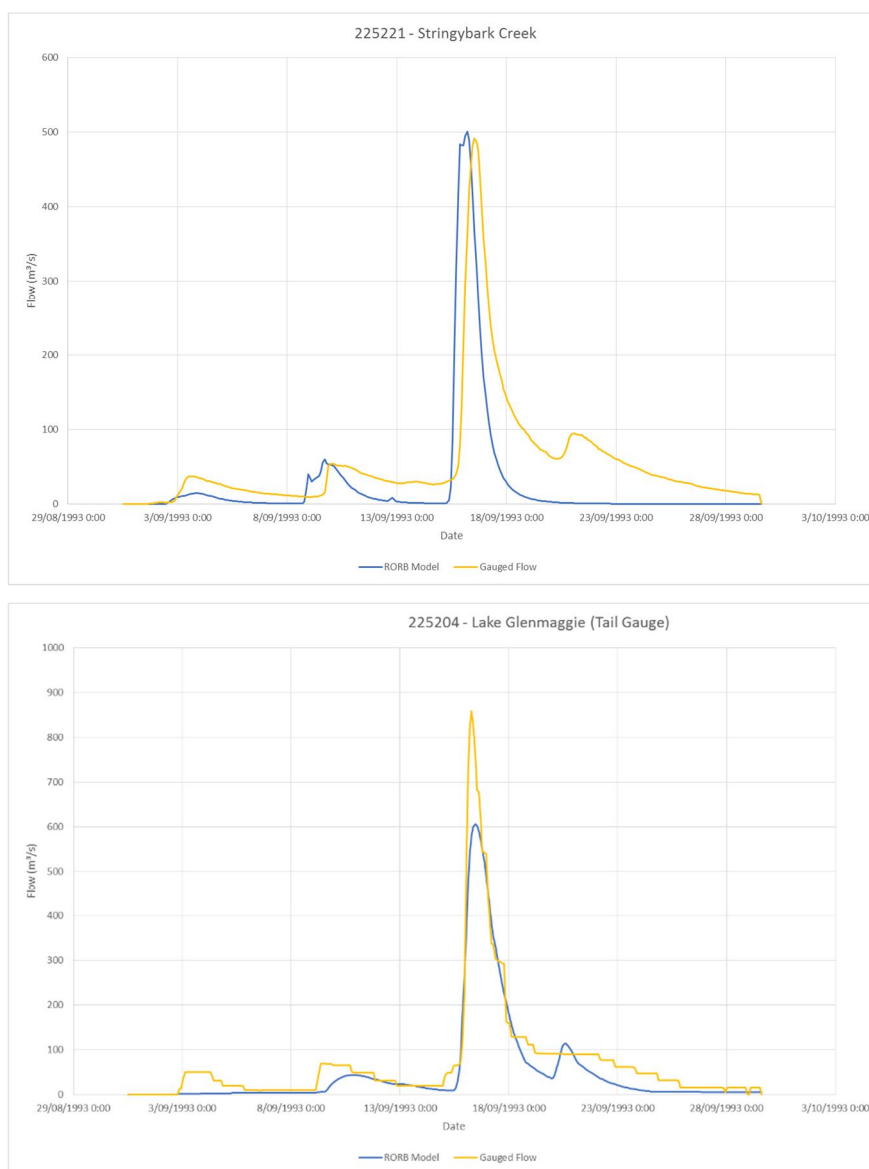
Gauge	k _c	m	IL (mm) Burst 1	CL (mm/h) Burst 1	IL (mm) Burst 2	CL (mm/h) Burst 2	IL (mm) Burst 3	CL (mm/h) Burst 3
226005 (Thoms Bridge)	80	0.8	10	0.2	34	1.0	40	0.5
226228 and 226224 (Rosedale Combined)	70	0.8	10	0.5	25	1.0	40	2.0
225231 (Cowwarr Weir)	70	0.8	20	1.0	10	1.2	70	2.0
225212 (Wandocka)	50	0.8	5	1.5	20	3.5	70	2.5
225221 (Stringybark Ck)	62	0.8	10	0.5	20	2.4	80	1.5
225204 (Lake Glenmaggie)	23	0.8	5	0.1	5	0.1	40	2.0
Outlet	75	0.8	10	1.0	10	1.0	10	1.0

ⁿ **Table 5-6 Summary of calibration parameters values and key model output for the event in September 1993**

Gauge	Peak(m ³ /s)		Time to Peak (hours)		Volume (m ³)	
	Calculated	Recorded	Calculated	Recorded	Calculated	Recorded
226005 (Thoms Bridge)	757	763	386	398	2.30E+08	2.56E+08
226228 and 226224 (Rosedale Combined)	1001	1006	398	384	3.43E+08	4.77E+08
225231 (Cowwarr Weir)	455	465	380	380	1.01E+08	6.81E+07
225212 (Wandocka)	452	417	392	402	1.10E+08	9.95E+07
225221 (Stringybark Ck)	501	492	378	386	6.68E+07	1.39E+08
225204 (Lake Glenmaggie)	606	859	384	380	1.25E+08	1.79E+08
Outlet	n/a	n/a	n/a	n/a	n/a	n/a







n **Figure 5-10 RORB calibration September 1993**

In general, a good calibration was achieved at each gauge with a few notable exceptions. With the 1993 event a similar issue, but to a lesser degree, to the 1978 event was found, that is the RORB model could not replicate the flow at 225204 (Lake Glenmaggie – Tail Gauge) as well as at 225221 (Macalister River @ Stringybark Creek). As with the 1978 event the calibration was focused on matching the hydrograph at 225221.

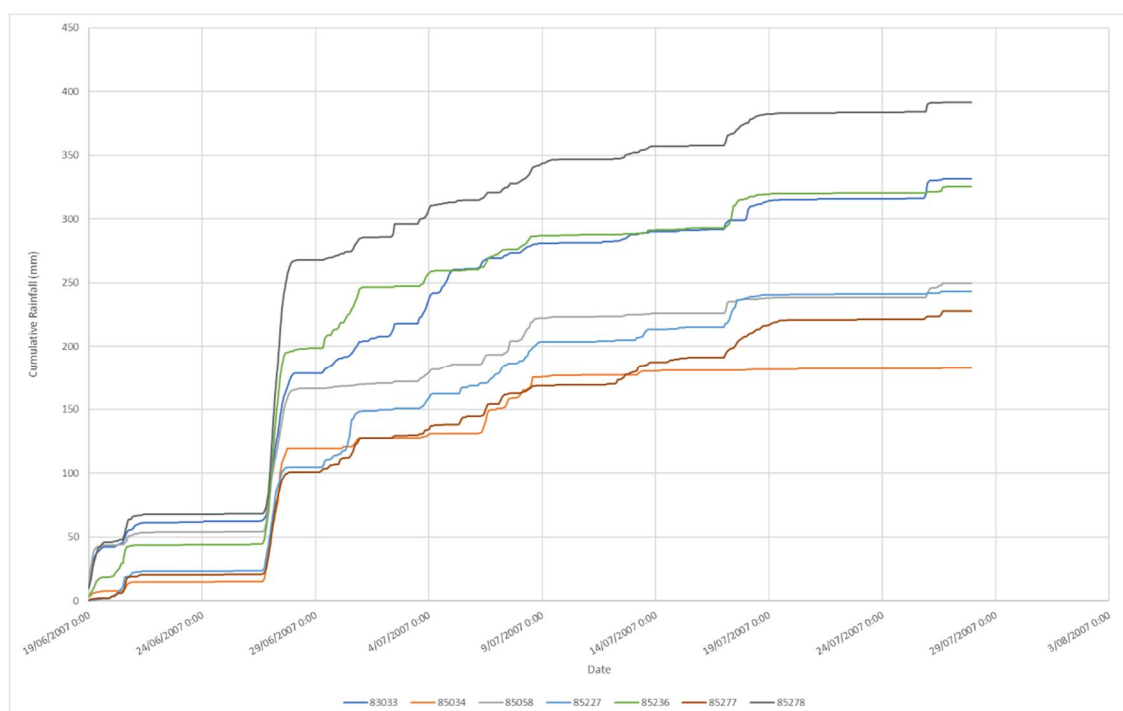
Also with the 1993 event it was noted that the peak at Rosedale (226228 and 226224) arrived before the flow at 226005 (Thoms Bridge), which is not expected behaviour for this floodplain. Discussion with Ventia did not provide insight into why this maybe the case for the 1993 event. As the calibration process is about determining an appropriate k_c of the catchment, the timing

issue for the 1993 event was not pursued any further as the shape of the hydrographs were a reasonable match to the recorded hydrographs.

5.2.4 June 2007

For the June 2007 event data were available at seven pluviographs, 83033, 85034, 85058, 85227, 85236, 85277 and 85278. All of these gauges were used in the calibration process (refer to Figure 4-1 for location of pluviographs). The temporal pattern of rainfall in each subarea was defined using the closest gauge. Figure 5-11 shows the pluviograph information available at each gauge. The pluviographs highlight the variability in rainfall depths over the catchment.

Rainfall depths were estimated by interpolating the AWAP rainfall data to the RORB model subarea centroids. Figure 5-12 shows the rainfall depths across the catchment.



n **Figure 5-11 Temporal patterns of rainfall depths extracted from pluviographs for the June 2007 event**

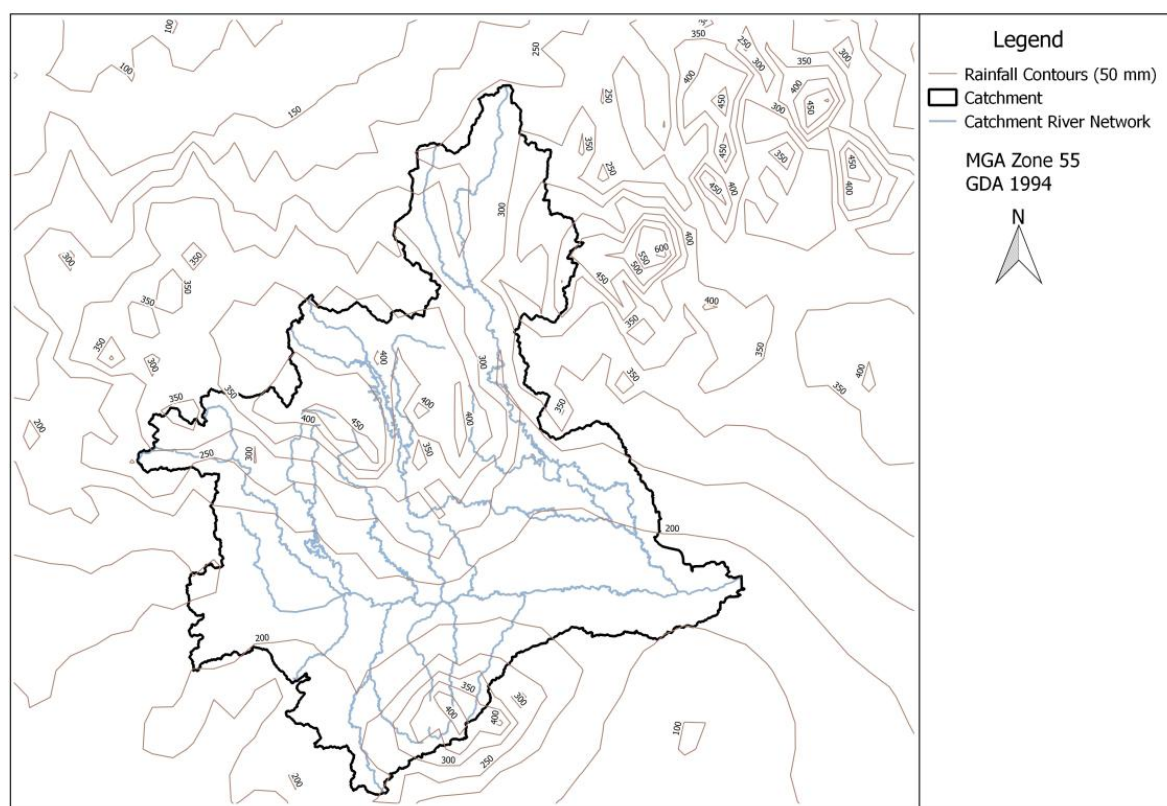


Figure 5-12 Spatial pattern of rainfall depths for the June 2007 event

For this event several streamflow gauges are available. The streamflow gauges used for this event were 226005 (Latrobe River @ Thoms Bridge), Rosedale combined (226228 and 226224), 225231 (Thomson River @ U/S of Cowwarr Weir) 225212 (Thomson River @ Wandocka), 225232 Thomson River @ Bundalaguah), 225221 (Macalister River @ Stringybark Creek) and 225204 (Macalister River @ Lake Glenmaggie – Tail Gauge). Baseflow was manually separated from the total flow hydrograph at each of the streamflow gauges. Appendix A shows the baseflow that was removed.

As with the 1993 event all four main dams in the catchment (Blue Rock, Glenmaggie, Moondarra and Thomson) had been built at the time of this event. Therefore for this event those all the dams were included in the RORB model. The starting reservoir levels were taken from the historical reservoir level data.

As with 1993 for this event each of the three mines, Yallourn, Hazelwood and Loy Yang were included in the model. The mines were included as a storage which were assumed to be at their current size. Whilst the assumption of the mine being at its current size is conservative the impact on flows along Latrobe is minor. The calibration run was undertaken with and without the mine in place and the impact on peak flows was found to be less than 1% at Rosedale.

A summary of the calibration results for the June 2007 event are shown in Table 5-7. A summary of the calibration results are shown in Table 5-8 with the hydrographs shown in Figure 5-13.

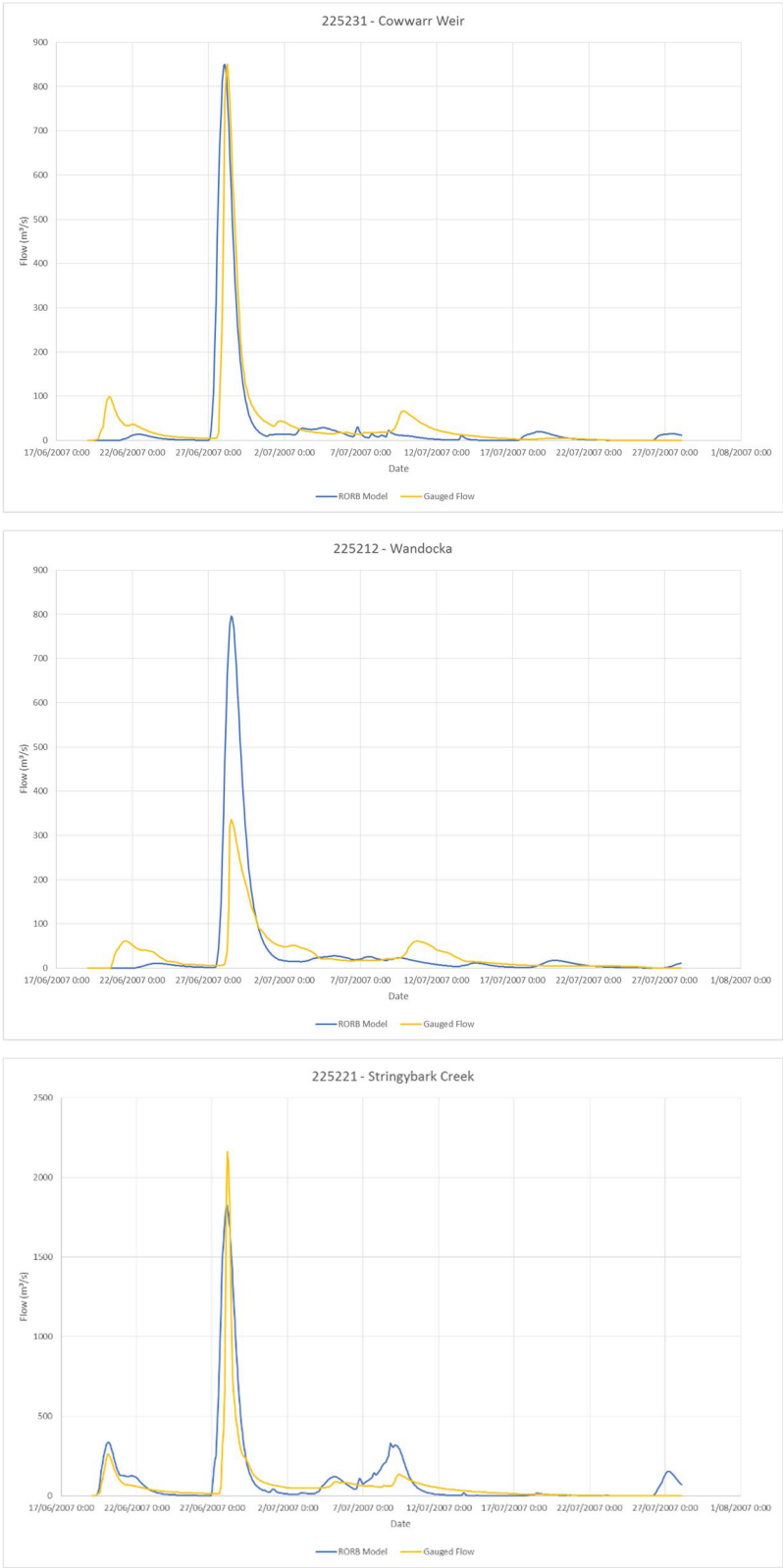
Table 5-7 Summary of calibration parameters values for the event in June 2007

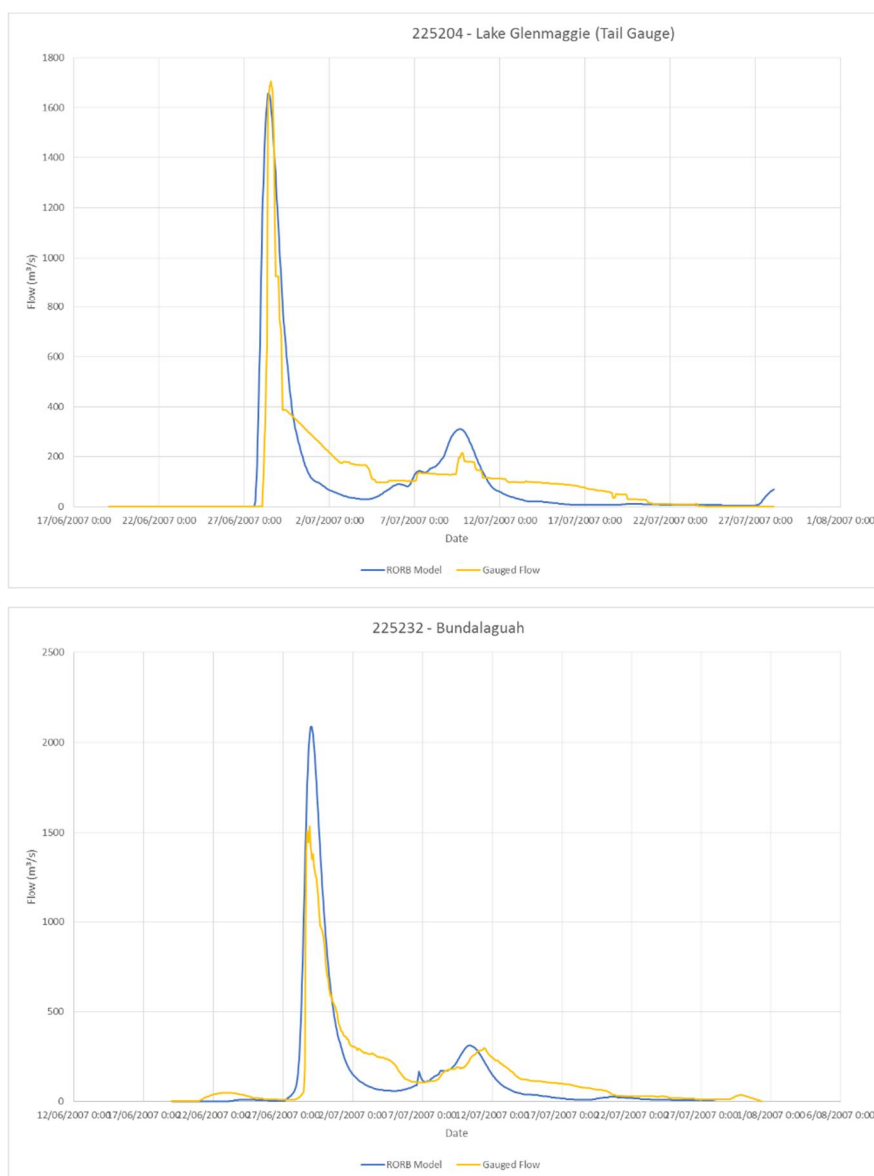
Gauge	k_c	m	IL (mm)	CL (mm/h)
226005 (Thoms Bridge)	113*	0.8	120	1.2
226228 and 226224 (Rosedale Combined)	90*	0.8	90	4.0
225231 (Cowwarr Weir)	70	0.8	50	0.6
225212 (Wandocka)	50	0.8	65	2.0
225221 (Stringybark Ck)	62	0.8	25	0.1
225204 (Lake Glenmaggie)	23	0.8	20	0.1
225232 (Bundalaguah)	75	0.8	20	4.0

* Note the k_c values were not used in choice of values for the Latrobe River as there was not a flood on the Latrobe River for this event

Table 5-8 Summary of key model outputs for the event in June 2007

Gauge	Peak(m ³ /s)		Time to Peak (hours)		Volume (m ³)	
	Calculated	Recorded	Calculated	Recorded	Calculated	Recorded
226005 (Thoms Bridge)	59	60	320	270	4.76E+07	4.12E+07
226228 and 226224 (Rosedale Combined)	66	68	252	336	7.13E+07	8.89E+07
225231 (Cowwarr Weir)	851	850	216	220	1.13E+08	1.25E+08
225212 (Wandocka)	795	336	226	226	1.26E+08	1.01E+08
225221 (Stringybark Ck)	1824	2164	214	214	3.45E+08	2.46E+08
225204 (Lake Glenmaggie)	1656	1705	224	228	3.39E+08	3.52E+08
225232 (Bundalaguah)	2087	1534	238	238	4.71E+08	





n **Figure 5-13 RORB calibration June 2007 (Note the hydrographs not shown on the Latrobe as there was not a flood on the Latrobe for this event)**

In general, a good calibration was achieved at each gauge with a few notable exceptions. As with the 1978 event the RORB model could not replicate the flow at 225212 (Thomson River @ Wandocka) if the flow at 225231 (Thomson River @ U/S of Cowwarr Weir) was replicated and vice versa. For the 2007 event the flow at 225212 was half of that at 225231. This was discussed with Ventia and there was some recollection that this anomaly had been noted in the past. However, no documentation was available to confirm the reason. As with the 1978 event it was decided to match the flow at 225231 (Thomson River @ U/S of Cowwarr Weir) rather than 225212 (Thomson River @ Wandocka).

5.3 Rating curve review

From the discussion above and in consultation with the WGCMA it was decided that it would be worth undertaking a rating curve review at key locations. A separate report was provided to the WGCMA on the rating curve review (HARC, 2018). A summary of the rating curve review in relation to the calibration is provided below for completeness. Note that in HARC (2018) the Latrobe River at Kilmany South (226227) and Sale Wharf (Flood Creek / Thomson River) (085272) were also reviewed but neither of these gauges were used in the calibration process so are not discussed in this section. The objective of the rating curve review was to determine the rating curve for high flow conditions (not low flows where the published rating curve would be expected to be reliable), for the following gauges:

- n 225212 Thomson River at Wandocka
- n 225232 Thomson River at Bundalaguah

To assist in the review of the rating curves the hydraulic model, TUFLOW, was used. The outputs from the TUFLOW models were used to derive a depth/height-flow relationship. The key features of the hydraulic model are:

- n Models inputs and parameters were taken from the calibrated Lower Thomson hydraulics model (refer to Section 10);
- n The exact locations of the river gauges were found using a combination of approximate DELWP coordinates, information gathered during a site visit, discussions with Ventia, aerial and street imagery;
- n Flow lines extended across the full floodplain, not just bank-to-bank;
- n Inflows were applied as scaled historic floods - for each gauge the largest flood on record was applied to the model and scaled by 150% to allow for curves to be generated for greater than recorded floods; and
- n Downstream boundaries were applied using the H-Q relationship automatically generated within TUFLOW – the downstream boundaries were located sufficiently far downstream so as to not influence the flood levels and flows at the gauge sites.

In each case, the official rating curve table published on DELWP's Water Monitoring portal (<http://data.wewewater.vic.gov.au/monitoring.htm> accessed 19/03/2018) was downloaded. Each of the gauge's published rating tables were compared to the rating curve produced by the model. If good bathymetry is available then good agreement between the rating curves derived from the modelling and the official published rating curves would be expected within the confines of the river channel, however deviation is expected when the flow spreads to the floodplain due to the lack of physically measurements of flood discharges and complexities of flows.

Whilst all effort was made to pinpoint the exact location of the streamflow gauges the location in the model may not be exact. A review of the horizontal flood surface showed changes in flood level over comparatively short distances up to 100 mm being common. Further differences are

expected as a 2D hydraulic model may not fully capture the wave action and other 3D effects that would be recorded by a stream gauge pressure sensor.

Of note also is that, for this assessment the gauge zero, as published on DELWP's water monitoring portal, is assumed to be correct. The gauge zero cannot be verified without field survey which was beyond the scope of this assessment.

To account for the various uncertainties mentioned above a tolerance of ± 100 mm offset to each of the rating curves has been added to the figures to illustrate the potential range in flow rates.

5.3.1 Thomson River at Wandocka

The Thomson River at Wandocka (225212) streamflow gauge is located on the Thomson River and is sited on the downstream (east) side of the Maffra-Rosedale Road bridge as shown in Figure 5-14. The Maffra-Rosedale Road rises from the lower floodplain and is significantly elevated over the Thomson River. The elevated road incorporates three bridges that drain the Thomson River as well as two remnant ox-bow channels to either side of the Thomson River. The elevated road returns to the floodplain level approximately 300 metres to the north and 200 metres to the south of the crossing. At these lower road levels the road is overtopped from the broader floodplain flooding until the roads rise again up to the escarpments.

Figure 5-15 presents the comparison between the published rating curve, the rating from the hydraulic model as well as the manual gaugings. Both the published and modelled curves are very close up to the 5 metre mark. At this level the full floodplain becomes engaged, with flows over the roads north and south of the elevated bridges, and the ratings curves begin to diverge. Due to the additional flow over the roads the hydraulic model predicts greater flows for a given depth than the published curve.

Based on the assessment it is believed that the published rating is reliably representing flows up to the 5.0 m mark. Above this level the published rating curve reliability reduces as the full floodplain becomes engaged.

Further to this, the levels and flows currently reported at Thomson River at Wandocka (225212) are inconsistent. Table 5-9 shows the levels and flows recorded for the events used in the calibration of the RORB model (refer to Section 5.2) for both Thomson River at Wandocka and Thomson River at U/S Cowwarr Weir. Table 5-9 shows that there is an inconsistency between Cowwarr Weir and Wandocka. As there is not a significant catchment between Cowwarr Weir and Wandocka the flows should not be too dissimilar. Table 5-9 also shows an inconsistency between events at Wandocka with the 1978 and 2007 recording the same level but having very different flows. The 1993 event has the highest recorded level but 1978 has a higher flow.

n **Table 5-9 Readings at Wandocka and Cowwarr Weir**

Year	Thomson River @ Wandocka (225212)		Thomson River @ U/S Cowwarr Weir (225231)	
	Level (m)	Flow (m³/s)	Level (m)	Flow (m³/s)
1978	6.78	660	8.89	1100
1993	6.83	420	5.57	450
2007	6.78	340	7.59	850

These issues were discussed with Ventia and the explanation given was different rating curves were used at different times. Given the uncertainty around the recorded levels at Wandocka, there is no change recommended to the hydrologic model calibration.

Due to these inconsistencies the decision to focus the calibration on Cowwarr Weir, which appeared to provide reasonable flow estimates for all three events, is confirmed to be a reasonable approach.



n **Figure 5-14 Gauge Location – Thomson River at Wandocka**

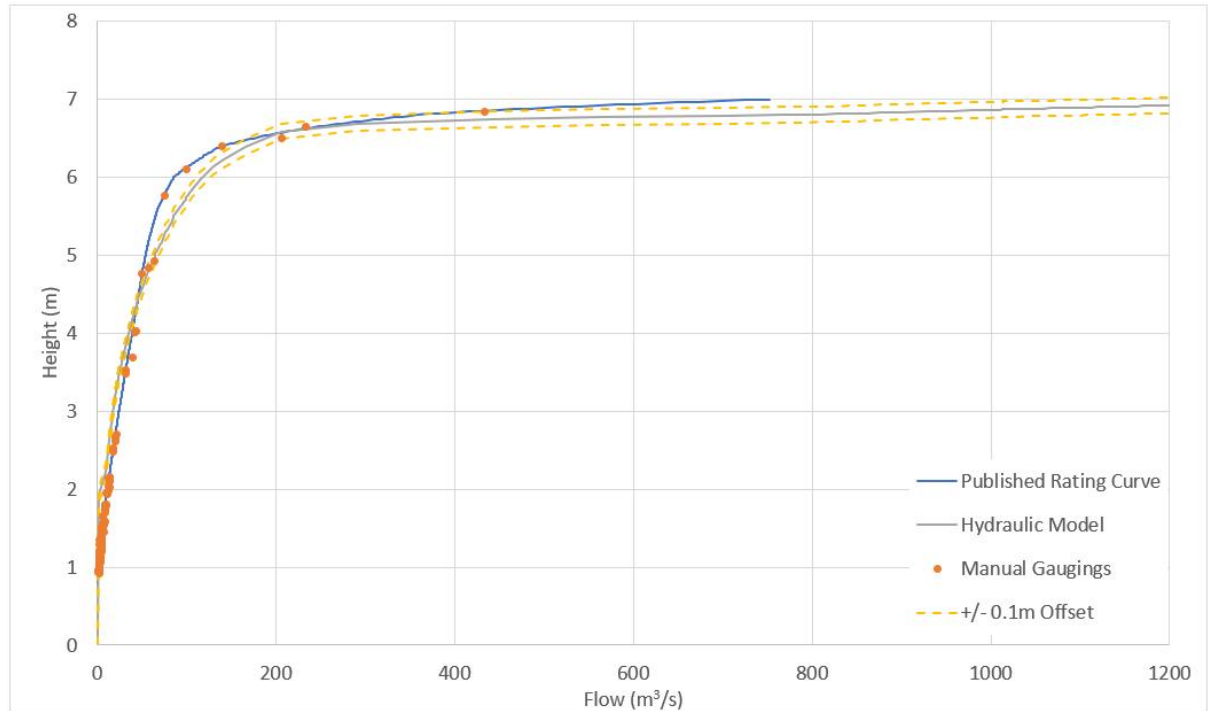


Figure 5-15 Rating Curve Comparison – Thomson River at Wandocka

5.3.2 Thomson River at Bundalaguah

The Thomson River at Bundalaguah (225232) stream gauge is located on the Thomson River approximately 9.5 km north west of Sale and approximately 1 km south of the intersection of Blyths Rd and Bundalaguah Rd. The gauge is located on the main branch of the Thomson River, however, as can be seen in Figure 5-16, there are numerous anabranches, oxbows and remnant channels further afield that shows the geological evidence of the rivers migration across the broader floodplain over time. These complexities would make the determination of a reliable rating curve without hydraulic modelling very difficult.

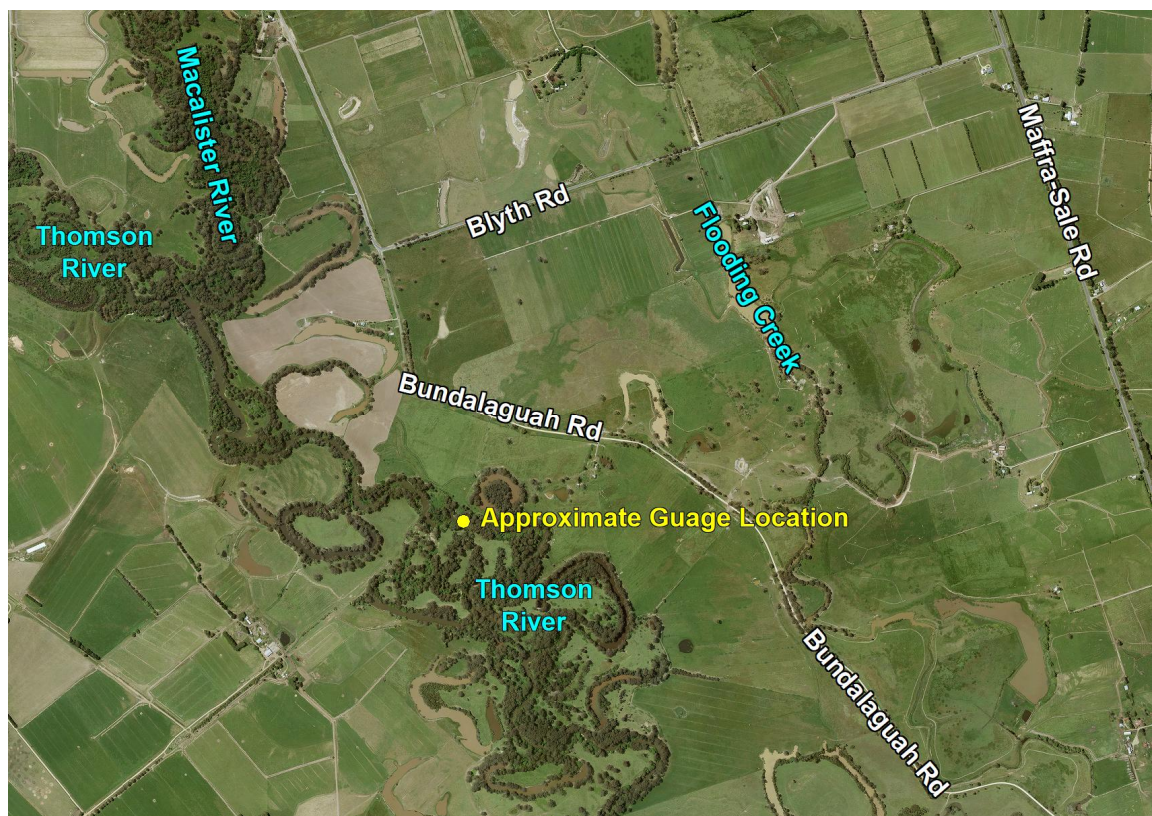
Figure 5-17 below presents a comparison between the published rating curve, the rating from the hydraulic model as well as the manual gaugings. Two hydraulic modelled curves are presented, one considers only the bank-to-bank flow, whilst the other considers the full flows across the broader 2.7 km wide floodplain including flows down Flooding Creek which is located east of the Thomson River. Due to the interactions of these waterways in larger events it would not be appropriate to consider them in isolation.

As can be seen in Figure 5-17 the published and modelled rating curves are reasonably close up to the 4 metre mark where the two diverge with the model predicting higher flows for a given depth. Whilst the modelled rating curve is higher than the published curve, it is not dissimilar to

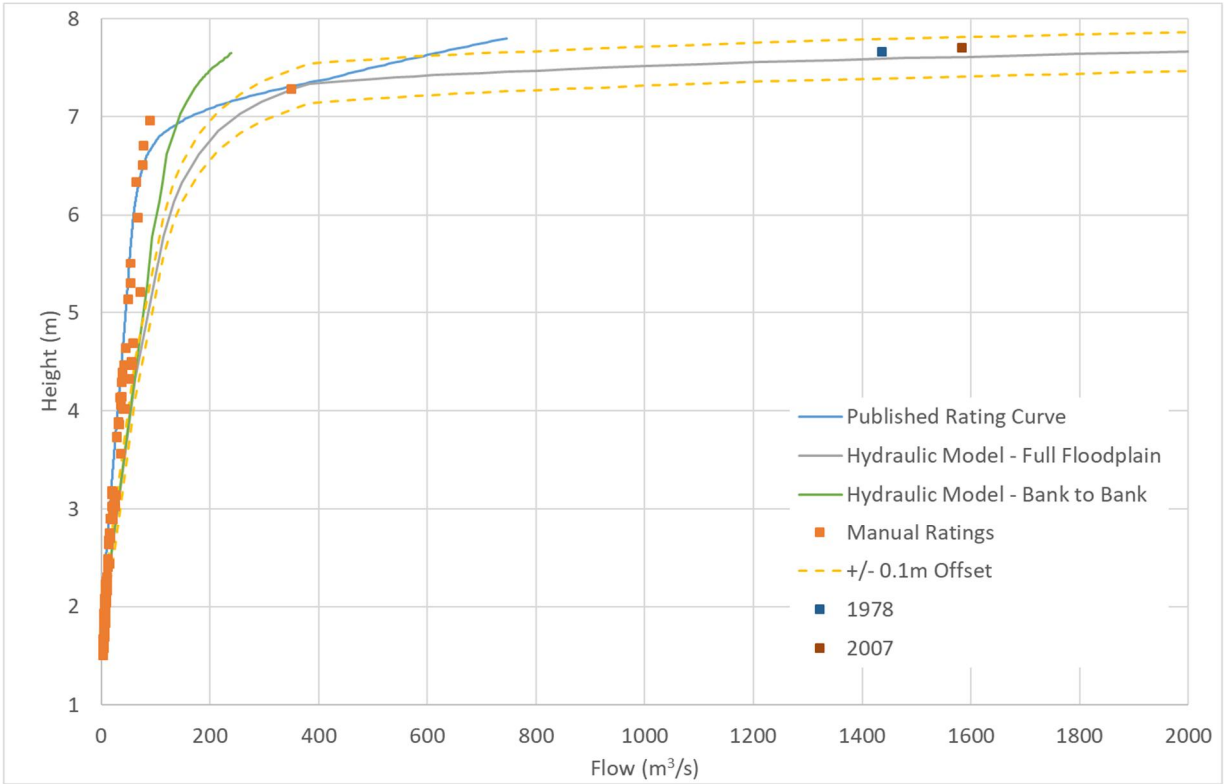
the higher of the measured gaugings up to the 7 m mark when considering the bank-to-bank flows. Above this level the published and modelled curves diverge significantly.

Based on the assessment it is believed that the published rating is unreliable above the 7.2 m mark. Below this level the published rating curve is reliably representing flows contained within the bank of the main river channel but does not necessarily account for flows that may be occurring in other remnant river channels or across the broader floodplain including Flooding Creek. Flows in these other channels and across the floodplain are a result of upstream breakaway flows from the Thomson and Macalister Rivers that occur prior to the top of bank being reached at the gauge site.

In addition, the two largest flood extents recorded at this gauge are the 2007 and 1978 events respectively. Both of these were plotted on Figure 5-17 confirming the hydraulic modelling results. The rating curve review confirms that the calibration process undertaken is reasonable for Bundalaguah.



n **Figure 5-16 Gauge Location – Thomson River at Bundalaguah**



n **Figure 5-17 Rating Curve Comparison – Thomson River at Bundalaguah**

5.4 Adopted routing parameters

In general, a good calibration was achieved against all events at each gauge with a few notable exceptions which were discussed under each year.

As with all hydrological modelling the variation between the recorded and modelled hydrograph can be due to a number of things i.e. change in catchment conditions, data errors, baseflow separation error, rainfall variability and the lack of adequate data to represent the variability across the catchment and the RORB model being only a representation of a variable and complex rainfall runoff process.

However, the calibration results were considered good enough to use to estimate the k_c value for the Lower Thomson catchment. Table 5-10 summarises the calibrated k_c values adopted from the calibration process.

Table 5-10 k_c Values from calibration

Location	k_c	d_{av}^*	k_c/d_{av}
226005 (Thoms Bridge)	80	51.0	1.57
226228 and 226224 (Rosedale Combined)	68	40.7	1.67
225231 (Cowwarr Weir)	70	66.4	1.05
225212 (Wandocka)	50	26.5	1.88
225221 (Stringybark Ck)	62	63.1	0.98
225204 (Lake Glenmaggie)	23	23.3	0.99
Remaining catchment	75	41.9	1.79

* d_{av} is the weighted average flow distance to the catchment outlet (this is calculated automatically in the RORB model)

The choice of k_c for the Lower Thomson catchment was largely based on the calibration results however, the results from the calibration were compared to a number of regional estimates.

For Victorian regions with a mean annual rainfall of greater than 800 mm k_c is estimated using equation 1 and with a mean annual rainfall of less than 800 mm k_c is estimated using equation 2 from ARR 2016 (Hansen et al, 1986).

$$k_c = 2.57 A^{0.45} \quad (1)$$

$$k_c = 0.49 A^{0.65} \quad (2)$$

Where A is the area in km².

The k_c value from calibration was also compared to another regional estimate by Pearse et. al. (2002). Pearse et. al. (2002) analysed a large database of routing parameters collated by the CRC for Catchment Hydrology and derived a prediction equation applicable to Victoria. The d_{av} for the catchment was used to predict the k_c value where k_c is directly proportional to d_{av} giving equation 3

$$k_c = C d_{av} \quad (3)$$

Where C is a characteristic of the catchment independent of the scale or size of the catchment and d_{av} is the weighted average flow distance to the catchment outlet (this is calculated automatically in the RORB model).

Pearse et al. (2002) also gave an expected value and one standard deviation (High and Low).

Table 5-11 provides a summary of the regional estimates. Table 5-11 shows the k_c from the calibration events is in line with the regional estimates.

Table 5-11 k_c values – regional estimates

Location	Area (km ²)	k_c (equation 1)	k_c (equation 2)	k_c (equation 3)			k_c (calibration)
				Expected	High	Low	
226005 (Thoms Bridge)	2657	89	82	64	106	38	80
226228 and 226224 (Rosedale Combined)	1487*	69	57	51	84	31	68
225231 (Cowwarr Weir)	1080	60	46	83	137	50	70
225212 (Wandocka)	337*	35	22	33	55	20	50
225221 (Stringybark Ck)	1542	70	58	79	131	47	62
225204 (Lake Glenmaggie)	349*	36	22	29	48	17	23
Remaining catchment	931*	56	42	52	87	31	75

* The area shown is between gauging stations

There have been a number of previous studies undertaken on this catchment. Most of these have used an URBS model (Thomson River Flood Study (WT, 2011), Latrobe River Flood Study (Cardno, 2015) and Macalister River Flood Study (WT, 2012)). Two studies of the Lake Glenmaggie catchment have used a RORB model and are comparable to this study. The two studies are:

- n Review of the Hydrology of the Glenmaggie Dam Catchment, SMEC 2010
- n Report for Dam Break and Consequence Assessment – Eastern Storages, GHD 2015

For the Lake Glenmaggie catchment SMEC and GHD used the same RORB catchment file and the same k_c value (i.e. 70). For both of these RORB models the k_c/d_{av} ratio was approximately 0.9 which is consistent with the value chosen for this study.

Two studies of the Lake Narracan catchment have used a RORB model and are comparable to this study. The two studies are:

- n Lake Narracan Design Review, SMEC 2000
- n Report for Dam Break and Consequence Assessment – Eastern Storages, GHD 2015

For the Lake Narracan catchment SMEC and GHD used the same RORB catchment file and the same k_c value (i.e. 90). For both of these RORB models the k_c/d_{av} ratio was approximately 1.8 which is consistent with the value chosen for this study.

6 Design hydrology approach and inputs

Design rainfall depths were derived for the catchments upstream of each of the streamflow gauges stations used in the verification process (refer to Section 7).

6.1 Overview of adopted design flood approach

The estimation of design floods has traditionally been based on the 'design event' approach, in which all parameters other than rainfall are input as fixed, single values. This concept is illustrated in Figure 6-1 for the case where a distribution of design rainfalls is combined with fixed values of losses, rainfall temporal patterns and spatial patterns. Considerable effort is made to ensure that the single values of the adopted parameters are 'AEP-neutral', that is, they are selected with the objective of ensuring that the resulting flood has the same annual exceedance probability as its causative rainfall.

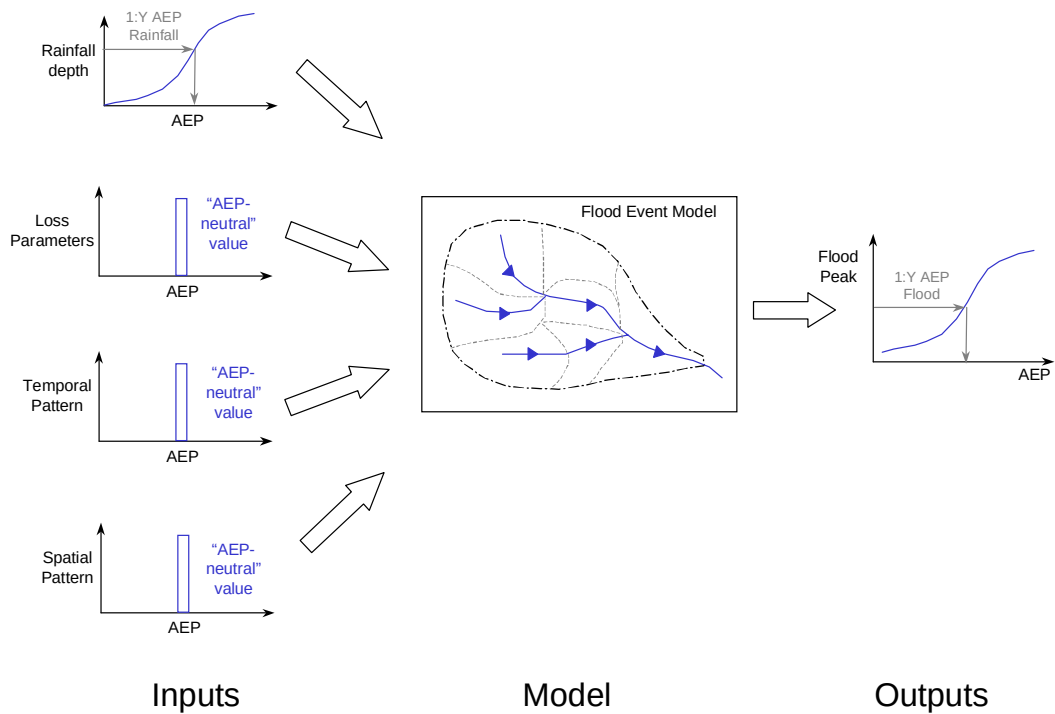
This approach suffers from the limitations that:

- n the AEP-neutrality of some inputs can only be tested on frequent events for which independent estimates are available;
- n for more extreme events, the adopted values of AEP-neutral inputs must be conditioned by physical and theoretical reasoning; and
- n the treatment of more complex interactions (such as the seasonal variation of inputs) becomes rapidly more complex and less easy to defend.

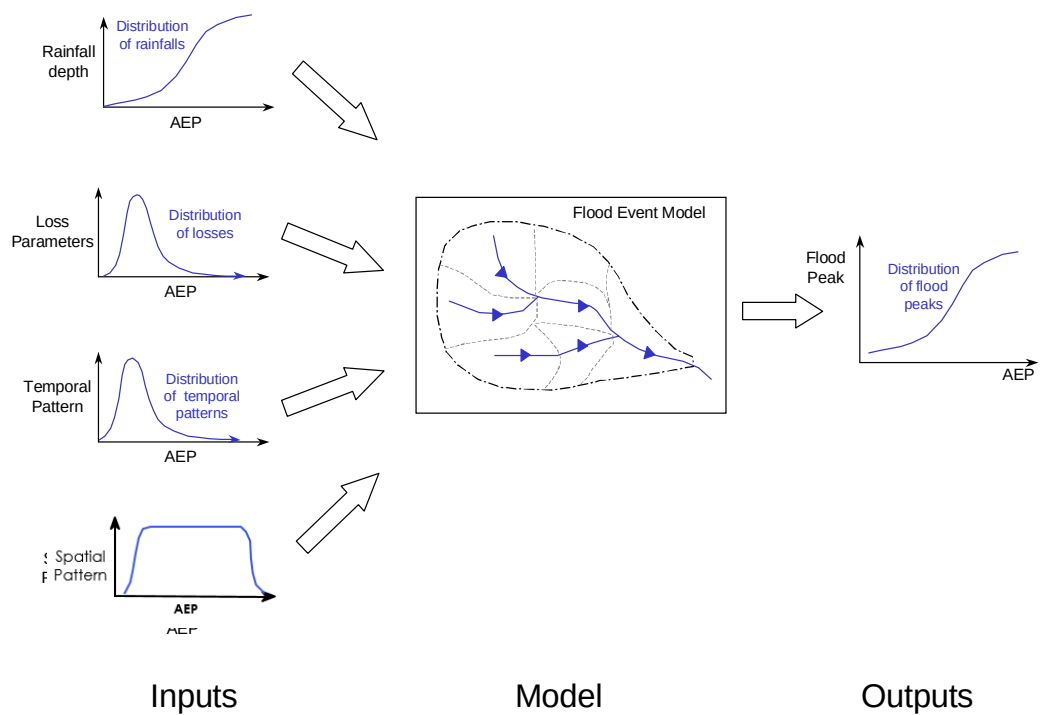
Joint probability techniques offer an improvement to the traditional design event method. These techniques recognise that any design flood characteristics (e.g. peak flow) could result from a variety of combinations of flood producing factors, rather than from a single combination. For example, the same peak flood could result from a moderate storm on a saturated catchment, or a large storm on a dry catchment. In probabilistic terms, a 1 in 100 AEP flood could be the result of a 1 in 50 AEP rainfall on a very wet catchment, or a 1 in 200 AEP rainfall on a dry catchment. Joint probability approaches attempt to mimic 'mother nature' in that the influence of all probability distributed inputs are explicitly considered, thereby providing a more realistic representation of the flood generation processes.

The method was adapted to focus on the aspects that are most relevant to the problem. For the lower Thomson River catchment, spatial distribution is important along with losses and temporal patterns. Therefore, full distributions for each of the main inputs was entered into the model. Figure 6-2 illustrates the method adopted.

The application of joint probability approaches to flood estimation is widely acknowledged to be a more thorough and defensible approach to design flood estimation than the design event approach in Australian practice, and has been incorporated in the 2016 version of Australian Rainfall and Runoff (ARR) (Ball et al., 2016).



n **Figure 6-1 Schematic illustration of the design event approach**



n **Figure 6-2 Schematic illustration of the joint probability approach**

The joint probability framework adopted for the study was developed by Nathan et al (2002, 2003) and is summarised in Figure 6-3. In essence the approach involves undertaking numerous model simulations, where the model inputs are sampled from non-parametric distributions that are based either on readily available design information or on the results of recent research.

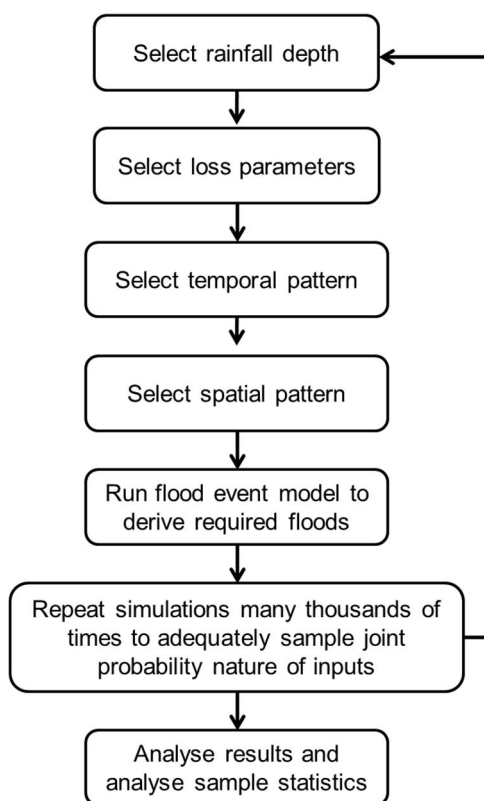


Figure 6-3 Overview of adopted joint probability framework

In developing the joint probability framework particular attention was given to ensuring that the model inputs and the manner in which they were incorporated was consistent with ARR (Ball et al., 2016). The following briefly describes the main inputs, and how they relate to established design information.

Select rainfall depth. Rainfall depths were stochastically sampled from the cumulative distribution of rainfall depths described in Section 6. The relationship between rainfall depth and AEP for a given burst duration was based directly on the Book 8 guidelines.

Select storm losses. Storm initial losses were stochastically sampled from a nonparametric distribution that was determined from the analysis of a large number of catchments across Australia (Hill et al., 2014). The limited number of investigations that have explored the correlation between initial and continuing loss values have concluded that there is little systematic dependence between the two. There is little information regarding the correlation between initial and continuing loss rates, and since antecedent conditions have most influence on

initial loss rates, in this study the continuing loss rates were held constant (Section 6.6). Current practice is for initial losses to be sampled from a distribution, while the continuing loss is held constant; this approach was used for the design flood modelling.

Select spatial pattern. Spatial patterns were randomly selected from a sample of spatial patterns relevant to the catchment area and duration of the storm. The spatial patterns were derived from large historic storms that have been observed in the region (Section 6.3).

Select temporal pattern. Temporal patterns were randomly selected from a sample of temporal patterns relevant to the catchment area and duration of the storm. The temporal patterns were derived from large historic storms that have been observed in the region (Section 6.4).

Monte-Carlo simulation. Simulations were undertaken using a stratified sampling approach in which the sampling procedure focuses selectively on the probabilistic range of interest. Thus, rather than undertake many millions of simulations in order to estimate an event with, say, a 1 in 100 probability of exceedance, a reduced number of simulations were undertaken over a specified number of probability intervals. In this study, the rainfall frequency curve was divided into 100 intervals uniformly spaced over the standardised normal probability domain, and 250 simulations were taken within each division. Thus, a total of 25,000 simulations were undertaken to derive the frequency curve corresponding to each storm duration considered.

6.2 Design Burst Rainfall Depths

6.2.1 Design rainfall for events more common than 1 in 2000 AEP

Catchment average point design rainfall depths for burst durations between 24 and 120 hours, and AEP 1 in 2 to 1 in 100, were estimated using the latest IFD (2016) analysis available from the Bureau of Meteorology. For burst durations between 24 and 120 hours, and 1 in 100 to 1 in 2000 AEP were estimated using the latest IFD (2016) analysis also available from the Bureau of Meteorology.

6.2.2 Areal reduction factors

The point rainfall estimates were converted to areal values using the areal reduction factors from Jordan et al. (2016) available via the new ARR data hub (Geoscience Australia, 2017). Conceptually, these factors account for the fact that larger catchments are less likely to experience high intensity storms over the whole catchment.

6.2.3 PMP Estimates

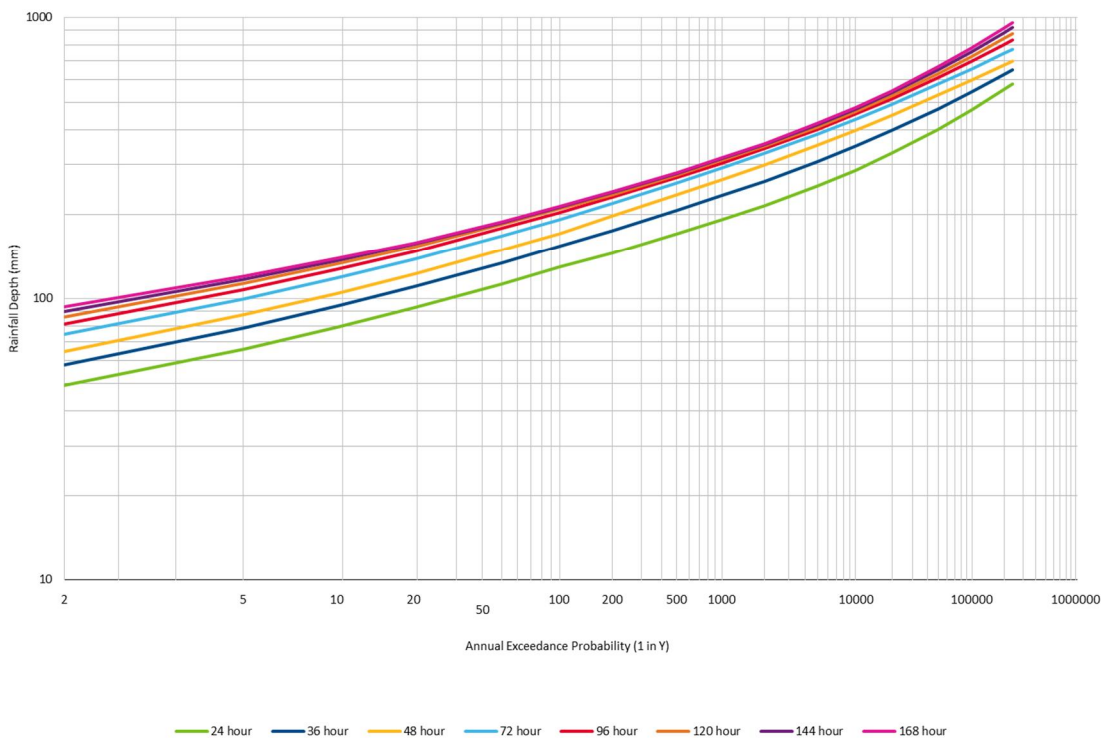
PMP estimates for burst durations between 24 and 120 hours were obtained using the Generalised Southeast Australia Method (GSAM) (Bureau of Meteorology, 2003b).

The AEP assigned to the PMP is a function of the method used in its derivation. The recommendations by Laurenson and Kuczera (1999) are for a lower limit of 1 in 10^7 for

catchments less than 100 km², and for the AEP of the PMP to vary as a power function of catchment area to an AEP of 1 in 10⁴ for a catchment area of 100 000 km².

6.2.4 Adopted design rainfall depths

Design rainfall depths adopted for the Rosedale streamflow gauge are shown in Figure 6-4 and Table 6-1. The rainfall depths applied to each of the streamflow gauges are shown in Appendix B.



n Figure 6-4 Design catchment average rainfall depths for Rosedale Streamflow Gauge

Table 6-1 Design catchment average rainfall depths for Rosedale Streamflow Gauge by burst rainfall duration

AEP (1 in Y)	24 hr	36 hr	48 hr	72 hr	96 hr	120 hr	144 hr	168 hr
2	49	58	65	74	81	86	90	93
5	66	78	87	100	108	113	117	120
10	79	94	104	118	127	133	137	139
20	93	110	122	138	148	153	157	158
50	113	134	149	168	178	184	187	188
100	130	154	171	192	203	209	212	214
500	146	175	198	219	230	236	239	241
1,000	171	207	235	259	270	276	280	282
2,000	192	234	266	293	305	311	315	318
240,000	580	650	700	770	830	878	919	955

6.3 Spatial patterns

As there is a large spatial variability across the catchment ten spatial patterns were assembled for each duration event (24 hrs and above) using the AWAP dataset. For each duration the top ten historical patterns were chosen. Patterns were scaled so that the catchment average rainfall depth for the design rainfall burst matched the depth generated stochastically by the sampling scheme.

Figure 6-5 shows the spatial patterns adopted for the 24 hour event. For example in the April 1990 event rainfall was concentrated in the western portion of the catchment (i.e. Latrobe upstream of Thoms Bridge) whereas for the April 1984 the rainfall was more uniformly distributed. Appendix B shows the spatial patterns for all duration events.

It should be noted that the spatial patterns were sampled independently of the temporal patterns. The need for integrated space-time patterns (where each temporal pattern is linked to a particular spatial pattern) was considered as a means to potentially reduce bias introduced by random sampling of an inconsistent pair of spatial and temporal patterns. Ultimately, the good quality reconciliation between the design and historic flood frequency curves (refer to Section 7), demonstrated that the approach used was capable of replicating the observed behaviour of the catchment and did not introduce bias.

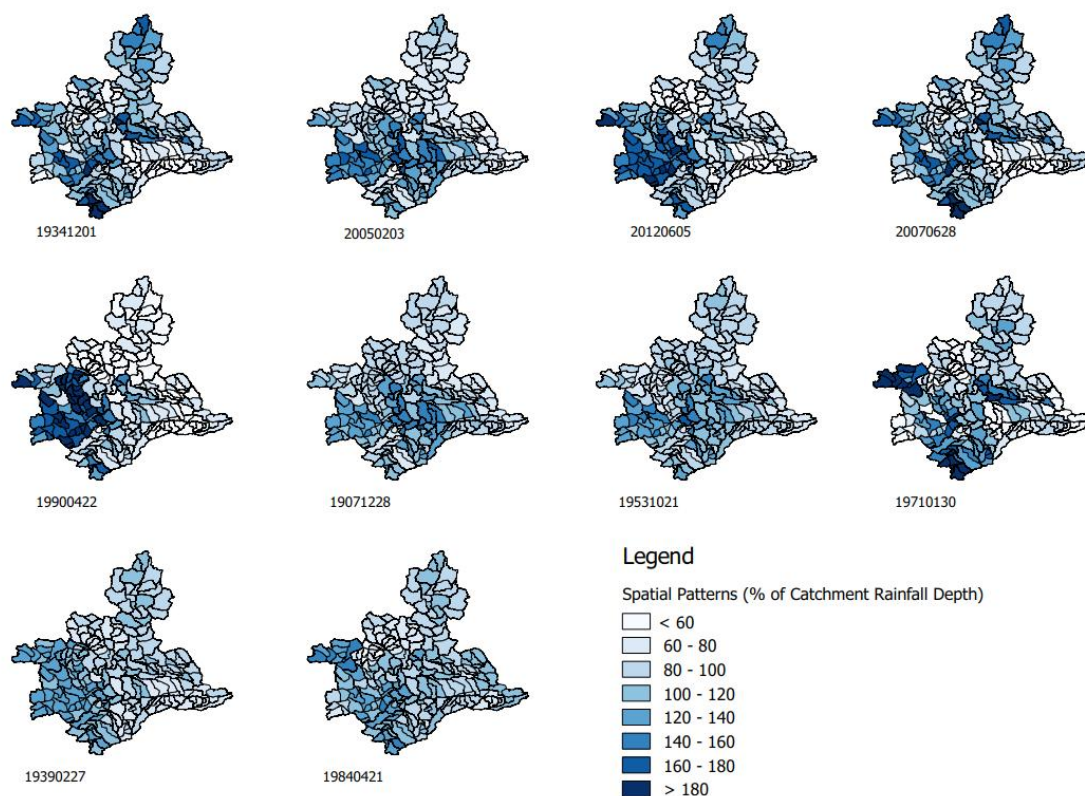


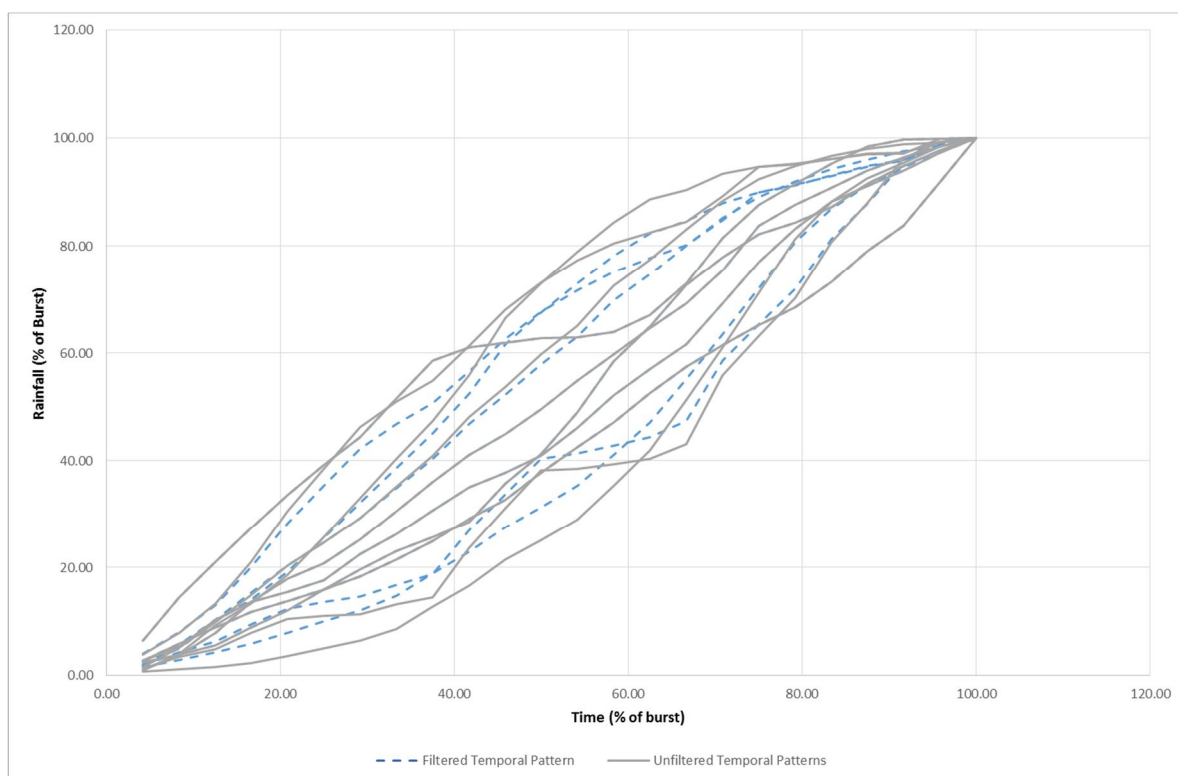
Figure 6-5 24-hour design spatial patterns (Date of event indicated as YYYYMMDD)

6.4 Temporal patterns

The sample of areal temporal patterns available from the ARR data hub (Geoscience Australia, 2017) was used in the Monte Carlo modelling of design floods from storm durations of 12 to 120 hours. The derivation of these patterns is discussed in ARR 2016 (Babister et al., 2016).

Before the temporal patterns were used, they required some smoothing to remove embedded bursts. An embedded burst in a sub-period of rainfall within a given temporal pattern that has a rarer AEP than the actual burst itself. The method described by Scoria et al. (2016) was used to smooth out the embedded bursts. As an example, Figure 6-6 shows the 48 hour design temporal patterns, before and after embedded bursts are removed.

All spatial and temporal patterns in the sets used for sampling were given equal probability of selection in the Monte Carlo simulation.



n **Figure 6-6 48-hour design temporal patterns before filtering and after filtering to remove embedded bursts**

6.5 Pre-burst rainfall depths and temporal patterns

Estimates of the total depth of rainfall antecedent to the main burst were obtained from the ARR data hub (Geoscience Australia, 2017). The data hub provides a distribution of pre-burst depths by duration and AEP. The median pre-burst depths for each duration was compared across AEPs, and for the purpose of design flood modelling, it was decided that adopting an average of the median for each duration was appropriate (Figure 6-7).

Although the ARR data hub provides pre-burst depths, it does not contain information regarding the temporal patterns. Therefore, temporal patterns of rainfall antecedent to the main burst were taken from Minty and Meighen (1999) and applied to burst durations of 12 hours and longer (Minty and Meighen, 1999).

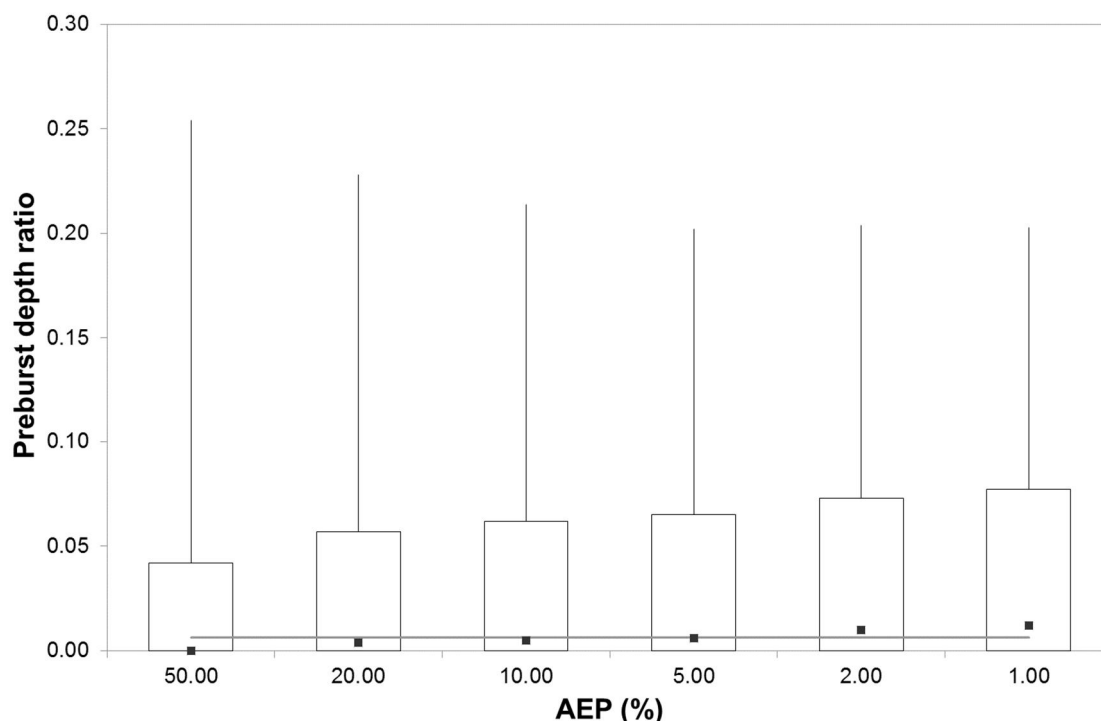


Figure 6-7 Pre-burst rainfall depths – 36 hour burst – shown as a ratio of burst depth, using a box plot of the 10th, 25th, 50th, 75th and 90th percentiles. The grey line shows the adopted value for the design flood modelling; this is the average of the median values across the available AEPs.

6.6 Losses

There are two key types of loss models that are typically adopted when modelling design floods:

- n Initial loss/continuing loss
- n Initial loss/proportional loss

Investigations by Hill et al. (2014) as part of the ARR 2016 revision (Hill and Thomson, 2016) were inconclusive as to which loss model works best. Even for catchments where one of the loss models performed better for a majority of events, there were still some events for which the other approach was better. Similarly, there was no obvious relationship between the relative performance of the loss models and hydro-climatic or catchment characteristics.

The advice in ARR is that the initial loss/continuing loss model is most suitable for design flood modelling, because it can be used to estimate flood peaks and volumes for all AEPs. In contrast, it is often difficult to derive unbiased estimates of flood quantiles using the initial loss/proportional loss model over the same range of AEPs. The initial loss/proportional loss model underestimates peak flows for extreme floods if the proportional loss is not varied appropriately with AEP; and to date there is little evidence about how proportional loss varies with AEP. Therefore, for this study an initial loss-continuing loss model was adopted.

The shape of the initial loss distribution used in the design flood modelling was derived by Hill et al. (2014) from flood modelling results for a large number of catchments across Australia. Hill et al. (2014) developed a non-dimensional distribution of initial loss values for each catchment, by representing initial losses as a proportion of the median loss. This allowed the distributions of initial losses across different catchments to be directly compared. The standardised distributions exhibited a high degree of consistency, and suggested that while the magnitude of initial losses may vary between different catchments, the shape of the distribution does not. That is, while it may be expected that typical loss rates vary from one catchment to another, the likelihood of a catchment being in a relatively dry or wet state is similar for all catchments. The adopted distribution of initial loss is shown in Figure 6-8.

The correlation between initial losses and continuing losses is not well understood. Current practice is for initial losses to be sampled from a distribution, while the continuing loss is held constant; this approach was used for the design flood modelling.

Values for the median initial loss and constant continuing loss rate for each of the catchments were estimated by verifying the flood quantiles produced by RORB to flood frequency analyses of observed flood peaks. Details of the verification process and the adopted losses are given in Section 7.

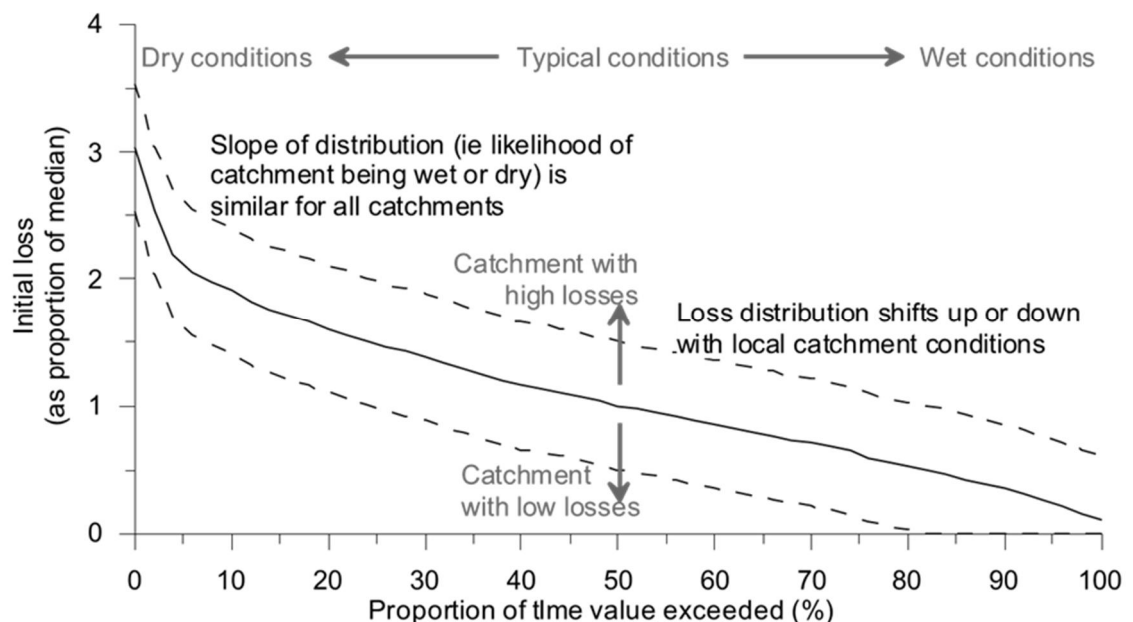


Figure 6-8 Cumulative probability distribution of initial loss, as a ratio of the median initial loss, adopted for design flood estimation (adopted from Hill et al., 2014)

6.7 Baseflow

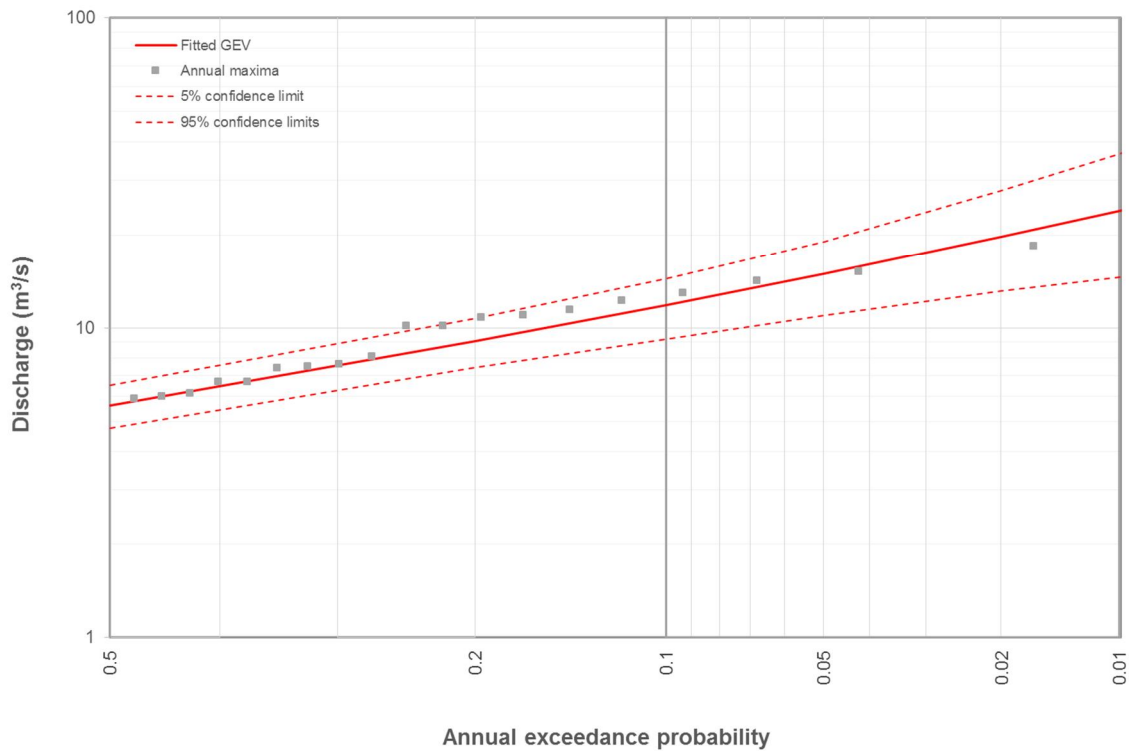
For each gauge site a procedure for allowing for baseflow, based upon flood frequency analysis of annual maxima extracted from the separated baseflow time series, was adopted.

For the calibration events, which were generally the larger flood events that had been observed at each of the streamflow gauges, baseflow was manually separated from the total flow hydrograph at each of the streamflow gauges.

The Lyne and Hollick (1979) digital baseflow filter was then applied to estimate the daily time series of baseflow at each of the streamflow gauges from the daily time series of total streamflow. The filter parameter of the Lyne and Hollick filter was adjusted until the baseflow associated with the peak from the digital filter matched, on average, the manually separated estimates of baseflow under the peak for the calibration flood events. The filter parameter adopted was 0.925 and 3 passes were applied.

Annual maxima flood peaks (from the total flow hydrograph) were then identified and the baseflow, estimated from the digital filter, associated with the annual maxima were then extracted. A frequency distribution of baseflow with AEP was then estimated by fitting a GEV distribution to the annual series of baseflow associated with peak flood events, using L-Moments. This provided the frequency distribution for baseflow under the peak that was applicable for floods that were more common than the 1% AEP event. Figure 6-9 shows an example of the GEV distribution at streamflow gauge 225231 (Thomson River @ U/S of Cowwarr Weir). Appendix D shows the GEV distributions for each gauge.

ARR Book 8 Chapter 6 states that the proportion of baseflow is typically small compared with direct runoff for very rare to extreme flood events. Therefore, ARR recommends that baseflow for extreme events should be between 20% and 50% greater than the baseflow in observed floods. It was therefore assumed for this study that the baseflow at the AEP of the PMP was 50% greater than the estimate of the baseflow for the 1% AEP design flood.



n **Figure 6-9 Flood frequency analysis fitted to gauged annual maxima baseflow associated with gauged annual maxima flows, for gauge 225231 (Thomson River @ U/S of Cowwarr)**

7 Hydrologic model verification

7.1 Method

Current practice in design flood estimation includes verification of the results from rainfall runoff modelling (such as RORB) against flood frequency analysis from observed streamflows, where available. There are several streamflow gauges in the study area that may be used to estimate the probability distribution for annual flood maxima. The initial and continuing losses estimated for calibration events may have a low bias because large floods are more likely to occur on catchments with wet antecedent conditions. Therefore, while a small sample of historic events provides useful data for the selection of RORB model routing parameters, these events provide less information about the appropriate losses to use in design flood modelling because the manner in which losses vary with rainfall depends on chance. Suitable initial and continuing loss values were estimated through a verification process, which involved varying the losses until there was an acceptable match between the RORB model results and flood frequency analyses of historic peak flows.

Gauged annual maxima were extracted from the DELWP water monitoring site (<http://data.water.vic.gov.au/monitoring.htm>) for each of the following gauges:

- n 226005 Latrobe River @ Thoms Bridge
- n 226228 and 226224 (Latrobe River @ Rosedale (Main Stream) and Rosedale (Anabranch))
- n 225231 Thomson River @ U/S of Cowwarr Weir
- n 225212 Thomson River @ Wandocka
- n 225232 Thomson River @ Bundalaguah
- n 225221 Macalister River @ Stringybark Creek
- n 225204 Macalister River @ Lake Glenmaggie (Tail Gauge)

For each streamflow gauge the flood frequency analysis involved fitting a Generalised Extreme Value (GEV) distribution (Wang, 1997) to the annual maxima. This was done as LH-moments in a spreadsheet. Prior to fitting the distributions, the multiple Grubbs Beck test in FLIKE was applied to determine the threshold for low-flow outliers for each gauge. A Bayesian fit was trialled in FLIKE but it did not fit the data across the AEP range as well as the LH-moment fit. Therefore, the LH-moments fit was used for this analysis.

RORB was run in Monte-Carlo simulation mode to estimate flood frequency quantiles for flood events with AEP of 10%, 5%, 2% and 1%. In all of the RORB model simulations, a value of 0.8 was adopted for the routing non-linearity parameter, m , which is consistent with guidance for simulation of large and extreme floods in ARR (Nathan and Weinmann, 2016). The value of the routing delay parameter, k_c , was adopted from the values identified from calibration of flood events (refer to Table 5-10). The verification process concentrated upon modifying the values of the median initial loss and continuing loss rate parameters to achieve a match between the RORB model and the flood frequency analysis of gauged data.

The verification process effectively anchors the estimates of design flood peaks from the RORB model across the range between 10% and 1% AEP. The verification process improved confidence in design flood estimates from the RORB model, in addition to calibration to selected flood events, because:

- n calibration was restricted only to a subset of flood events for which there were adequate pluviograph rainfall data to model the flood in RORB, whereas all gauged flood peaks may be adopted in the verification process, permitting the use of a longer data set of floods and often resulting in the consideration of larger flood events; and
- n loss parameters typically vary across a wide range between individual flood events, due to variations in antecedent climatic conditions. Calibration to a small number of flood events provides an unreliable basis for estimating initial and continuing loss parameters, whereas the verification process fits the loss parameters to a much larger sample of flood events and therefore provides a considerably more reliable basis for estimation of loss parameters for design flood event modelling.

7.2 Results

7.2.1 226005 Latrobe River @ Thoms Bridge

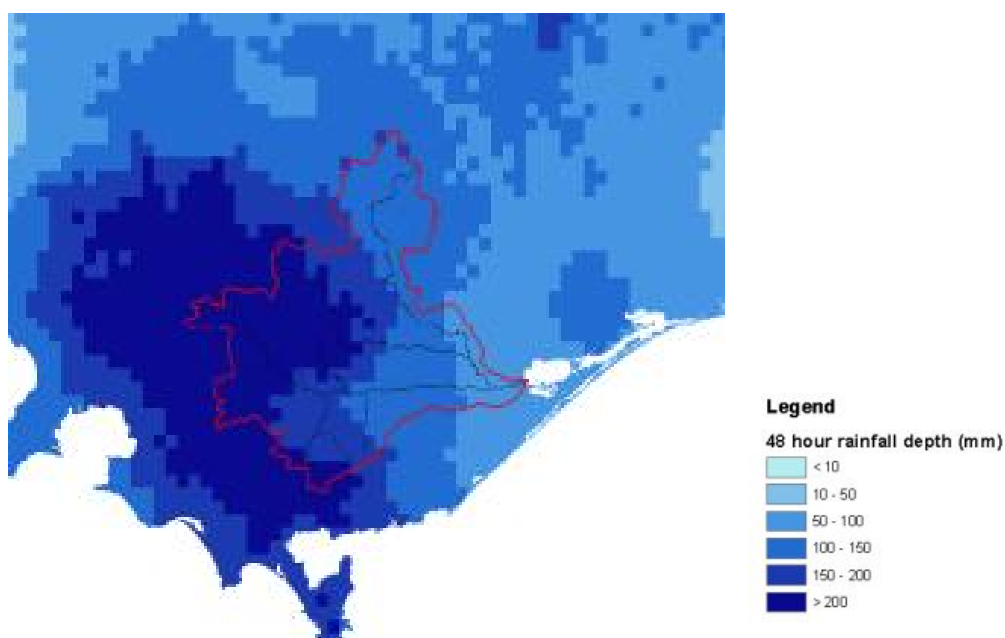
There are 55 years of gauged annual maxima at this site, from 1962 to date. In 1934 there was a large flood event on the Latrobe River. Figure 7-1 shows that in December 1934 over 200 mm fell on the upper part of the catchment over a 48 hour period. As the 1934 event is the largest on record it is important to include it in the flood frequency analysis. There is an estimate of the 1934 event at Rosedale of 3,506 m³/s (Rural Water Commission of Victoria, 1990). The RORB model was used to estimate the flow for the 1934 event at Thoms Bridge. The spatial pattern for the 1934 event was taken from the AWAP data and the temporal pattern was taken from the "Catalogue of Significant Rainfall Occurrences Over Southeast Australia" (Bureau of Meteorology, 1995). The losses were adjusted until a match was achieved to the peak flow estimate at Rosedale. The losses used were an initial loss of 20 mm and a continuing loss of 2.9 mm/hr. The peak at Thoms Bridge was then taken from the RORB model and used in the flood frequency analysis. The RORB model estimated the flow at Thoms Bridge to be 3,062 m³/s.

The second largest event on record is the 1952 event which was recorded at Rosedale as 1534 m³/s. The 1952 event was one of the calibration events (refer to Section 5.2 for details on this event). From this event a flow of 1055 m³/s was estimated at Thoms Bridge. This value was also used in the flood frequency analysis.

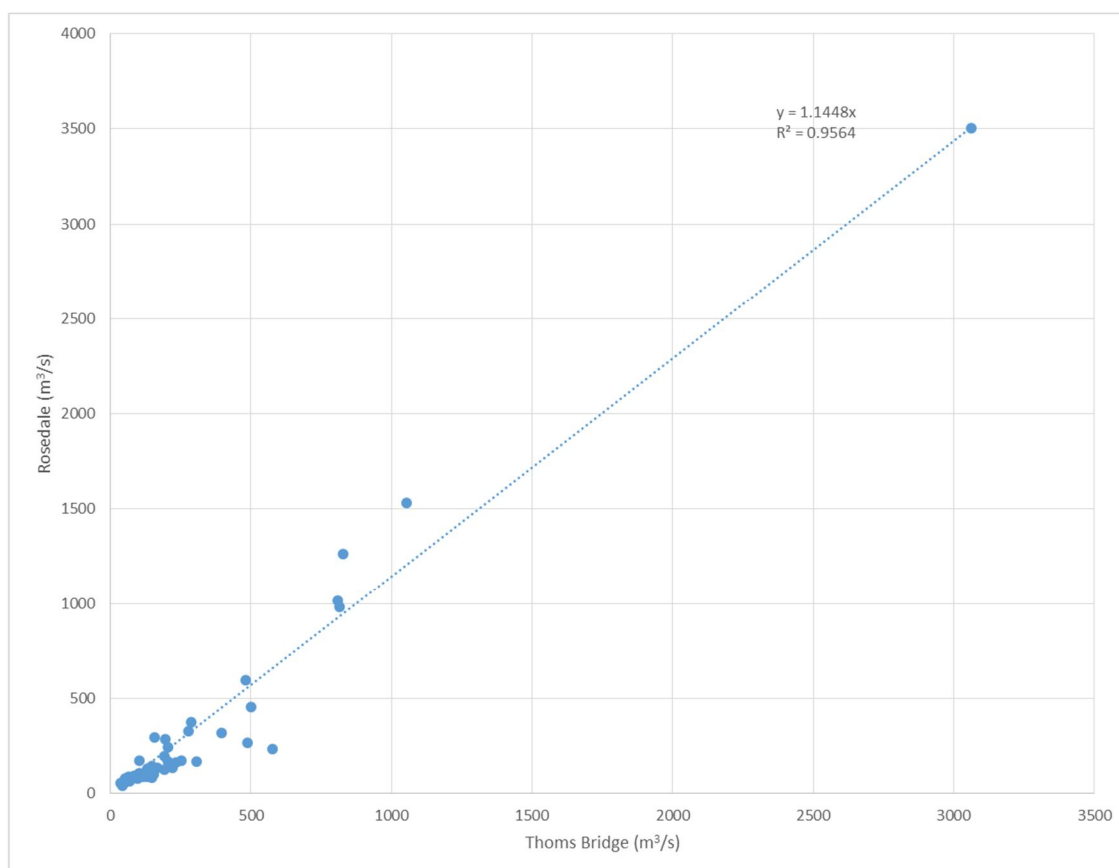
In addition, there is recorded data at Rosedale from 1936 to date (refer to Section 4). To fill in the remainder of the data at Thoms Bridge, that is from 1936 till 1961, after which time there are recorded flows at Thoms Bridge, a plot of the peak flows at Thoms Bridge compared to those at Rosedale was used to develop a relationship between the two gauges. The relationship developed is shown in Figure 7-2. A check was undertaken to ensure that the same event was being used at both gauges. Using a relationship to extend a period of record does introduce

some uncertainty. However, as the recorded flows at Rosedale do not indicate that there were any significant events in the period were the relationship is being used the impact of the relationship on the flood frequency analysis is small. In addition as the model is being verified to the gauge at Rosedale, less reliance is placed on the Thoms Bridge gauge verification.

Figure 7-3 shows that the GEV distribution provides a reasonable fit to the infilled and gauged annual maxima. Figure 7-3 also shows the GEV distribution based on gauged flow only. Figure 7-3 shows that the 1934 event in particular has a large impact on the flood frequency curve. The multiple Grubbs Beck test determined that there were no low-flow outliers. An LH-moment of four was found to provide the best fit to the annual maxima.



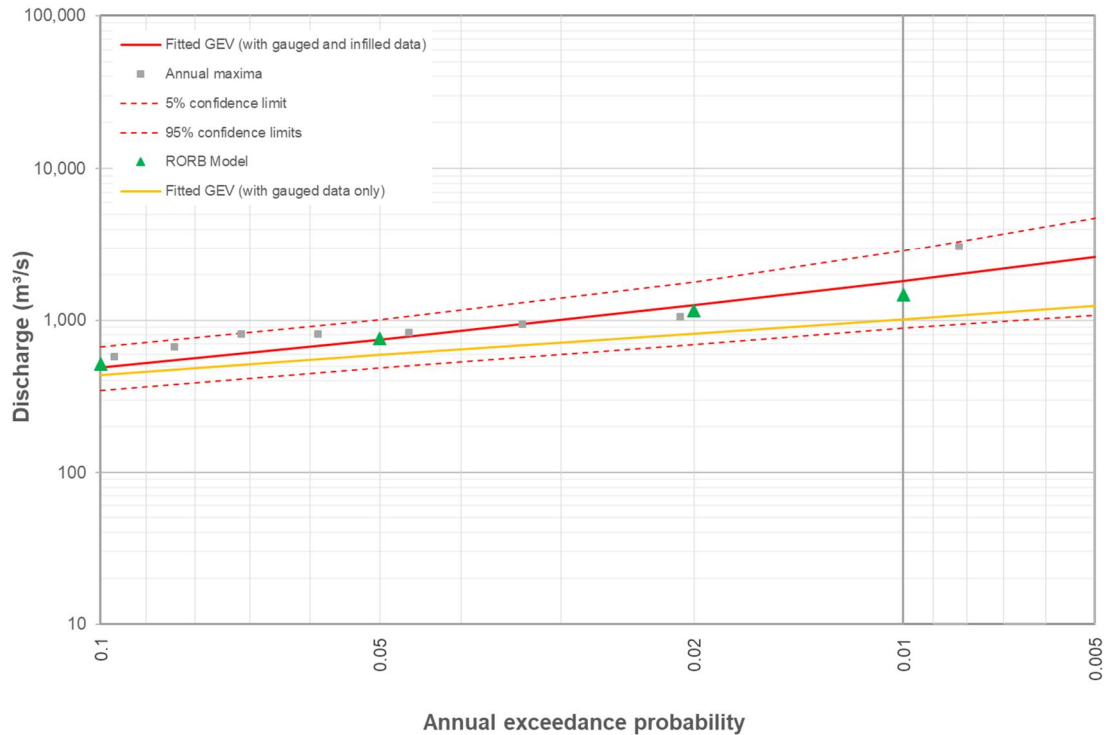
n **Figure 7-1 48 hour Rainfall Depth (mm) for December 1934 Event**



n **Figure 7-2 Relationship between flows at Rosedale and Thoms Bridge**

Figure 7-5 also demonstrates that the RORB model provides a reasonable match to the distribution fitted to infilled and gauged annual maxima for the 10%, 5%, 2% and 1% AEP flood quantiles.

For the Latrobe River @ Thoms Bridge catchment a k_c of 80, median IL of 20 mm and CL of 1.5 mm/h were adopted for all Monte-Carlo simulations of floods in the catchment.



n **Figure 7-3 Flood frequency curve fitted to gauged annual maxima at streamflow gauge 226005, Latrobe River @ Thoms Bridge, and verification with RORB model Monte-Carlo run outputs for flood quantiles between 10% and 1% AEP (for k_c of 80, median IL of 20 mm and CL of 1.5 mm/h)**

7.2.2 226228 and 226224 (Latrobe River @ Rosedale (Main Stream) and Rosedale (Anabranh))

There are 80 years of gauged annual maxima at this site, from 1936 to date. As mentioned above there is an estimate of the 1934 event at Rosedale of 3,506 m³/s (Rural Water Commission of Victoria, 1990). Figure 7-6 shows that the GEV distribution provides a reasonable fit to the gauged annual maxima. The multiple Grubbs Beck test determined that there were no low-flow outliers. An LH-moment of four was found to provide the best fit to the annual maxima.

Figure 7-6 also demonstrates that the RORB model provides a reasonable match to the distribution fitted to gauged annual maxima for the 10%, 5%, 2% and 1% AEP flood quantiles.

For the Latrobe River @ Rosedale (Main Stream and Anabranh) catchment a k_c of 68, median IL of 20 mm and CL of 1.5 mm/h were adopted for all Monte-Carlo simulations of floods in the catchment.

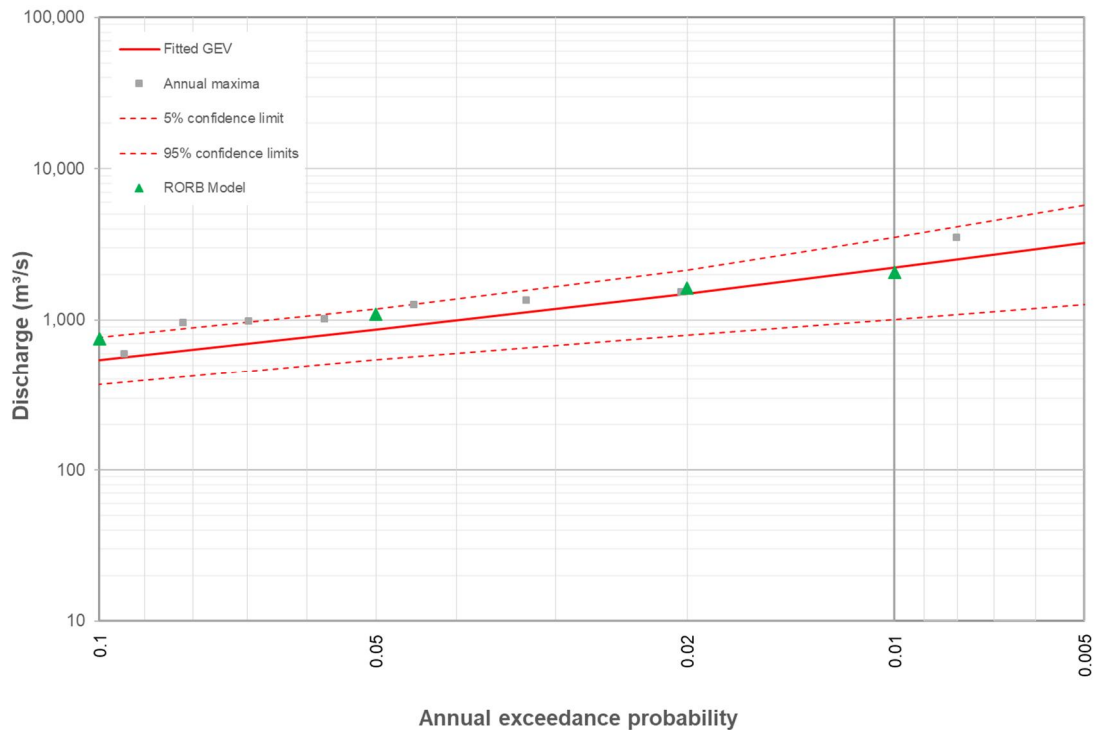


Figure 7-4 Flood frequency curve fitted to gauged annual maxima at streamflow gauge 226228 and 226224, Latrobe River @ Rosedale (Main Stream and Anabranh), and verification with RORB model Monte-Carlo run outputs for flood quantiles between 10% and 1% AEP (for k_c of 68, median IL of 20 mm and CL of 1.5 mm/h)

7.2.3 225231 Thomson River @ U/S of Cowwarr Weir

There are 41 years of gauged annual maxima at this site, from 1976 to date. Construction of Thomson Dam began in 1976 and was opened in 1983. During the construction period a large flood event occurred in 1978. As the dam has an impact on the flows recorded at 225231 and in 1978 the dam was not complete this event was not included in the flood frequency curve. For the verification process it was assumed that Thomson Dam started at the median level (that is 429.2 m AHD) which was determined from the historical reservoir levels. This assumption was tested by undertaking a RORB model run assuming that the reservoir started full. The flows at Thomson River U/S of Cowwarr Weir increased by only 3% when assuming Thomson Reservoir is full. Figure 7-5 shows that the GEV distribution provides a good fit to the gauged annual maxima. The multiple Grubbs Beck test determined that there were no low-flow outliers. An LH-moment of two was found to provide the best fit to the annual maxima.

Figure 7-5 also demonstrates that the RORB model provides a reasonable match to the distribution fitted to gauged annual maxima for the 10%, 5%, 2% and 1% AEP flood quantiles.

For the Thomson River U/S of Cowwarr Weir catchment a k_c of 70, median IL of 20 mm and CL of 1.0 mm/h were adopted for all Monte-Carlo simulations of floods in the catchment.

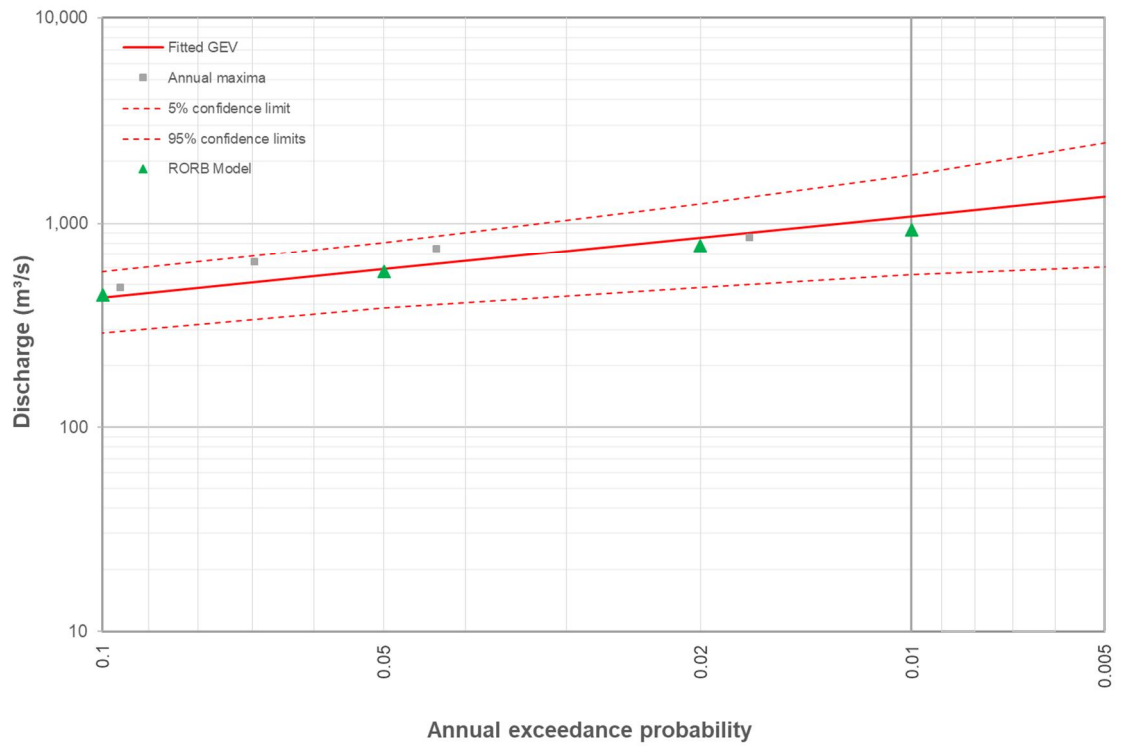


Figure 7-5 Flood frequency curve fitted to gauged annual maxima at streamflow gauge 225231, Thomson River @ U/S Cowwarr Weir, and verification with RORB model Monte-Carlo run outputs for flood quantiles between 10% and 1% AEP (for k_c of 70, median IL of 20 mm and CL of 1 mm/h)

7.2.4 225212 Thomson River @ Wandocka

There were 54 years of gauged annual maxima at this site, from 1963 to date. This gauge is also influence by the Thomson Dam therefore, as with Cowwarr Weir all flows prior to the construction of the dam including the 1978 event were not included. As mentioned in Section 5.2 and Section 5.3.1 there is some uncertainty about the 2007 event at Wandocka. The calibration process indicated that the flow should in in the order of 790 m³/s but according to the recorded levels (refer to Table 5-9) the 2007 event was lower than the 1993 event which from the RORB model calibration was in the order of 450 m³/s. Figure 7-6 shows that the GEV distribution using the gauged flows and assuming the 2007 flow was in the order of 790 m³/s. With the 2007 event at 790 m³/s it becomes the number one ranked event which has a large influence on the flood frequency curve. Due to the uncertainty of the 2007 event it was decided to still focus the verification on the flood frequency curve based on the gauge flows. This decision was also done in the knowledge that the verification at Cowwarr has a larger influence on flows on the Thomson River compared to the area between Cowwarr and Wandocka. In addition as the rating curve at Cowwarr is more certain more emphasis was placed on the verification at Cowwarr. The multiple Grubbs Beck test determined that there were no low-flow outliers. An LH-moment of zero was found to provide the best fit to the annual gauged maxima.

Figure 7-6 demonstrates that the RORB model provides a reasonable match to the distribution fitted to gauged annual maxima for the 10%, 5%, 2% and 1% AEP flood quantiles.

For the Thomson River @ Wandocka catchment a k_c of 50, median IL of 20 mm and CL of 2.0 mm/h were adopted for all Monte-Carlo simulations of floods in the catchment.

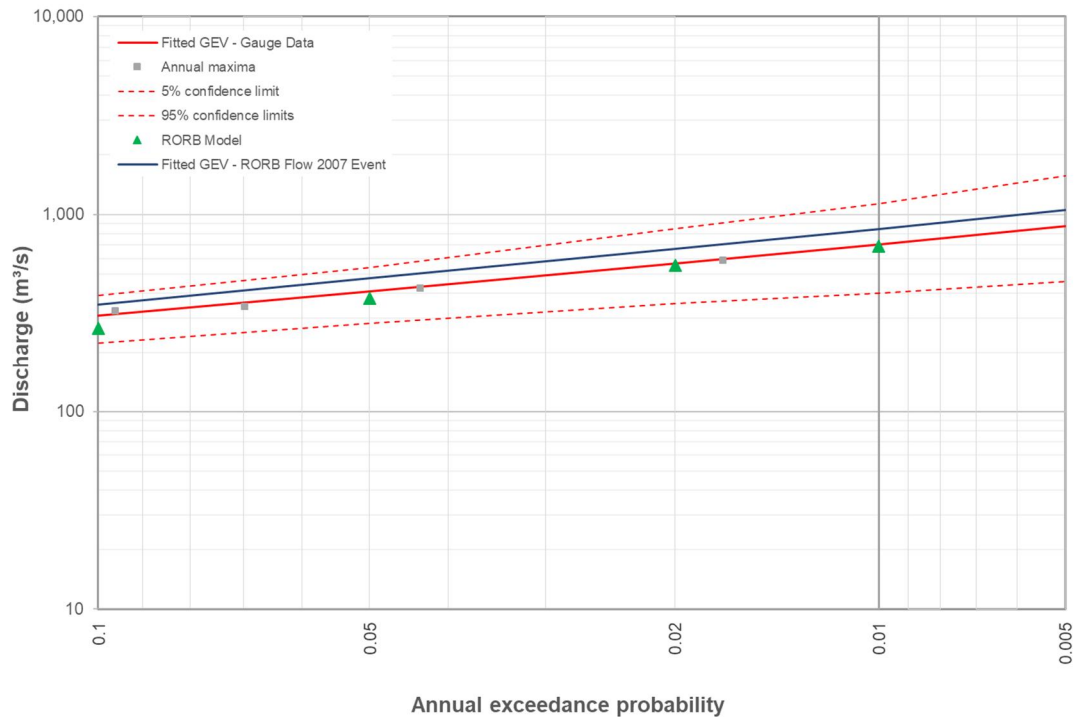


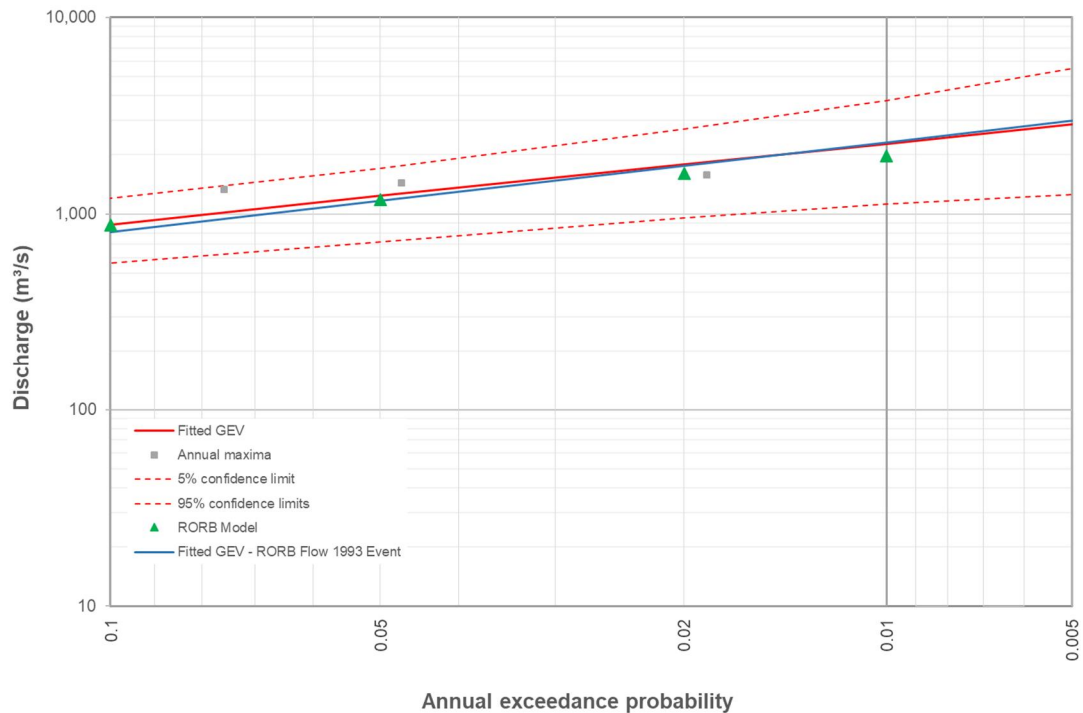
Figure 7-6 Flood frequency curve fitted to gauged annual maxima at streamflow gauge 225212, Thomson River @ Wandocka, and verification with RORB model Monte-Carlo run outputs for flood quantiles between 10% and 1% AEP (for k_c of 50, median IL of 20 mm and CL of 2 mm/h)

7.2.5 225232 Thomson River @ Bundalaguah

There were 40 years of gauged annual maxima at this site, from 1977 to date. However, there is missing data from 1990 to 1995. As mentioned previously there was a large event in 1978 on the Thomson River which would have been influenced by the Thomson Dam. However, as this gauge is downstream of the confluence of the Macalister River the impact of Thomson Dam is diminished somewhat. Therefore, the 1978 event was included in the analysis for Bundalaguah, acknowledging that the flow used maybe higher than if the same event was to occur today with Thomson Dam in place. Also, there was a flood event in 1993 (refer to Section 5.2.3) which was not captured by the streamflow gauge. Figure 7-7 shows the GEV distribution using the recorded gauge flows and the recorded gauge flows with the estimate of flow from RORB for the 1993 event (i.e. 992 m³/s). Both provides a reasonable fit to the gauged annual maxima. The multiple Grubbs Beck test determined that there were no low-flow outliers. An LH-moment of two was found to provide the best fit to the annual maxima.

Figure 7-7 also demonstrates that the RORB model provides a reasonable match to the distribution fitted to gauged annual maxima for the 10%, 5%, 2% and 1% AEP flood quantiles.

For the Thomson River @ Bundalaguah catchment a k_c of 75, median IL of 20 mm and CL of 1.5 mm/h were adopted for all Monte-Carlo simulations of floods in the catchment.



n **Figure 7-7 Flood frequency curve fitted to gauged annual maxima at streamflow gauge 225232, Thomson River @ Bundalaguah, and verification with RORB model Monte-Carlo run outputs for flood quantiles between 10% and 1% AEP (for k_c of 75, median IL of 20 mm and CL of 1.5 mm/h)**

7.2.6 225221 Macalister River @ Stringybark Creek

There were 49 years of gauged annual maxima at this site, from 1968 to date. The curve is being heavily influenced by the flow in 2007 with an estimated peak flow of 2,173 m³/s compared to the next biggest recorded event of 730 m³/s in 2012. Reviewing the data at 225204 Macalister River @ Lake Glenmaggie (Tail Gauge) indicates that the 2007 event would most likely be an event that was less frequent than the 1% AEP event (currently it is plotting between the 2% and 1% AEP event). Figure 7-8 shows that the GEV distribution provides a reasonable fit to the gauged annual maxima. The multiple Grubbs Beck test determined that there were no low-flow outliers. An LH-moment of zero was found to provide the best fit to the annual maxima.

Figure 7-8 also demonstrates that the RORB model provides a good match to the distribution fitted to gauged annual maxima for the 10%, 5%, 2% and 1% AEP flood quantiles.

For the Macalister River @ Stringybark Creek catchment a k_c of 62, median IL of 20 mm and CL of 2.5 mm/h were adopted for all Monte-Carlo simulations of floods in the catchment.

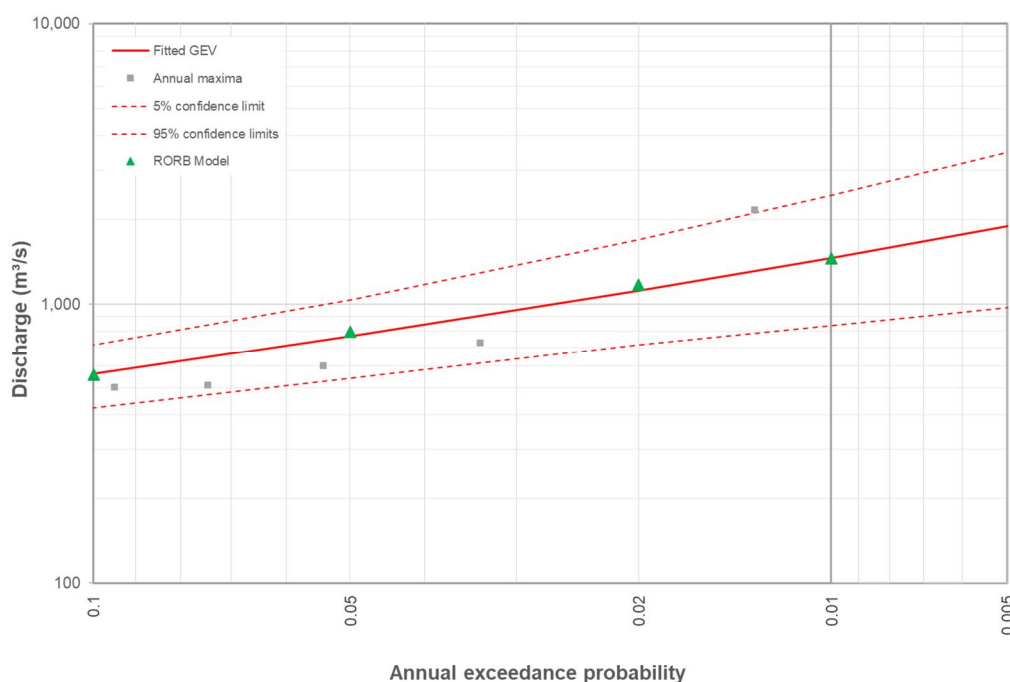
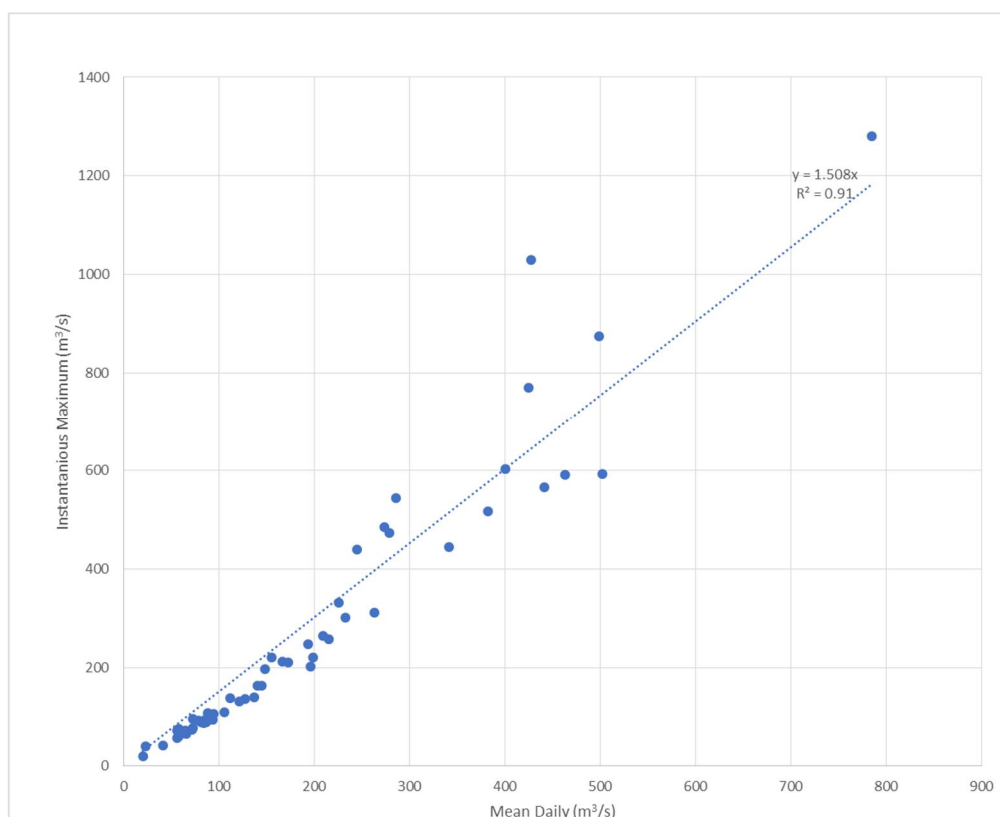


Figure 7-8 Flood frequency curve fitted to gauged annual maxima at streamflow gauge 225221, Macalister River @ Stringybark Creek, and verification with RORB model Monte-Carlo run outputs for flood quantiles between 10% and 1% AEP (for k_c of 62, median IL of 20 mm and CL of 2.5 mm/h)

7.2.7 225204 Macalister River @ Lake Glenmaggie (Tail Gauge)

There were 98 years of gauged annual maxima at this site, from 1919 to date. Only mean daily flow was available from 1919 to 1960. The mean daily flows were converted to instantaneous maximum for the period from 1919 to 1960 by plotting yearly instantaneous maximum to yearly maximum mean daily to create a relationship between the two flows. This relationship was then used to convert the mean daily flows to instantaneous maximums from 1919 to 1960. The relationship is shown in Figure 7-10.



n **Figure 7-9 Relationship between Mean Daily and Instantaneous Maximum**

The complication with this streamflow gauge is that it is located downstream of Lake Glenmaggie. Lake Glenmaggie was built between 1919 to 1926 and held 132,000 ML. In 1958 the storage was increased to 177,630 ML by the construction of 14 radial gates. Therefore, flows recorded at the streamflow gauge will be influenced by the gate operation, particularly for more frequent (e.g. 1 in 5 AEP) events. Also the gauge flows will be influenced by the increased storage level and the starting level in Lake Glenmaggie at the start of the storm.

As a results two flood frequency curve were plotted, one with the full period of record and one with the data from 1958 onwards (when the radial gates were in installed). Figure 7-11 and Figure 7-12 shows that the GEV distribution provides a reasonable fit to the gauged annual maxima. A greater emphasis was placed on the GEV distribution with the data from 1958 onwards, as this reflects current conditions (Figure 7-12). The multiple Grubbs Beck test determined that there were no low-flow outliers. An LH-moment of two was found to provide the best fit to the annual maxima.

The RORB model was run with two different scenarios:

- n assuming the gates were open at the start of the event and the storage was at full supply level (FSL);
- n assuming the gates were open at the start of the event and the storage was drawdown.

The drawdown curve was calculated from the historical levels supplied by SRW from 1955 to 2014. Figure 7-10 shows the drawdown curve calculated.

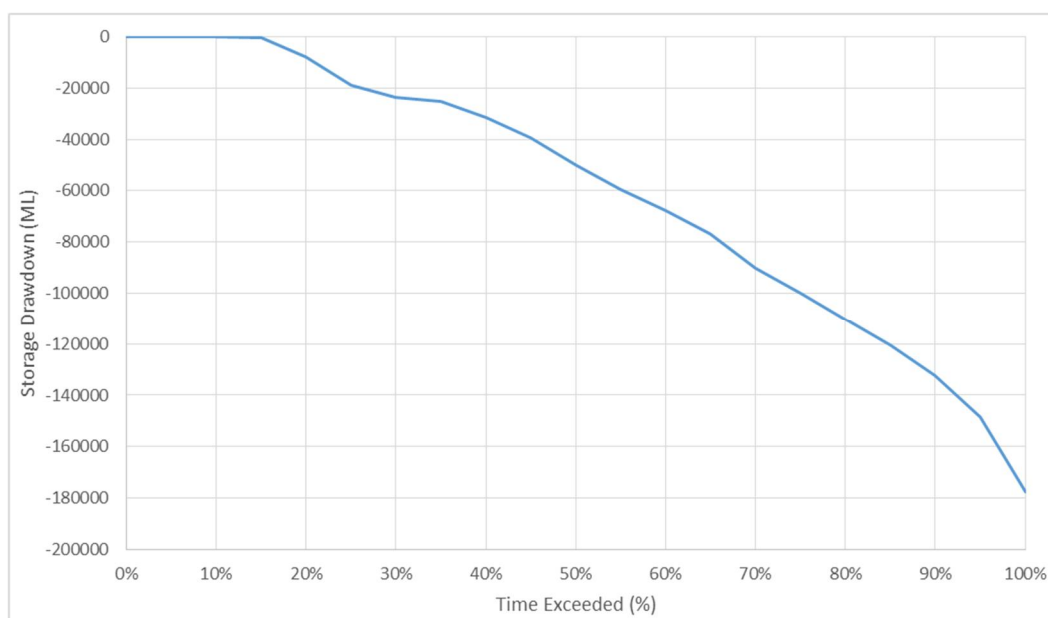
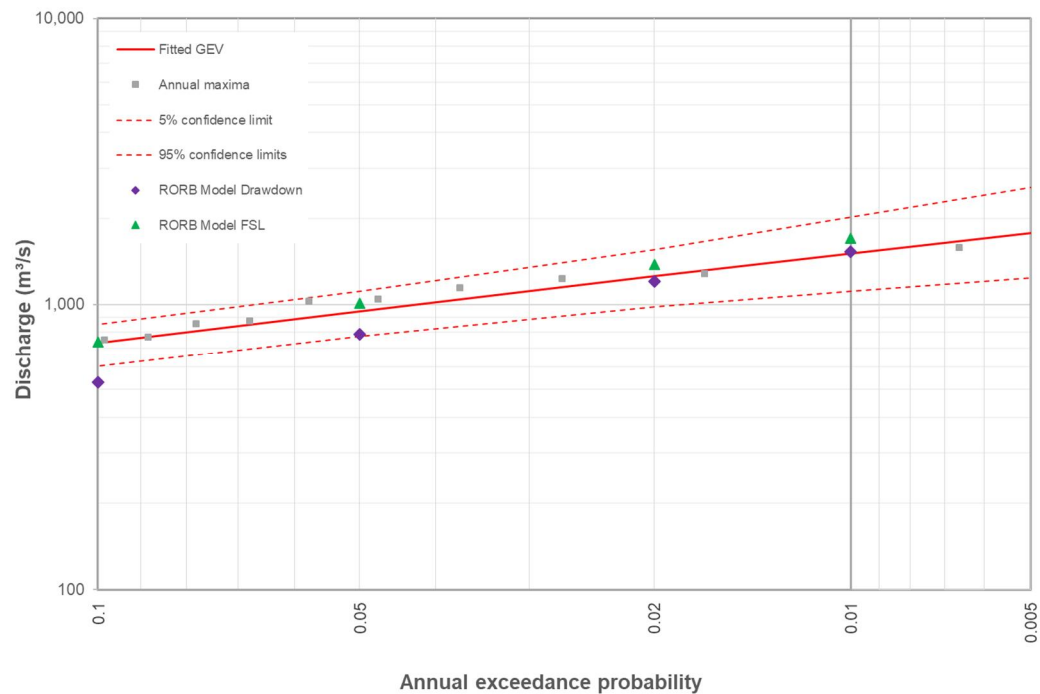


Figure 7-10 Drawdown Curve for Lake Glenmaggie

Figure 7-11 and Figure 7-12 demonstrates that the RORB model provides a reasonable match to the distribution fitted to gauged annual maxima for the 10%, 5%, 2% and 1% AEP flood quantiles assuming the storage is starting full and it provides a reasonable match for the 2% and 1% AEP with the storage drawdown taken into account. Figure 7-11 and Figure 7-12 also demonstrates that the starting level has less of an influence for the large events as the 2% and 1% AEP estimates start to converge for the two different RORB runs. Also it indicates that the gates seem to have little impact as the RORB model is able to replicate the large flows with the assumption that the gates are open at the start of the event.

For the Macalister River @ Lake Glenmaggie (Tail Gauge) catchment a k_c of 23, median IL of 20 mm and CL of 1.5 mm/h were adopted for all Monte-Carlo simulations of floods in the catchment.



n **Figure 7-11 Flood frequency curve fitted to gauged annual maxima between 1919 to 2016 at streamflow gauge 225204, Macalister River @ Lake Glenmaggie (Tail Gauge), and verification with RORB model Monte-Carlo run outputs for flood quantiles between 10% and 1% AEP (for k_c of 62, median IL of 20 mm and CL of 1.5 mm/h)**

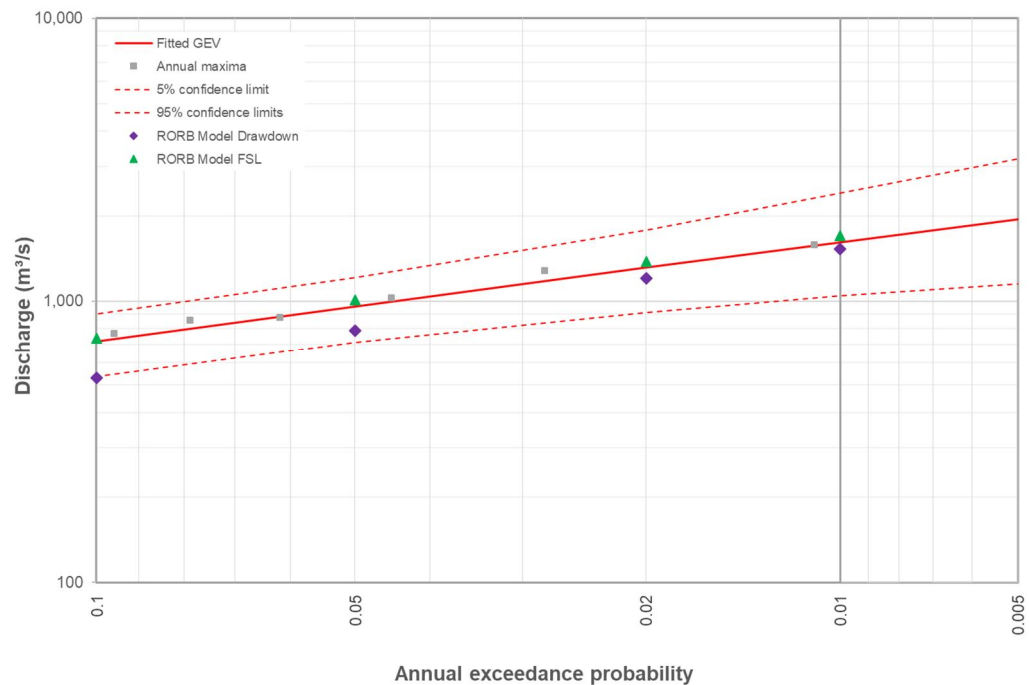


Figure 7-12 Flood frequency curve fitted to gauged annual maxima between 1958 and 2016 at streamflow gauge 225204, Macalister River @ Lake Glenmaggie (Tail Gauge), and verification with RORB model Monte-Carlo run outputs for flood quantiles between 10% and 1% AEP (for k_c of 62, median IL of 20 mm and CL of 1.5 mm/h)

7.3 Adopted Parameters

Table 7-1 summarises the parameters adopted for the verification of the RORB model.

Table 7-1 Summary of Parameters

Location	k_c	m	IL (mm)	CL (mm/hr)
226005 (Thoms Bridge)	80	0.8	20	1.5
226228 and 226224 (Rosedale Combined)	68	0.8	20	1.5
225231 (Cowwarr Weir)	70	0.8	20	1.0
225212 (Wandocka)	50	0.8	20	2.0
225221 (Stringybark Ck)	62	0.8	20	2.5
225204 (Lake Glenmaggie)	23	0.8	20	1.5
Remaining catchment	75	0.8	20	1.5

8 Hydraulic data review

This section describes the key information used in the hydraulic investigation.

8.1 Observed Flood Levels and Extents

Surveyed flood levels were downloaded from Vicmap data (<http://services.land.vic.gov.au/landchannel/content/productCatalogue>). Predominately surveyed flood levels in the study area are for the 1978 and the 2007 events. There are a number of other historical flood levels (i.e. 1923, 1933, 1934, 1939, 1970 and 1977) but these are isolated points and do not provide the same coverage as the 1978 and 2007 events.

It was confirmed with the WGCMA that the surveyed flood levels from VicMap data was a complete dataset.

A number of flood extents are also available, namely, 1934, 1977, 1978, 1990, 2007 and 2012. The WGCMA also provided georeferenced aerial photos of the 2007 event.

Figure 8-1 shows the available flood levels and extents for the study area.

Along the Princes Highway near Sale there are four bridge openings. One over the Wurruk Floodway, Thomson River, the Thomson River Floodplain and Flooding Creek. A copy of the drawings provided by VicRoads are shown in Appendix F.2.

Along the South Gippsland Highway, south of Sale, there are five bridges which VicRoads supplied drawings for. A copy of the drawings provided by VicRoads is shown in Appendix F.3.

In addition to the road bridges, there are two footbridges located to the north of the Princes Highway, near Sale. One footbridge crosses Thomson River the other Flooding Creek. VicRoads provided a drawing of the existing footbridge that crosses Thomson River only. A copy of the drawing provided by VicRoads is shown in Appendix F.4.

VLine

There are three railway bridge crossings within the study area. All three are located approximately one kilometre north of the Princes Highway near Sale. VLine provided details on each of the bridges shown in Table 8-1. A copy of the Thomson River Bridge plan was provided and is contained in Appendix G.

ⁿ **Table 8-1 VLine Bridge Summary**

Bridge Location	Bridge Deck Type	Dimensions (number and length of spans)
Thomson River overflow (204.91km)	Timber transom bridge – single track	8 No. x 9m spans
Thomson River (205.29km)	Timber transom bridge – single track	14 no. x 9m spans + 3 no. x 13.5m spans
Flooding Creek (205.57km)	Timber transom bridge – single track	6 no. x 9m spans

Council

Council provided a database detailing a number of their hydraulic structures. Along with the database Council provided drawings of a number of bridges, but not all. The bridge information supplied by Council is shown in Appendix H.

8.3 Previous Flood Studies

The WGCMA provided a number of reports to provide background information for this project. The main reports are listed below:

- ⁿ Cowwarr Flood Study (Water Technology, 2012)
- ⁿ Macalister Flood Study (Water Technology, 2012)
- ⁿ Latrobe River Flood Study (Cardno, 2015)

9 Topographic Data

9.1 Overview

To undertake detailed hydraulic modelling requires high quality ground surface information. For this study, aerial captured ground survey, LiDAR, was supplied by WGCMA. The LiDAR was supplied as processed regularly spaced grids rather than the raw irregular data. This pre-processed LiDAR data was used to generate a Digital Elevation Model (DEM) of the study area and surrounds. A number of LiDAR sources were supplied by WGCMA which were captured at different times, to different accuracies and different coverage areas. This Section details the various data sources used for this Study as well as the quality assurance checks undertaken to provide confidence in the accuracy and use of the data and to determine the appropriate hierarchy in the creation of the DEM.

In addition to the LiDAR data the WGCMA also provided some survey data located within the study area. The survey information was checked against the LiDAR data.

As the LiDAR data does not penetrate water, bathymetry data, which is survey below water, is required. The WGCMA supplied some bathymetry data which covered the lower end of the study area. The bathymetry data was reviewed against the available data.

9.2 LIDAR Dataset

The WGCMA supplied LiDAR from three different sources:

- n Macalister Irrigation District (MID_and_Latrobe)
- n Dowd Morass (dem_merge1ml)
- n West Gippsland Rivers (DSE_Rivers_West_Gippsland)

With each of the datasets, metadata was provided, detailing the accuracy of each of the datasets. The reported accuracy for each dataset is summarised in Table 9-1.

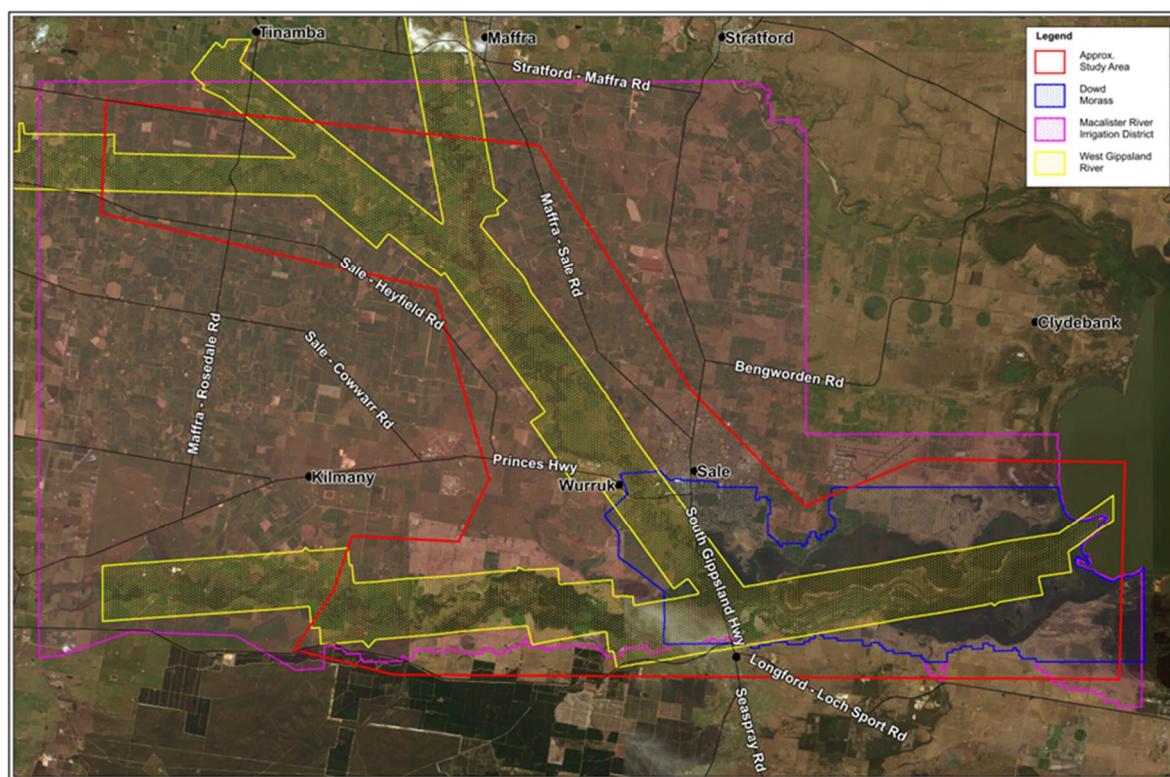
n **Table 9-1 Summary of Reported LIDAR Accuracy**

Data Source	Vertical Accuracy	Horizontal Accuracy	Resolution
Macalister Irrigation District	± 10 cm	± 25 cm	1 m
Dowd Morass*	± 15 cm	± 15 cm	1 m
West Gippsland Rivers	± 20 cm @ 78% CI [^]	± 19 cm @ 67% CI [^]	0.5 m

* Different accuracy reported in different sections as this is a merged dataset

[^] CI – Confidence interval

The extent of each LIDAR dataset is shown in Figure 9-1



n **Figure 9-1 LIDAR Extents**

To generate a DEM of the study area where multiple LiDAR datasets exist it is good practice to review each to determine the hierarchy for their use. Typically, the most reliable data is used as a priority with lower performing datasets used to infill areas where better data doesn't exist.

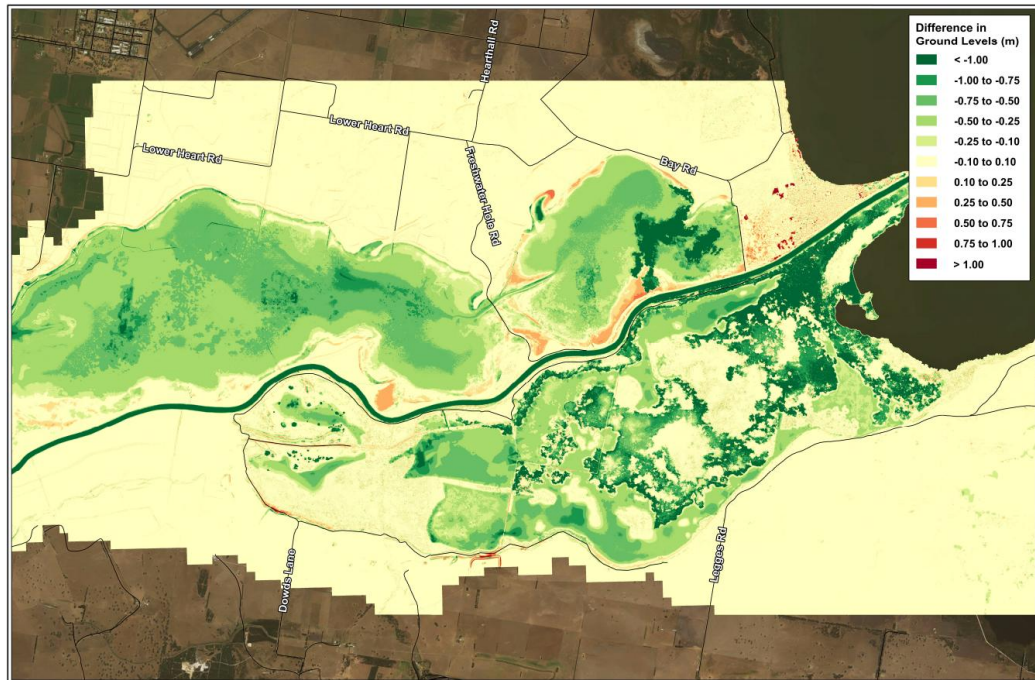
Once the accuracy of each LiDAR dataset is determined the best performing datasets are stamped on one another to form a single cohesive DEM of the study area. Through this process the best possible outcome for the study can be achieved as the final DEM is used in the hydraulic modelling to represent the existing ground surface. From the results of the hydraulic modelling, maps are produced along with it being used to inform the flood intelligence process.

9.2.1 Comparison of LiDAR Datasets

To compare the LiDAR datasets the difference between each one was compared by subtracting one from the other. Figure 9-2 shows the difference between the Dowd Morass DEM minus the Macalister Irrigation DEM. Figure 9-3 shows the difference between the Dowd Morass DEM minus the West Gippsland Rivers DEM.

The Dowd Morass DEM is reported to have included bathymetry data and as LiDAR does not penetrate through water it is expected that there would be significant differences between data sets in the areas where there is water, such as in the Dowd Morass.

Both Figure 9-2 and Figure 9-3 show that outside of the areas where water is located there is good agreement (± 0.1 m) between data sets.



n Figure 9-2 LIDAR Comparison – Dowl Morass minus Macalister Irrigation District



n Figure 9-3 LIDAR Comparison – Dowl Morass minus West Gippsland Rivers

9.2.2 Permanent Survey Marks Comparison

In total 246 Permanent Survey Marks (PSMs)² were used in the assessment of the various LiDAR data sources. The PSMs were supplied by the DELWP (formally DEPI). The PSMs used were only those with a vertical order of 3 or better, however many of the marks are along highways, and have only approximate horizontal coordinates as they were scaled from 1:100,000 maps. During the review of the PSMs within the study area a small number were removed as they were unreliable.

Figure 9-4 shows the location of the PSMs within the study area. Due to the different LiDAR coverage areas not all PSMs were inspected for each LiDAR data source. Each PSM was compared to each LiDAR dataset and the difference calculated, from this a number of statistical assessments were undertaken to determine the vertical accuracy of each dataset. The quoted and statistical assessment of the vertical accuracy of each of the LiDAR data sets is presented below in Table 9-2.

The Dowd Morass dataset intersected too few PSM points (three) for a reliable assessment. Of the remaining datasets, the Macalister Irrigation District and West Gippsland River, both LiDAR datasets were found to reasonably represent the ground surface based on the assessment of the PSMs within the catchment. Both datasets were found to have a mean and median variance of ± 20 cm from the PSMs. However, when considering the upper and lower quantiles, the Macalister Irrigation District DEM was found to best represent the ground surface with an even distribution around the mean.

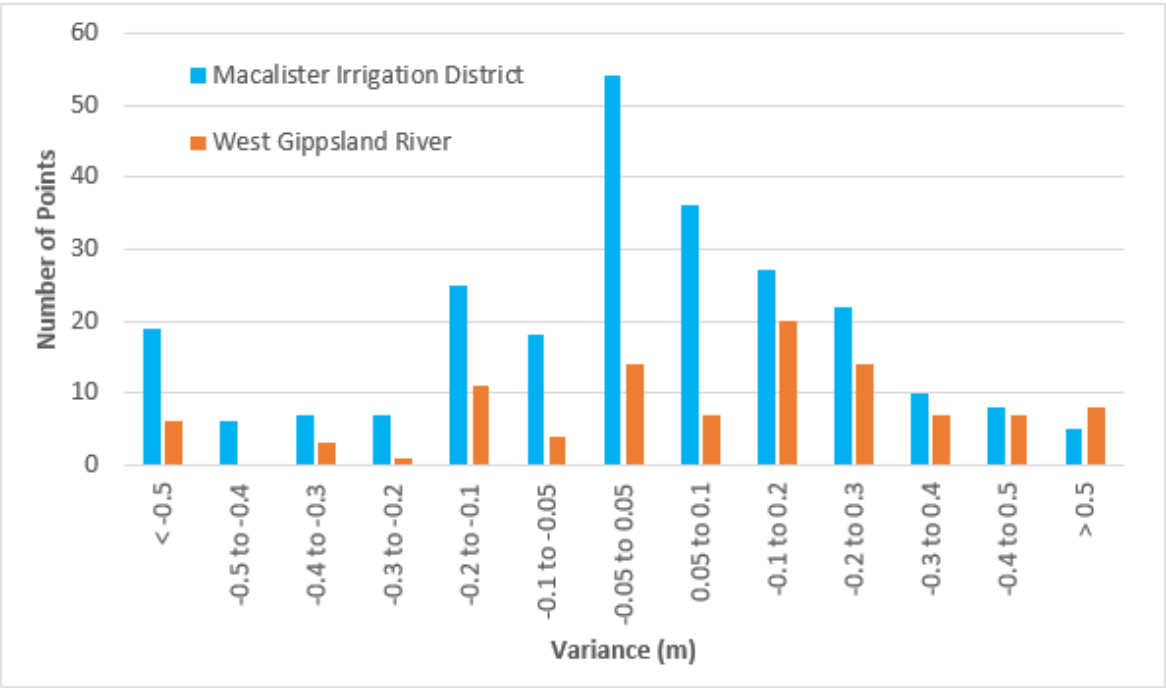
The above observations can be seen visually by comparing the histogram spread of the spread of individual points as shown in Figure 9-4. In Figure 9-4 the Macalister Irrigation District DEM is represented as the blue bars and West Gippsland Rivers DEM as the orange bars.

A comparison of the Macalister Irrigation District DEM and each PSM is shown in Figure 9-4.

Table 9-2 Summary of Reported LiDAR Accuracy – PSM Comparison

Data Source	Macalister Irrigation District	Dowd Morass	West Gippsland Rivers
Quoted Accuracy	± 10 cm	± 15 cm	± 20 cm @ 78% CI ²
No. of PSM points	244	3	102
Mean	-0.02	-0.21	0.11
Median	0.02	-0.20	0.12
Standard Deviation	0.32	0.32	0.31
Lower Quartile	-0.11	-0.60	-0.04
Upper Quartile	0.13	0.18	0.28

² PSMs are objects placed to mark key survey points on the Earth's surface.



n Figure 9-4 PSM – LiDAR Comparison



9.3 Survey Data

The WGCMA supplied two sources of survey data:

- n Within the Dowd's Morass Reserve by Fisher Stewart (2001); and
- n Along the Latrobe River done for Gippsland Water (1994)

Both ground and bathymetric survey was undertaken by Fisher Stewart in 2001 of the Dowd's Morass State Game Reserve. This section discusses the ground survey only, Section 9.4 discusses the bathymetric survey.

9.3.1 Comparison of Fisher Stewart Survey Data with LiDAR

The Fisher Stewart survey included spot survey levels within the reserve. This survey intersects with the three LiDAR datasets. Each survey point was compared to each LiDAR dataset and the difference calculated, from this a number of statistical assessments were undertaken to determine the vertical accuracy of each dataset. The quoted accuracy and the statistical assessment of the vertical accuracy of each of the LiDAR data sets compared to the Fisher Stewart 2001 survey is presented in Table 9-3.

The results in Table 9-3 indicate that the LIDAR datasets are all negatively biased compared to the survey. As each of the LiDAR data set are generally in agreement (refer to Section 9.2) and have a reported accuracy this indicates that the Fisher Stewart survey is not a reliable source.

The above observations can be seen visually by comparing the histogram spread of the spread of individual points as shown in Figure 9-6. In Figure 9-6 the Macalister Irrigation District DEM is represented as the blue bars, West Gippsland River DEM as the orange bars and the Dowd Morass DEM as grey bars.

A comparison of the Macalister Irrigation District DEM and each PSM is shown in Figure 9-7.

n **Table 9-3 Summary of Reported LIDAR Accuracy – Fisher Stewart Survey Floodplain Comparison**

Data Source	Macalister Irrigation District	Dowd Morass	West Gippsland Rivers
Quoted Accuracy	± 10 cm	± 15 cm	± 20 cm @ 78% CI [^]
No. of Points Interrogated	1250	1118	402
Mean	-0.21	-0.25	-0.12
Median	-0.22	-0.21	-0.13
Standard Deviation	0.48	0.51	0.45
Lower Quartile	-0.47	-0.45	-0.35
Upper Quartile	0.00	0.01	0.10

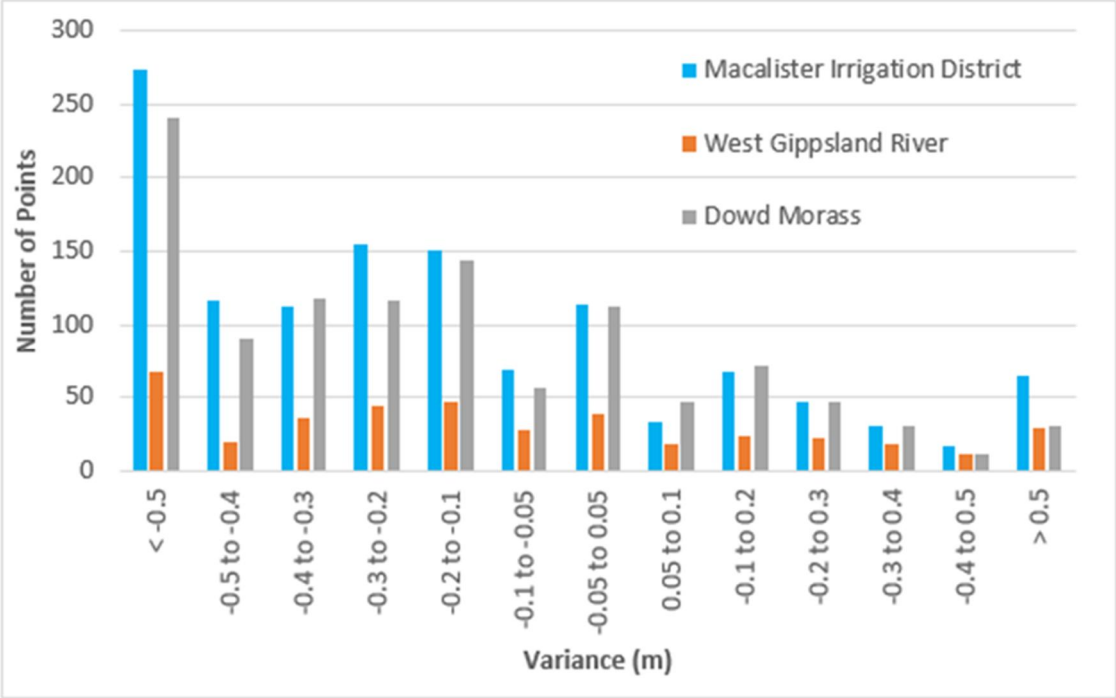


Figure 9-6 Fisher Stewart Survey – LiDAR Comparison

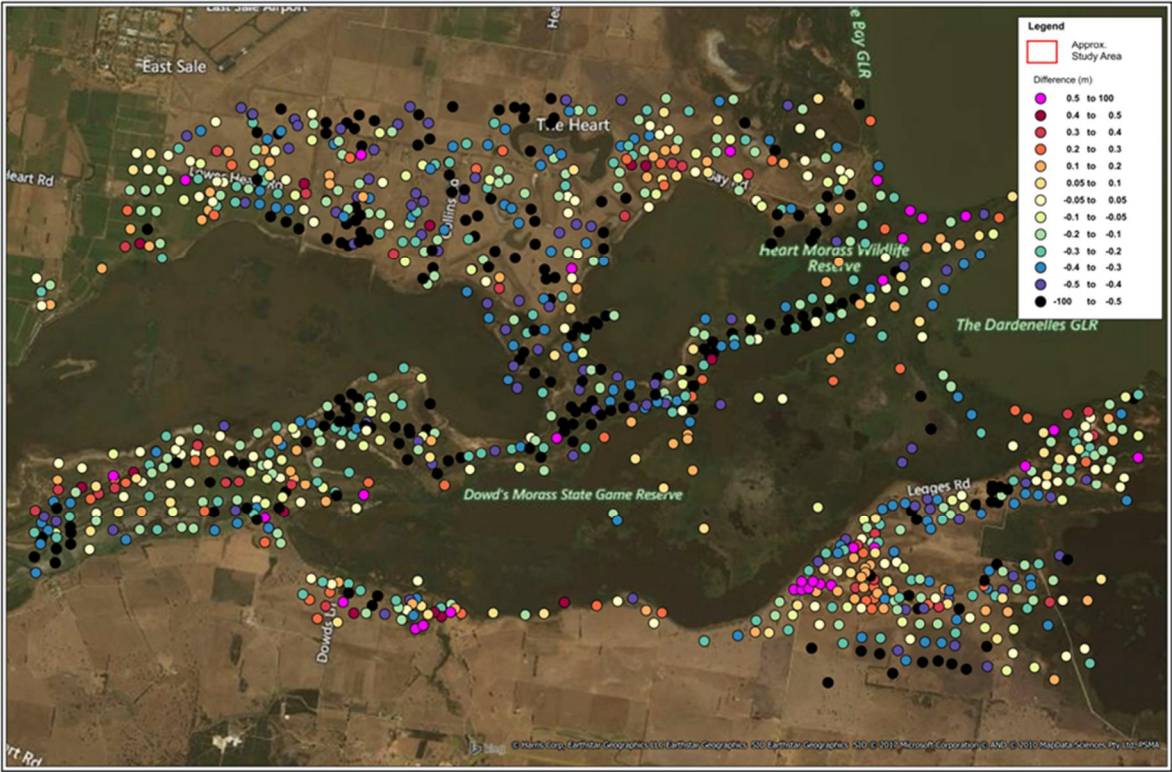
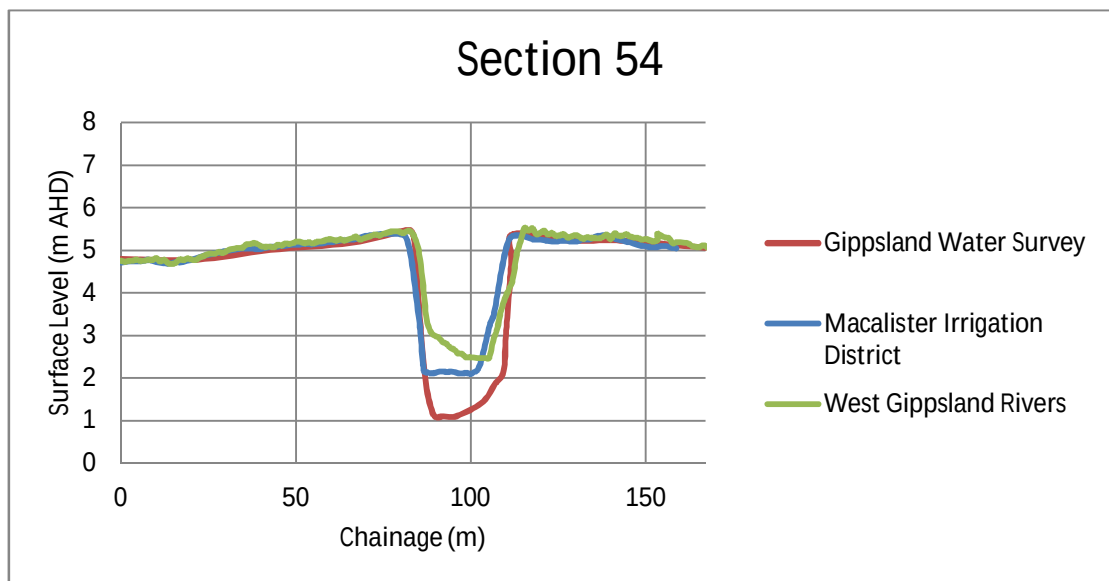


Figure 9-7 Fisher Stewart Survey – LiDAR Comparison

9.3.2 Comparison of Latrobe River Survey done for Gippsland Water (1994)

The survey on the Latrobe River was presented as cross sections. The Macalister Irrigation District DEM and the West Gippsland River DEM overlapped all of the cross sections within the study area and the Dowd Morass DEM overlapped three cross sections. The cross sections were plotted against the LiDAR data. A sample of the comparison is shown in Figure 9-8 to Figure 9-10. The location of the cross sections is shown in Figure 9-11.



n **Figure 9-8 Latrobe River Survey Cross Section 54 compared to LiDAR**

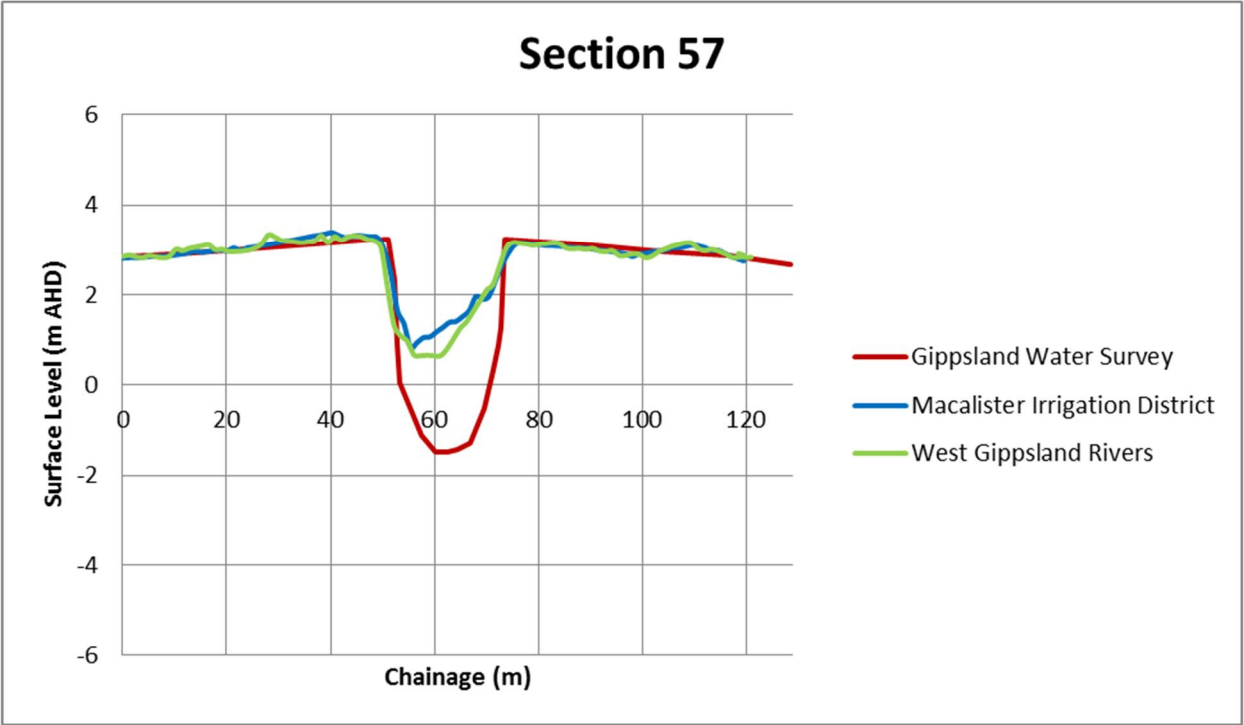


Figure 9-9 Latrobe River Survey Cross Section 57 compared to LiDAR

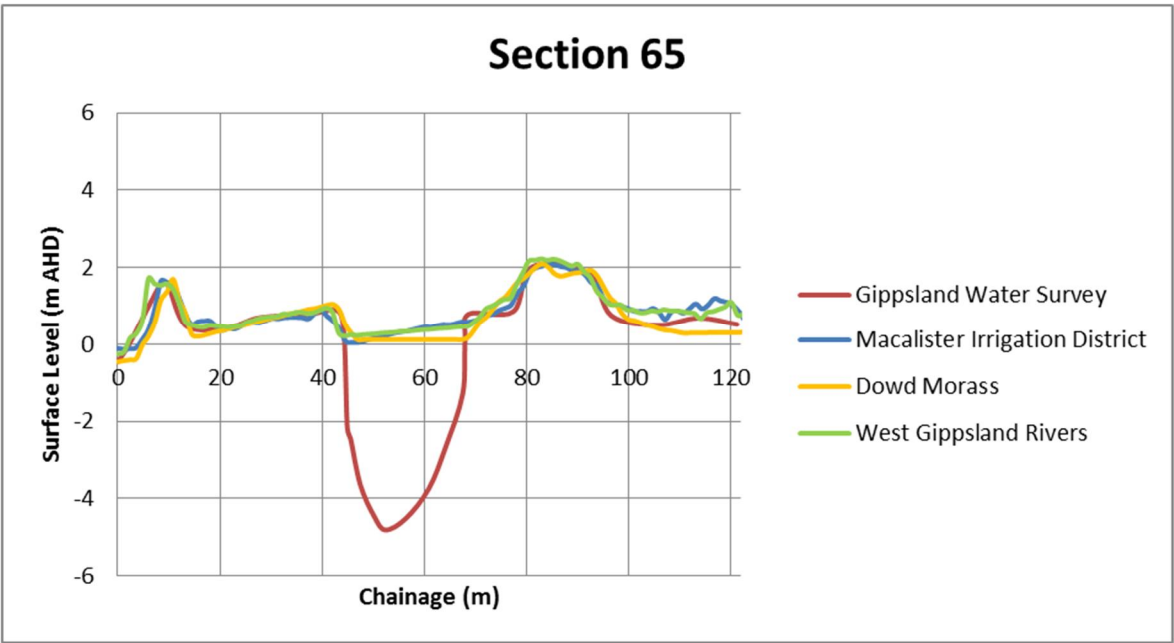


Figure 9-10 Latrobe River Survey Cross Section 65 compared to LiDAR



n **Figure 9-11 Latrobe River Survey Cross Section Locations**

The general observation from the cross section comparison is that each LiDAR dataset matches each other and matches the levels on the floodplain. As expected the closer the cross sections get towards Lake Wellington and there is deeper water in the river the match of the LiDAR to the river bed becomes poor.

9.4 Bathymetry

The WGCMA supplied three sources of bathymetry data:

- n Fisher Stewart (2001) survey points;
- n Lower reach of the Latrobe and Thomson River (2013) DEM; and
- n Dowd Morass DEM

As mentioned in Section 9.3 both ground and bathymetric survey was undertaken by Fisher Stewart in 2001 of the Dowd's Morass State Game Reserve. This section discusses the bathymetry survey only, Section 9.3 discusses the ground survey. The Fisher Stewart bathymetry survey was supplied as a series of spot heights.

The bathymetric survey of the lower reach of the Latrobe and Thomson River were produced as an outcome of the Latrobe Estuary Environmental Water Requirements Study (Water Technology, 2013). The accuracy of the 2013 bathymetric survey was not stated. This data was supplied in the form of DEM.

The DEM for the Dowd Morass, mentioned that bathymetric survey was undertaken using a hovercraft, and the bathymetric data was merged into the dataset.

Table 9-4 Summary of Reported bathymetry DEM Accuracy – Fisher Stewart 2001 Comparison

Data Source	Dowd Morass	Lower Reach Latrobe and Thomson River
Quoted Accuracy	± 15 cm	Unknown
No. of Points Interrogated	9935	10132
Mean	1.89	0.66
Median	1.88	0.67
Standard Deviation	1.00	0.58
Lower Quartile	1.28	0.41
Upper Quartile	2.51	0.89

With respect to the bathymetry, both datasets were a poor match to the Fisher Stewart survey. However, the best performing dataset was the Lower Reach Latrobe and Thomson River bathymetry with a mean bias of 66cm. As discussed in Section 9.3.1, there is reason to cast doubt on the reliability of the survey data and this uncertainty may extend to the bathymetry data as well.

In addition to the above, two of the Latrobe River cross sections were in the same location as lower reach Latrobe and Thomson River bathymetry. These cross sections were plotted against the lower reach Latrobe and Thomson River bathymetry DEM. The comparison is shown in Figure 9-12 and Figure 9-13. The location of the cross sections is shown in Figure 9-11.

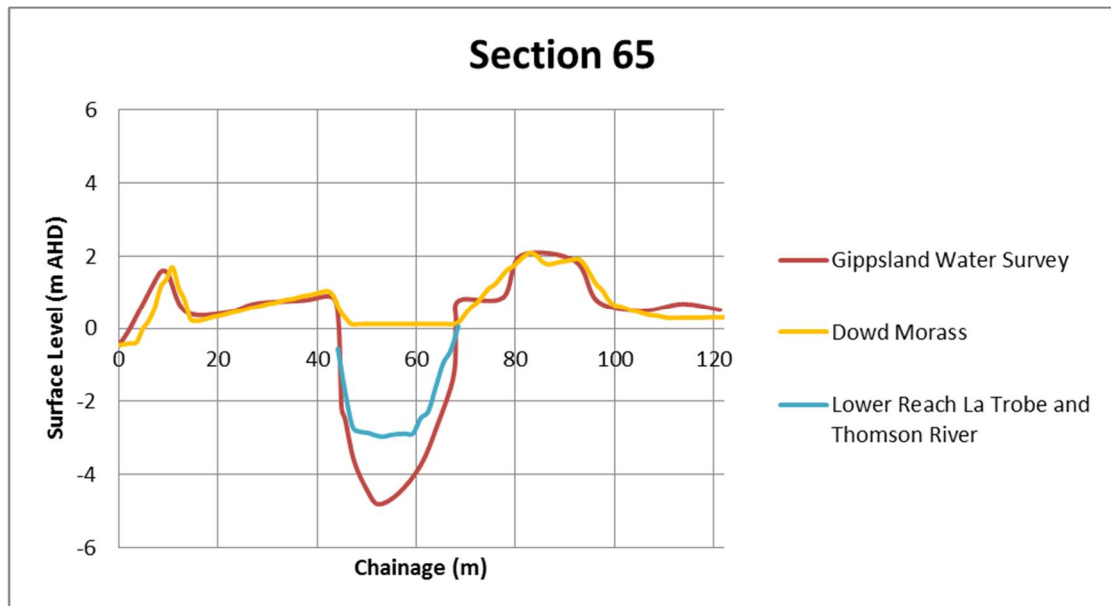


Figure 9-12 Latrobe River Survey Cross Section 65 compared to Lower Reach Latrobe and Thomson River bathymetry

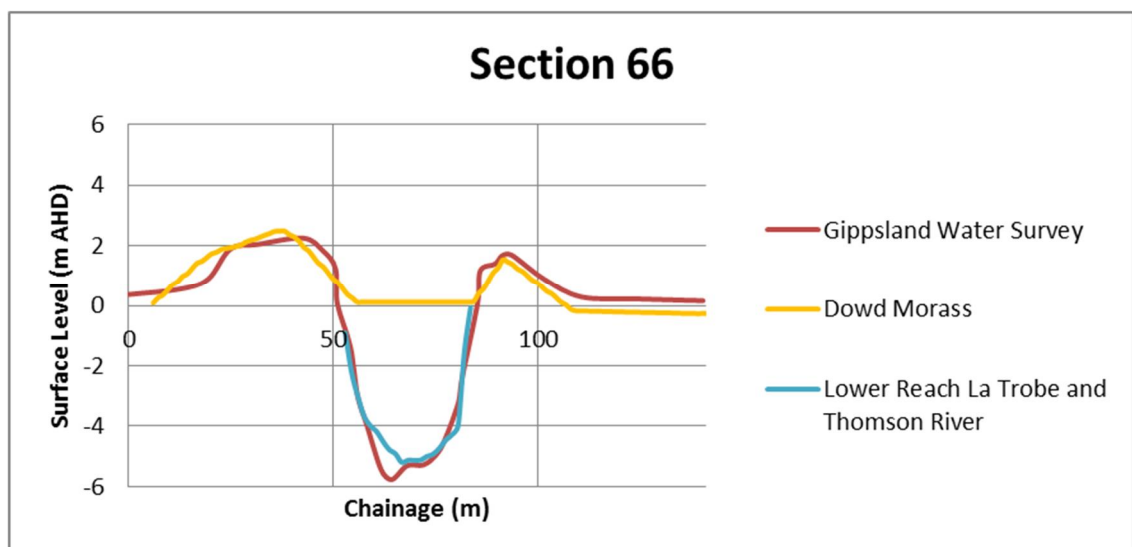


Figure 9-13 Latrobe River Survey Cross Section 66 compared to Lower Reach Latrobe and Thomson River bathymetry

Comparison to the Gippsland Water Survey confirms that the best performing dataset, in terms of bathymetry is the Lower Reach Latrobe and Thomson River bathymetry DEM.

9.5 Summary

All LiDAR datasets were found to accurately represent the vertical topography within the study area based on the comparisons to each dataset, the State PSM network data and the cross

section data. Within the Dowd Morass Reserve area the lower reach Latrobe and Thomson River bathymetry DEM was found to be the best performing.

Based on the findings of this analysis the final DEM used for the hydraulic model is (in order of highest priority to lowest):

- 1) Lower reach Latrobe and Thomson River bathymetry
- 2) Dowd Morass
- 3) Macalister Irrigation District

Whilst the West Gippsland River LiDAR was found to accurately represent the terrain it was decided to not use this dataset in the hydraulic model to minimise the number of boundary edge discrepancies that can occur where different datasets are used.

As mentioned above the DEM used a combination of a number of data sources. There were a number of areas in the Dowd Morass DEM that appeared to approximate the terrain. These issues were discussed with the WGCMA before the WGCMA advised that the Dowd Morass DEM be adopted (personal communication, WGCMA, 5/6/17).

Part of the reason for the decision to use the Dowd Morass was that it included ground survey data. This is particularly important in the floodplain areas where there are water bodies because the ground survey picked up the bed levels. In the Dowd Morass DEM in the floodplain away from water bodies it can be seen from the triangulation that the surveyor has picked up key features as well as levels more generally across the floodplain, but the spacing of the points is less dense than is in the Macalister River Irrigation District LiDAR data over the same area. This means the Digital Terrain Model (DTM) based on ground survey is less detailed appearance compared with the LiDAR data, but it is expected that the ground survey will generally be more accurate than LiDAR data so was used in preference. In these dry floodplain areas the Dowd Morass DTM is generally lower than the Macalister River Irrigation District LiDAR data, typically around 200 mm. Importantly it is expected that the differences between the DTM's will have very little impact on flood levels as the depths are significant and this part of the floodplain acts like a giant "bathtub" where the level is influenced in part by the tailwater levels. When using multiple DEM/DTM data sources in flood modelling and mapping there is invariably a ground level discontinuity along the interface between the DTMs. Where there are significant flood depths and the discontinuity is not significant compared with the depth, as is the case here, then the discontinuity will not noticeably impact on flood levels. It does mean that it may be evident in depth mapping, but this is unavoidable without significant effort to artificially transition the datasets.

10 Hydraulic Model

This section documents the hydraulic model development and calibration process undertaken for the study. The model was developed to provide the flood mapping component of the study. Specifically, this sections documents:

- n The hydraulic model development
- n Calibration and validation of the hydraulic model
- n Draft 1% AEP design event modelling.

10.1 Hydraulic Model Development

To determine the various mapping outputs required for the study, specifically flood extent, flood depth, flood height, velocity, hazard and other hydraulic properties, a two-dimensional (2D) hydraulic model was developed. For the Lower Thomson Flood Investigation study a linked 1D/2D hydraulic model was developed using TUFLOW High Performance Computing (HPC). TUFLOW HPC solver uses an explicit finite volume solution scheme.

Within the TUFLOW HPC model the waterway and floodplain were represented in the 2D domain, with culverts represented as embedded 1D elements. The benefits of modelling the waterways and floodplain in the 2D domain include:

- n Explicitly represents the spilling and remerging of flows between the waterway and the floodplain
- n Explicit modelling of bend losses
- n Accounts for contraction and expansion losses through constrictions
- n Better representation of velocity across the waterway by providing cell-by-cell velocities across the waterways rather than limited to a horizontally averaged velocity.

Model inflows were extracted from the hydrologic model developed for the catchment, documented in the hydrology report (HARC, 2017).

10.1.1 TUFLOW Model Version

Model runs were performed with the latest version (at time of assessment) of TUFLOW HPC, specifically, 2017-09-AC-iSP-w64.

10.1.2 Model Extent

On the Lower Thomson River the hydraulically modelled study area extends from 4.5 km west of Maffra-Rosedale Road. The northern extent of the model was located on the Macalister River approximately 1 km south of the Maffra. The south-west extent of the model is located near Crooks Lane on the La Trobe River.

Lake Wellington formed the downstream boundary of the hydraulic model.

The hydraulic model extent is shown in Figure 10-2.

10.1.3 Topography

The geometry of the 2D floodplain and watercourses were established by reading in a uniform grid of square elements from the DEM. This grid (or zpt layer) forms the basis of the hydraulic modelling of the catchment by providing the topography. The DEM used in the hydraulic model was based on the three digital elevation datasets as detailed above in Section 9.

10.1.4 Grid Resolution

One of the key considerations in hydraulic modelling is the selection of an appropriate grid element size. Grid element size affects the resolution, or degree of accuracy, of the representation of the physical properties of the study area as well as the size of the computer model and its resulting run times. Selecting a smaller grid size will result in both higher resolution and longer model run times.

To ensure accurate representation of flooding within the catchment a grid size of 5 metres was adopted for the model. In adopting this grid size, the above issues were considered in conjunction with the final objectives of the study. TUFLOW HPC treats each square grid element in a similar manner as TUFLOW Classic, with each grid containing information on ground topography, sampled from the DEM and surface resistance to flow (Manning's 'n' value) at $\frac{1}{2}$ the grid resolution. In effect each grid cell is made of 9 information points which allows control of hydrodynamic elements, such as flood depth, volume and spilling at a sub-grid scale.

Watercourses

The waterways within the system are categorised as highly sinuous with significant anabranches and waterholes consistent with a river system that has migrated around the floodplain. Typically, these are a minimum of 20-30m wide. On the 5 metre grid adopted for this study the waterways were represented by a minimum of 4 grid cells. This is within the range recommended by the TUFLOW manual as suitable.

Hydraulic Controls

Levees, irrigation channels, railway embankments and roads form hydraulic controls within the study area. Control levels on select levees, irrigation channels and roads crests were specially captured within TUFLOW using z-lines. The hydraulic controls that were specially captured were those that were narrow and hence the 5 m model grid resolution may not have sufficiently defined the control levels of the feature. Conversely, wider controls, such as most roads and the railway embankment were found to be well defined by the 5 m model grid and hence did not need additional emphasis or reinforcement.

10.1.5 2D Hydraulic Structures

Large hydraulic structures for this study consist of the bridges over the various waterways. It is important to ensure that these impediments and constrictions to flow are accurately represented. Due to their large size these structures are modelled in the 2D model domain. The location of these bridges is shown in Figure 10-2.

Bridge structures were modelled as layered 2D flow constructions with the appropriate losses derived from Waterway Design: A Guide to the Hydraulic Design of Bridges, Culverts and Floodways (Austroads, 1994). The layered flow constrictions used to model these bridges allows for typical bridge characteristics such as deck height and thickness, pier shape and width and blockages associated with guard or hand rails to be directly incorporated into the 2D domain.

The details of these were extracted from supplied plans for the major bridges owned and managed by VicRoads and VicTrack. For a number of Council bridges, plans were unavailable. Where plans were not available the losses and dimensions were estimated based on typical bridge configurations and loss parameters.

VicRoads has undertaken considerable road works since 2002 on the Princess Highway and South Gippsland Highway. These works include duplication on the Princess Highway and the elevation of the South Gippsland Highway. These structures were not included in the hydraulic model during the calibration as they would potentially add additional hydraulic losses. These structures were included in the modelling of the design events.

10.1.6 1D Hydraulic Structures

Small, sub-grid sized, hydraulic structures such as culverts were modelled as 1D elements dynamically linked to the 2D domain. The details of these culverts were provided by Council. Only the culverts provided by Council were included in the model. It is likely that there would be other minor culverts in the catchment, the details of which were not available. The exclusion of these minor culverts from the model would not influence the results of the model given their small size in comparison to the volumes of water in the floodplain.

The location of each of the culverts included in the model are shown in Figure 10-2.

10.1.7 Boundary Conditions

A typical hydraulic model incorporates three different boundary conditions. These are:

- n Inflow boundaries
- n Outflow boundaries
- n Linking boundaries.

Inflow Boundaries

Inflow boundaries consist of two types, external and lateral inflows. External inflows are those occurring at the extremities of the hydraulic model, and lateral inflows are the runoff inflows from contributing areas that occur within the 2D model domain. These inflow boundaries were determined from the hydrologic model developed for this study and documented in Section 11. A rainfall runoff model (RORB) was established for the entire catchment. The RORB model was then calibrated to a number of historical events and then verified to a number of gauges within the catchment. Flows were extracted from the RORB model to place into the hydraulic model. These inflow boundaries were applied as unsteady (flow vs. time) boundaries directly to the individual watercourses in the 2D domain.

For the lower Thomson study there were four upstream inflow boundaries. These were located at the upstream extent of Thomson River, Boggy Creek, Macalister River and the La Trobe River.

The hydraulic model included an additional 12 inflow boundaries representing the lateral inflows that occur from contributing catchment areas within the 2D model domain. These were applied as distributed (flow over area) inflows.

Outflow Boundaries

The downstream boundary was located at Lake Wellington. For the calibration events a height-time relationship was placed into the model which was taken from the observed levels within Lake Wellington.

For the design events the maximum level reached in Lake Wellington was based on the inflow volume of the design hydrograph. Figure 10-1 shows the relationship used between volume of the inflow hydrograph and the level in Lake Wellington. The relationship between volume and the levels in Lake Wellington was based on the 314 flood events modelled during the “Gippsland Lakes – Flood Level Modelling Project” by Grayson et al. Appendix J details the analysis undertaken to derive the relationship in Figure 10-1.

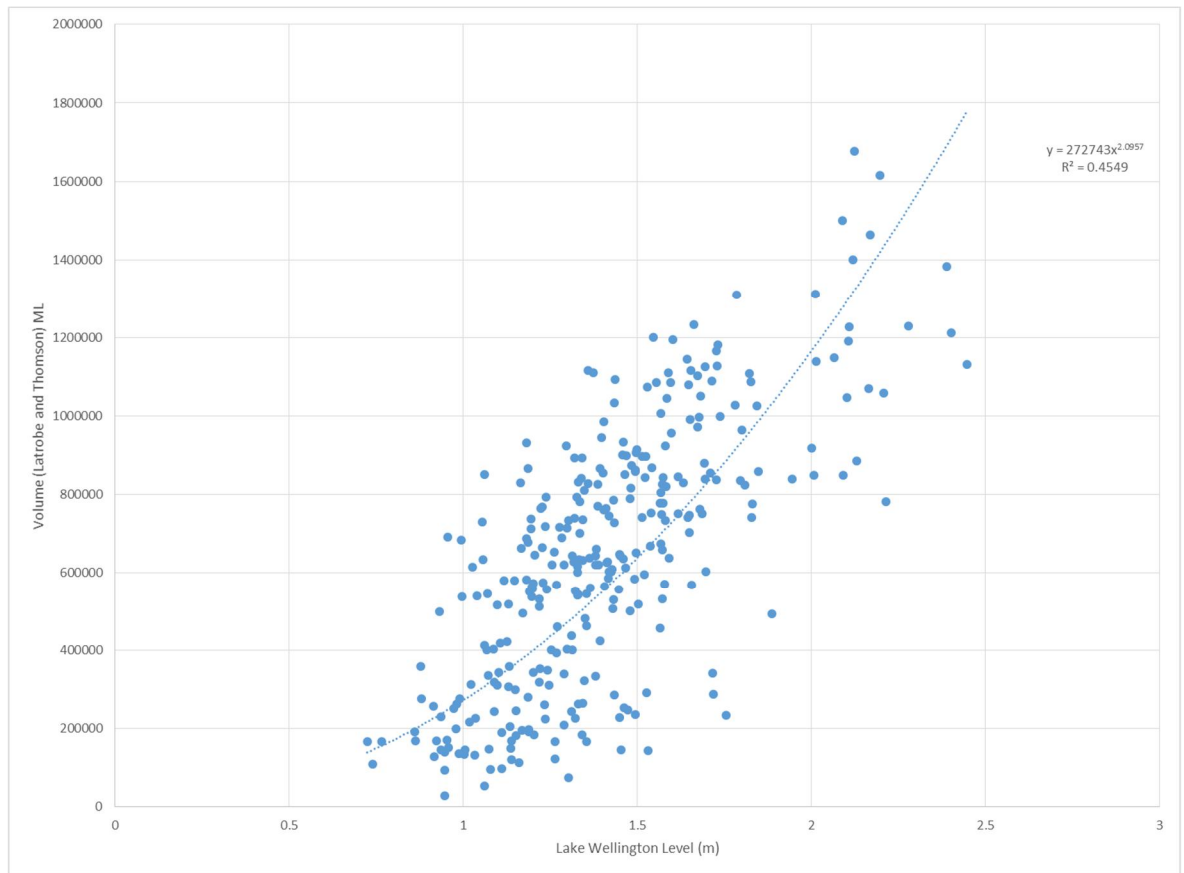


Figure 10-1 Relationship used for the downstream boundary condition

The downstream boundary was setup as a one-way weir attached to a steady state level in Lake Wellington. In this configuration floodwaters cannot leave the model until the levels in the 2D domain exceed the level in Lake Wellington. This is a conservative approach to allowing water to leave the model as in reality some water would leave whilst the lake rises, whilst at the same time not introducing additional volume of water into the model that should not occur.

Sensitivity testing of the downstream boundary was trialled for the 1 in 100 (1%) AEP flood event with the downstream flood level varied between 0.43 m AHD and 2.2 m AHD. The findings of this sensitivity testing showed that, where there are people at risk, the peak flood levels were not overly sensitive to downstream tail levels within Lake Wellington (refer to Appendix J for details of the sensitivity analysis).

Linking Boundaries

As described above in Section 10.1.6, the hydraulic model incorporated a number of 1D elements that were dynamically linked to the 2D domain. These links were located at the upstream and downstream of each of the culverts to allow flows to interchange water between the two domains. Each culvert had an appropriate entrance and exit loss applied to the 1D element. The number

of grid cells for each 1D/2D link was selected to ensure that the links were not introducing additional entrance or exit losses.

10.1.8 Surface Roughness

The surface roughness layer, or Manning's 'n' layer, for the floodplain were based on areas of different land-use type as indicated in the planning scheme, aerial photography and during the site inspections. Initially these values were based on standard texts such as Open Channel Hydraulics (Chow 1959), but they were refined during the calibration and validation process (Refer Section 10.2). The adopted manning's values are shown in Table 10-1 and the surface roughness layer is shown in Figure 10-3.

Table 10-1 Surface Roughness Values

Land Use	Manning's 'n'
Farms, Residential & Industry	
Roadways (including reserve)	0.025
Low Density Residential Areas	0.100
Residential Areas	0.200
Commercial and Business Areas	0.300
Services and utilities	0.040
Railway	0.040
Cemetery	0.080
Schools	0.060
Farm Zones	0.060
Parks & Waterways	
Open Channel	0.035
Parklands and Reserves	0.040
Conservation and Resource Zones	0.080
Scattered Vegetation, Grassy or Shrubby Channel	0.080
Moderate Vegetation	0.100
Dense Vegetation	0.150
Sale Common & Morass Waterholes	0.040

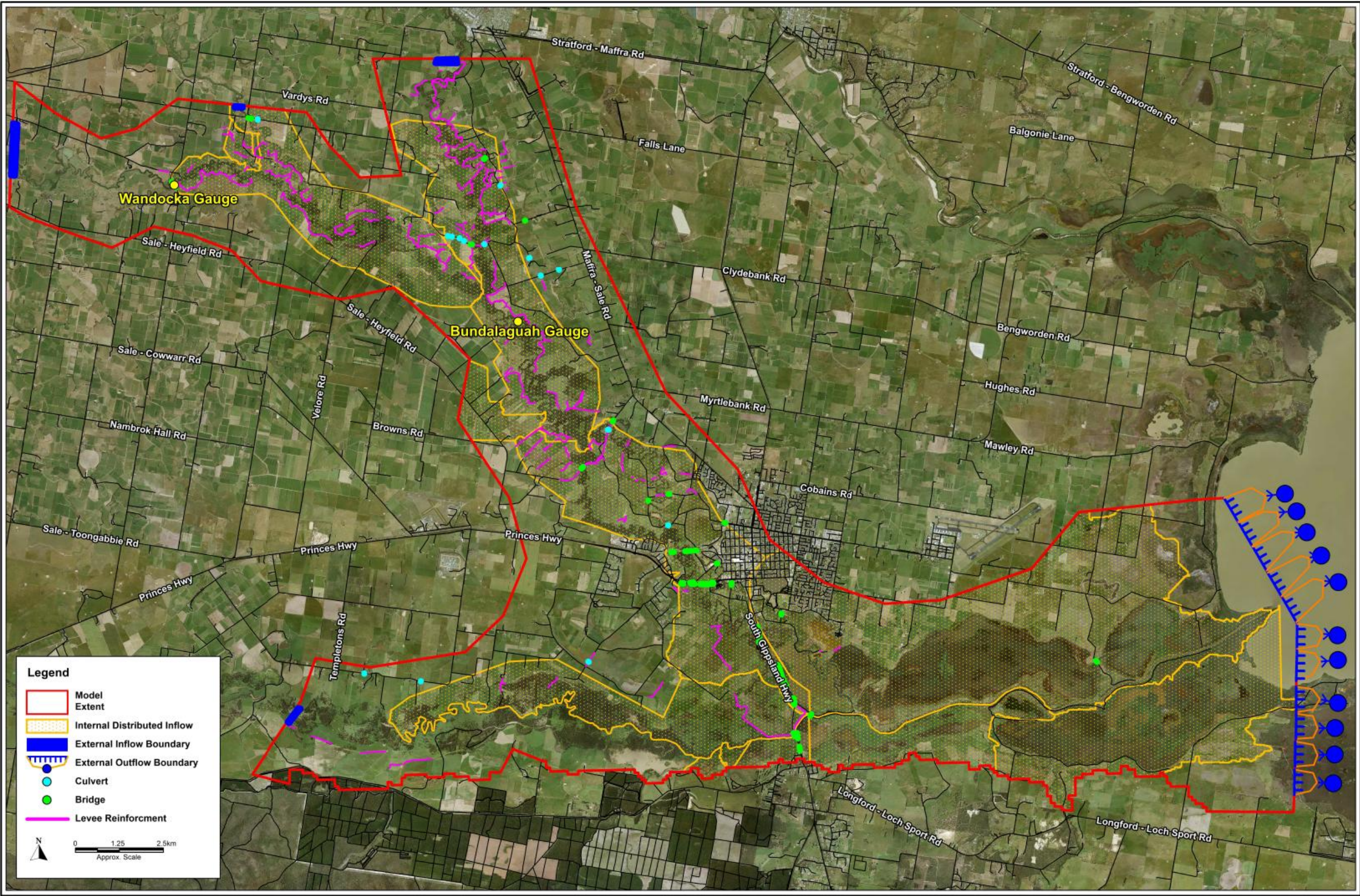


Figure 10-2 Hydraulic Model Schematisation

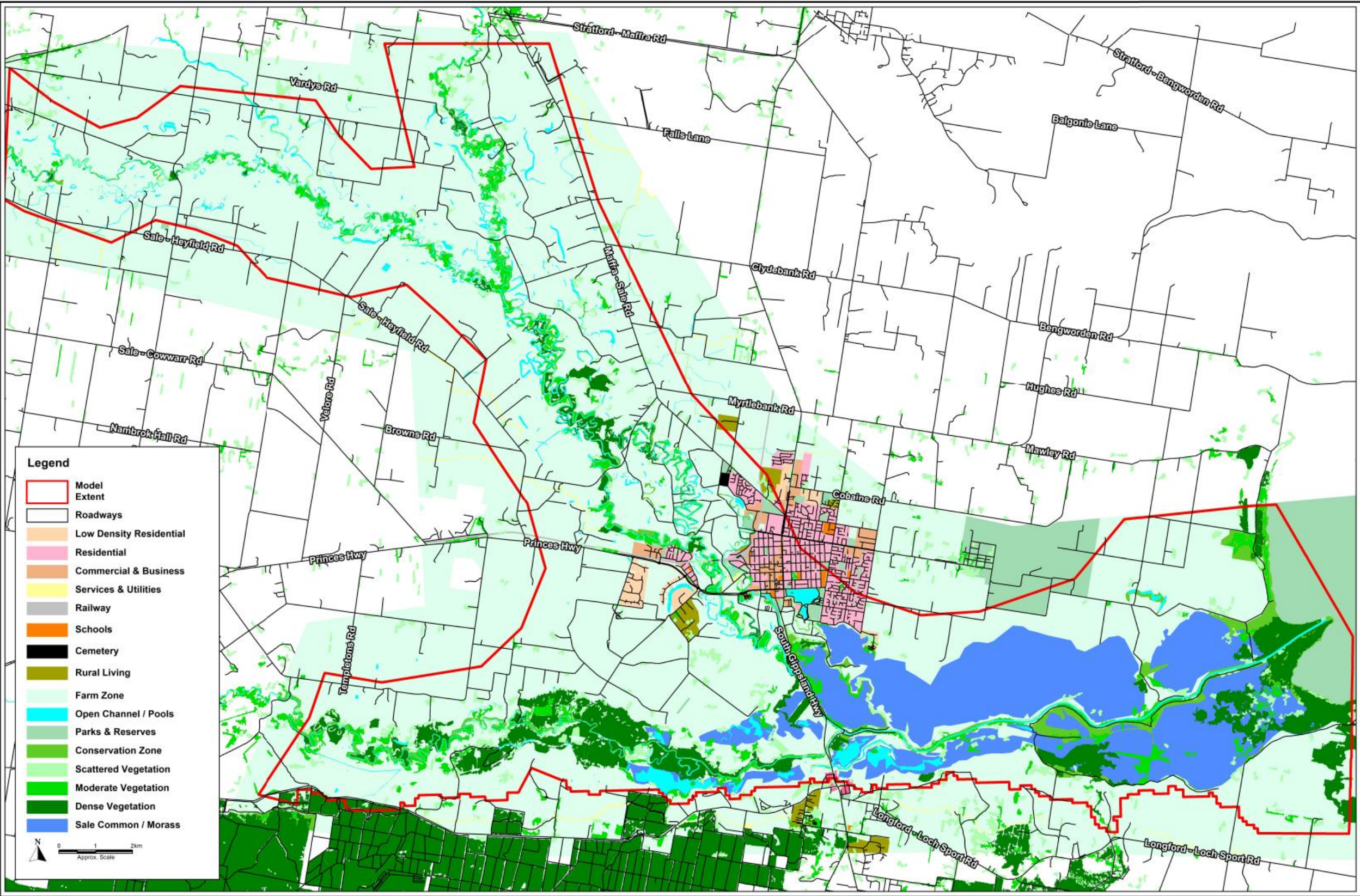


Figure 10-3 Surface Roughness Distribution

10.2 Hydraulic Model Calibration & Validation

The calibration of the hydraulic model is a critical process of any model development. Best practice in model calibration considers all available historic information, which typically would include stream gauge, historic flood extents and flood marks. A review of available data showed that for the purposes of model calibration the best events were 1978, 1993 and 2007.

The 1978 was the largest flood event experienced by many in the community and was also the event with the largest amount of survey marks. The 2007 flood event was significant on the Thomson River and Macalister River however very little rain fell on the Latrobe River catchment. Considerable survey was undertaken following this event, mostly along the Thomson and Macalister Rivers. In comparison the 1993 flood event was relatively small and as a consequence only a small amount of flood marks were surveyed, with all flood marks in the Sale region.

For this study a model calibration and validation process was undertaken. Specifically, the hydraulic model was calibrated to the events with the greatest amount of available data (1978 and 2007). Through the calibration process parameters were adjusted within typical bounds until an acceptable fit to the historic information was achieved. The model was then validated by running the 1993 flood event through the model and comparing to the historic gauge data and flood marks.

The calibration and validation process undertaken for this study are outlined below:

1. Collect and verify if possible relevant historic data including flood marks, flood extents and stream gauge information;
2. Event selection;
3. Hydrologic model calibration, as described in Section 7;
4. Optimise the TUFLOW model parameters for the calibration events within typical bounds;
5. Jointly iterate the hydrologic and hydraulic modelling through a feedback process; and
6. Validate the TUFLOW model against an independent flood event.

The following section document the results of the calibration and validation process whilst the adopted parameters are documented above in Section 10.1.

10.2.1 Hydraulic Model Calibration Event – 1978

The 1978 flood event is the largest event in living memory within the catchment and unlike the more recent 2007 flood event, the 1978 event was a considerable event on all three major tributaries. Due to the significance of the flood event a great deal of data was captured following the event. This included 273 flood marks listed in the Victorian Flood Database and digitised GIS flood extents.

As discussed in Section 5.2, for the 1978 event the RORB model could not replicate the flow at 225212 (Thomson River @ Wandocka) if the flow at 225231 (Thomson River @ U/S of Cowwarr

Weir) was replicated and vice versa. This was discussed with Ventia and it was noted that “the rating for 225231 is extrapolated beyond approximately 382 m³/s, which is the highest gauging conducted at the site. The rating for 225212 is extrapolated beyond approximately 434 m³/s which is the highest gauging conducted at the site. The current rating at 225212 displays that the river has broken out on to its flood plain while the rating at 225231 does not give this indication”. Given the location of the sites this variation is expected and was confirmed during the rating curve review of 225212 (refer to Section 5.3.1) but does not explain why 225231 has much higher flows than 225212. In consultation with the WGCMA it was decided to match the flow at 225231 as the gauge is located in a defined cross section and therefore there is likely to be more certainty in the rating curve. In addition to the above, as the RORB model matches the flows estimate at 225232 (Thomson River @ Bundalaguah) well this adds confidence in the RORB estimates at 225231, which flows into 225232.

Figure 10-5 and Figure 10-6 present the modelled and observed flood level comparison for the Bundalaguah (225232) and Wandocka (225212) gauges. The calibration at the Wandocka gauge was overall good with a peak difference of 0.10 m which could be conceivably accounted for in small sub-grid scale water level differences in the vicinity of the gauge, or alternatively local runoff or other localised sub-grid effects. The fit at the Bundalaguah gauge is similar. The initial mismatch at the start of the event, particularly at Bundalaguah, is an artefact of the hydrological input where the start of the hydrograph initially rises faster than the observed hydrograph. This offset could be due to a number of issues such as the temporal patterns, losses and the assumptions on baseflow.

Whilst numerous flood marks are available for the 1978 event, close inspection of the flood marks raised concern over the reliability of many of the recorded flood marks. The concerns were raised based on:

- n The horizontal alignment of the marks appears to be scaled off historic maps. This is evident by what appears to be two separate attempts to locate each of the marks; this is why there is commonly two marks in close proximity. At some locations the marks are located on different sides of a hydraulic control (e.g. road or levee) where there is a significant difference in flood level but the marks have the same level. An example of this is presented below in Figure 10-7.
- n Inconsistent flood levels down the waterway were identified. Two types of inconsistency were identified. The first was where levels were found to increase in the downstream direction without an obvious hydraulic explanation. This is demonstrated in Figure 10-7. The second type of inconsistency is where significant variance was found within a local area. An example of this is demonstrated at the Princes Hwy where there is nearly 3 metres of vertical differences in the flood marks as shown in Figure 10-8.
- n Lastly, for almost all flood marks, the vertical level has been rounded to the nearest 0.1 metres which means that up to 50 mm discrepancy with the flood model could occur as a result of the rounding.

Flood marks that were obviously inconsistent with each other were removed from the assessment. Only flood marks that were inconsistent with other flood marks and were clearly erroneous were removed. Flood marks that were not consistent with the modelling results were retained with no effort made to alter the narrative of the calibration result by removing outliers. Duplicate points were also removed. In total 135 marks were removed with 138 remaining. Whilst this means a large percentage of the flood marks were removed, most of these were duplicate points as demonstrated in Figure 10-7. A statistical summary comparison of the observed and modelled flood levels is presented in Table 10-2 and visually in Figure 10-4.

Figure 10-14 presents the modelled flood extent along with a spatial comparison of the modelled and observed flood level at the flood marks. Overall a very good calibration was achieved based on a comparison with the flood extent and flood marks. Generally, the flood extent matched very well with the flood marks, however this is not overly surprising given the contained floodplain. Approximately 80% of the floodmarks were within ± 200 mm with the remainder split higher (9%) or lower (11%).

Based on the available records it is believed that overall a very good calibration has been achieved.

Table 10-2 Statistical Summary of Comparison of Observed and Modelled Flood Levels - 1978 Flood Event

Data Source	Historic Flood Heights
No. of Points Interrogated	138
Mean	0.00
Median	-0.02
Standard Deviation	0.21
Lower Quartile	-0.12
Upper Quartile	0.09

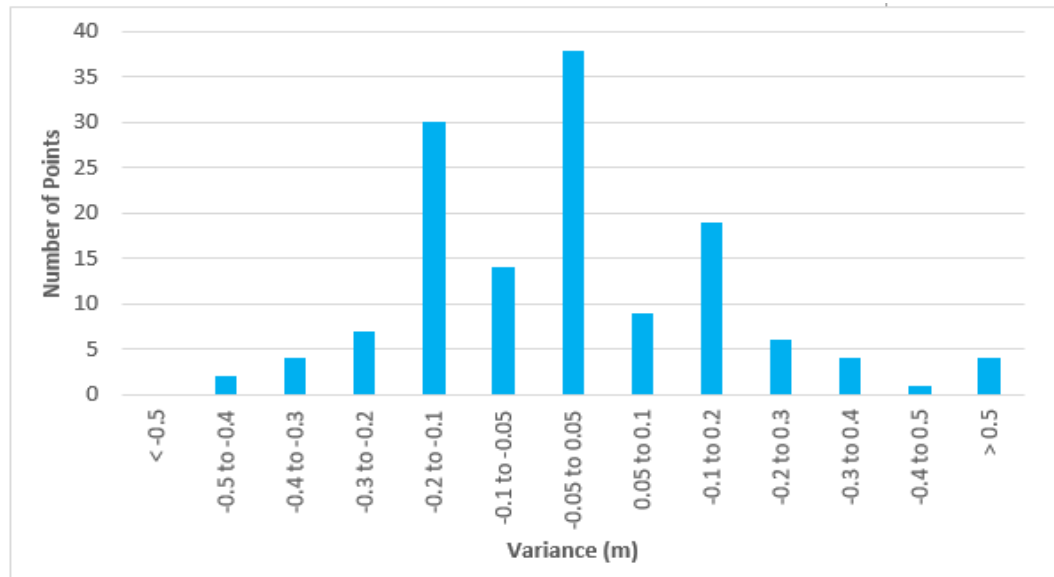


Figure 10-4 Statistical Summary of Comparison of Observed and Modelled Flood Levels - 1978 Flood Event

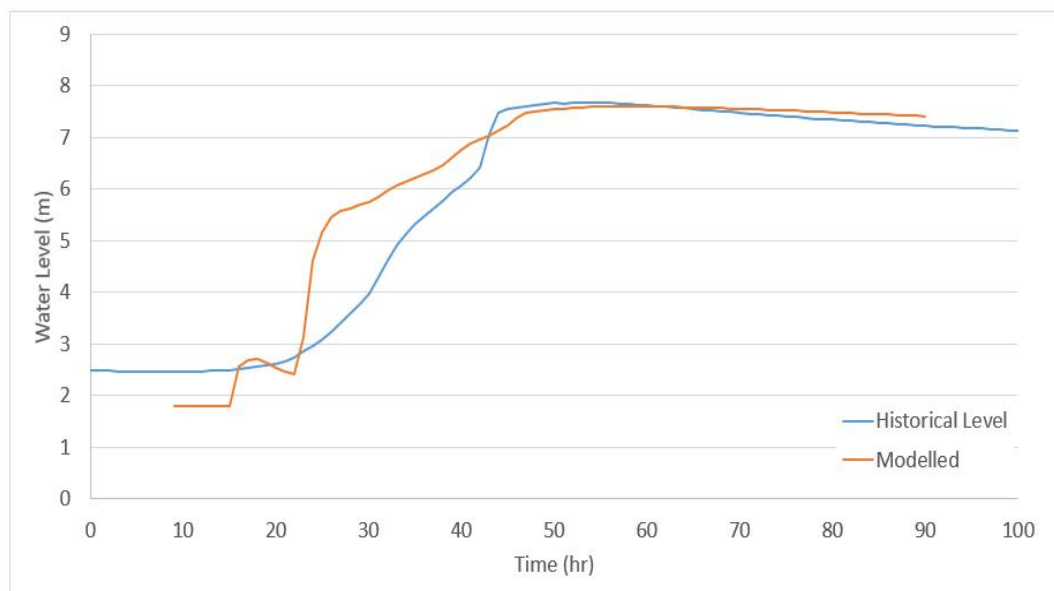
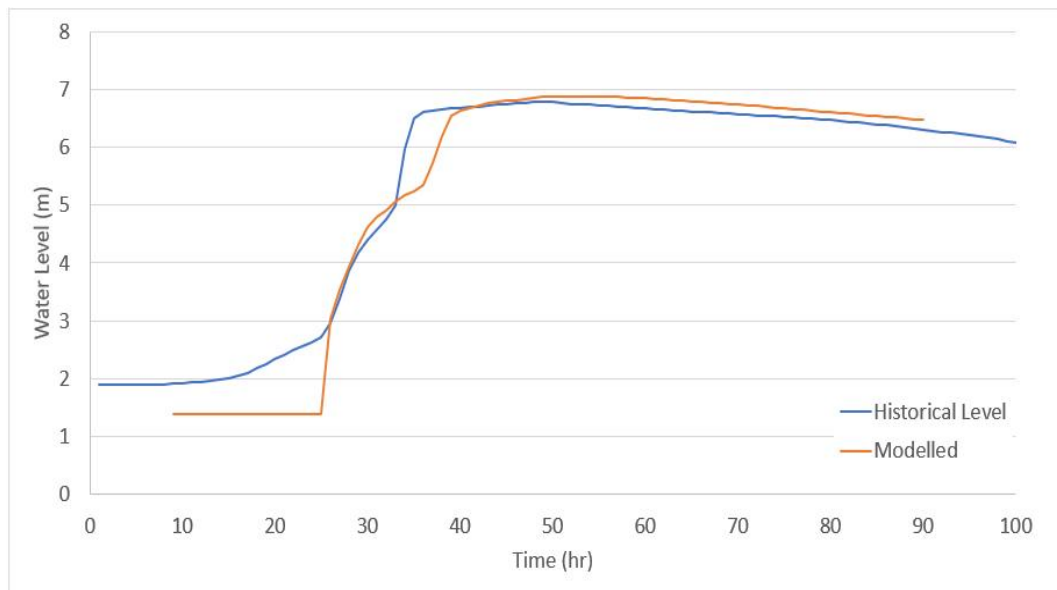


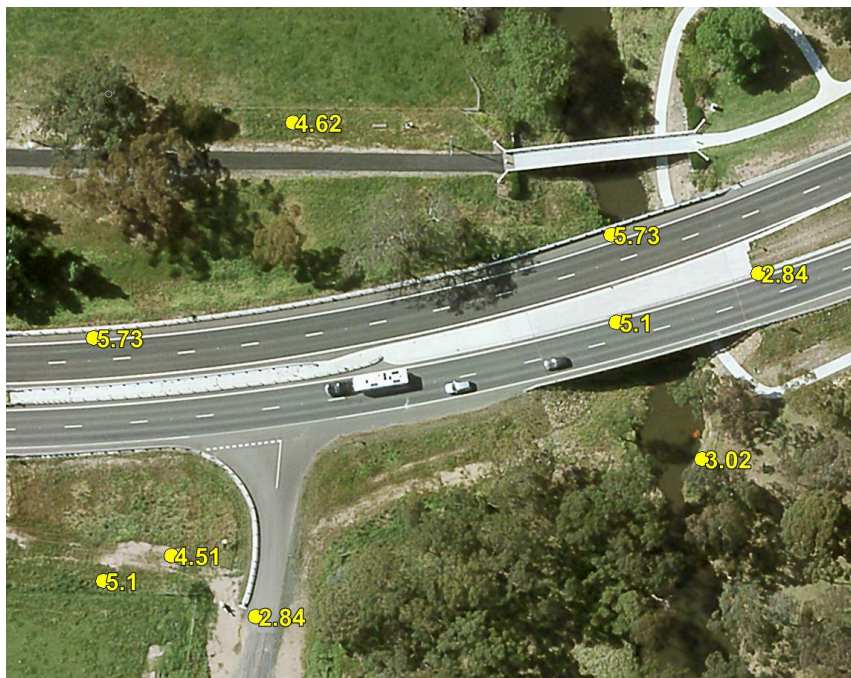
Figure 10-5 Calibration Results 1978 Event - Bundalaguah Gauge



n **Figure 10-6 Calibration Results 1978 Event – Wandocka Gauge**



n **Figure 10-7 Example of duplicate flood marks indicating potential horizontal error and inconsistent vertical levels of 1978 flood marks**



n **Figure 10-8 Example of inconsistent vertical levels of 1978 flood marks**

10.2.2 Hydraulic Model Validation Event – 2007

The 2007 flood event was similar to the 1978 flood event on the Thomson and Macalister Rivers, however it was significantly smaller on the Latrobe River with almost no response from the catchment. For the 2007 event, 83 flood marks were captured along with a digitised flood extent. A statistical summary comparison of the observed and modelled flood levels is presented in Table 10-3 and visually in Figure 10-9.

As with the 1978 event the RORB model could not replicate the flow at 225212 (Thomson River @ Wandocka) if the flow at 225231 (Thomson River @ U/S of Cowwarr Weir) was replicated and vice versa. For the 2007 event the flow at 225212 was half of that at 225231. This was discussed with Ventia and there was some recollection that this anomaly had been noted in the past. However, no documentation was available to confirm the reason. As with the 1978 event it was decided to match the flow at 225231 (Thomson River @ U/S of Cowwarr Weir) rather than 225212 (Thomson River @ Wandocka).

Figure 10-10 and Figure 10-11 present the comparison of the modelled and observed flood depths at the Bundalaguah and Wandocka gauges respectively. Similar to the 1978 event, other than time shift, inherent in the hydrology, the model closely reproduced the Wandocka gauge flood levels, general shape and peak levels. At the Wandocka gauge the modelled peak flood level was within 26 mm of the observed. The comparison is not as good at the Bundalaguah

gauge where the modelled flood level is 130 mm lower than the observed. This difference is consistent with the difference at the flood mark to the west of the gauge which reported a similar difference (160 mm).

As shown in Figure 10-15, the digitised GIS flood extent was found to be a very good match with the modelled flood extent. The comparison to flood marks shows that approximately 70% of flood marks were within ± 200 mm with the remainder distributed higher (25%) and lower (5%).

Table 10-3 Statistical Summary of Comparison of Observed and Modelled Flood Levels - 2007 Flood Event

Data Source	Historic Flood Heights
No. of Points Interrogated	83
Mean	0.07
Median	0.05
Standard Deviation	0.22
Lower Quartile	-0.09
Upper Quartile	0.21

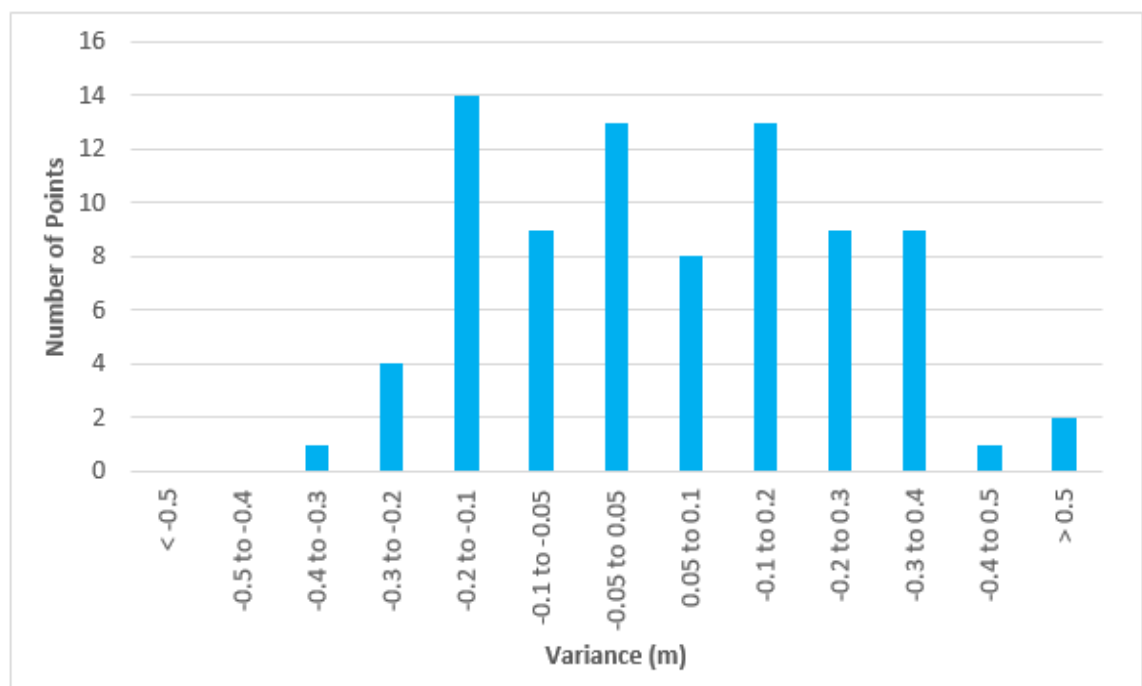
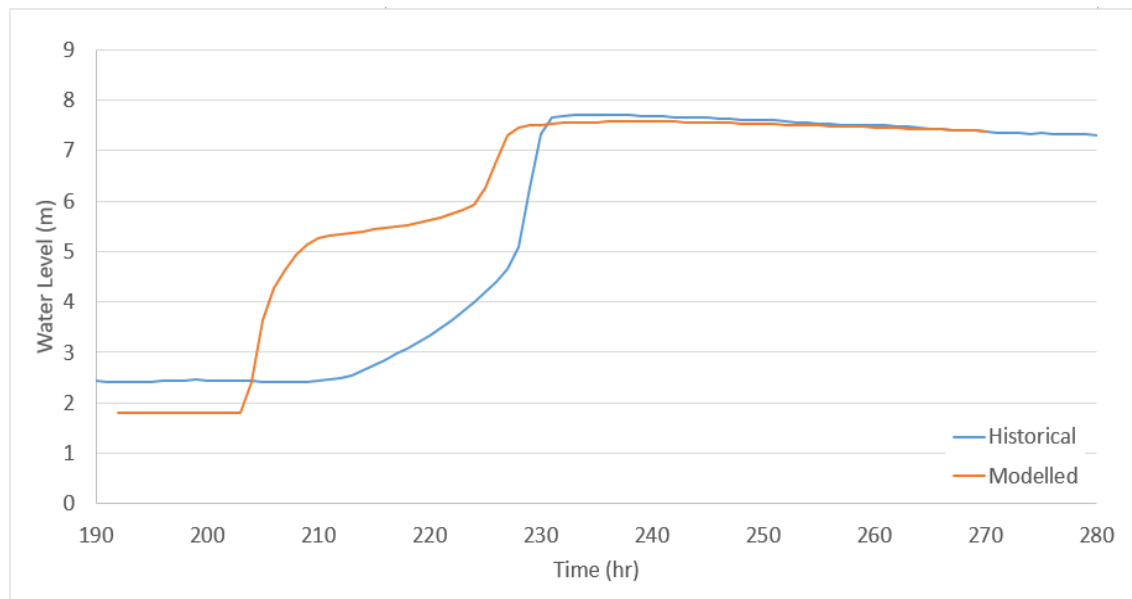
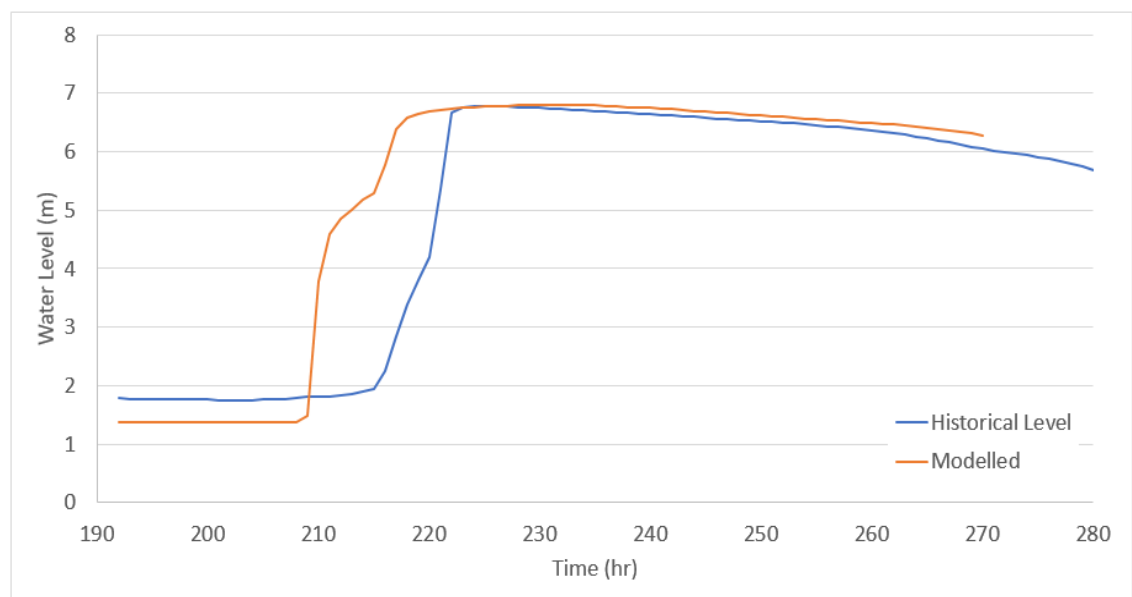


Figure 10-9 Statistical Summary of Comparison of Observed and Modelled Flood Levels - 2007 Flood Event



n **Figure 10-10 Validation Results 2007 Event - Bundalaguah Gauge**



n **Figure 10-11 Validation Results 2007 Event – Wandocka Gauge**

10.2.3 Hydraulic Model Validation Event – 1993

The 1993 flood event was the smallest flood event investigated in this study. As such comparatively few flood marks were recorded and there was no GIS flood extent to compare the model against. In total 11 flood marks were available for comparison. Further, the failure of the Bundalaguah stream gauge meant that only the Wandocka gauge is available. A statistical summary comparison of the observed and modelled flood levels are presented in Table 10-4 and visually in Figure 10-12.

The comparison between the modelled and observed flood level at the Wandocka gauge is presented in Figure 10-13. Figure 10-13 shows that other than a timeshift there is a reasonable match between the observed and the modelled given the 1993 flood event is a validation event rather than a calibration event.

The results of the validation of the 1993 event flood marks are presented in Figure 10-16. Given the limited information available and uncertainty in these flood marks the results of the model validation are reasonable with 65% of the flood marks within ± 200 mm, with the statistical analysis indicating the model is generally underestimating levels.

ⁿ **Table 10-4 Statistical Summary of Comparison of Observed and Modelled Flood Levels - 1993 Flood Event**

Data Source	Historic Flood Heights
No. of Points Interrogated	11
Mean	-0.15
Median	-0.15
Standard Deviation	0.18
Lower Quartile	-0.22
Upper Quartile	-0.04

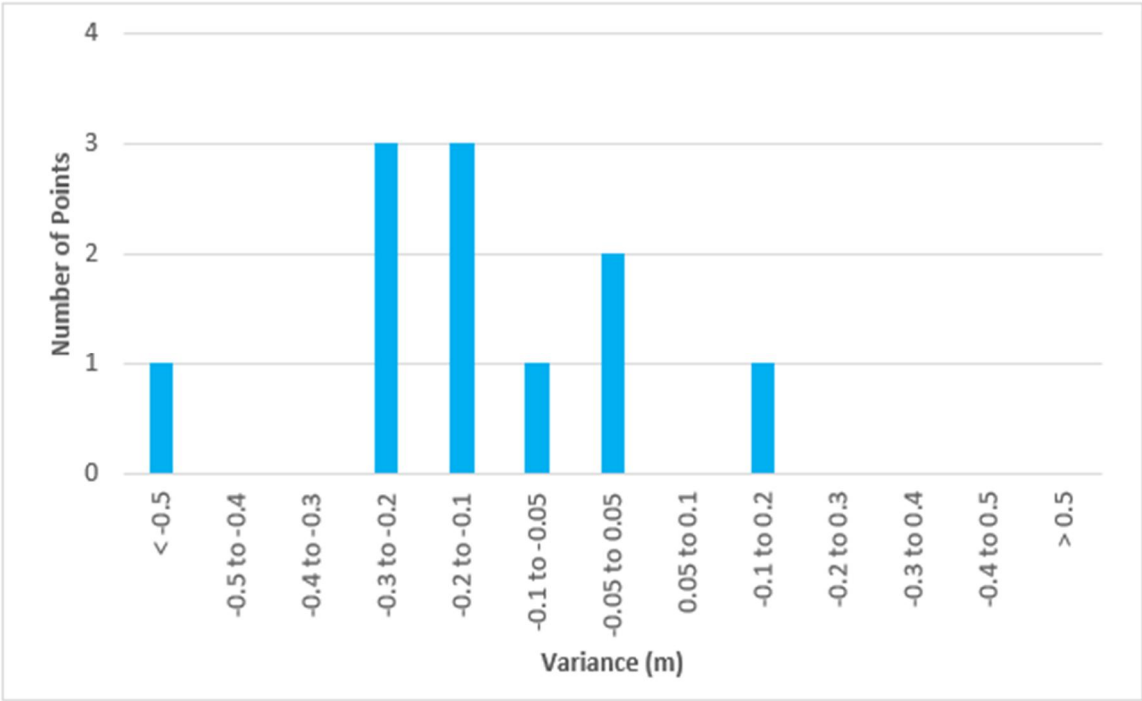


Figure 10-12 Statistical Summary of Comparison of Observed and Modelled Flood Levels - 1993 Flood Event

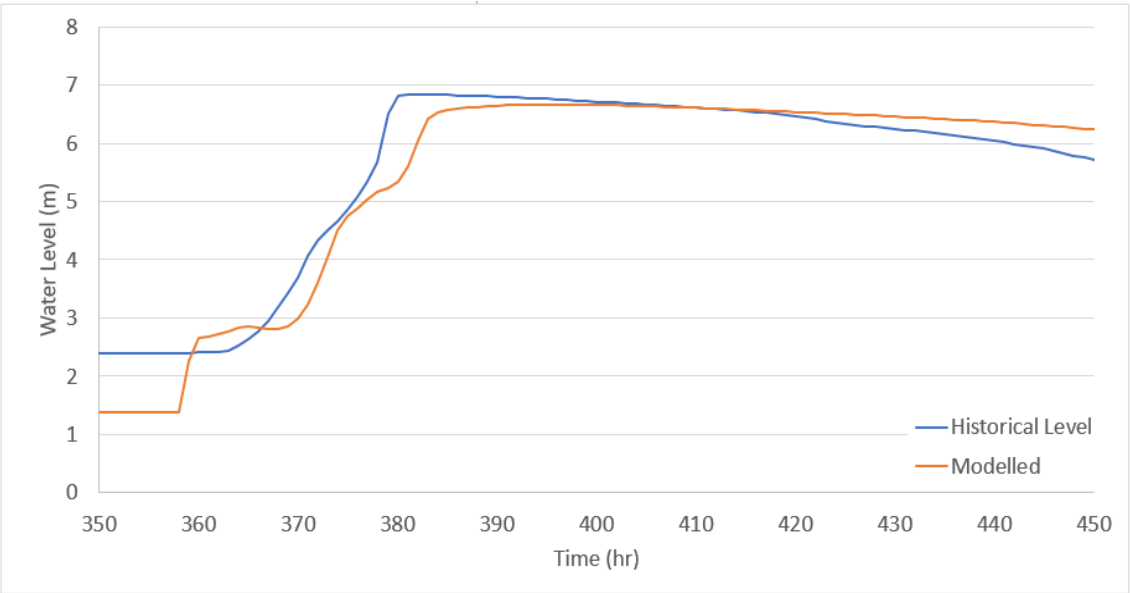


Figure 10-13 Validation Results 1993 Event – Wandocka Gauge

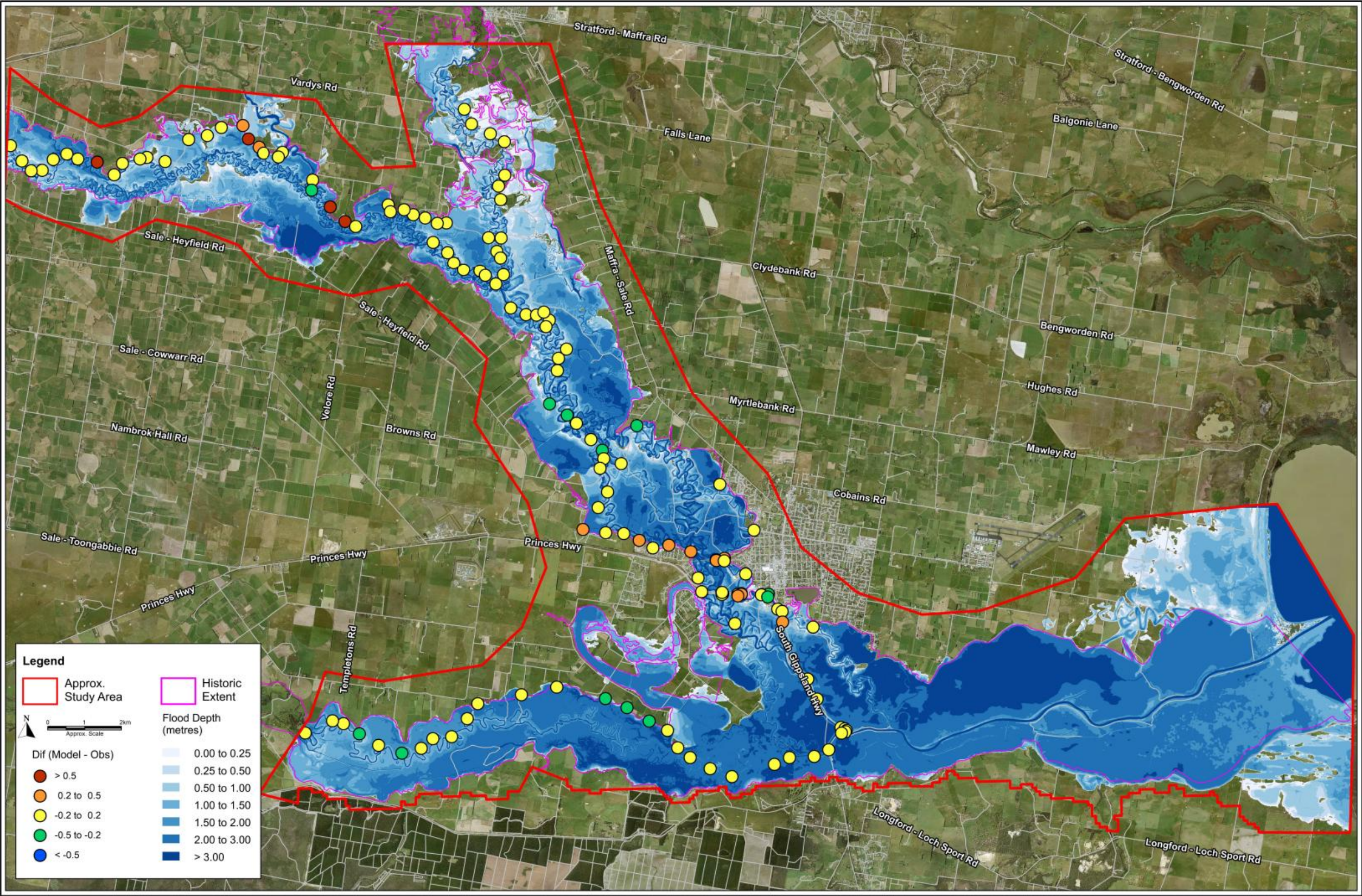


Figure 10-14 Hydraulic Model Calibration Results 1978 Event

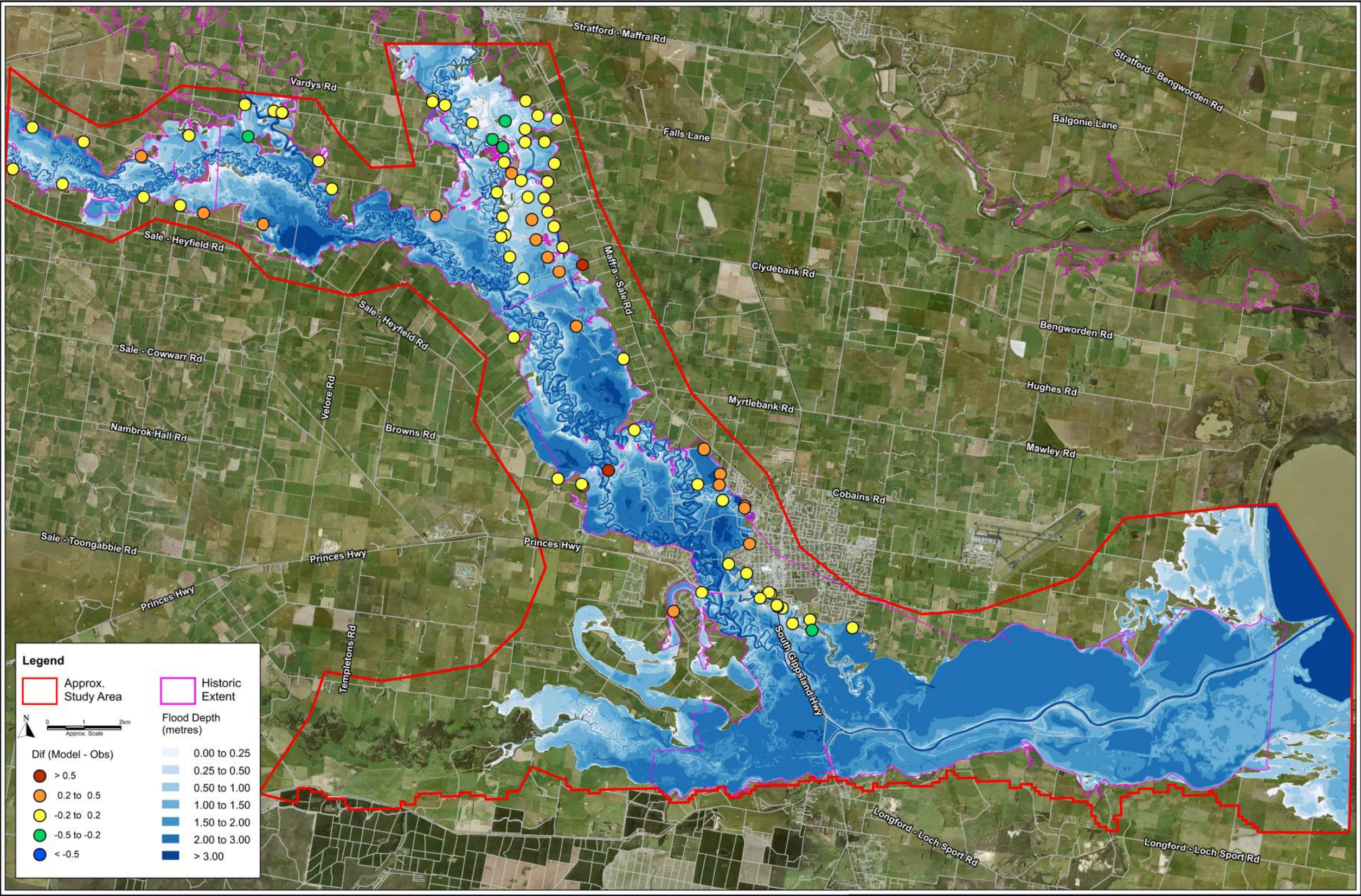


Figure 10-15 Hydraulic Model Calibration Results 2007 Event

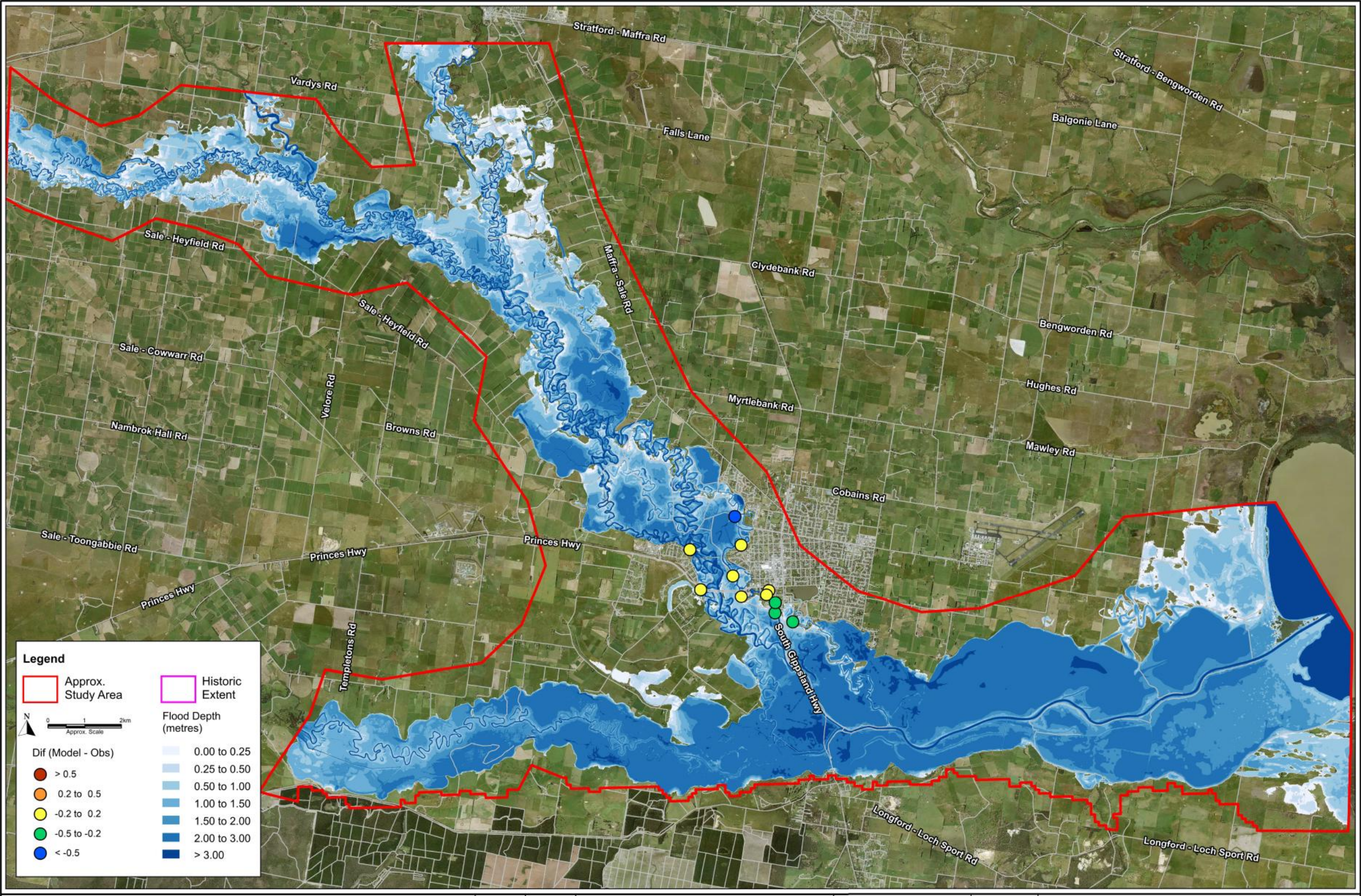


Figure 10-16 Hydraulic Model Validation Results 1993 Event

10.3 Sale wharf rating curve

As mentioned earlier a separate report was provided to the WGCMA on the rating curve review (HARC, 2018). As the gauge at Sale Wharf is used for flood warning a rating curve was developed for the gauge at Sale Wharf.

The Sale Wharf gauge is located on the relatively minor Flooding Creek waterway that skirts the western and southern edge of Sale. There is no existing rating curve for the Sale Wharf gauge. Further, there is limited information on the location of the gauge and the zero level. The location of the stream gauge has been approximated off what appears to be a gauge staff as seen in Google-Street View services and is believed to be located on the northern edge of the creek at the bend in the wharf (refer to Figure 10-17). The gauge height zero of the gauge is also unknown, it is possible that it is in m AHD but this cannot be confirmed. Therefore, the outputs of this assessment have been generated in m AHD which can be converted back to the gauge level should a professional surveying of the gauge be undertaken in the future.

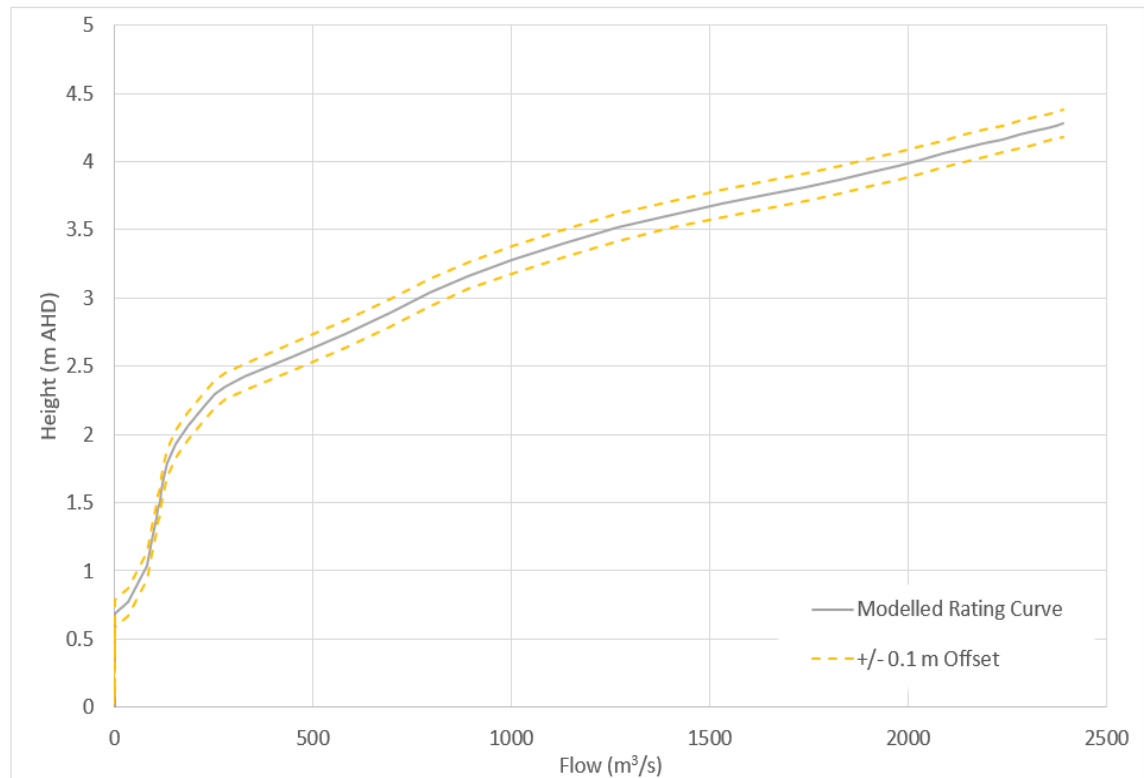
Flood waters flowing along Flooding Creek are highly interdependent on flooding along the lower Thomson River. Flooding Creek gets within 150 metres of the Thomson River at the railway crossing before the two waterways diverge with Flooding Creek running along the Sale escarpments whilst the Thomson River heads in a more southerly direction. Both waterways meet downstream of Sale immediately upstream of the South Gippsland Highway.

Due to the interactions between the Thomson River and Flooding Creek the rating curve that has been generated is based on a combined flow of the Thomson River and Flooding Creek flows. The reporting location used for the assessment relates flood level at the gauge with total flows at the Princess Highway which includes the Thomson River and overbank flows.

The rating curve is shown in Figure 10-18. To account for the various uncertainties mentioned above a tolerance of ± 100 mm offset to each of the rating curves has been added to the figures.



n **Figure 10-17 Gauge Location – Flooded Creek at Sale Wharf**



n **Figure 10-18 Modelled Rating Curve – Flooding Creek at Sale Wharf**

11 Design flood hydrology

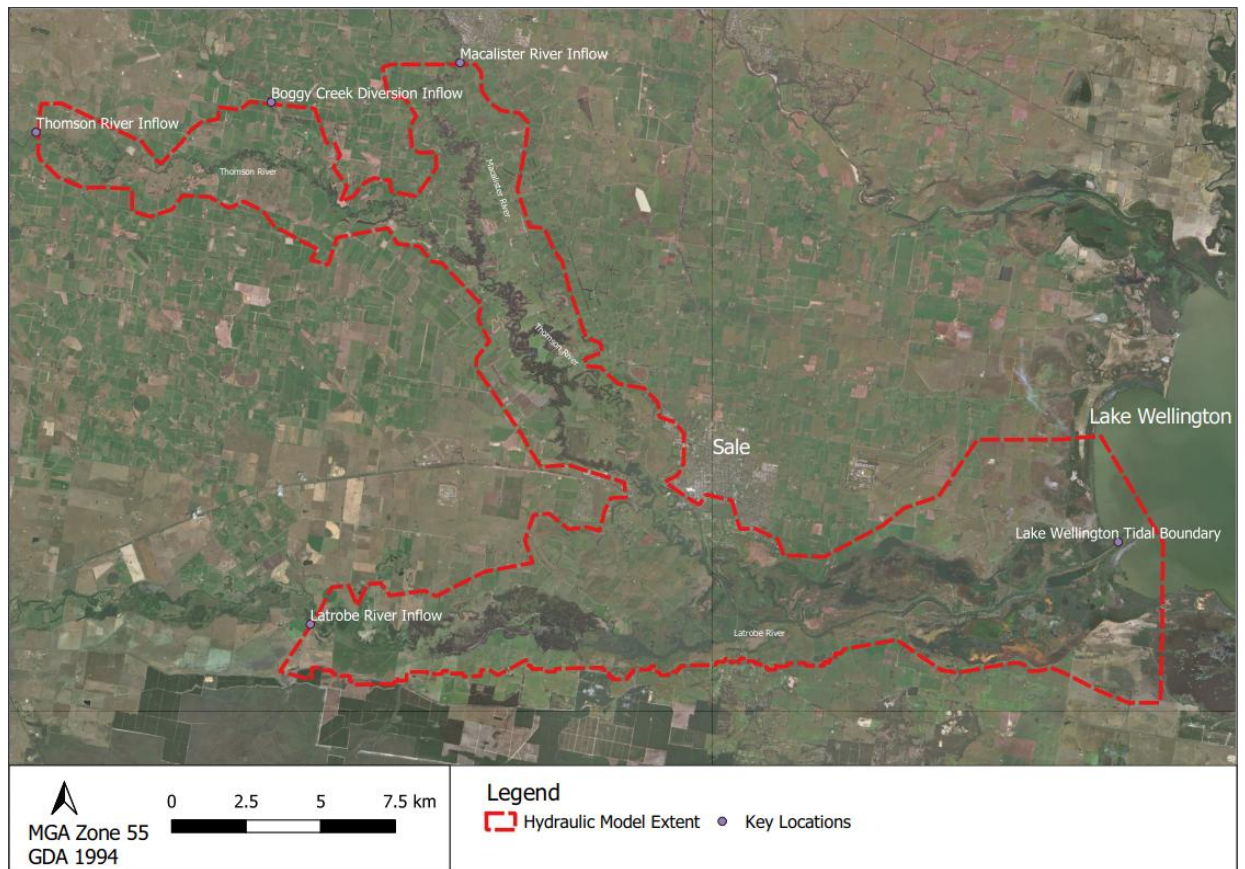
11.1 Flood frequency curves and design hydrographs

To generate design flood maps the 20%, 10%, 5%, 2%, 1% and 0.5% AEP and PMF hydrographs are required for input into the hydraulic model. In order to generate hydrographs the RORB model (Section 5) was run in the joint probability framework described in Section 6.1, with the design inputs summarised in Sections 6.2 and the adopted parameters summarised in Section 7.

The joint probability framework provides a peak flow, where the hydraulic model requires a set of hydrographs. The results of the Monte Carlo analysis are presented as median peak flow estimates rather than single hydrographs, with the natural variability of the key inputs built into the median estimates. The median peak flows are not biased one way or the other by selection of a single arbitrary rainfall temporal or spatial pattern. Hydrographs were chosen that matched the median peak flows.

For the hydraulic model 24, 36 and 72 hour hydrographs were extracted for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP and PMF flood events on the Latrobe River 11 km downstream of Rosedale, Macalister River near Singletons Road, Boggy Creek near Boggy Creek Road, Thomson River upstream of Wandocka and the Latrobe River at Lake Wellington. Internal hydrographs were also extracted for the subareas in the study area. Figure 11-1 shows the key input locations for the model.

Three sets of hydrographs were produced, Latrobe dominated event, Thomson dominated event and the entire catchment (named outlet) event.



n **Figure 11-1 Key Input Locations for Hydraulic Model**

For the events on the Macalister River it was assumed that Lake Glenmaggie was at FSL at the start of the storm and the gates were opened. This decision was based on the verification process, which indicated that this scenario best represented the historical flood frequency curve.

For the events on the Thomson River the joint probability of initial reservoir levels in Thomson Dam was incorporated. The historic storage levels in Thomson reservoir were supplied by Melbourne Water. The historic storage levels were used to characterise the drawdown distributions used in the design flood modelling (Figure 11-2).

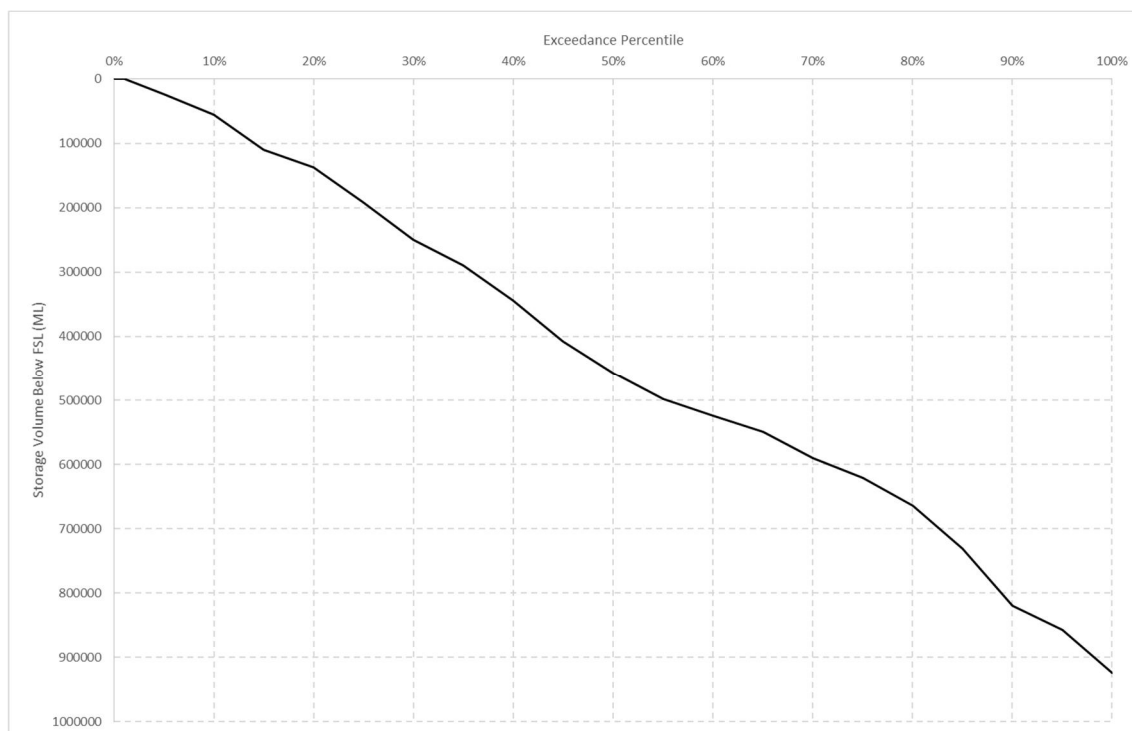


Figure 11-2 Thomson Reservoir Drawdown

Volume is potentially important for this floodplain. To account for this the hydraulic model was run for each of the three duration storms (e.g. 24, 48 and 72 hour).

The flow split from Macalister River into Boggy Creek was estimating using the hydraulic modelling undertaken for the Macalister River (WT, 2012). This relationship was placed into the RORB model. Table 11-1 shows a summary of the flow split.

Table 11-1 Flow Spilt

Macalister D/S Glenmaggie (m ³ /s)	Boggy Creek (m ³ /s)	Macalister River (m ³ /s)
0	0	0
324	187	137
702	405	150
1659	860	799

Table 11-2 to Table 11-4 shows the peak flows at key locations in the study area for each of the focus catchments that flow into the hydraulic model. The design flood hydrographs at key locations are shown in Appendix E.

Table 11-2 Peak flows from RORB model – Whole model focus catchment (Outlet)

Location	AEP (%)					
	20%	10%	5%	2%	1%	0.5%
Latrobe River at Rosedale	490	810	1170	1680	2110	2615
Macalister River near Singletons Road	100	140	180	330	530	760
Boggy Creek near Boggy Creek Road	140	260	500	660	760	905
Thomson River at Wandoka	190	300	440	640	790	980
Latrobe River at Lake Wellington	805	1280	1810	2640	3370	4230

Table 11-3 Peak flows form RORB model - Latrobe River focus catchment

Location	AEP (%)					
	20%	10%	5%	2%	1%	0.5%
Latrobe River at Rosedale	505	790	1120	1650	2100	2655
Macalister River near Singletons Road	70	105	145	205	267	450
Boggy Creek near Boggy Creek Road	80	140	245	505	620	720
Thomson River at Wandoka	80	135	210	340	460	595
Latrobe River at Lake Wellington	690	1110	1620	2510	3270	421

Table 11-4 Peak flows form RORB model - Thomson River focus catchment

Location	AEP (%)					
	20%	10%	5%	2%	1%	0.5%
Latrobe River at Rosedale	905	1310	1765	2450	3000	3640
Macalister River near Singletons Road	115	150	190	355	555	800
Boggy Creek near Boggy Creek Road	165	325	535	675	780	935
Thomson River at Wandoka	170	260	370	545	700	870
Latrobe River at Lake Wellington	1265	1915	2665	3790	4755	5895

As mentioned earlier for the design events the maximum level reached in Lake Wellington was based on the inflow volume of the design hydrographs. Figure 10-1 shows the relationship used between volume of the inflow hydrograph and the level in Lake Wellington.

11.1.1 PMF

The definition of the Probable Maximum Flood (PMF) provided in Book 8 of ARR is the flood resulting from the Probable Maximum Precipitation under the worst catchment conditions that can be reasonably expected to occur (Nathan and Weinmann, 2016). While simple in concept, the estimation of the PMF requires many assumptions regarding the “reasonableness” of various flood producing factors such as the areal and temporal distribution of the PMP, initial and continuing losses, initial reservoir level and in particular how they combine. Different selections of inputs can have a marked influence on the magnitude of the PMF.

For this study where a storm was centred over the whole Latrobe River a deterministic PMF was derived. The deterministic PMF was estimated using an approach consistent with Section 4 of ARR Book 8 (Nathan and Weinmann, 2016):

- n initial loss of 0 mm;
- n continuing loss rate of 1 mm/h;
- n most conservative peak outflow flood derived from the GSAM suite of temporal patterns in the Monte-Carlo sample that was used for estimation of design floods; and
- n all reservoirs in the catchment start at FSL prior to commencement of the flood event.

Table 11-5 shows the PMF flow for different duration storms.

n **Table 11-5 - PMF flows at the model outlet**

Event Duration (hr)	Flow (m ³ /s)
24	18,420
36	20,200
48	21,360
72*	21,660
96	22,560

* Critical duration storm

11.2 Sensitivity analysis

An important aspect of any hydrological and hydraulic modelling is the undertaking of appropriate sensitivity testing. Sensitivity testing helps to understand the influence of key parameters and the model schematisation on the result. The following section discusses the sensitivity analysis undertaken.

11.2.1 Hydrological inputs

The Monte Carlo framework accounts for the key inputs which influence flows (i.e. temporal patterns, spatial patterns and losses) and incorporates these into flow estimates.

Figure 11-3 shows an output from a Monte Carlo run of RORB at Sale with each grey cross representing a different individual run of the RORB model with randomly sampled inputs. Figure 11-3 shows that a 1 in 100 AEP rainfall if it falls on a dry catchment could produce a flow of 1,900 m³/s or the same rainfall if it falls on a wet catchment could produce a flow of 4,000 m³/s (purple arrow). Likewise, a peak flow of 3,000 m³/s could be generated by a 1 in 50 or a 1 in 300 AEP rainfall event (green arrow). In this way the Monte Carlo analysis already takes into account the impact of the variation of key parameters.

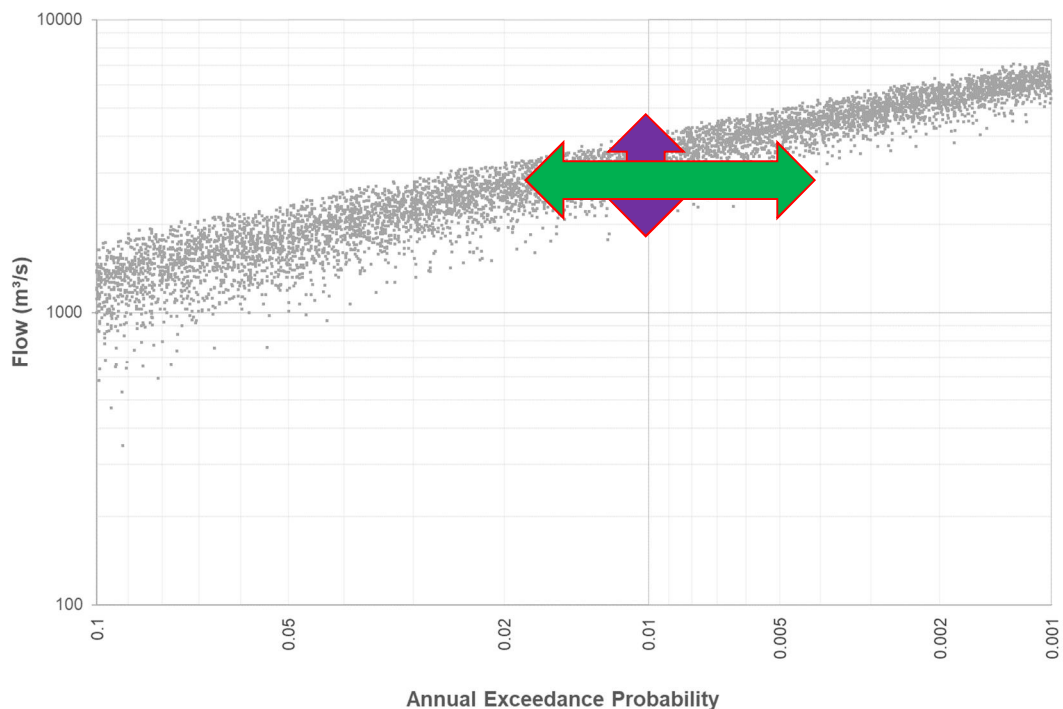


Figure 11-3 Design Flows – Monte Carlo Output using RORB

11.2.2 Climate Change

The latest available evidence suggests that there will be an increase in design rainfall intensities as a result of climate change. This increase is bounded by the current advice from the Bureau of Meteorology that climate change may not impact PMP estimates.

ARR offers preliminary advice on estimation of the increase in design rainfall intensities associated with a range of climate change scenarios. The chapter in ARR on climate change uses output from the Climate Futures web tool developed by the CSIRO. Climate change projections are focussed on Natural Resource Management (NRM) 'clusters'. "Projected changes from Global Climate Models (GCMs) can be explored for 14 20-year periods and the four Representative Concentration Pathways (RCPs) for greenhouse gas and aerosol concentrations that were used to drive the GCMs. The RCPs are designated as 2.6, 4.5, 6.0 and 8.5, and are named according to radiative forcing values (W m^{-2}) in the year 2100 relative to pre-industrial values" (ARR, 2016).

Lower Thomson is located in the 'Southern Slopes Mainland' NRM 'cluster'. Considering a planning horizon out to 2090, and recent predictions in green-house gas concentrations, a consequence risk rating of medium and a RCPs of 8.5 are appropriate choices for the design setting. From the data hub it indicates that the design rainfall intensities will increase in the order of 16.3% for the Latrobe River catchment.

Table 11-6 shows the impact on the design flows as a result of climate change following the procedure in ARR (i.e. increase in rainfall intensity). However, it should be noted that climate change is likely to have other indirect impacts on the flood producing factors. These could include generally lower average rainfalls, resulting in generally higher loss rates. Also, due to the lower rainfall between flood producing events storage are possibility drawn down more. Thus, it is by no means certain that increases in design rainfall will inter alia result in increases in flood estimates.

Table 11-6 Peak flows considering climate change from RORB model – whole model focus catchment (outlet)

Location	Flow (m^3/s)	
	1% AEP - Existing	1% AEP - Climate
Latrobe River at Rosedale	2114	2693
Macalister River near Singletons Road	528	809
Boggy Creek near Boggy Creek Road	764	980
Thomson River at Wandoka	794	1182
Latrobe River at Lake Wellington	3369	4482

To test the impact of climate change on the 1% AEP event the flows shown in Table 11-6 (i.e. outlet - 48 hour) were placed into the hydraulic model and run. The results are shown in Section 12.

11.2.3 Bushfire

Forested areas dominate much of the upper reaches of the Thomson, Latrobe and Macalister River catchments. Over 50% of the total study catchment is forested. These high levels of forestation leave the catchment susceptible to dramatic changes in its flood hydrologic characteristics if a large-scale bush fire was to take place. Two recent, local examples in the Acheron River and Tarago Rivers catchments have shown that fires can cause as much as a three-fold increase in catchment peak flows when compared to a similar event prior to the occurrence of bushfires (SKM, 2009; BMT WBM, 2018). The amount of increase in runoff is proportional to the amount of the catchment that is burnt. For this study a nominal worst case scenario has been considered, modelling what could be the effect on peak flows if all the forested areas in the catchment were to be severely burnt. Figure 11-4 show the location of forested areas within the catchment.

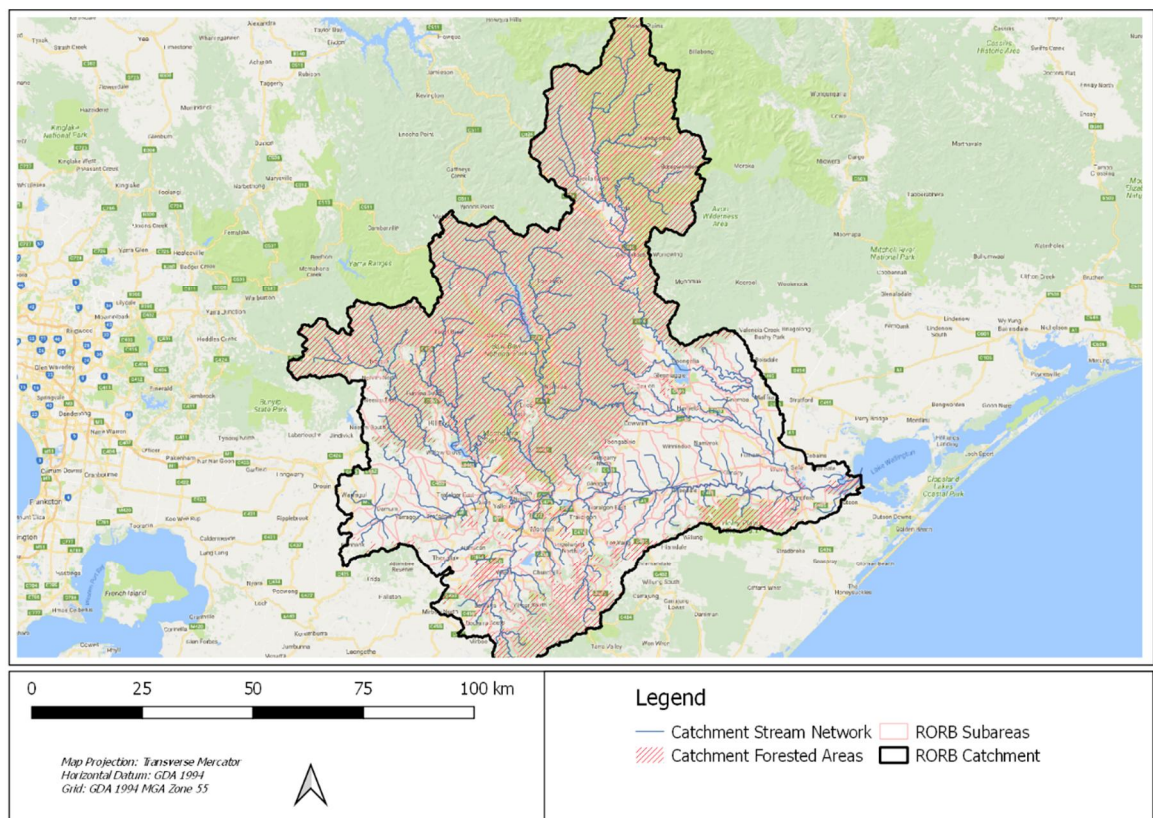


Figure 11-4 Forested Areas in Catchment

In 2009 the Burned Area Emergency Response report (BAER, 2009) detailed what effect the February 2009 fires had on the runoff in the catchment upstream of Lake Tarago. They determined runoff coefficient, in areas of varying severity burns, as shown in Table 11-7.

Table 11-7 Burn severity classes and runoff coefficients assigned in the Bunyip-Noojee Complex West (BAER,2009)

Burn Severity Class	Description	Runoff Coefficient (1% AEP)
Unburned/Lightly Burned	Post-bushfire conditions similar to pre-bushfire conditions	0.4
Low	- Rapid native vegetation recovery - Low probability of accelerated hillslope erosion - Low flood source potential - May act as a buffer to flooding from moderate and high severity burned area	0.6
Moderate	- Scorched tree leaves provide some ground cover - Areas may act as flood source areas - Accelerated hillslope erosion - Moderate potential to adversely impact downstream values at risk	0.8
High	- High potential as a flood source area - High probability of accelerated hillslope erosion - Understorey vegetation is slow to recover to pre-burn conditions - High potential to adversely impact downstream values at risk	0.95

For this investigation it was assumed that the burn severity class was high. As the RORB model has used the IL/CL loss model and Table 11-7 refer to a runoff coefficient an equivalent IL/PL (where Proportional Loss (PL) is $1 - \text{Runoff Coefficient RC}$) was determined.

The RORB model was run for each verification catchment using an IL/PL model with a zero initial loss parameter such that the equivalent runoff coefficient was determined by adjusting the runoff coefficient to match the 1% AEP flood determined from the model run with IL/CL. The equation below then used the verified runoff coefficients, along with the proportion of the gauge catchment burnt, to determine the burst catchment runoff coefficient.

$$\text{Runoff Coefficient}_{\text{Burnt Catchment}} = \text{Area}_{\text{Burnt}} * 0.95 + \text{Area}_{\text{Unburnt}} * \text{Runoff Coefficient}_{\text{Unburnt}}$$

The runoff coefficients determined for each gauge location is shown in Table 11-8.

Table 11-8 - Verification gauge runoff coefficient for burnt and unburnt catchment.

Streamflow gauge No.	Streamflow gauge locations	Equivalent runoff coefficient - current catchment conditions (unburnt)	Equivalent runoff coefficient - with burnt forest areas
225221	Macalister River @ Stringybark Creek	0.61	0.94
225204	Macalister River @ Lake Glenmaggie	0.8	0.94
225231	Thomson River @ Cowwarr Weir	0.87	0.95
225212	Thomson River @ Wandocka	0.66	0.91
225232	Thomson River @ Bundalaguah	0.74	0.91
226005	Latrobe River @ Thoms Bridge	0.62	0.77
226228	Latrobe River @ Rosedale	0.68	0.79
	Remaining catchment	0.68	0.74

Using the ratio of the burnt catchment runoff coefficients to the unburnt runoff coefficient the percentage of unburnt losses can be directly translated back to the IL/CL model (e.g. for 225221 – percentage of unburnt losses = $(1-0.94/1-0.61)$). Table 11-9 shows the IL/CL calculated for the burnt catchments.

Table 11-9 - Burnt and unburnt catchment losses.

Streamflow gauge No.	Streamflow gauge locations	Unburnt Catchment		Burnt Catchment		
		IL	CL	Percentage of Unburnt Losses (%)	IL	CL
225221	Macalister River @ Stringybark Creek	20	2.5	15.7	3.1	0.4
225204	Macalister River @ Lake Glenmaggie	20	1.5	31.2	6.3	0.5
225231	Thomson River @ Cowwarr Weir	20	1.0	40.6	8.1	0.4
225212	Thomson River @ Wandocka	20	2.0	26.5	5.3	0.5
225232	Thomson River @ Bundalaguah	20	1.5	33.9	6.8	0.5
226005	Latrobe River @ Thoms Bridge	20	1.5	61.6	12.3	0.9
226228	Latrobe River @ Rosedale	20	1.5	65.6	13.1	1.0
	Remaining Catchment	20	1.5	82.5	16.5	1.2

The 1% AEP (Outlet - 48 hour) was then run in RORB with the burnt catchment losses listed in Table 11-9 to determine the increase in peak flows. To test the impact of bushfire the 1% AEP

event the flows shown in Table 11-10 were placed into the hydraulic model and run. The results are shown in Section 12.

Table 11-10 - 1% AEP (outlet – 48 hour) design flows for burnt and unburnt catchment

Location	Flow (m ³ /s)	
	1% AEP - Unburnt	1% AEP - Burnt
Latrobe River at Rosedale	2114	2602
Macalister River near Singletons Road	528	881
Boggy Creek near Boggy Creek Road	764	985
Thomson River at Wandoka	794	796
Latrobe River at Lake Wellington	3369	4961

11.2.4 Blockage

There are a relatively limited number of major hydraulic structure crossings in the study area. These major structures have varying levels of susceptibility to blockage during a major flood. The susceptibility of these structures to partial blockage was reviewed based on advice contained within ARR. The ARR procedure was developed to quantify the most likely blockage level and mechanism for a small bridge or culvert when impacted by sediment or debris laden floodwater. It considers the following when estimating a likely blockage scenario, which is then adjusted based on the severity of the flood:

- n debris type and dimensions;
- n debris availability;
- n debris mobility;
- n debris transportability;
- n structure interaction; and
- n random chance.

The blockage runs were undertaken for the 1% AEP for the following scenarios:

- n Bridges on the Maffra-Rosedale Rd 50% blocked.
- n Railway bridges just north of Princes Hwy 50% blocked.

- n Princes Hwy bridges 50% blocked.

The results are shown in Section 12.

11.2.5 Manning's n

The main parameter that is adjusted in the calibration process of the hydraulic model is Manning's n values. The main aim of the hydraulic model calibration process is to adjust Manning's n within typical bounds to match surveyed flood levels. This process gives the best estimate of Manning's n. For the sensitivity analysis the following runs were undertaken for the 1% AEP event:

- n Manning's n + 20%

- n Manning's n – 20%

The results are shown in Section 12.

11.2.6 DEM

As mentioned in Section 9.5 there were a number of areas in the Dowd Morass DEM that appeared to approximate the terrain. These issues were discussed with the WGCMA before the WGCMA advise that the Dowd Morass DEM be adopted (personal communication, WGCMA, 5/6/17). However, to test the impact of DEM on the flood levels in areas where bathymetry data was not available the bed level was lowered by 2 m and the 1% and 20% AEP design events run and flood levels compared to the adopted results. The results are discussed in Section 12.

12 Design Event Flood Mapping and Sensitivity Analysis Results

This section presents an overview of the mapping process and describes the existing conditions flood mapping outputs and sensitivity analysis results.

12.1 General

Once flood waters breach the waterway and flow onto the relatively flat floodplain, the steep escarpments work to contain the overall extent of the flood waters. This results in significant flood depths across the full floodplain width in rarer events, with similar areas inundated in relatively small flood events but to much lower depths. As events become rarer and bigger the area inundated grows relatively gradually, but does become much deeper. For example, a 0.5% AEP flood event inundates approximately a 50% greater area than the more frequent 20% AEP flood events despite as much as three to four times the volume of flood waters. This is due to the steep escarpments containing the width of the floodplain in all but the most extreme flood events (PMF).

Flood velocities within the study area were found to be typically low. Due to the wide expansive floodplain velocities less than 0.5 m/s were found to be the prevailing velocity. Where the floodplain contracted velocities are slightly higher. The most notable areas of contraction are at Sale between the Railway and the South Gippsland Highway and near Cornwell and Riversdale Road on the Thomson Rivers. At these locations the floodplains contract to approximately 900 metres and 500 metres wide respectively. At these contractions the peak velocities are typically up to about 1 m/s in the floodplain which is still slow when compared to many floodplains. Along the Latrobe River and east of the South Gippsland Highway velocities were found to rarely exceed 0.6 m/s.

In the 1% AEP flood event the Princes Highway remains largely flood free except for an approximately 400 metres long section east of Flooding Creek. Flooding over the Princes Highway was found to reach approximately 0.35 metres deep.

The South Gippsland Highway experiences far greater depths. In the 1% AEP flood event the highway would be closed for about 1 km north of Cox's Bridge and approximately 100 metres south of Long Water Hole Bridge at Longford. Whilst the approaches are inundated the bridges remain flood free and could serve as refuge for any trapped motorist until such a time as rescue is possible or flood waters recede.

During a 1% AEP event most local roads within the catchment would likely experience closures due to depth as well as velocity over the roads making traversing from one side of the floodplain to the other a hazardous endeavour.

As mentioned in Section 9.5 there were a number of areas in the Dowd Morass DEM that appeared to approximate the terrain. As there was not additional information in which to use to modify the terrain in a manner that had a reasonable basis it was decided to run the model with the available DEM. However, it is acknowledged that Dowd Morass DEM does not appear to capture sections of the Latrobe River. For this area the grids used for the mapping were lowered by 2 metres.

12.2 Planning Maps

TUFLOW tracks the maximum of each map output during the simulation period on a geo-referenced grid cell by grid cell basis for each computation cell within the hydraulic model. This maximum is outputted from TUFLOW as a geo-referenced raster grid. For each AEP investigated nine design events were run, representing the AEP flood on the Latrobe River only, the AEP flood on the Thomson River only and the AEP flood on the total catchment (Latrobe and Thomson River combined – labelled outlet) for three storm durations; specifically the 24 hour, 48 hour and 72 hour duration floods. For the Latrobe River and Thomson River focused catchments a smaller flow was placed into the other river e.g. for the AEP flood on the Latrobe a smaller flow was placed on the Thomson River and vice versa. For the 0.5%, 1%, 2% and 5% AEP a 20% AEP was used for the 10% and 20% AEP a baseflow value of 28 m³/s was used. This was done such that when the Latrobe River and the Thomson River combined near Sale the combined flow was not rarer than the AEP event from the total catchment flow. Notionally, the Thomson River focused catchment dominates to Coxs Bridge, the Latrobe River at approximately Pearsonsdales and the remainder the total catchment (outlet). For each AEP investigated a peak flood envelope was created from the individual durations for each map type (head, depth, velocity, hazard), effectively creating a maximum of the maximums.

For each event the volume of the hydrographs i.e. Latrobe and Thomson combined was calculated and the relationship shown in Figure 10-1 was used to set the maximum level that would be reached in Lake Wellington.

These maps are composite representations of design flood surfaces across the entire study area, and do not represent any one particular possible flood event. As such, they are mainly intended for use in flood planning. As they are not “real” design events but a combination of different durations and flow events, the maps do not have levels at the gauges. However, for information, the head at each of the gauges for each of the AEP events is shown in Table 12-1.

Table 12-1 – Head levels at the gauge locations

AEP (1 in X)	Head (m AHD)		
	Thomson River at Wandocka	Thomson River at Bundalaguah	Thomson River at Sale
5	25.87	12.46	2.88
10	25.98	12.57	3.22
20	26.04	12.64	3.53

AEP (1 in X)	Head (m AHD)		
	Thomson River at Wandocka	Thomson River at Bundalaguah	Thomson River at Sale
50	26.13	12.73	3.91
100	26.18	12.81	4.24
200	26.24	12.96	4.55
PMF	26.61	14.58	7.87

Land Subject to Inundation Overlay (LSIO) and Floodway Overlay (FO) maps have also been prepared (using a combination of runs). The LSIO identifies land liable to inundation by overland flow, in flood storage or in flood fringe areas affected by the 1% AEP flood. The FO was defined as the LSIO where depth > 0.3m and depth x velocity > 0.3. Small isolated 'puddles' and 'islands' were filtered, where small was defined as areas that are less than 20 m².

Appendix K shows the planning maps.

12.3 Flood Emergency Maps

Maps have been produced for each of the runs undertaken. These can be used for flood emergency management. A large set of maps has been provided to enhance the ability to manage and respond to floods which are either Latrobe or Thomson dominated, as well as whole catchment dominated events where both river systems are contributing equally.

Each of these maps has been linked to the gauges in the study area. Maps for the minor, moderate and major flood (as defined by the BoM) have also been produced. A depth has not been placed at the Sale Wharf because, as discussed in Section 10.3, the zero gauge at Sale wharf needs to be confirmed. Notionally the minor, moderate and major flood has been based on the flood impacts but is approximately a 1 in 5, 10 and 20 AEP.

Appendix L shows the flood emergency maps.

12.4 Calibration Events Maps

For each of the calibration events, i.e. 1978, 2007 and 1993 flood maps have been produced which show the flood levels recorded at the streamflow gauges in the study area. These maps could also be used as emergency flood maps.

Appendix M shows the historical maps.

12.5 Sensitivity Maps

12.5.1 Climate change

Appendix N shows the incremental increase in levels as a result of the model run. It shows that the flood levels in a 1% AEP (outlet – 48 hour) increase by up to 1.8 m.

12.5.2 Bushfire

Appendix O shows the incremental increase in levels as a result of the model run. It shows that the flood levels in a 1% AEP (outlet – 48 hour) increase by up to 1.5 m around the Princes Highway bridge.

12.5.3 Blockage

Appendix P (P.1) shows the difference in head between the bridges on the Maffra-Rosedale Rd being unblocked compared to 50% blocked. This suggests that the impact is localised with a maximum increase of 2 cm.

Appendix P (P.2) shows the difference in head between the bridges on the railway just north of Princes Hwy being unblocked compared to 50% blocked. This suggests that the impact is localised with a maximum increase of 10 cm.

Appendix P (P.3) shows the difference in head between the bridges on the Princes Hwy being unblocked compared to 50% blocked. This suggests that the impact is localised with a maximum increase of 12 cm.

12.5.4 Manning's n

Appendix O shows the incremental increase in levels as a result of the model runs (Manning's $n \pm 20\%$). It shows that the flood levels in a 1% AEP (outlet – 48 hour) increase by up to 0.3 m and decrease by up to 0.3 m.

12.5.5 DEM

As mentioned in Section 9, along the Latrobe River channel, the DEM used all the supplied bathymetry. Beyond those areas where there was no bathymetry data, no attempt was made to add in a channel due to the lack of information to reasonably do so. Any loss in conveyance would be accounted for in the other calibration parameters but ultimately the channel is small compared to the conveyance of the engaged floodplain. A sensitivity test was undertaken to understand the influence of the river bathymetry on flood levels more generally across the floodplain. In areas where bathymetry data along the Latrobe was not available the bed level was lowered by 2 m and the 1% and 20% AEP design events run and flood levels compared to the adopted results. In the 1% AEP event the lowering of the bed by 2 m lowered the flood levels

across the Latrobe River floodplain by typically 20 to 40 mm, in locations where the peak flood depth typically ranges from 2 m to 3 m. Similarly, in the 20% AEP event the flood levels were lower by typically 30 to 60 mm in locations where the peak flood depth is typically about 1 m. As can be seen the inclusion or otherwise of the river bathymetry below the water level does not significantly impact on flood levels. If anything the flood levels may be slightly conservative when used in the planning context.

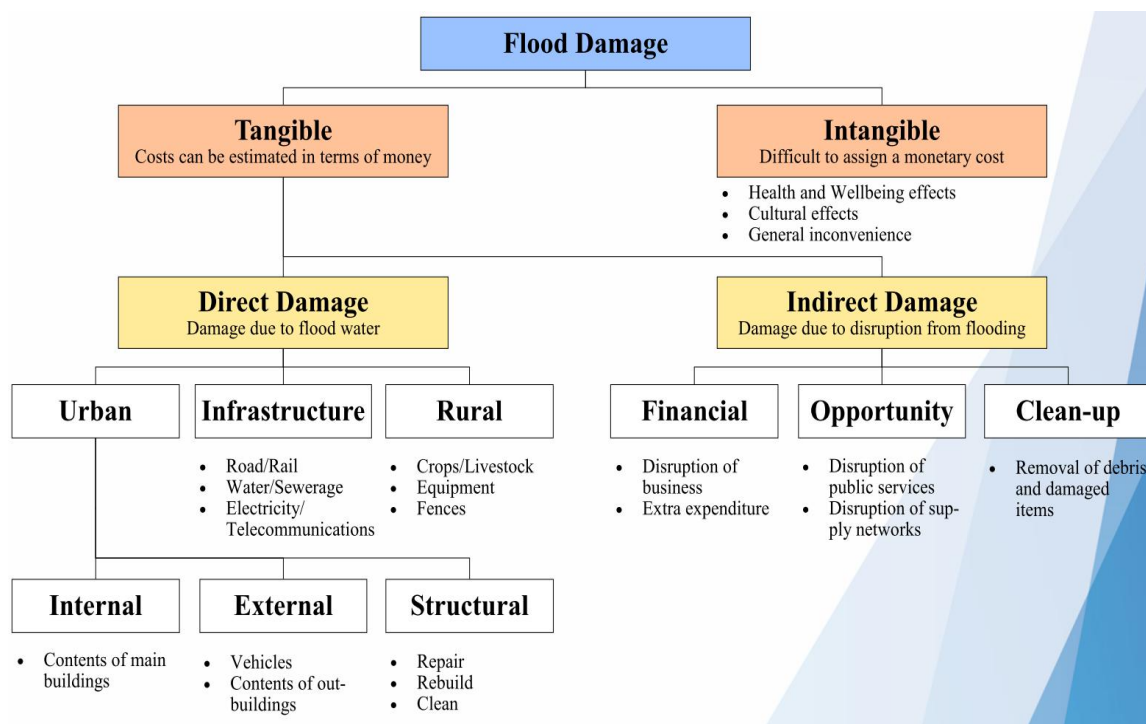
13 Flood Damage Assessment

This section of the report describes the economic assessment of flood damages as part of the flood study.

13.1 Background

For the lower Thomson floodplain the economic costs of flooding has been quantified for each design event up to the 0.5% AEP. In doing so it allows the calculation of the Average Annual Damage (AAD) from flooding to the lower Thomson community. The AAD is the best estimate for tangible damages to the community it would sustain over an extended time period. In this case, the AAD is determined for the range of flood events from the 20% to the 0.5% AEP.

For the purposes of assessment, flood damage is classified in several ways as outlined in Figure 13-1 below. The two primary divides in flood damage are that between tangible and intangible damages and the divide between direct and indirect costs. A cost is defined as intangible where there is difficulty assigning a dollar value to that damage. For example, the effects on a person's mental health of a flood destroying their house are far more difficult to quantify than the damage to the house itself. Direct damage is that caused to physical objects by the flood water, where indirect damage is caused by disruptions to economic and physical activity. An example of indirect damage would be a store surrounded by the flood but not inundated; it cannot service customers so potential income is lost.



n **Figure 13-1 Types of Flood Damage**

13.2 Methodology Overview

For the assessment of commercial and residential damages the ANUFLOOD and O2 stage-damage curves were used to estimate flood damages to buildings. The ANUFLOOD curves were sourced from the Queensland Department of Natural Resources and Mines (QDNRM) (2002), whilst the O2 curves were created by O2 Environmental in 2012. For the purposes of estimating agricultural flood damage the Rapid Appraisal Method (RAM) for floodplain management methodology was adopted. The RAM methodology was developed by the Victorian Department of Natural Resources and Environment (NRME) in 2000. The original purpose of developing the methodology was to facilitate a consistent estimation of flood damages to enable benefit cost analyses across different floodplains to aid state and federal wide funding decisions.

13.3 CPI

Due to the age of the RAM, ANUFLOOD and O2 prices it was necessary to update them to present value dollars. To do so, the relevant dollar values were updated to present day values by factoring them using Consumer Price Index (CPI). The change in CPI since the original publication was sourced from the Australian Bureau of Statistics.

13.4 Direct Damages

13.4.1 Residential

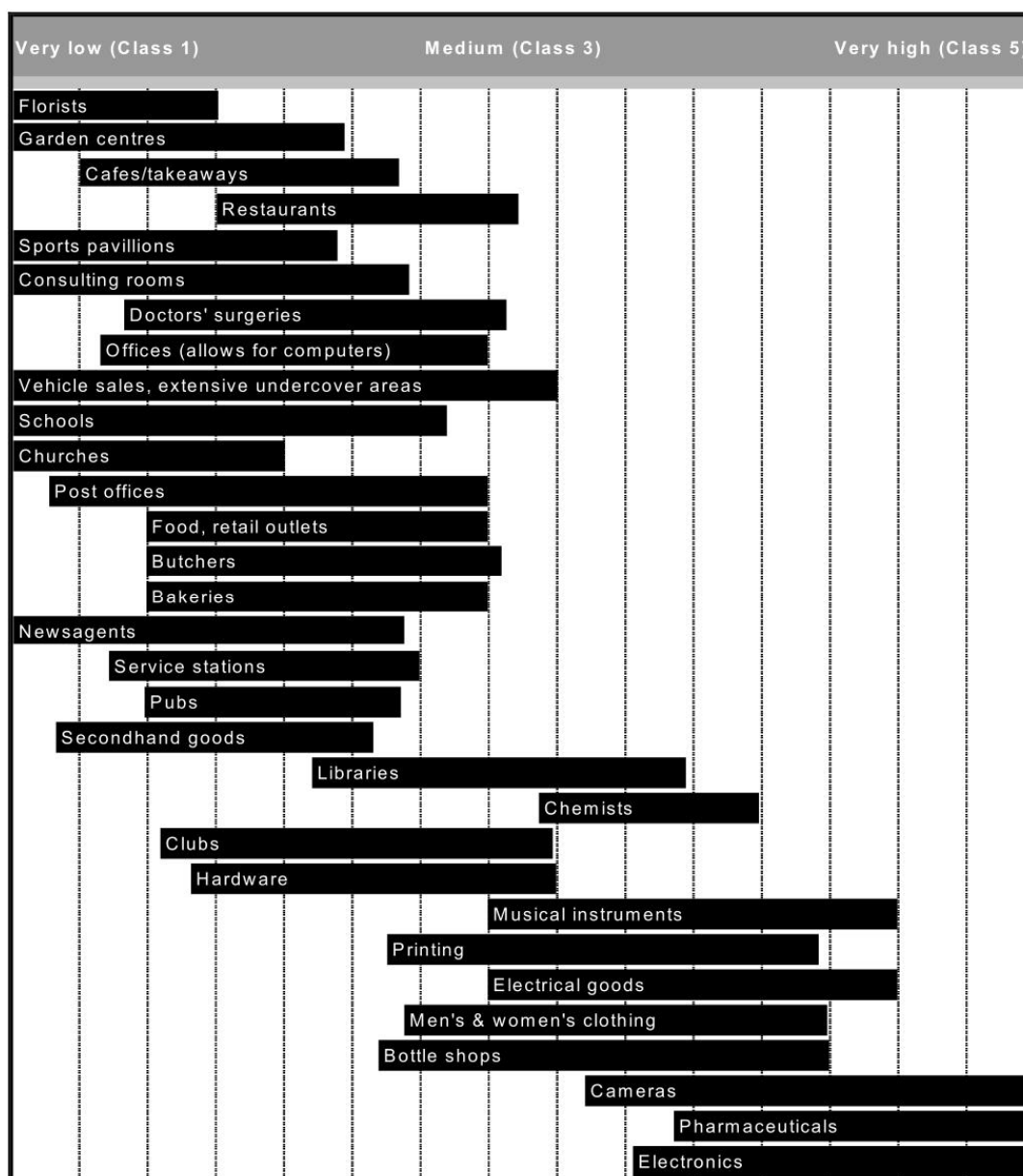
For residential properties O2 stage-damage relationships were adopted for this study. The curves depend on the size of the building and its depth of flooding above floor level. Unlike the ANUFLOOD stage-damage curves, the O2 curves also consider the size of the building they also consider additional information such as: the type of dwelling (detached/multi-story/high-set/etc). O2 also separate and quantify external damage (cars, fences and the like), property contents and the building structural form itself.

There is limited information on the structure of the residential buildings within the floodplain. For example, the construction style and whether the build is elevated can have a major effect on the estimated damages. The lower Thomson region has a long and documented history of flooding with a very well-defined floodplain. Whilst it is expected that many of the buildings within the floodplain are elevated, for the purposes of this assessment it has been assumed that the buildings are slab on ground. This is a conservative assumption and may overestimate the damages but in lieu of better information this is considered appropriate. Within the 0.2% AEP flood extent residential properties were identified from the supplied aerial photography and ground levels were taken from the LiDAR DEM and flood levels from the modelling results.

13.4.2 Commercial

For commercial properties the ANUFLOOD curves were adopted for this study. These were sourced from QDNRM (2002). ANUFLOOD commercial stage-damage relationships consider size of the building, the building and contents use (value class) and the depth of flooding above the floor level. The ANUFLOOD value classes are presented in Figure 13-2 and represent that some commercial operations are susceptible to larger financial losses than others when subjected to flooding. An example of the stage-damage curves used is shown in Figure 13-3 for small ($< 186 \text{ m}^2$) and medium ($186 - 650 \text{ m}^2$) sized commercial properties.

Within the 0.2% AEP flood extent commercial buildings were identified from the supplied aerial photography and internet search. Each was then classified by best estimate of use from the aerial photography and through use of google maps and street view where available. Unsurprisingly, most of the structures within the flood extent are sheds associated with agriculture use, however there is also some retail and offices. Sheds were set as Value Class 1 (very low value), whilst retail, offices and car dealerships were set as Value Class 2 or 3 as appropriate.



n Figure 13-2 ANUFLOOD commercial damage value classes

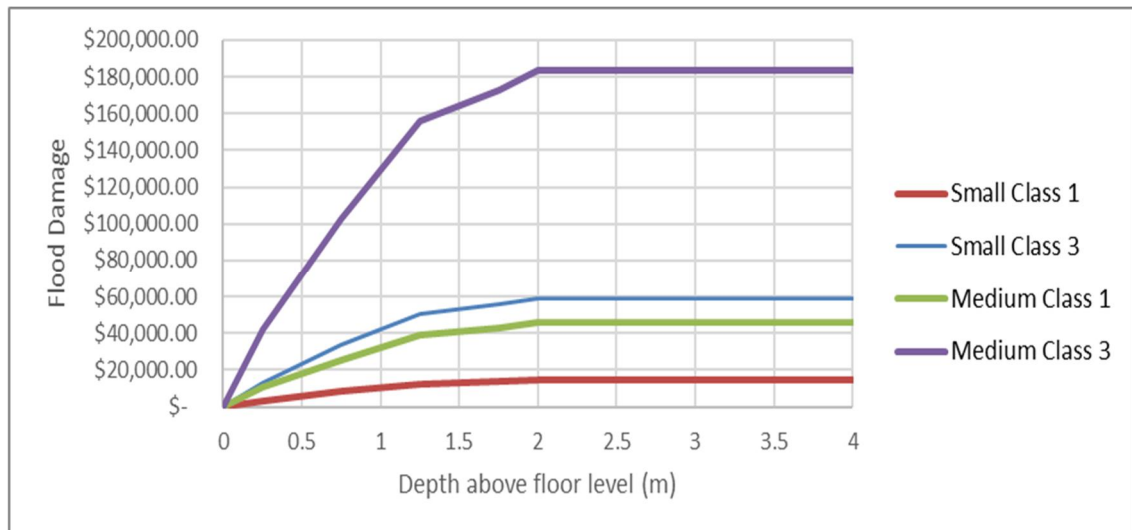


Figure 13-3 Example Stage-Damage curves

13.4.3 Road and Bridge Damage

During a flood road and bridges can suffer in various manners, from simple accelerated wear of the bitumen or formation of pot holes to the complete destruction of bridges or scouring of sections of road embankment and sub-base. The RAM methodology proposes a unit damage per km of road inundated, the CPI adjusted cost per km are shown in Table 13-1. RAM distinguishes between major and minor sealed roads as well as for minor unsealed roads. For each flood event the length affected of each type was determined based on VicMap roads information.

Table 13-1 Unit damage for Roads and Bridges (reproduced from RAM factored by CPI, NRE 2000)

Road Type	Cost per km of Road Inundated (\$/km)
Major Sealed Road	\$96,100
Minor Sealed Road	\$30,100
Unsealed Road	\$13,600

13.4.4 Agricultural Damage

Agricultural damage can be affected by a significant number of factors including:

- n Time of Year affects crop damage and growth
- n Warning time affects ability to move livestock
- n Greater flood depth can impact many crops
- n Duration of Flooding affects soil conditions
- n Velocity and Scour potential of flood waters; and

n Type of Agriculture (e.g. cropping, livestock pastures, horticulture)

With appropriate experience and warning there are actions a prepared community can take to reduce the flood damages. Based on the flood modelling, historic flood events, and the ever improving forecast ability of the Bureau of Meteorology it has been assumed that there would be greater than 12 hours warning. From the RAM methodology this assumption holds that all livestock will be able to be safely moved out of the floodplain prior to inundation. Under this assumption damage caused to pastures are primarily to fencing and top soil and not to livestock.

From the flood modelling and historic flood events it was deemed that floodwaters are likely to stay high over much of the floodplain for a week or more. This length of duration results in additional damage to pastures and crops.

To undertake the assessment of economic damages it is necessary to develop a database identifying all properties within the estimated extent of the 0.5% AEP flood event. This database contains a property identifier, total area inundated for each flood event and information on land use. The property database is then used as an input applied to the damage relationships to determine the economic costs of flooding on a property by property basis.

For the purposes of the determining land use, the Victorian Land Use Information System (VLUIS) 2016 GIS dataset was used. The VLUIS dataset was created by the Spatial Sciences Group of the Agriculture Victoria Research Division in the Department of Economic Development, Jobs, Transport, and Resources. This dataset covers the entire landmass of Victoria at the cadastral parcel level and separately describes the land tenure, land use and land cover. Within the Lower Thomson floodplain seven primary land uses are identified in the VLUS and each was assigned the closest corresponding RAM classification. These are presented in Table 13-2.

n **Table 13-2 VLUIS 2016 vs RAM Classification**

VLUIS 2016 Classification	RAM Classification
Grazing irrigated modified pastures	Irrigated pastures
Rural residential with agriculture	Dryland pastures
Irrigated cropping	Irrigated broadacre crops
Grazing modified pastures	Dryland pastures
Cropping	Dryland broadacre crops
Horse studs	Dryland pastures
Softwood plantation forestry	Dryland pastures

A summary of the key agricultural damage assumptions is presented below in Table 13-3.

n **Table 13-3 Summary of Agricultural Damage Assumptions**

Parameter	Assumption
Season	Assumed to be spring

Parameter	Assumption
Duration of Inundation	Greater than 7 days
Flood Warning	Greater than 12 hours
Land Use	VLUIS 2016 GIS

For each parcel the land use damage per hectare from RAM was used to assign a value per flood event. The RAM values were factored by CPI as discussed above, and based on the assumptions listed in Table 13-3. The agricultural damage dollar value per hectare is presented in Table 13-4.

Table 13-4 Agricultural Damage (\$/ha)

Land Use	Dryland pastures	Irrigated pastures	Dryland broadacre crops	Irrigated broadacre crops
Damage	\$49 / ha	\$600 / ha	\$217 / ha	\$437 / ha

13.4.5 Infrastructure

Infrastructure damages to community infrastructure that includes parks and ovals, water and utilities are difficult to quantify. RAM has recommendations for road damages however provides no guidance on other community infrastructure (NRE, 2000). The exclusion of other infrastructure would tend to underestimate flood damages. Therefore, for the purposes of this study the damage to infrastructure have been estimated to be 15% of direct damage as has been done for other similar studies based on advice from NSW Office of Environment and Heritage (AECOM 2014 & WBM, 2011).

13.5 Indirect Damages

Calculation of indirect damages for the Lower Thomson floodplain was not feasible for this study so the 30% of total damage as recommended in RAM (NRE, 2000) was adopted.

13.6 Intangible Damages

The previous discussion relating to flood damage has been in relation to tangible damage which can be estimated in dollars. Intangible damage cannot be readily quantified in economic terms but are none the less important. According to the Rapid Appraisal Method (RAM - DNRE, 2000) intangible damages fit under two broad categories:

- n Social (e.g. health, safety and personal impacts)
- n Environmental impacts

The “Disaster Loss Assessment Guidelines” (EMA, 2002) states that people value the intangible losses from a flooded home principally loss of memorabilia, stress and resultant ill-health as at least as great as their tangible dollar losses.

The flood damage assessment presented in Section 13.7 has not considered the ‘intangible cost’.

13.7 Summary of Economic Damages

The estimated economic direct damages by type determined by using the flood estimation methods is presented below in Table 13-5. A summary of the buildings flood affected, total tangible damages and total damages is presented in Table 13-6. The estimated flood damages show a fairly sizable direct damage in even a 20% AEP flood event.

As can be seen in Table 13-5, in the smaller, more frequent flood events it is the agriculture and road damages that dominate. However in larger events, whilst the agriculture damage increases, it does so at a much slower rate when compared to residential and commercial buildings.

In the larger, rare, flood events it is the damage to residential and commercial properties that dominate. Whilst there are comparatively few buildings identified at risk, the depth of flooding working on the assumption of slab-on-ground construction means that the depths are often large in these events. As discussed above, this assumption is conservative, and it is likely that many of these buildings would be located on stumps or otherwise elevated above ground level however there is insufficient available information to make any alternative assessment at this time.

Table 13-5 Breakdown of Tangible Damages by Class

AEP (%)	Residential Damages* (\$)	Commercial Building Damages* (\$)	Agricultural Damages (\$)	Road & Bridge Damages (\$)	Infrastructure Damages (\$)	Indirect Damages (\$)
20%	-	182,000	2,379,000	1,154,000	557,000	1,282,000
10%	337,000	604,000	2,875,000	1,678,000	824,000	1,895,000
5%	884,000	1,877,000	3,060,000	1,914,000	1,160,000	2,669,000
2%	4,862,000	4,685,000	3,313,000	2,412,000	2,291,000	5,269,000
1%	9,352,000	7,773,000	3,447,000	2,670,000	3,486,000	8,018,000
0.5%	16,253,000	11,148,000	3,549,000	2,971,000	5,088,000	11,703,000

*based on the assumption of slab-on-ground construction

Table 13-6 Summary of Damages

AEP (%)	No. Residential Buildings Affected*	No. Commercial Buildings Affected*	Total Damages (\$)
20%	0	10	5,554,000
10%	7	28	8,213,000
5%	15	44	11,564,000
2%	45	76	22,832,000
1%	69	95	34,746,000
0.5%	96	96	50,712,000

*based on the assumption of slab-on-ground construction

13.8 Average Annual Damage

Average annual damages is the economic term for the probabilistic economic cost to the floodplain each year when averaged over a long period of time. This of course does not mean every year the floodplain would experience this level of damage as the AAD accounts for the economic likelihood of rare and highly damaging floods as well as frequent events that may result in little or no damage. To calculate the AAD it is necessary to consider the 'area under the curve' of a probability vs damages plot. For the purposes of the AAD calculations it was assumed that no damage would occur in a 33% (1 in 3) AEP flood event. The AAD based on the total tangible damages under existing conditions is presented below in Table 13-7.

Table 13-7 Existing Conditions Average Annual Damages

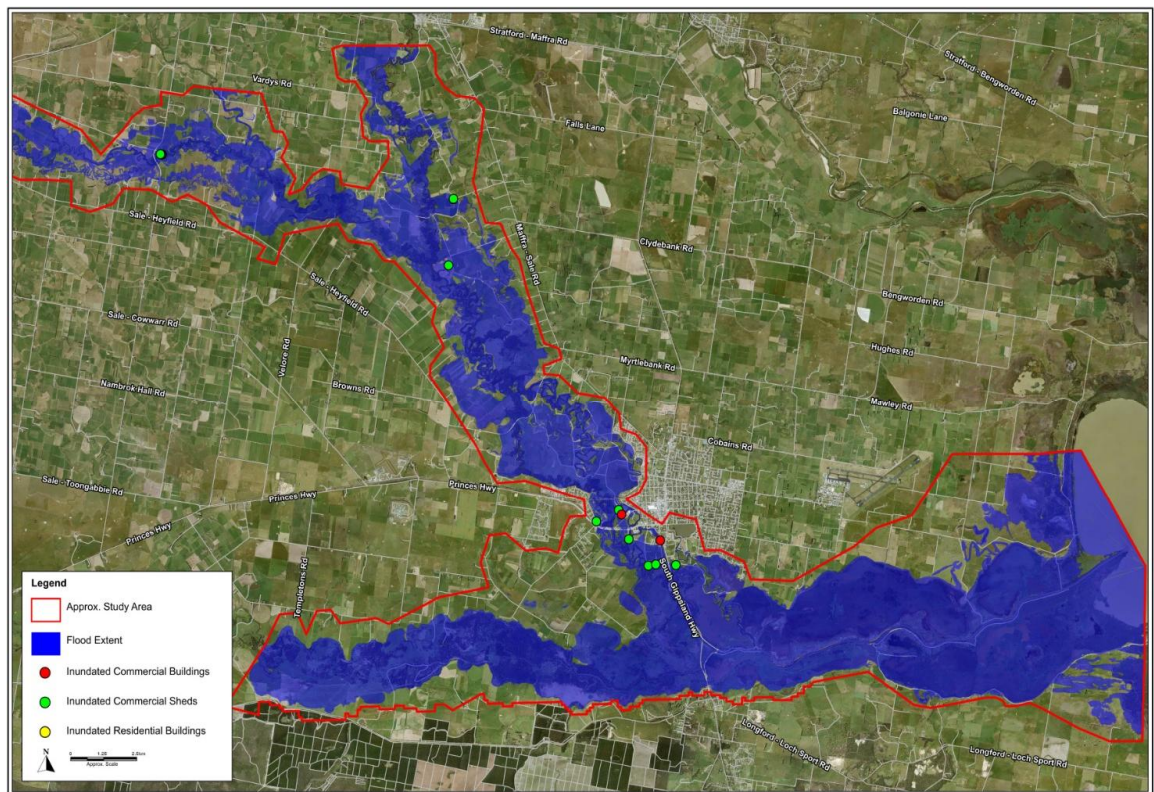
AEP	Total Damages (\$)	Contribution to AAD (\$)
33%	0	0
20%	5,554,000	361,000
10%	8,213,000	688,000
5%	11,564,000	494,000
2%	22,832,000	516,000
1%	34,746,000	288,000
0.5%	50,712,000	214,000
Total AAD		2,561,000

14 Flood Mitigation

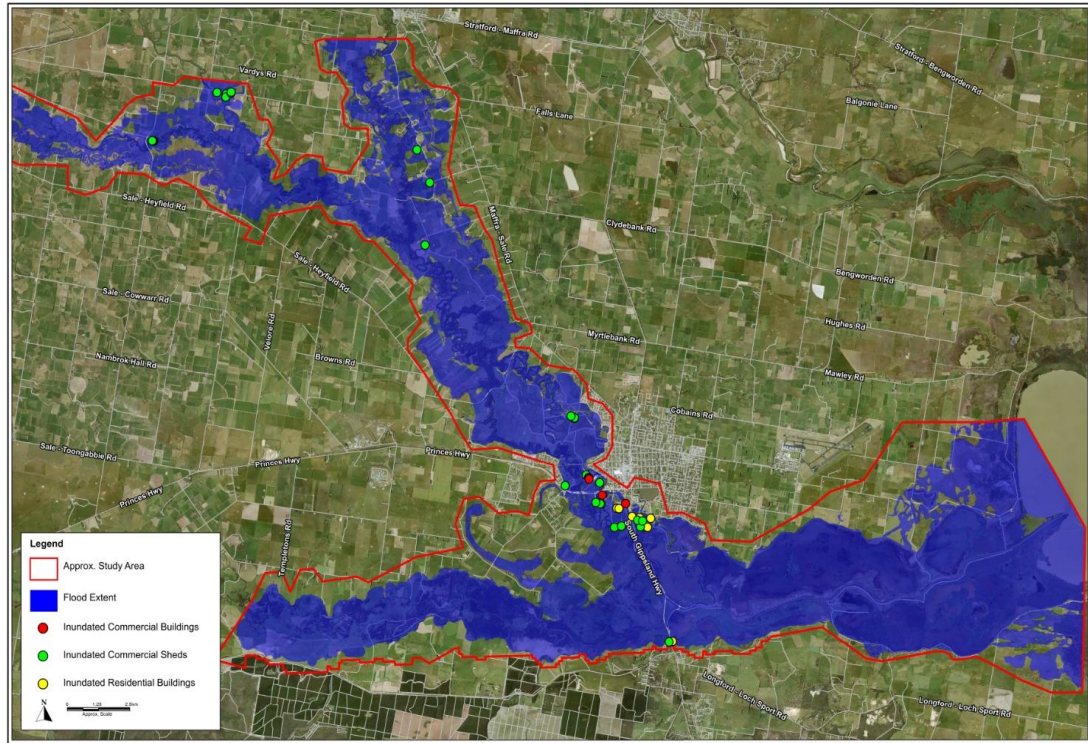
14.1 Background

As part of this review of potential mitigation options both structural and non-structural mitigation options were considered. The review undertaken was a high-level assessment and discusses potential flood mitigation options as part of the flood study without undertaking detailed hydraulic modelling.

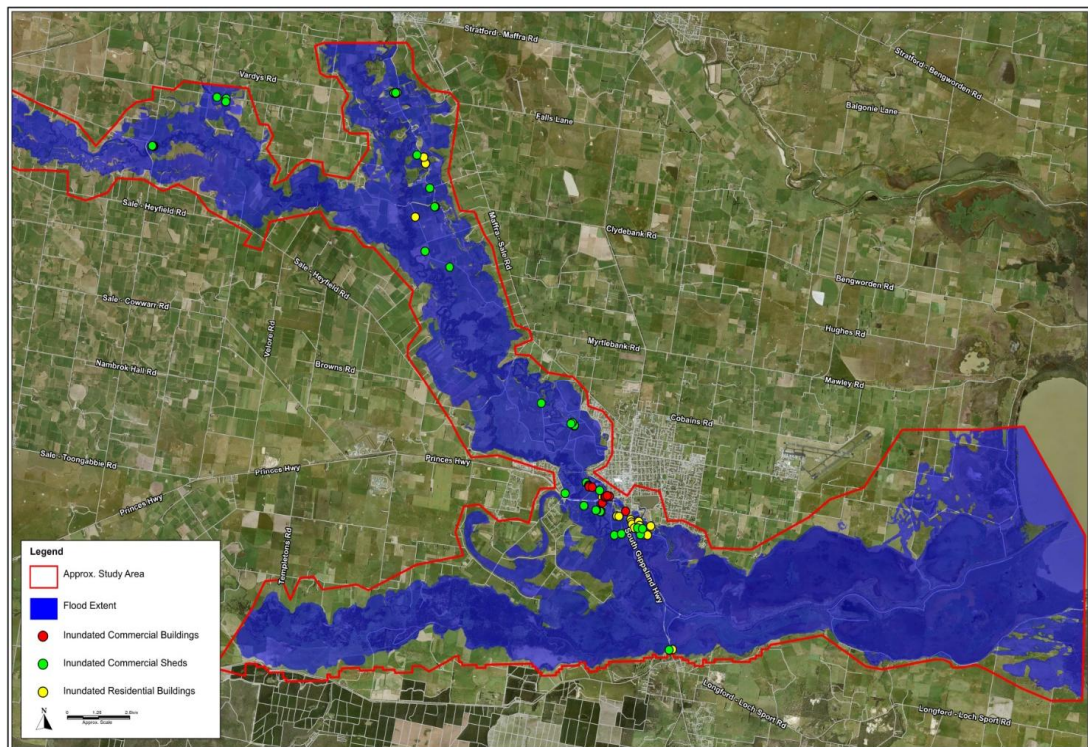
Figure 14-1 through Figure 14-6 show the number of buildings inundated (assuming the conservative assumption of slab-on-ground construction) throughout the floodplain.



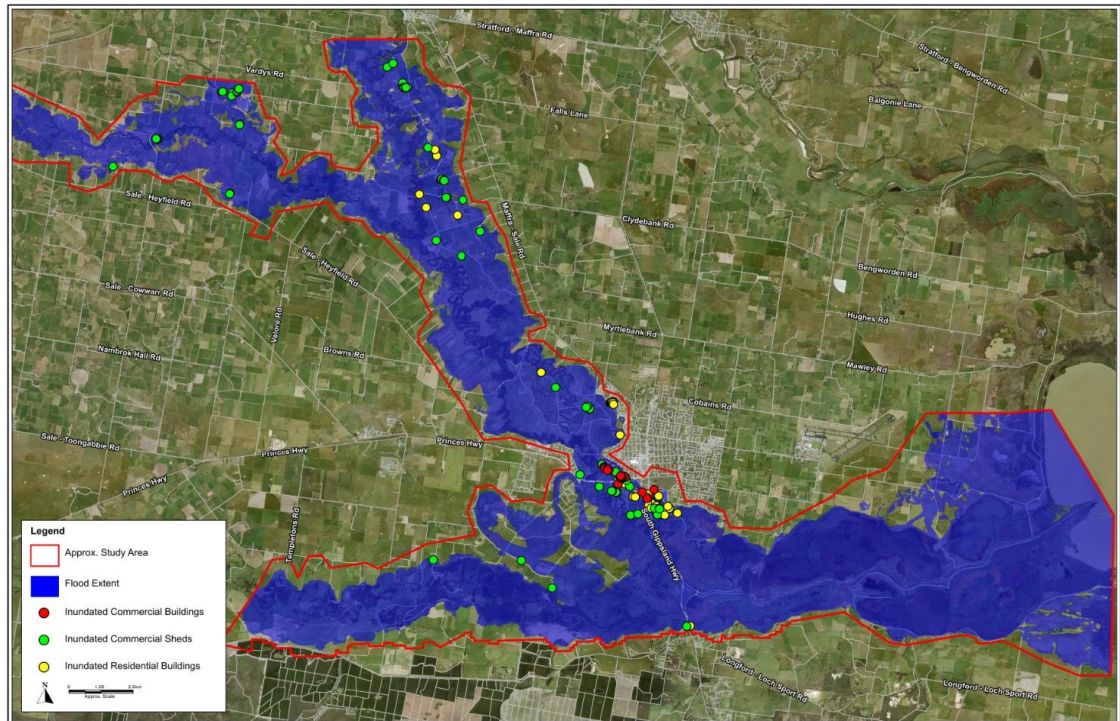
n **Figure 14-1 20% AEP Flood Extent and Properties Inundated**



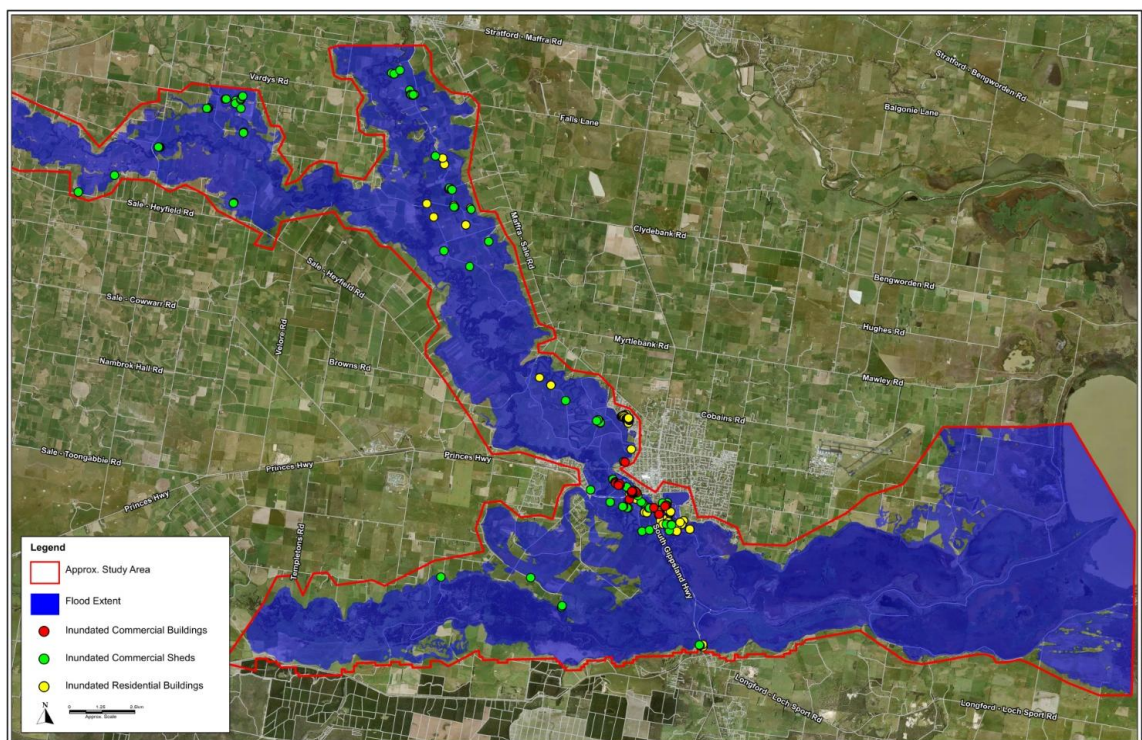
n **Figure 14-2 10% AEP Flood Extent and Properties Inundated**



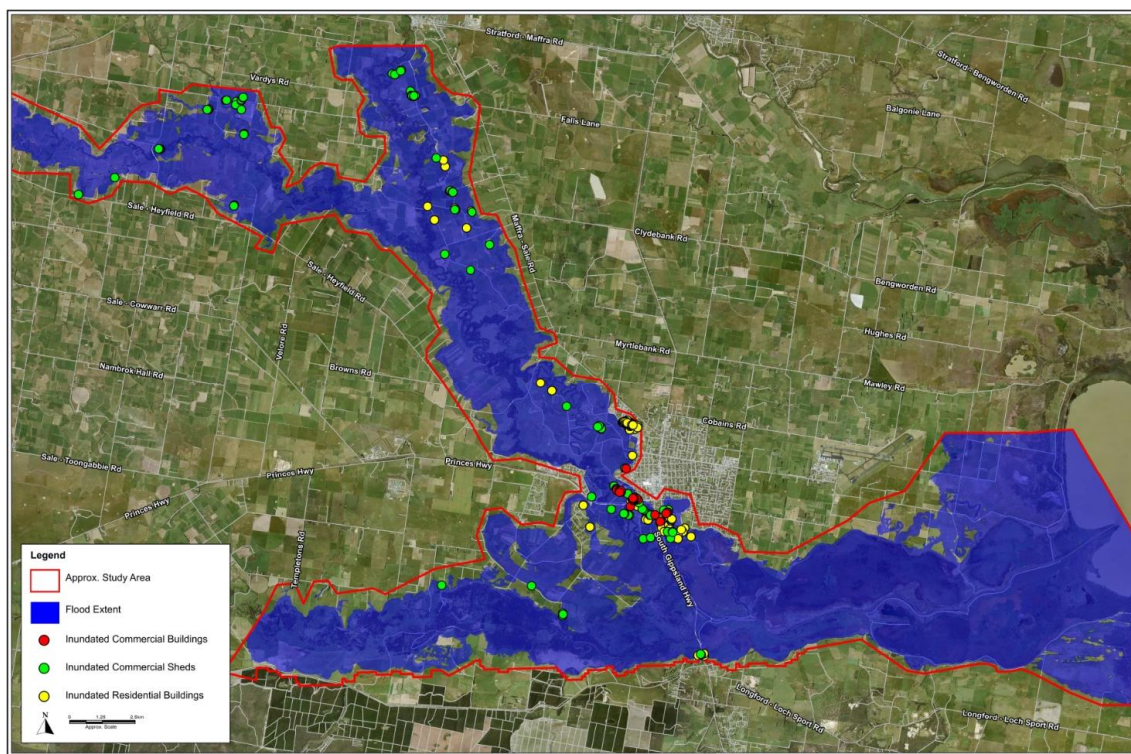
n **Figure 14-3 5% AEP Flood Extent and Properties Inundated**



n **Figure 14-4 2% AEP Flood Extent and Properties Inundated**



n **Figure 14-5 1% AEP Flood Extent and Properties Inundated**



n **Figure 14-6 0.5% AEP Flood Extent and Properties Inundated**

14.2 Levees

Levees are often an effective way of reducing flood risk to a community and are regularly used to protect property throughout Victoria. However, due to the cost of installation, ongoing need for maintenance, regular inspections, repairs and visual amenity, levees are often not desired by many communities and managing organisations. Due to the costs, levees are most effective at protecting property when there are many properties in close proximity and typically not cost effective at protecting individual homesteads or in rural living zones.

A review of Figure 14-1 through Figure 14-6 show a number of buildings inundated (assuming the conservative assumption of slab-on-ground construction) are scattered throughout the floodplain as well as clumps in and on the fringes of Sale. A review of these flood affected buildings show two locations that were considered for further investigation.

The first location identified as a potential candidate is the relatively new housing development located along Cemetery Rd near Woondella Bvd as shown in Figure 14-7. The hydraulic modelling shows that this area becomes inundated in a 2% AEP flood event. Due to the age of the LiDAR it may be that this area has been filled as part of the development. It would therefore be recommended that Council investigate the ground levels and finished floor levels of these properties before undertaking further mitigation assessments, however should it be found that the

area is indeed at risk then Council could investigate a combined levee and road raising project as part of future upgrades to this section of road when it is next renewed.

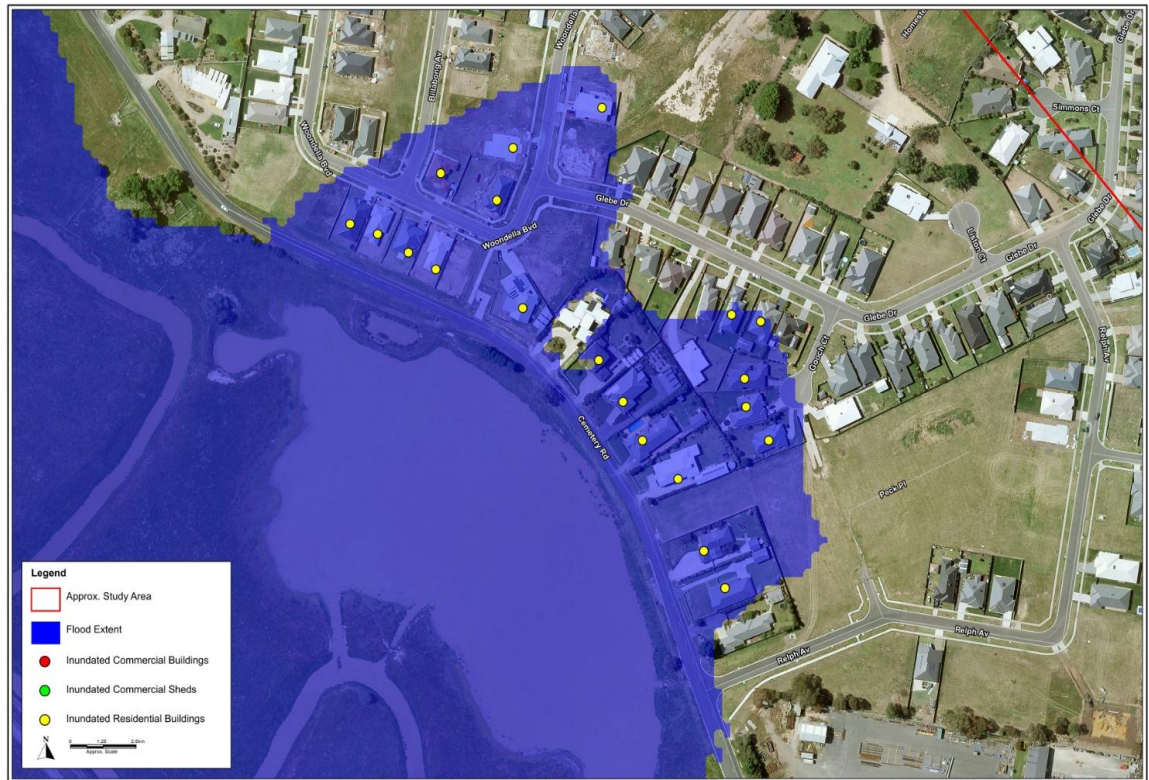
The other potential candidate for a levee is along the bank of Flooding Creek at the Princes Hwy / Foster St as shown in Figure 14-8. The modelling shows that this area becomes inundated in approximately the 5% AEP flood event. This area contains numerous residential and commercial buildings. To protect these buildings would likely require a levee along the bank of Flooding Creek and the raising or modification of Princes Hwy / Foster St to stop backwaters from inundating these properties. As this area of the floodplain is constricted it is possible that the isolating of this area would cause increase in flood levels on upstream properties.

A review of other locations around Sale and the broader floodplain indicate that the buildings are too far apart, and hence it is highly unlikely that it would be economically feasible to construct levees to protect these properties.

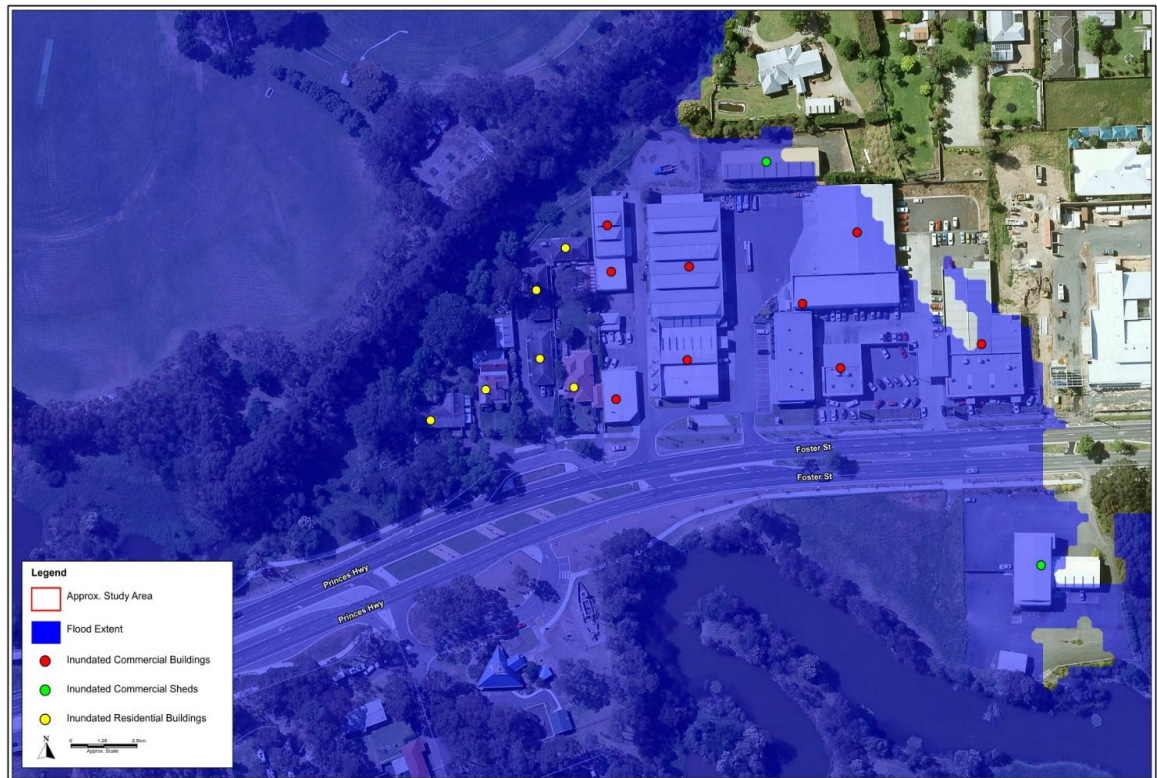
14.2.1 Recommendations

Based on this high-level review it is recommended that:

- n Council review the finished levels of the new housing development around Cemetery Rd and if this area is found to be at risk then consider road raising to form a defacto levee as part of future road upgrade or investigate the construction of a levee adjacent to the road on the river side.
- n Review the finished floor levels of the inundated properties near Princes Hwy and Foster St to more accurately determine the flood risk of these properties. If a high risk is determined then consider undertaking a conceptual mitigation assessment and benefit-cost assessment to determine whether it is practical to implement a levee.



n **Figure 14-7 Cemetery Rd, Sale 1% AEP Flood Model Results**



n **Figure 14-8 Princes Hwy / Foster St, Sale 1% AEP Flood Model Results**

14.3 Flood Warning

14.3.1 Aim and Function of Flood Warning Systems

Flood warning is an effective and credible non-structural flood mitigation or flood risk reduction measure. Successful system implementation requires attention to all system elements as well as the striking of a balance between each of those elements appropriate for the community it will serve. A “one size fits all” or standard approach is not appropriate. What works for one community may not necessarily be appropriate for another.

Put simply, flood warning systems provide:

- n A means of gathering information about impending floods;
- n Communicating that information to those who need it (those at risk); and
- n Facilitating an effective and timely response.

Thus, flood warning systems aim to enable and persuade people and organisations to take timely action to increase personal safety and to reduce the damage caused by flooding³. Key to this for those at risk is:

- n The availability of information about flood risk;
- n Easy access to relevant and timely real time rainfall and water level data / information; and
- n Knowing what needs to be done in the lead up to and during a flood event.

14.3.2 The Total Flood Warning System Concept

In 1995 the Australian Emergency Management Institute published a best-practice manual entitled Flood Warning: an Australian Guide (AEMI, 1995), and in so doing, introduced the concept of the 'Total Flood Warning System' (TFWS). While the original manual has been updated and republished as Manual 21 of the Australian Emergency Manuals Series (EMA, 2009), the concepts, practices and key messages from the original manual endure.

The Victorian Floodplain Management Strategy (VFMS) (DELWP, 2016) and the West Gippsland Floodplain Management Strategy (WGCMA, 2017) also promote the TFWS concept and provide clarification on roles and responsibilities for system development and operation.

14.3.3 Total Flood Warning System Building Blocks

An effective flood warning system is made up of several building blocks (Figure 14-9). Each building block represents an element of the TFWS.

Flood warning systems (and investments in their implementation) that are not designed in an integrated manner and that over-emphasise the collection of input data and / or the production of (highly accurate) flood forecasts relative to the attention given to other elements, often fail to fully meet the needs of the at-risk communities they have been set up to serve. An appropriately developed and integrated system considers not only the production of a timely and informative alert⁴ of a potential flood, but also the efficient dissemination of that alert to those who need to respond in an appropriate manner. A community that is informed, flood aware and prepared (i.e. flood resilient) is more likely to receive the full benefits of a warning system.

It follows that actions to improve flood response and community flood awareness using technically sound data will by themselves result in some reduction in flood losses.

³ More generally, the objective of early warning is to empower individuals and communities, threatened by natural or similar hazards, to act in sufficient time and in an appropriate manner so as to reduce the possibility of personal injury, loss of life and damage to property, or nearby and fragile environments (UN, 1997).

⁴ An alert may take the form of access to real-time data, an SMS or message via social media from a credible source, a forecast of expected flood conditions, advice of indicative flood conditions, and so on.



ⁿ **Figure 14-9 Elements of the Total Flood Warning System (source: VFMS, 2016)**

14.3.4 Flood Warning for the Lower Thomson Floodplain

14.3.4.1 Context

The West Gippsland Floodplain Management Strategy (WGCMA, 2017) characterises flood risk for the lower Thomson floodplain and Sale as “significant”. Consistent with that characterisation, the current study indicates that potential for flood damages from around the 20% AEP (1 in 5 AEP) event:

- ⁿ Arises from farming activities, disruption to local and regional transportation and potential for loss of life on flooded roads across the rural floodplain downstream from Heyfield; and
- ⁿ Is significant within Sale with access along a number of key roads compromised and a number of properties flooded.

While depths and velocities within the main channels of the watercourse do present as high hazard during even frequent events, flood depths and velocities within the overbank floodplain are, in general, low hazard apart from the main flow paths in the area upstream from the Princes Highway Bridge at Sale, particularly in the vicinity of Waterworks Road. Key roads across the floodplain including the South Gippsland Highway are wetted from around the 20% AEP (1 in 5 AEP) event. Community facilities and services are in the main not directly impacted by flooding.

The West Gippsland Floodplain Management Strategy proposes a strategic direction that articulates the need for community and regional resilience as a key and sustainable response to flood risk. This is consistent with State and Federal Government policy. The suggested approach to flood warning for the lower Thomson communities is similarly consistent. It is aimed at a system that will provide information to enable individuals to make informed decisions about risk and what they need to do. The emphasis is therefore on “what works best for these communities” with due regard for flood risk, available flood warning and response times, and the funding and other responsibilities associated with implementing and maintaining elements of a flood warning system.

The estimated effective flood warning time⁵ for the lower Thomson River floodplain under current conditions, is around 12 hours during a large flood and a few hours longer for a small flood. This places the lower Thomson River floodplain well outside the flash flood category as per Bureau of Meteorology definitions⁶ in BoM (1996) and as discussed in Victorian Flood Warning Consultative Committee (VFWCC) (2001) and BoM (2018).

14.3.4.2 Existing Total Flood Warning System Elements

A flood warning system already exists for the lower Thomson floodplain. While the system has undergone some strengthening over the years, most recently following the 2007 flood when additional telemetered rainfall stations were installed, the volunteer community based flood warden system remains an important element. The warden system is aimed particularly at the farming community downstream from Cowwarr Weir and provides current flow information.

A review of the role of VICSES in flood warning following the June 2007 flooding in Gippsland (VICSES, 2007) included documentation and discussion of flood warning, response and related activities across the region during that event (see also Molino Stewart, 2008)⁷. While informative from an historical perspective, neither report (VICSES, 2007 and Molino Stewart, 2008) was aimed specifically at documenting or reviewing the flood warning system for the lower Thomson River floodplain although the role of the flood wardens was covered in both reports. The VICSES report included notes from meetings with flood warning system stakeholders that also refer to the flood wardens but that demonstrate some differences in understanding of the warden’s role and relationship with other system stakeholders.

The Emergency Services Commissioner also undertook a review of the June 2007 flooding in Gippsland. The focus of that review was on examining the performance of the emergency

⁵ Effective flood warning time is defined as the time available after receiving advice (or being aware) of an impending flood before flood water prevents appropriate flood response action.

⁶ Flooding within 6 hours of causal rain.

⁷ The report presents a chronology of the event and warnings issued together with a discussion of what each of the flood warning system stakeholder agencies did during the event. It also considers the flood awareness of residents before, during and after the flood, identifies information dissemination tools and reviews how the warnings and information flow influenced resident’s preparedness, decision making and behaviour. The methodology included agency interviews, media monitoring and community surveys. A raft of recommendations was delivered by the report.

management arrangements in terms of preparedness for, response to and recovery from the flood and at capturing and understanding learnings. It also looked at the adequacy of warning systems and arrangements as well as organisational roles and responsibilities of emergency services under the (then) draft State Flood Plan with attention on the (then) current flood policy documentation and municipal emergency management plans for the areas affected.

A number of other reports were produced following the June / July 2007 floods in east and west Gippsland⁸. None of those reports provide additional insight to flood warning matters.

The existing flood warning system comprises:

- n A data collection network to support flood forecasting activities comprising:
 - n Eleven (11) telemetered rain gauges within or very close to the catchment at Mt Useful, Aberfeldy Township, Bells Portal, Thomson Dam, Mt St Gwinear, Mt Baw Baw, u/s Cowwarr Weir, Murderers Hill, Mt Gregory, Myrree (Thomson-Yarra Divide) and Sale. Data is available from the BoM website at hourly increments for Mt Useful, Mt Baw Baw, Murderers Hill and Sale and at 3-hourly increments for u/s Cowwarr Weir⁹.
 - n Nine (9) telemetered river gauges divided into data and forecast locations¹⁰ with data available from the BoM website at approximately 3-hourly intervals in the lead up to and during high flow events.
 - n Data locations: Beardmore, The Narrows, Heyfield (Thomson River), Heyfield (Rainbow Creek) and Bundalaguah;
 - n Forecast locations: Coopers Creek, u/s Cowwarr Weir (forecasts are based on advice from SRW), Wandocka and Sale Wharf.
 - n As most sites are multi-purpose (i.e. not installed purely for flood warning purposes), the network is funded by a mix of stakeholder agencies.
- n A flood warning service provided by BoM that comprises:
 - n Flood watches¹¹ for the Thomson and Macalister catchments when antecedent and weather conditions warrant, usually as part of a flood watch for all west Gippsland catchments;

⁸ The report *The Gippsland Floods of June / July 2007: Documentation and Review* by the East and West Gippsland Catchment Management Authorities provides a comprehensive summary of flood related reports produced in the months after these events.

⁹ Data is currently available from FloodZoom in near real-time for all eleven rain gauges but not from the BoM website.

¹⁰ Data, information and forecast locations are defined in the Version 3.1 of the FF&WS Service Level Specification for Victoria (BoM, April 2018) available from http://www.bom.gov.au/vic/flood/brochures/VIC_SLS_current.pdf.at

¹¹ The BoM will issue a flood watch when the combination of forecast rainfall and catchment conditions indicates flooding is possible. The aim is to provide early advice to communities and emergency service organisations of the potential for flooding from a developing weather situation.

- n Qualitative¹² forecasts for Coopers Creek that aim to provide at least 6 hours lead time of the expected exceedance of minor flood level (i.e. a rise to above 2.3m) at the gauge;
- n Forecasts of expected levels at u/s Cowwarr Weir based on advice received from SRW;
- n Quantitative¹³ forecasts for Wandocka and Sale Wharf that aim to provide at least 6 hours lead time of the expected exceedance of the minor flood level (i.e. a rise to above 6.2m and 2.4m) at the respective gauges.
- n Established flood class levels for Cooper Creek, u/s Cowwarr Weir, Wandocka and Sale Wharf.
- n Appendices for the Thomson River and for Sale within the Wellington MFEP.
- n A Local Flood Guide (LFG) for Sale.
- n Approximate 1% AEP flood extent mapping for the majority of the lower Thomson floodplain arising from the Flood Data Transfer Project in 2000 (DNRE, 2000).

The current study has delivered the following updated and additional TFWS elements:

- n Updated flood inundation and related mapping¹⁴;
- n An updated Municipal Flood Emergency Plan (MFEP) with flood consequence information for the lower Thomson floodplain and for Sale; and
- n Suggestions for further development of the TFWS.

A discussion of the existing flood warning system for the Thomson River, against each of the eight TFWS building blocks, is provided in Table 14-1.

14.3.4.3 Considerations

The division of responsibilities associated with the establishment, maintenance and operation of flood warning systems as documented in VFWCC (2001) have been endorsed by the relevant Ministers at both State and Federal level. More recent developments have seen the BoM establish a Service Level Specification (SLS) that identifies the flood forecast and warning service it provides for specific locations across the State (BoM, 2018). BoM is currently moving to establish a fee-for-service approach (i.e. a cost recovery model) for the development (on a priority basis) and maintenance of flood forecasting tools and services for locations not currently included in the SLS. The Victorian Floodplain Management Strategy (DELWP, 2016) provides

¹² A qualitative flood prediction typically comprises the expected class of flooding (i.e. minor, moderate or major) and a broad description of the expected timing of that flooding at the location.

¹³ A quantitative flood prediction typically comprises expected class of flooding (minor moderate, major) along with more specific information about the expected height and timing of water levels at the location.

¹⁴ While only key maps have been included in the MFEP, all mapping delivered by this study (together with the reports) is expected to be loaded to FloodZoom and to also be available from both the WGCMA and Wellington Shire Council. It is further expected that during a flood, CMA and Council officers will have direct access to copies of the original model results in GIS format along with the corresponding reports through respective agency hosting arrangements.

clarification on roles and responsibilities for TFWS development and operation in Victoria. Policy 16a is directed at flood warning.

Policy 16a clearly identifies the role of local government in TFWS development and delivery. In simplified terms and with specific reference to the lower Thomson floodplain:

- n BoM will continue to operate, maintain and improve the existing flood forecasting service with qualitative warnings provided for Coopers Creek, warnings provided for U/S Cowwarr Weir and quantitative warnings provided for Wandocka and Sale Wharf;
- n Any extension of that service including to other locations in the catchment, would be subject to the BoM's cost recovery model wherein DELWP would cover the capital cost of flood forecast model development and BoM the cost of operating, maintaining and continually improving that forecast model;
- n The capital cost of any new rain or river gauges would be met by the Victorian and Australian Governments but all on-going maintenance costs would need to be met by the Wellington Shire Council;
- n Arrangements as per the Emergency Management Manual Victoria (EMMV) would apply for development and delivery of other TFWS elements.

Looking ahead and as an out-working from the Services Standardisation Project, BoM has been collaborating in Victoria with Emergency Management Victoria (EMV) and VICSES on scoping an automated alerting project. It is understood the project involves BoM systems automatically identifying exceedance of critical levels on data ingested from selected telemetered rain and river gauges and alerting of that exceedance to EMV. It is further understood that EMV and VICSES are investigating how to use those alerts to generate warnings of potential or actual river level rises. The work appears to offer exciting potential to alert and warn at-risk communities of developing flood events in areas not commanded by existing flood prediction services – as a push to the VicEmergency website and App and as more formal public issue warnings from VICSES. It is not suggesting that the project offers a ready-made solution to achieve additional forecasting locations within the lower Thomson floodplain, subject to successful development and trialling, the future potential for the more timely issue of initial flood warnings is evident.

There are a number of decisions required in relation to how each of the TFWS elements could be developed and implemented for the lower Thomson floodplain. Regardless, the main messages from the 2005 Flood Warning Service Development Plan for Victoria (VFWCC, 2005) remain valid. Those applicable to the Thomson include:

- n Making existing data and information / flood intelligence easily accessible to the at-risk communities;
- n Assisting at-risk communities use that data and intelligence (for example: personalised “what does it mean for me” letters, pamphlets and related information);
- n Developing / providing tools that add value to or drag value from available data and intelligence;

- n Developing a (local) means of providing an indication of likely flooding with some lead time for (say) Heyfield (upstream of the study area) and for which BoM does not currently provide a warning service;
- n Driving maximum value from flood study outputs and mapping for local community benefit;
- n Focussing on what will achieve a reduction in damages; and
- n Providing the data, information and tools to enable at-risk communities build resilience.

In view of existing TFWS elements and what has been delivered by the current study, it is suggested that the key issue for the lower Thomson floodplain and specifically for Sale, is how available rainfall data and flood consequence information can be made available to the at-risk communities in the rural areas and in Sale. It is suggested that the following would assist:

- n Ready public access to all available raw rainfall data¹⁵.
- n An increase in the target lead time for issue of flood warnings by BoM.
- n Ready public access to flood intelligence (i.e. mapping perhaps as soft copies or through an interactive GIS hosted by Wellington Shire Council (WSC) and / or WGCMA, flood intelligence cards, etc) so that the communities can determine likely impacts and individual consequences and initiate appropriate response actions.

Most of the above should be able to be achieved with minimal cost. Opportunities do exist for local government to seek and secure Commonwealth and State funding to assist with set up costs. Operational and on-going costs remain a local government responsibility.

¹⁵ Easy and timely access to data is important for communities at risk from flooding. The BoM website data maps and tables provide such an avenue. Commitment is required from BoM that rain data from all gauges within the catchment will be available on a 1 or 3-hour update cycle through the tables and maps (as appropriate).

ⁿ **Table 14-1 Flood Warning System Building Blocks and current arrangements for the Thomson River (with due regard for the EMMV, VFWCC (2001), EMA (2009), VFMS (2016) and BoM (2018))**

Building Blocks of a Flood Warning System	Entities Involved in Victoria	Basic Tools	Current arrangements for the Thomson River floodplain
DATA COLLECTION & COLLATION	BoM provides real time data for flood warning from the national rain gauge network and provides technical assistance for improved data collection networks to support flood warning systems. MW provides real time river and additional rain data for flood warning for the Port Phillip and Westernport region. River and other rain data availability assured through the DSE-managed Regional Surface Water Monitoring Partnerships (involve BoM, DSE, RWCs, CMAs, LG, etc). LG (as the prime beneficiary) has O&M funding responsibilities for upgraded flood warning networks if gauges have been installed primarily for flood warning purposes	Data collection network (e.g. rain & stream gauges, weather radar, satellite images).	The existing data collection network (rain and river gauges) was augmented following the June 2007 flood using capital funds provided by the State Government. The majority of on-going costs associated with those new sites are being met by SRW and Wellington Shire with the balance being funded by BoM. There are 11 relevant rain gauges: Mt Useful, Aberfeldy Township, Bells Portal, Thomson Dam, Mt St Gwinear, Mt Baw Baw, u/s Cowwarr Weir, Murderers Hill, Mt Gregory, Myrree (Thomson-Yarra Divide) and Sale. There are 9 relevant river gauges divided into data and forecast locations¹⁶. § Data locations: Beardmore, The Narrows, Heyfield (Thomson River), Heyfield (Rainbow Creek) and Bundalaguah.

¹⁶ Data, information and forecast locations are defined in the *Service Level Specification for Flood Forecasting and Warning Services for Victoria – Version 3.1* (BoM, April 2018) available from http://www.bom.gov.au/vic/flood/brochures/VIC_SLS_current.pdf.

Building Blocks of a Flood Warning System	Entities Involved in Victoria	Basic Tools	Current arrangements for the Thomson River floodplain
	(VFMS, 2016). WC's provide BoM with information on storage status and releases.		§ Forecast locations: Coopers Creek, u/s Cowwarr Weir (based on advice from SRW), Wandocka and Sale Wharf. Not all flood producing storms are captured by the data collection network as there are a variety of flood producing mechanisms.
		System to convey data from field to forecast centre (e.g. radio or phone telemetry).	Data sites communicate in the main via radio telemetry although current data can be obtained via telephone from some of the sites. SRW and BoM have established a mutual data access agreement to facilitate data sharing.
		Data management system to check, correct, store, display data.	Data from a number of rain and all available river sites within and adjacent to the Thomson catchment are available through the BoM website. They are also available to SRW at Cowwarr Weir.
		Information on water storage levels, inflows and operations.	SRW provides verbal (telephone) advice to: · BoM when the initial, minor, moderate and major flood levels / flows are expected to be achieved at Cowwarr Weir beginning at an initial flow of 4,900ML/d. · VICSES (via established procedures) at the same trigger levels / flows; · Volunteer community flood wardens at predefined trigger flows beginning at 1,000ML/d. Last advice is provided at

Building Blocks of a Flood Warning System	Entities Involved in Victoria	Basic Tools	Current arrangements for the Thomson River floodplain
			37,000ML/d when major flood flow (40,000ML/d) is expected; · VICSES and VicPol at extreme flood flow (60,000ML/d).
		Arrangements and facilities for system / equipment maintenance and calibration. For example, the Regional Surface Water Monitoring Partnerships, data warehousing, etc.	On-going costs associated with the rain and river data collection network that supports the flood warning service for the Thomson River are funded primarily by SRW, Wellington Shire and BoM through the Regional Surface Water Monitoring Partnership.
FLOOD DETECTION & PREDICTION (i.e. Forecasting)	BoM prepares flood forecasts for rural areas and provincial centres. Murray forecasts determined in conjunction with River Murray Operations. MW prepares flood forecasts for the main streams in the Port Phillip and Westernport region. BoM provides predictions of weather conditions likely to lead to flash flooding for the whole State. LG is primarily responsible for flash flood forecasting but likely to be assisted by MW in the Port Phillip and Westernport region.	Information on critical levels / effects at key and other locations.	SRW's Eastern Storages Flood Plan includes information on flows at which selected assets, infrastructure and key roads on the downstream floodplain are likely to be threatened by flooding. This and other information is available in the Wellington Shire MFEP, some of which is also provided in the Sale FloodSafe Local Flood Guide produced by VICSES in July 2015. SRW SitReps are forwarded to the ICC during a flood event.
		Appropriately representative flood class levels at key locations.	Representative flood class levels and flows have been established at the upstream Cowwarr Weir river gauge for some considerable time as follows: minor 3.7m: 7,500ML/d; moderate 4.5m: 20,000ML/d; major 5.5m: 40,000ML/d.

Building Blocks of a Flood Warning System	Entities Involved in Victoria	Basic Tools	Current arrangements for the Thomson River floodplain
			Flood class levels have also been established for Coopers Creek, Wandocka and Sale Wharf.
		Flood forecast techniques (i.e. hydrologic and rainfall-runoff models, stream flow and height correlations, simple nomograms based on rainfall). URBS models developed for most of the larger Victorian catchments.	BoM have fitted an URBS model to the Thomson catchment. When a significant rainfall event is forecast, this model is used to predict the possible range and scope of flooding from a suite of likely rainfall depths assumed to be spatially and temporally uniformly distributed over the catchment. Model results are shared with the SRW, VICSES and other agencies to assist pre-flood planning and are indicative only.
		Meteorological analyses and data.	Food warnings issued by BoM for the Thomson River are informed by advice of outflows from Cowwarr Weir from SRW. In order to enable safe operation of Cowwarr Weir, SRW calculate inflows. This calculation is based on change in storage level as per standard storage flood routing techniques. SRW also use the upstream rain and river gauges to gain an appreciation of the likely size of the expected inflow. However, not all flood producing storms are captured by the exiting data collection network. SRW provides verbal (telephone) advice to BoM of actual and expected outflows from Cowwarr

Building Blocks of a Flood Warning System	Entities Involved in Victoria	Basic Tools	Current arrangements for the Thomson River floodplain
			Weir beginning at an initial flow of 4,900ML/d. Similar advice is provided to VICSES. SRW also provides verbal (telephone) advice to volunteer community flood wardens at predefined flows beginning at 1,000ML/d. Last advice is provided at 37,000ML/d when major flood flow (40,000ML/d) is expected. Trigger levels and contact details are contained in SRW's Eastern Storages Flood Plan. Flood forecasts for Coopers Creek are qualitative, for u/s Cowwarr Weir are informed by advice from SRW, and for Wandocka and Sale Wharf are quantitative.
MESSAGE CONSTRUCTION	Warning messages are prepared by: ∅ BoM for weather conditions likely to lead to flash flooding for the whole State; ∅ BoM for flooding in rural areas and provincial centres; ∅ MW for flooding in the Port Phillip and Westernport region but disseminated through BoM system; ∅ LG for flash flooding in municipal areas. Opportunity exists for enhancement of messages by VICSES / LG through inclusion of local impacts and related information.	Warning messages / products and message dissemination system.	Flood watches are issued by BoM to notify communities and other stakeholders within broad areas (e.g. West Gippsland rather than the Thomson catchment) of the potential flood threat from a developing weather situation. They provide a 'heads up' of likely flooding. Flood watches are based on an assessment of the developing weather situation and indicators of current catchment wetness. They provide generalised statements about expected forecast rainfall totals, the current state of the catchments within the target area and indicate the streams at

Building Blocks of a Flood Warning System	Entities Involved in Victoria	Basic Tools	Current arrangements for the Thomson River floodplain
			risk from flooding. Instructions for obtaining rain and stream level observations and access to updated Watches and Warnings are also included. Normally, the BoM would issue a Flood Watch 24 to 36 hours in advance of any likely flooding and issue updates as required. If at any time during that period there was an imminent threat of floods occurring, the Flood Watch would be upgraded to a Flood Warning. Flood Warnings for the Thomson River are firm predictions of flooding based on recorded rainfall and river height information. Flood warnings are categorised as 'minor', 'moderate' or 'major' (see BoM website for an explanation of these terms and current flood class levels) and indicate the expected severity of the flood. Flood warnings also include where available: § Rainfall amounts for selected locations within and adjacent to the catchment; § River heights and trends (rising, steady, falling) at river gauge locations within the catchment; § A weather outlook and the likely impact of expected rainfall on flooding; and § A warning re-issue date and time. Note: The term "significant rises" may be used in the early stages of an event when it is clear

Building Blocks of a Flood Warning System	Entities Involved in Victoria	Basic Tools	Current arrangements for the Thomson River floodplain
			that river levels will rise but it is too early to say whether flooding will occur. BoM aim to achieve 6 hours warning lead time on the exceedance of flood class levels.
MESSAGE DISSEMINATION (i.e. flood alerting and notification: communicating the warning message and information)	BoM to VICSES, LG, VicPol, CMAs and media. VICSES alerts relevant agencies and organisations when BoM issues flood warning(s) and enhances the warning(s) by issuing community safety information and action statements. VICSES may refer relevant agencies and organisations to BoM website or to VICSES website and / or Flood and Storm Information Line (when activated) for key messages and action statements. LG disseminate information further. Not clear that messages are disseminated sufficiently to at-risk communities. BoM provides ALERT system co-operators with ENVIROMON software to collate and	Formal media channels ¹⁷ – TV, radio and print.	SRW provides verbal (telephone) advice to the volunteer community flood wardens at predefined outflows from Cowwarr Weir beginning at 1,000ML/d. Advice is repeated at increasing flows including at minor, moderate and major flood levels up to 40,000ML/d (major flood). The early advice is aimed at assisting decisions to remove pumps and stock from near the river. Flood wardens relay information received from SRW to local landholders via telephone tree. Flood wardens and the telephone tree were established for and are maintained locally. It is understood that the flood wardens are covered through VICSES insurance in a similar manner to
		Internet (e.g. email, BoM website, VICSES website, social media).	
		Tape message services (e.g. the VICSES Flood and Storm Information Line for key messages and action statements).	
		Other channels - fax / faxstream, phone / pager (e.g. SMS such as offered by StreetData, voice, local communication 'trees'), voice messaging systems (e.g. Emergency Alert), community radio (e.g. FM-88).	
		Doorknocking.	

¹⁷ ABC Radio has entered into a formal agreement with the Victorian Government and the Bureau of Meteorology to broadcast, in full, weather related warnings including those for flood. The agreement provides for the interruption of normal programming at any time to allow the broadcast of warning messages. This agreement is aimed at ensuring that flood (and other) warnings issued by the Bureau are broadcast in their entirety and as soon as possible after they are received in the ABC's studio.

Building Blocks of a Flood Warning System	Entities Involved in Victoria	Basic Tools	Current arrangements for the Thomson River floodplain
	display data and initiate flood alerts that are based on exceedance of criteria such as rainfall volumes or rates and / or river levels or rates of rise.	Flood wardens and local telephone trees (e.g. downstream from Cowwarr Weir). Other opportunities for at-risk communities to confirm warning details.	SES volunteers. Flood Watches and Warnings are issued by BoM via a mix of fax and email to VICSES, VicPol, the media (radio and TV - ABC and local), and a range of other stakeholder organisations including Wellington Shire Council, West Gippsland CMA, DELWP, SRW, Red Cross, VicRoads and Telstra. While the BoM's warning dissemination system monitors the delivery of faxes (a delivery failure trips an alert which results in a follow up telephone call from a BoM staff member), it does not monitor the success or otherwise of email delivery. VICSES as the Control Agency for flood also issue flood warning messages that include more detailed information including flood consequences to the media and to a wider audience via the electronic media, websites and social media. Flood Bulletins are issued by VICSES to the media and other stakeholders. During larger floods, VICSES, in conjunction with SRW, host local community (town hall) meetings aimed at reinforcing flood warning messages, providing additional information and better targeting assistance.

Building Blocks of a Flood Warning System	Entities Involved in Victoria	Basic Tools	Current arrangements for the Thomson River floodplain
			VICSES initiate the Emergency Alert during severe flooding and when evacuations are required.
INTERPRETATION (i.e. what does the forecast height mean for me or you)	LG and community but is spread across LG, VICSES and CMAs. VICSES has adopted a lead role and employs specialist expertise to assist in this regard. Opportunity for MW and CMAs to assist LG / VICSES through provision of flood related expertise and experience re impacts, etc – both during planning for and responding to flood.	Interpretative tools (i.e. flood inundation maps from experience, studies, VFD and related databases; flood information cards; flood histories; local knowledge; flood emergency plans that have tapped community knowledge and experience as well as flood related studies and other sources; etc).	SRW's Eastern Storages Flood Plan includes information on flows at which selected assets, infrastructure and key roads on the downstream floodplain are likely to be threatened by flooding. This and other information is provided in the Wellington Shire MFEP, some of which is also provided in the Sale FloodSafe Local Flood Guide produced by VICSES in July 2015 WGCMA and consultant flood analysts provide specialist expertise to the ICC / VICSES to assist with the identification of likely flood impacts (in terms of water depths, extents and assets at risk) and necessary response actions. Becomes difficult for the CMA to provide resources to fulfil this role during a large event because of the need to meet statutory obligations with respect to flood data collection and collation, and related matters.
RESPONSE	VICSES are the Control Agency for flood response. Strong involvement from LG, VicPol and community. Should be driven by flood emergency plans (MFEPs - MEMP Sub-Plans) that include local flood	Flood management tools (e.g. MFEPs complete with inundation maps and past 'intelligence', effective public dissemination of flood information, local	Flood intelligence on which to base response activities is currently sparse as there are only limited flood inundation extent and depth maps available for the reach from Cowwarr Weir to a short distance downstream from Heyfield and

Building Blocks of a Flood Warning System	Entities Involved in Victoria	Basic Tools	Current arrangements for the Thomson River floodplain
	intelligence gained from experience and extracted from flood study deliverables. Should also be driven by personal and business flood response plans. MFEPs are owned and maintained as a joint VICSES / LG document that captures CMA input.	flood awareness, individual and business flood action plans, etc).	between Wandocka and Bundalaguah arising from a Macalister River flood, some historic spot flood heights and no flood intelligence tables. The mapping and spot levels are available through FloodZoom. None of the information is contained in the Wellington Shire MFEP although there is some information on past floods. While farmers are more aware of likely flood impacts on their own properties due to community “memory”, much of the community has not lived through a large flood. Road closures by Wellington Shire Council, VicRoads and / or VicPol as required. ICC and MECC established as required with VicPol fulfilling the coordination role as per State incident management arrangements
		Community flood education and flood awareness raising, flood response guidelines and related information – all those tools that together work to build flood resilient communities (see the Awareness building block below).	VICSES has produced a Local Flood Guide for Sale.

Building Blocks of a Flood Warning System	Entities Involved in Victoria	Basic Tools	Current arrangements for the Thomson River floodplain
REVIEW	All stakeholder entities including the VFWCC and communities potentially have opportunity to provide review comments. LG, MW, CMAs and VICSES have a role in collecting post-flood data (hydrologic, flood extent, impacts, damages, etc).	Personal and business flood action plans (see EMA website, VICSES tool kit, etc).	
		Comprehensive use of available experience, knowledge and information.	WGCMA along with consultant flood analysts provide specialist expertise to the ICC / VICSES to assist with the identification of likely flood impacts and necessary response actions. SRW also provide input and advice if and as required or able.
		Post-event debriefs (agency, community), etc	VICSES facilitate community debriefs after severe flood events. Stakeholder agencies also engage in an incident and / or individual debriefs.
		Review and update of personal, business and other flood action plans.	
		Collection of flood 'intelligence' and flood damage data during and after the event (e.g. rapid impact assessments, CMA, DELWP, WC and LG activities, etc).	WGCMA undertake a comprehensive data collection and collation exercise during and immediately after significant flood events (aerial photography, flood extents, peak flood levels / depths, impacts) consistent with their Statement of Obligations. This data is available to be shared with other stakeholder agencies (e.g. to update flood intelligence records and related materials).

Building Blocks of a Flood Warning System	Entities Involved in Victoria	Basic Tools	Current arrangements for the Thomson River floodplain
			VICSES undertake rapid impact assessments during a flood event and share key information through regular SitReps. Generally, data collected during flood events is available to be shared with other stakeholder agencies.
AWARENESS	VICSES has adopted a lead role with the roll-out of the FloodSafe program. Involvement from LG, MW and CMAs (and WCs in some instances).	Identification of vulnerable communities and properties (i.e. flood inundation maps, information on flood levels / depths and extents, property-specific flood depths, etc).	The VFD datasets (available through FloodZoom) provide some historic spot flood levels within the floodplain. Flood extents, depth and elevation mapping is available through FloodZoom for a reach from Cowwarr Weir to a short distance downstream from Heyfield and between Wandocka and Bundalaguah arising from a Macalister River flood. SRW's Eastern Storages Flood Plan includes some flood intelligence that would be useful to VICSES and Wellington Shire.
		Activities and tools (e.g. participative community flood education, flood awareness raising, flood risk communication) that aim to build flood resilient communities (i.e. communities that can anticipate, prepare for, respond to and recover quickly from floods while	A Local Flood Guide has been prepared for Sale. It is not clear how many residents on the floodplain downstream from Cowwarr Weir have prepared personal or business flood plans.

Building Blocks of a Flood Warning System	Entities Involved in Victoria	Basic Tools	Current arrangements for the Thomson River floodplain
		also learning from and improving after flood events).	
		The VICSES FloodSafe and StormSafe (flash / stormwater flooding) programs.	VICSES produced a FloodSafe Local Flood Guide for Sale in July 2015. SRW's website includes information on SRW's (and others') role in the flood warning system.
		Local flood education plans – developed, implemented and evaluated locally (e.g. Cities of Maroondah, Whitehorse, Wodonga, Benalla and Greater Geelong).	
		Flood response guidelines, residents' kits, flood level information, flood inundation maps, flood markers, property-specific flood charts (e.g. Glenorchy, Horsham, Dimboola, Warracknabeal), flood levels in meter boxes (e.g. Benalla, Traralgon) and on rate notices, etc.	

14.3.5 Flood Warning System Improvements

The following sections outline how each of the TFWS elements could be improved at minimum cost in order to achieve an effective improvement to the flood warning system that has some utility to the rural areas of the floodplain as well as to Sale.

14.3.5.1 Data Collection and Collation

The TFWS service level assessment (MCA, 2017) that informed the West Gippsland Floodplain Management Strategy (WGCMA, 2017), indicated that the existing data collection network is generally commensurate with flood risk. However, while data from all nine (9) telemetered river level gauges in the catchment are available from the BoM website, data from only five (5) of the eleven (11) telemetered rain gauges is available. It is suggested that near real-time access to an increased number of rain gauges would improve community awareness of the likelihood and scale of potential flooding during rain events.

It is suggested that WSC, with support from VICSES and WGCMA, approach BoM to provide near real-time public access via the BoM website to data from all eleven telemetered river gauges in or adjacent to the Thomson River catchment.

14.3.5.2 Flood Detection & Prediction

The TFWS service level assessment (MCA, 2017) that informed the West Gippsland Floodplain Management Strategy (WGCMA, 2017), indicated that the existing flood forecasting system is generally commensurate with flood risk. Nevertheless, it is suggested that given that BoM uses a rainfall-runoff model for forecasting floods on the Thomson floodplain, a forecast lead time in excess of the 6 hours target documented in the SLS (BoM, 2018) and closer to the 12 hours effective warning time identified as part of this study should be achievable.

It is suggested that WSC, with support from VICSES and WGCMA, approach BoM to increase the target flood forecast lead time for the Thomson River catchment.

Flood class levels, determined against standard definitions¹⁸, are used to establish a degree of consistency in the categorisation of floods. A desk top review of those in place for Wandocka and Sale as part of this study suggest that the levels appear to be about right. There is however, a substantial length of floodplain between Wandocka and Sale. In order to assist the flood warning process and increase community awareness of flooding and associated risks, it is suggested that WSC give consideration to establishing flood class levels for Bundalaguah (with due regard for the rating curve review discussed in Section 5.3.2). The process would involve coordination between Council, VICSES, WGCMA and BoM and is relatively straight-forward.

¹⁸ Standard definitions for minor, moderate and major flood class level are available from the BoM website.

Initial conservative flood class levels derived from consideration of study deliverables are proposed for Bundalaguah in Table 14-2. A more detailed analysis could be expected to result in some refinement of these levels.

Table 14-2 Proposed Flood Class Levels

Location		Minor	Moderate	Major
Bundalaguah	Proposed	7.2m	7.4m	7.6m
U/S Cowwarr Weir	Existing	3.7m	4.5m	5.5m
Wandocka		6.2m	6.5m	6.7m
Sale Wharf		2.4m	3.0m	4.0m

14.3.5.3 Interpretation

The flood inundation maps and WSC MFEP Appendices updated as part of the current study provide the base information to enable the communities and stakeholder agencies to determine the likely effects of a potential flood. This means however that the flood inundation maps and relevant Appendices of the MFEP, and more specifically the flood intelligence cards for the rural floodplain and Sale, need to be readily available to member of the at-risk communities.

14.3.5.4 Message Construction and Dissemination

It is likely that for most Thomson catchment residents, the initial alert of likely flooding comes from a combination of a BoM issued flood watch via electronic and social media, environmental indicators (i.e. heavy rain) and advice by way of the flood wardens downstream from Cowwarr Weir. In future, this should be augmented by consideration of the flood inundation maps delivered by this study in conjunction with the MFEP Appendices.

WSC and VICSES to continue to actively promote subscription to the EMV hosted VicEmergency alerting system.

14.3.5.5 Response

The WSC MFEP Appendices and associated flood intelligence cards have been populated for the lower Thomson floodplain and Sale as part of the current study. Information in the MFEP includes available intelligence relating to flooding in the catchment. Flood inundation extent and depth maps have been added together with a list of areas and roads likely to be flooded.

14.3.5.6 Community Flood Awareness

The Local Flood Guide (LFG) for Sale was produced in July 2015. It needs to be updated to reflect the outcomes from the current study: extents are broader and impacts more severe than currently communicated. The intelligence (i.e. technical text) for an updated LFG for Sale and a new LFG for the rural parts of the lower Thomson floodplain could easily be extracted from the relevant MFEP Appendices. It is suggested that LFGs should be built, printed and made available for both areas.

Activities and materials that emphasise personal safety and that provide information on how the TFWS works, where data is available, how that data can be used, what flood watches and warnings mean and what individuals should do to stay safe and protect their property should be initiated to develop, maintain and renew flood awareness within the communities. This extends to making relevant parts of the MFEP publicly available (e.g. Council offices, library, website, etc).

14.3.5.7 Summary of Suggested TFWS Updates for the Thomson River Floodplain

A summary of the suggested improvements to the TFWS for the Thomson River floodplain is provided in Table 14-3 below against each of the TFWS building blocks with due regard for the EMMV, VFWCC (2001), EMA (2009), VFMS (2016) and BoM (2018).

Table 14-3 Summary of Suggested TFWS Updates

Building Blocks of a Flood Warning System	Suggested Actions for the Thomson River Floodplain
DATA COLLECTION & COLLATION	WSC, with support from VICSES and WGCMA, approach BoM to provide near real-time public access via the BoM website to data from all telemetered rain gauges in or adjacent to the Thomson River catchment.
DETECTION & PREDICTION (i.e. Forecasting)	WSC, with support from VICSES and WGCMA, approach BoM to increase the target flood forecast lead time for the Thomson River catchment. WSC give consideration to adopting the proposed flood class levels for Bundalaguah. This will necessitate coordination between Council, VICSES, WGCMA and BoM and is a relatively straight-forward process.
INTERPRETATION (i.e. an ability to answer the question "what does this mean for me - will I be flooded and to what depth".	Deliverables and intelligence arising from the Lower Thomson Flood Study have been captured to the MFEP. WSC to ensure flood inundation maps and relevant Appendices of the MFEP along with the relevant flood intelligence cards are readily available to the Thomson River floodplain communities.
MESSAGE CONSTRUCTION	The initial alert of likely flooding is likely come from a combination of a BoM issued flood watch via electronic and social media, environmental indicators (i.e. heavy rain) and advice by way of the flood wardens downstream from Cowsarr Weir. In future, this should be augmented by consideration of the flood inundation maps delivered by this study in conjunction with the MFEP Appendices.
MESSAGE DISSEMINATION (i.e. Communication and Alerting)	WSC and VICSES to continue to actively subscription to the EMV hosted VicEmergency alerting system.
RESPONSE	Following (or perhaps in concert with) acceptance of the MFEP by WSC and VICSES, encourage and assist residents and businesses to develop individual flood response plans. A package that assists businesses and individuals is available from VICSES and provides an excellent model for community use.
REVIEW	Review and update of local flood intelligence (i.e. flood characteristics, impacts, etc), local alerting arrangements, response

Building Blocks of a Flood Warning System	Suggested Actions for the Thomson River Floodplain
	plans, local flood awareness material, etc (initially) after every flood that triggers a response. Best driven by WSC with input from VICSES, WGCMA and Council.
AWARENESS	Develop, maintain and renew flood awareness through activities and materials that emphasise personal safety and that provide information on how the TFWS works, where data is available, how that data can be used, what any alerts mean and what individuals should do to stay safe and protect their property. As part of this .. Update, republish and redistribute the Sale LFG. .. Develop a LFG for the rural parts of the Thomson River floodplain using intelligence included in the MFEP. Print and make available to the wider community. WSC and VICSES to: .. Load and maintain material including the MFEP to the WSC and VICSES websites with appropriate links to relevant useful sites; .. Routinely revisit and update awareness material to accommodate lessons learnt, additional or improved material and to reflect advances in good practice; and Routinely repeat distribution of awareness material and consider other measures.

14.4 Road Closures and Access

During a flood event road closures and access is important to allow the free movement of people and moveable assets (for example machinery and livestock) out of harm's way. As flood waters rise it is an unfortunate reality that many people do not adequately heed, or are not aware of, the risk of driving through floodwaters. Often this is due to underestimating the flood depth across the road, inadequate flood markers or lack of road closure signs due to the necessary time and human resources to manually setup the signs during a flood.

As described above, due to the long history of flooding and the well defined floodplain the majority of major roads are located outside of the floodplain. For example both the Sale-Heyfield Rd and Maffra-Sale Rd run parallel with the floodplain but are flood free having been built on the escarpments. However there remains many lower trafficked roads within the floodplain that services the local communities.

14.4.1 Access

As shown above in Figure 14-1 through Figure 14-6, within the floodplain there is comparatively little that can be done for much of the community to improve access during floods. Raising roads to improve access within the floodplain to service individual homesteads and farms is simply not feasible. The required level of raising along with the required bridging and culverts would not be economically justified. Therefore, the best way to increase safety would be the installation of

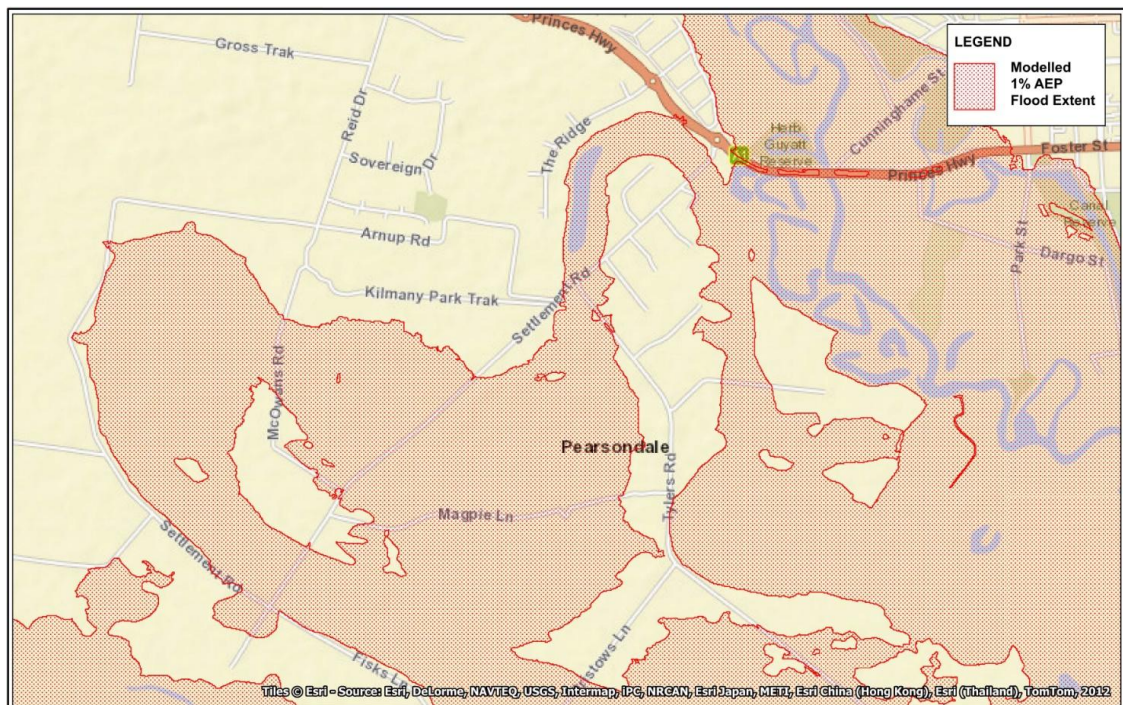
flood depth warning markers where they presently do not exist to provide information to dissuade people attempting to travel through flood waters. Where feasible, automated road closure signs based off riverine telemetry could also be considered. This would also relieve the burden on police and emergency services from travelling to and installing temporary signs during an event.

One area where road access improvements may be feasible is the community of Wurruk and Pearsondale, to the south-west of Sale, specifically, those based around Tylers Rd and Settlement Rd. This community is ringed by an old remnant anabranch of the Thomson River as shown in Figure 14-10. During flood events this anabranch becomes engaged which causes the community, which is located on a local high island, to become isolated. Selective raising and bridging of the lowest sections of both Tylers Rd and Settlement Rd would mean that these communities would not become isolated during a flood event and would allow the free movement of people.

14.4.2 Recommendations

Based on the assessment the following recommendations are made:

- n Consider the installation of flood depth warning signs and the adoption of automated road closure signs based off a trigger system;
- n Consider the feasibility of local road raising to enable access to flood free “high islands”



n **Figure 14-10 Warruk & Pearsondale “High Island” with 1% AEP Flood Model Results**

14.5 Planning Controls

The primary purpose of flood related planning controls is to trigger consideration of the level of flood risk associated with the use and/or development of flood-prone land. In the long term, planning controls are one of the cheapest and most effective means of reducing a community's flood risk by encouraging people to avoid developing flood-prone land if possible and to minimise potential impacts on existing flood-prone development (e.g. by requiring a higher flood level) when it is renewed.

Development of new planning controls for the lower Thomson region is not an element of this investigation. Draft planning maps and documentation suitable for implementing amendment of the existing flood related planning controls for the lower Thomson region could be developed by Council based on the outputs of this study.

14.5.1 Planning Overlay Background

Land use planning controls and building regulations provide mechanisms for ensuring appropriate use and development of flood-prone land. The objective of land use planning controls is to balance the likelihood of flooding with the consequences (the flood risk). Over time, these controls limit the growth in flood damages. The Victorian Planning Provisions (VPPs) are employed by all Victorian municipalities and set out a consistent planning scheme format. The stated objectives are to protect life, property and community infrastructure from flood hazard, and to preserve flood conveyance capacity, floodplain storage and natural areas of environmental significance.

- n The VPPs provide for two overlays and one zone associated with mainstream flooding as follows:
- n Land Subject to Inundation Overlay (LSIO);
- n Floodway Overlay (FO); and
- n Urban Floodway Zone.

14.5.1.1 Land Subject to Inundation Overlay (LSIO)

The LSIO identifies land liable to inundation by overland flow, in flood storage or in flood fringe areas affected by the 1% AEP flood. The permit requirements of LSIO are intended:

- n to ensure that development maintains the free passage and temporary storage of floodwaters,
- n to minimise flood damage,
- n to be compatible with the flood hazard and local drainage conditions,
- n not to cause any significant rise in flood level or flow velocity,
- n to protect water quality in accordance with relevant State Environment Protection Policies (SEPPs).

Planned emergency facilities (hospitals, schools and police stations etc.) should be excluded from this area (refer to VPP Clause 13.03-1s). Permit requirements (development conditions) may be specified. The development of the LSIO for Lower Thomson was discussed in Section 12.2.

14.5.1.2 Floodway Overlay (FO)

The FO identifies waterways, main flood paths, drainage depressions and high hazard areas collectively referred to as the “floodway” portion of the floodplain. NRE’s “Advisory Notes for Delineating Floodways” (Edwards, 1998) has guided the delineation of floodway land in Victoria, based upon flood frequency, and level of hazard (based on depth and velocity considerations). The development of the FO for Lower Thomson was discussed in Section 12.2.

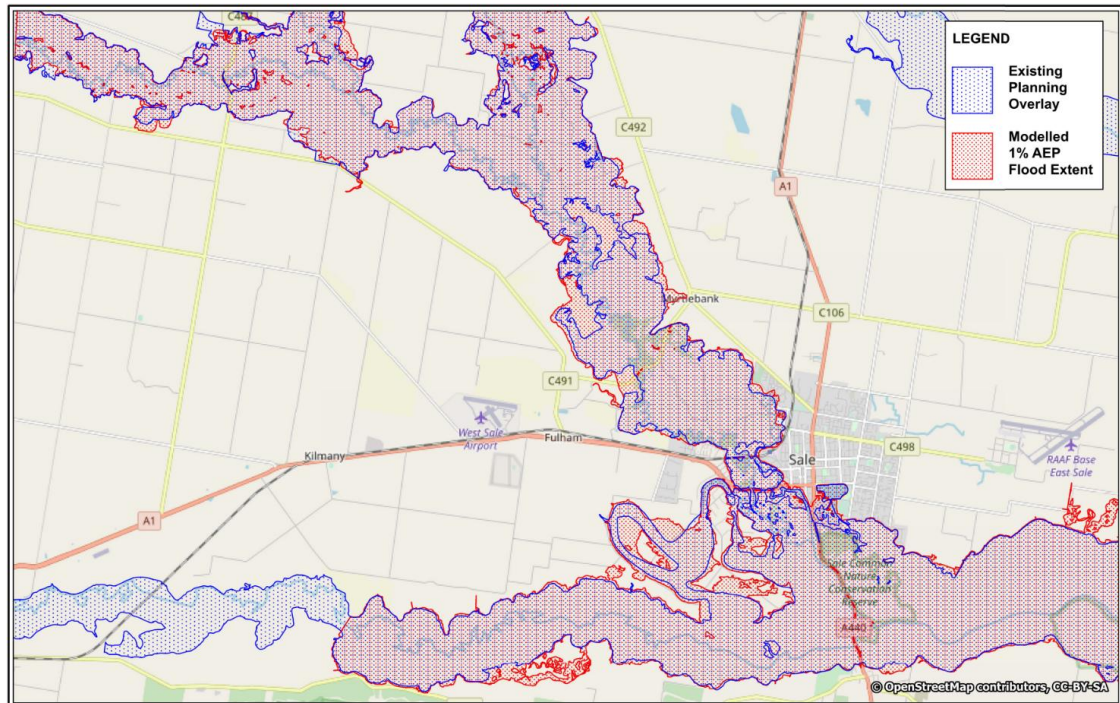
14.5.2 Existing Planning Controls

The existing controls include an LSIO and FO in the planning scheme is compared next to the 1% AEP flood extent in Figure 14-11. As can be seen there is generally a good match between the existing planning controls and latest modelling however there are obvious points of difference, with many areas not in the existing planning overlay that have been identified as potentially flood prone.

14.5.3 Recommendations

It is recommended that:

- n Council review the existing planning layers and consider adopting new FO and LSIO based on hydraulic hazard criteria from the latest modelling developed as part of this study; and
- n Implement declared flood levels as per the Water Act 1989 based on those determined as part of this study.



n **Figure 14-11 Comparison of the Existing Planning Scheme and 1% AEP Flood Model Results**

14.6 Summary and Conclusion

Due to the long history of settlement and flood events there is a reasonable understanding of flood risk in the community. Due to this knowledge and proactive management there is relatively little assets at risk within the catchment that can be readily mitigated. Due to this there are no obvious large structural mitigation options that would result in considerable savings to life or property. This report documents some smaller scale options considered and makes some recommendations that Council and the WGCMA may wish to consider in greater details. These include:

- n Council review the finished levels of the new housing development around Cemetery Rd and if this area is found to be at risk then consider road raising to form a defacto levee as part of future road upgrade, or investigate the construction of a levee adjacent to the road on the river side.
- n Review the finished floor levels of the inundated properties near Princes Hwy and Foster St to more accurately determine the flood risk of these properties. If a high risk is determined then consider undertaking a conceptual mitigation assessment and benefit-cost assessment to determine whether it is practical to implement a levee.
- n Consider updates to the TFWS.
- n Consider the adoption of automated road closure signs based off a trigger system.
- n Consider feasibility of local road raising to enable access to flood free “high islands”.

- n Council review the existing planning layers and consider adopting new FO and LSIO based on hydraulic hazard criteria from the latest modelling developed as part of this study; and
- n Implement declared flood levels as per the Water Act 1989 based on those determined as part of this study.

15 Conclusion

This project forms part of the Regional Flood Mapping Program. Outputs from the Regional Flood Mapping Program can be used by Catchment Management Authorities (CMAs), Local Government Authorities (LGAs) and VICSES to meet a range of business requirements. Outputs can be used to define flood related controls in Municipal Planning Schemes. They can be used to develop flood intelligence products, inform emergency response planning and assist in the preparation of community flood awareness and education products. Furthermore, outputs from the Program can be used to support the assessment of flood risk for insurance purposes.

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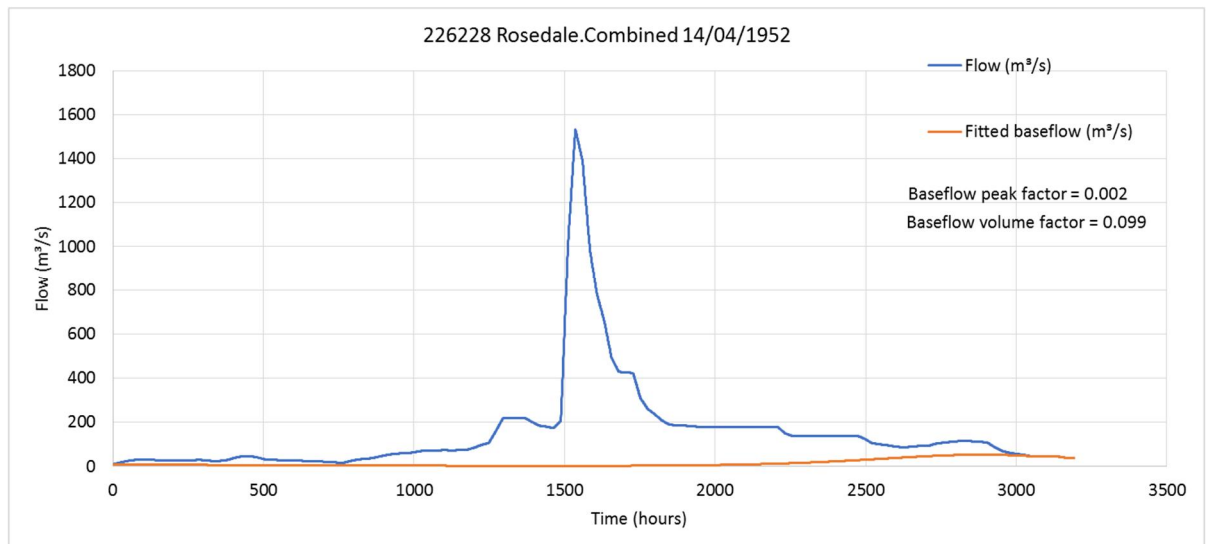
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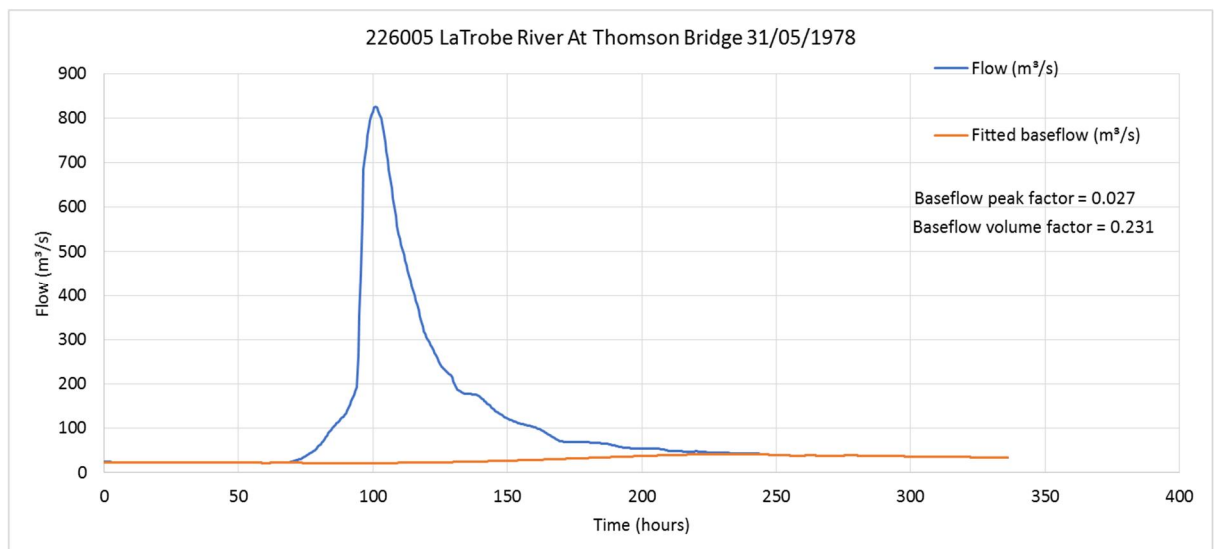
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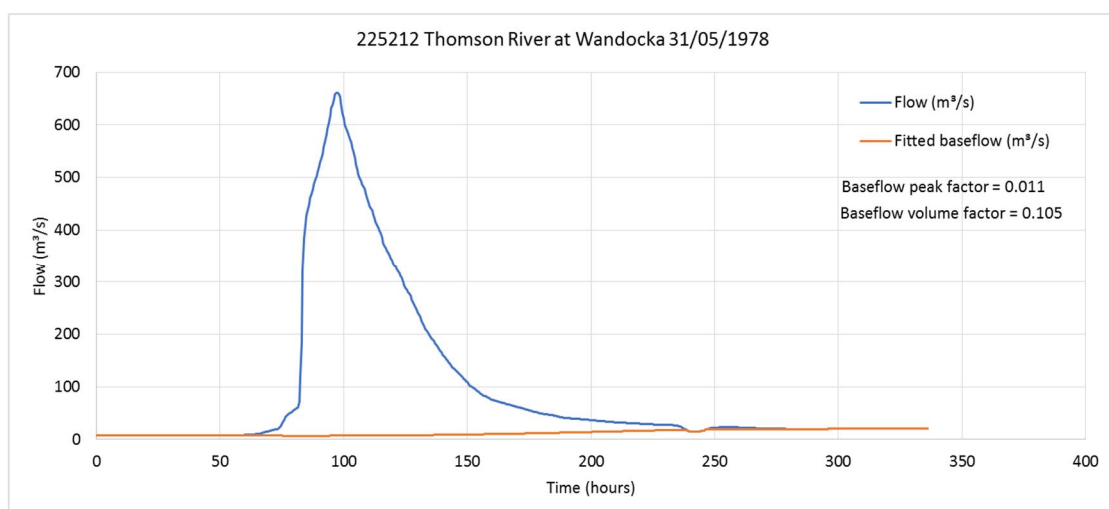
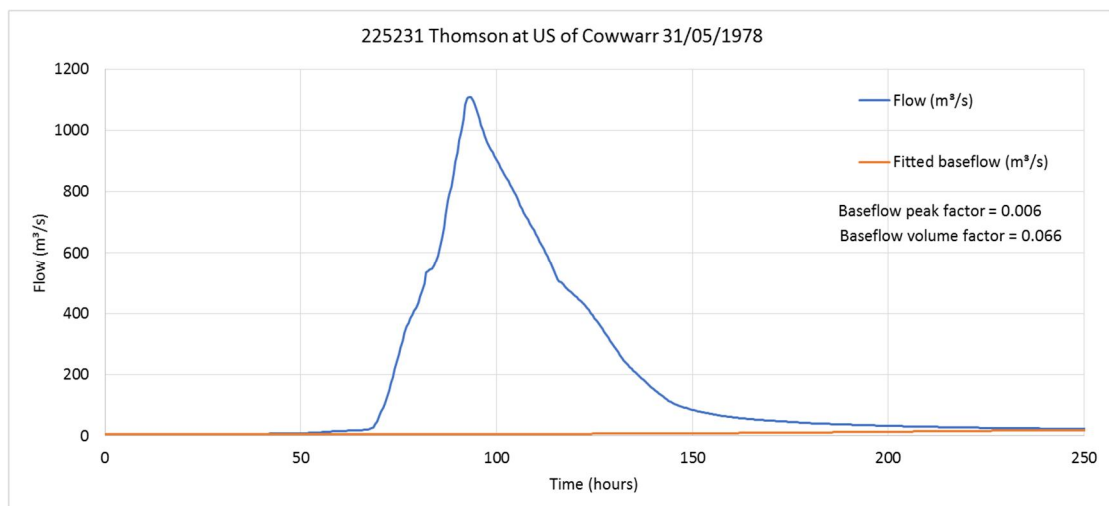
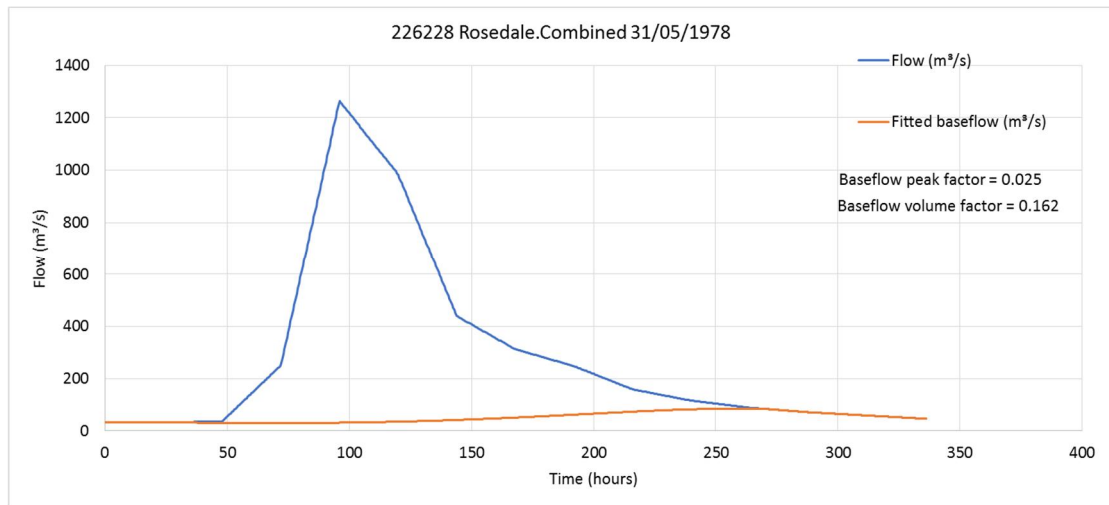
Appendix A Baseflow Separation for Calibration Events

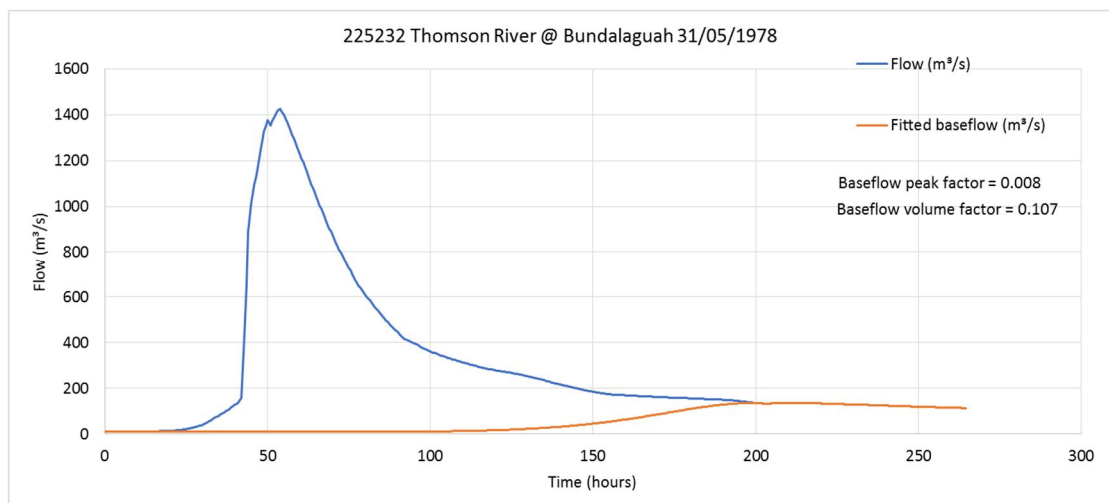
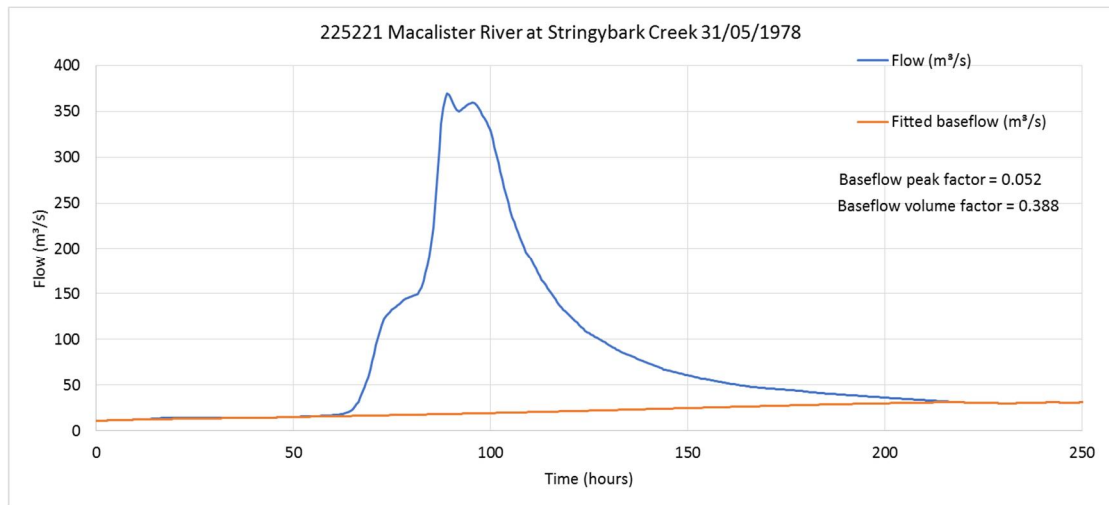
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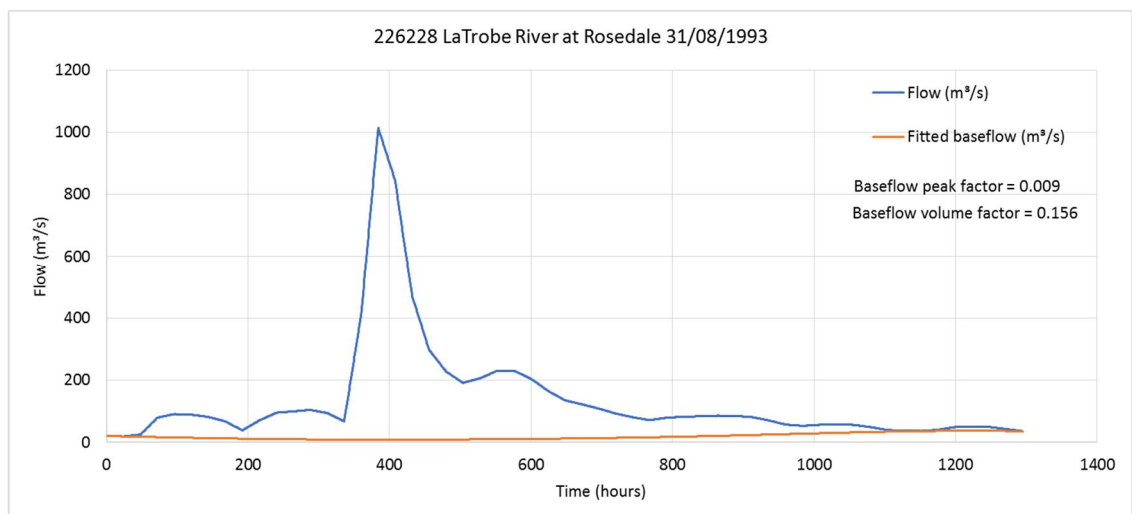
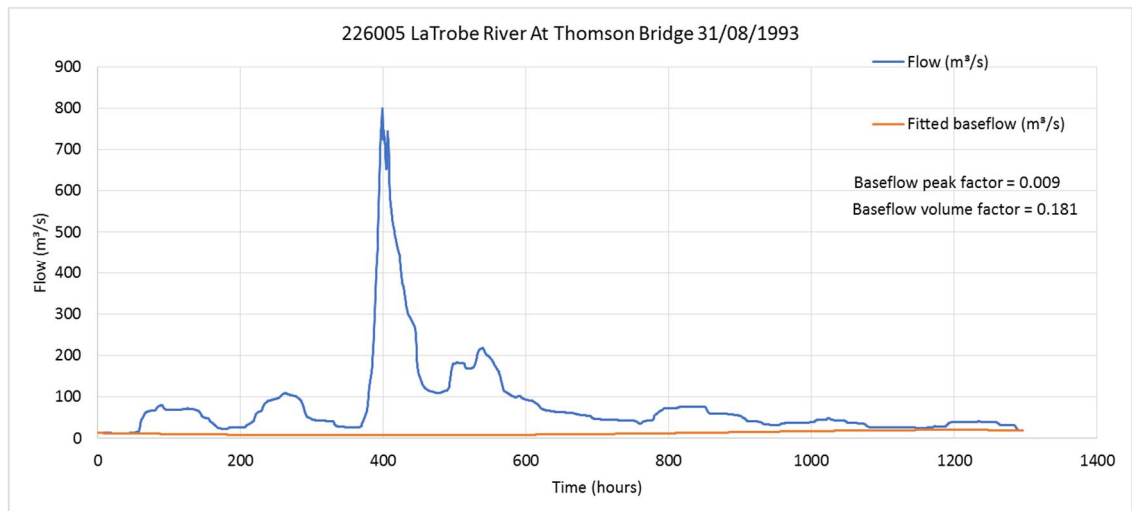
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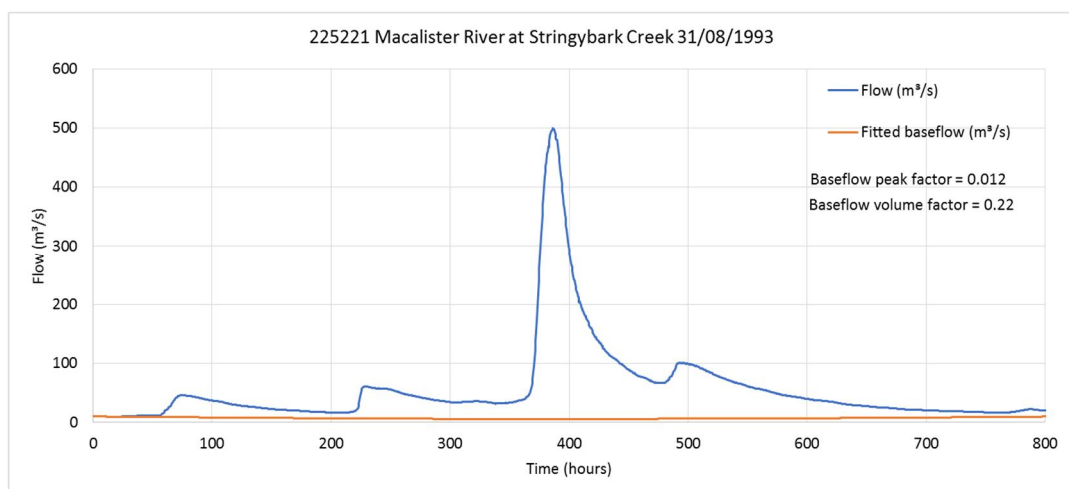
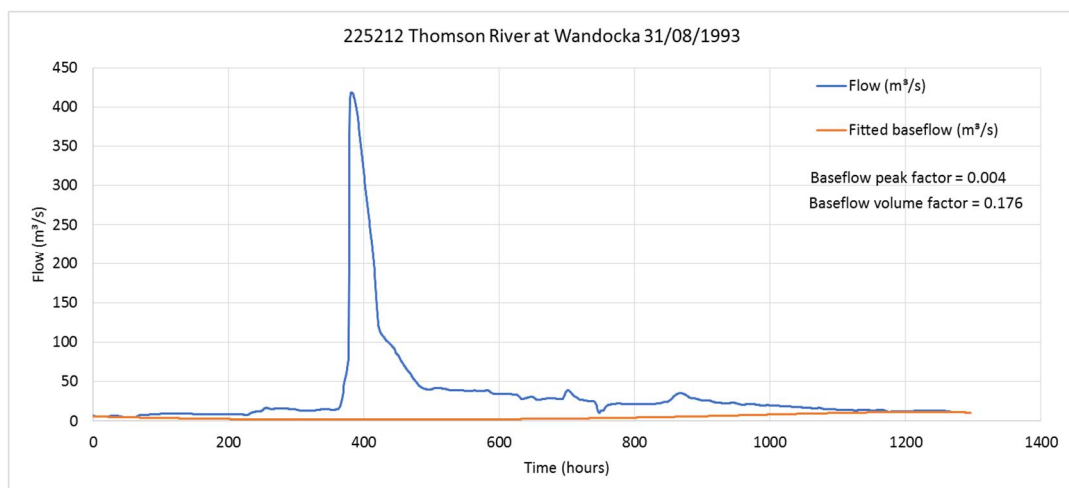
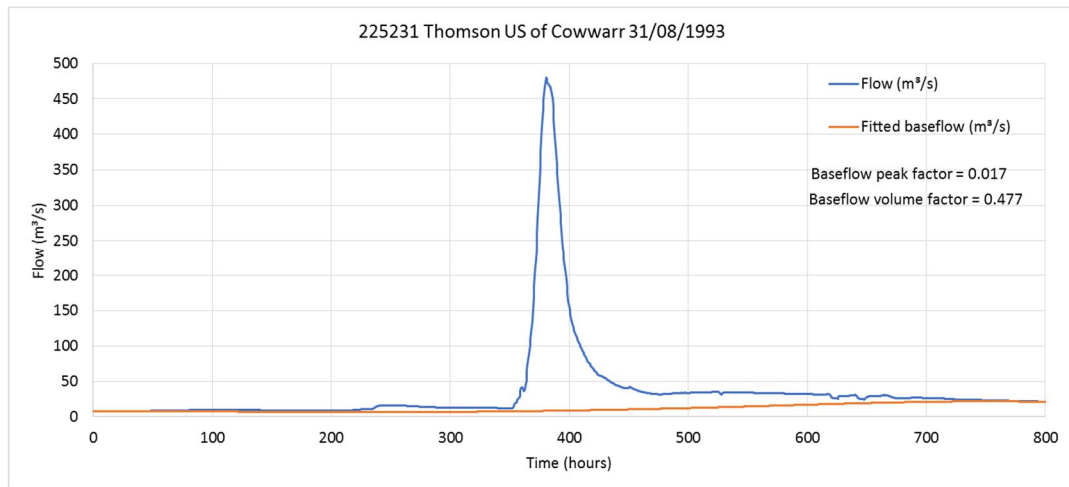




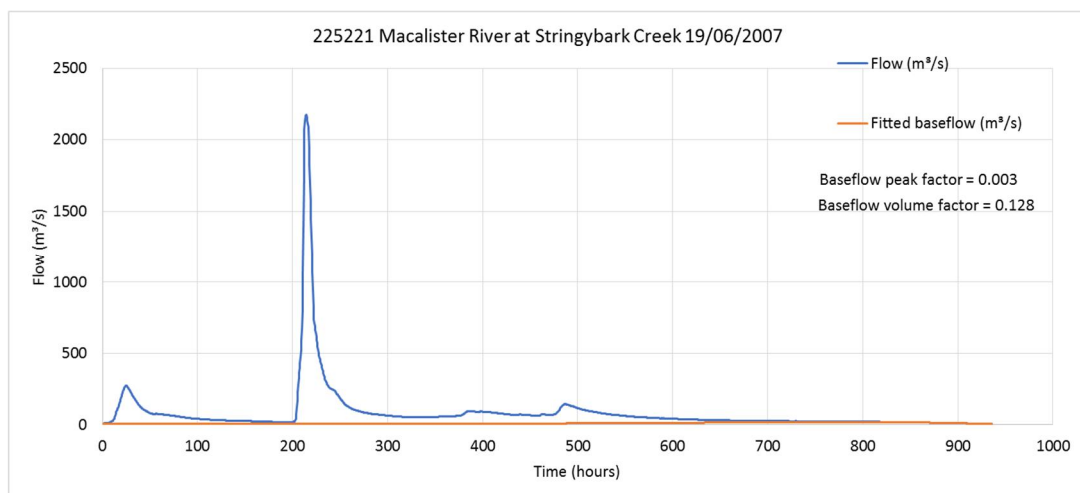
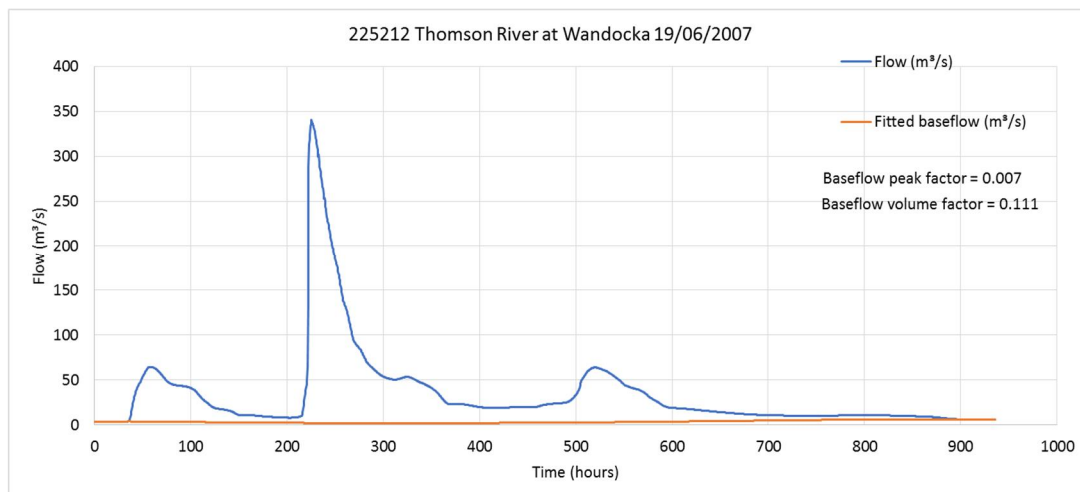
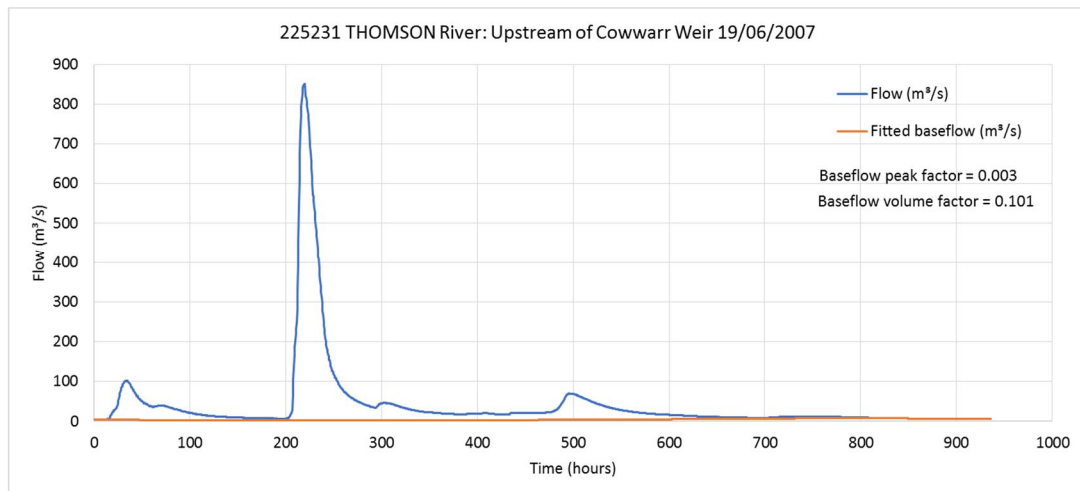


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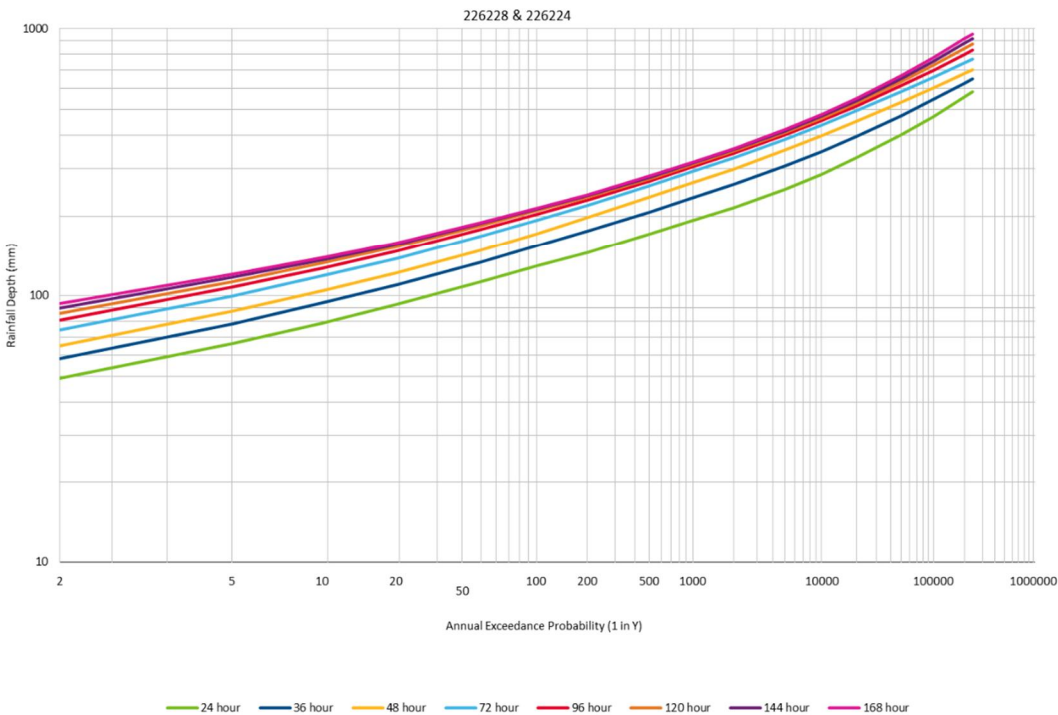
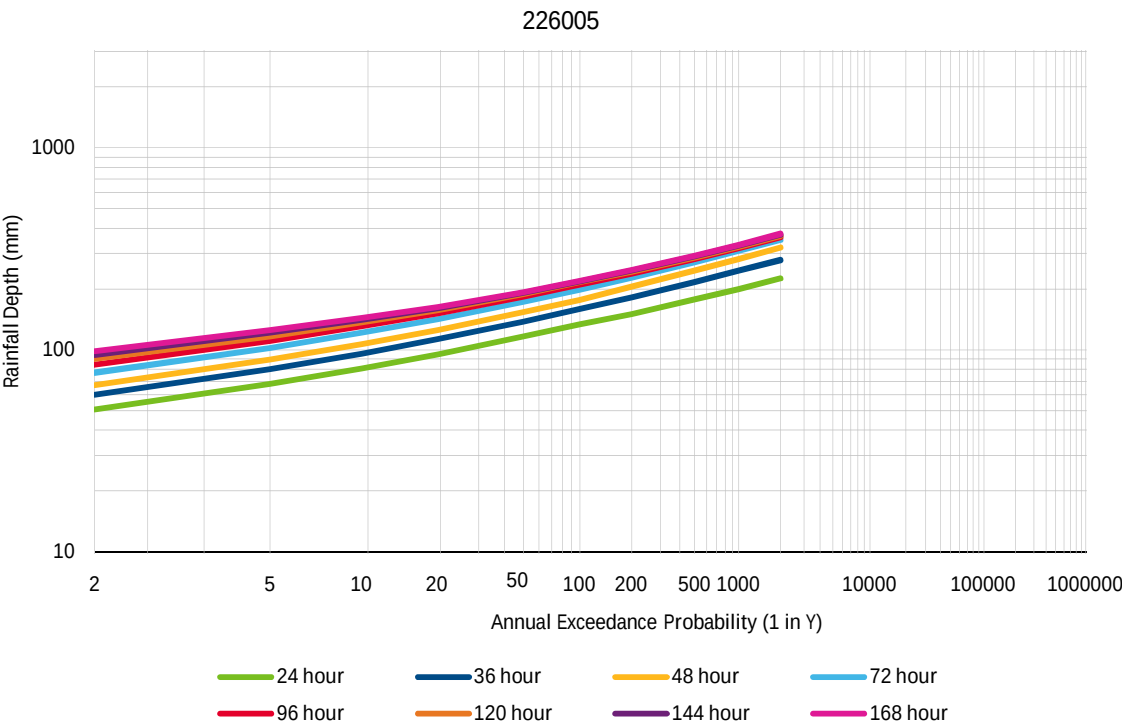


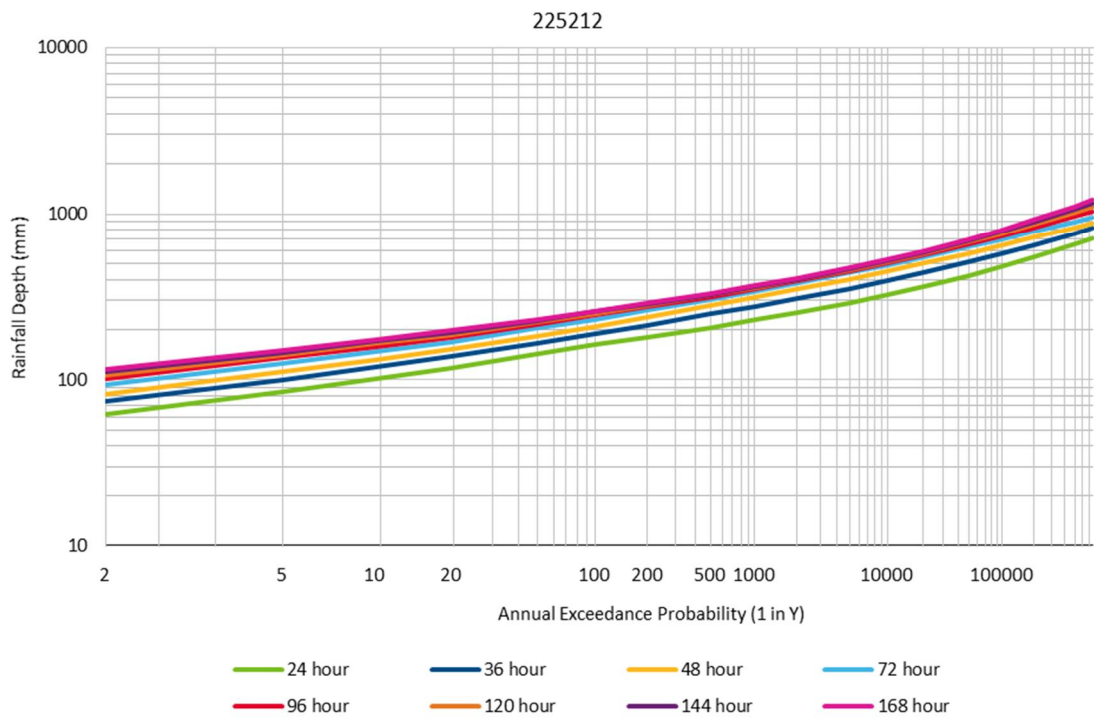
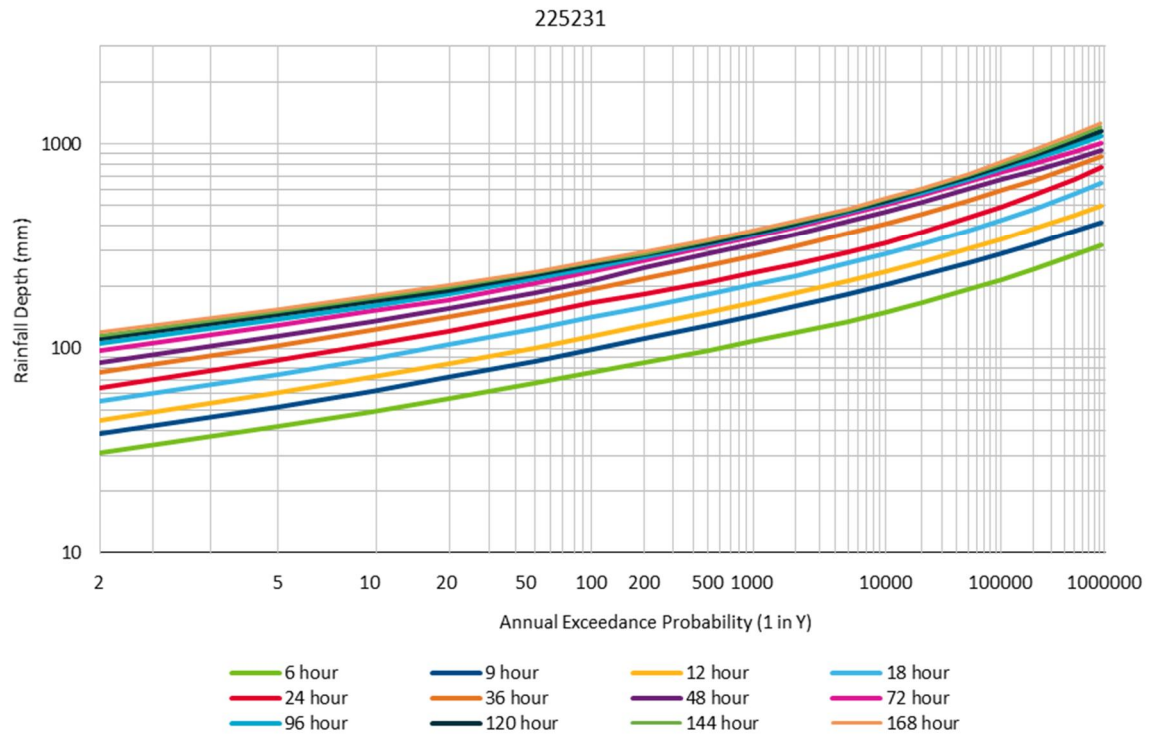


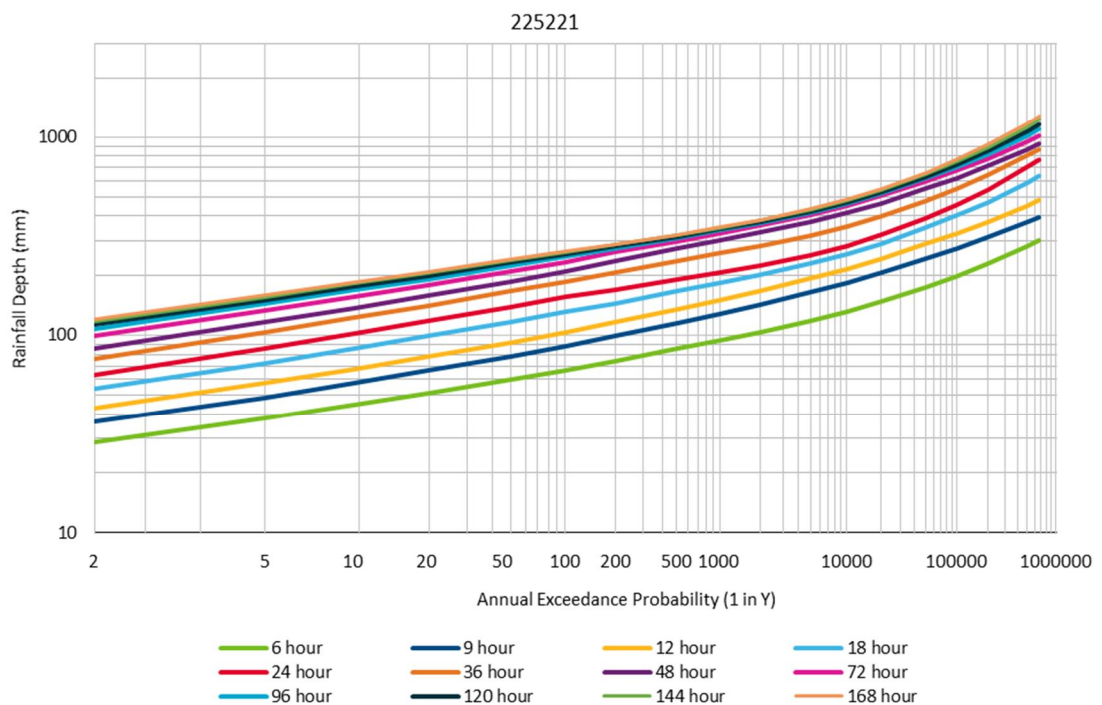
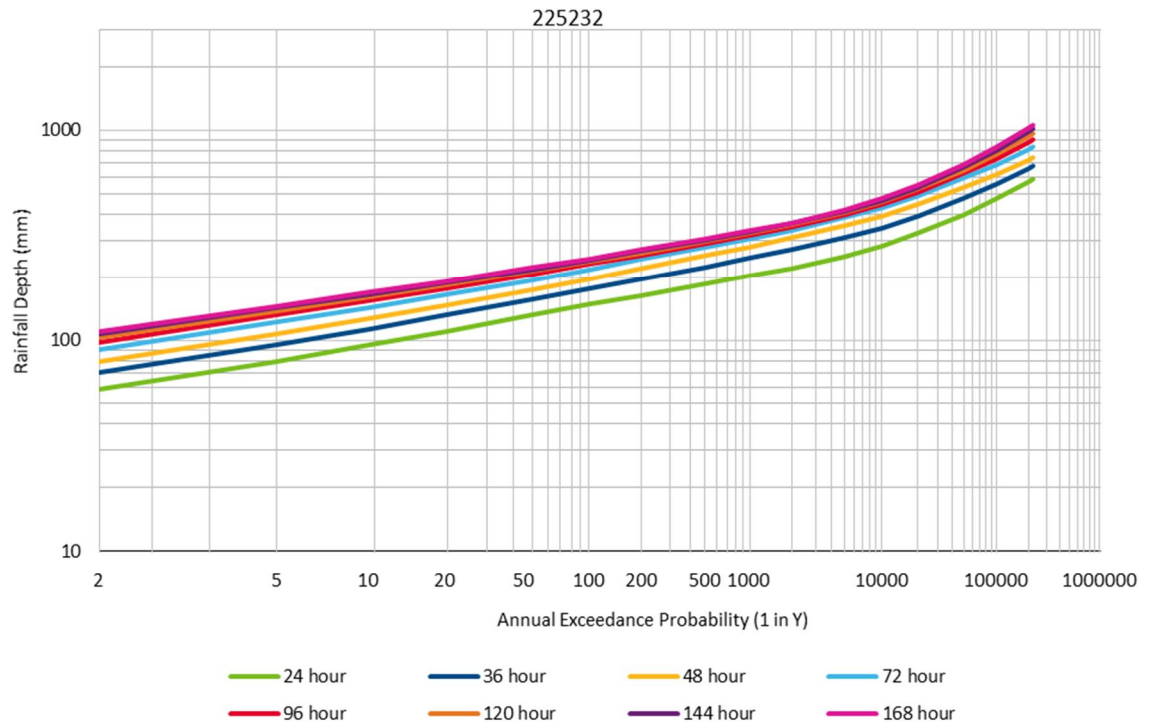
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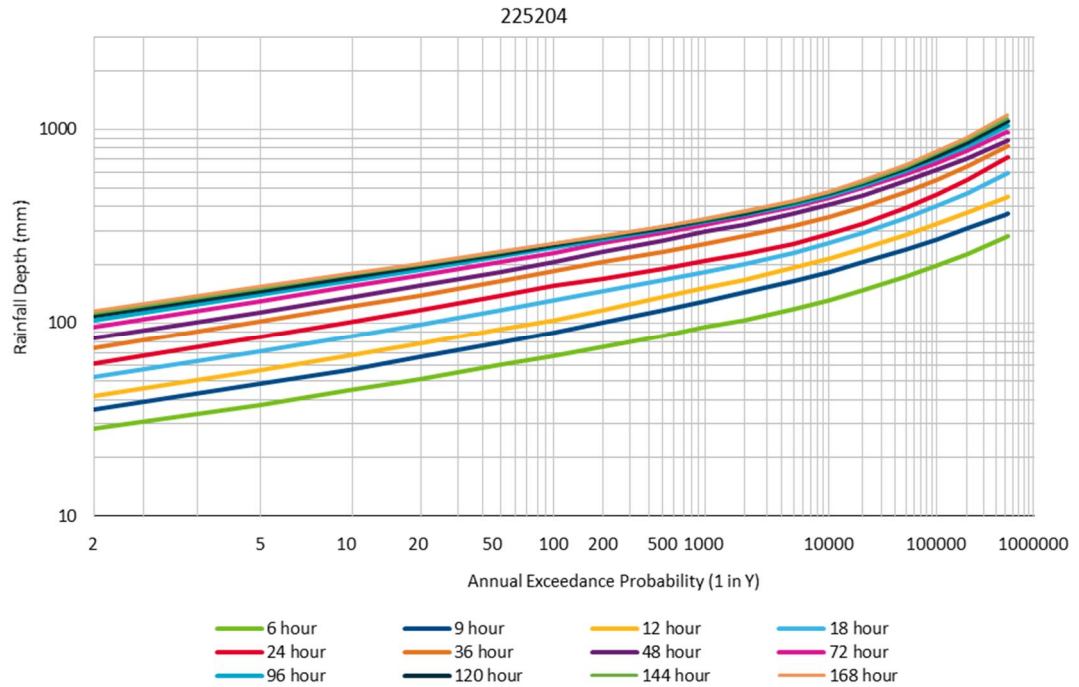


Appendix B Rainfall Depths

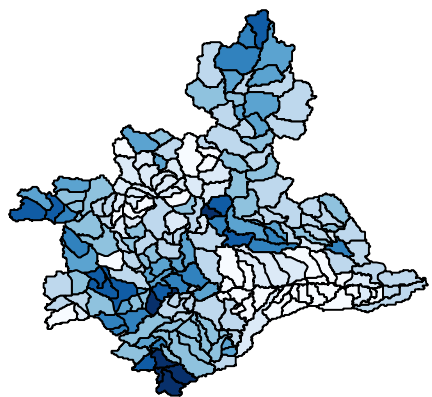




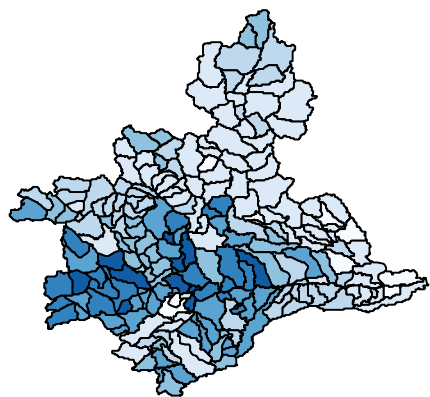




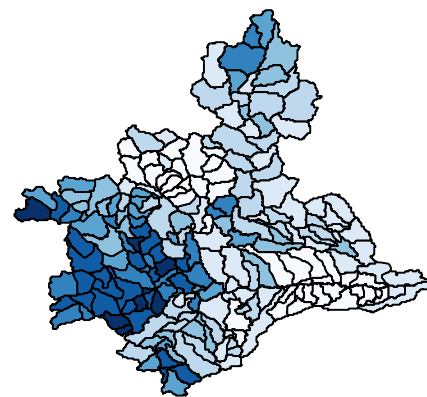
Appendix C Spatial Patterns



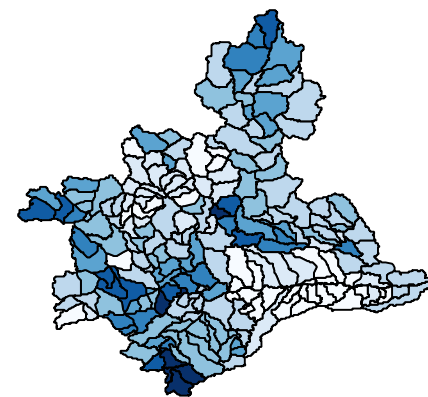
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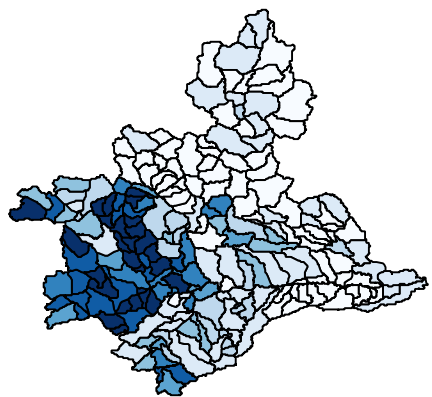
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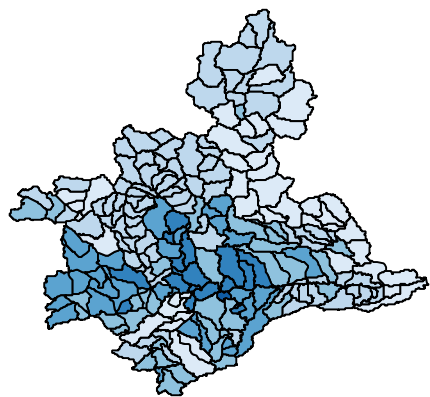
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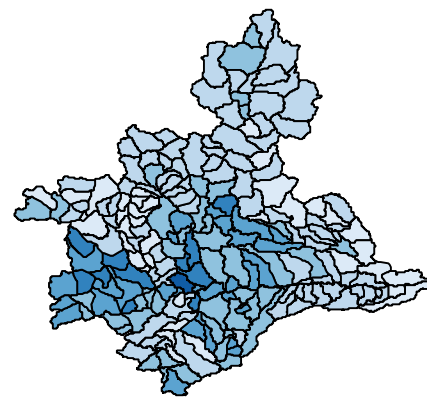
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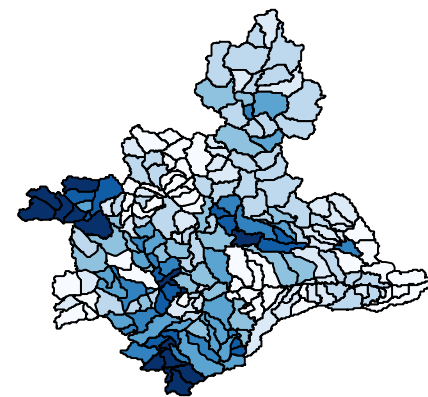
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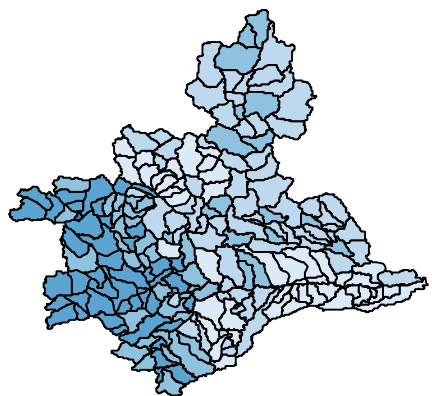
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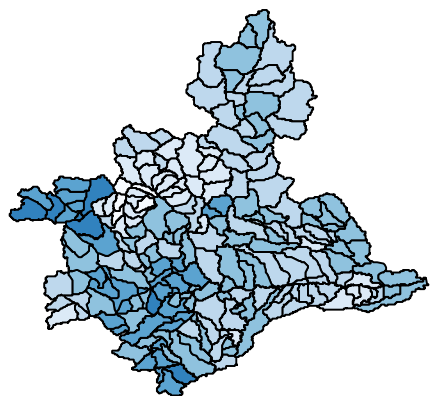
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19710130



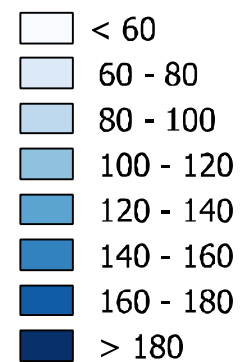
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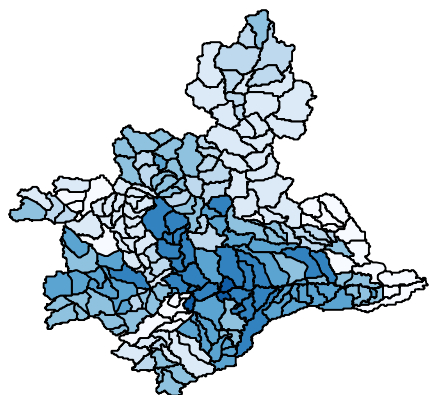


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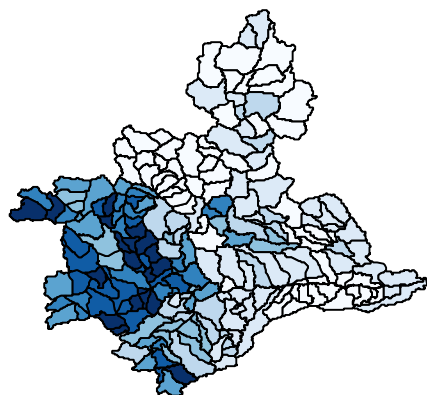
Legend

Spatial Patterns (% of Catchment Rainfall Depth)

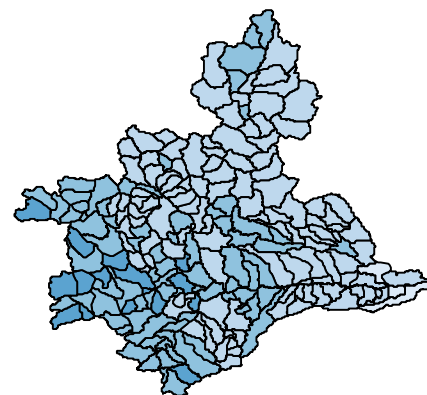




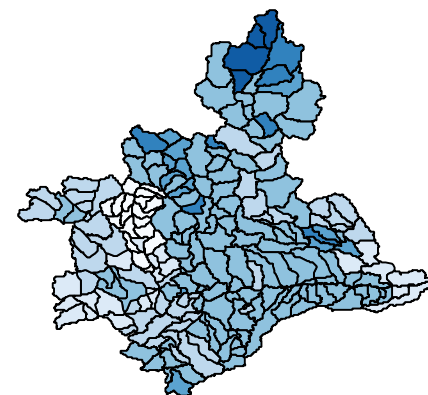
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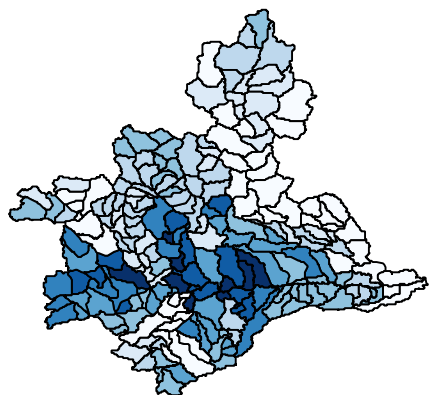
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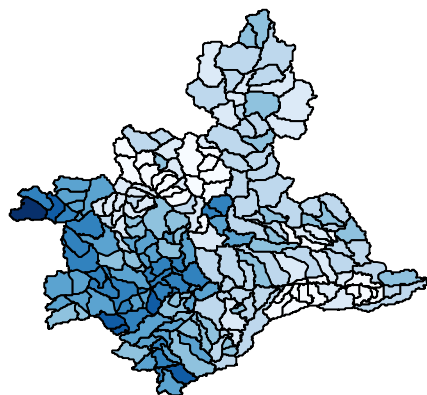
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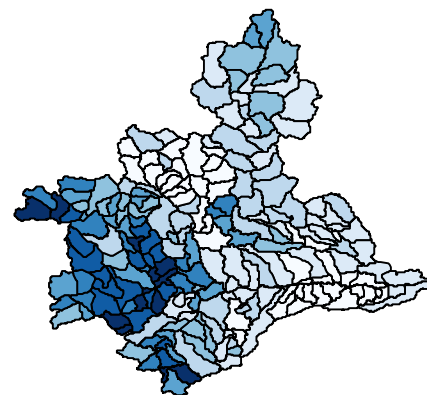
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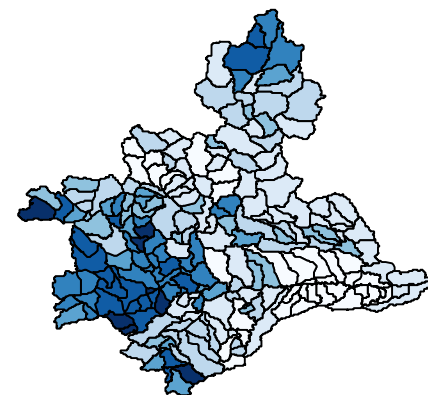
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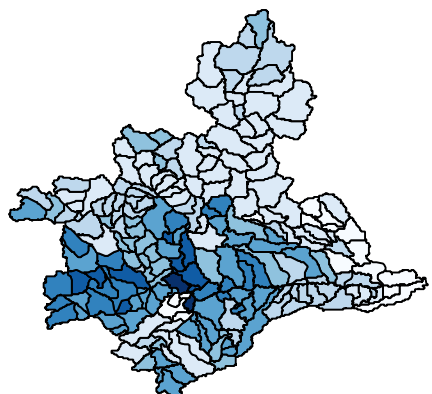
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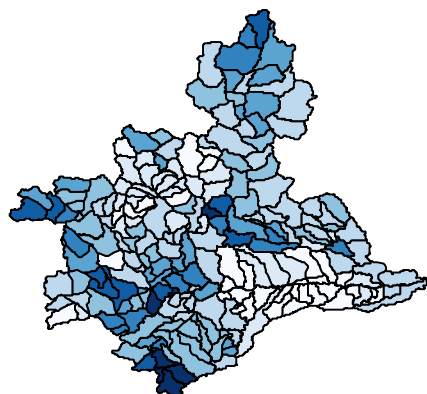
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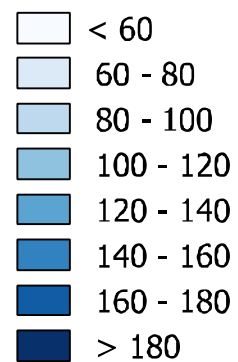
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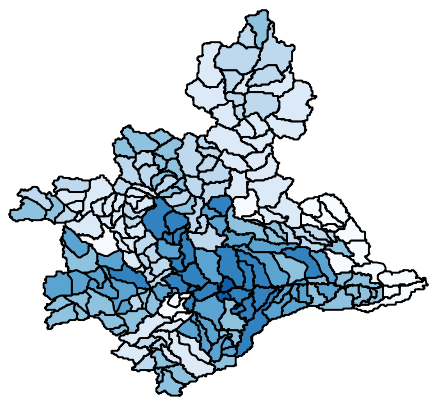


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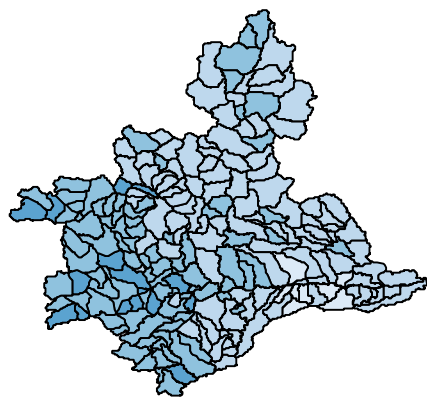
Legend

Spatial Patterns (% of Catchment Rainfall Depth)

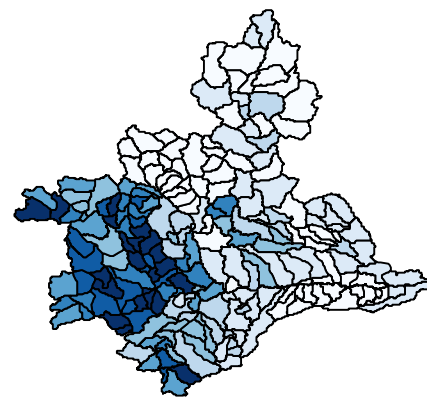




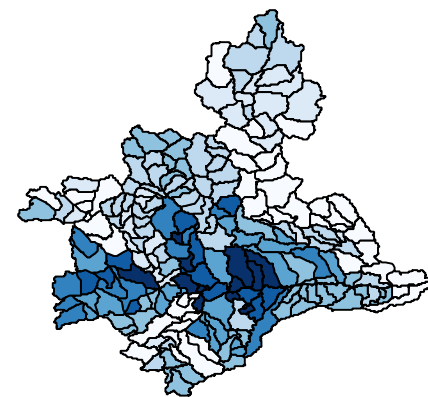
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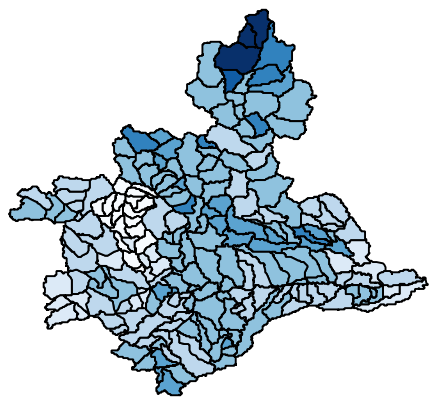
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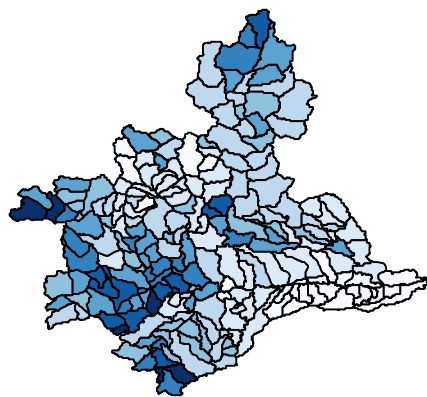
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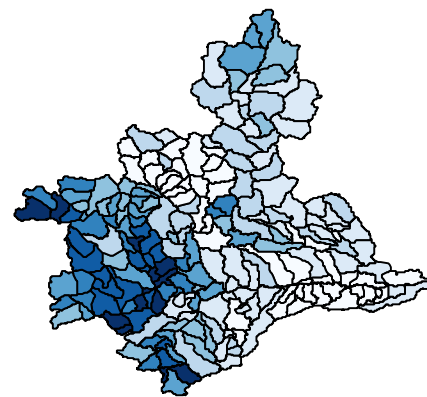
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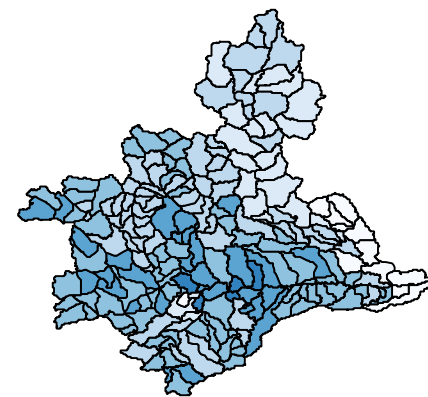
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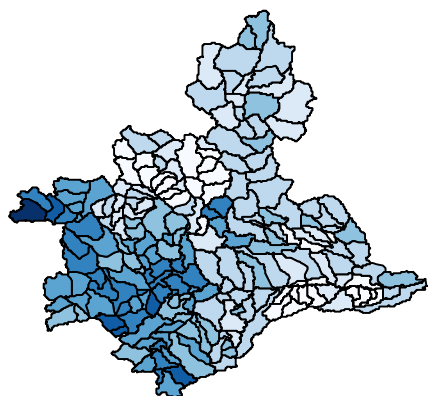
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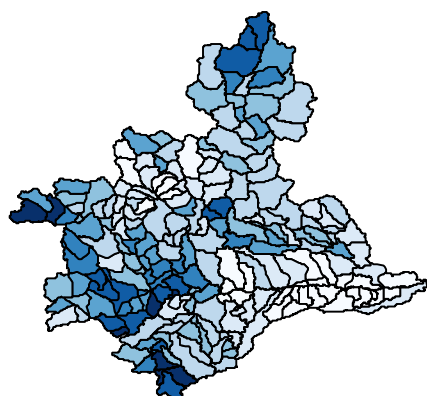
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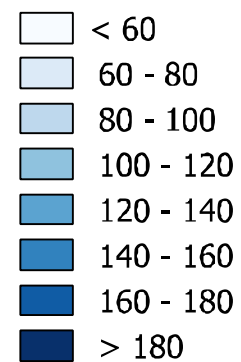
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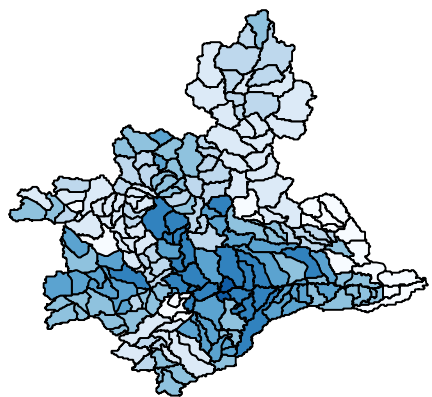


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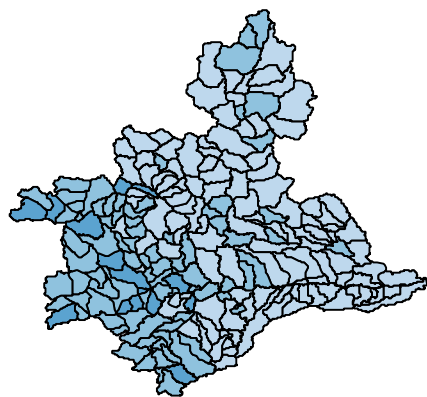
Legend

Spatial Patterns (% of Catchment Rainfall Depth)

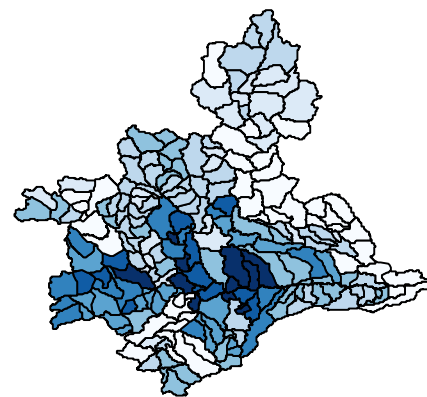




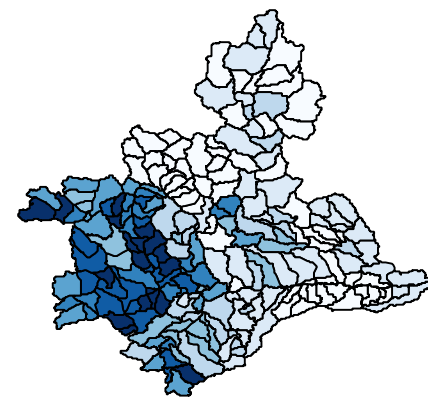
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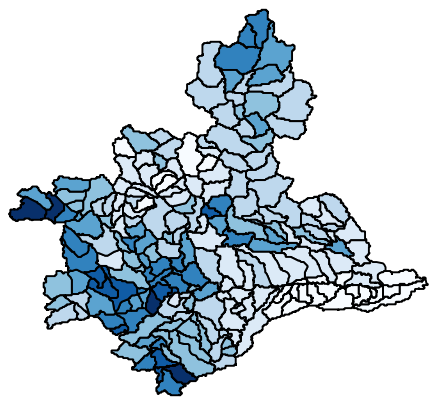
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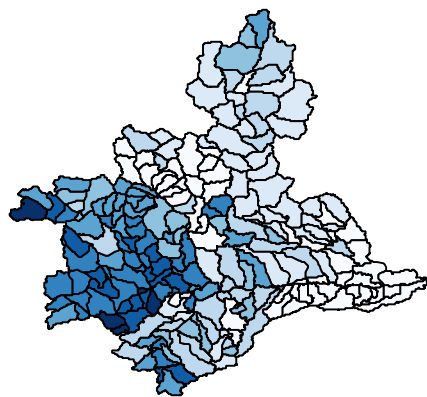
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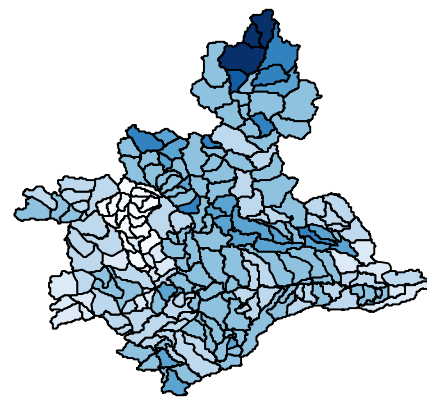
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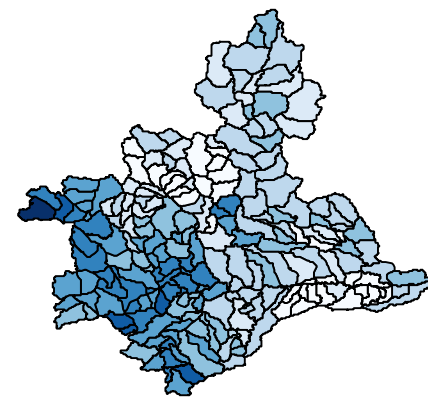
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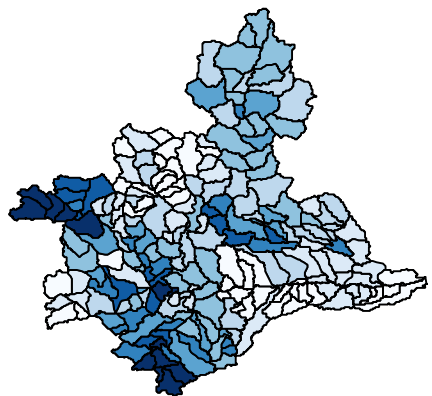
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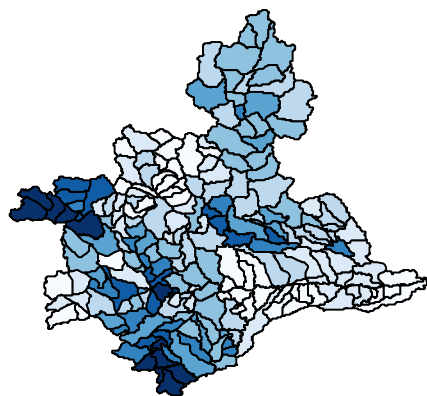
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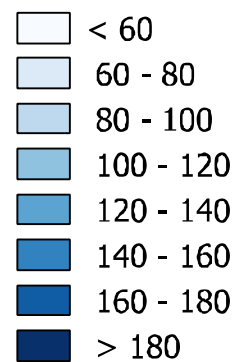
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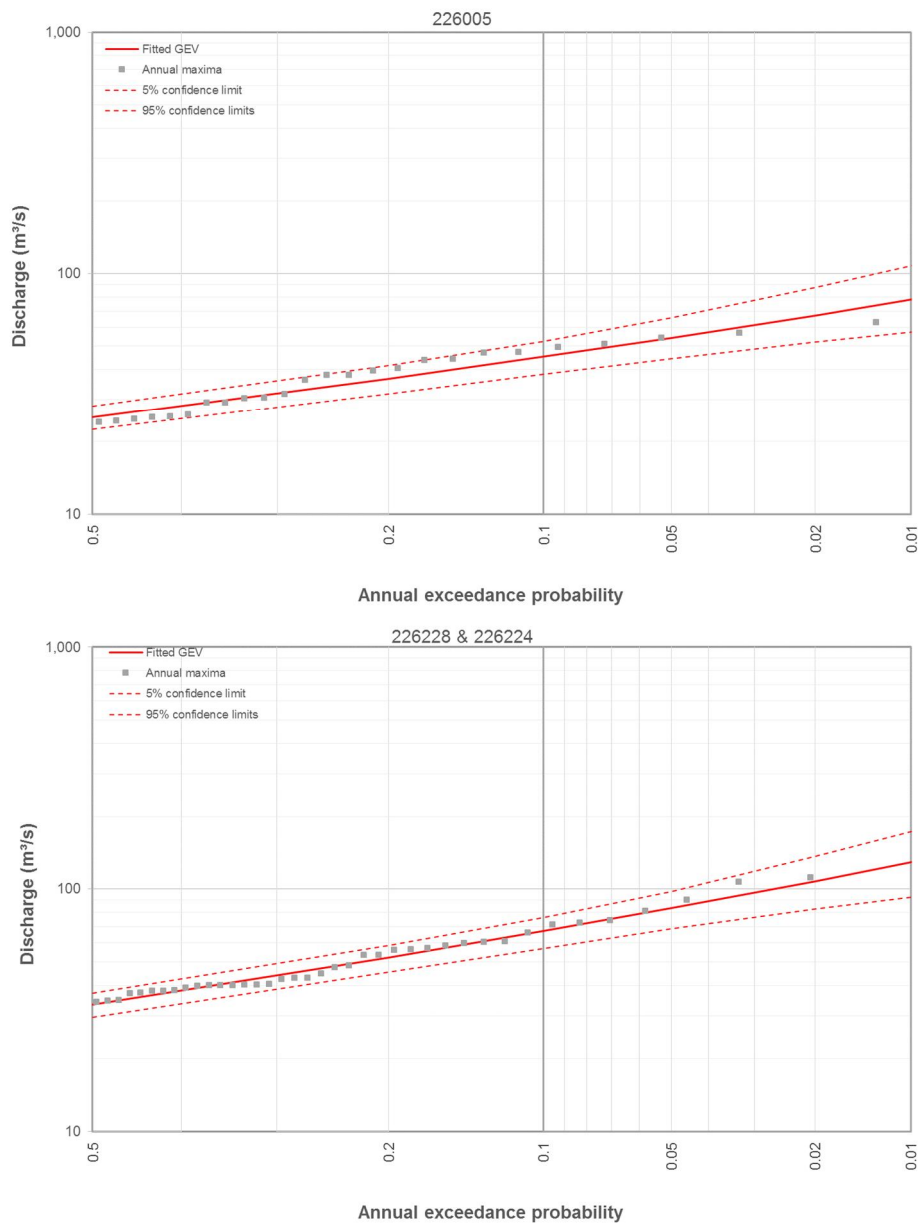
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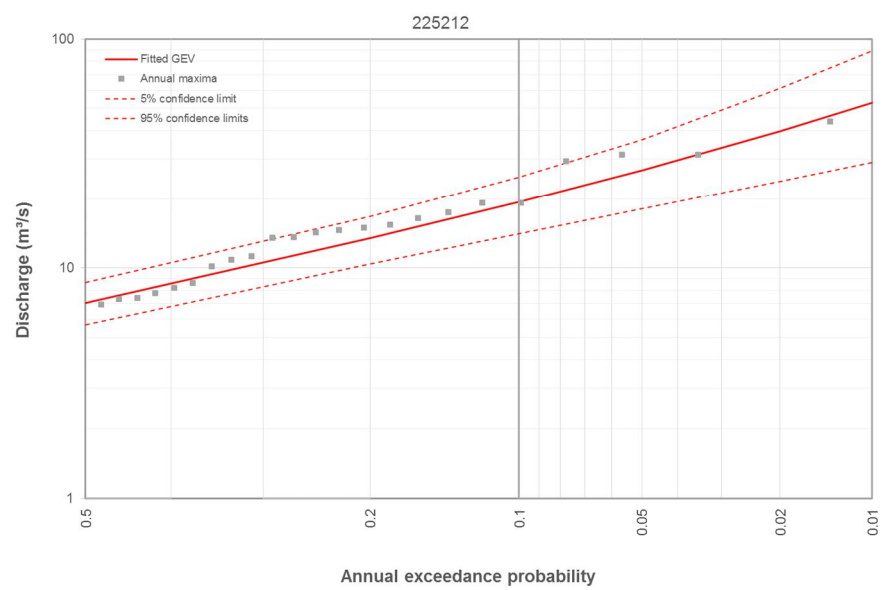
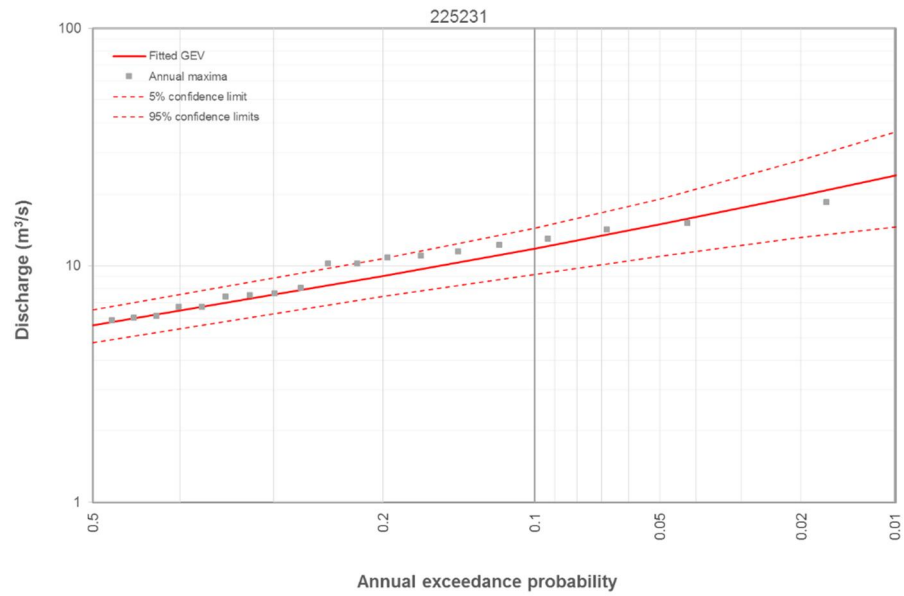
Legend

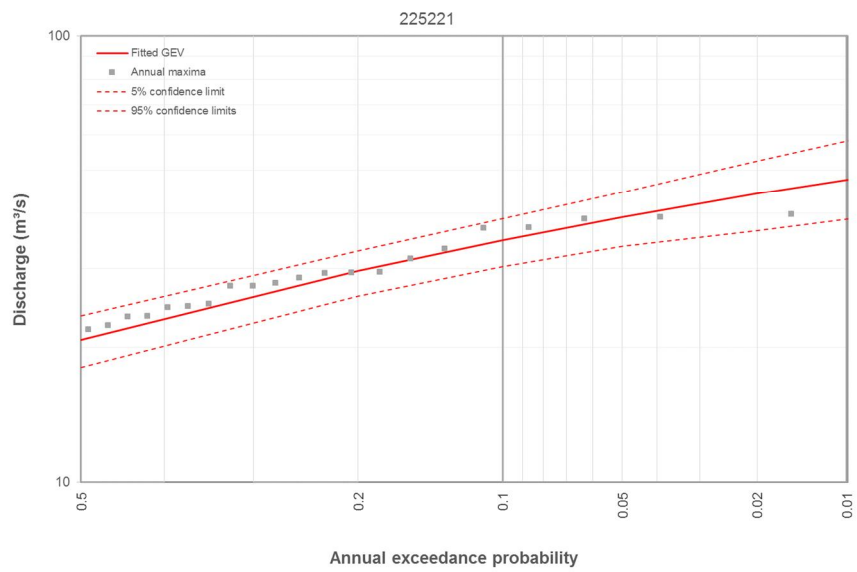
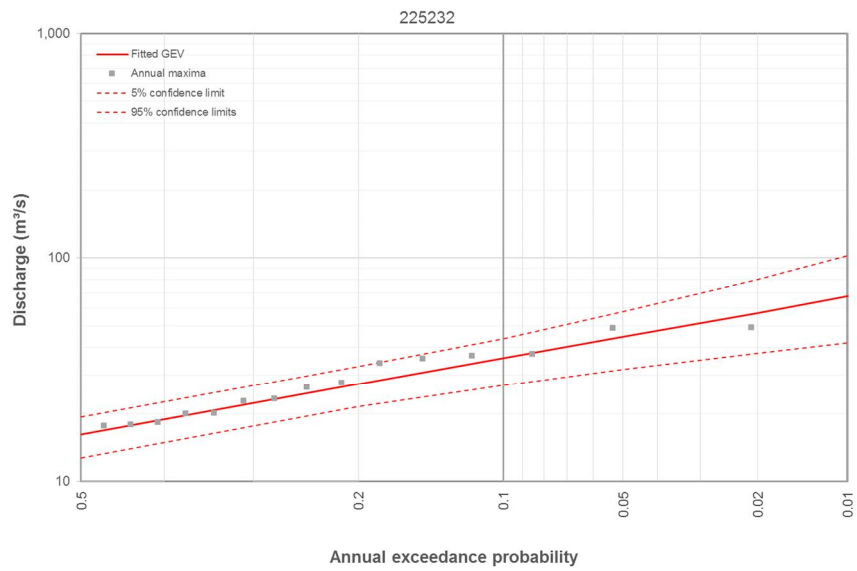
Spatial Patterns (% of Catchment Rainfall Depth)

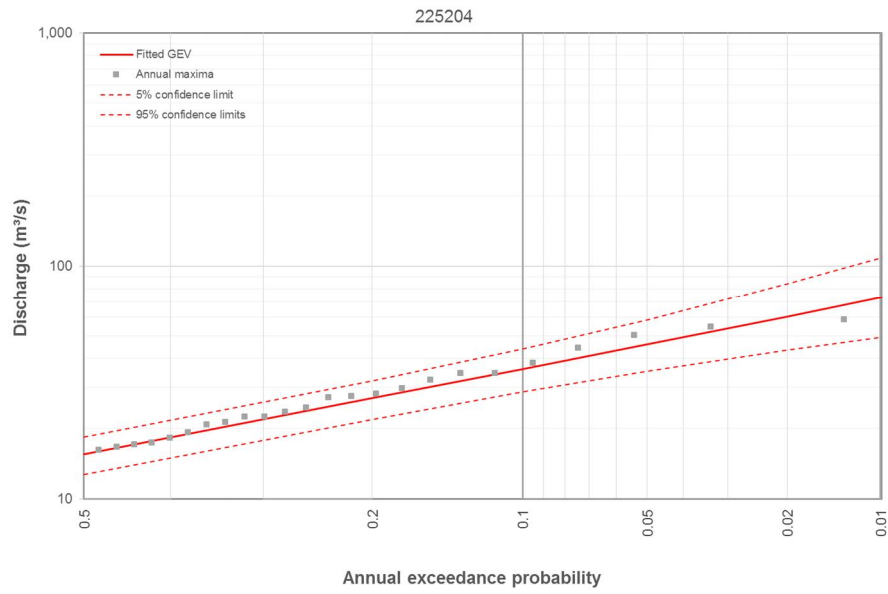


Appendix D Baseflow - Design

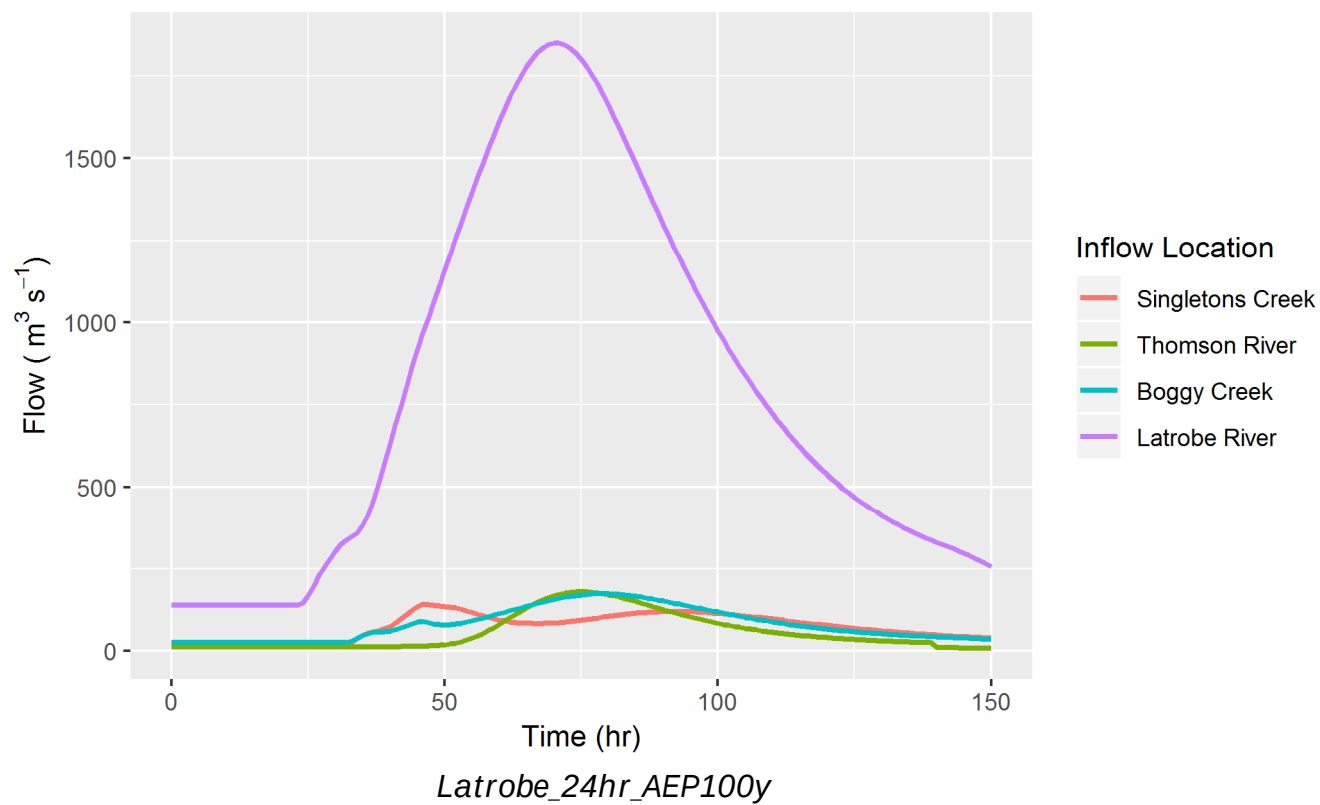


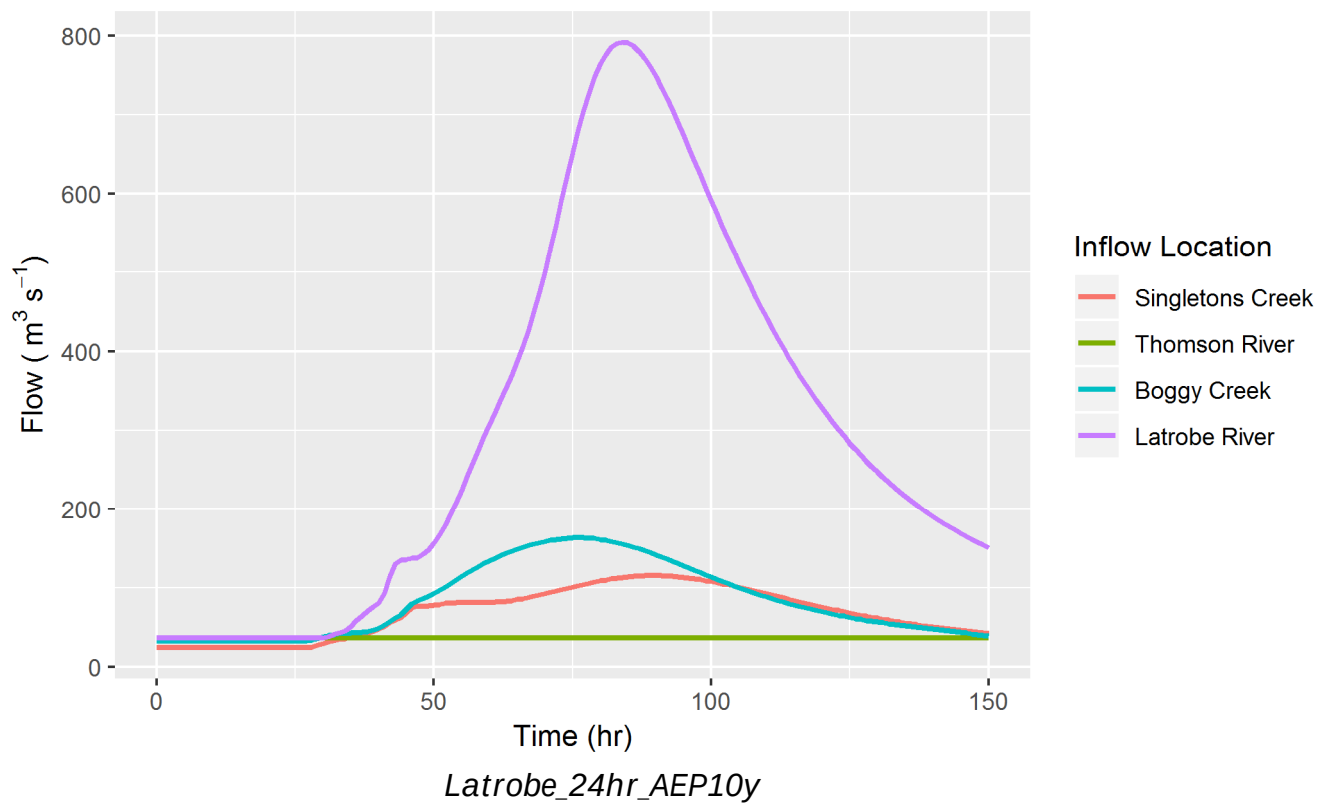


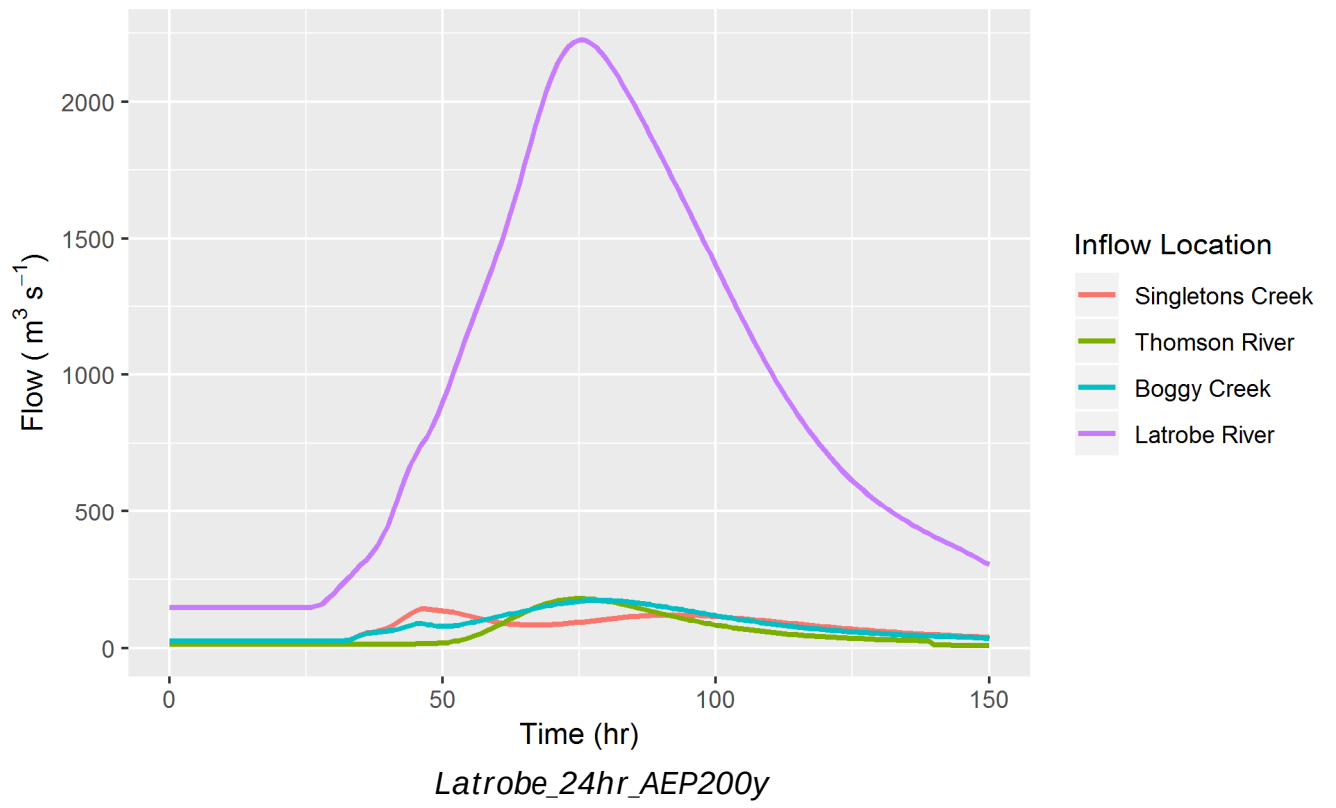


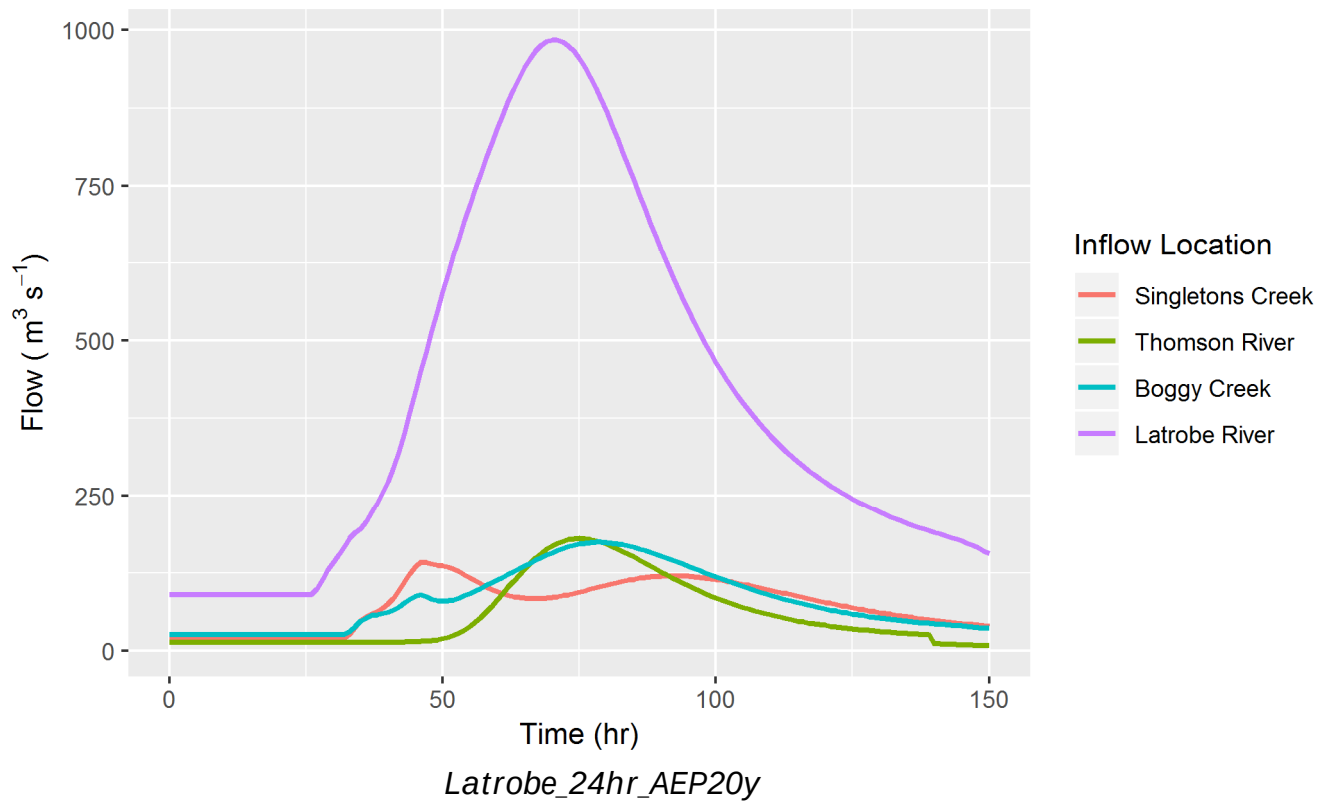


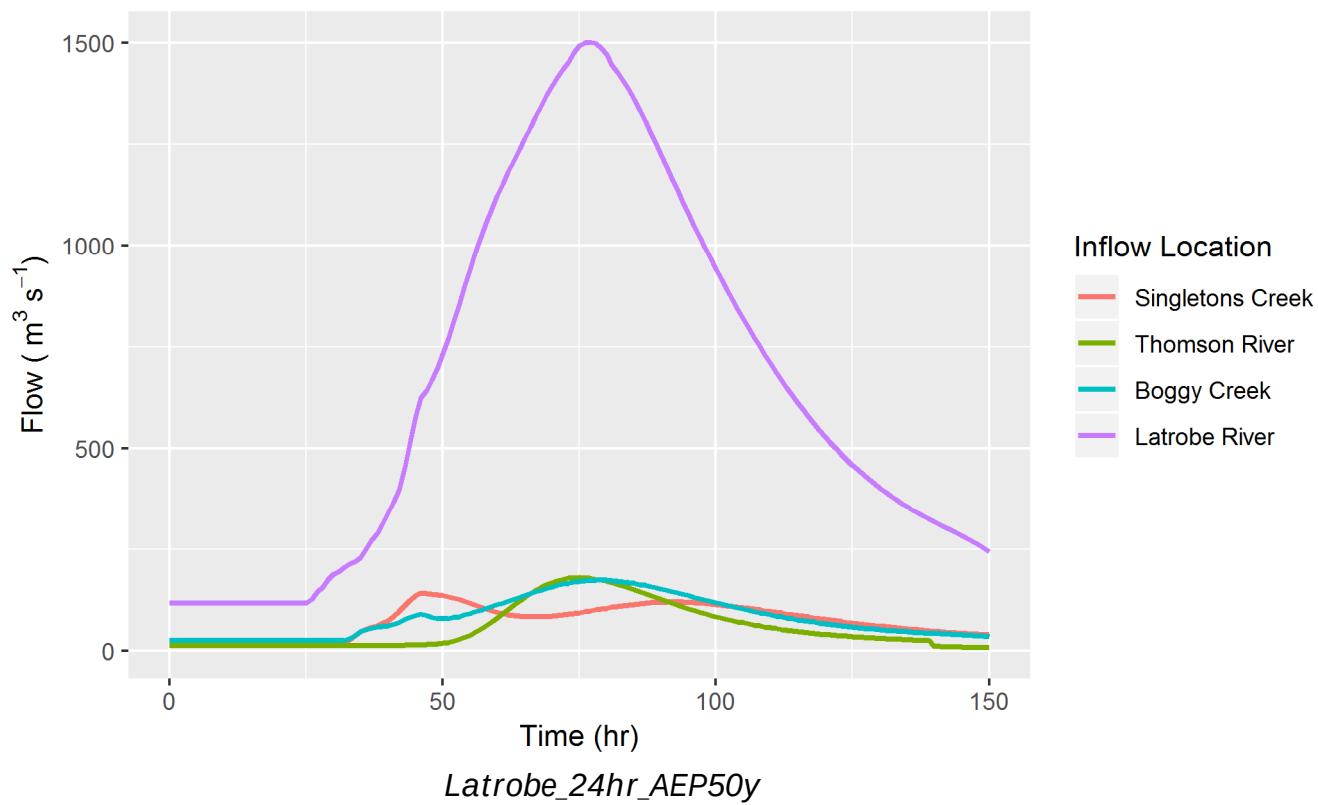
Appendix E Design Hydrographs

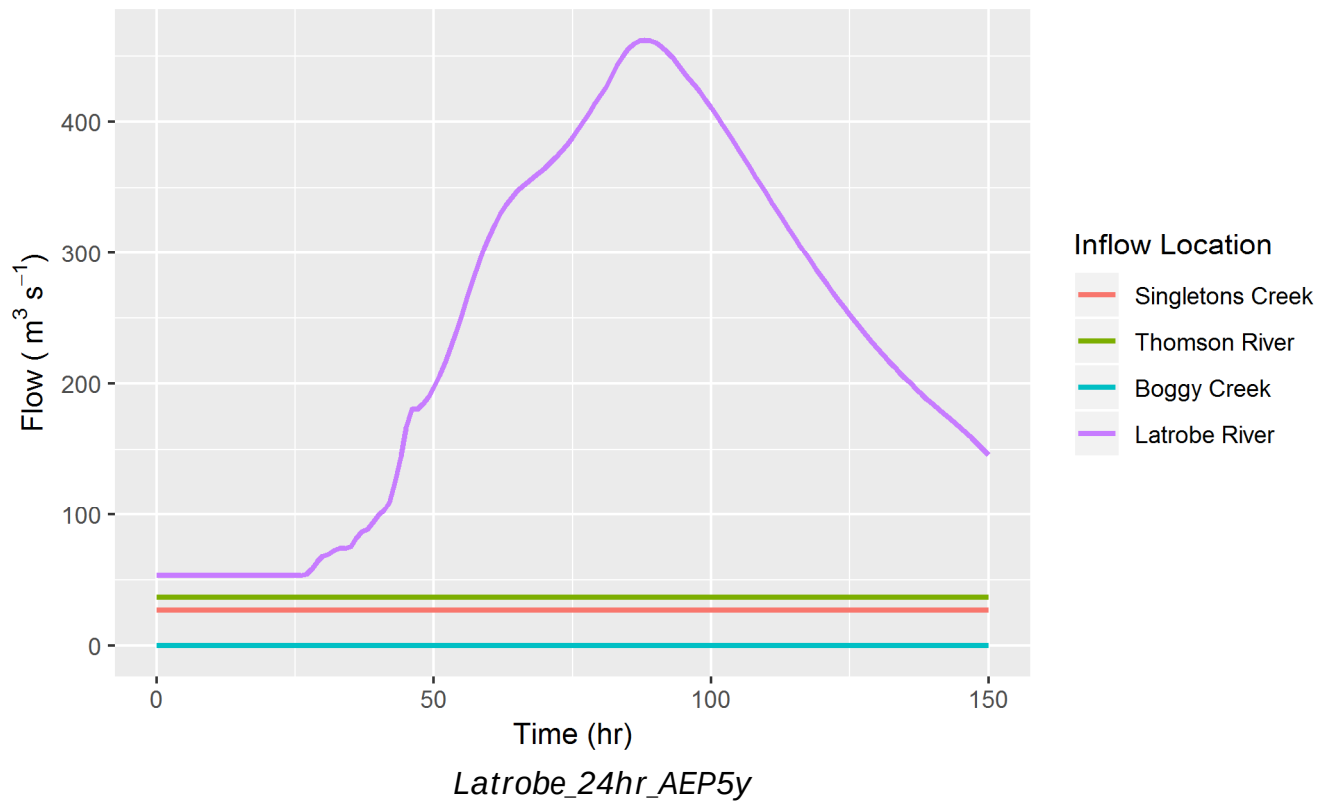


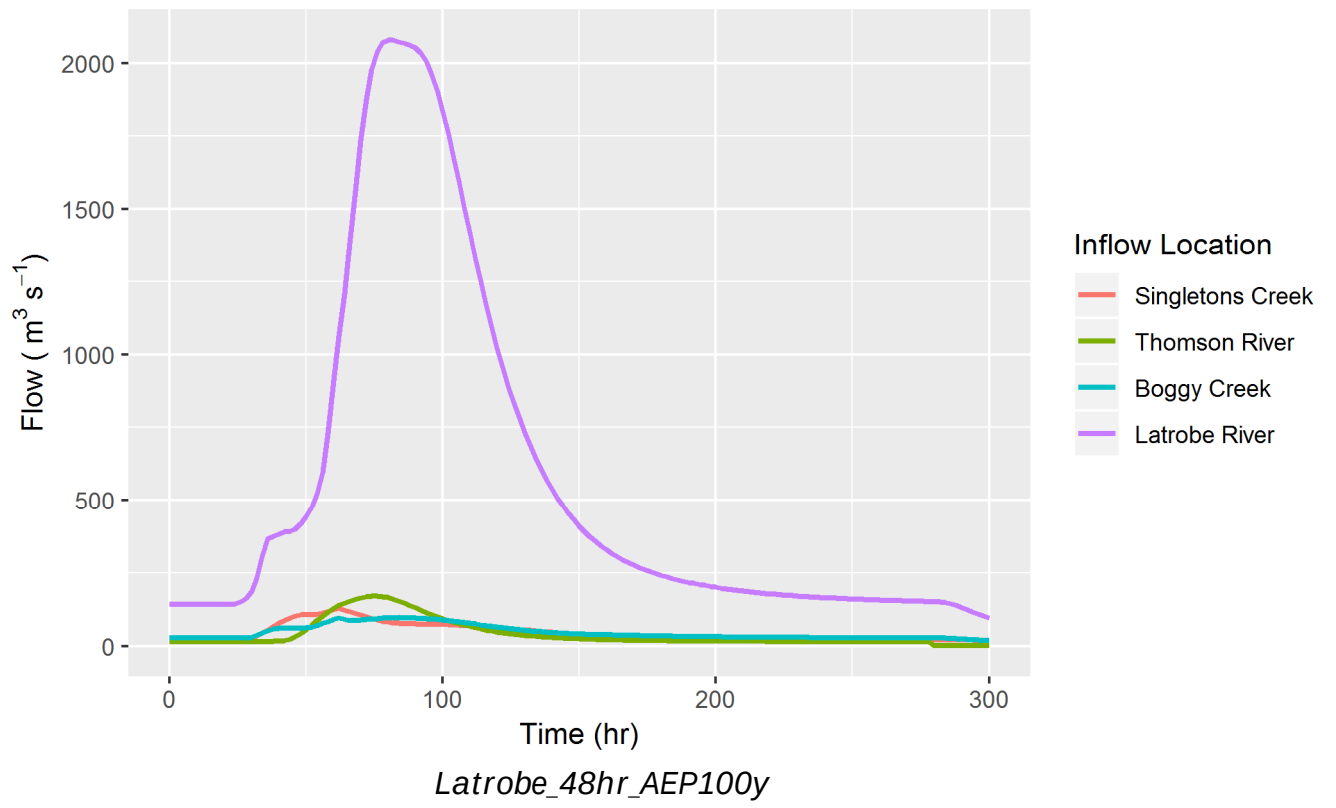


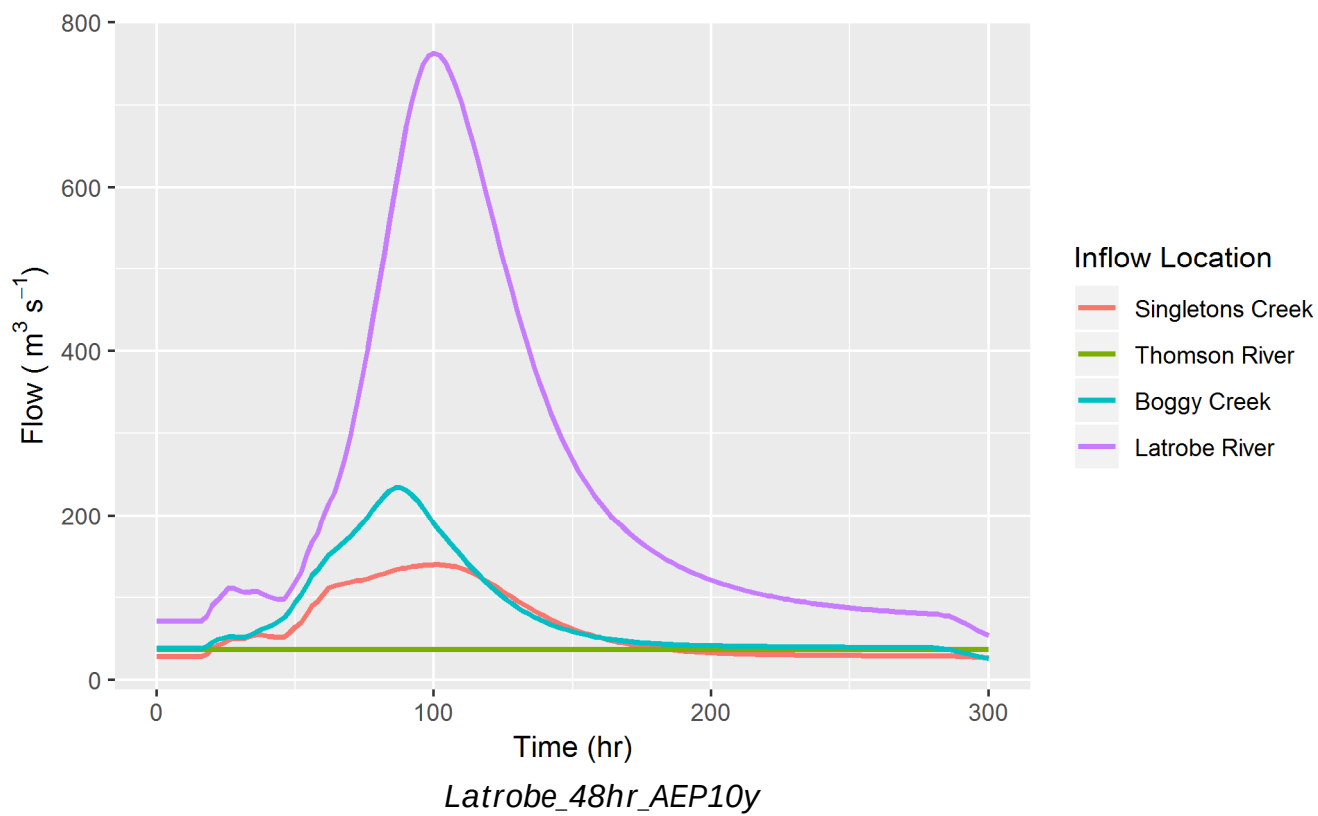


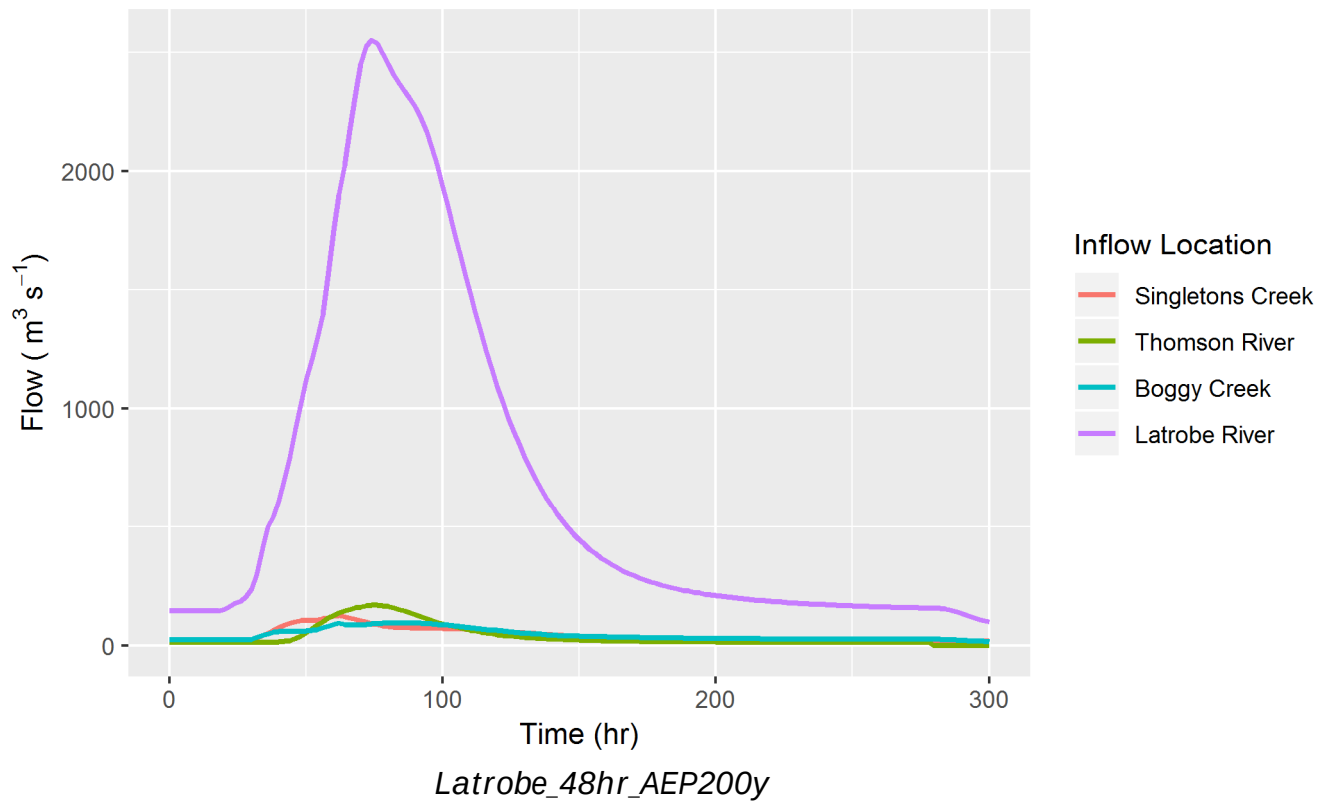


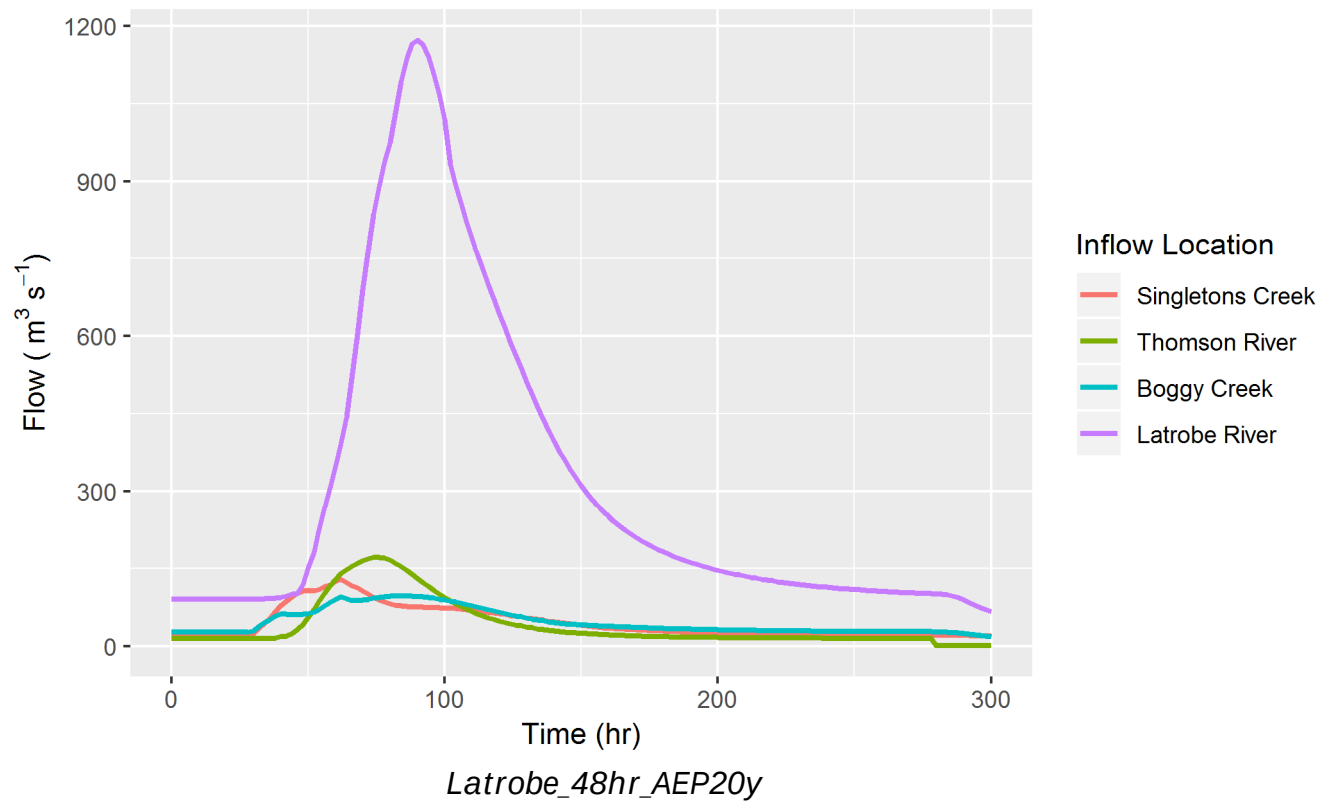


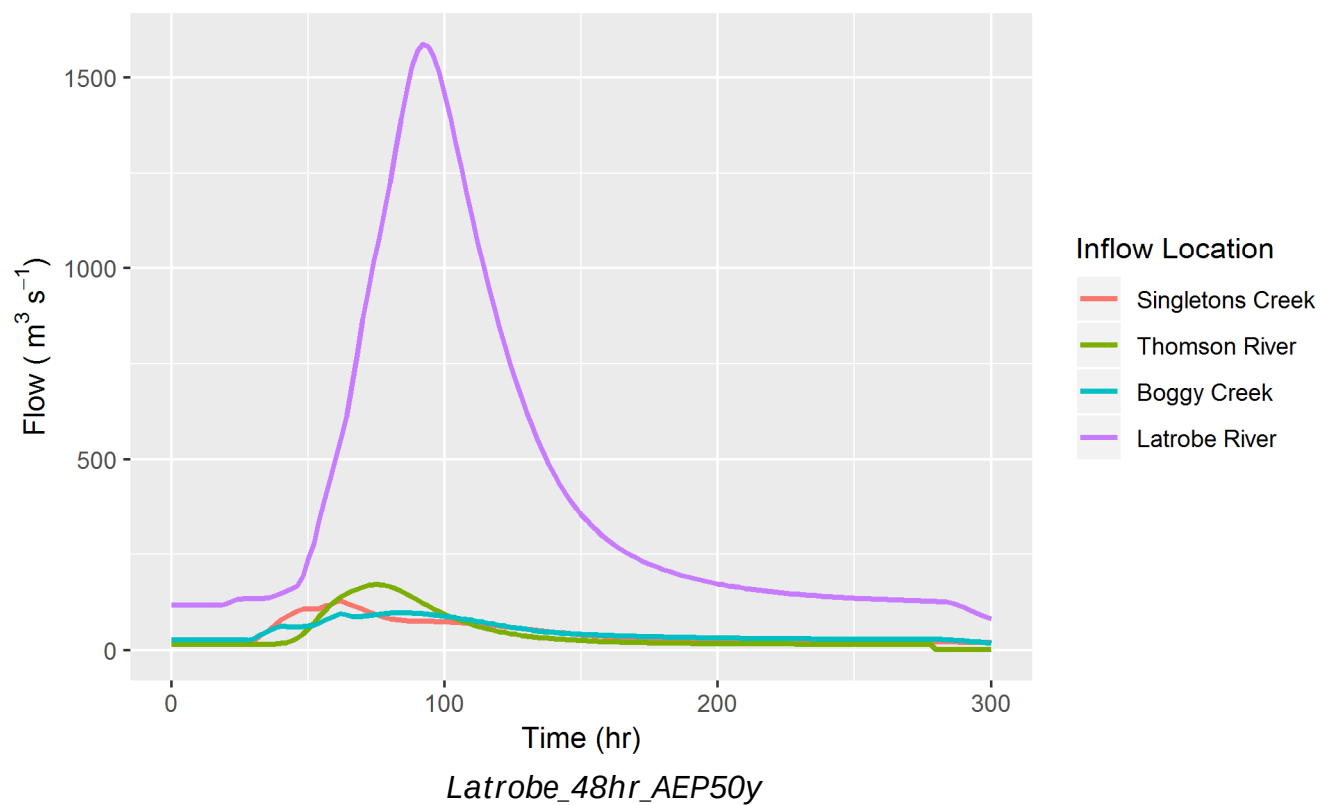


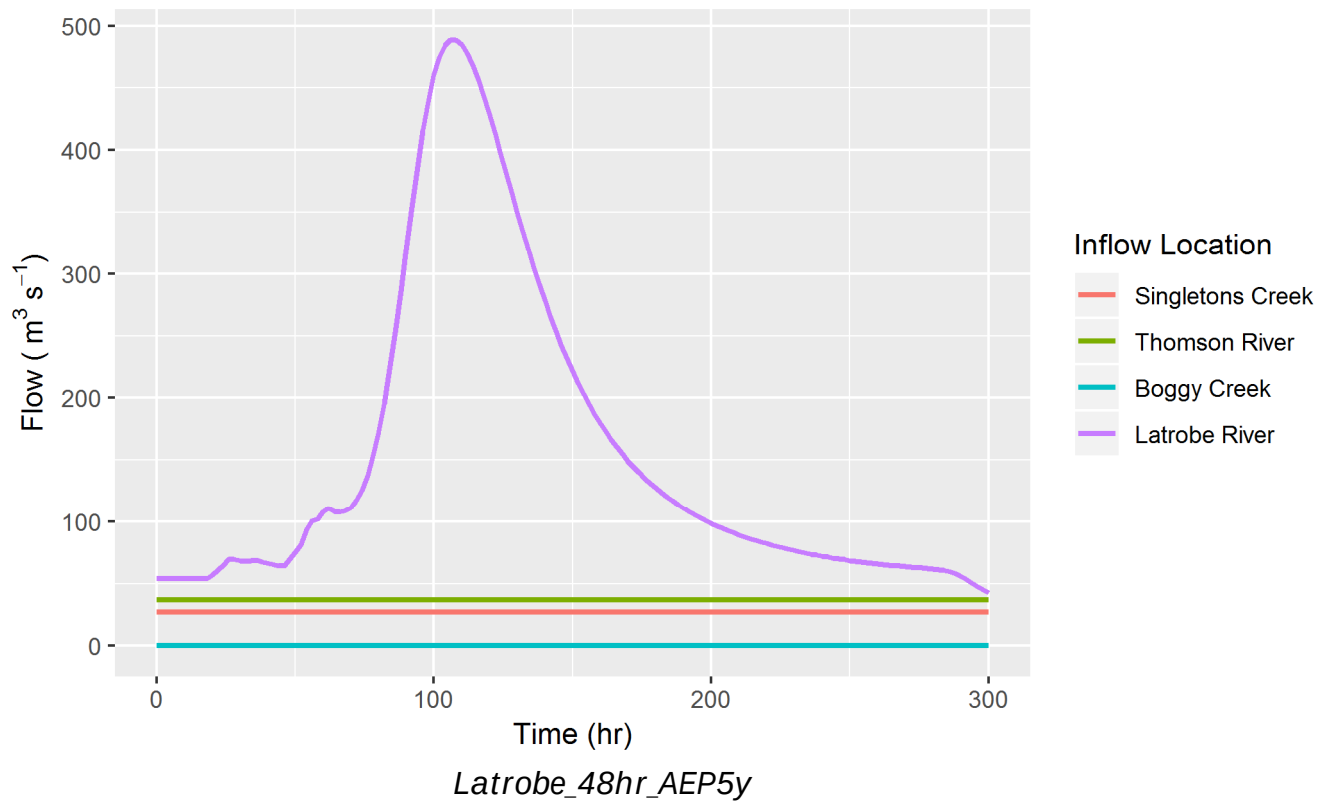


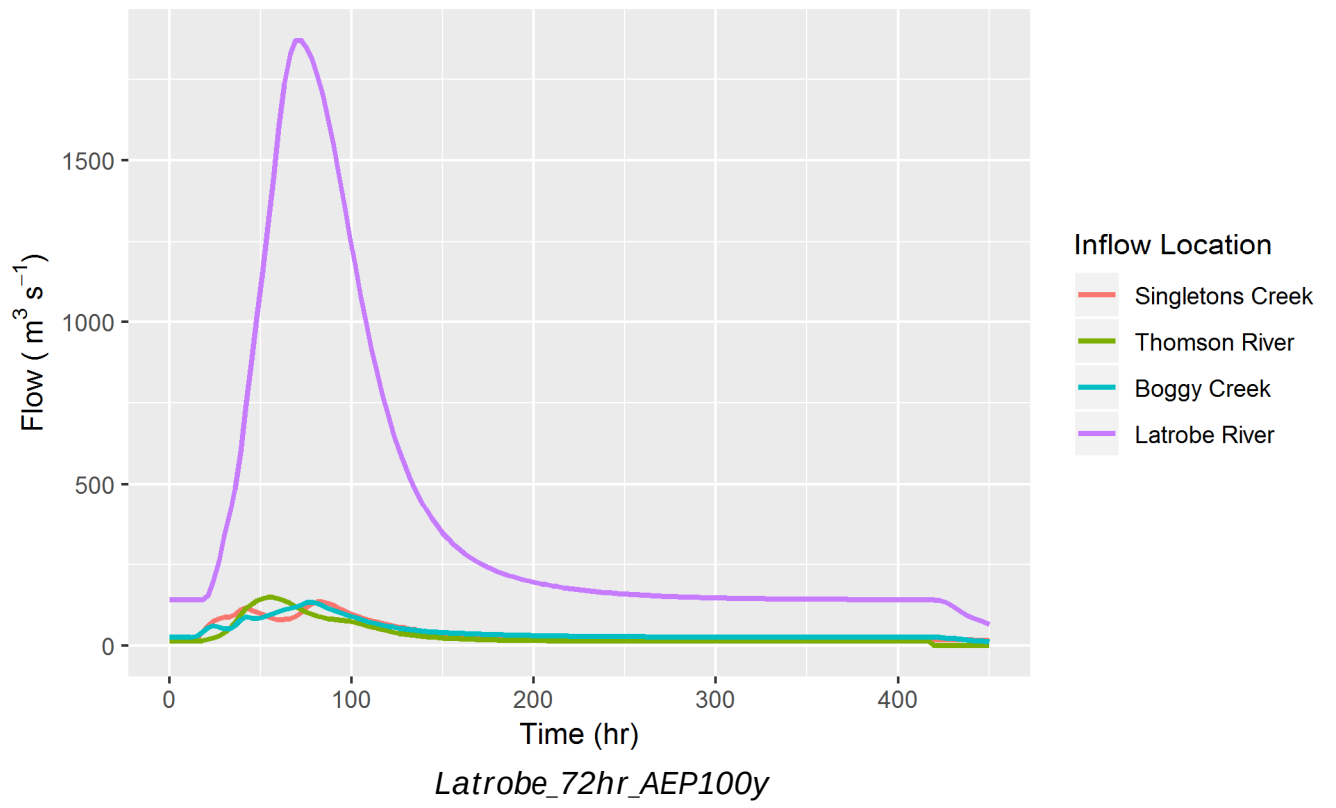


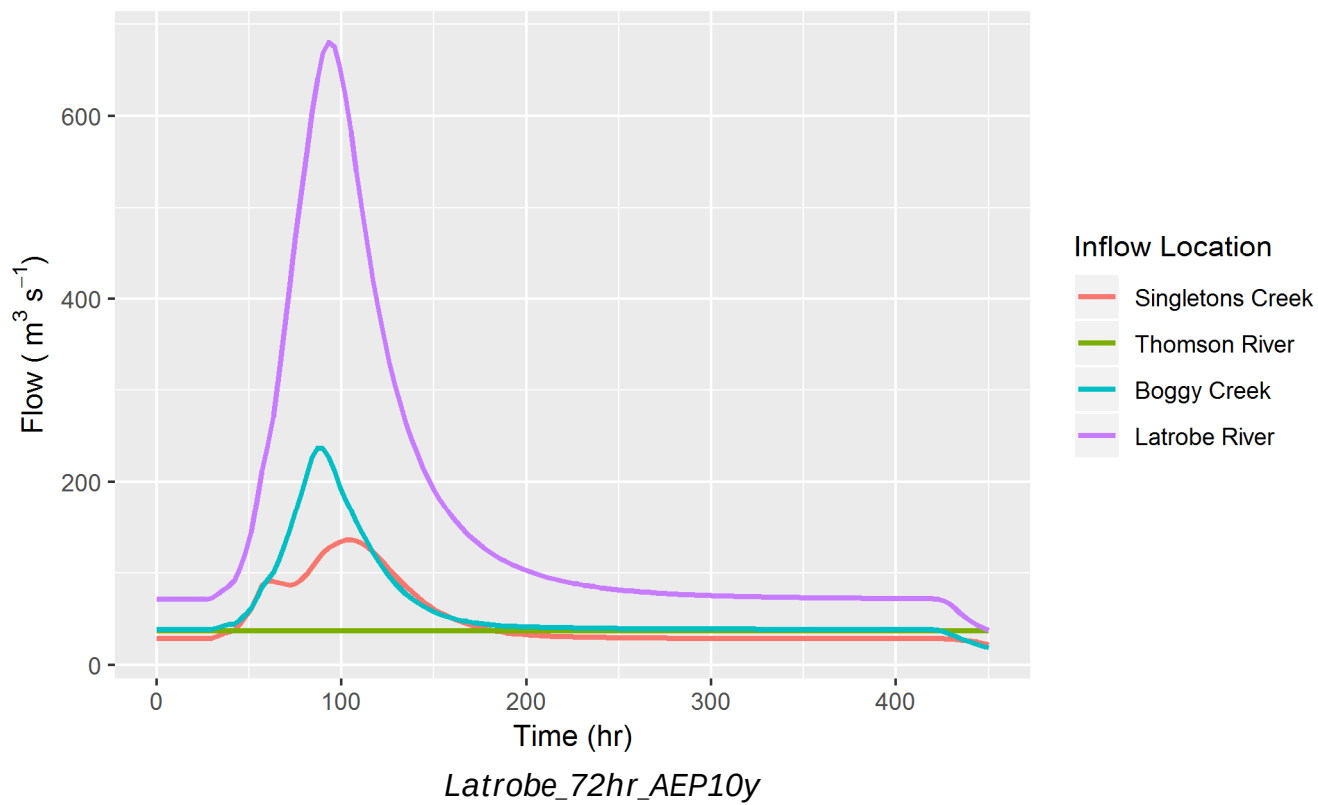


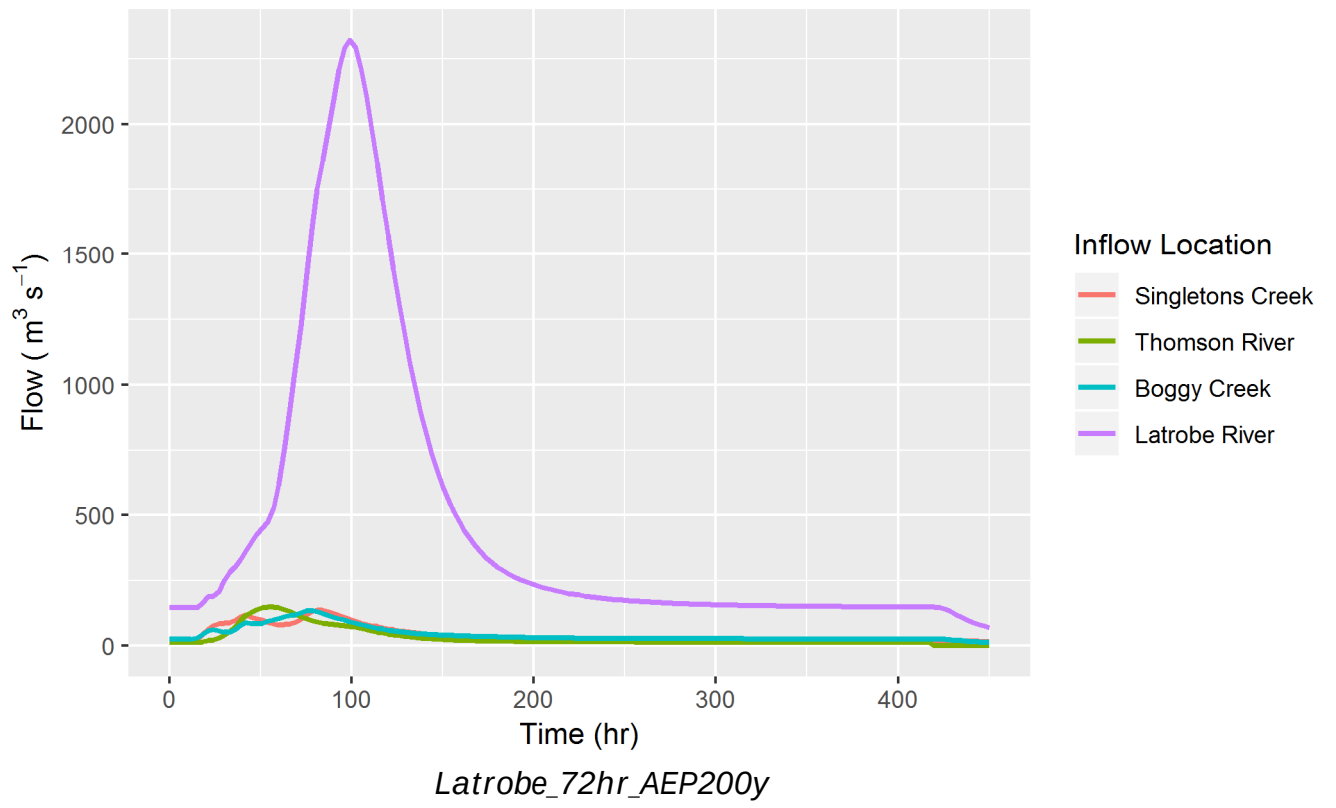


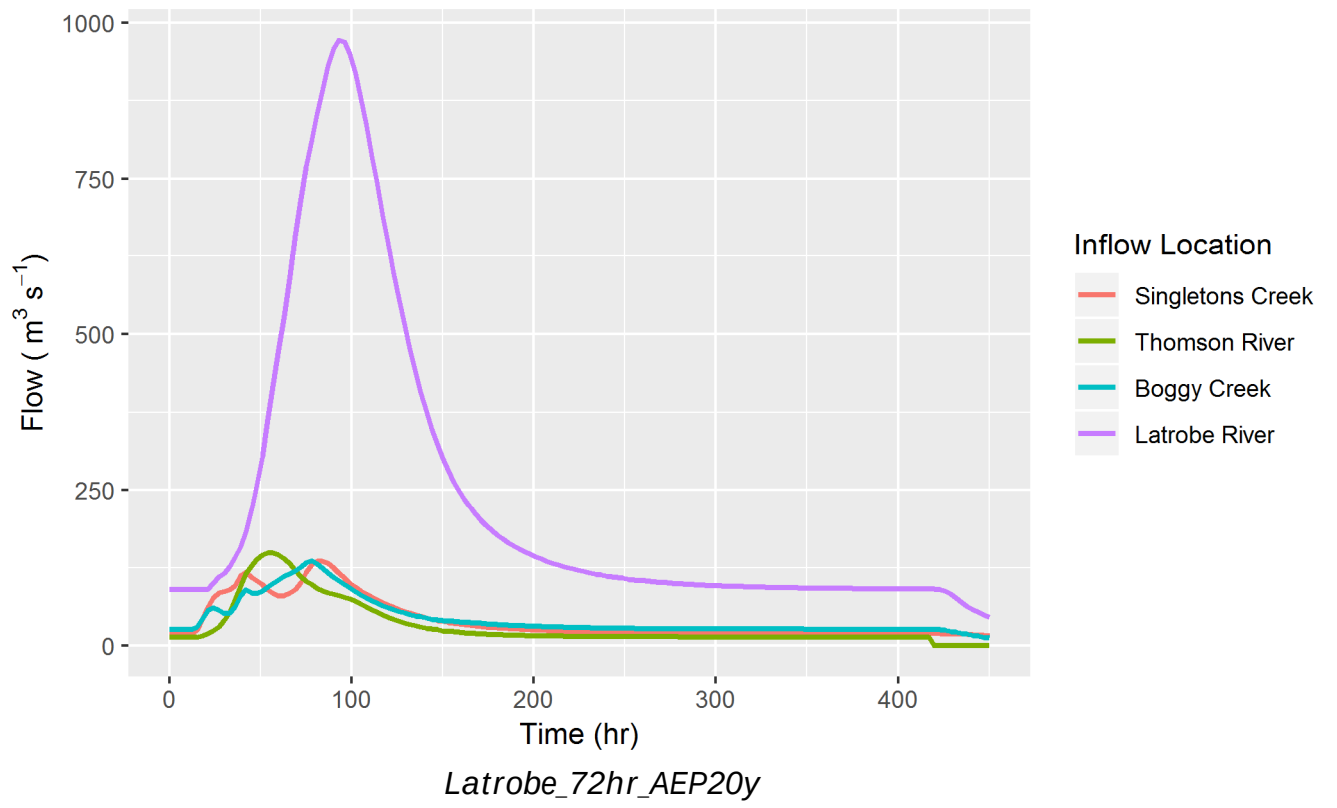


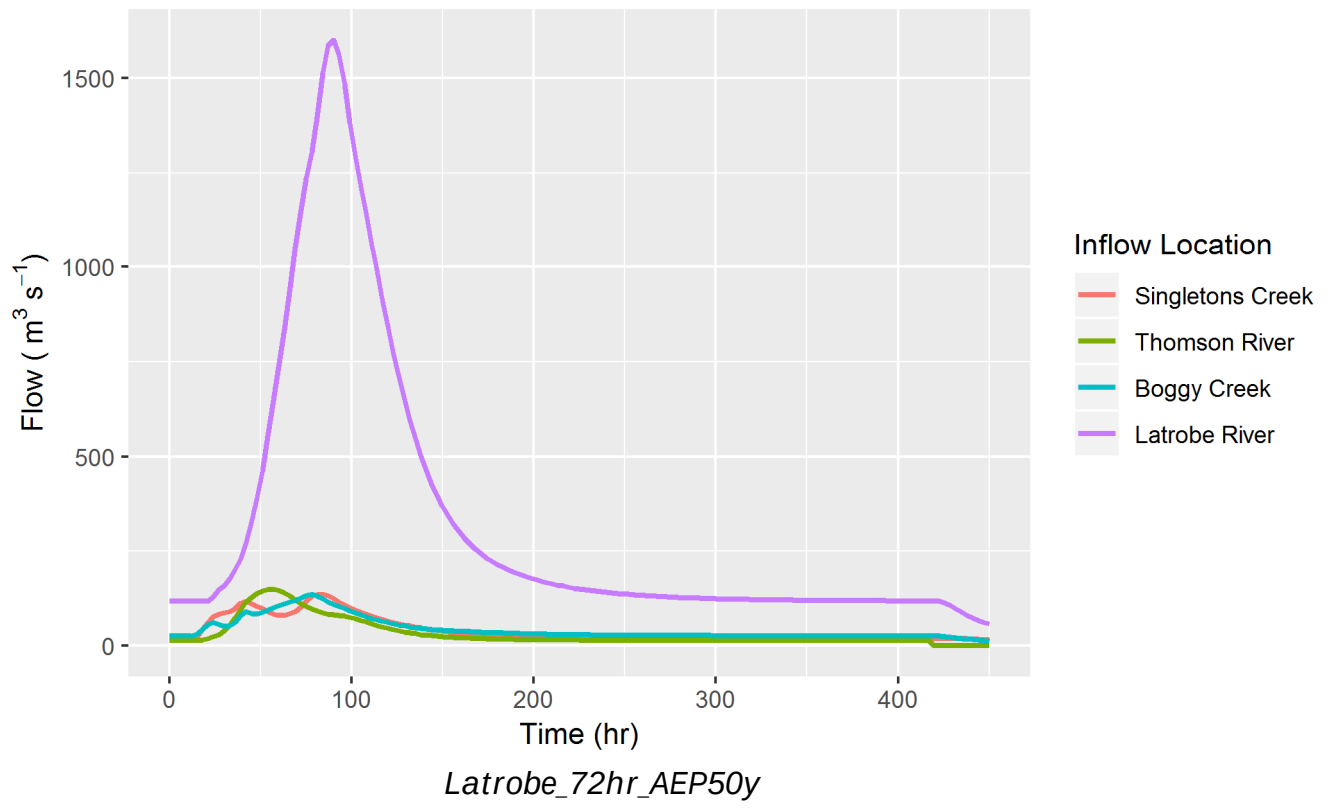


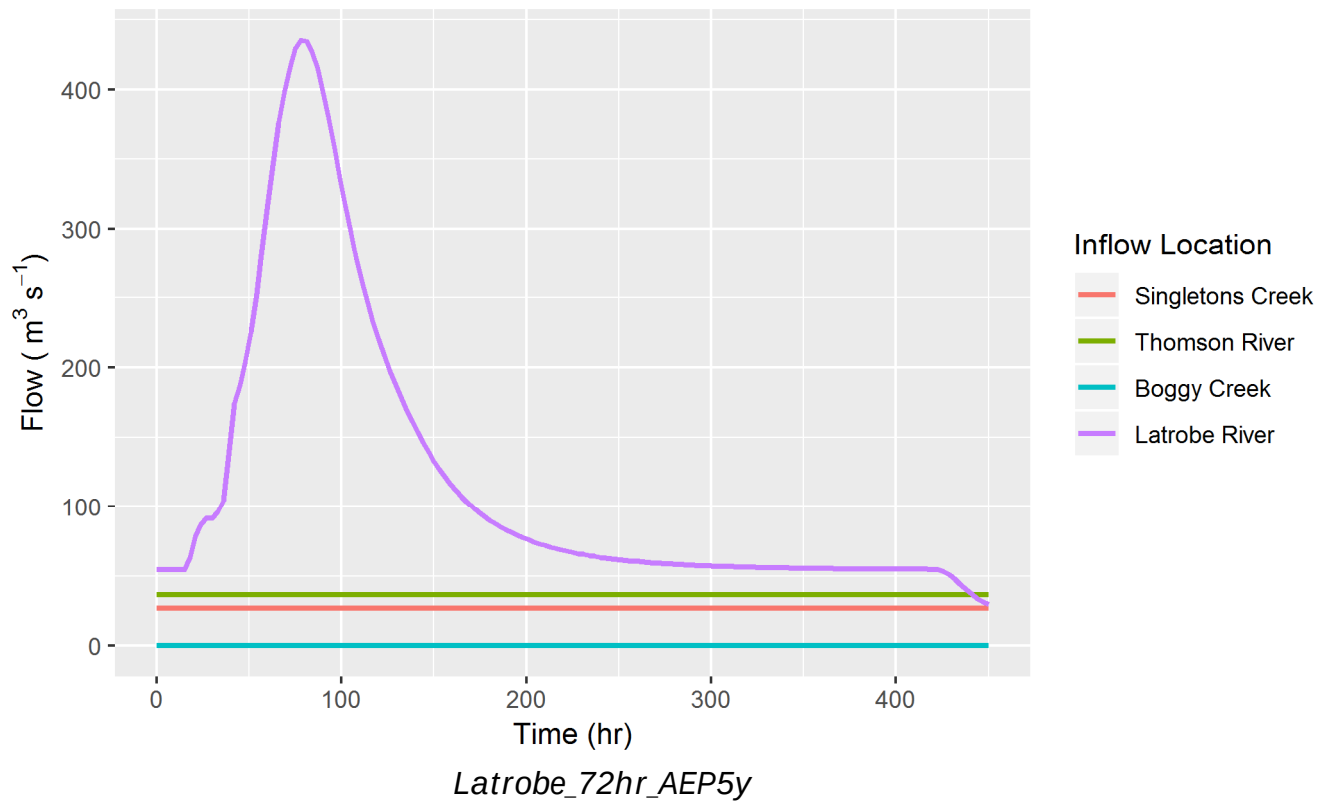


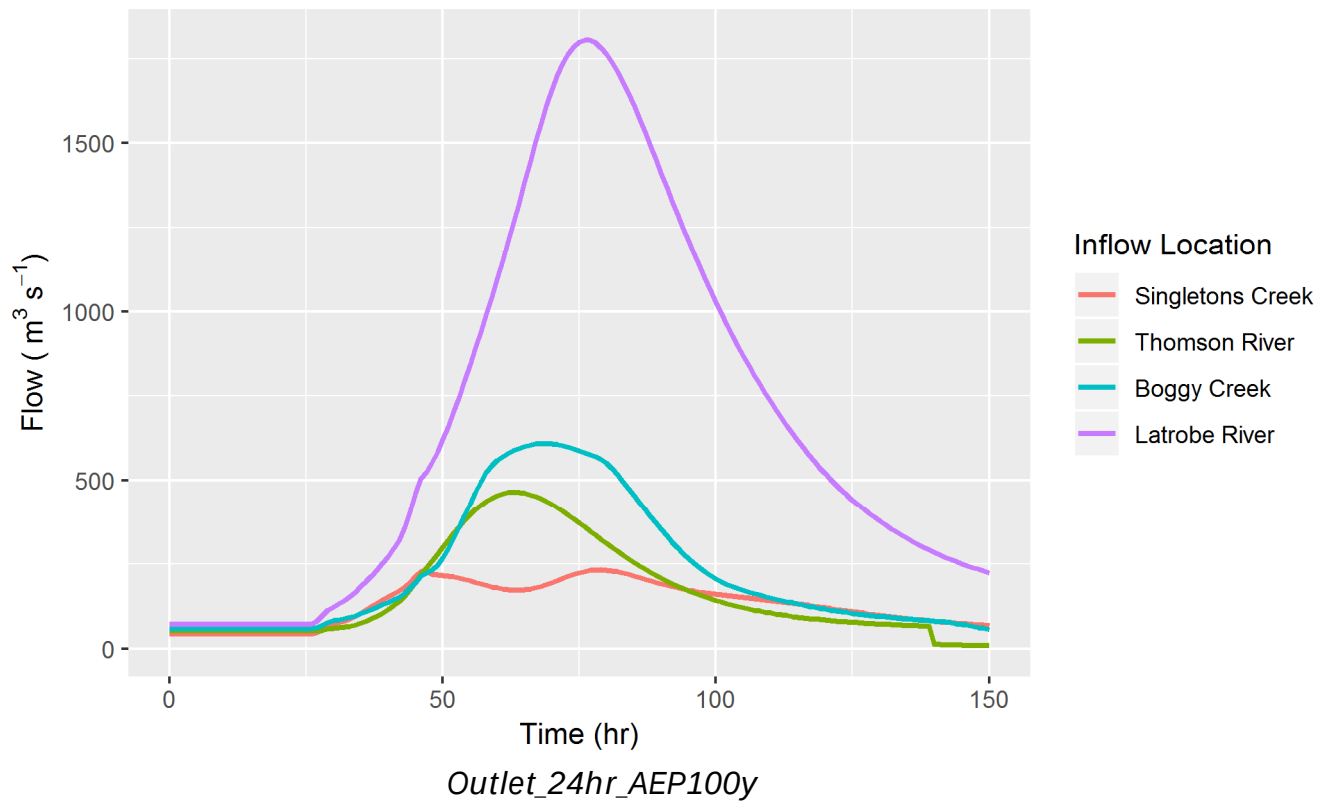


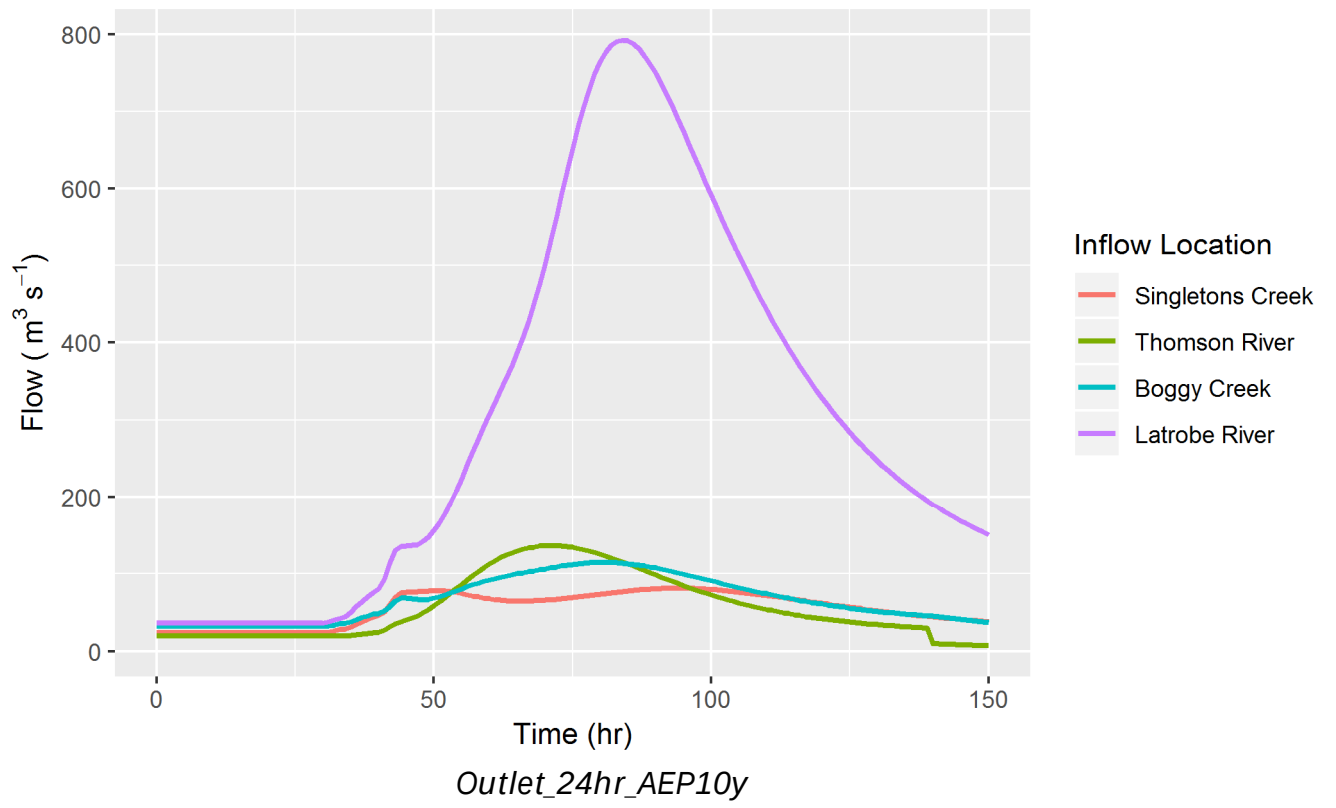


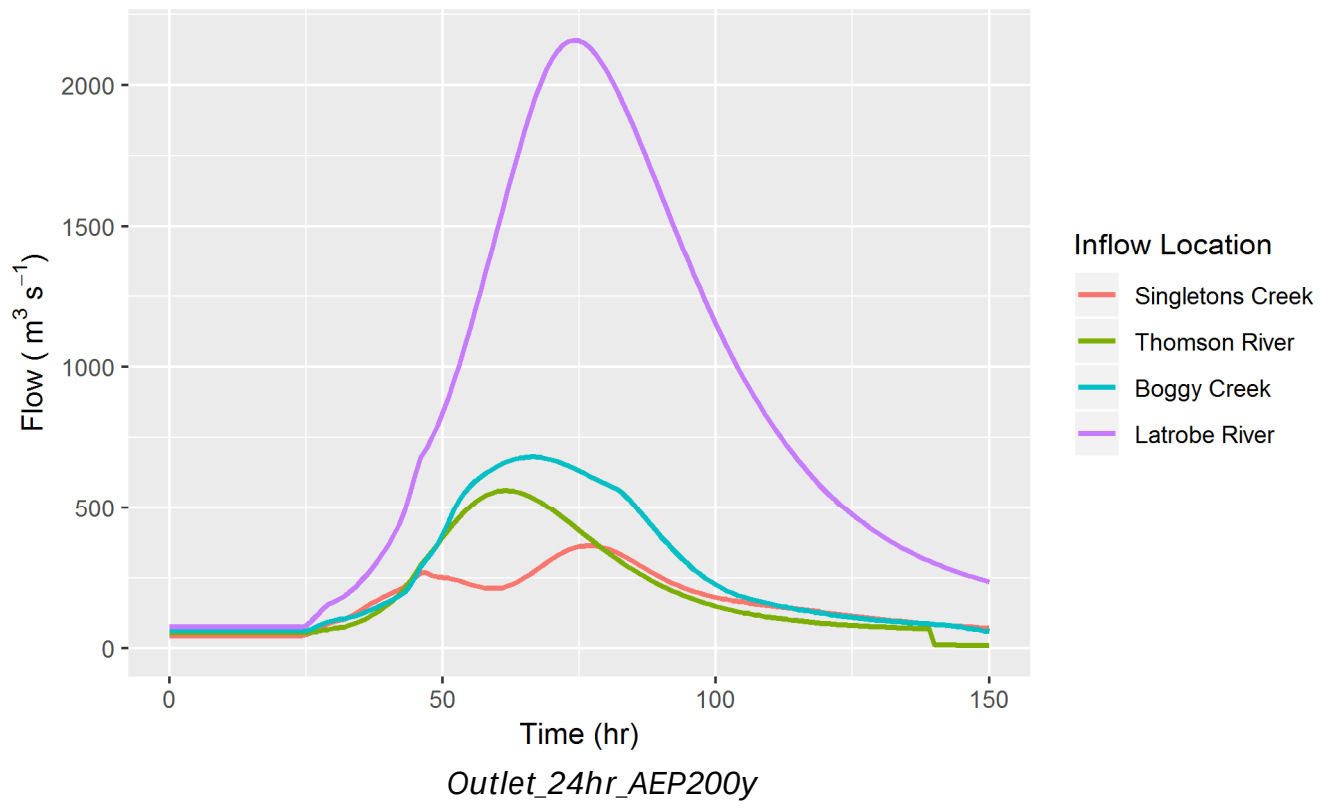


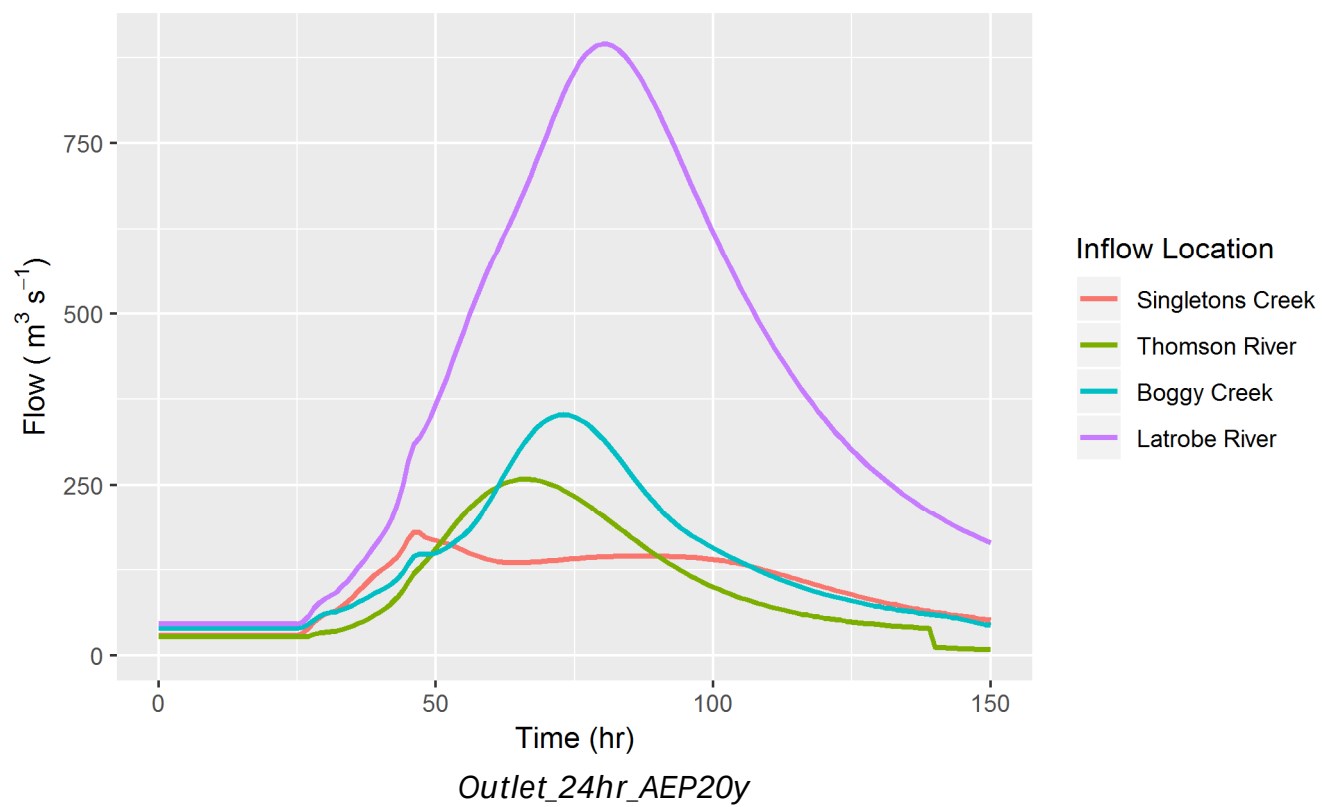


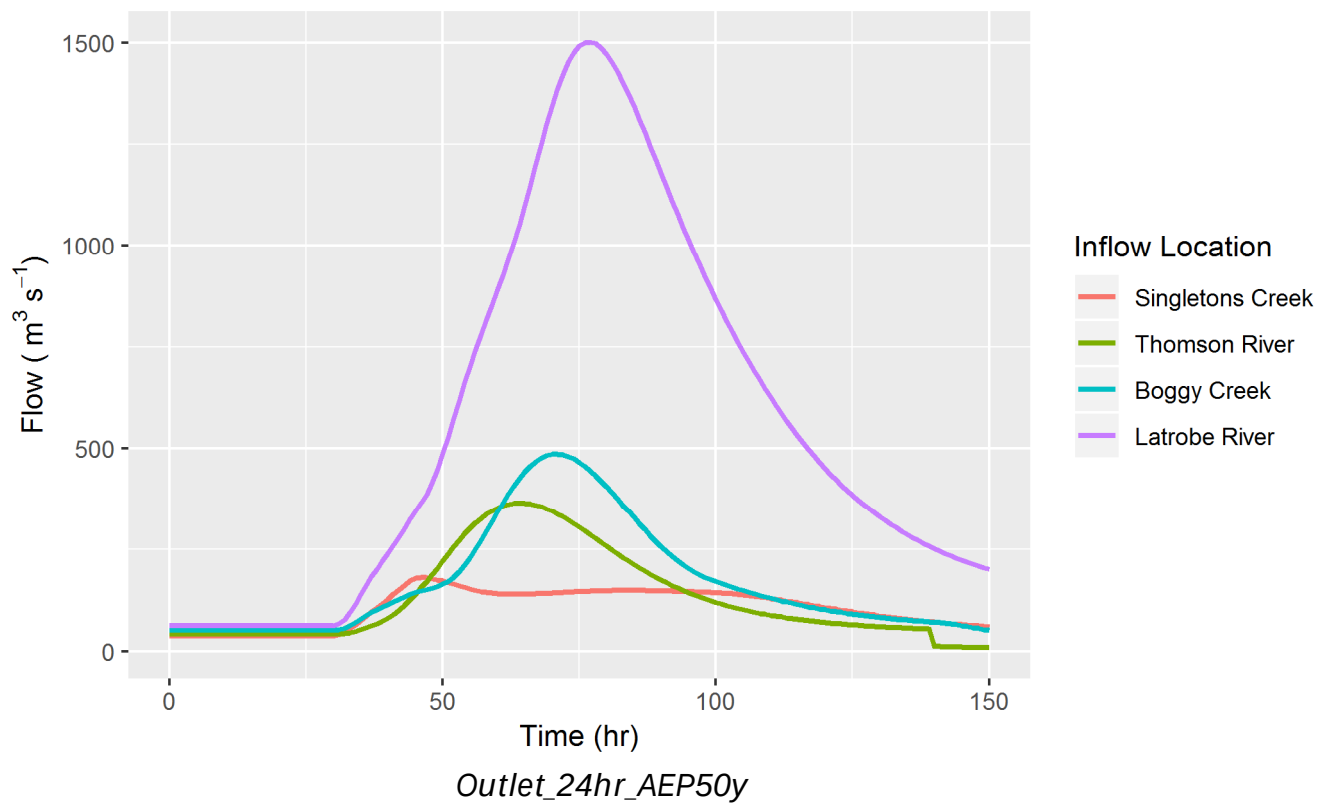


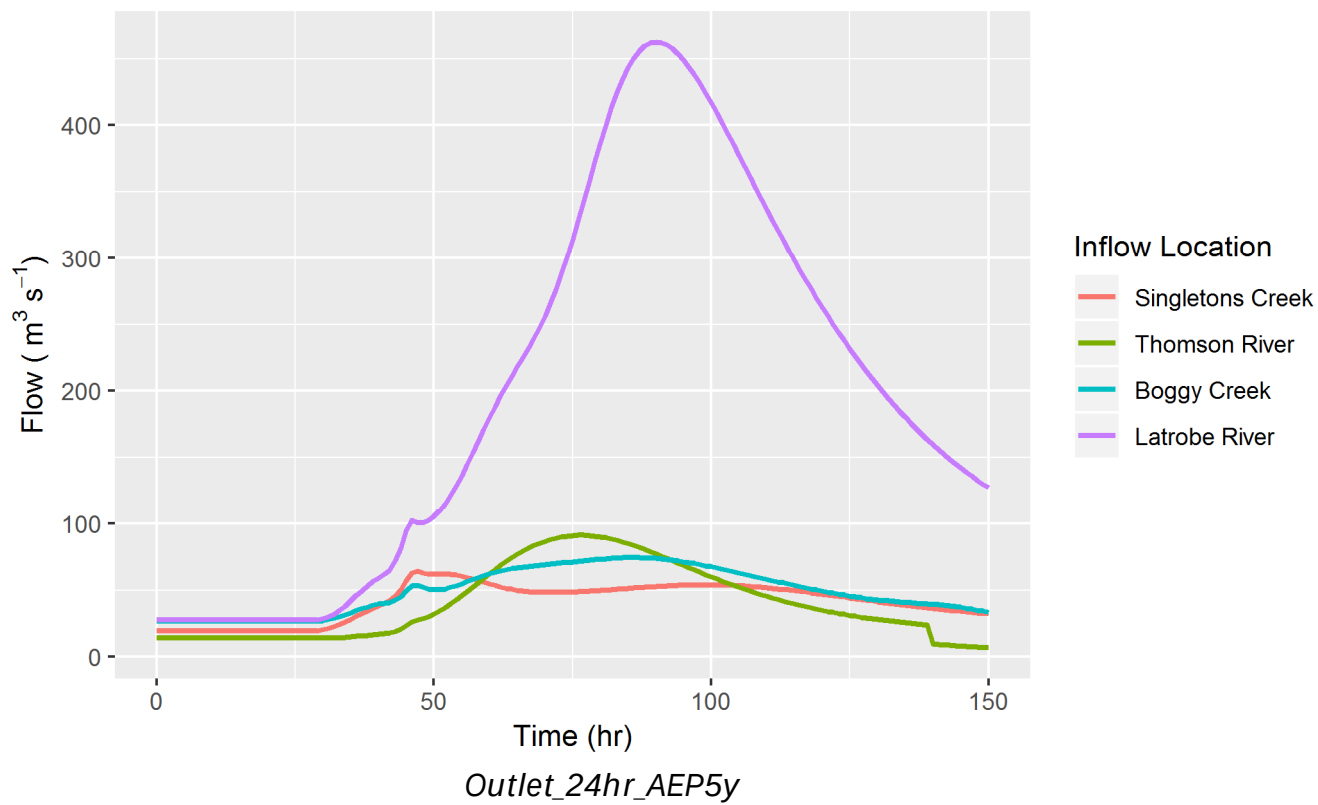


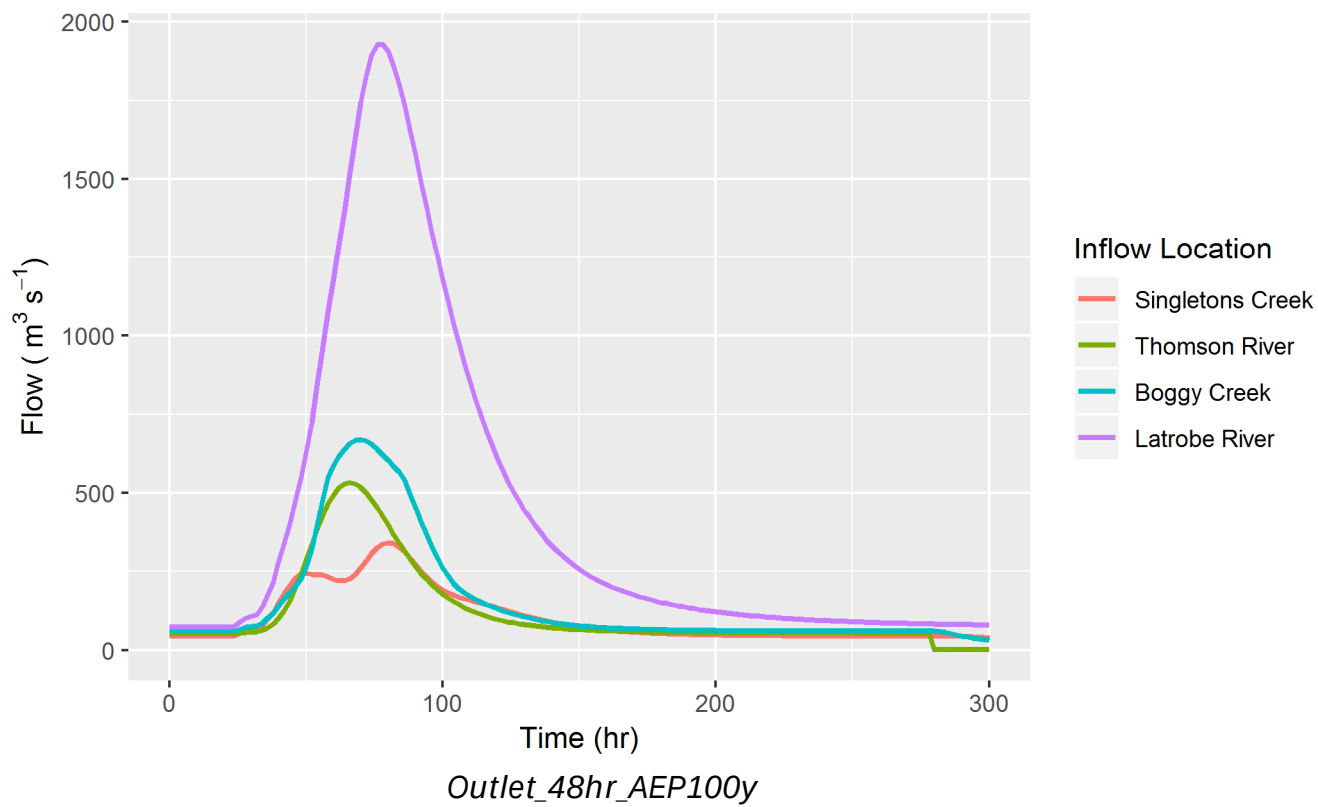


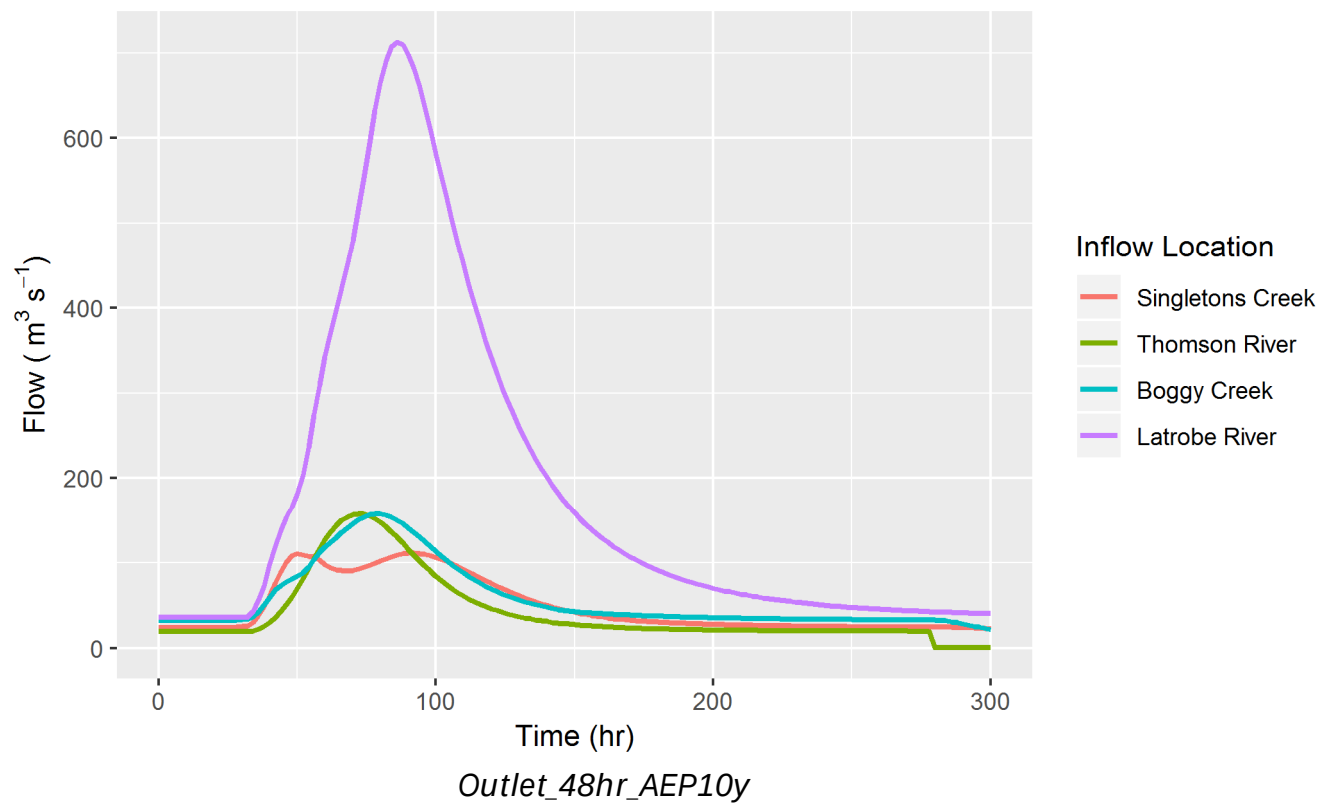


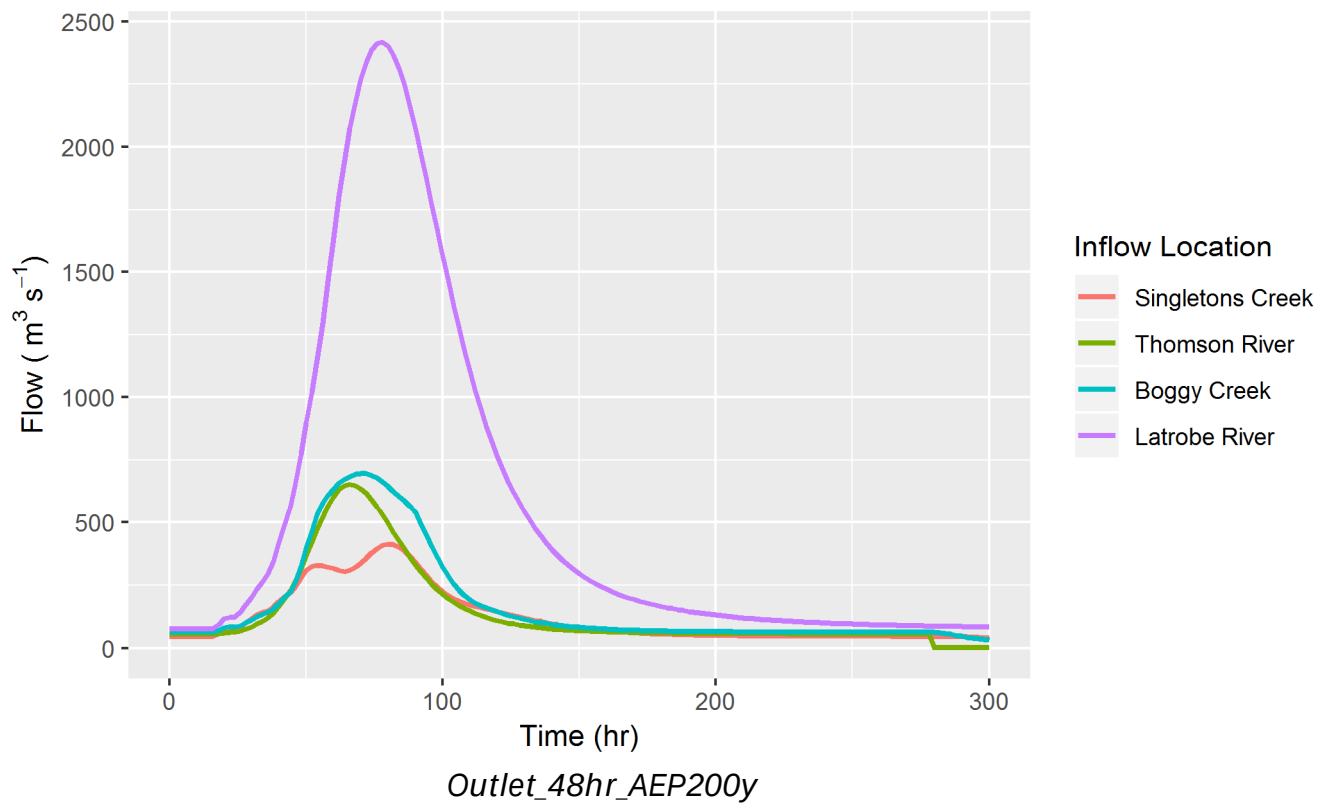


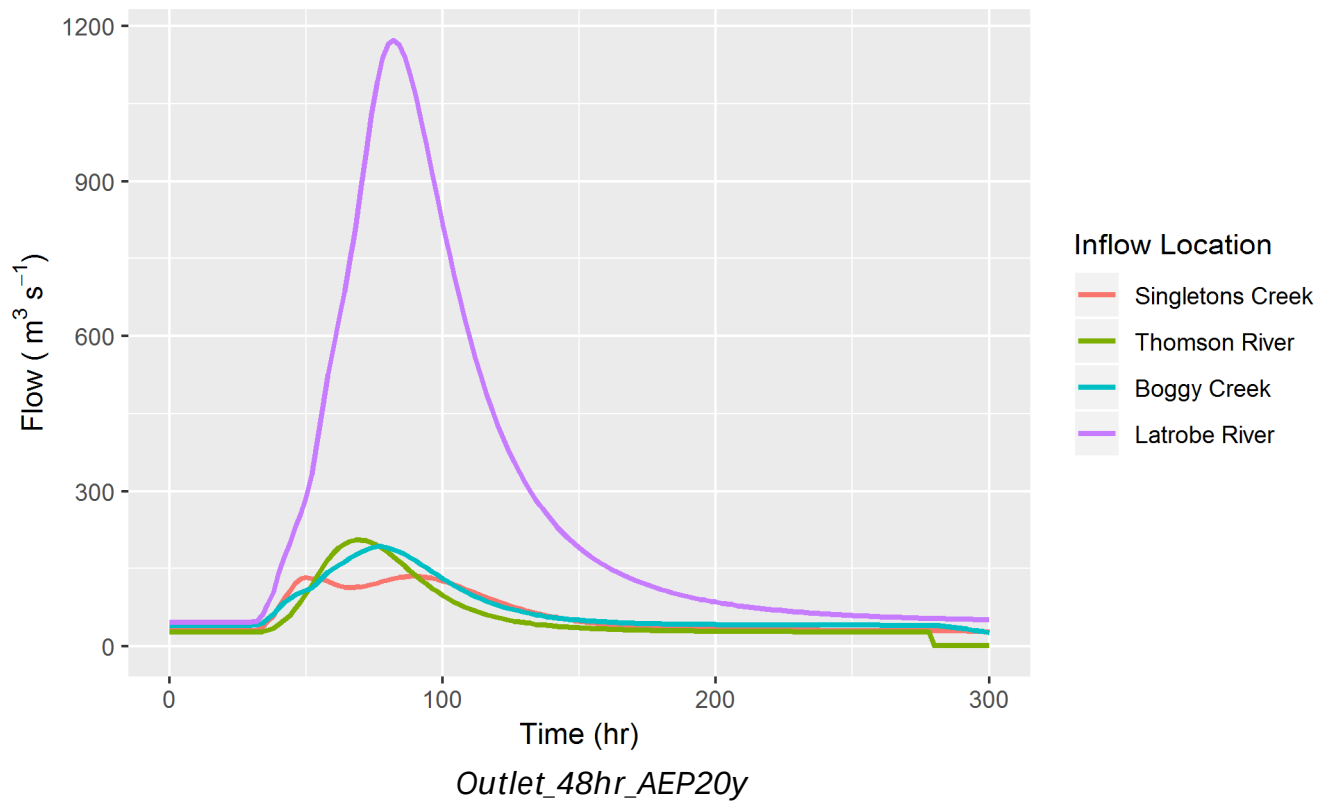


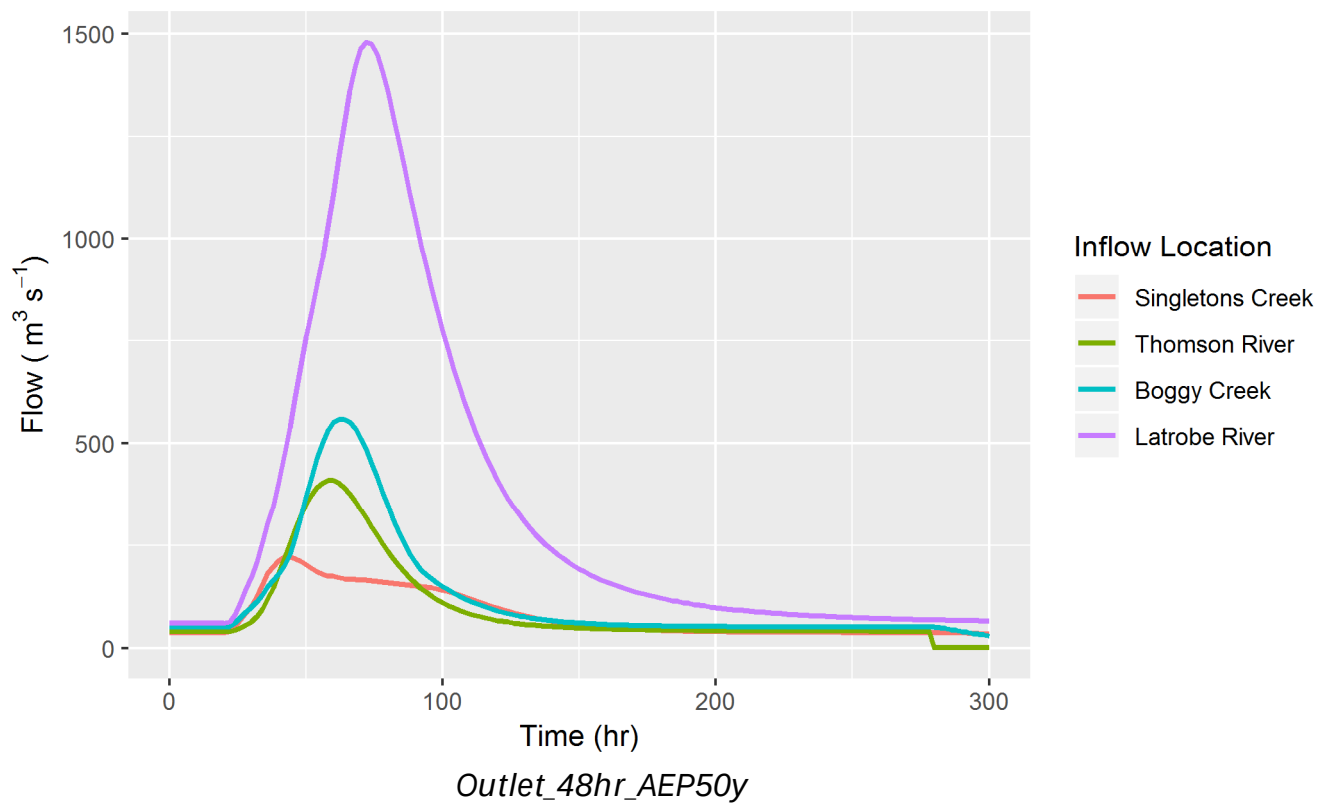


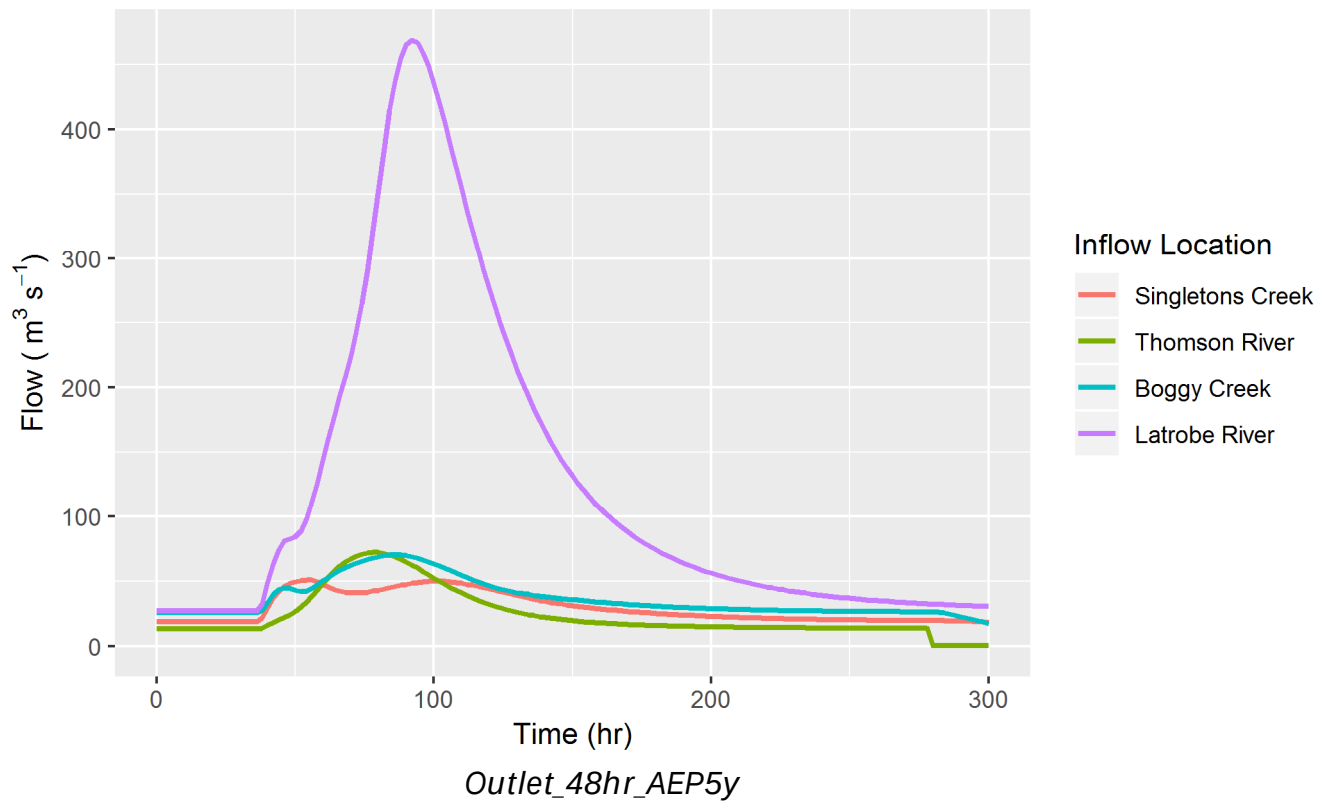


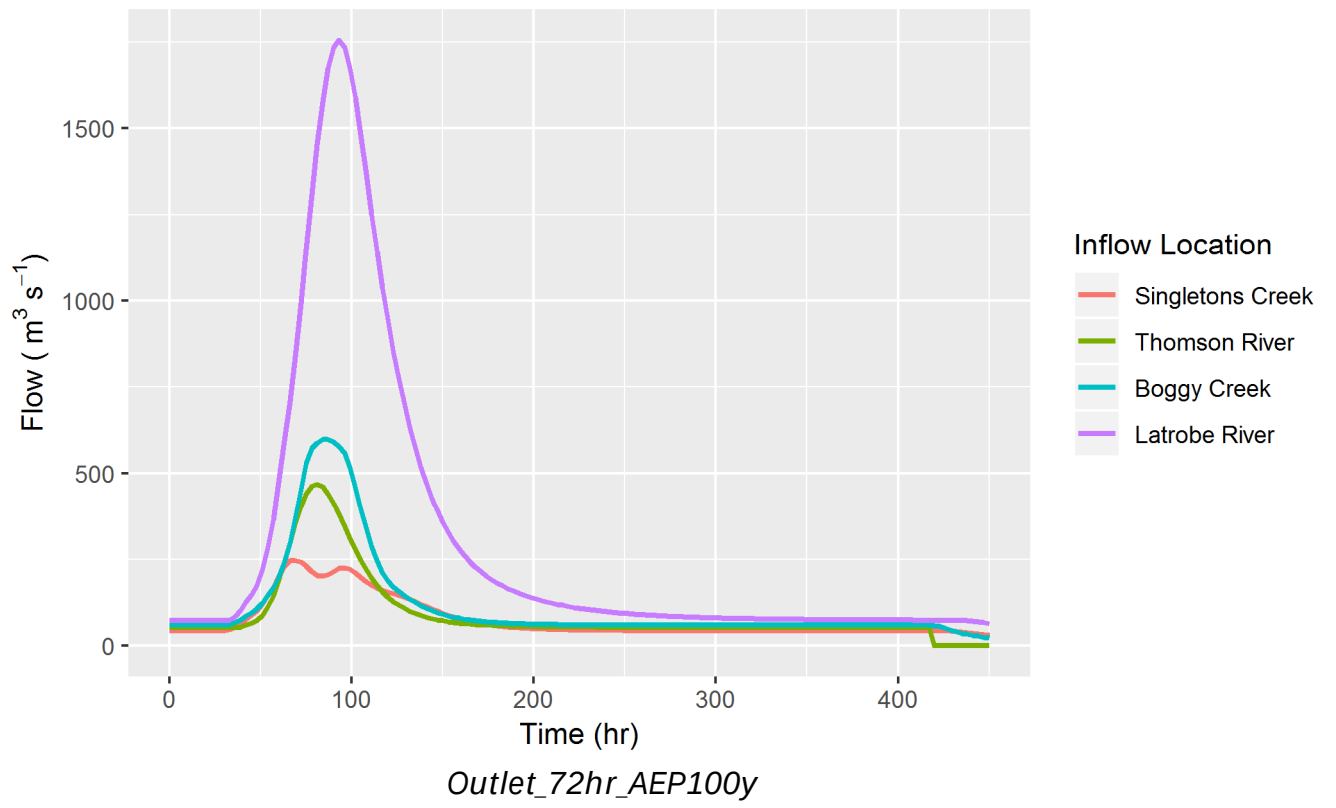


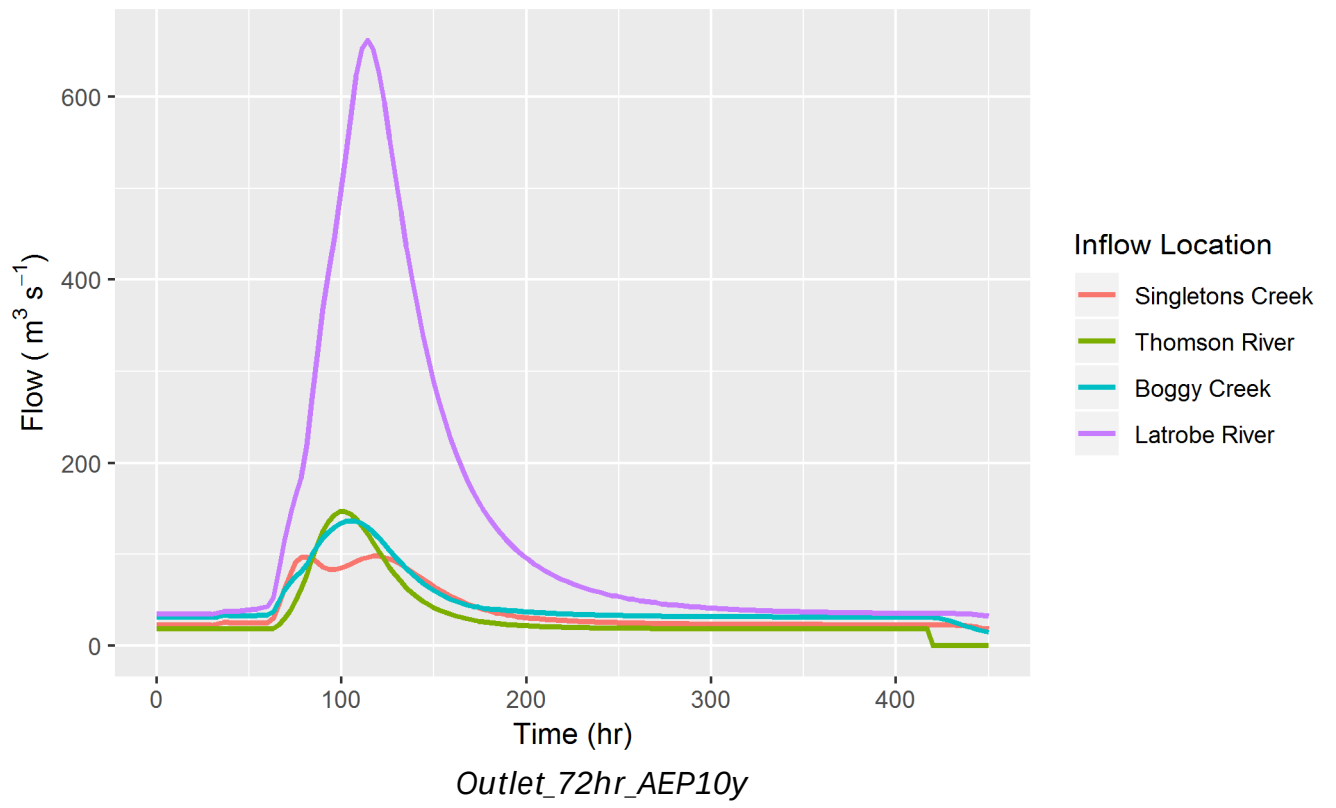


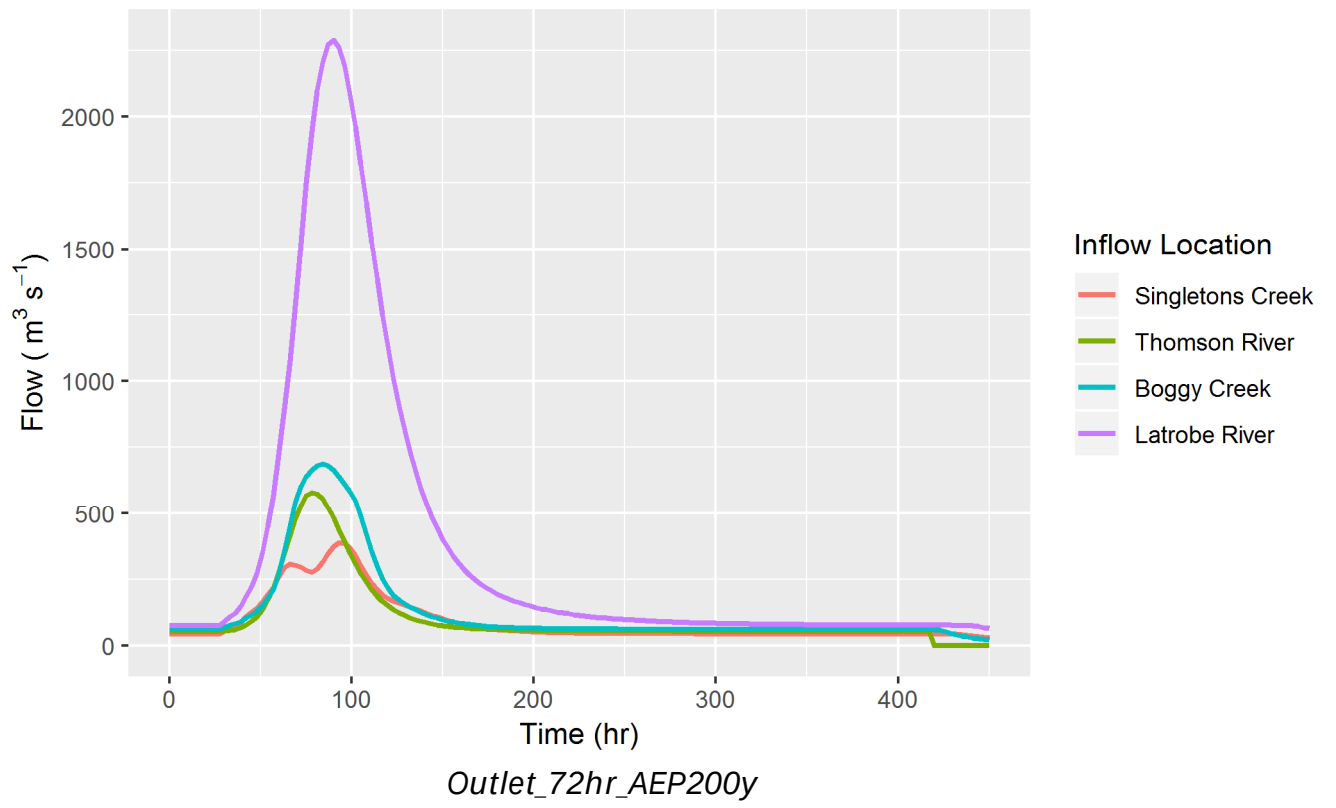


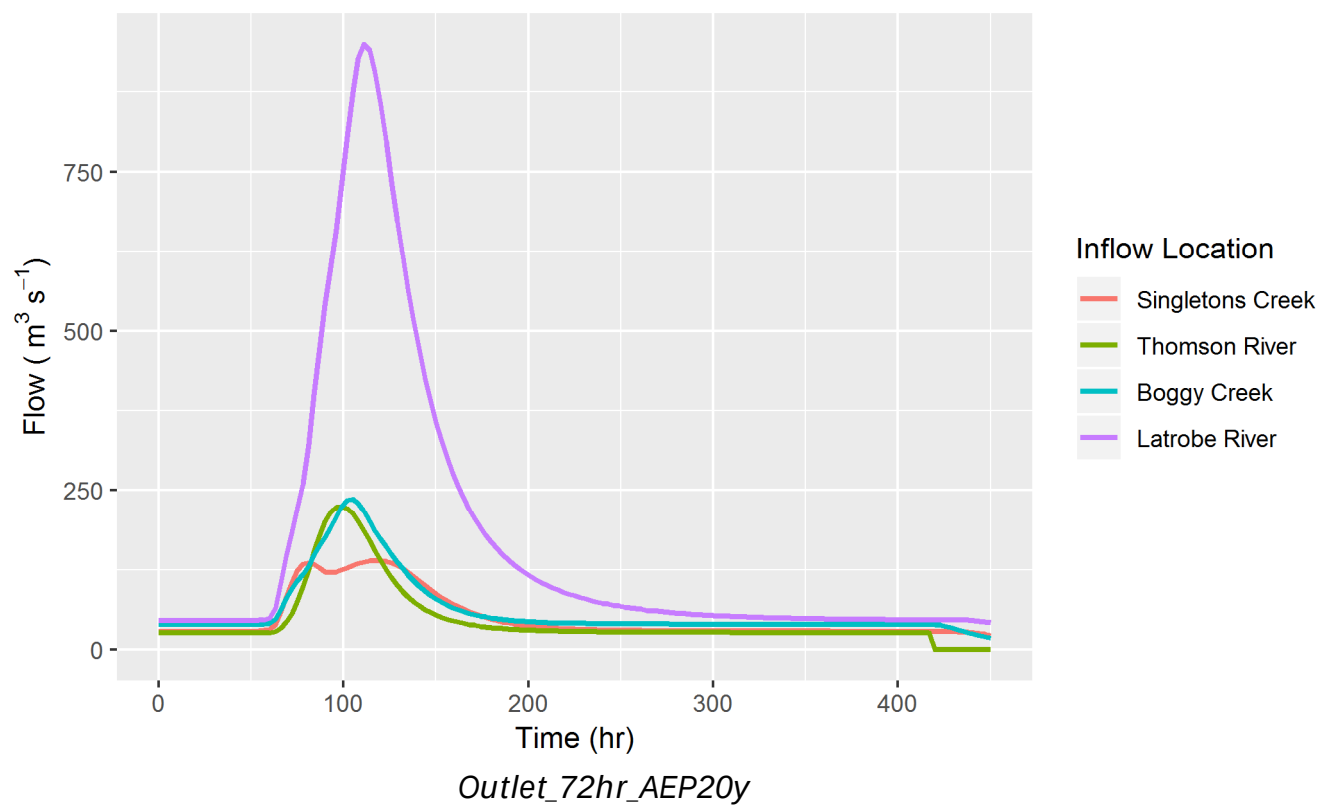


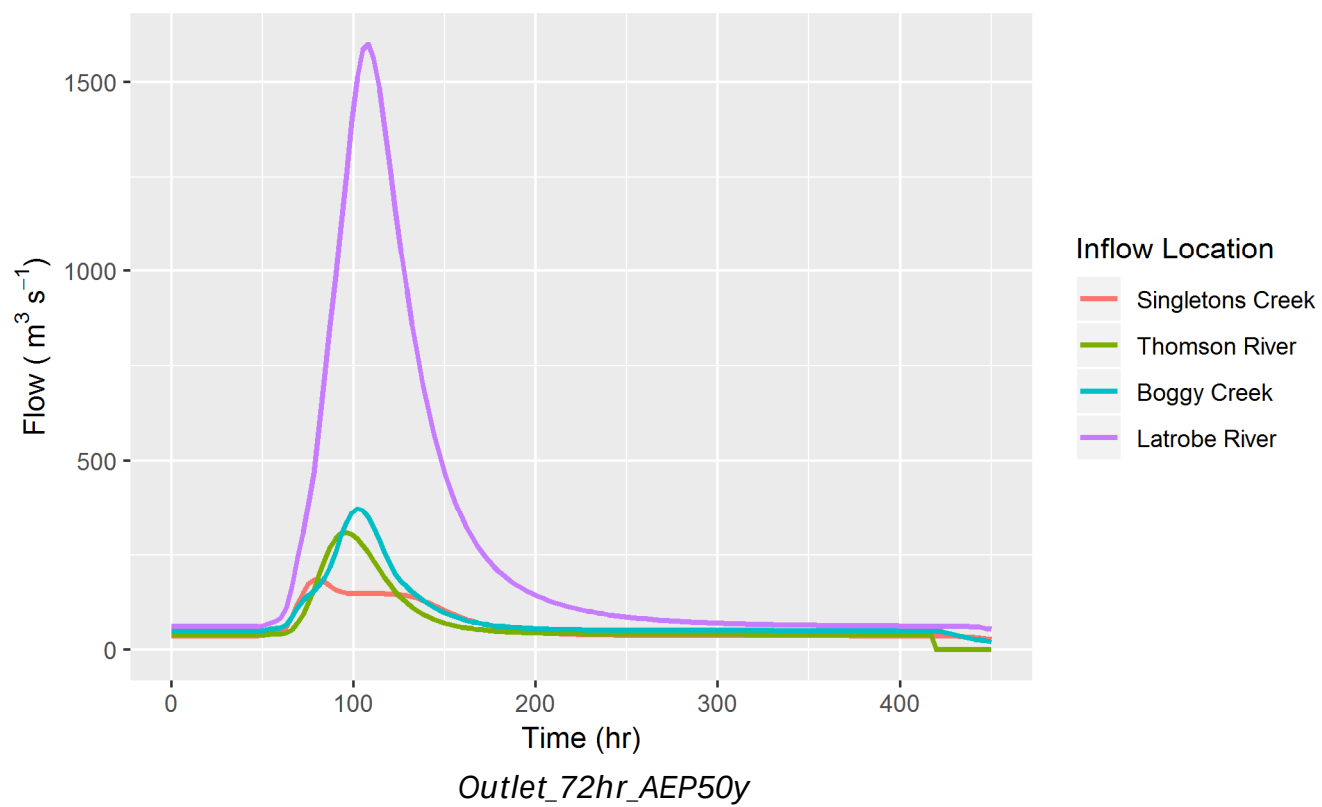


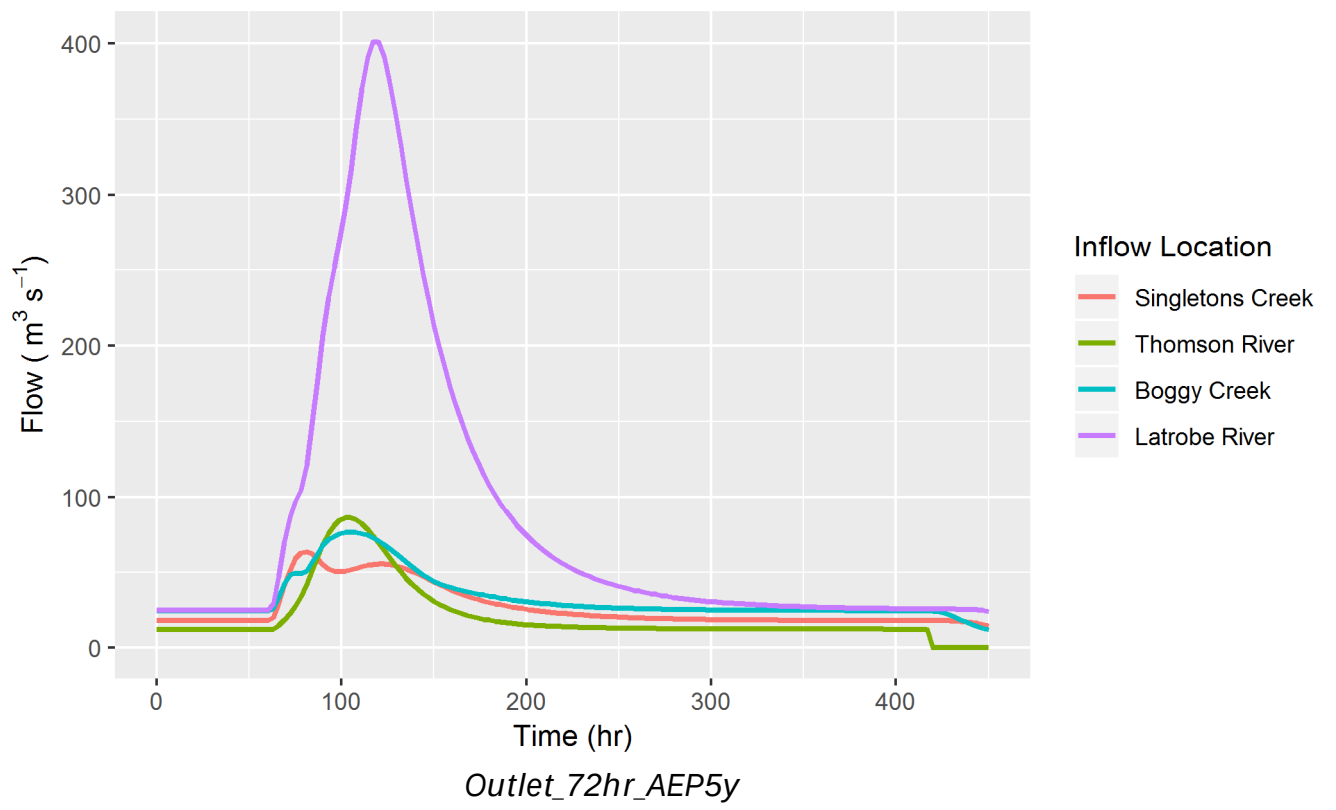


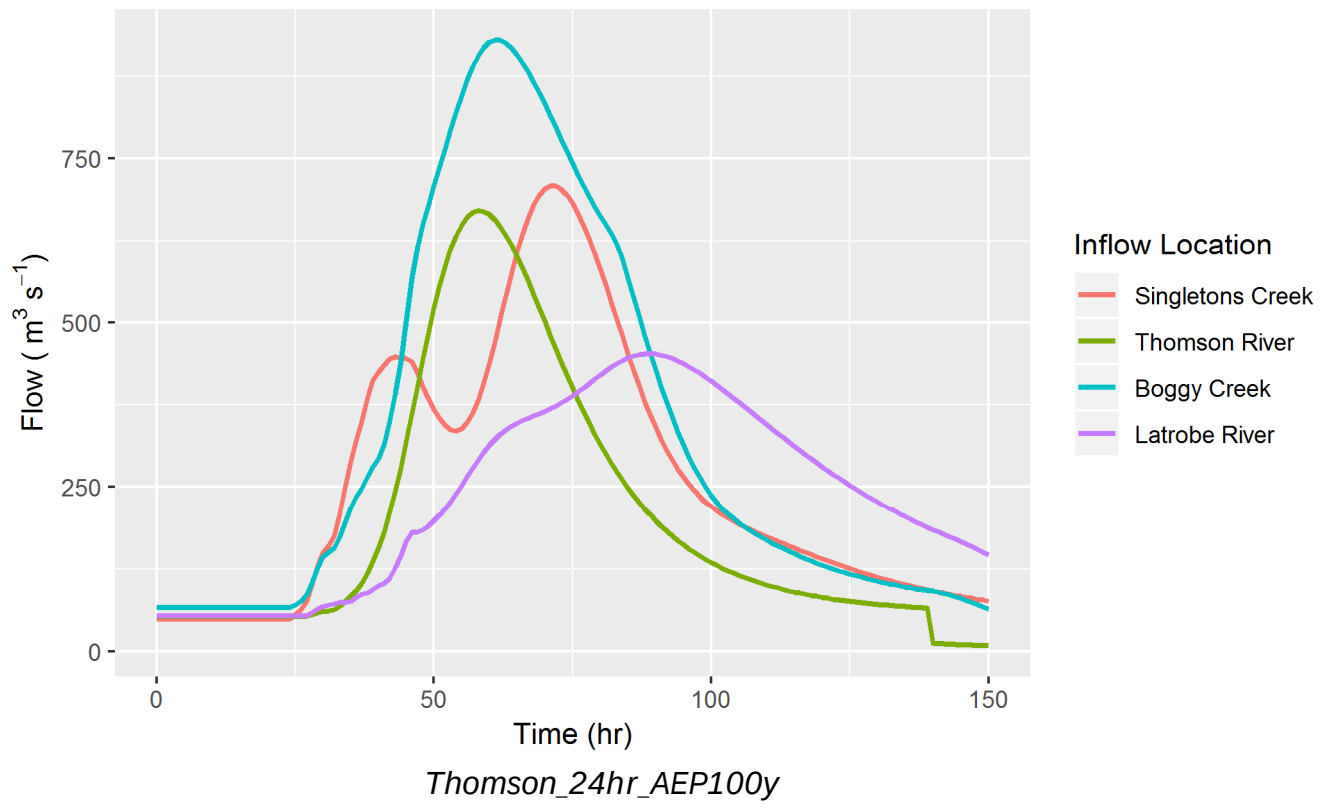


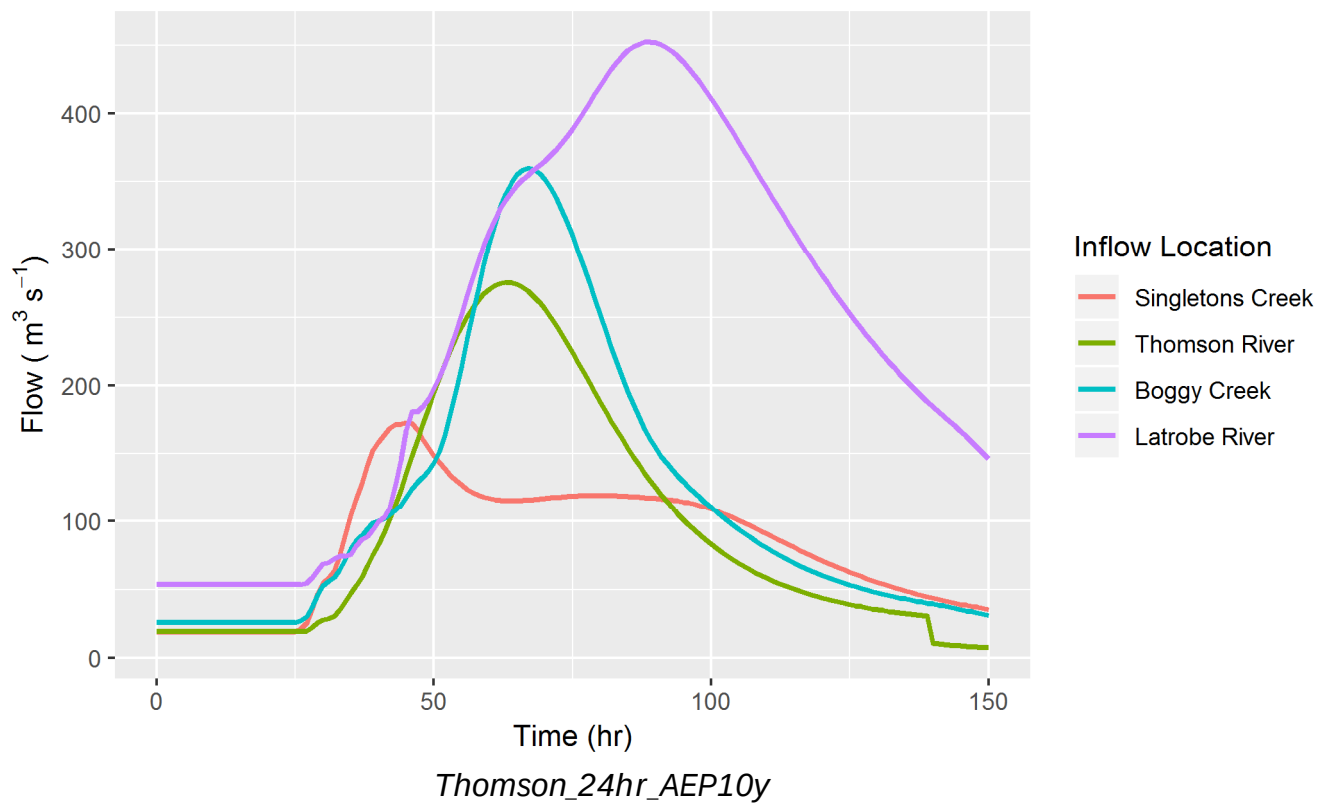


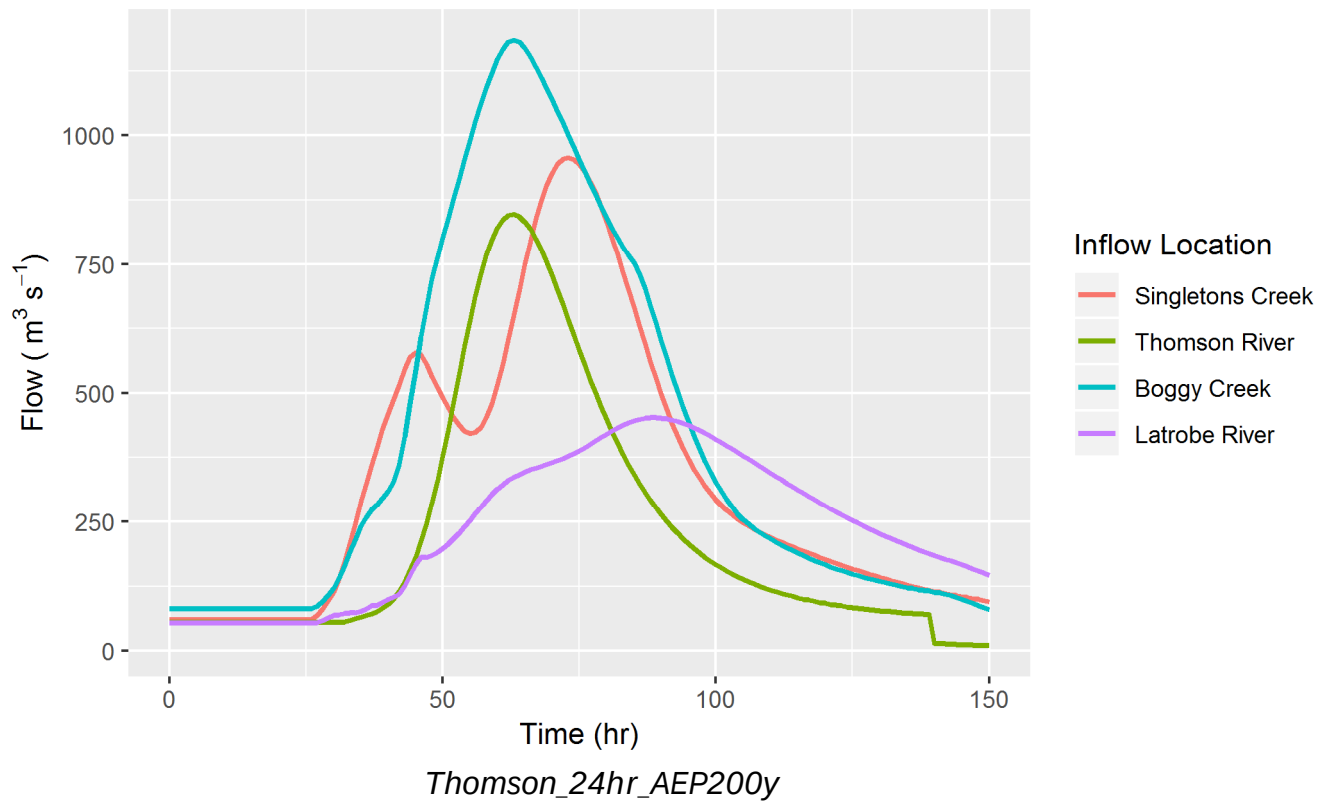


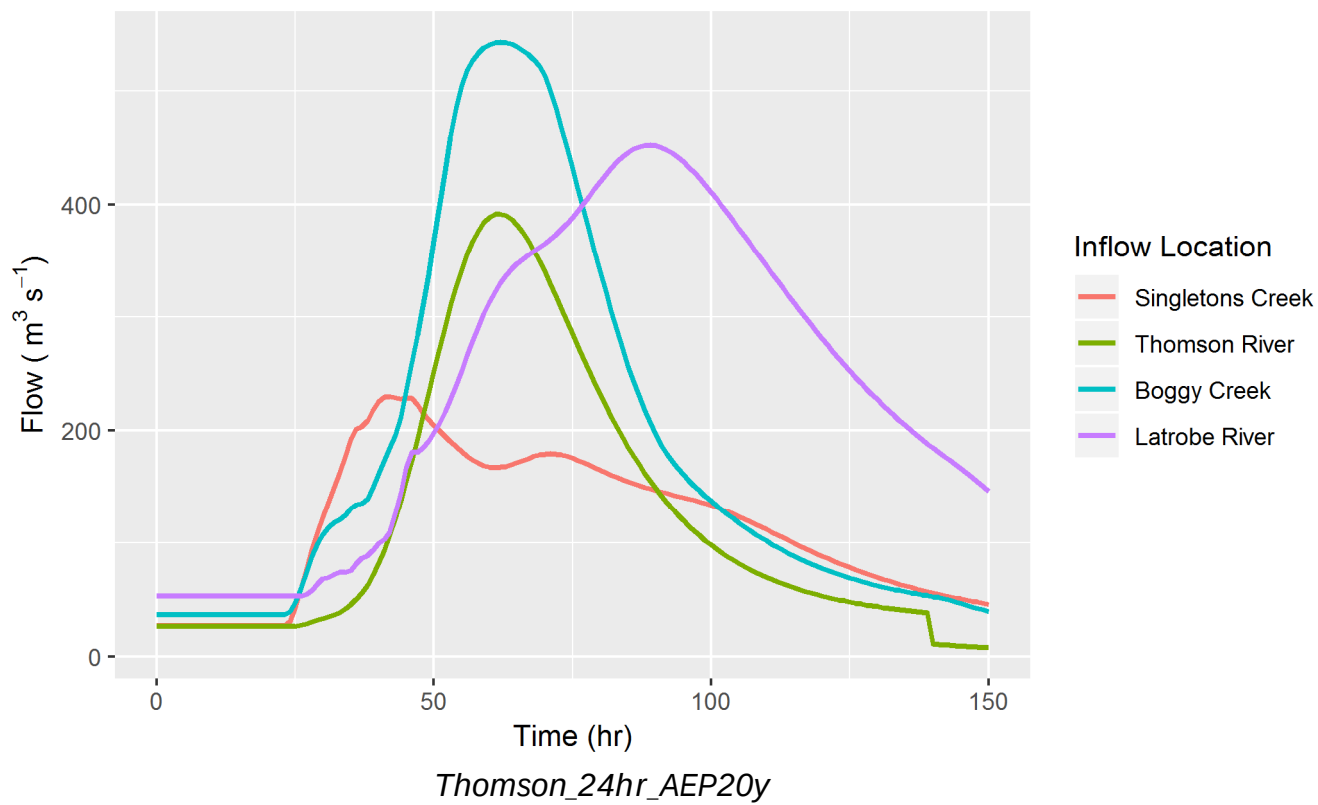


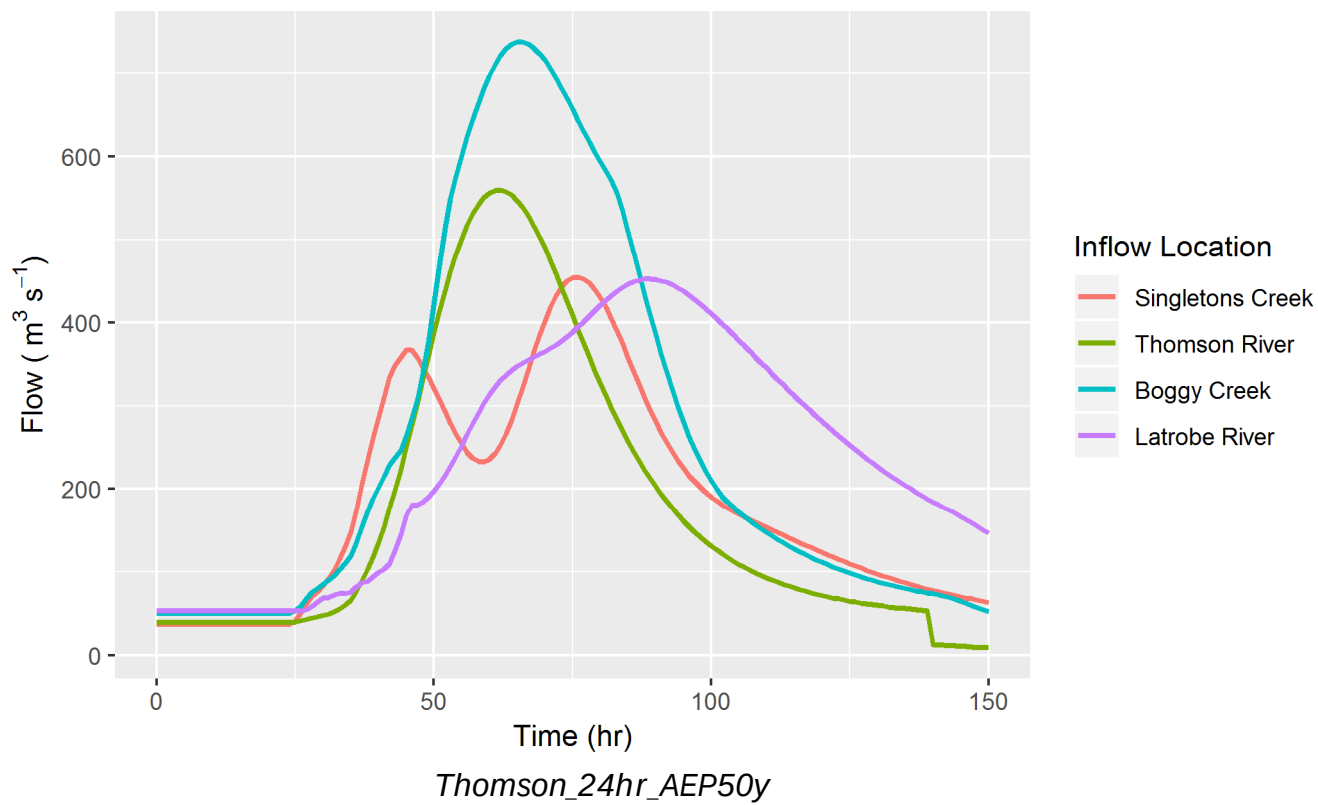


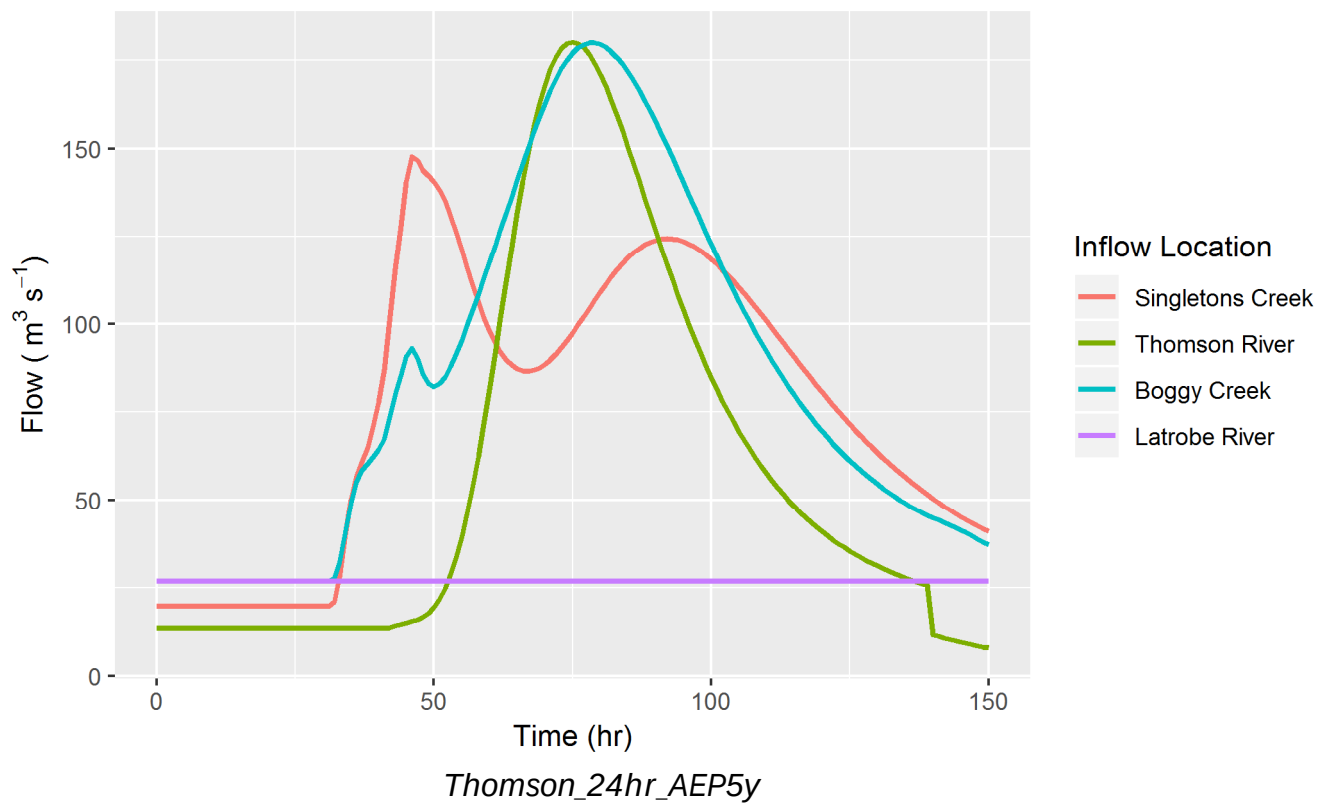


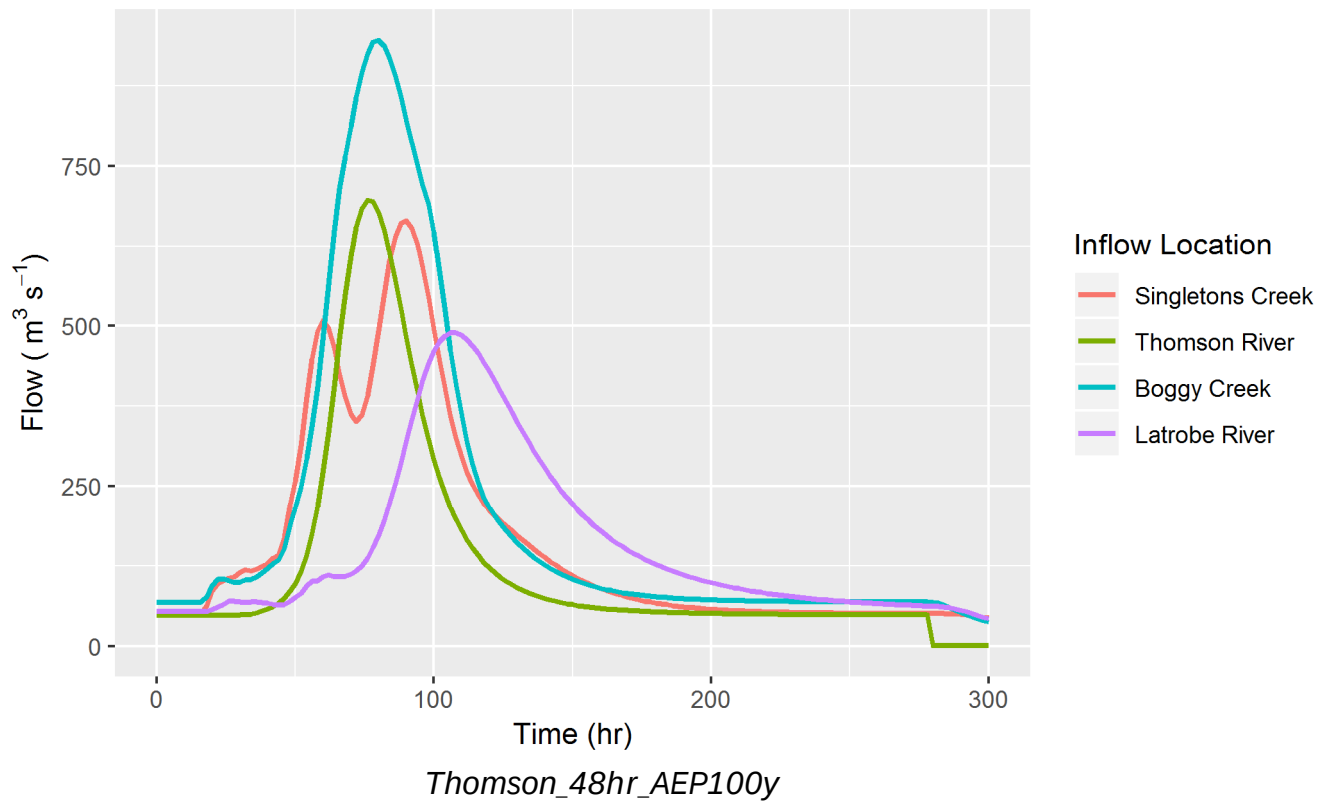


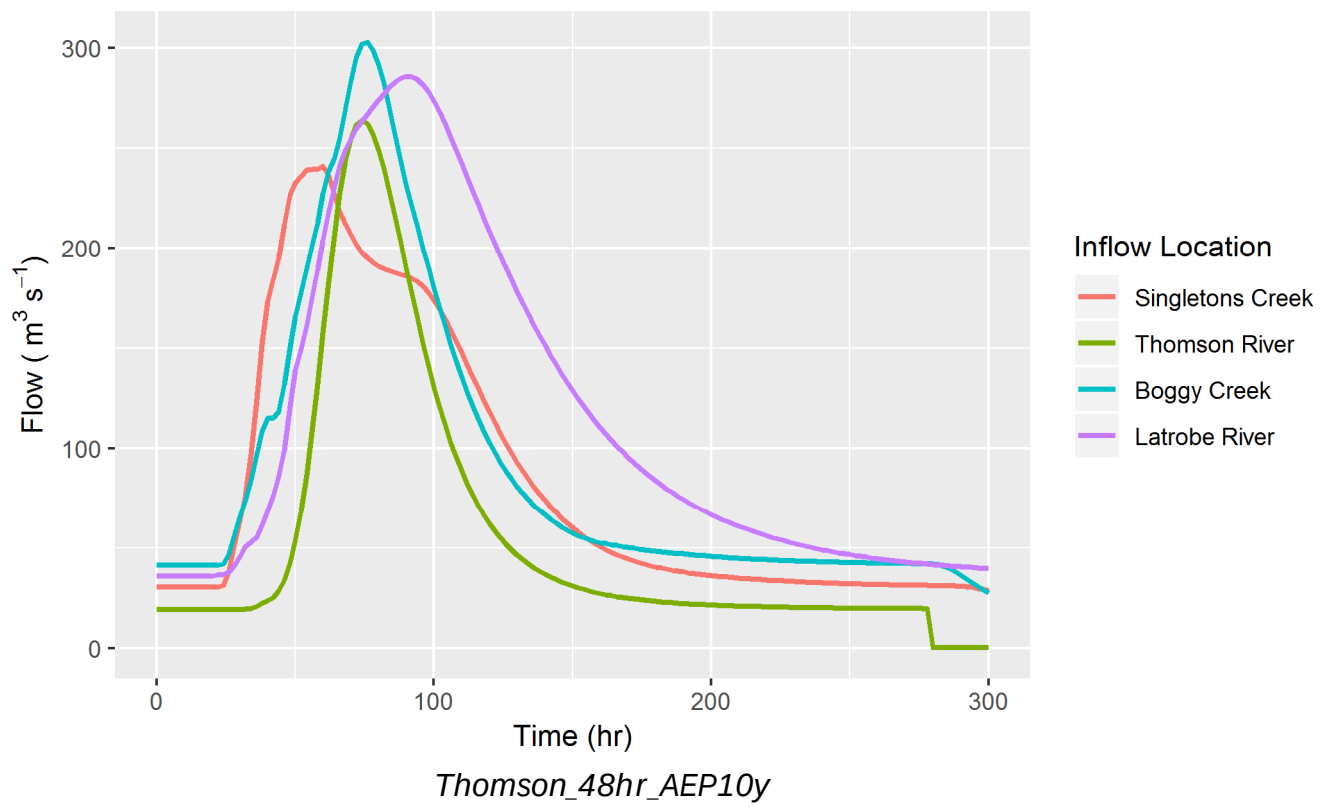


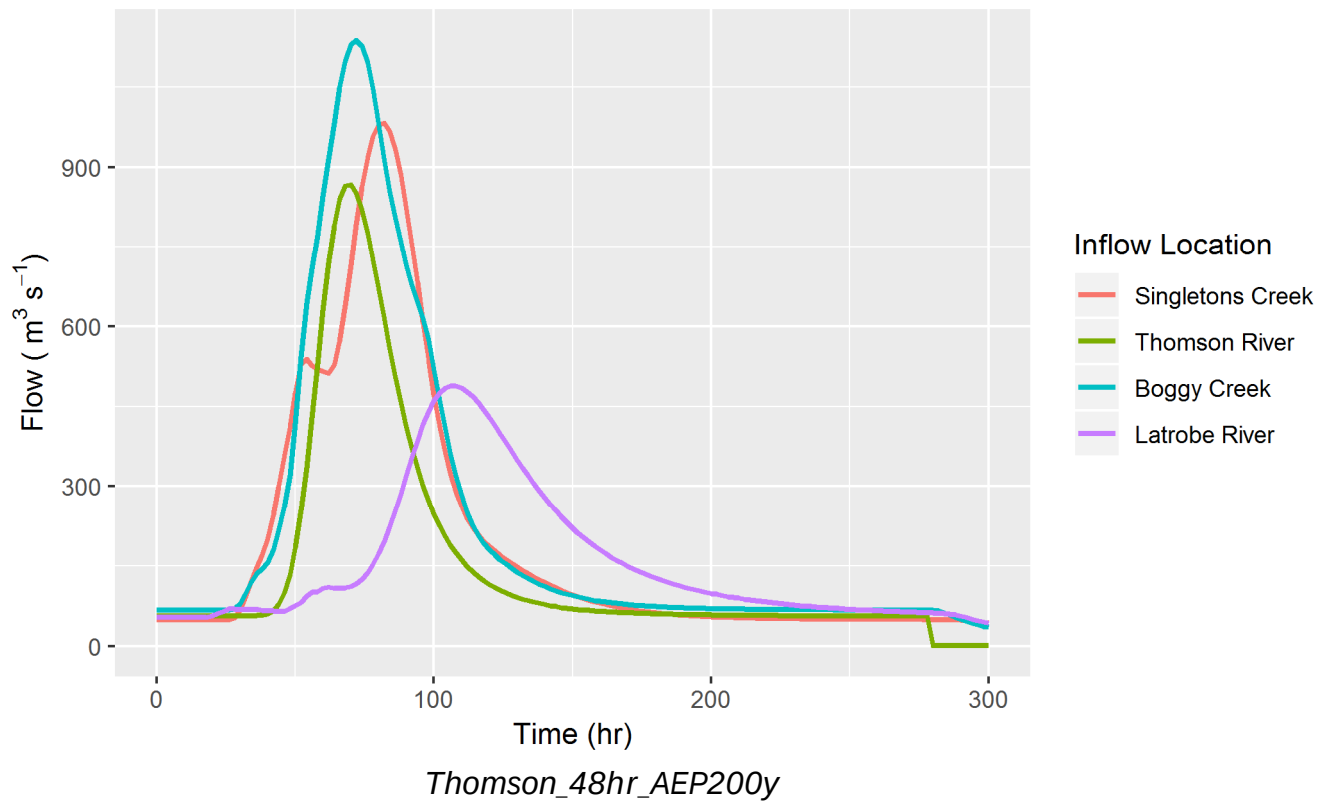


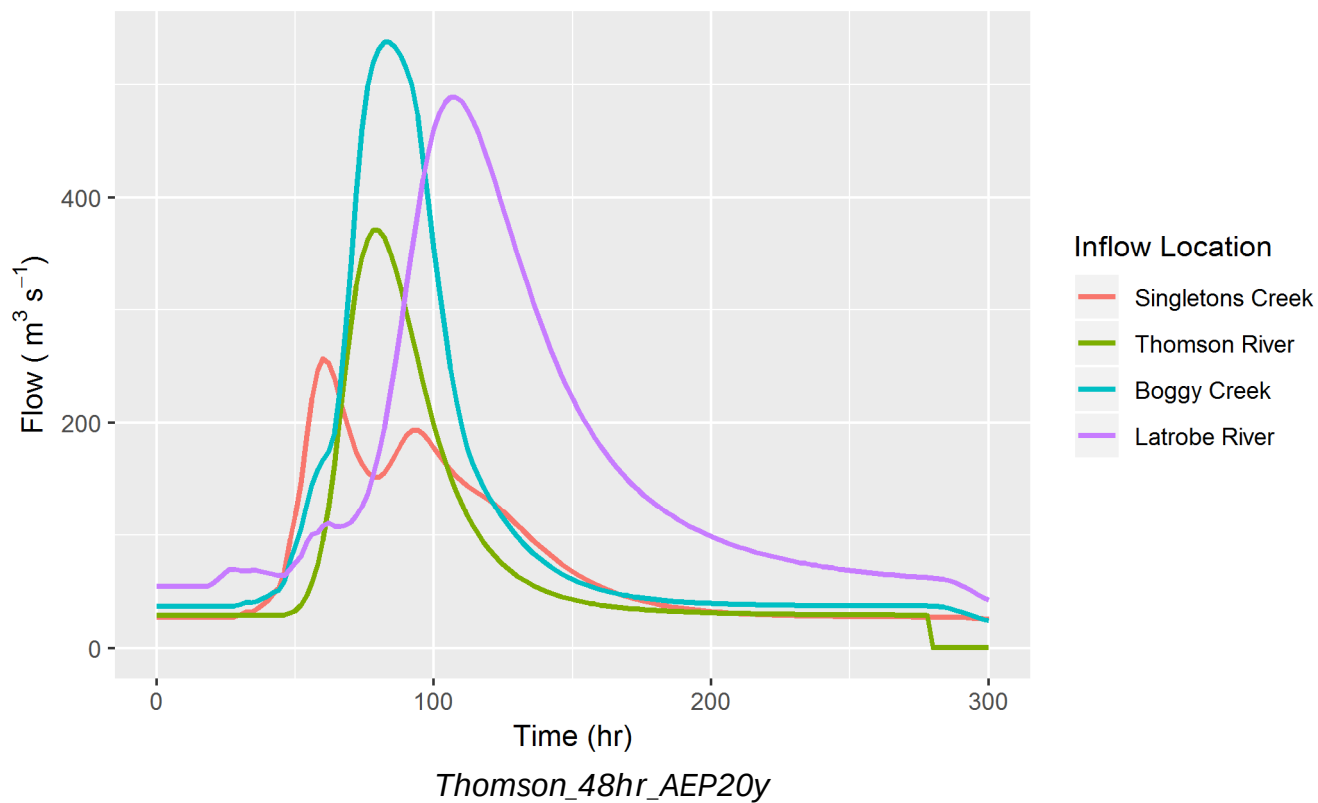


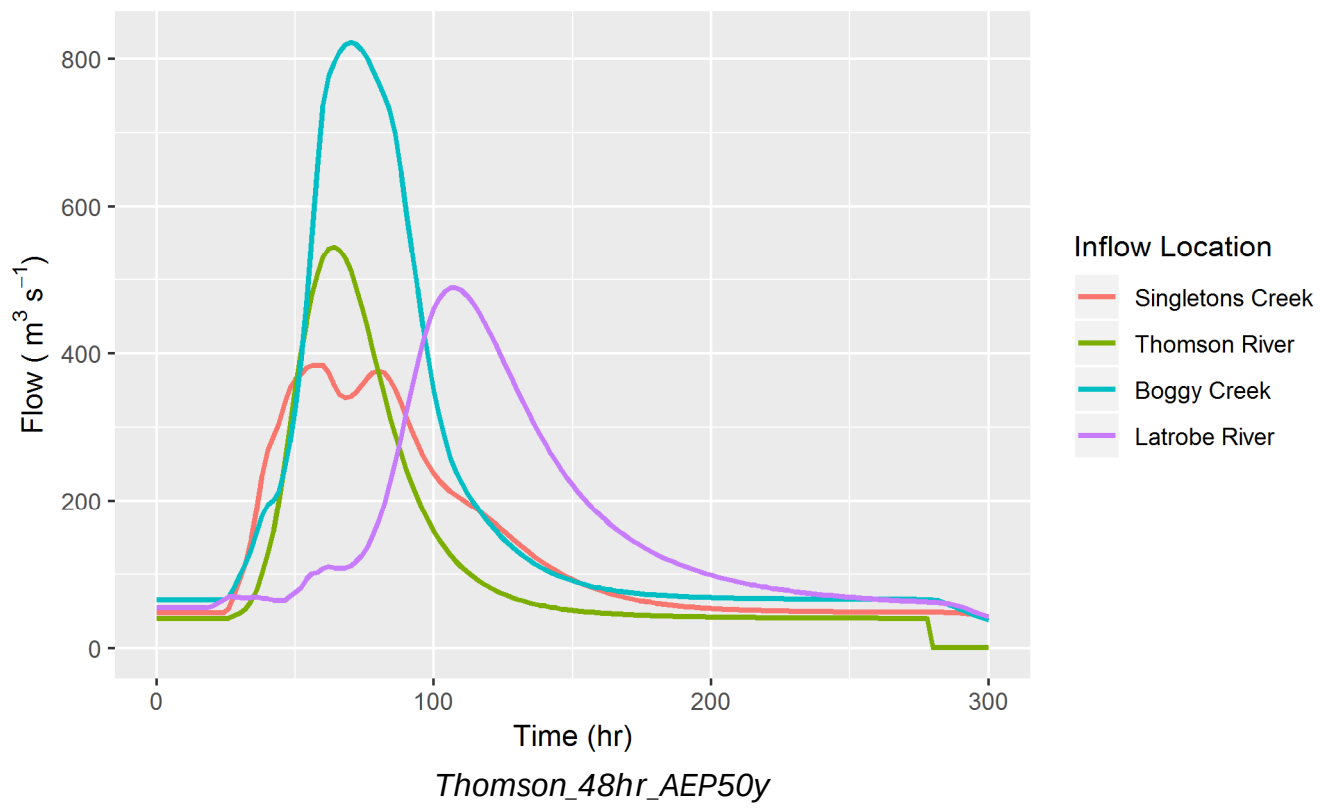


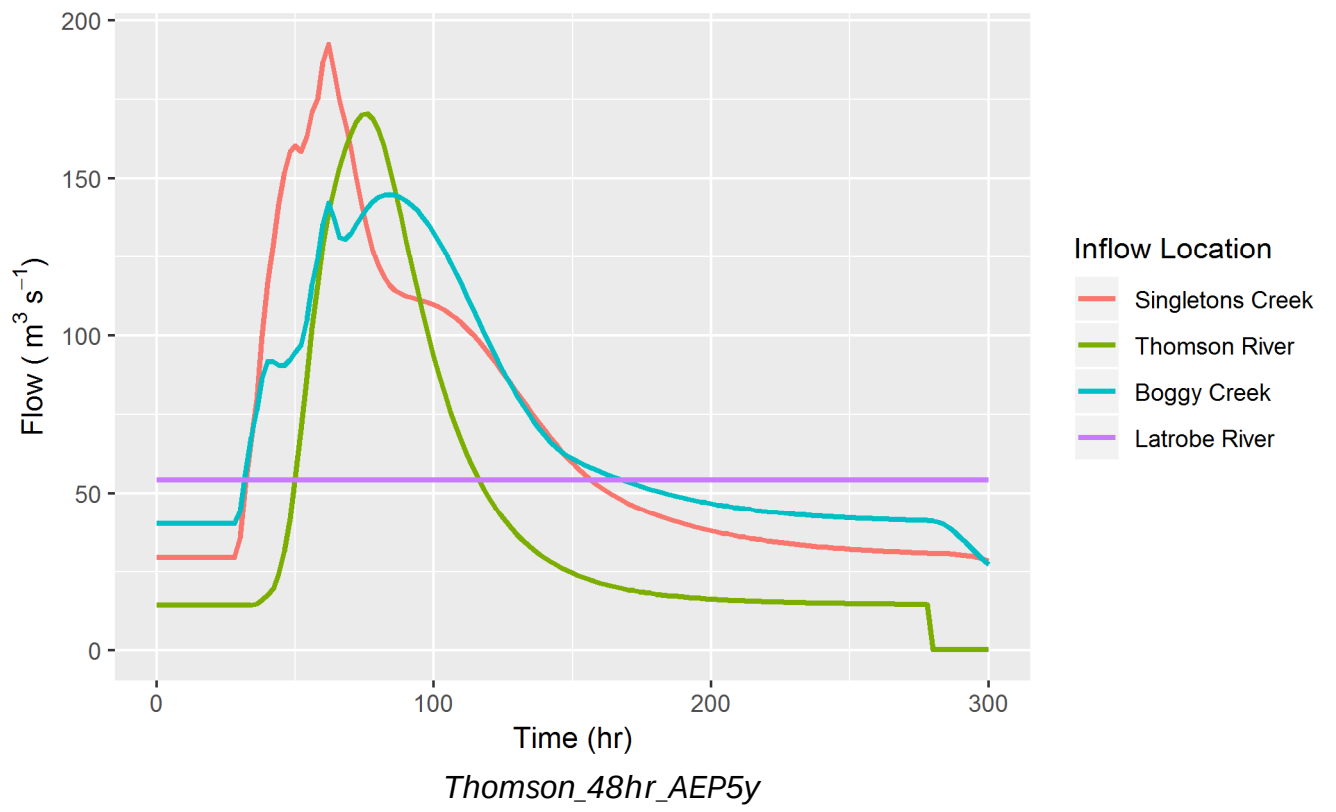


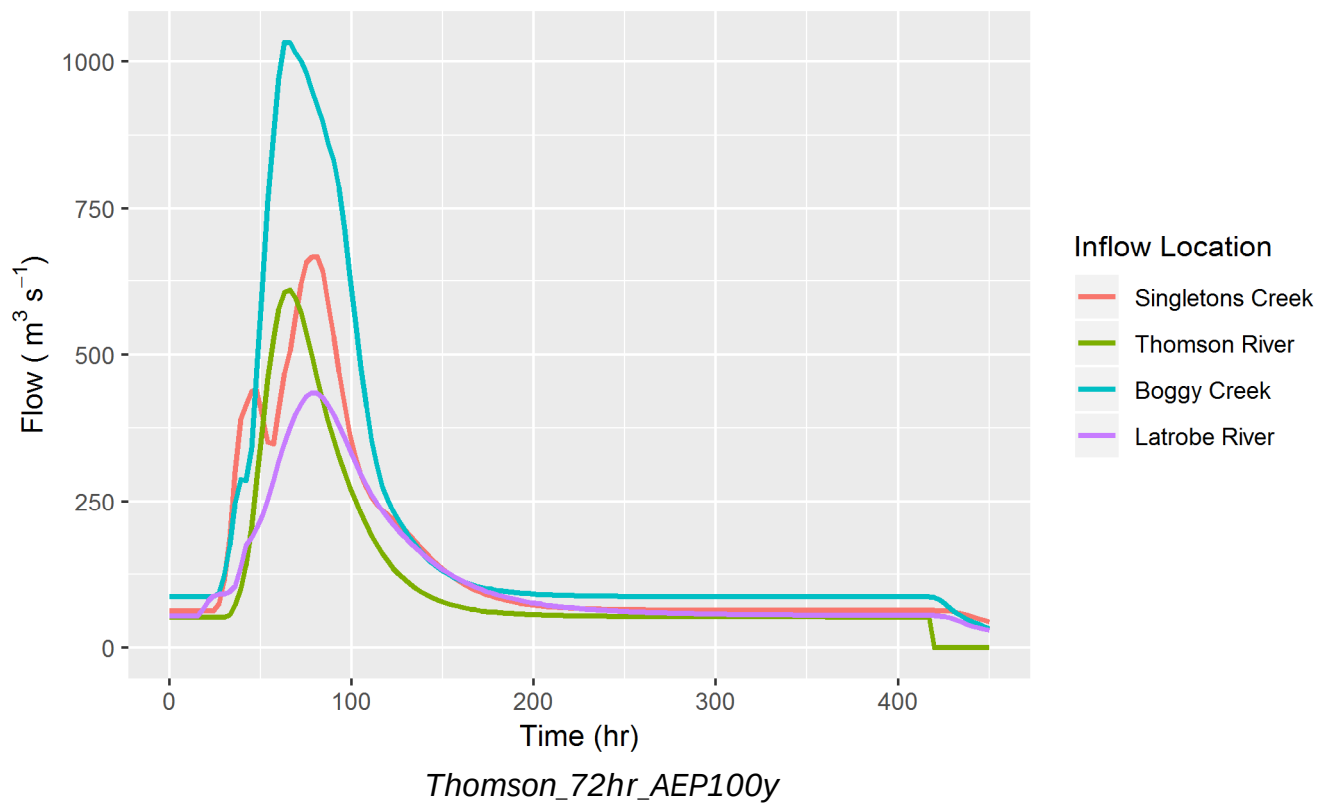


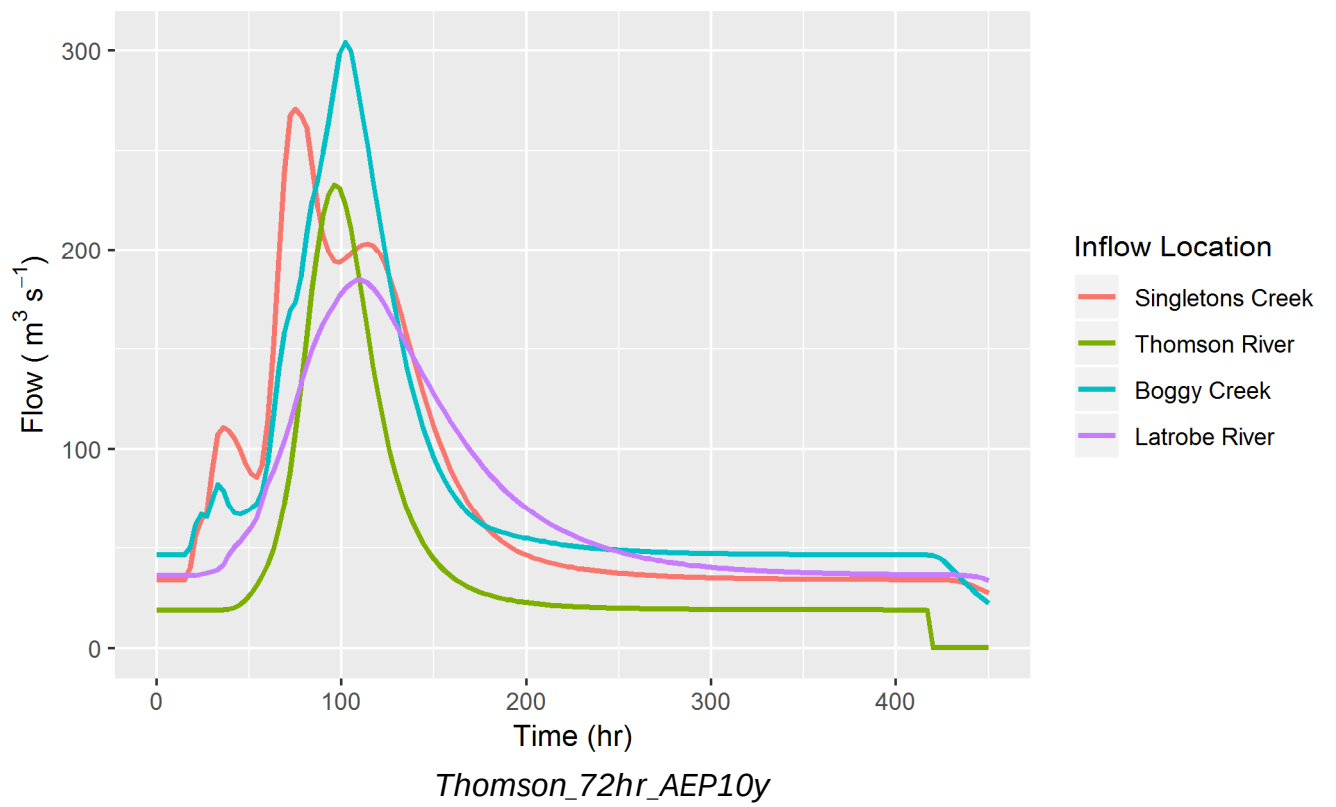


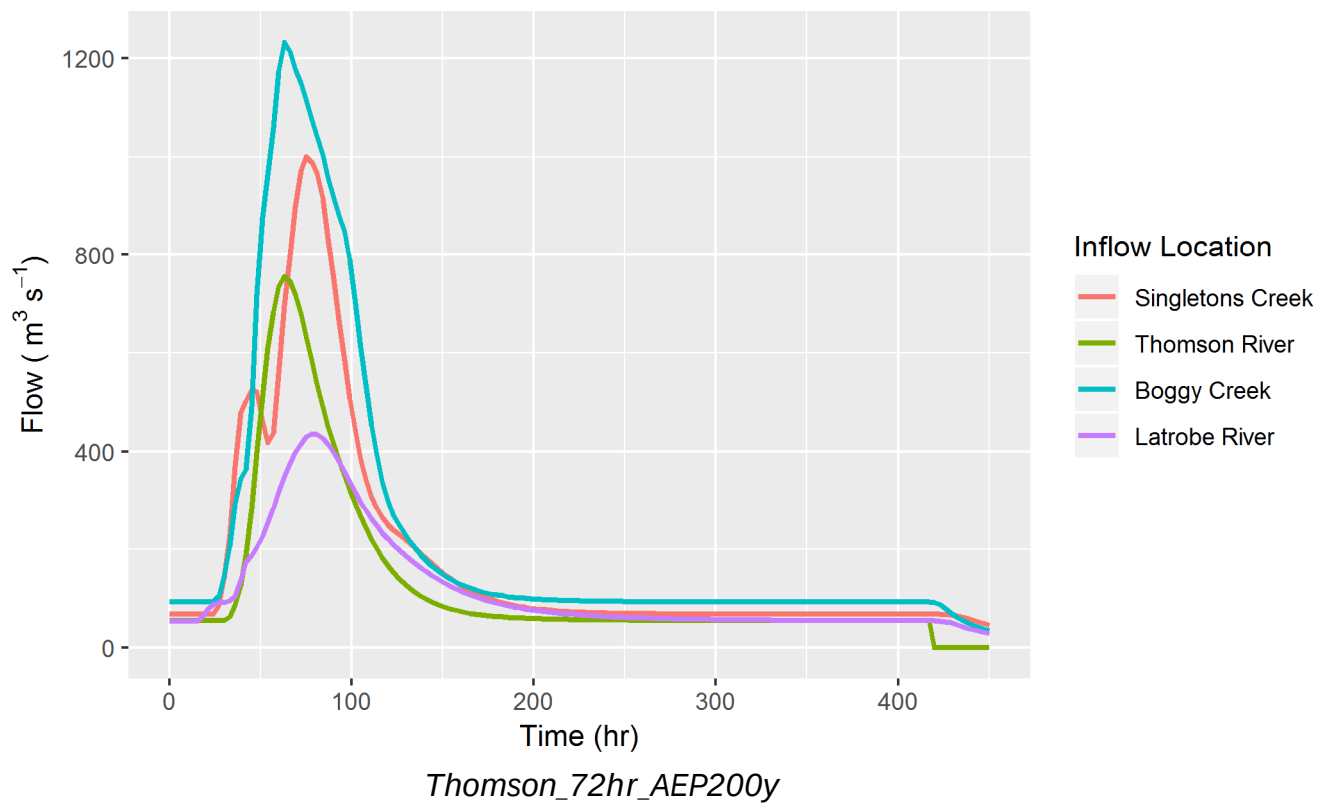


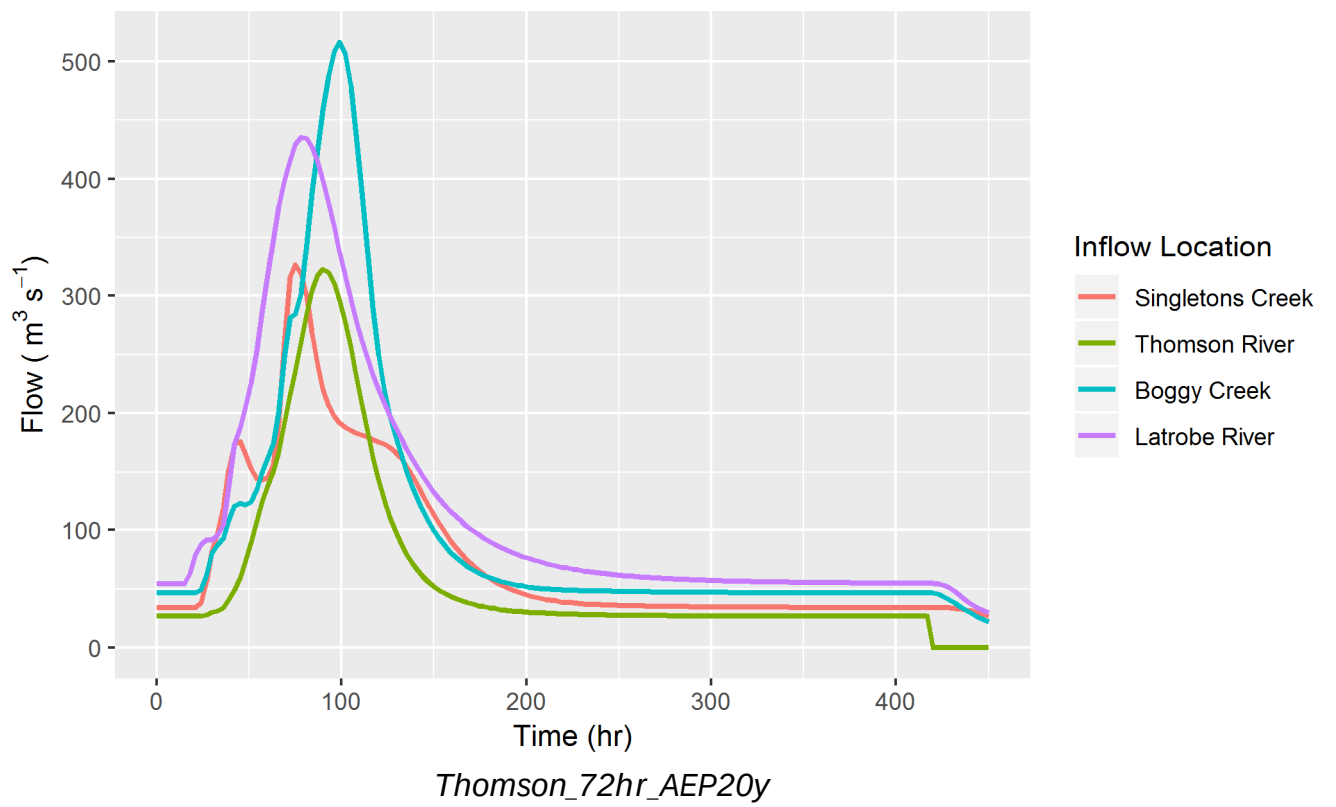


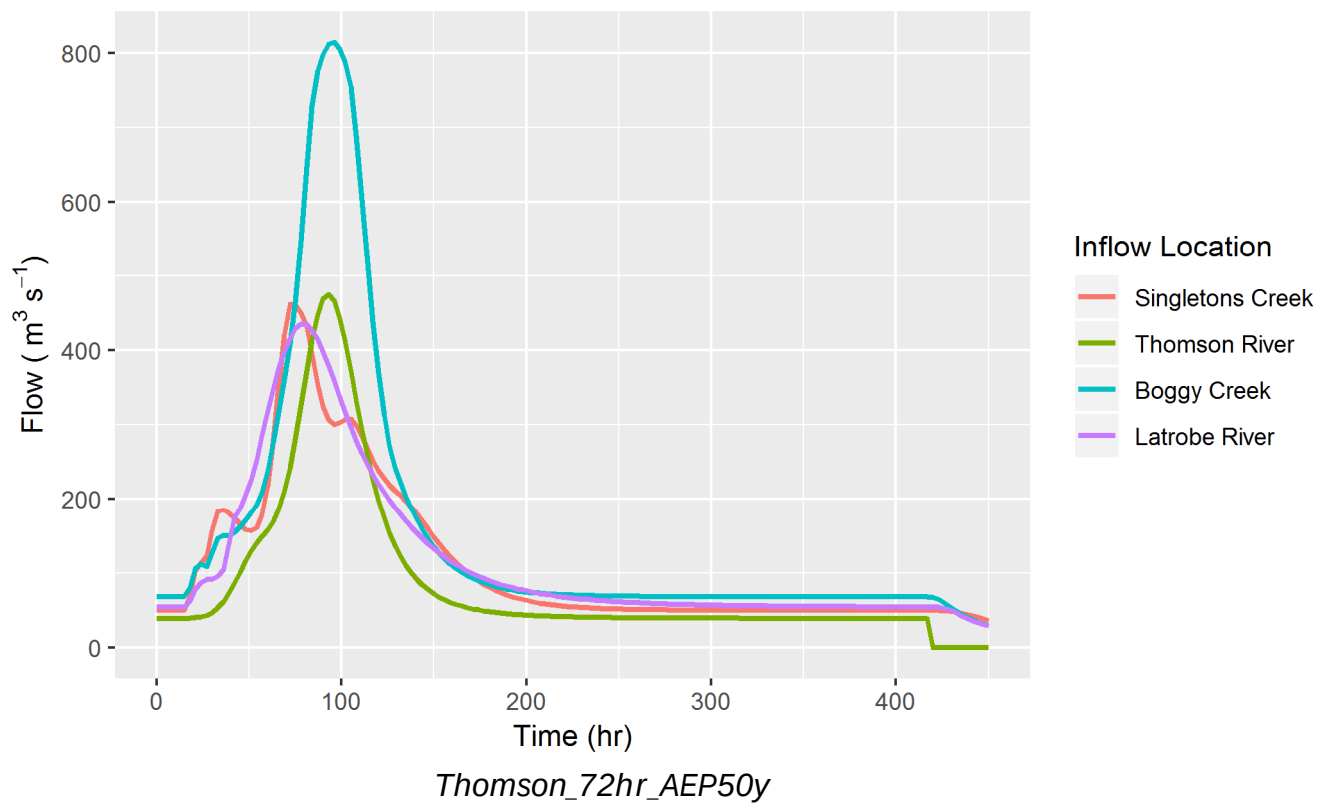


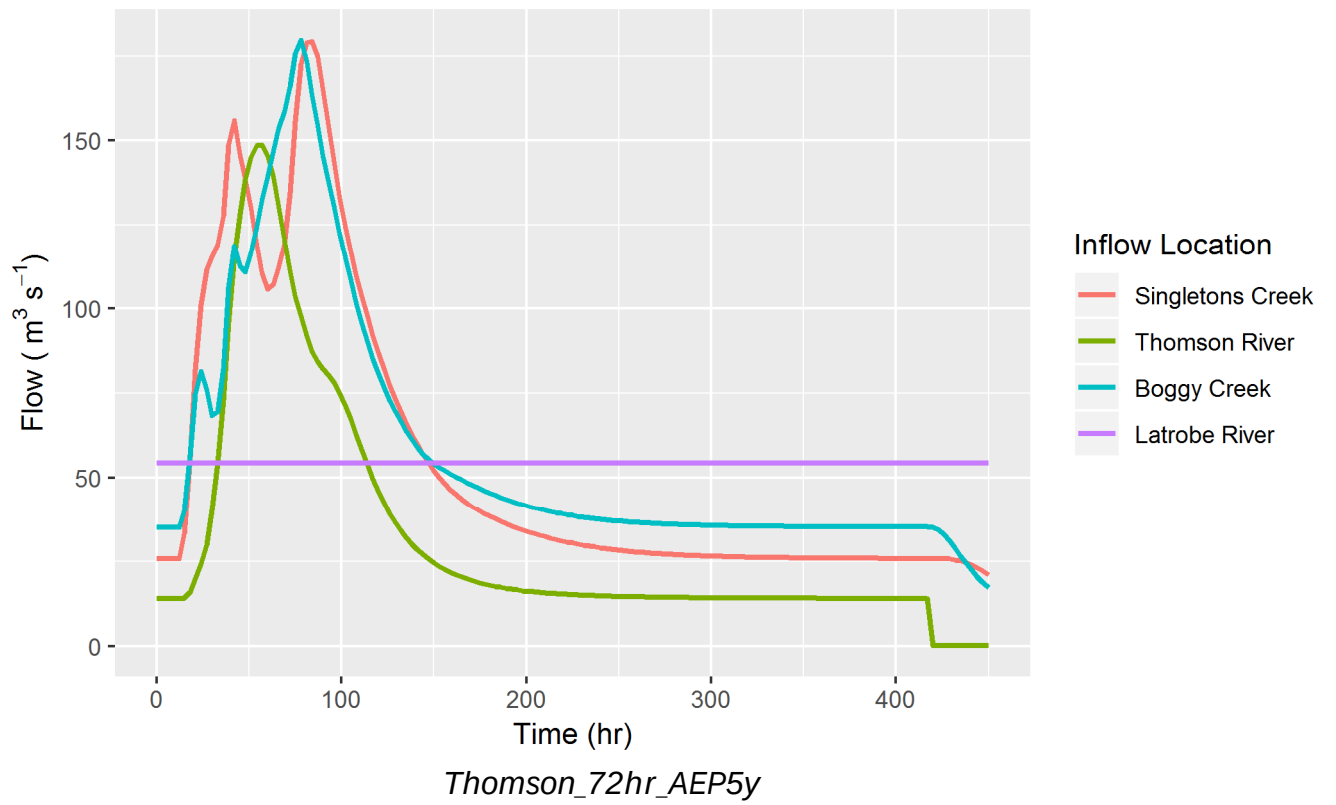






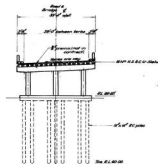
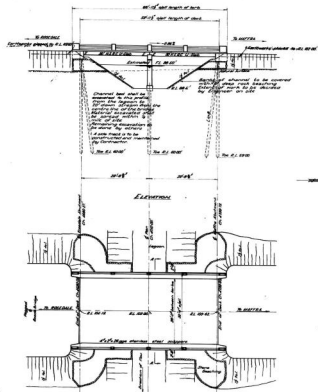






Appendix F VicRoads Bridge Drawings

F.1 Maffra to Rosedale Road (Thomson @ Wandocka)



- ## ABSTRACT

1. The following standard reference sheets shall be used in conjunction with these changes:
 400 Descriptive Concrete Notes
 402 Siting of Structures
2. All changes on the old are to be of finished surface.
3. The contractor is to provide a plan frame with a 1/4" (6.35mm) joint for the center of the bridge deck, movable bearing as directed by the Engineer.
4. Earthwork of the approaches to this bridge has been placed at the discretion of the Engineer. The contractor is to be responsible for the sub base has been constructed by the

HALF-SCALE PRINT
The walls of the drawings on this sheet are printed at half-scale. Please order with drawing.

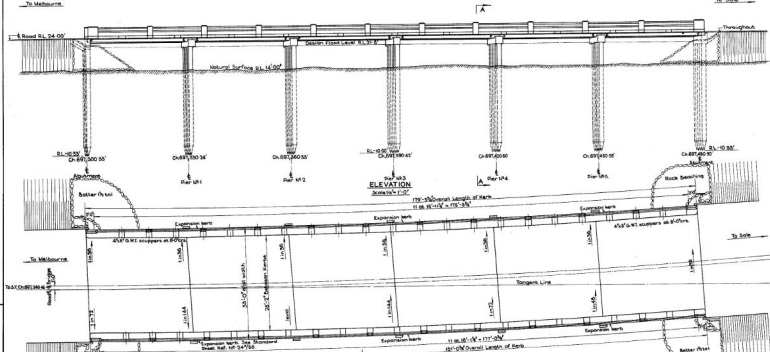
[illegible]

F.2 Princes Highway near Sale

To Melbourne

NOTE:
Abutment piles shall be driven
through consolidated fill as given
in the specification

To Sale



Note:
Crossfalls shown on plan are for
first ground surface.
Pile caps shall be 4' x 4' and
shall be 4' x 4' at the abutments
to 2' x 2' at the piles.



SECTION A-A

Scale 1/2" = 1'-0"



SETTING OUT DIAGRAM

Not to Scale

TABLE OF SETTING OUT

Station	Back Sight	Sight	Back Sight	Sight	Definition
Sta. 10	60' 17"	60' 17"	0' 00"	60' 17"	BP 18
Sta. 11	0' 00"	60' 17"	0' 00"	60' 17"	BP 18
Sta. 12	115' 17"	115' 17"	0' 00"	115' 17"	BP 17
Sta. 13	115' 17"	115' 17"	0' 00"	115' 17"	BP 16
Sta. 14	115' 17"	115' 17"	0' 00"	115' 17"	BP 15
Sta. 15	115' 17"	115' 17"	0' 00"	115' 17"	BP 14
Sta. 16	115' 17"	115' 17"	0' 00"	115' 17"	BP 13
Sta. 17	115' 17"	115' 17"	0' 00"	115' 17"	BP 12
Sta. 18	115' 17"	115' 17"	0' 00"	115' 17"	BP 11
Sta. 19	115' 17"	115' 17"	0' 00"	115' 17"	BP 10
Sta. 20	115' 17"	115' 17"	0' 00"	115' 17"	BP 9

Location	Size	Length	SP	Bar off	Design Load
Melbourne Road	14" x 14"	33' 0"	5	9' 5 1/2"	25T
Bar 101	14" x 14"	33' 0"	6	9' 5 1/2"	25T
Bar 102	14" x 14"	33' 0"	5	9' 5 1/2"	25T
Bar 103	14" x 14"	33' 0"	6	9' 5 1/2"	25T
Bar 104	14" x 14"	33' 0"	6	9' 5 1/2"	25T
Bar 105	14" x 14"	33' 0"	6	9' 5 1/2"	25T
Bar 106	14" x 14"	33' 0"	6	9' 5 1/2"	25T



LOCALITY PLAN

Scale 1" = 40 Chains

REFERENCE PEGS

Chainage	Location	RL
621' 300'	50' Lign.	14' 40"
621' 340'	E. Peg	14' 40"
621' 340'	40' Lign.	14' 55"
621' 350'	40' Lign.	14' 42"
621' 440'	40' Lign.	14' 23"
621' 480'	40' Lign.	14' 10"
621' 540'	E. Peg	15' 15"

COUNTRY ROADS BOARD
ROAD PRINCIPLES HIGHWAY EAST SEC 2
SHEP CITY OF SALE
BRIDGE 6 N° 30' PRESTRESSED SLAB SPANS
LOCATION THOMSON RIVER FLOOD OPENING AT 103'

DESIGN	CONSTRUCTION	GENERAL ARRANGEMENT
DESIGNED	RECOMMENDED	E.E. L.S. CONTRACT NO.
DRAWN	NO. 3 P.P.	5142-HH-396
TRACED	CHECKED	DATE
CHECKED	DATE	PROJECT NO.
REMARKS	APPROVED	1 3 8045

Drawing N° 02, 44

De Meijerine Springer

79 of 96

Diagram of a continuous beam with 6 supports and 5 equal spans of 10' each. The total length is 50'.

PLAN

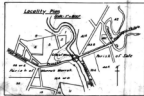
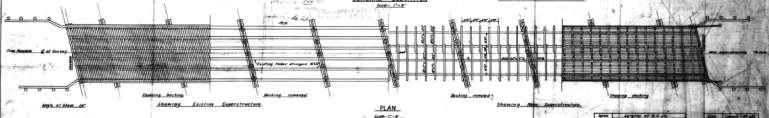
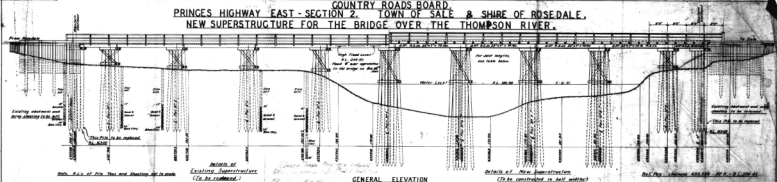


LOCALITY PLAN

ROAD PRINCES HIGHWAY EAST SEC 2.
BRIDGE 47'-0" - 61' - 63' - 63' - 47'-0" EIT. & R.C.
OVER THOMPSON RIVER. 132.0

REVIEWER'S SIGNATURE CONSTRUCTION	1	25 Nov 2012	DESIGNED	DESIGN	RECOMMENDED	NO SET	CONTRACT NO.
			DRAWN				
			MADE		12.10.12		52 ND 333
			CHECKED	POWER	CHD ENGINEER		
				PL			
			SUBMITED		APPROVED	DATE	PROJECT NO.
						12/10	6766
	DATE	DESCRIPTION	DATE	DESIGNED BY	CHIEF ENGINEER	DATE	48500
		2566 Roadrail Spacing 1		12/10	CHAIRMAN	12/10	

**COUNTRY ROADS BOARD,
PRINCES HIGHWAY EAST - SECTION 2, TOWN OF SALE & SHIRE OF ROSEDALE,
NEW SUPERSTRUCTURE FOR THE BRIDGE OVER THE THOMPSON RIVER.**



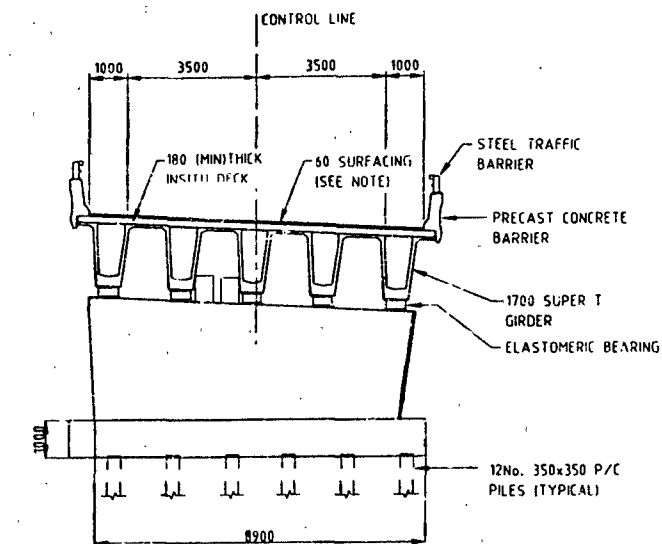
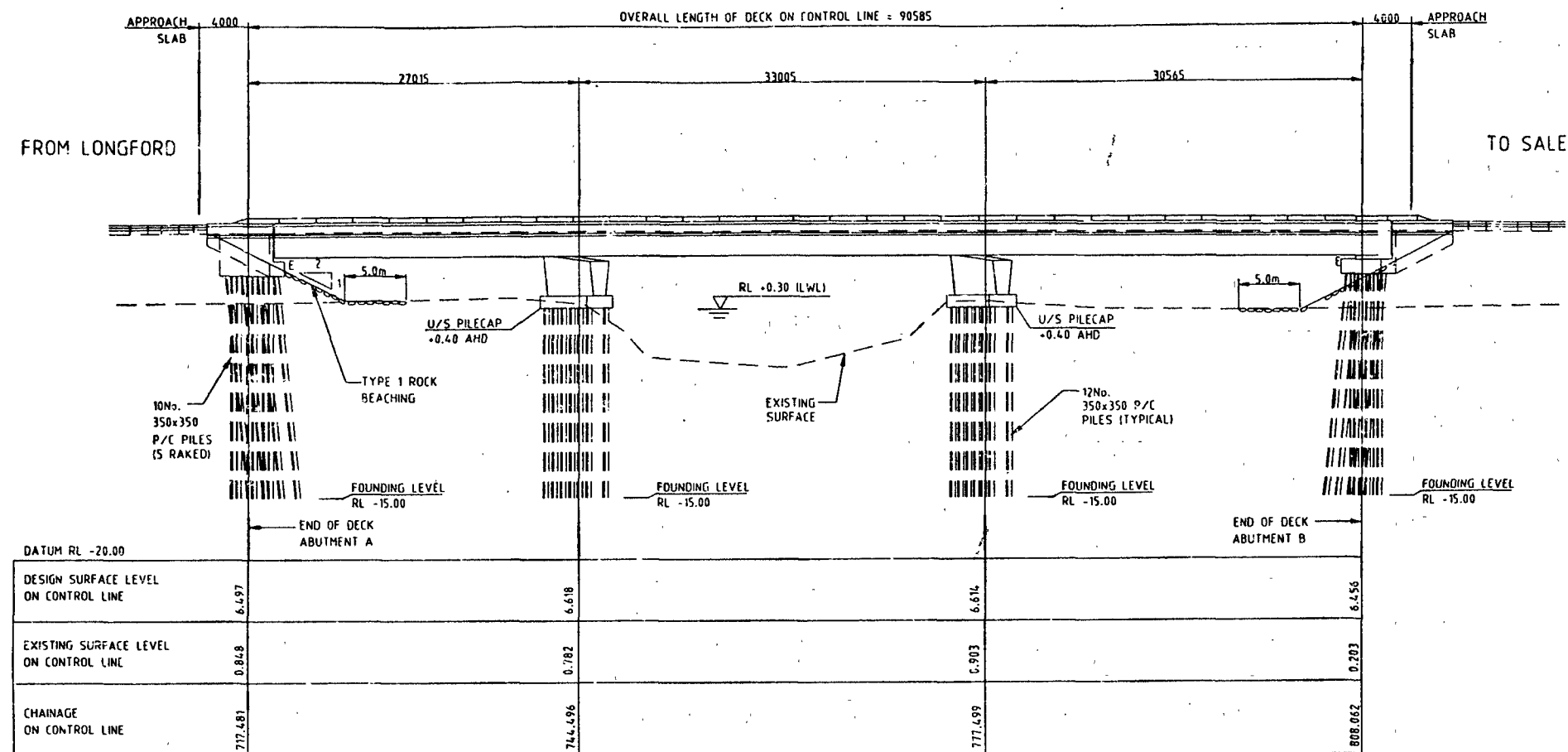
Span No.	Lengths of S.P. in			
1	100'	100'	100'	100'
2	100'	100'	100'	100'
3	100'	100'	100'	100'
4	100'	100'	100'	100'
5	100'	100'	100'	100'
6	100'	100'	100'	100'
7	100'	100'	100'	100'
8	100'	100'	100'	100'
9	100'	100'	100'	100'
10	100'	100'	100'	100'

Span No.	Length of S.P. in
1	100'
2	100'
3	100'
4	100'
5	100'
6	100'
7	100'
8	100'
9	100'
10	100'

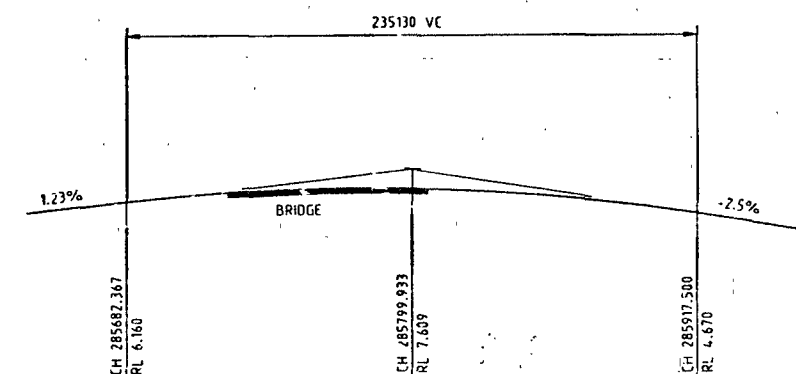
Summary of S.P. in required

Designed by: Checked by:
 Drawn by: Approved by:
 Date: Scale:

F.3 South Gippsland Highway south of Sale



SECTION 01



VERTICAL ALIGNMENT

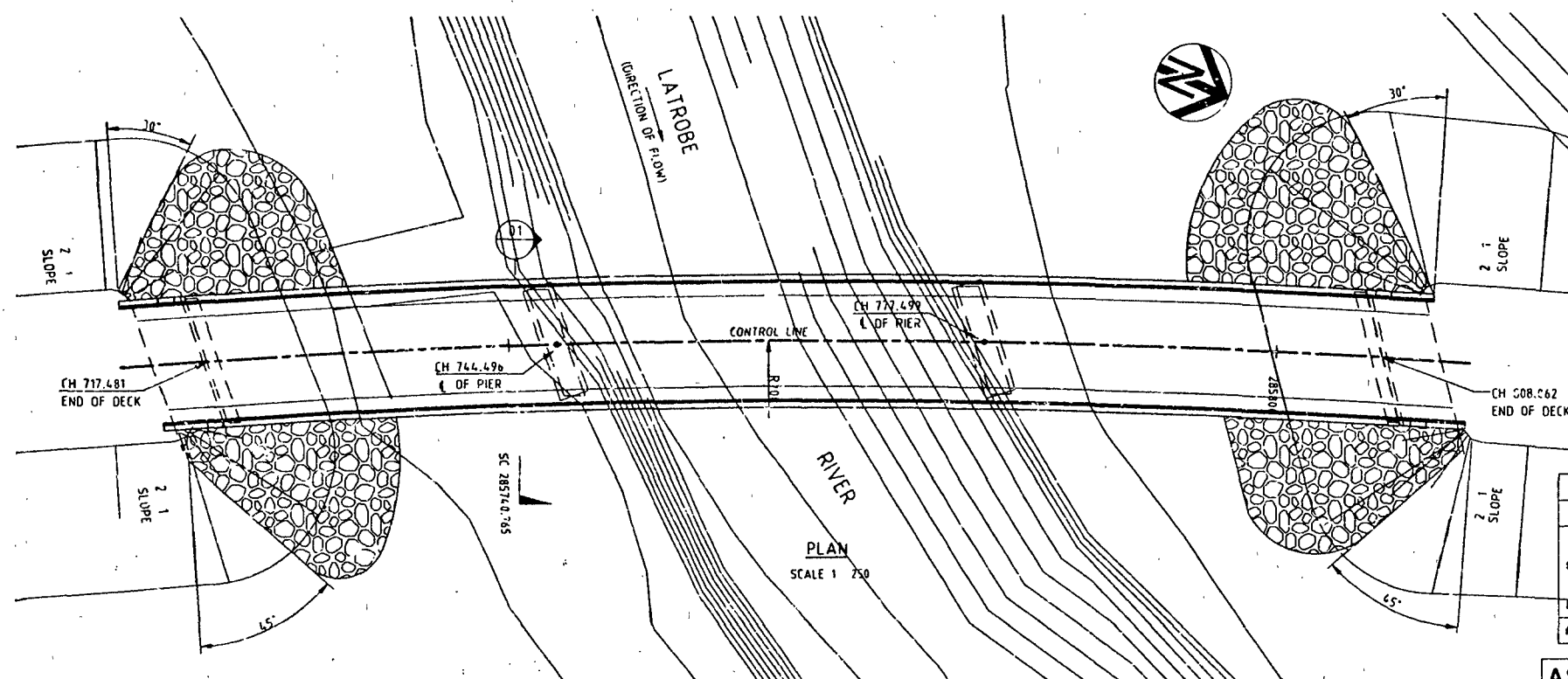
NOTES

1. CONCRETE EXPOSURE CLASSIFICATION B1
2. CHAINAGES AND REDUCED LEVELS ARE IN METRES.
3. REDUCED LEVELS ARE RELATED TO AUSTRALIAN HEIGHT DATUM
4. ALL LEVELS SHOWN AND LEVELS MARKED T.B.A. ARE INDICATIVE ONLY . ACTUAL LEVELS ARE YET TO BE DETERMINED.
5. DESIGN LOADING -
 - AUSTRALIAN BRIDGE DESIGN CODE AND VICROADS TECHNOTE 99/001
 - SM1600
6. PILE ULTIMATE LOAD AT PIERS 1600KN (DRIVEN TO REFUSAL)
PILE ULTIMATE LOAD AT ABUTMENTS 120CKN (DRIVEN TO REFUSAL)
7. CONCRETE GRADES -
 - GIRDGERS VR450/50
 - ALL OTHER CONCRETE VR330/32

BITUMINOUS SURFACING

SPRAYED STRAIN ALLEVIATING MEMBRANE WITH
20mm DEEP REGULATION LAYER AND 40mm (NOM) ASPHALTIC CONCRETE WEARING COURSE
TOTAL THICKNESS 60mm.

PILE AXIAL CAPACITY			
PILE LOCATION	DESIGN ULTIMATE LOAD / PILE N° (kN)	PILE TEST LOAD N (kN)	
		PDA TESTING:	
		INDIVIDUAL OR REPRESENTATIVE PILE	REPRESENTATIVE PILE
ABUTMENTS	1200	1670	1900
PIERS	1600	2225	2550



SMEC AUSTRALIA PTY LTD	
AS CONSTRUCTED	
SIGNED _____	DATE _____
NAME _____	CPeng _____
MICROFILM No _____	

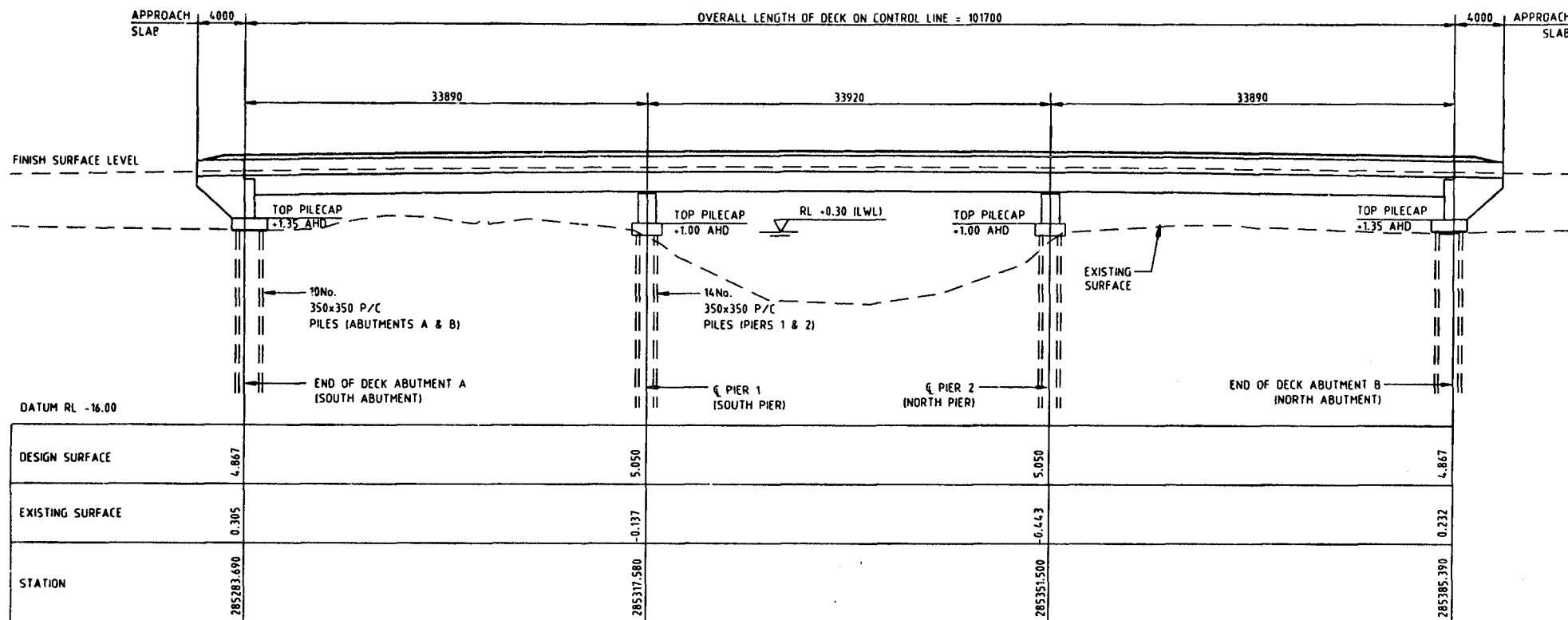
AS CONSTRUCTED DRAWING

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								DRAFTING CHECK			
								DESIGNER			
								DESIGN CHECK			
								PROJECT MANAGER			

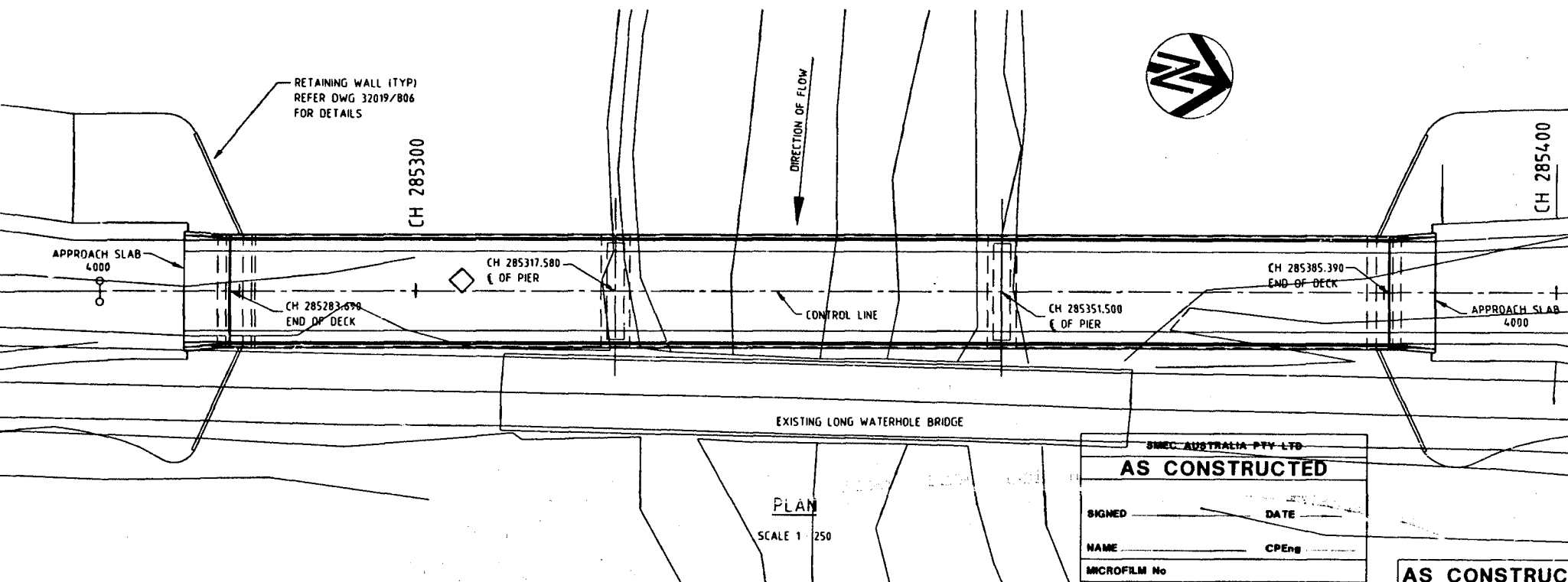


PROJECT TITLE SOUTH GIPPSLAND HIGHWAY
SWING BRIDGE PROJECT CONTRACT No 4881
LATROBE RIVER BRIDGE
GENERAL ARRANGEMENT

SCALE	DRAWING STATUS	PROJECT / DRAWING No	ISSU
AS SHOWN	AS CONSTRUCTED	32019 / 201	1



ELEVATION
SCALE 1 : 250



SMEC AUSTRALIA PTY LTD

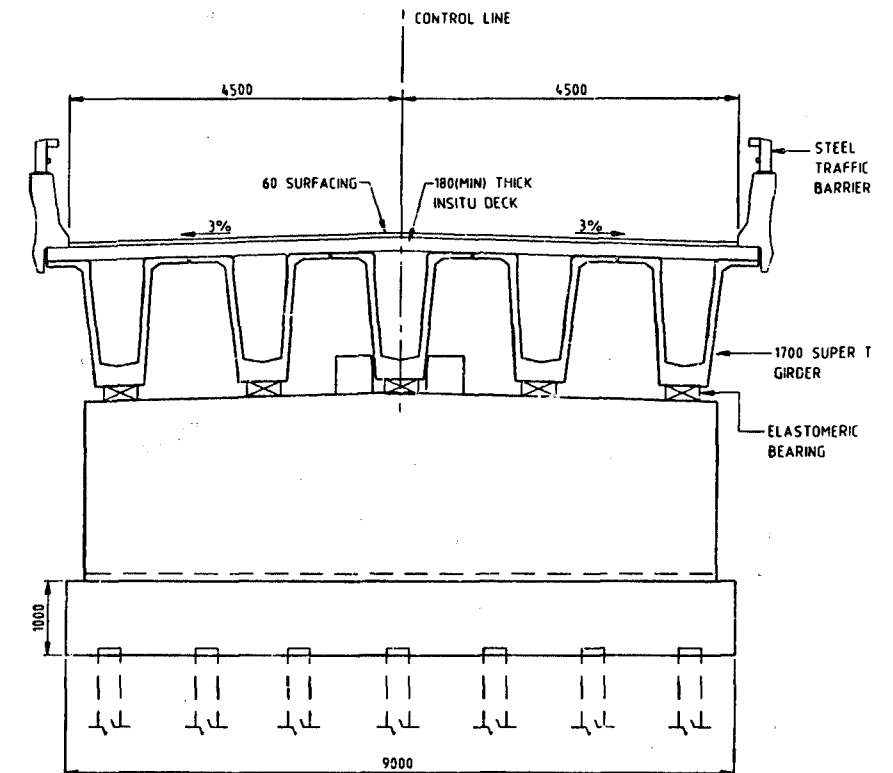
AS CONSTRUCTED

SIGNED _____ DATE _____

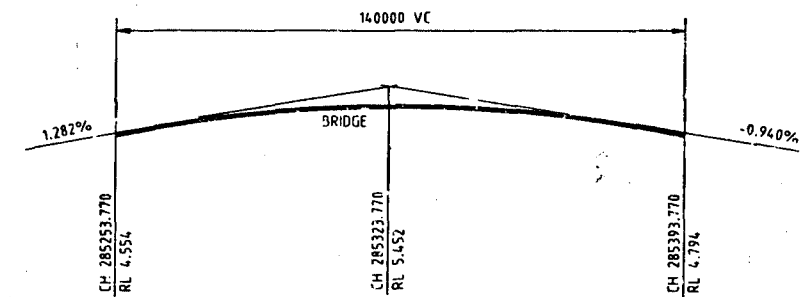
NAME _____ CPEng

MICROFILM No _____

AS CONSTRUCTED DRAWING



TYPICAL CROSS SECTION AT PIER
SCALE 1 : 50



VERTICAL ALIGNMENT
(IN T.S.)

NOTES

- CONCRETE EXPOSURE CLASSIFICATION B1
- CHAINAGES AND REDUCED LEVELS ARE IN METRES.
- REDUCED LEVELS ARE RELATED TO AUSTRALIAN HEIGHT DATUM
- DESIGN LOADING -
- AUSTRALIAN BRIDGE DESIGN CODE AND VICROADS TECHNOTE 99/001
- SM1600
- PILE ULTIMATE LOAD AT PIERS 1800 KN (DRIVEN TO REFUSAL)
PILE ULTIMATE LOAD AT ABUTMENTS 1800 KN (DRIVEN TO REFUSAL)
- CONCRETE GRADES -
- GIRDERS VR450/50
- ALL OTHER CONCRETE VR330/32

BITUMINOUS SURFACING

SPRAYED STRAIN ALLEVIATING MEMBRANE WITH
10mm COVER AGGREGATE AND 55mm ASPHALTIC CONCRETE WEARING COURSE
TOTAL THICKNESS 60mm.

PILE LOCATION	DESIGN ULTIMATE LOAD / PILE N° (kN)	PILE TEST LOAD N° (kN)	
		PDA TESTING	
		INDIVIDUAL OR REPRESENTATIVE PILE	REPRESENTATIVE PILE
ABUTMENTS	1800	2500	2850
PIERS	1800	2500	2850

Bridge Drawing No. 481676

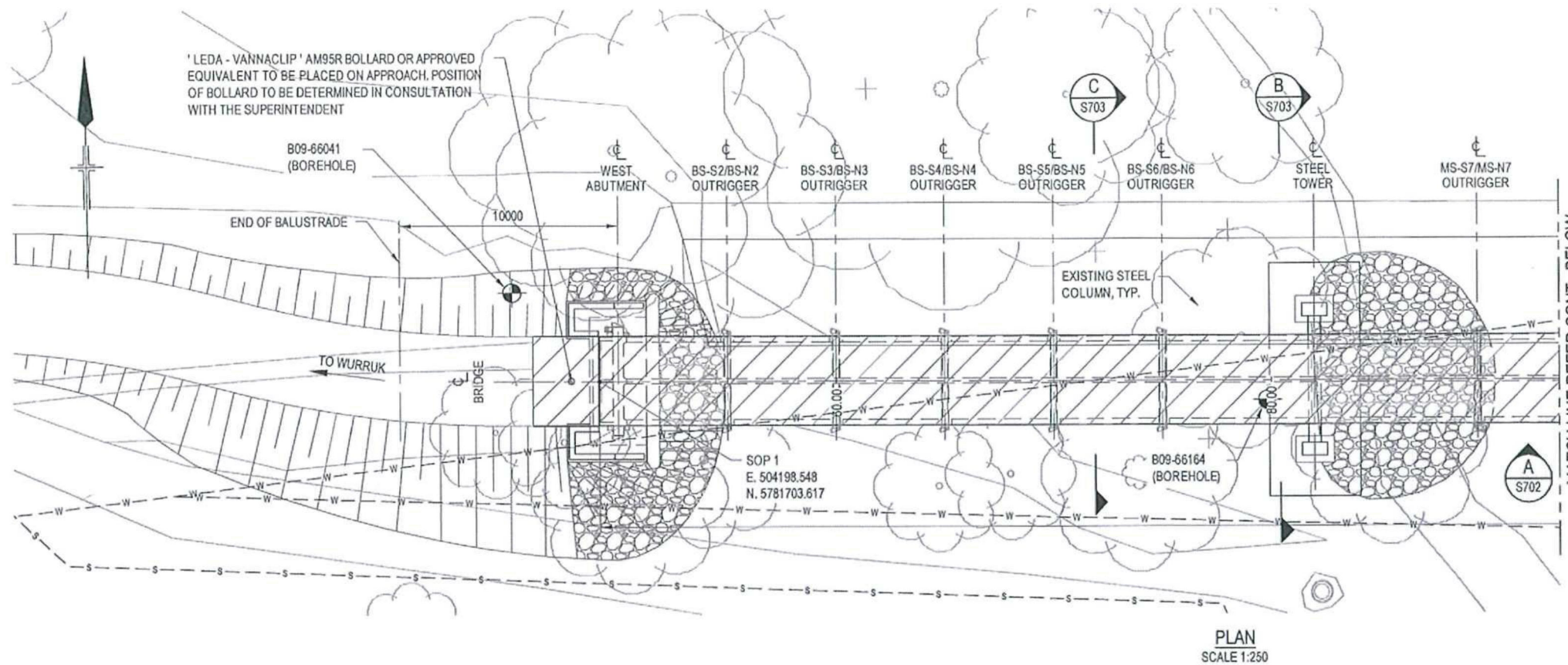
TITLE	INITIAL	SIGNATURE	DATE
DRAFTSPERSON			
DRAFTING CHECK			
DESIGNER			
DESIGN CHECK			
PROJECT MANAGER			



PROJECT TITLE
SOUTH GIPPSLAND HIGHWAY
SWING BRIDGE PROJECT CONTRACT No 4821
LONG WATERHOLE BRIDGE
GENERAL ARRANGEMENT

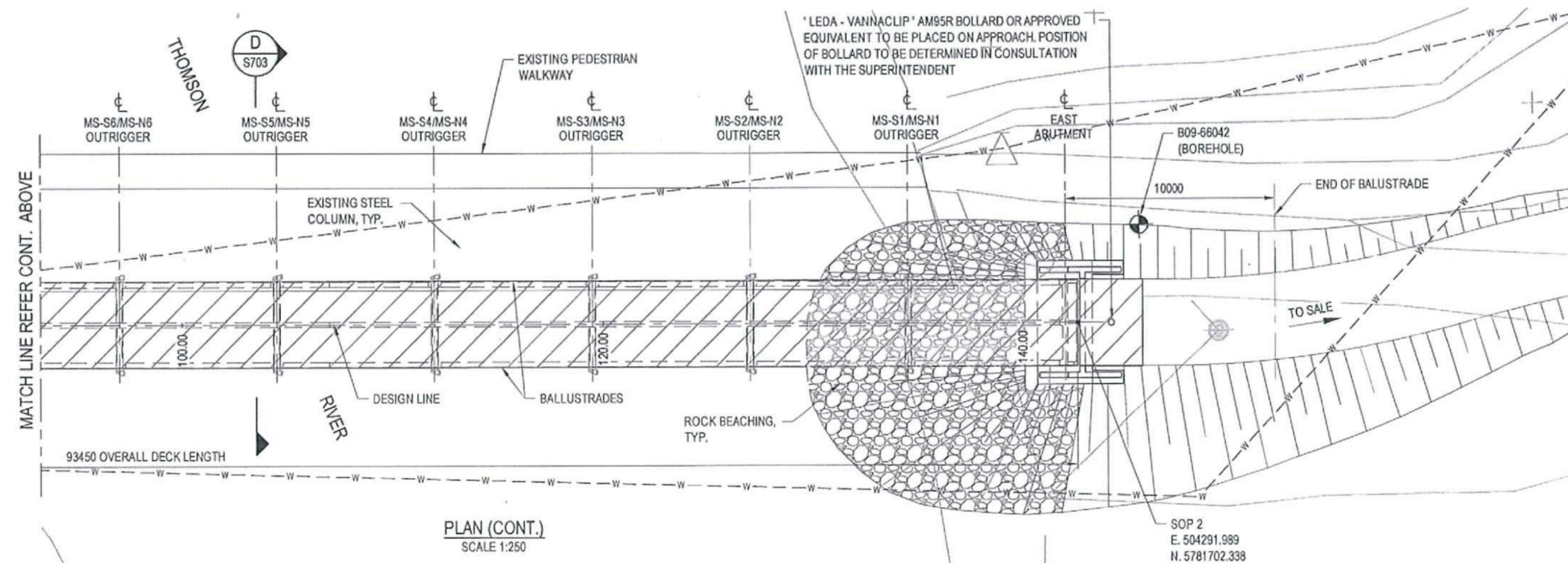
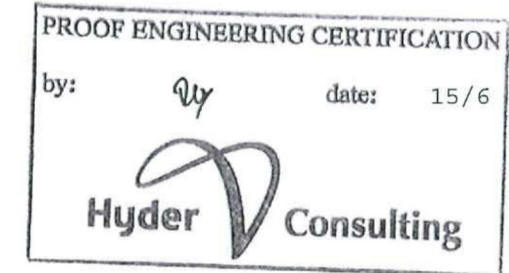
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AS SHOWN	AS CONSTRUCTED	32019 / 701	W

F.4 Footbridge – North of Princes Highway near Sale



NOTES:

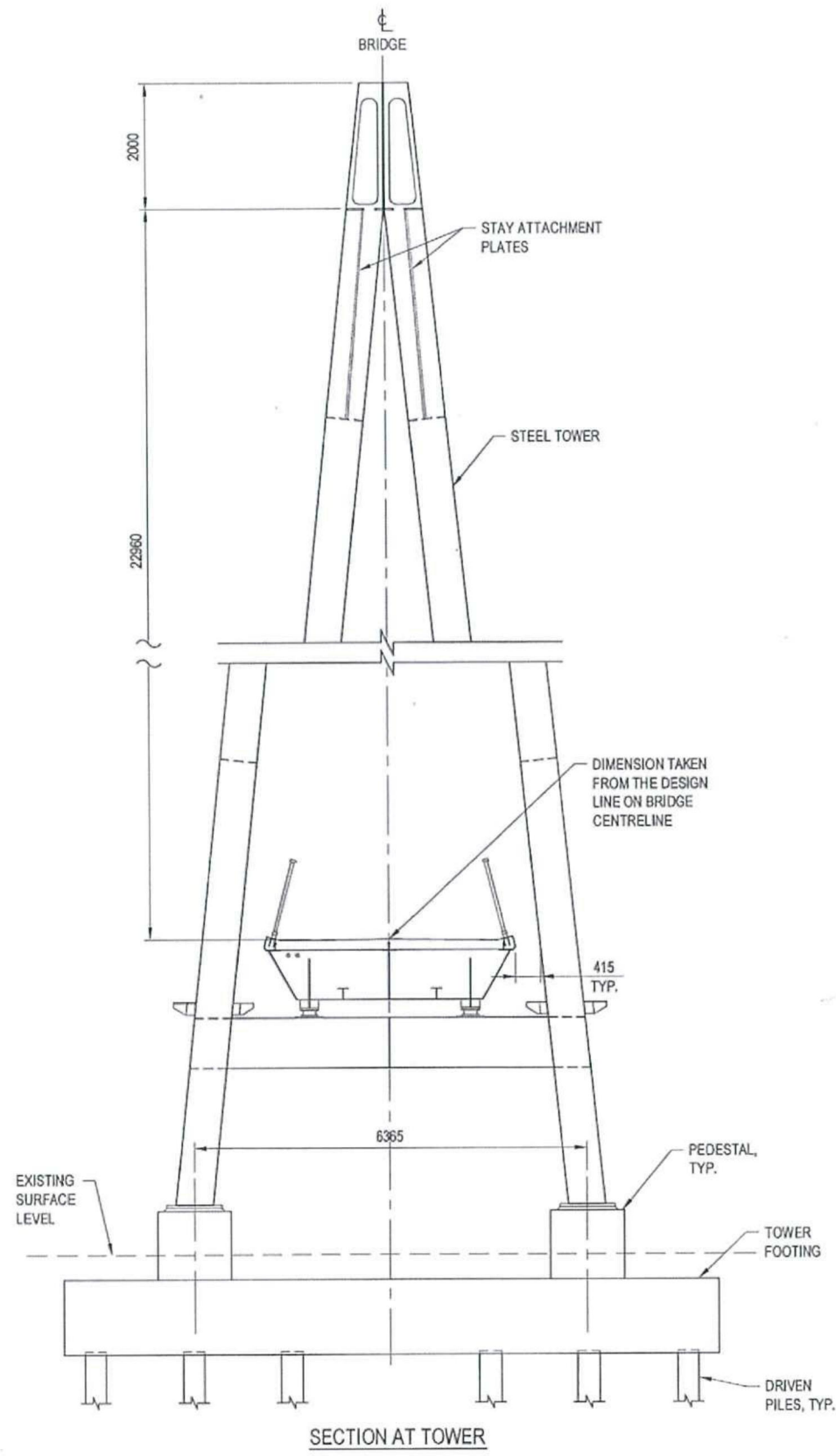
- FOR GENERAL NOTES REFER TO DRGS. S002, S003 & S004.
- FOR DESIGN LINE INFORMATION REFER TO CIVIL DRAWINGS.
- SOP 1 AND SOP 2 ARE TAKEN AT BOTH ENDS OF DECK ALONG BRIDGE CENTRELINE.



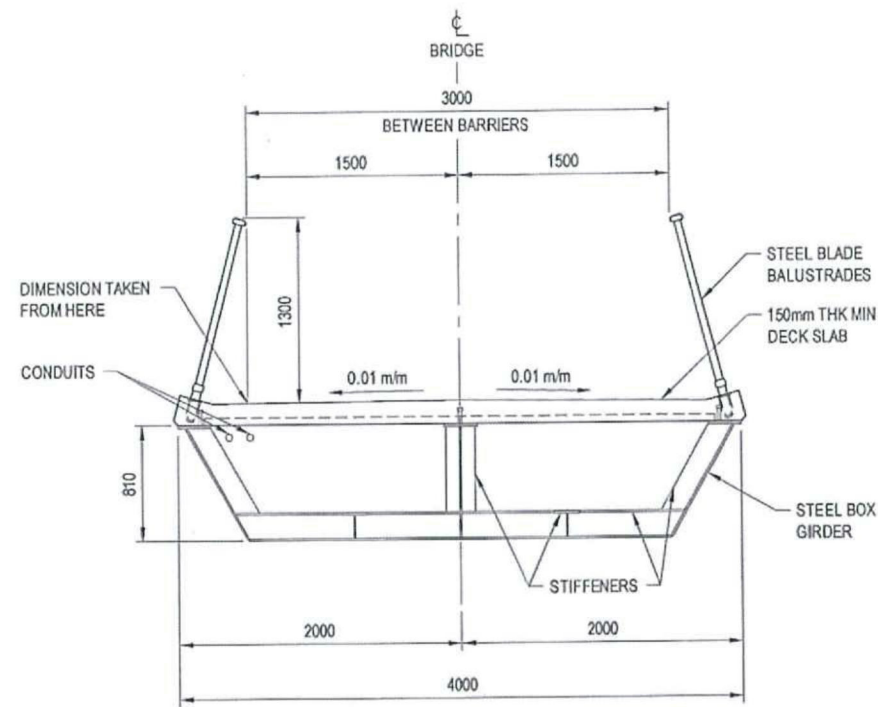
WARNING
SERVICES SHOWN ON THIS DRAWING ARE APPROXIMATE ONLY. THE EXACT LOCATION IS TO BE CONFIRMED ON SITE BY CONTRACTOR PRIOR TO COMMENCEMENT OF WORKS.

0 2500 5000 7500mm
SCALE 1:250 AT ORIGINAL SIZE

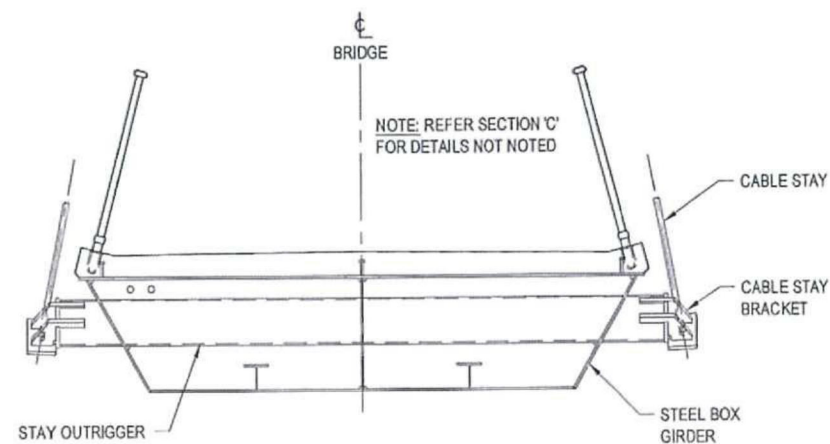
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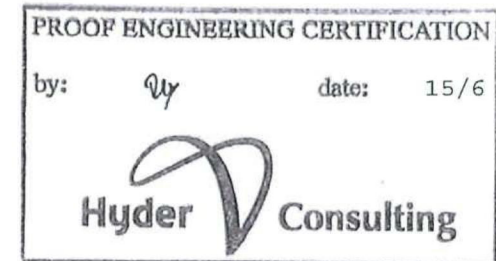
B SECTION
S701 SCALE 1: 100



C SECTION
S701 SCALE 1: 50



D SECTION
S701 SCALE 1: 50



- NOTES:**
- FOR GENERAL NOTES REFER TO DRGS S002, S003 & S004.

0 1000 2000 3000mm
SCALE 1:100 AT ORIGINAL SIZE

0 500 1000 1500mm
SCALE 1:50 AT ORIGINAL SIZE

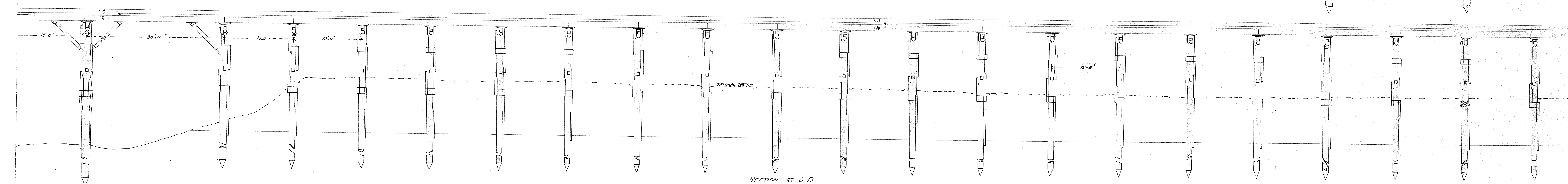
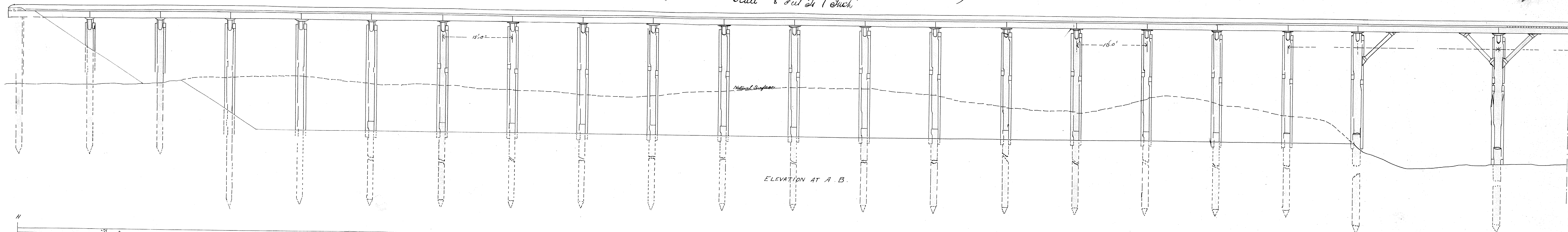
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Appendix G VLine – Thomson River

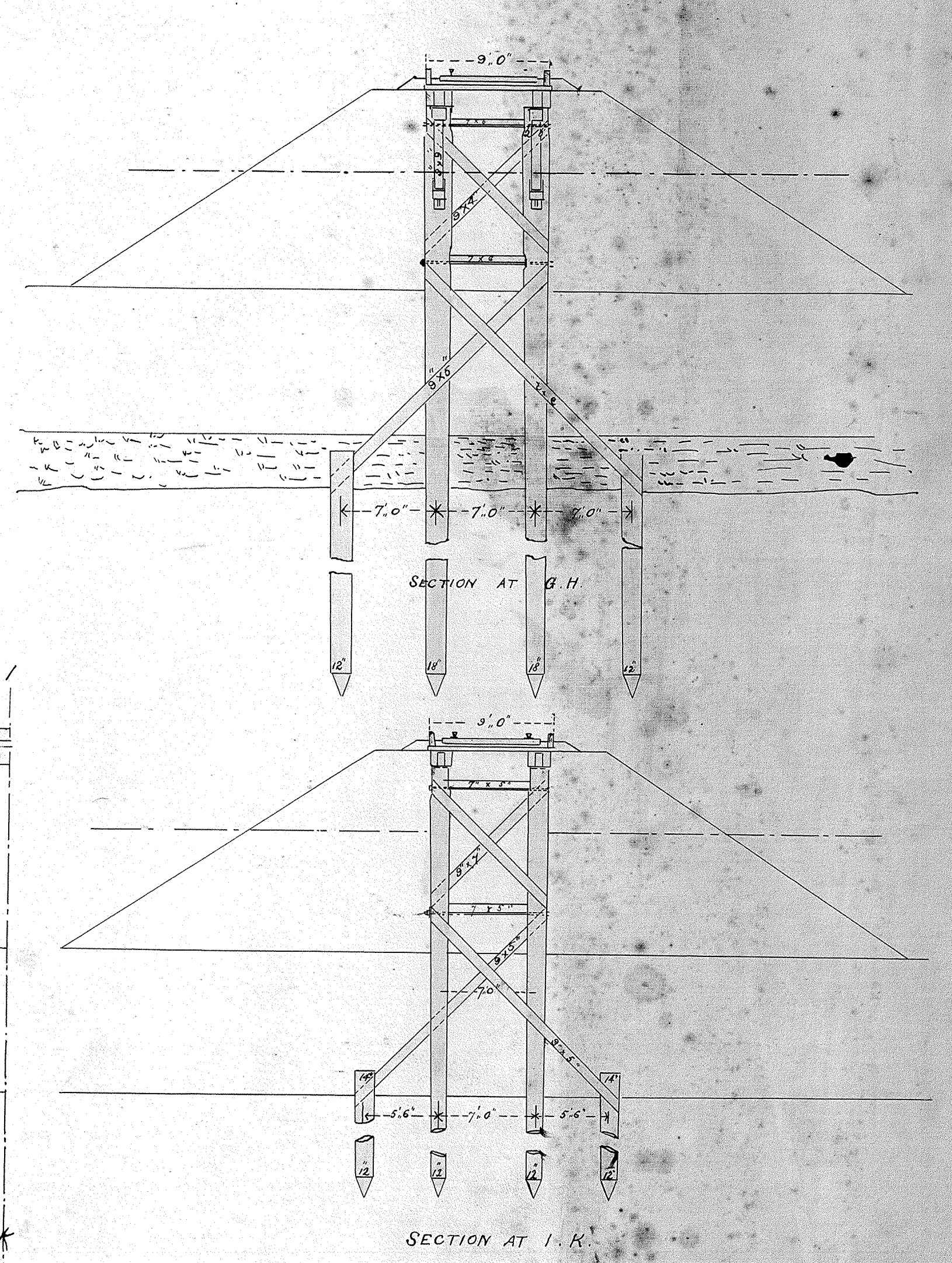
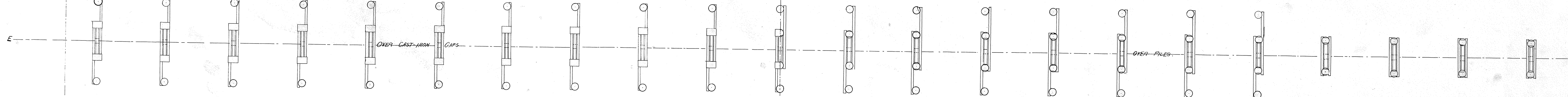
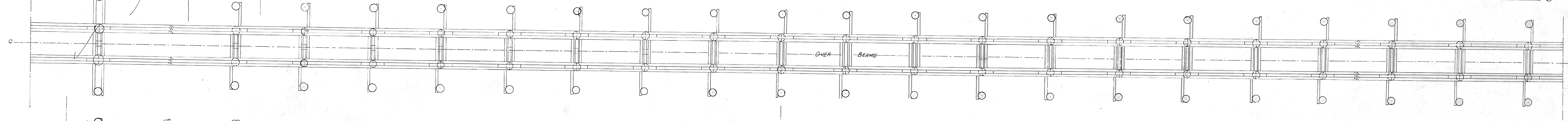
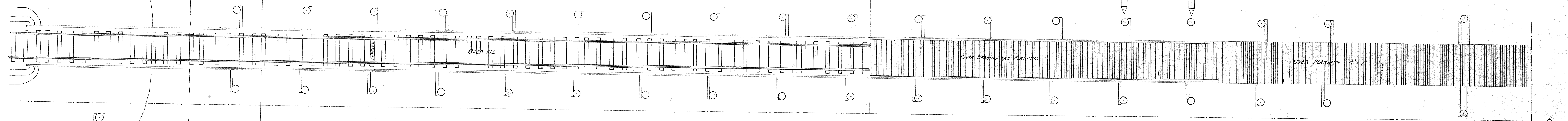
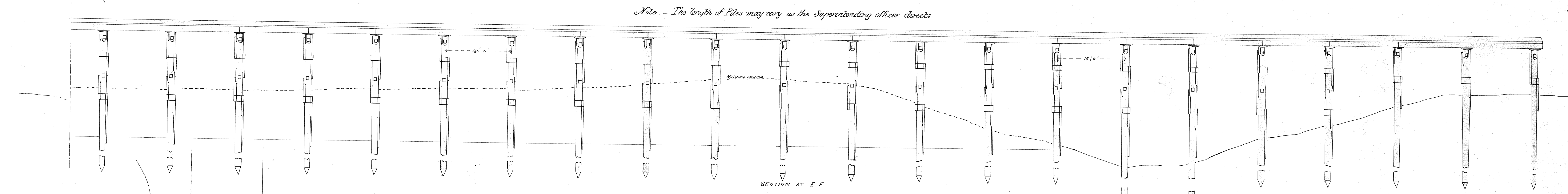
VICTORIAN RAILWAYS.

Reppelland Railway
Only 3 spans *via 3 spans* *each 30 ft* *each 30 ft* *each 15 ft*
Scale 8 ft to 1 inch

CONTRACT 637.



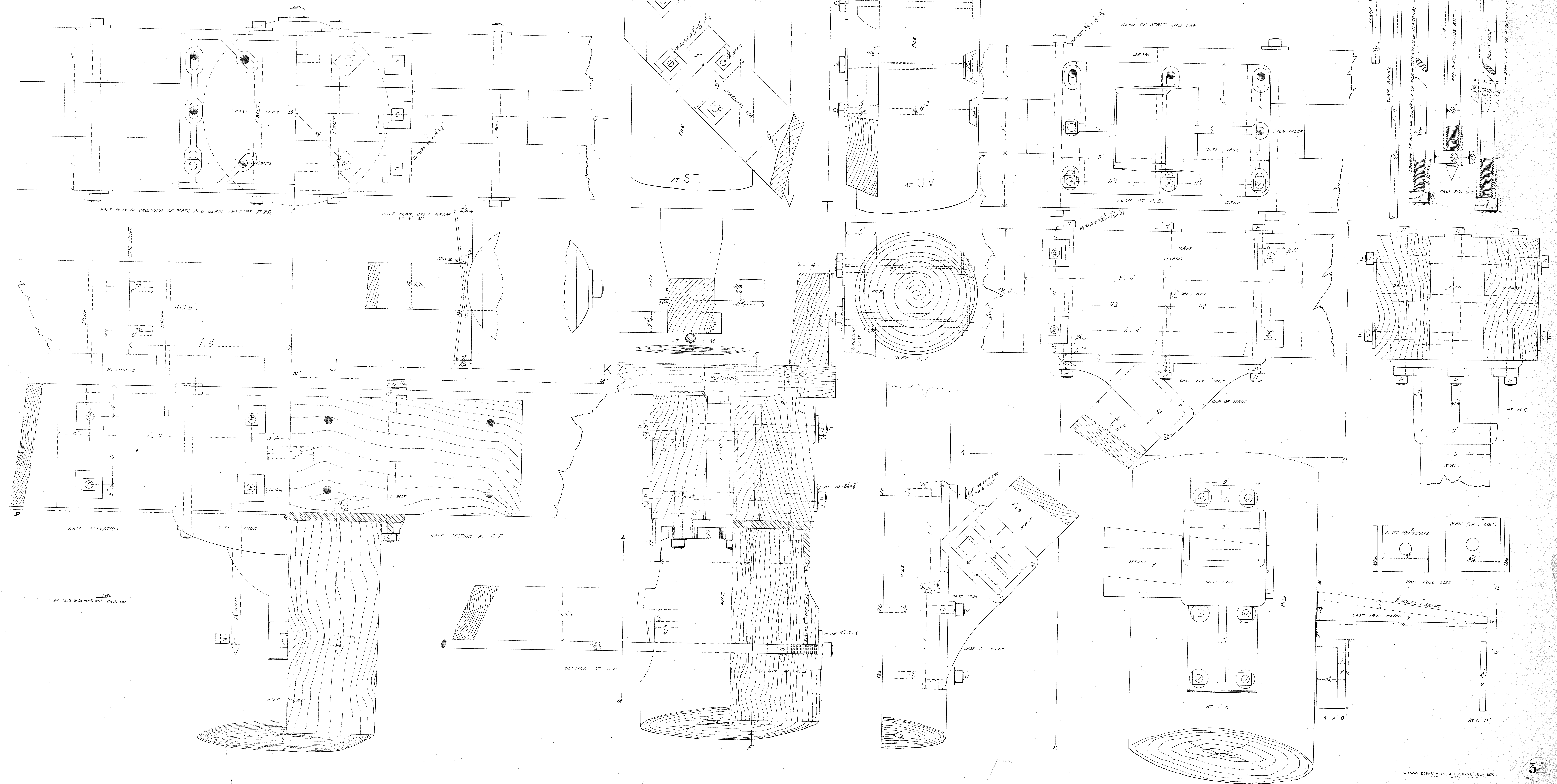
Note. - The length of Piles may vary as the Superintending officer directs



10/1/96

VICTORIAN RAILWAYS.

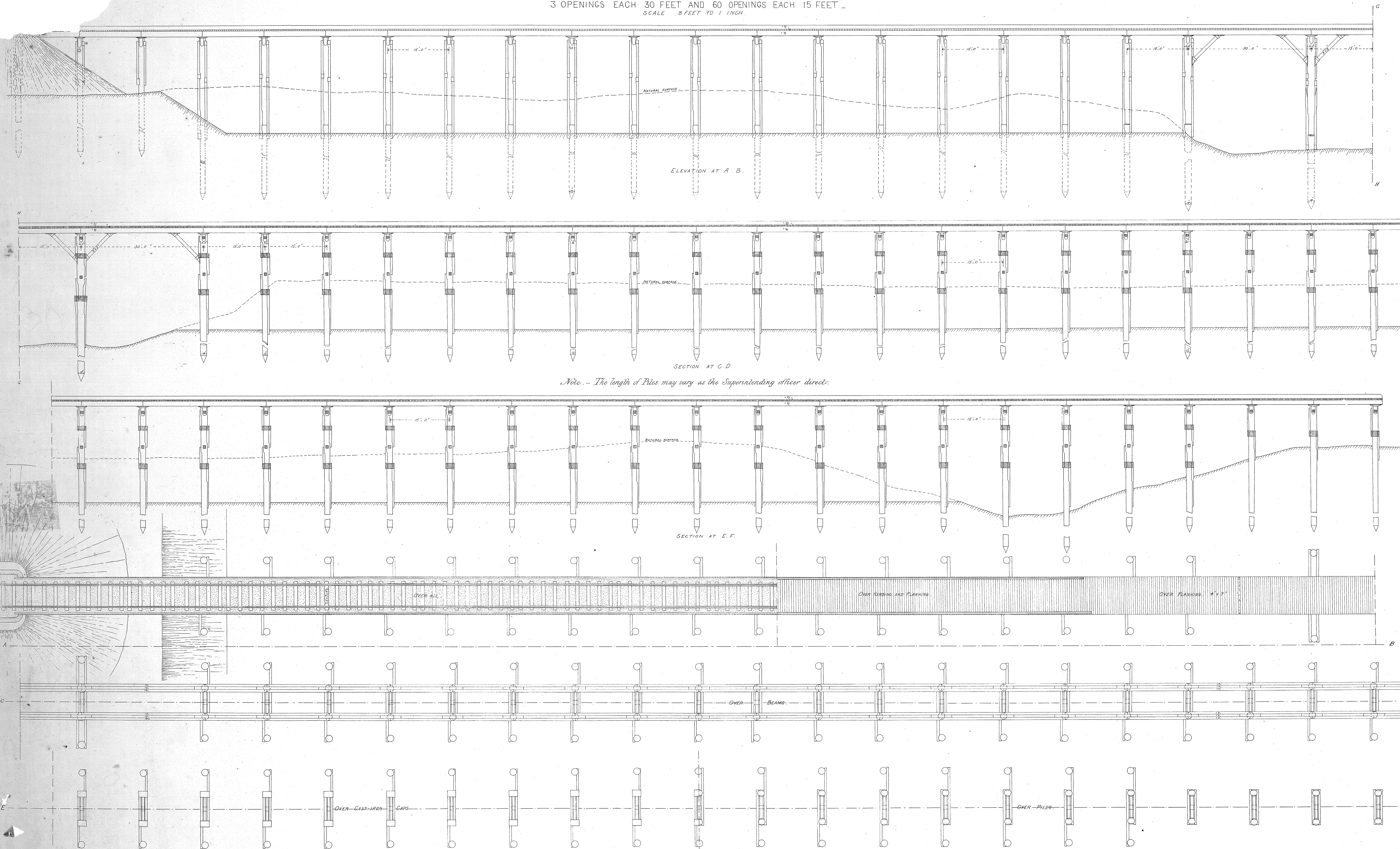
DETAILS OF 30 FEET OPENINGS
SCALE, 3 INCH = 1 FOOT.



VICTORIAN RAILWAYS.

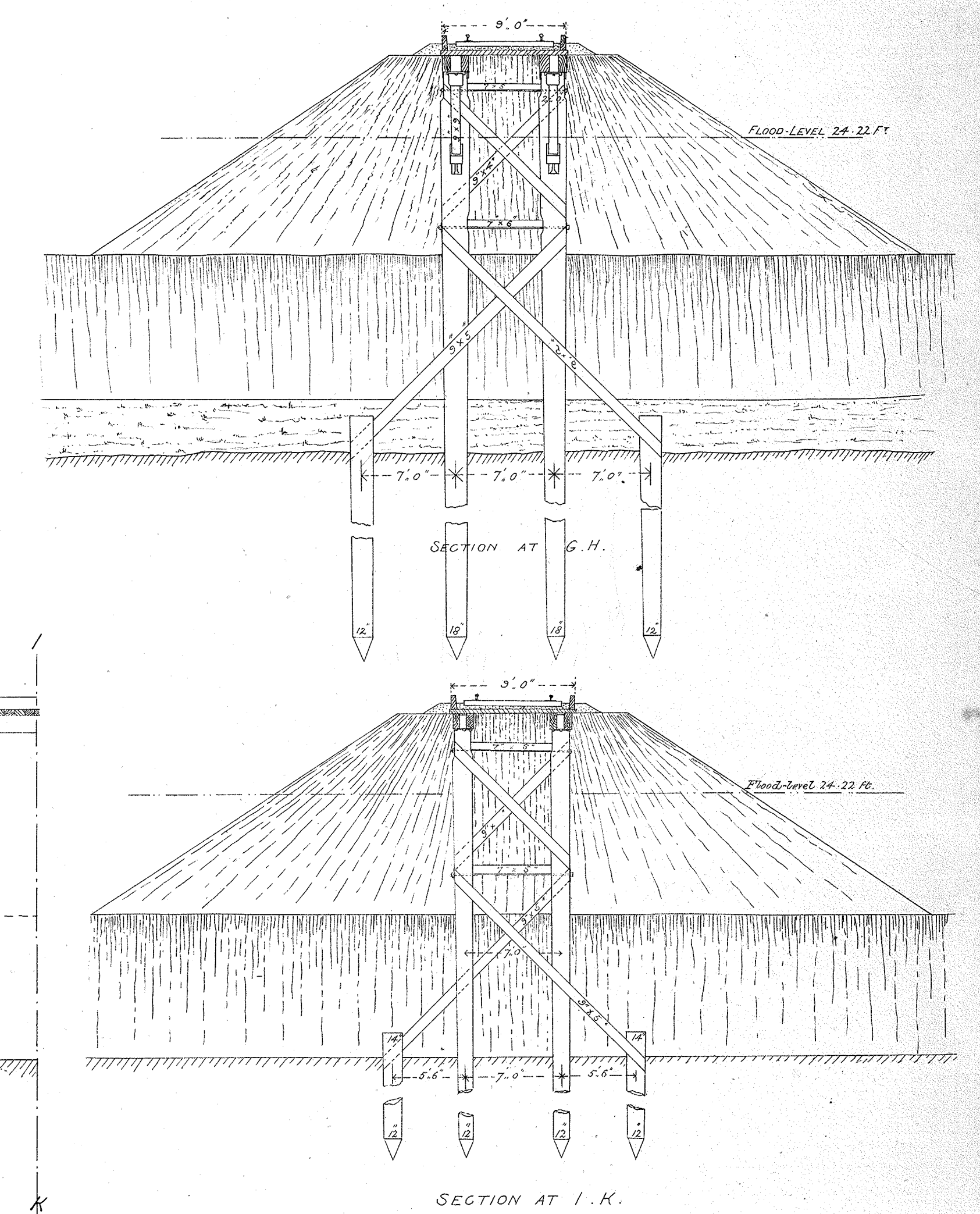
GIPPSLAND RAILWAY.

BRIDGE OVER THOMSON RIVER AT SALE -
3 OPENINGS EACH 30 FEET AND 60 OPENINGS EACH 15 FEET -
SCALE 8 FEET TO 1 INCH.

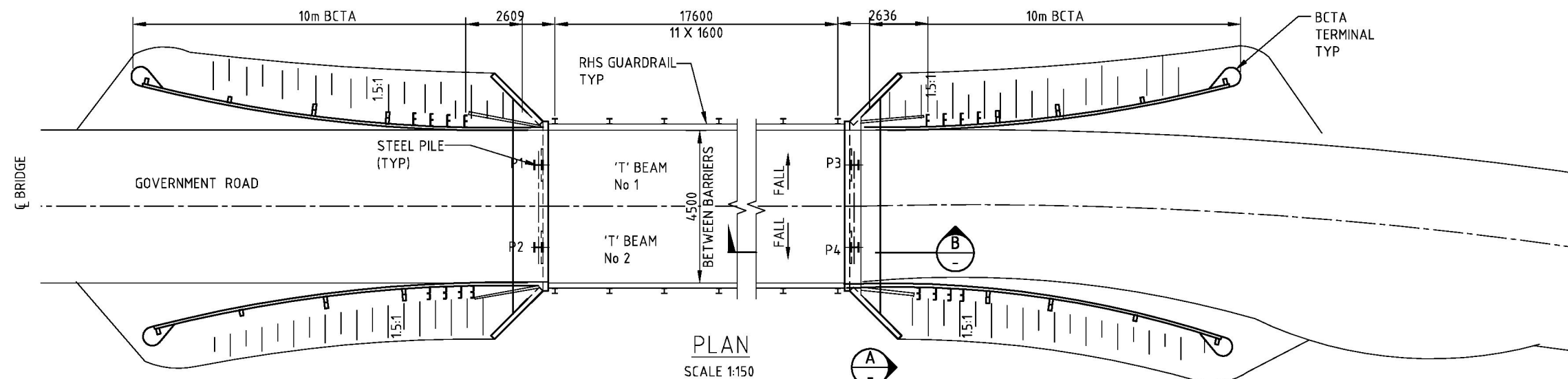


Note. - The length of Piles may vary as the Superintending officer directs.

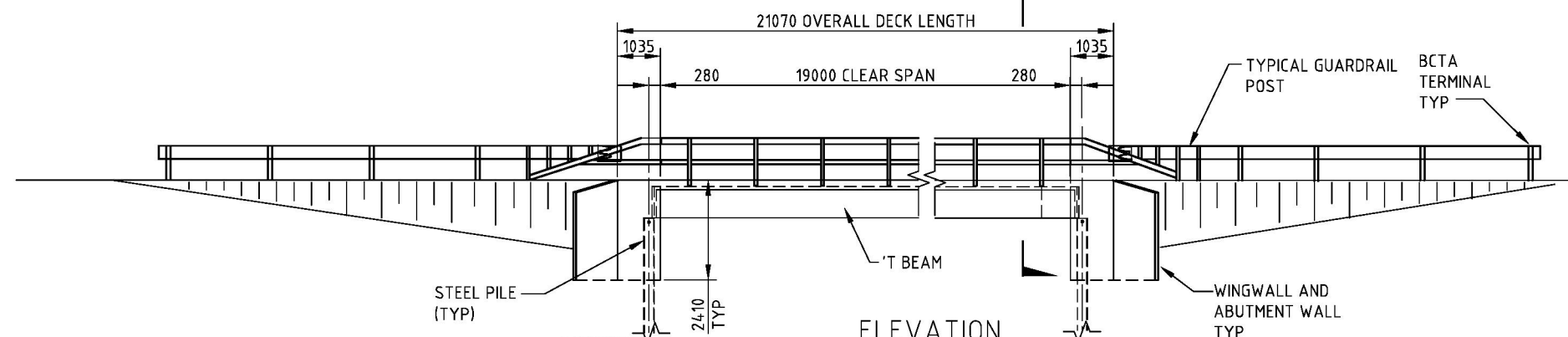
CONTRACT 637.



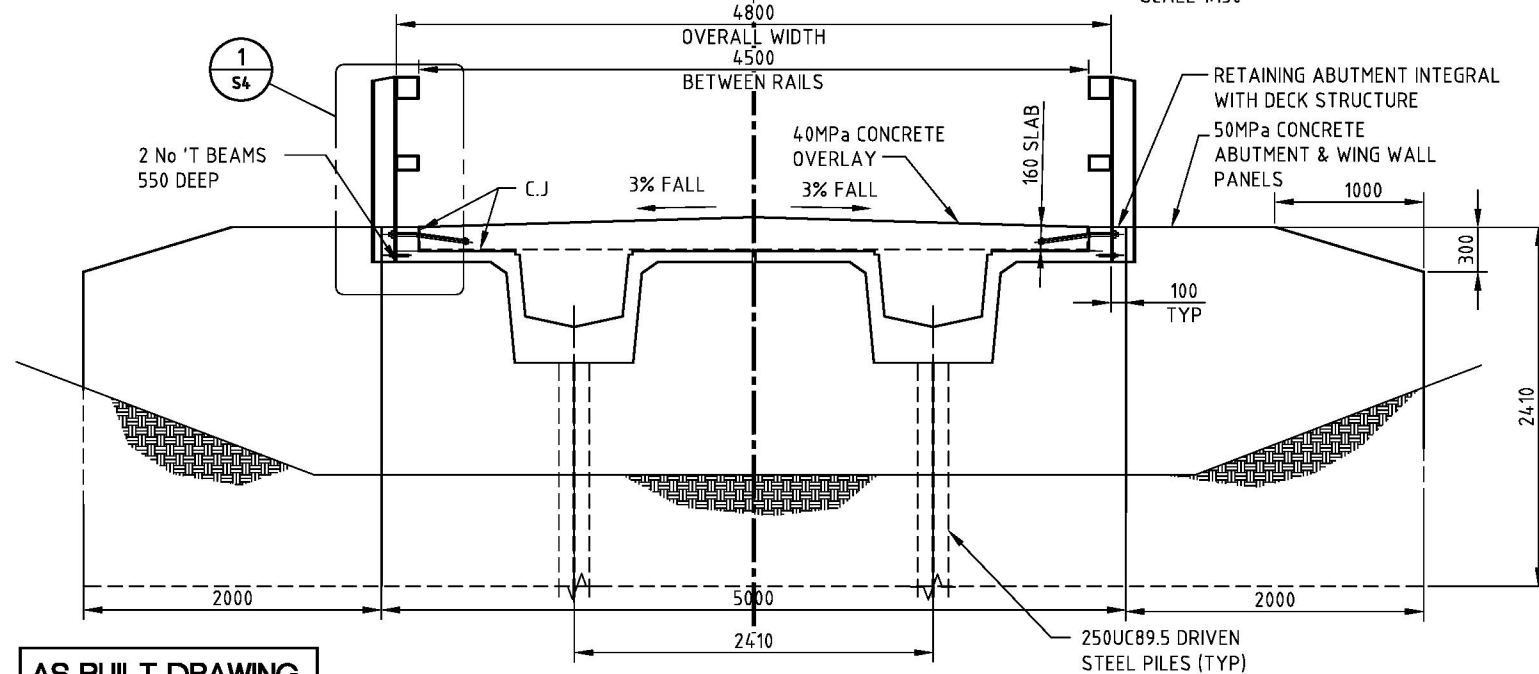
Appendix H Council Bridges



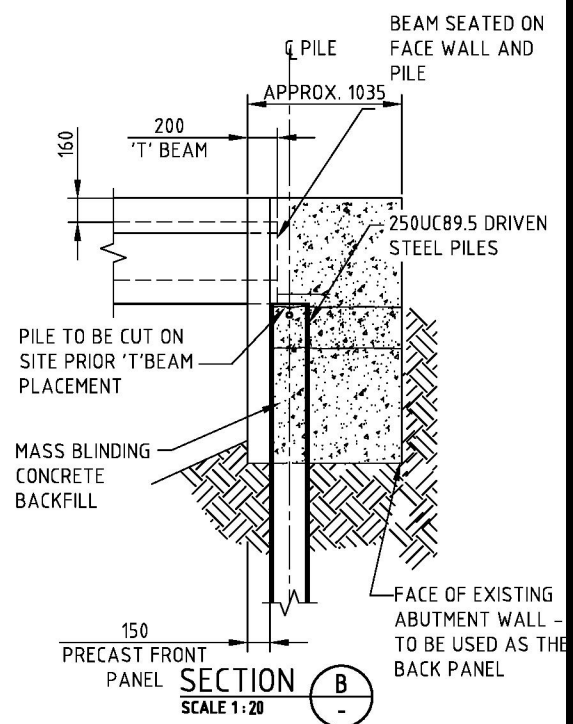
PLAN
SCALE 1:150



ELEVATION
SCALE 1:150



SECTION A-A
SCALE 1:50



SECTION B-B
SCALE 1:20

NOTES

1. WORKMANSHIP AND MATERIALS TO BE IN ACCORDANCE WITH RELEVANT AUSTRALIAN STANDARDS.
2. BRIDGE BARRIER COMPLIES WITH REGULAR PERFORMANCE LEVEL.
3. BARRIER AND GUARD FENCE DEATILS ARE TO CONFORM TO VICROADS STANDARD DRAWINGS Nos. SD3501, SD3511, SD3521, SD3547, SD3551, SD3561, SD3571, SD4071, SD4082.
4. STEELWORK SHALL BE HOT DIP GALVANISED AFTER FABRICATION IN ACCORDANCE WITH AS/NZS 4680.
5. GRADE 8.8 BOLTS, NUTS AND WASHERS TO AS 1252 GALVANISED TO AS/NZS 4680 UNLESS NOTED OTHERWISE.
6. BARRIER POSTS SHALL BE VERTICAL.
7. CONCRETE SHALL BE SPECIAL CLASS PERFORMANCE CONCRETE AS FOLLOWS:

CONCRETE GRADE	CHARACTERISTIC COMPRESSIVE STRENGTH AT 28 DAYS f'_c (MPa)	CEMENTITIOUS MATERIAL CONTENT (kg/m^3) (MIN.)	WATER/CEMENTITIOUS MATERIAL RATIO (MAX)
SC450/50	50	450	0.40
SC400/40	40	400	0.45
SC330/32	32	330	0.50

8. REINFORCEMENT GRADE 500N HOT ROLLED DEFORMED BAR TO AS 4671.

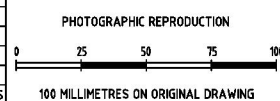
9. EXPOSURE CLASSIFICATION FOR SURFACES OF CONCRETE SHALL BE: SUBSTRUCTURE C, SUPERSTRUCTURE B1.
10. CONCRETE COVER (EXPOSURE B1).

CONCRETE STRENGTH f'_c (MPa)	32 (MPa)	40 (MPa)	50 (MPa)
STANDARD FORM, NORMAL COMPACTION.	-	40mm	35mm
RIGID FORM, INTENSE COMPACTION.	-	30mm	25mm

11. WELDING SHALL BE IN ACCORDANCE WITH AS1554 - PART 1 E48XX ELETRODES.
12. ON COMPLETION OF SITE WELDING ANY DAMAGED COATINGS SHALL BE MADE GOOD BY SPOT PAINTING WITH AN APPROVED COLD GALV. SYSTEM, OR GALSTICK.
13. DESIGN LIVE LOAD IN ACCORDANCE WITH AS5100.2 DESIGN LOADS : SM1600 (LL)
14. PILE LOADS: SERV (kN) = 675
ULT (kN) = 1092
PILE TO BE A MINIMUM 6000 LENGTH BELOW ABUTMENT BASE
15. ALL COMPONENTS U.N.O. HAVE COMPRESSIVE STRENGTH OF 50MPa. COMPONENTS CAST INSITU SUCH AS CONCRETE DECK OVERLAY AND CONCRETE BEHIND PRECAST T-BEAM TO BE 40MPa COMPRESSIVE STRENGTH
16. FOR GUARD FENCE CONNECTION TO BCTA REFER TO DRW. NO. BM 11072 S4.

AS BUILT DRAWING
APPROVED:
DATE: 18/04/2012

REV	APP'D	DATE	AMENDMENTS
3	-	18.04.2012	AS BUILT DRAWINGS
2	-	30.11.2011	ABT PANELS - HEIGHT CHANGED ACCORDING TO COUNCIL REQUIREMENTS
1	-	21.11.2011	ISSUED FOR APPROVAL



DATUM
CAD REFERENCE No. -

BRIDGE & MARINE ENGINEERING PTY LTD

DESIGNED
DRAWN
APPROVED

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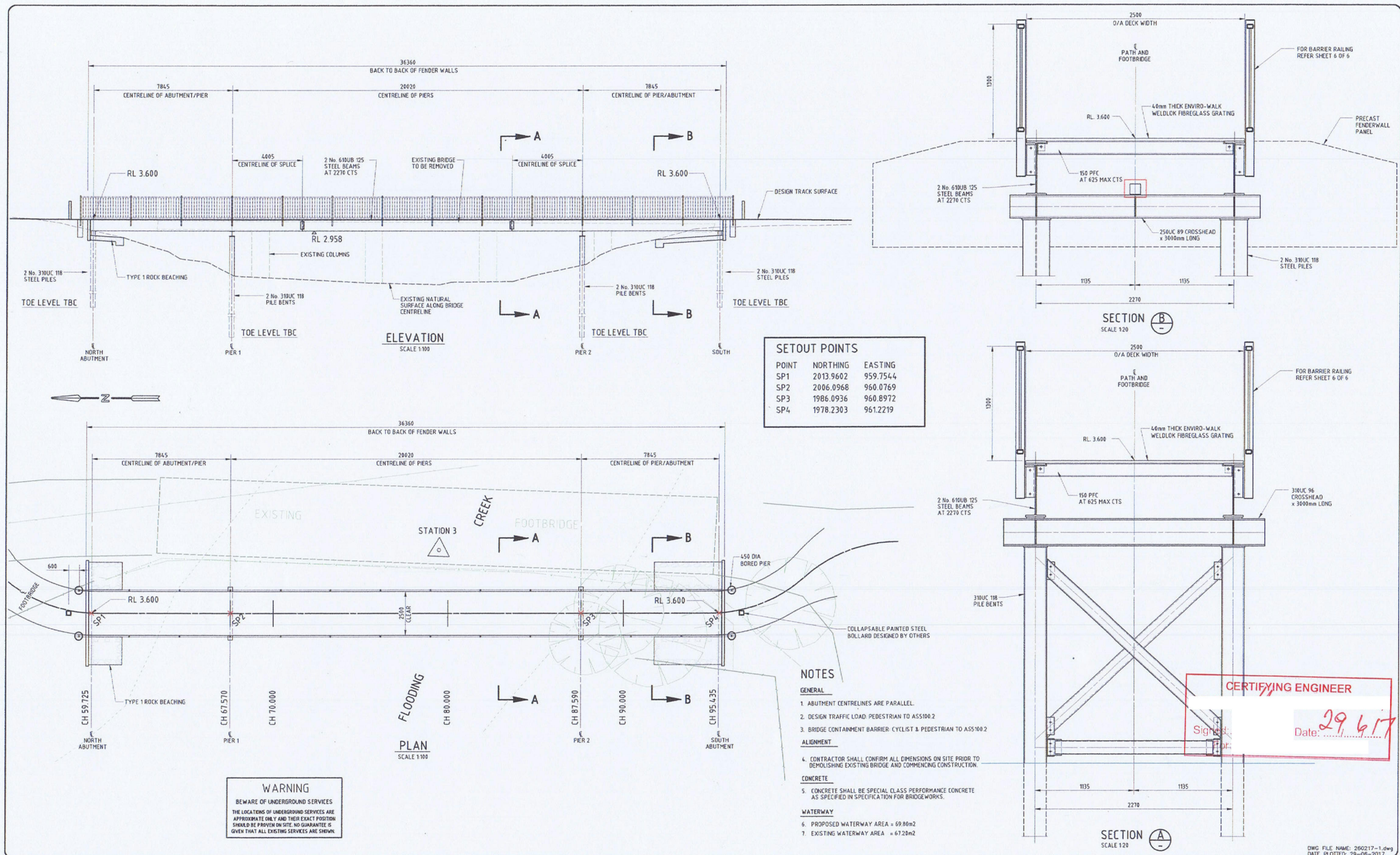


RAGLAN ST BRIDGE
SALE
WELLINGTON SHIRE

BRIDGE & MARINE AUSTRALIA

GENERAL ARRANGEMENT & SECTION

CONTRACT No.	SHEET No.	DRAWING No.	APPEND.
-	1 OF 4	BM10072-S1	3



No.	REVISION	DATE	BY

DATE	ISSUED TO	COPIES	BY

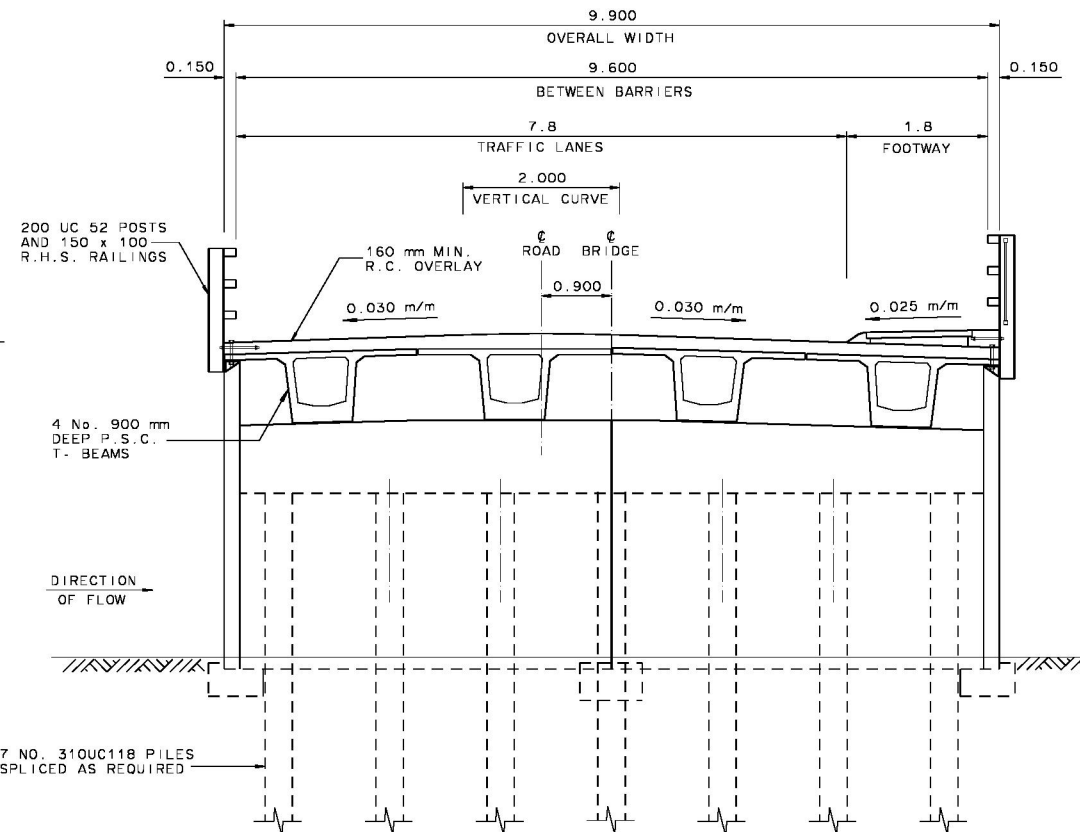
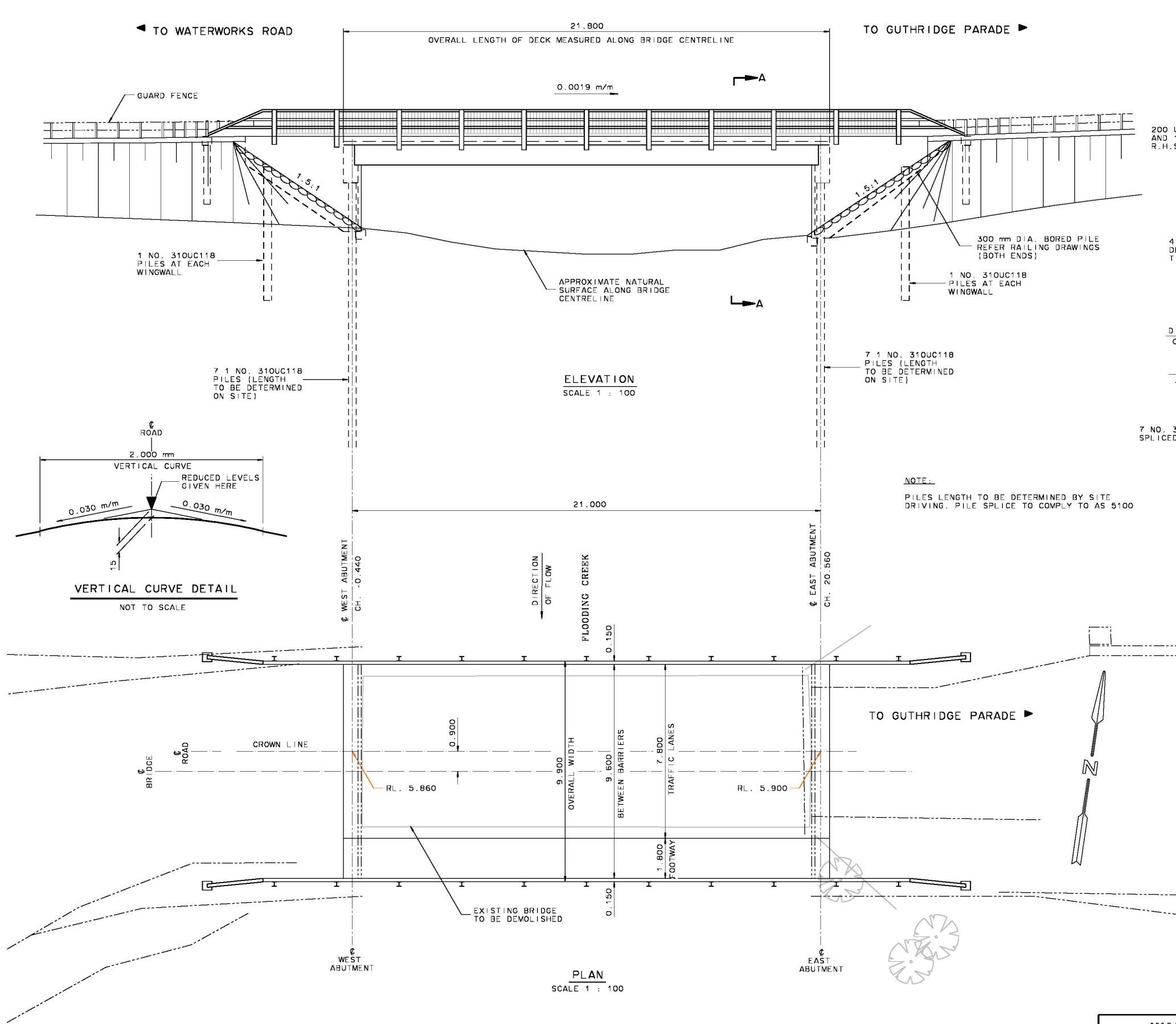
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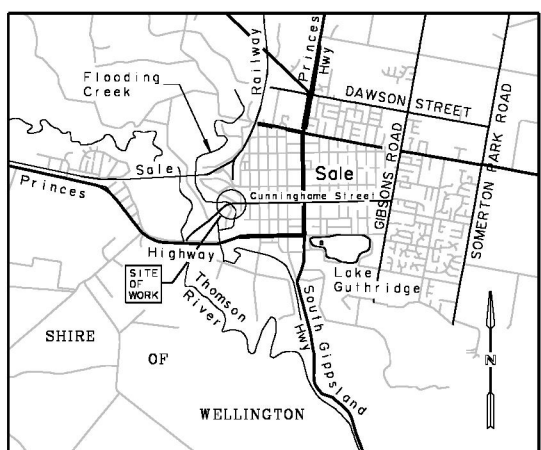
CLIENT

CHRIS O'BRIEN & COMPANY PTY LTD
CONSULTING CIVIL & STRUCTURAL ENGINEERS

DRAWN	GENERAL ARRANGEMENT	DATE
DESIGNED	PROJECT	FEB 2017
CHECKED	BRADYS FOOTBRIDGE REPLACEMENT	SCALE
SIGNED	OVER FLOODING CREEK ON	AS SHOWN
	SOUTHSIDE OF SALE	SHEET No.
		1 OF 6
		PROJECT No.
		260217



SECTION A - A
SCALE 1 : 50



LOCALITY PLAN
NOT TO SCALE

NOTES

CONCRETE

1. CONCRETE SHALL BE SPECIAL CLASS PERFORMANCE CONCRETE AS SPECIFIED IN SPECIFICATION FOR BRIDGEWORKS.
2. EXPOSURE CLASSIFICATION FOR SURFACES OF CONCRETE SHALL BE INDICATED BELOW UNLESS NOTED ON THE DRAWING. IN CONTACT WITH THE GROUND...B1 ABOVE GROUND...B1

GENERAL

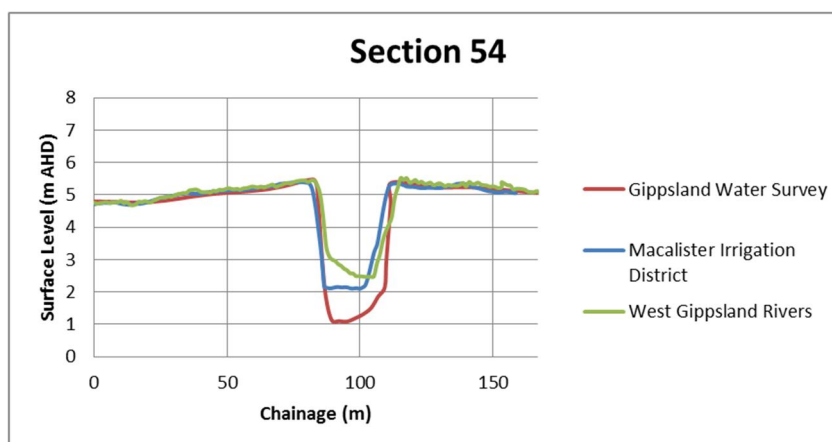
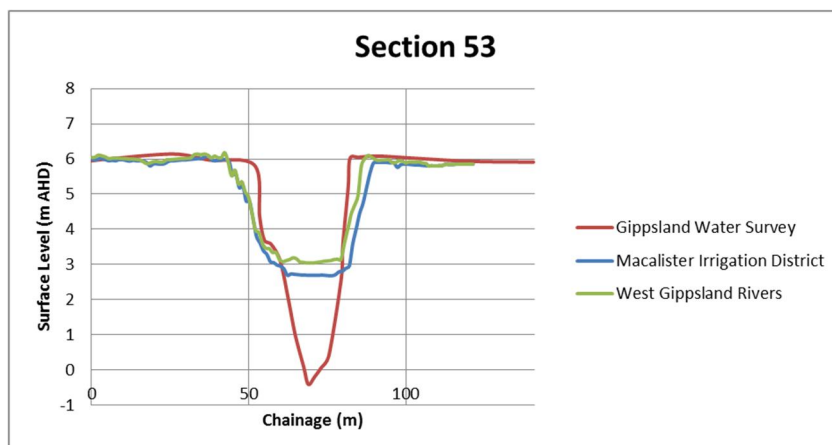
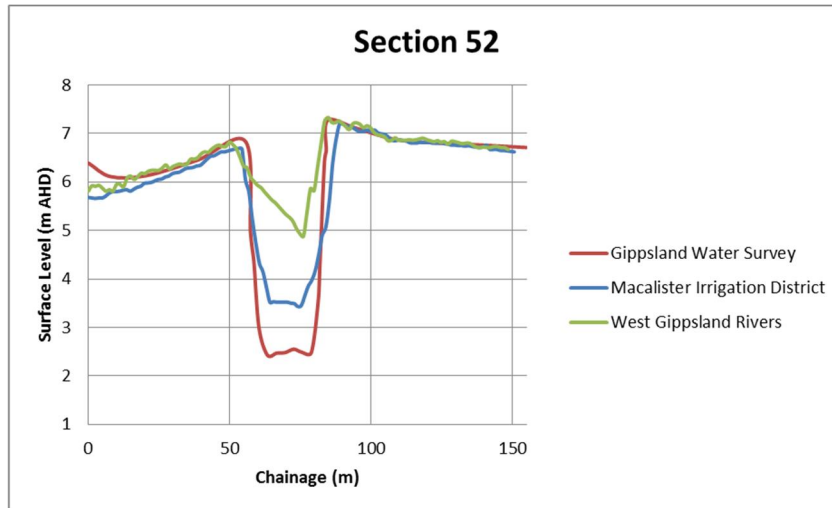
3. CHAINAGES ARE MEASURED ALONG DESIGN LINE.
4. DECK LEVELS ARE TO TOP OF CONCRETE.
5. ABUTMENT CENTRELINES ARE PARALLEL.
6. LOCATION OF BRIDGE TO BE CHECKED AND CONFIRMED ON SITE PRIOR TO DEMOLISHING EXISTING BRIDGE AND ANY CONSTRUCTION AND FABRICATION.
7. EXISTING SERVICES SHALL BE REATTACHED TO THE BRIDGE.
8. CONTRACTOR SHALL SUBMIT SERVICE CONNECTION DETAILS FOR APPROVAL.

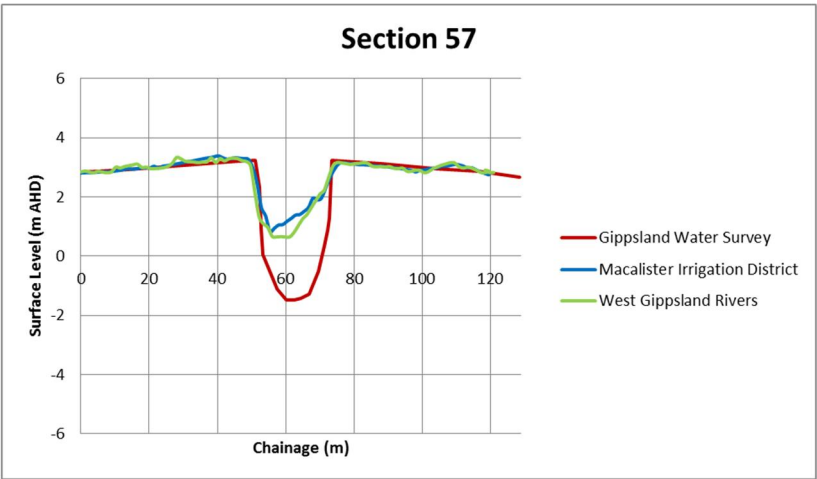
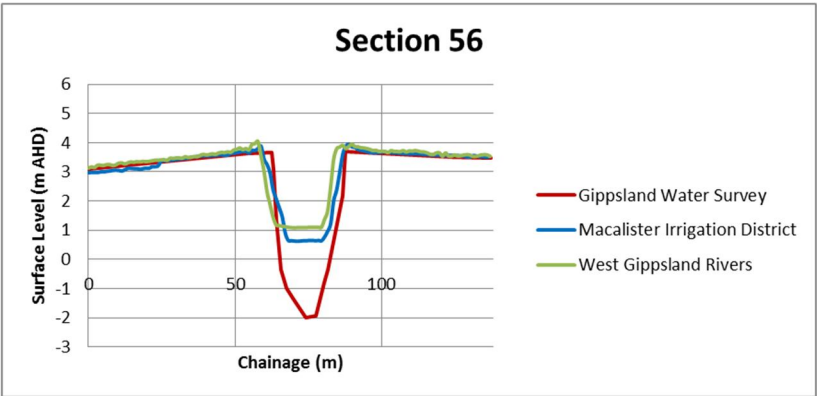
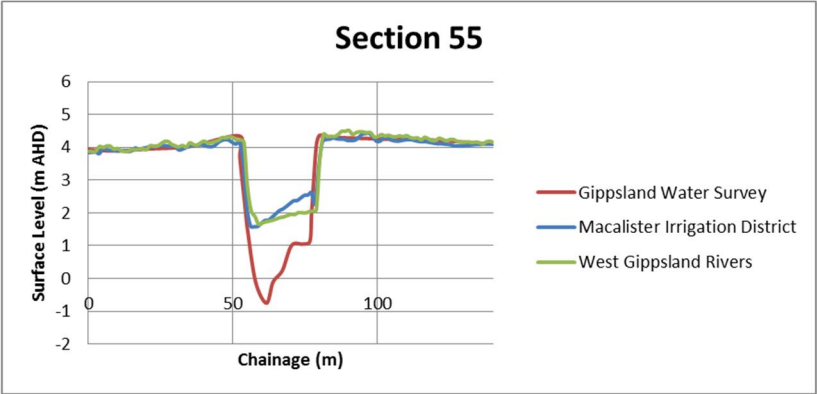
WARNING

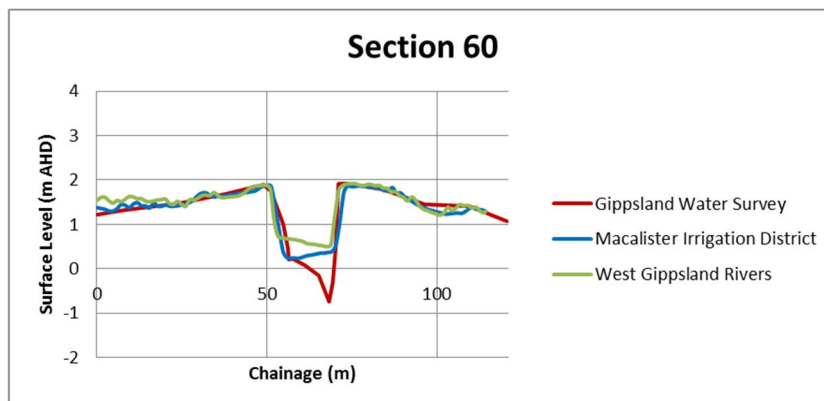
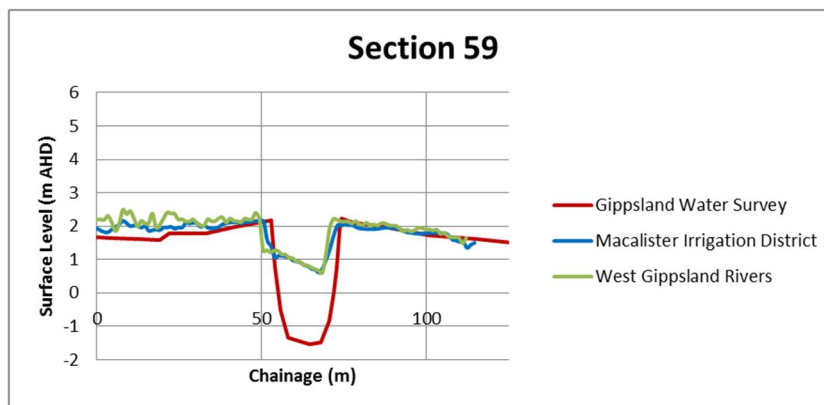
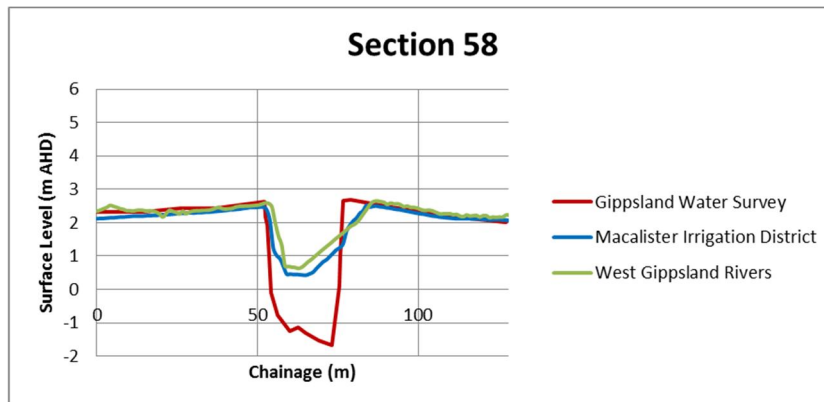
BEWARE OF UNDERGROUND SERVICES
THE LOCATIONS OF UNDERGROUND SERVICES ARE APPROXIMATE ONLY AND THEIR EXACT POSITION SHOULD BE PROVEN ON SITE. NO GUARANTEE IS GIVEN THAT ALL EXISTING SERVICES ARE SHOWN.

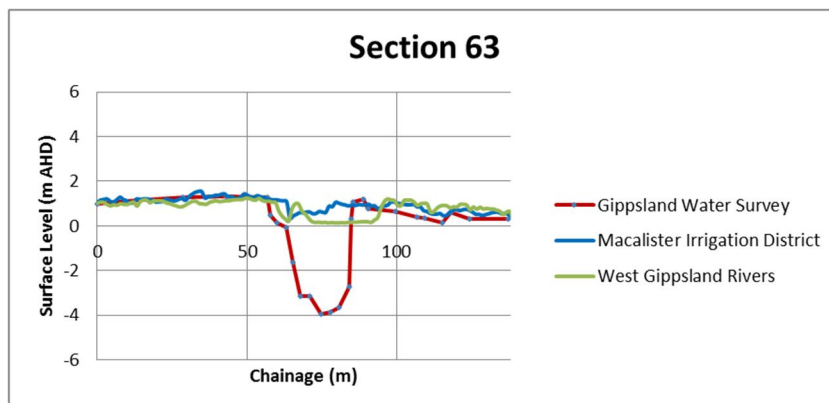
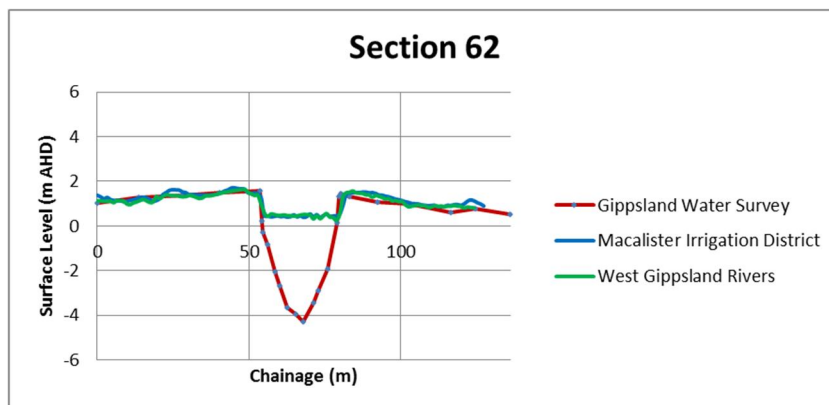
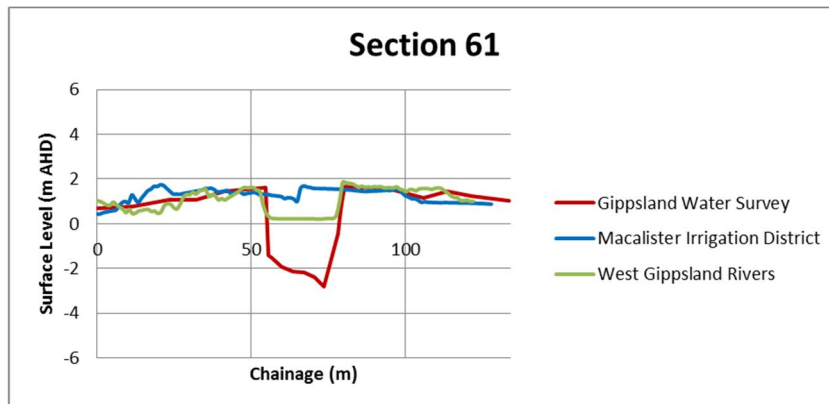
NOTE: CONTRACTOR TO CHECK BRIDGE ABUTMENT LOCATIONS PRIOR TO COMMENCING CONSTRUCTION POSITION MAY NEED TO BE ADJUSTED TO MATCH THE CREEK PROFILE

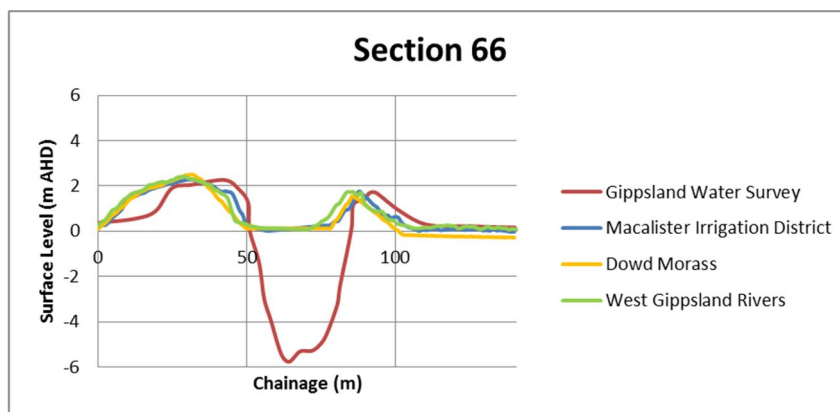
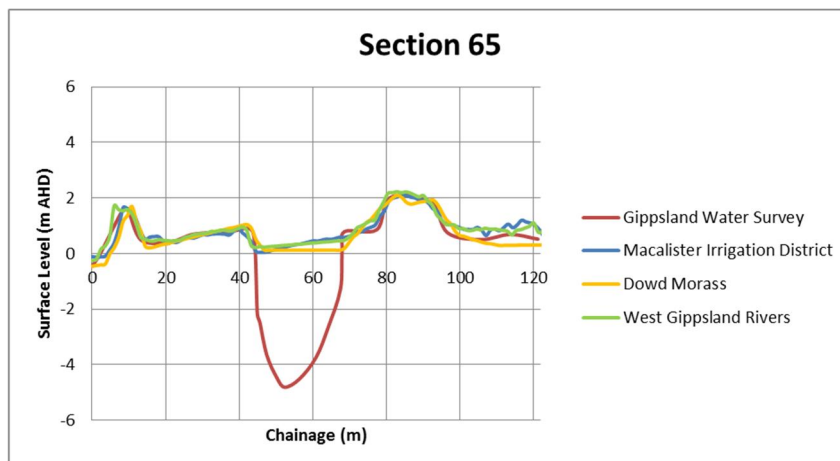
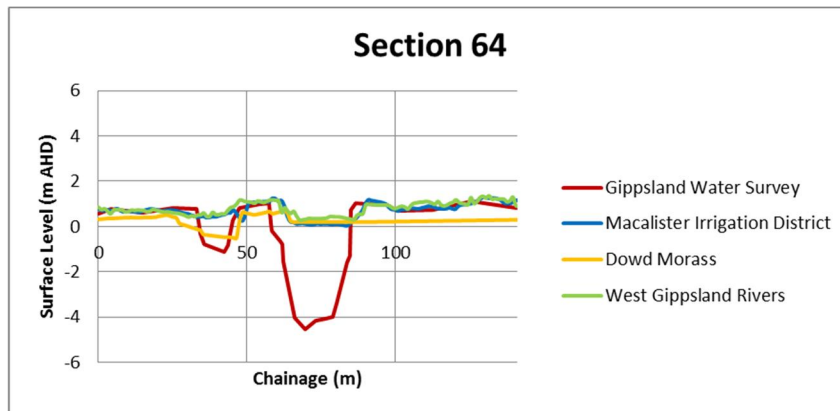
Appendix I Cross Sections











Appendix J Tailwater analysis

J.1 Review of analysis techniques

Estimation of the interaction between river and ocean floods in estuarine areas has received considerable attention in recent years, culminating in the release of a detailed methodology and supporting software tools as part of the 2016 revision of Australian Rainfall and Runoff.

The subject is dealt with in some detail in Chapter 5 of Book 6 of ARR2016. The guidance notes that there is a statistical dependence between extreme rainfall and storm surge type events. This generates a 'joint probability zone' where riverine and ocean floods interact with each other, as shown in Figure E-1. Within this zone, there is a range of possible water levels which arise from combinations of inflow floods and ocean levels.

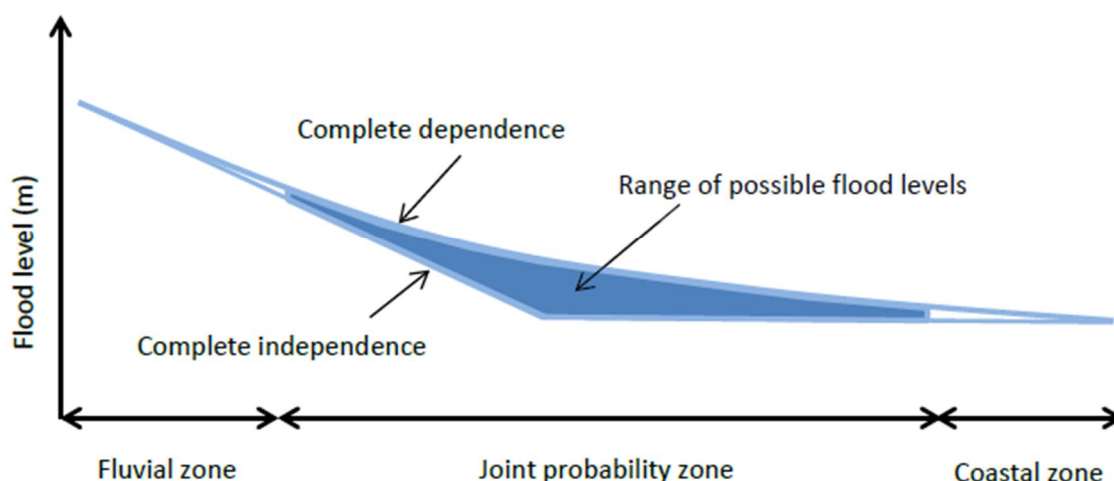


Figure E-1: Schematic of riverine and estuarine flooding joint probability zone (ARR2016)

The upper range of the joint probability zone is classified as 'complete dependence'. This refers to the case when the probability of exceedance of the riverine flood is the same as the probability of exceedance of the ocean flood. An example of this is a 1 in 100 AEP river flood coupled with a 1 in 100 AEP storm surge. Similarly, the lower range of the joint probability zone is classified as 'complete independence' – where a 1 in 100 AEP river flood might occur on a normal tide level.

ARR2016 provides a design variable method for estimating probability neutral water levels within the joint probability zone given a range of inflow floods and storm surge levels. The technique (which is implemented in an on-line tool) fits a bivariate probability distribution based on a local dependence parameter, which has been estimated for the entire Australian coastline using recorded levels.

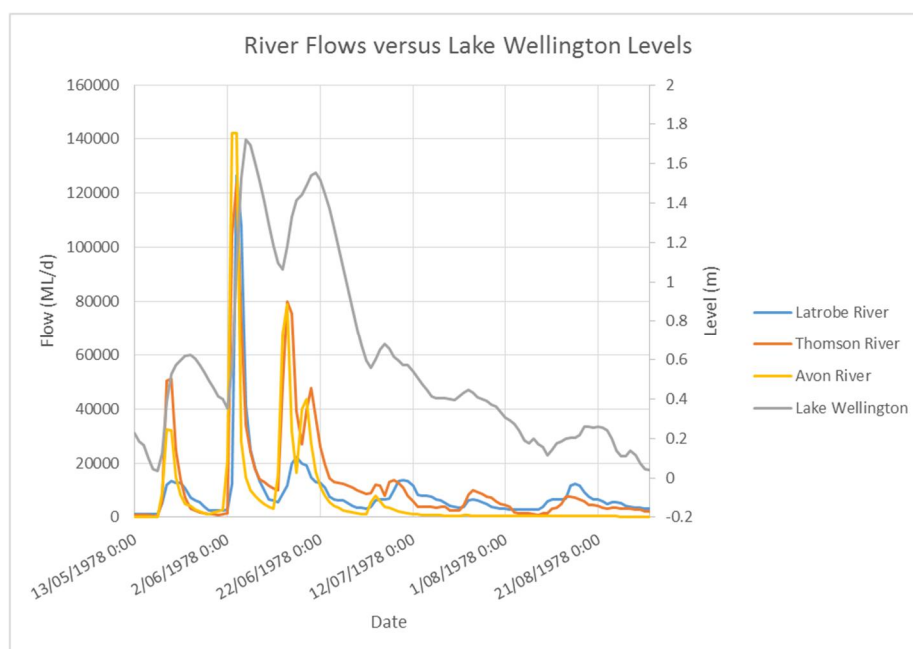
A key assumption of the design variable method is that the riverine flood and ocean flood levels are separate but dependent probability distributions. To clarify, this means that riverine flooding and storm surge may be, but are not always, generated from the same overall weather event. The resulting uncertainty in the likelihood that an extreme rainfall event also results in a storm surge event is the focus of the design variable method.

J.2 Study area background

Water levels in Lake Wellington are potentially impacted by three forces: wind, ocean level and river floods (Grayson et al, 2004). Of these three, inflows from the river systems which drain into the lakes are by far the most important. Wind conditions also play a significant effect on water levels in Lake Wellington, whereas tidal and storm surge effects are significantly less important given the attenuation between Lakes Entrance and Lake Wellington.

Review of the stream flow and level data in Lake Wellington indicates that there is indeed strong correlation between floods in either the Latrobe, Thomson and/or Avon and levels in Lake Wellington. For example, the 1978 flood had significant flooding on the Thomson River, Latrobe River and the Avon River and the water levels rose significantly in Lake Wellington. Figure E-2 shows the recorded flows on each of the rivers compared to water levels in Lake Wellington. Figure E-2 shows the strong correlation of level in Lake Wellington and the inflows from the rivers. It also shows that levels vary with time and volume is important.

Figure E-3 shows the same information for the 2007 event which had significant flooding on the Thomson River and Avon River only. However, the same observations from the 1978 event can be seen.



n **Figure E-2 1978 Event**

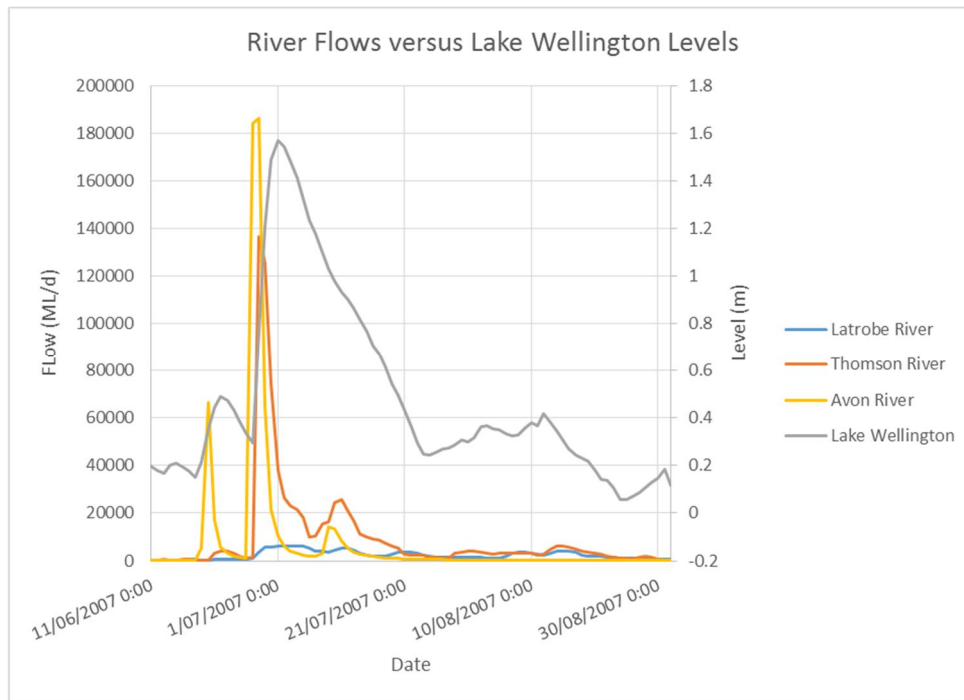


Figure E-3 2007 Event

Figure E-4 shows the total three day volume compared to the maximum level in Lake Wellington. Figure E-4 also demonstrates that there is a strong dependence between Thomson and Latrobe River inflows the water level in Lake Wellington.

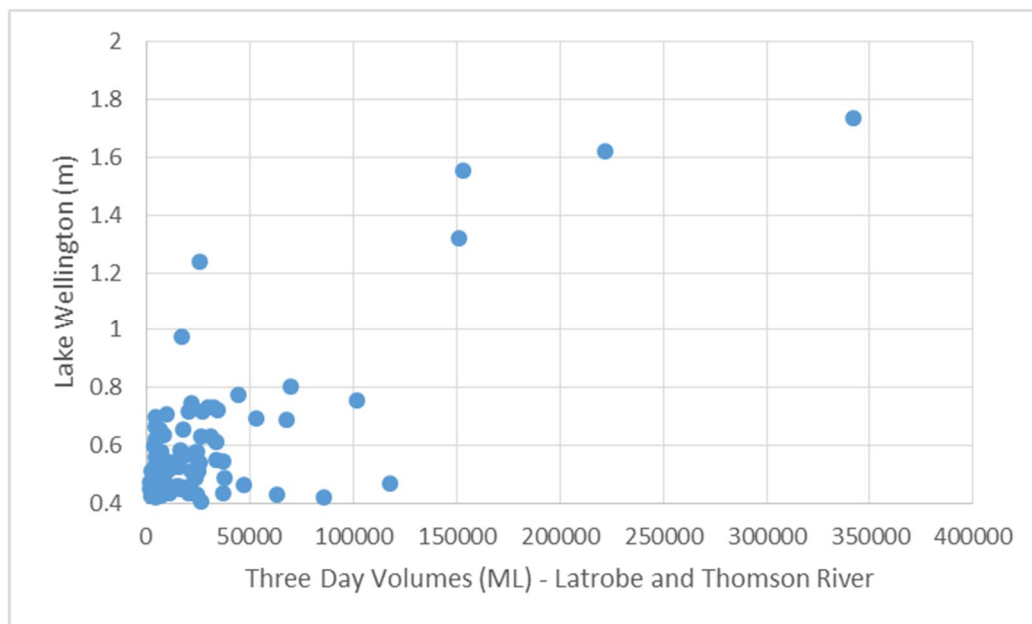


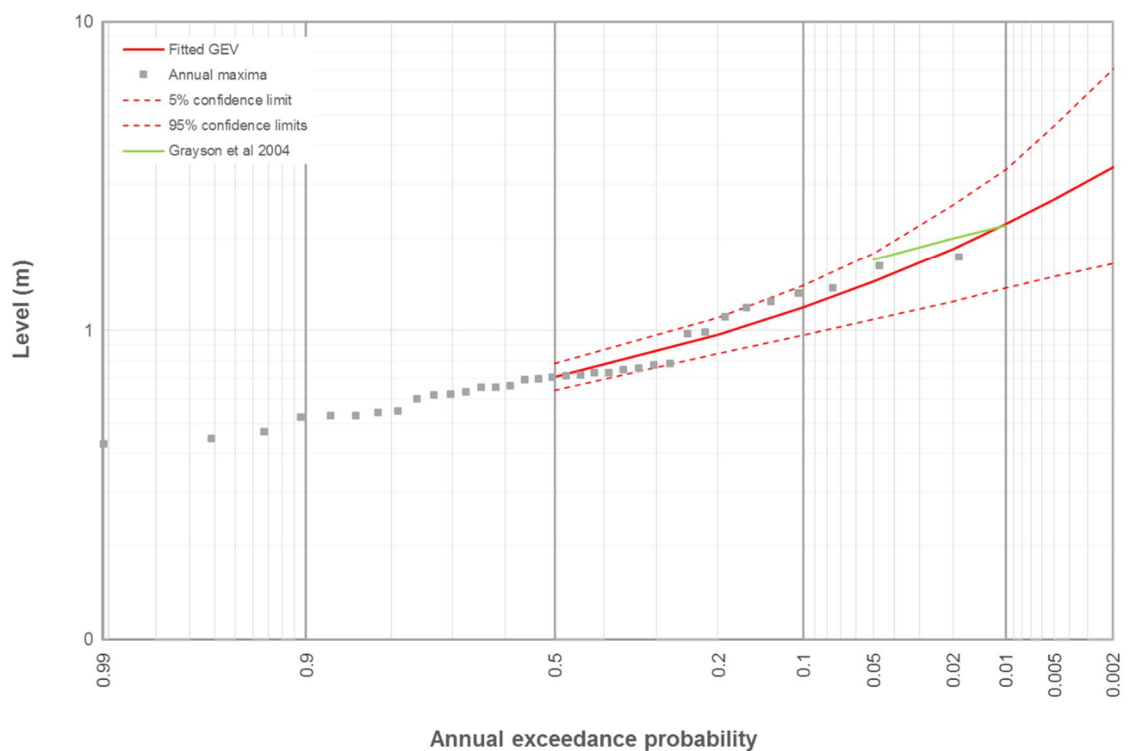
Figure E-4 Lake Wellington Level (m) compared to 3 day Volume – Latrobe and Thomson Rivers

Grayson, R, et. al. in the Gippsland Lakes Flood Level Modelling Project (2004) report made the following observation about flood levels in Lake Wellington. “Wind effects are particularly important on Lake Wellington, with river flooding being critical to water levels in the land between the major rivers and the Lake”.

J.3 Tailwater Levels

Initially a level frequency curve was fitted to the data recorded at 226041 Lake Wellington @ Bull Bay. Level data is available at 226041 from 1975 to date. There is a large amount of missing data between 1986 and 1991 so these years were not used in the analysis. Figure E-5 shows the frequency curve at 226041 with LH shift zero with the low level threshold of 0.4. Figure E-6 shows the frequency curve at 226041 with LH shift four with the low level threshold of 0.4.

Figure E-5 and Figure E-6 also shows the 5%, 0.5% and 1% AEP estimates in Lake Wellington from Grayson, R, et. al. (2004). These are modelled water level frequency estimates which account for the effect of wind.



n **Figure E-5 226041 Lake Wellington @ Bull Bay Level Frequency Curve (LH Zero)**

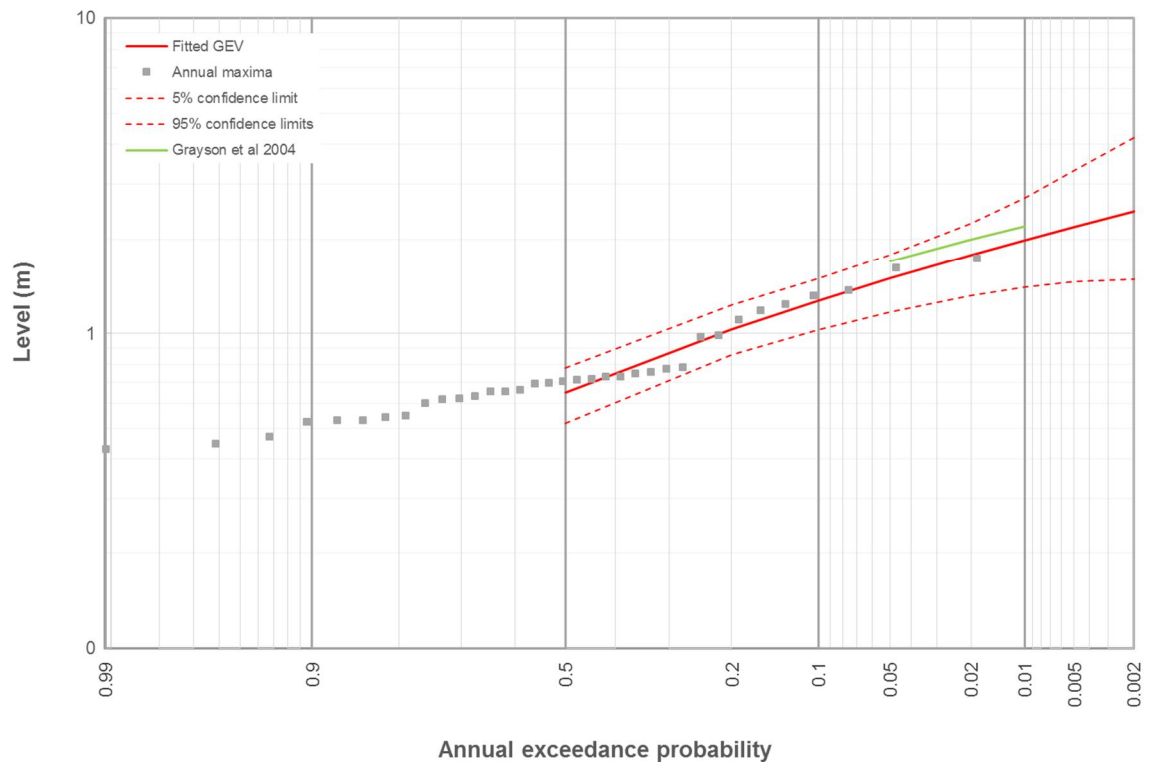
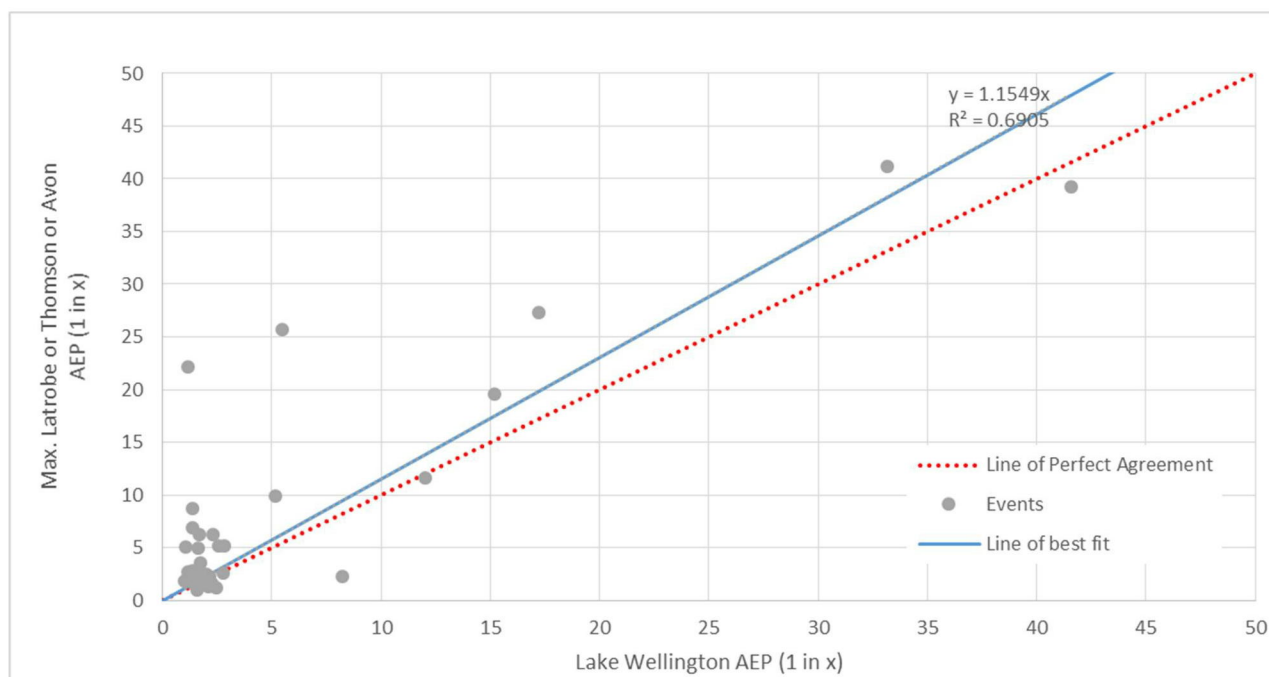


Figure E-6 226041 Lake Wellington @ Bull Bay Level Frequency Curve (LH 4)

To assist in the understanding of the dependence of a flood in either the Latrobe, Thomson and/or the Avon River to the levels in Lake Wellington the AEP of a flood in the rivers was compared to the AEP of the level in Lake Wellington.

To estimate the AEP in either the Latrobe, Thomson and/or the Avon River the flood frequency analysis undertaken as part of the hydrology (HARC, 2017) was used. To estimate the AEP in Lake Wellington, for the same flood event, the frequency curve shown in Figure E-5 was used.

Figure E-7 shows the relationship between the AEP in Lake Wellington compared to the maximum AEP in Latrobe, Thomson and/or Avon River.



■ **Figure E-7 AEP in Lake Wellington compared to the AEP in Latrobe, Thomson or Avon River based on Historical Events**

Figure E-7 indicates that there is a strong correlation between floods on the river and level in Lake Wellington. For example if there was a 1 in 20 AEP event on the Latrobe River the relationship in Figure E-7 would indicate the AEP in Lake Wellington would be approximately a 1 in 17 AEP.

This analysis demonstrates that there is a very strong dependence between water level in Lake Wellington and inflows from the major river systems. For larger floods close to the 1 in 100 AEP, this can be described as completely dependent based on the terminology described in ARR2016. In other words, it is highly likely that a 1 in 100 AEP river inflow is correlated with a 1 in 100 AEP lake water level.

However, as there are only a few large events shown in Figure E-7 it was suggested by (at the request of HARC, undertook an independent review of the proposed methodology for the tailwater levels on the 1 November 2017) that the 314 flood events modelled by Grayson et al., 2004 could be incorporated into Figure E-7 to confirm the relationship.

The AEP of Latrobe and Thomson River flows (combined) from Grayson et. al. were plotted against the AEP of the maximum Lake Wellington level, also from Grayson et. al. The plot is shown in Figure E-8 which indicates that this is a large amount of variability in the data and does not confirm the relationship shown in Figure E-7.

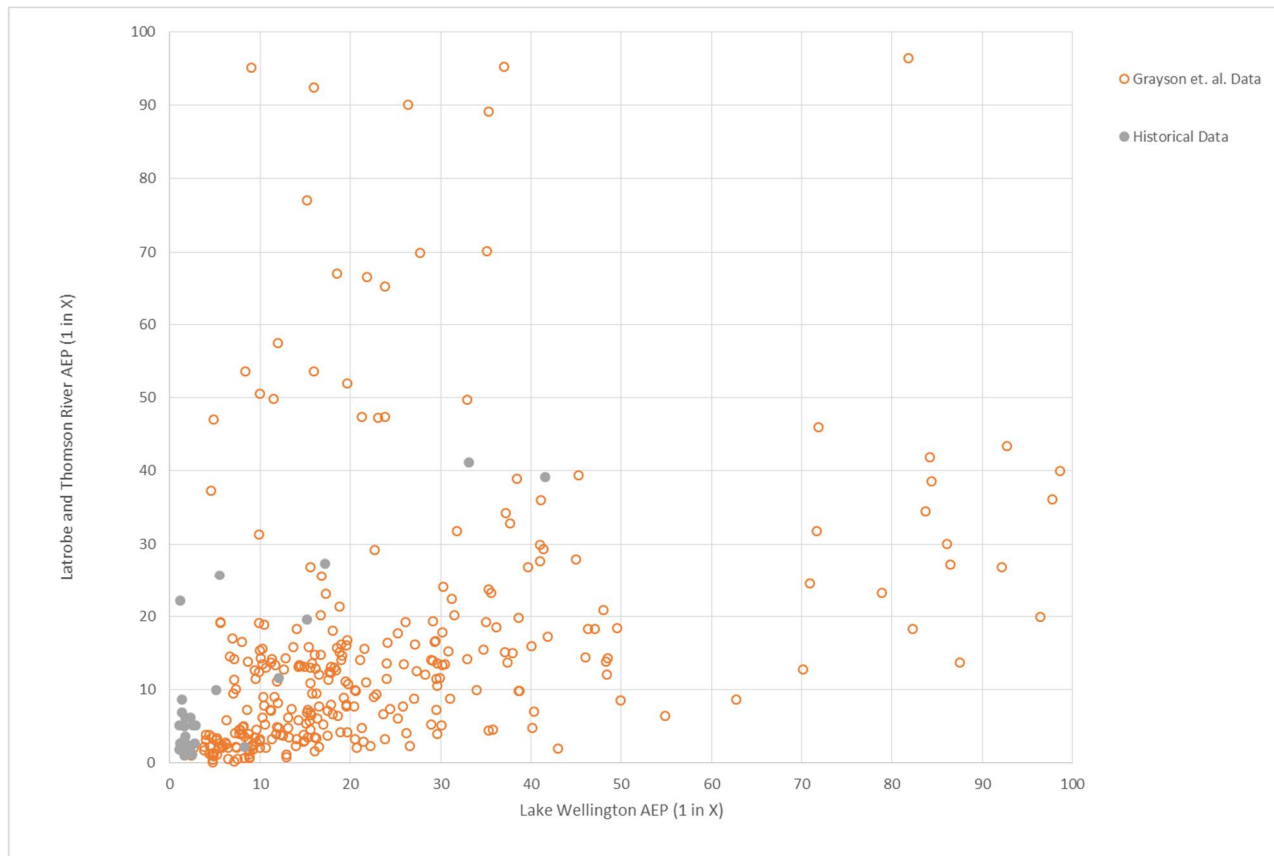
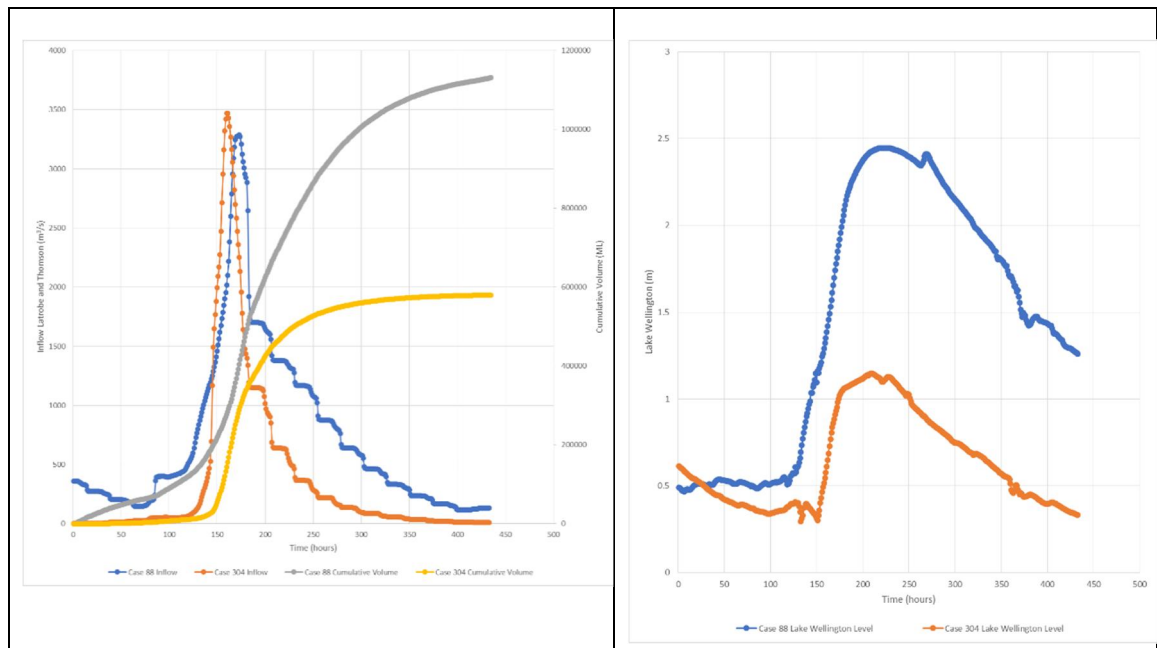


Figure E-8 AEP in Lake Wellington compared to the AEP in Latrobe and Thomson based on Grayson et al. 2004 Events

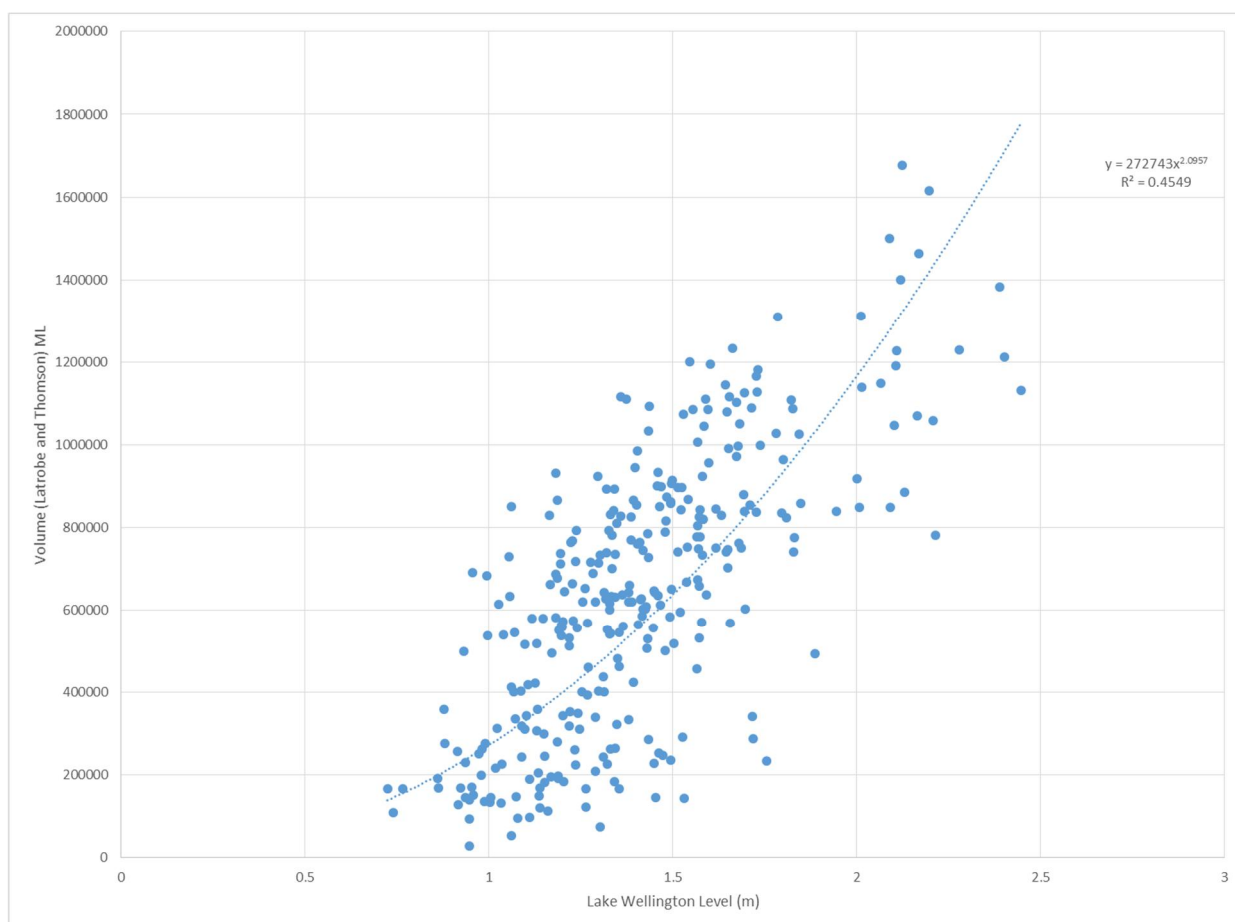
To check why a large AEP event on the Latrobe / Thomson River could result in a low AEP Lake level and vice versa, two events were looked at from the Grayson et. al dataset. Two of the events on the upper and lower end of the scatter were chosen, that is, one event with a high AEP flow and a low AEP lake level and a high AEP flow and a high AEP lake level (Case 88 and 304).

Figure E-9 shows the inflows, cumulative volume (left hand panel) and the levels in Lake Wellington (right hand panel) for the two cases. Figure E-9 shows that whilst the peaks of the two events are similar the difference in volume appears to be a significant driver behind the significant difference in levels in Lake Wellington.



n **Figure E-9 AEP in Lake Wellington compared to the AEP in Latrobe and Thomson based on Grayson et al. 2004 Events**

To check the relationship between volume and the levels in Lake Wellington a volume for each of the 314 flood events modelled by Grayson et al. was calculated and plotted against the maximum level in Lake Wellington for the same event. The relationship is shown in Figure E-10 and indicates that there is a relationship.



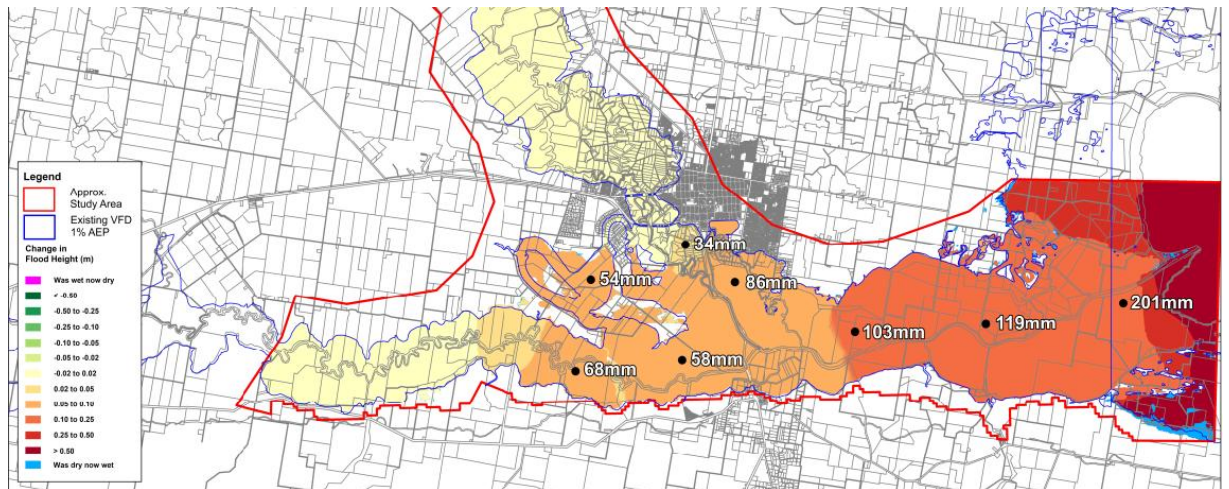
n **Figure E-10 Volume into Lake Wellington compared to Level in Lake Wellington based on Grayson et al. 2004 Events**

J.4 Impact of tailwater levels

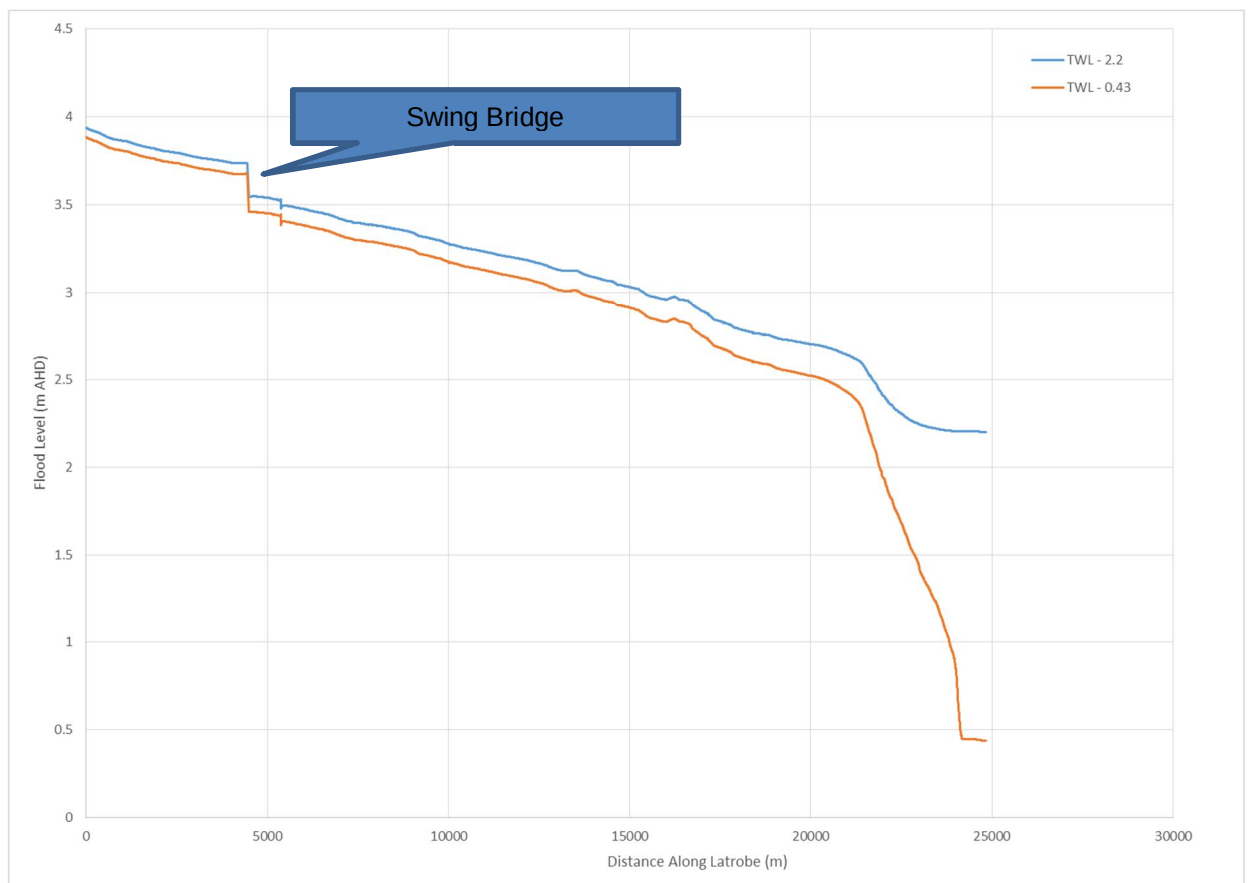
The other aspect to consider is the impact that various tailwater levels have on flood levels within the floodplain. The hydraulic model was run with a 1 in 100 AEP flood in the river along with a peak tailwater level of 0.43 m and 2.2 m in Lake Wellington (these levels are a 1 in 1 and a 1 in 100 AEP level on Lake Wellington, respectively – refer to Figure E-5).

Figure E-11 shows the difference in flood levels for the two different tailwater events. Figure E-11 shows that the difference in the areas where there are people at risk is up to 60 mm. Figure E-12 shows a long section along Latrobe River with the different tailwater levels.

The results shown in Figure E-11 are considered to be an extreme example as Figure E-8 indicates that, if there was a 1 in 100 AEP flood on the Latrobe, Thomson or Avon River a tailwater level as low as a 1 in 1 AEP event would be extremely unlikely.



n Figure E-11 Difference in 1 in 100 AEP level with Lake Wellington at 0.4 and 2.2 m



n Figure E-12 Long Section – Latrobe with Lake Wellington at 0.43 and 2.2 m AHD

J.5 Proposed Approach

Based on the information presented in this Appendix the level in Lake Wellington will be based on the volume of the flood event entering into Lake Wellington with the level reached in Lake Wellington being in accordance with the relationship shown in Figure E-10.

Appendix K Flood Planning Maps

Appendix L Flood Emergency Maps

Appendix M Historical Maps

Appendix N Climate Change Maps

Appendix O Bushfire Maps

Appendix P Blockage

P.1 Maffra-Rosedale Rd

P.2 Railway just north of Princes Hwy

P.3 Princes Hwy

Appendix Q Manning's n Maps