Hydraulic Calibration Report

Flood Risk Management Study – Lower Barwon River and Lower Moorabool River

Corangamite CMA, City of Greater Geelong and Golden Plains Shire Council

January 2018

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1. INTRODUCTION

1.1 Overview

Corangamite CMA in partnership with the City of Greater Geelong and Golden Plains Shire Council engaged Water Technology to undertake the Lower Barwon and Lower Moorabool Rivers Flood Risk Management Study. The overall objective of this project is to review and revise existing flooding information and produce detailed flood mapping for a range of flood modelling scenarios within the study area. The project will undertake a definitive flood investigation for the floodplain reaches within the study area, including collation of available relevant data, a comprehensive hydrological assessment, and determination of robust flood levels, velocities, depths and extents for a range of design floods. The project will develop an improved understanding of flood behaviour to enable improved land use planning and emergency response. This document is the third of a series of technical reports which will be prepared during the study. This report documents the development and calibration of the hydraulic model.

1.2 Study Area

The study area is defined by the lower reaches of the Barwon River and the Moorabool River to the mouth of the Barwon River including Waurn Ponds Creek and a number of small tributaries (Figure 1-1). The study area extends upstream to the Bates ford streamflow gauge on the Moorabool River and the Pollocksford streamflow gauge on the Barwon River.

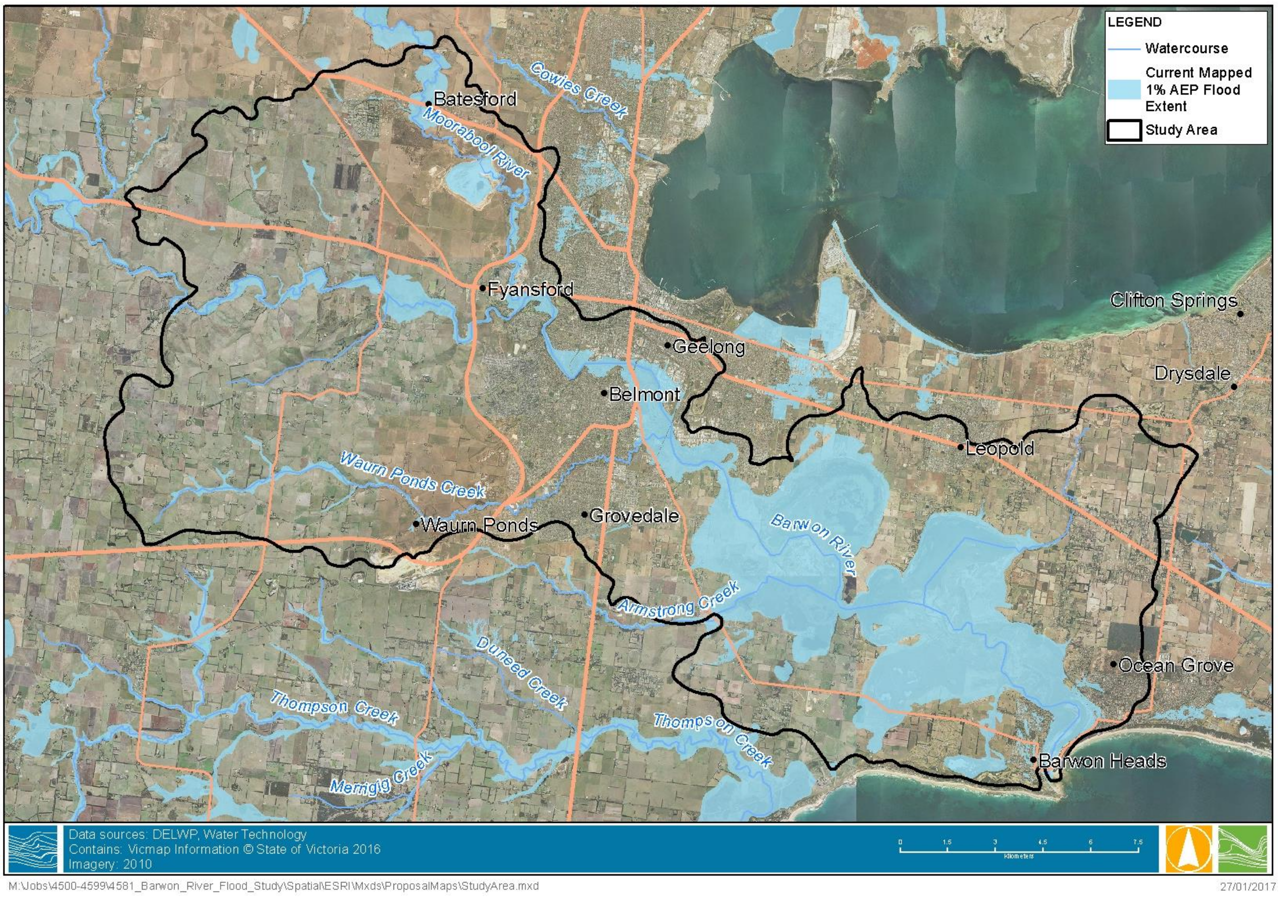

Figure 1-1 Study Area

The Barwon River and Moorabool River are large river systems with a combined catchment area of 5,130 km^2. The Barwon River catchment is the larger of the two systems with an area of approximately 2,800 km^2 upstream of the Moorabool confluence whilst the Moorabool River has a catchment area of approximately 1,150 km^2. Of note is the Woady Yaloak River diversion into the Barwon River. This waterway normally drains into Lake Corangamite, but during floods is diverted into Warrambine Creek which flows into the Barwon River upstream of Inverleigh. The Woady Yaloak River catchment area is approximately 1,360 km^2. A number of tributaries such as Waurn Ponds Creek and Armstrong Creek flow into the Barwon River within the study area, along with several other smaller creeks.

2. MODEL DEVELOPMENT AND SCHEMATISATION

The following section provides detail on the development of the hydraulic model including the model schematisation and key inputs.

2.1 Modelling Approach

The approach adopted for the hydraulic model is a 1D/2D MIKE FLOOD coupled model, using flexible mesh and GPU technology.

Flexible mesh refers to an unstructured grid, compared to conventional hydraulic models that consist of grid cells (squares) of uniform size. The flexible mesh uses triangles and quadrilateral shapes which can vary in size and geometry. This enables modelling with smaller mesh resolutions within the channel and banks of waterways or in areas of interest, and larger mesh elements on the outer floodplain areas or in deep, flat wetlands for example.

MIKE FLOOD 2017 allows for the coupling of a 2D flexible mesh domain with a 1D network. Simulations utilise parallelised calculations via the Graphics Processing Unit (GPU) for the 2D component and the Central Processing Unit (CPU) for the 1D component. This parallel solution technique results in increased calculation speed, allowing for higher precision (greater resolution) without drastically increasing simulation times.

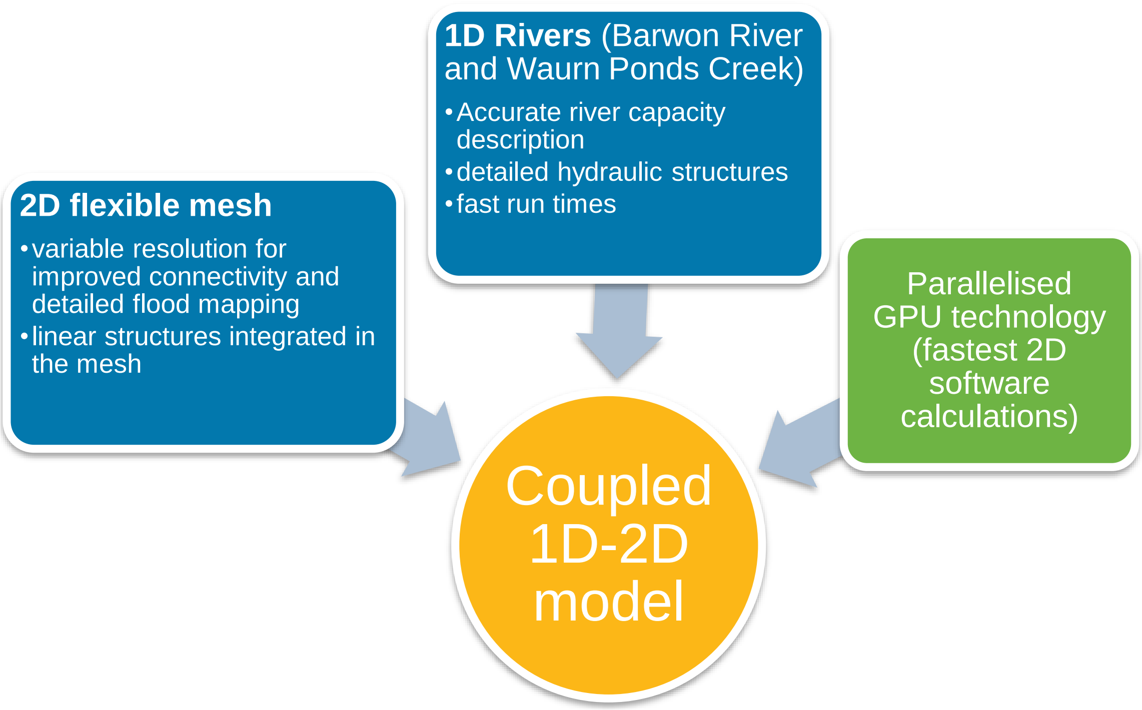

Figure 2-1. 1D/2D modelling concept

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2.2 Topography

A number of topographic and structural survey data sets exist across the study area and are described below.

2.2.1 LiDAR

Various DELWP LiDAR data sets of differing coverage, accuracy, and currency were available for use, however following a review of these it was determined that newly captured LiDAR should be acquired given deficiencies in the quality of the existing datasets. The Corangamite CMA commissioned new LiDAR to be captured over the entire study area, as detailed in Table 2-1. The LiDAR was flow in in early January 2017.

Table 2-1 Details of Newly Captured LiDAR

Date of Capture	DEM Resolution	Vertical Accuracy	Horizontal Accuracy
5-7 January 2017	1 m	±0.10 m	±0.20 m

Water Technology conducted a review of the newly captured LiDAR including comparing it to accurate ground verification survey data. The verification survey was captured along flat road crests at various locations across the study area by St Quentin Consulting surveyors in April 2017.The comparison found that whilst there was generally a good overall agreement between the LiDAR and the ground survey, with a mean difference of -0.1 m, the LiDAR appeared to be less accurate in the Northern part of the study area, showing a mean difference of -0.33 m compared to the ground survey. Additional ground survey was undertaken by the surveyors in the Batesford area in May 2017 in order to further investigate the discrepancy in the Northern part of the study area. Comparisons with the additional survey data confirmed that there were some issues with the LiDAR accuracy, showing a mean difference of -0.3 m.The LiDAR supplier was requested to investigate and re-process the LiDAR data, which was completed in June 2017. Further comparisons of the re-supplied LiDAR with the ground survey showed acceptable differences and the revised LiDAR data was considered suitable for use in the hydraulic model development. The final LiDAR data set and the location of the ground survey points used in the comparison are shown in Figure 2-2.

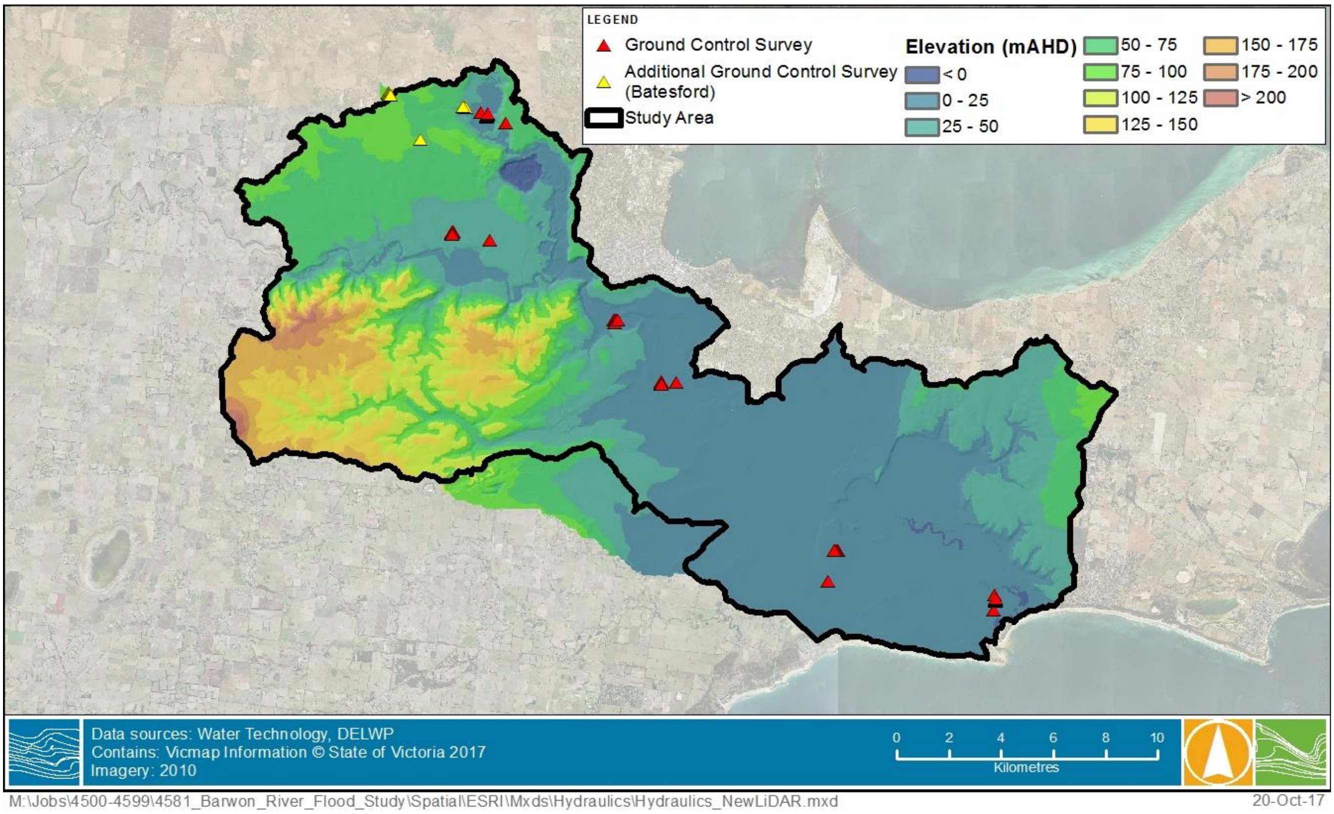

Figure 2-2 Newly Captured LiDAR and Location of Ground Survey Points

2.2.2 Bathymetry

Detailed hydrographic survey data for the lower Barwon River (from the Moorabool River confluence to the river mouth at Barwon Heads) was made available from the Corangamite CMA for use on the project. The raw survey data was interpolated by Water Technology using ArcGIS 3D Analyst tools, to produce a regular 1 m grid of bathymetric depths within the Barwon River channel.

This gridded bathymetric DEM was then merged with the newly captured LiDAR, producing a combined DEM that gives the best possible representation of both the study area topography and also the Barwon river channel profile.

Bathymetric levels of Lake Connewarre and the adjacent wetlands, which were produced by Water Technology on a previous study for Corangamite CMA, were also used in the final merged DEM, as they provided a better representation of the lake bed than the LiDAR. The bathymetric data used in the final merged DEM is shown in Figure 2-3.

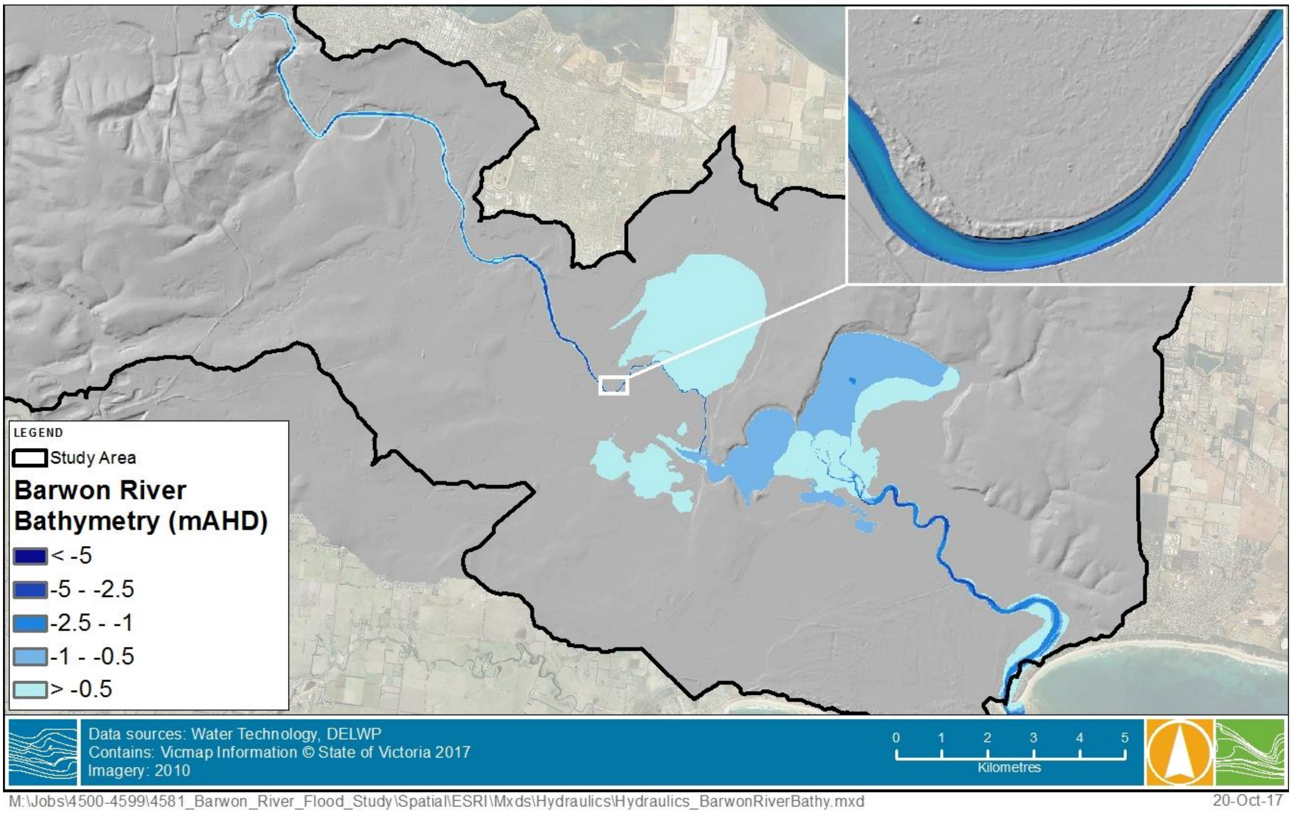

Figure 2-3 Bathymetry Data Used in the Final Merged DEM

2.3 Roughness

The Manning's 'n' roughness parameter has important effects on flood velocities, flow paths, flood depths and extents. Manning's 'n' roughness values were derived from the latest planning zone data. The map was developed using satellite imagery and has been refined manually based on aerial imagery. Roughness values were assigned based on industry standard practice and were assessed during sensitivity analysis of the hydraulic modelling. The list of Manning's 'n' values applied to the 2D hydraulic model are shown in Table 2-2-2.

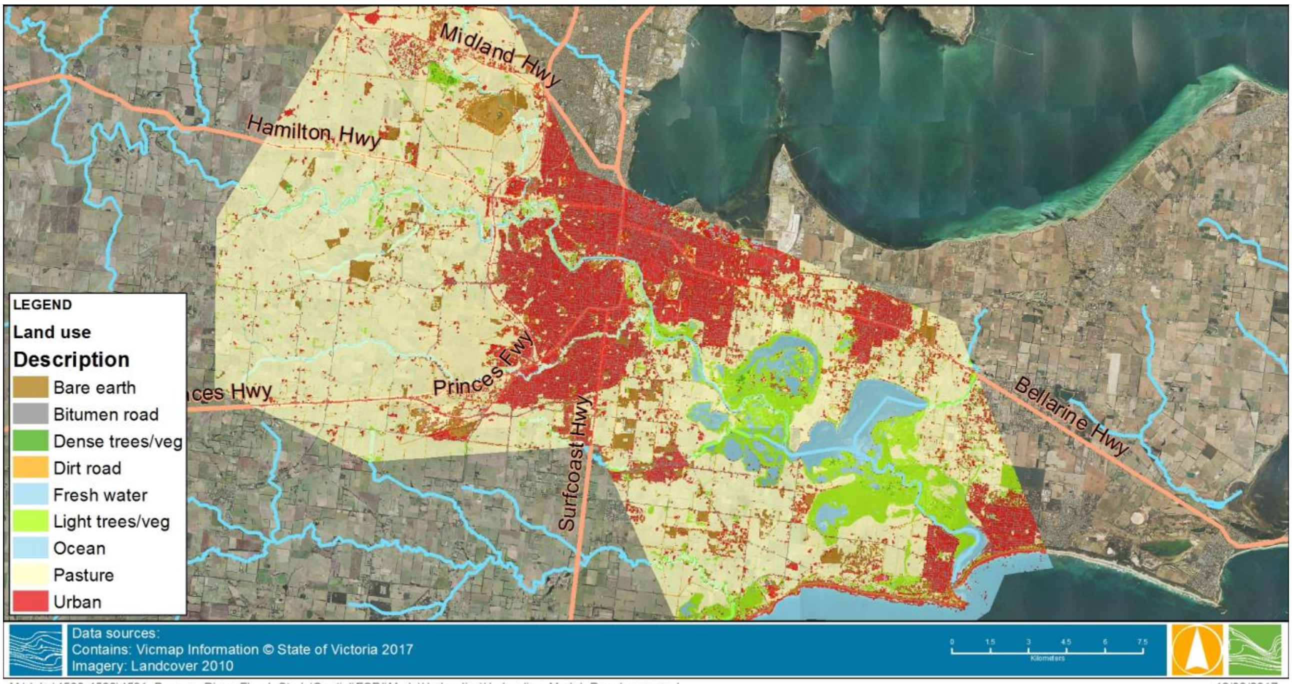

Figure 2-4. Roughness map

Table 2-2-2. Roughness coefficients applied to the 2D model

Land use type	Manning's 'n'
pasture	0.04
bitumen road	0.02
dirt road	0.03
Urban	0.10
light trees/veg.	0.05
dense trees/veg.	0.07
bare earth	0.03
ocean/fresh water	0.02

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2.4 Mesh development

The MIKE mesh generator software was used to develop the structure of the mesh. The mesh was developed iteratively, starting with a coarse mesh for more efficient modelling (faster runs), with iterative refinements to provide improved connectivity through the various floodplains, accurate flood extents and achieve a better calibration. The compromise between run-time and model resolution is key to the model development. The 2D mesh can be supplemented with detailed linear features called dike lines, representing roads, channel banks and levees.

The mesh is developed by digitising essential hydraulic and topographical features by way of polylines and/or polygons, such as waterways, channels, roads and levees that will dictate the triangulation of elements within the domain. Mesh resolution parameters (e.g. maximum element size) are also defined for specified areas, thereby enforcing finer elements where needed to represent smaller drainage lines and larger elements within Lake Connewarre and Reedy Lake for example.

Several linear structures such as roads and levees that had potential to act as hydraulic controls, were added to the 2D domain using “dike” structures. Dikes in the model are polylines that control the flow through specific geometry which can be sampled from the detailed LiDAR information. The location and crest levels of these features were extracted from the LiDAR and overtopping is calculated in the model via weir equations.

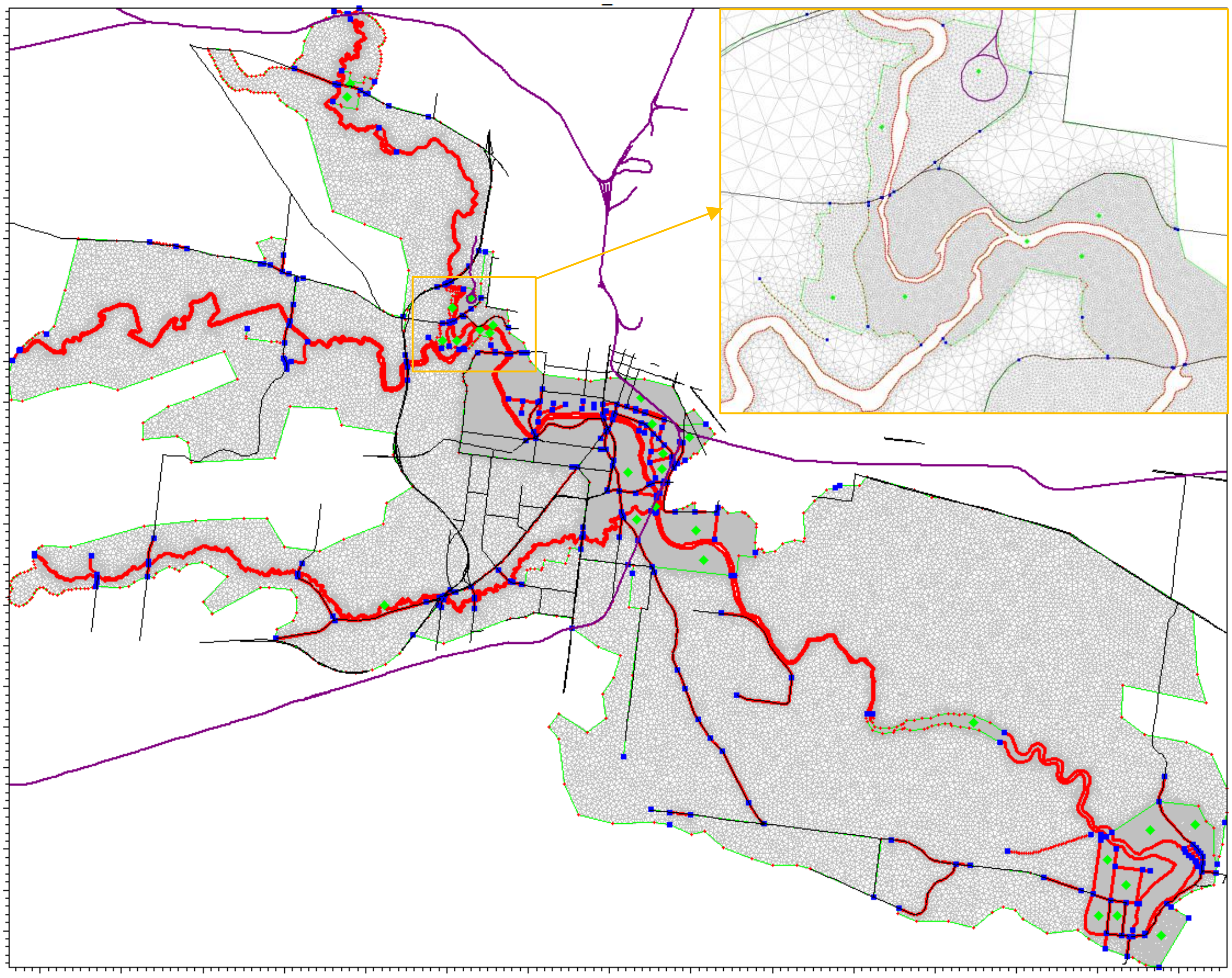

Figure 2-5 Flexible Mesh structure

2.5 1D model

The Barwon River from Shannon Avenue to the Lake and Waurn Ponds Creek are described via a 1D model representation.

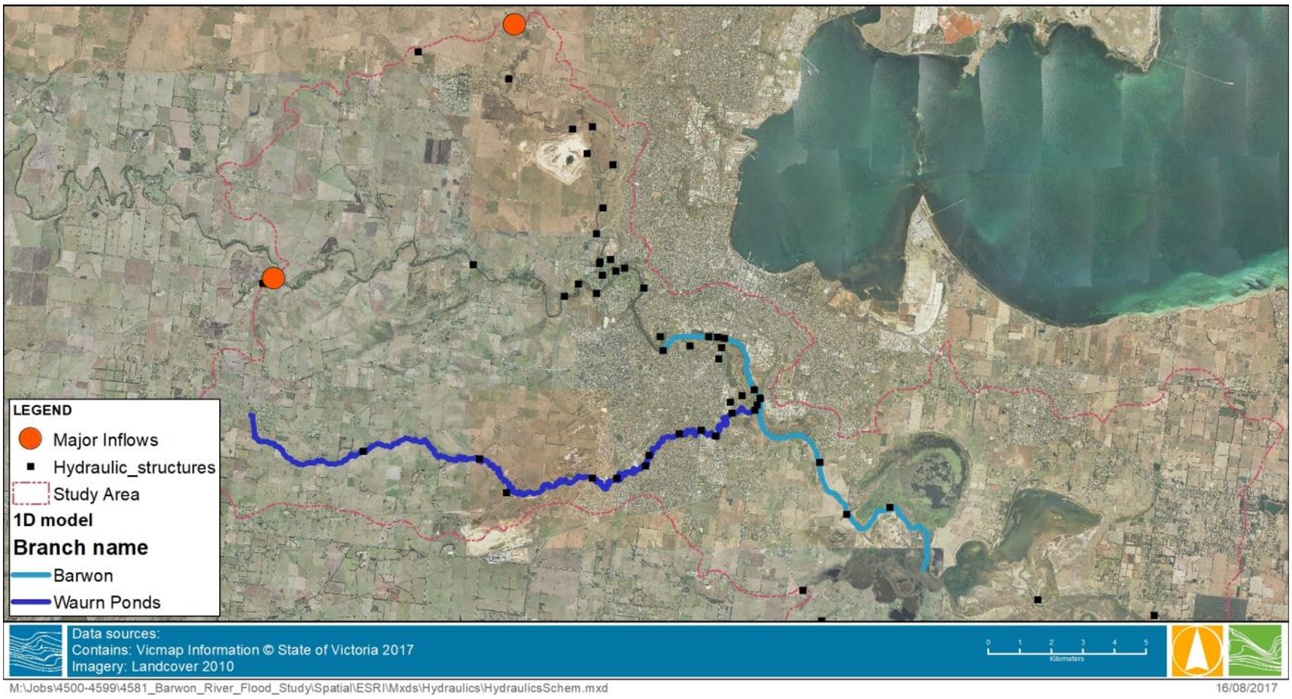

Figure 2-6 1D branches reaches

A number of hydraulic structures have also been added in the model via 1D branches linked to the 2D model. This approach allows to explicitly include these structures and accurately describe their geometry in the 1D model. The cross-sections representing the main channel capacity have been extracted from the DEM built from the merging of LiDAR and bathymetry survey. The river bed as well as the river banks are accurately modelled within the 1D component.

Cross-sections spaced at a maximum interval of 200 m are included in the 1D model. The spacing between cross-sections is as low as 5 m in some locations.

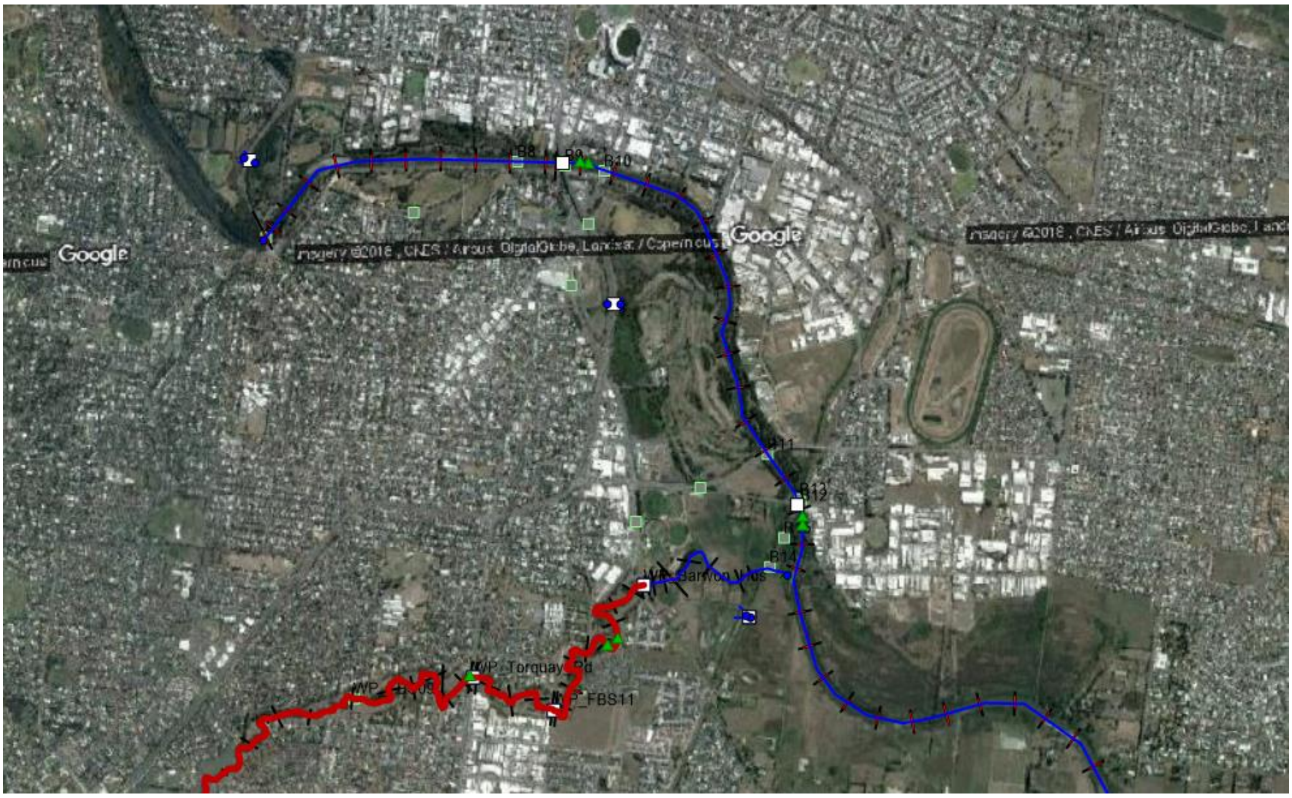

Figure 2-7 Coupled model showing the 1D and 2D components around the confluence of the Barwon and Moorabool rivers

All structures impacting the flow along the main channel of the waterways are included in the 1D model. These include bridges, weirs and culverts. A few examples of structures in the model are given in the following figures.

Lower Barrage

Figure 2-8 Example of 1D structures (Breakwater Road and Lower Barrage on the Barwon River, Culverts under Rossack Drive on Waurn Ponds Creek.

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Barwon River from Shannon Ave bridge to the Lake entrance and Waurn Ponds Creek is represented along its entire reach length in 1D, laterally linked to the 2D floodplain. The length of watercourses represented in the 1D model are as follows:

- Barwon River: 14,622 m;
- Waurn Ponds Creek: 25,505 m.

2.6 Linking the models

MIKE Flood is a coupling software that dynamically links 1D and 2D components in a single model. The fluxes are exchanged both ways via links between the rivers (1D) and floodplains (2D). Lateral links allow linking between the banks of a river and the floodplain, to capture any overflow that may occur, as described in Figure 2-9.

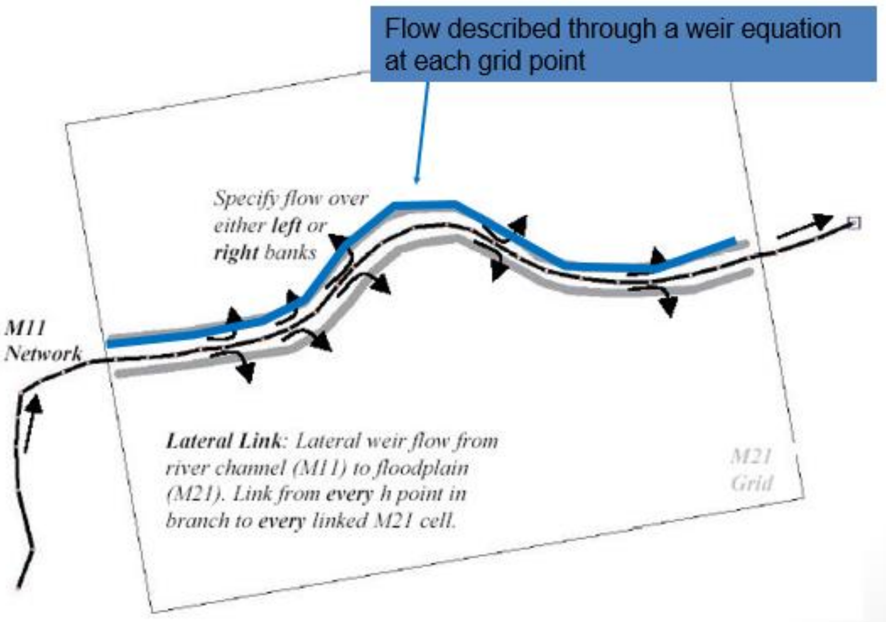

Figure 2-9 Lateral links between 1D and 2D models

1D water level calculation points are connected to 2D cells and water is exchanged between the channel and the floodplain based on water levels in either domain. Therefore, flooding above banks and returning flows to the river bed are dynamically calculated along the laterally linked branches. A distinction is made between the right and left bank of the river, it is therefore important to accurately describe bank levels in the two models (1D and 2D).

The coupling of 1D and 2D models takes advantage of both technologies within a unique integrated model. 1D models are particularly well adapted for the description of flows within rivers and different hydraulic structure formulations, with very fast calculations. 2D models allow for flow calculations within a floodplain where the direction of flow is unknown and accurate depth and velocity mapping is required.

The Barwon River and Waurn Ponds Creek are entirely linked to the 2D model on both sides. Special attention has been applied to the accuracy of the overtopping levels on each reach.

2.7 Boundary Conditions

2.7.1 Inflows

Barwon and Moorabool rivers

Upstream boundaries for the Barwon River and Moorabool River are located at streamflow gauges. The gauge record during past events at these gauges was used for calibration when available. For design flood modelling, the inflows are based on flood frequency analysis and scaling of historic hydrographs. This is described further in the hydrology report (Water Technology 2017).

Waurn Ponds Creek

For Waurn Ponds Creek a hydrologic model, using the rainfall-runoff program RORB, was developed to determine historic and design inflows at various locations along the waterway.

Local tributaries

A number of small, local tributaries of the Barwon and Moorabool Rivers will be flood mapped within this study. Most of these local tributaries have very small upstream catchment areas which means using a traditional methodology based on a rainfall runoff model has some limitations. For this reason, a direct rainfall approach is to be adopted whereby rainfall will be applied directly to a hydraulic model across the entire catchment area of each local tributary. The modelling of the local tributaries will occur once the modelling of the main waterways has been finalised. Downstream conditions in the local tributary sections will be set by applying tailwater levels determined from the modelling of the main waterways.

The direct rainfall hydrology utilised in the modelling is detailed in the hydrology report while the results of the hydraulic modelling will be presented in the draft study report.

It is noted that runoff from the local tributaries is not being considered in the main hydraulic model of the Barwon and Moorabool Rivers, other than Waurn Ponds Creek. Peak flood levels along this reach are driven by upstream catchment flows and runoff from the local tributary catchments has a minimal contribution, both in absolute terms and with respect to timing of peaks. This has been confirmed by modelling a range of calibration events with good calibration being achieved in these events with no local tributary runoff accounted for.

2.7.2 Downstream boundary

The Barwon River has a coastal influence, with tide, storm surge and estuary entrance conditions likely to influence flood levels in the lower sections of the Barwon River and Lower Barwon Wetlands. Coastal processes influencing the estuary include tides, storm surge, and entrance conditions. The mouth of the Barwon River is one of the few rivers along Victoria's southern coastline which remain permanently open, discharging to Bass Strait.

The downstream boundary of the model is the estuary and river mouth at Barwon Heads. Ocean water levels were applied to represent tidal variations during the historic flood events. The closest ocean monitoring station is located at Lorne which is owned by the Port of Melbourne Corporation (PoMC). Observations are available at this station from 1993 onwards. This data will be used for the calibration and validation event modelling.

The tidal gauge at Lorne demonstrates a wide range of tidal conditions as shown in Figure 2-10 and Table 2-2-4, including a storm surge of approximately 0.4 m in addition to the spring high tide. The tidal range at Lorne is shown to be up to 1.8 m which is similar to Barwon Heads given their close proximity. Records (Hinwood and Wallis, 1979) indicate that tides at Barwon Heads can be up to around 10 cm higher than Lorne due to amplification of the M2 lunar tidal constituent that occurs from Western Bass Strait towards Central Bass Strait.

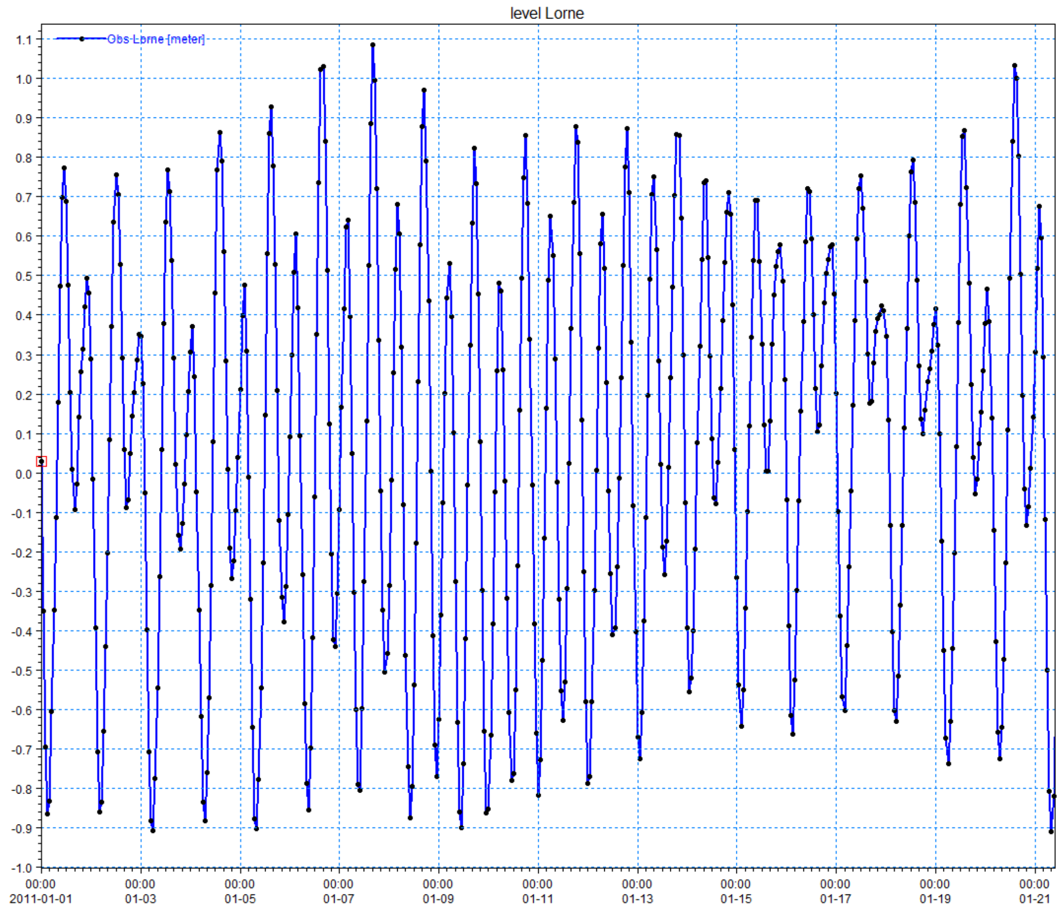

Figure 2-10 Ocean levels monitored at Lorne

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Table 2-2-3 Lorne Astronomical Time (PoMC)

Tide	Lorne Tidal Gauge (m AHD)
Highest Astronomical Tide (HAT)	1.3
Mean High Water Spring	0.8
Mean High Water Neap	0.4
Mean Low Water Neap	-0.4
Mean Low Water Spring	-0.8
Lowest Astronomical Tide (LAT)	-1.3

It is important to consider that there are two types of tidal phenomena that effect water levels in the lower Barwon River and estuary. The first is the astronomical tidal cycle which is driven by the gravitational forces of the earth, moon and sun. These tidal water levels can be predicted with great accuracy, well in advance. Observed tides are often different to the predicted levels due to the influence of local weather systems. These are referred to as meteorological tides.

The metrological conditions which drive catchment flood events in coastal areas may also generate elevated ocean water levels (termed "storm tides"). In the Barwon River system, parts of the catchment may experience rainfall at the same time as the storm tide occurs. However, the large scale of the Barwon River catchment means that typically the peak of the storm tide will have passed before the peak of the catchment-generated flood reaches the lower floodplain. Furthermore, two barriers located on the Barwon River (Breakwater Road and Barwon Barrage at Reedy Lake, downstream of Geelong) block the tidal wave from progressing upstream and limit the effect of ocean levels on inundation extents in Geelong.

Storm surge is the common term used to describe variations in coastal water levels that exceed that which can be attributed solely to the astronomical tide. Storm surges are generated by meteorological processes that include the inverse barometric pressure affect, coastally trapped waves and wind setup leading to an increase in sea-level over a number of days. Subtracting the predicted water-level variation due to the astronomical tide from the observed water-level record determines the tidal residual.

To develop a representative storm tide scenario that captured the critical temporal and spatial characteristics of storm tides, analysis of available storm surge and meteorological data at Lorne was undertaken. This analysis produced estimated existing conditions 1% AEP and 10% AEP Storm Tide water levels as shown in Table 2-5.

Table 2-2-4 Estimated Lorne storm surge and storm tide levels – Existing Conditions[1]

Average Recurrence Interval (years)	Average Exceedance Probability (%)	Storm Surge (m AHD)	Storm Tide (m AHD)
10	10	0.84	1.56
20	5	0.9	1.63
50	2	0.97	1.73
100	1	1.02	1.82
200	0.5	1.07	1.92

[1] Port Philip Bay Coastal Inundation, Water Technology, 2017

In the absence of any closer, long-term tidal record and given the proximity of the Barwon River mouth to Lorne, it was considered reasonable to use the assessment of recorded tidal influences from Lorne at Barwon Heads. The Storm tide levels adopted as part of the design modelling are shown in Table 2-5.

Table 2-5 Adopted Storm Tide levels at Barwon Heads – Existing Conditions[2]

Location	Waves (Hs)	1% AEP Storm Tide	10% AEP Storm Tide
	(m)	(m AHD)	(m AHD)
Barwon Heads	3.0-4.6	1.82	1.56

Further to the assessment of oceanic water levels at the estuary consideration must also be given to the coastal processes which may influence the mouth of the estuary during major flood events. A detailed study of the physical processes which occur in relation to sand scour and equilibrium have been studied at Barwon Heads following flooding which occurred on the Barwon River in 1978. This study "The stability and Variability of a Coastal inlet and Fixed Bed and Mobile Side"[3] investigated, over a 3-year period, how the water levels and profile of the Barwon River mouth responded to changed flow and meteorologic events. The study results concluded that whilst the depth of the inlet remained fixed by the underlying bedrock the cross-sectional area and width of the channel tended to expand and retreat in response to changing river flows. Results also indicated that flood flows influence the cross-sectional area of the river mouth the most (causing enlargement) however it is also noted that the nature and rate of recovery to the system was also rapid following floods. The most important finding being that the inlet is observed to enlarge in response to flood conditions.

[2] Port Philip Bay Coastal Inundation, Water Technology, 2017
[3] The Stability and Variability of Coastal Inlet with Fixed Bed and Mobile Sides, R.C Nelson and A.J Keats, 1978

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3. MODEL CALIBRATION

This section discusses the refinement of the hydraulic model parameters through calibration against observed flood levels, extents and water level data, and outlines the validation of adopted model parameters.

The calibration process consisted of systematic comparison of observed and modelled water levels and flood levels/extents. Surveyed flood marks, general observations and aerial photographs of the floods formed the basis of the calibration. The model parameters were adjusted to obtain the best correlation between the modelled and observed data. The validation process applied the calibrated model parameters to another flood event to assess model performance. In total, the model performance was calibrated and validated to four historic floods.

It should be noted that while flood mark survey is available for the calibration events, there is inherent inaccuracies in their collection and hence uncertainty in relation to the acquired levels. The levels are primarily based on flood debris marks which may be significantly higher or lower than the true peak due factors such as debris piling up on the upstream side of an obstruction or debris collecting on the recession of a flood, and obstructions causing a bow wave effect (with higher levels on the upstream face and lower on the downstream face).

A certain degree of judgement is required in the collection of this data and inaccuracies in the data at some locations are likely.

3.1 Calibration events

Model calibration was undertaken for the 1995, 2001 and 2011 flood events. The calibrated model was then validated against the most recent flood event that occurred in September 2016.

The boundary conditions were established based on available data at the time of each flood including tidal information from the Lorne sea level gauge.

Table 3-1 shows the estimated flood frequency of the different design flood events. This shows that there is a large gap between the 1995 flood and the other 3 events, which are all less than 5 year ARI magnitude.

Table 3-1 Estimated Flow Frequency of Calibration Events at Geelong (McIntyre Bridge)

Historic Flood	Est. Peak Flow (Ml/d)	Est. Frequency (AEP)	Est. ARI (years)
Nov 1995	95,990	3%	35
Jan 2011	28,080	30%	3
Apr 2001	27,043	30%	3
Sep 2016	19,440	40%	2

3.2 Calibration results

3.2.1 November 1995

The November 1995 flood is one of the largest on record. The large flood along the Barwon River through Geelong was the result of several days of significant rainfall within the upper catchment, with rainfall over 3 days ranging between 80-150 mm.

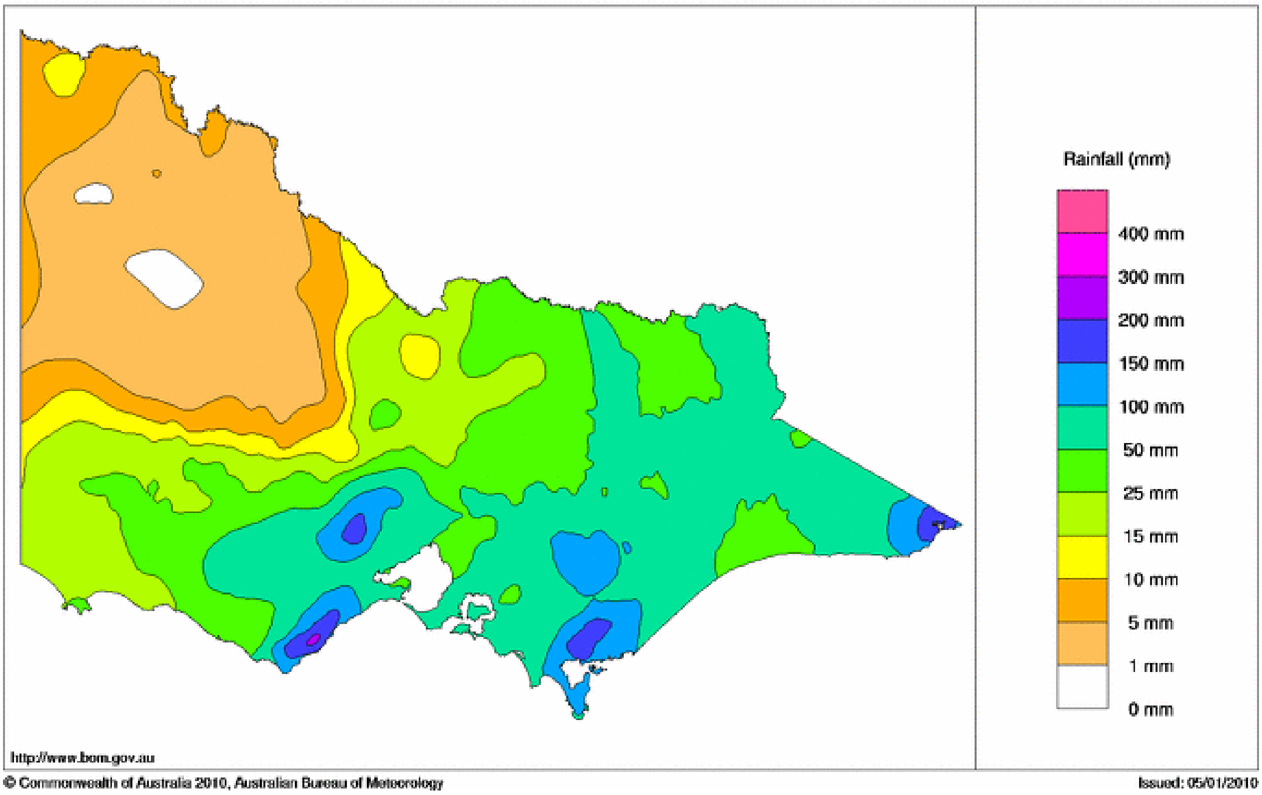

Figure 3-1 Weekly Daily Recorded Rainfall - Week ending 9/11/1995

Table 3-2 November 1995 – Event Catchment Rainfall

Daily Rainfall (mm)/ Station	Nov 3	Nov 4	Nov 5	Nov 6	Nov 7	Nov 8	Total
Forrest (090040)	0.2	-	-	113.8	40.6	0.4	**155.0**
Barwon Downs (090004)	0	0.4	36.0	57.6	27.2	0	**121.2**
Birregurra PO (090008)	0	-	-	54.6	5.0	0.6	**60.2**
Winch PO (090167)	0	-	-	58.0	32.0	1.0	**91.0**
Shelford (087059)	0	0	-	50.6	28.8	6.4	**85.8**
Grovedale (87163)	0.2	0	13.0	40.0	31.0	0.6	**84.8**
Barwon Heads (087010)	-	-	14.2	26.0	19.0	0.2	**59.4**

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The peak flow in the Barwon River at McIntyre bridge for the November 1995 flood is estimated to be approximately 1,100 m^3/s. This is 3 to 4 times larger than the other calibration events. It should be noted that no streamflow record exists at the gauge for this event. The flow estimation given above was calculated from a routing model (GHD 1997) as well as estimated peak water levels and the rating curve at that time. There is likely to be some uncertainty associated with this estimate.

Information available from flood warning documentation (Rural Water Commission) indicate the following stage water heights at McIntyre Bridge as shown below in Table 3-3 and Figure 3-2. This shows that the modelled rising limb and peak of the flood match very closely, whilst the model under estimates levels on the falling limb. This suggests there may be missing volume in the falling limb of the hydrograph.

Figure 3-3 shows a comparison of the gauged inflows and modelled combined flow for the Barwon River at McIntyre Bridge.

Table 3-3 Comparison of Recorded and Modelled Stage height @ McIntyre Bridge Geelong

Date, Time	Recorded Stage Height (m)	Modelled Stage Height (m)
7/11/1995, 6.00am	4.00	3.89
7/11/1995, 11.30am	4.40	4.31
7/11/1995, 6.40pm	4.98	4.91
7/11/1995, 10.45pm	4.98	5.07
8/11/1995, 4.00am	5.23	5.25
8/11/1995, 6.00am	5.2 (approx.)	5.24
8/11/1995, 4.00pm	5.0 (approx.)	4.67
9/11/1995, 9.00am	4.21	3.45
9/11/1995, 3.00pm	3.86	3.19
10/11/1995, 8.00am	3.1	2.71
11/11/1995, 8.20am	2.53	2.22
12/11/1995, 9.30am	2.19	Out of simulation period

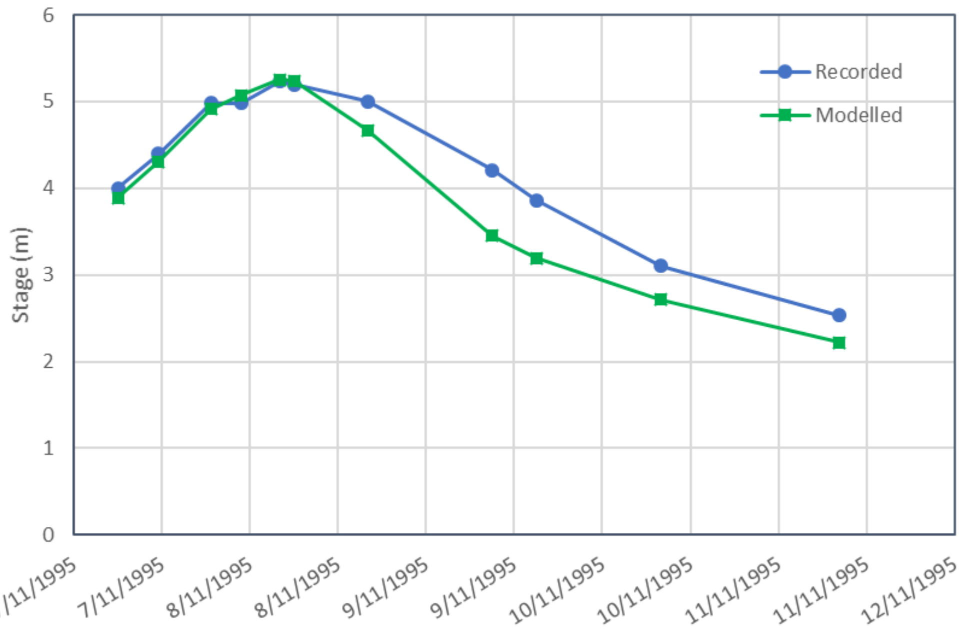


Figure 3-2 November 1995 flood – recorded and modelled levels at McIntyre Bridge

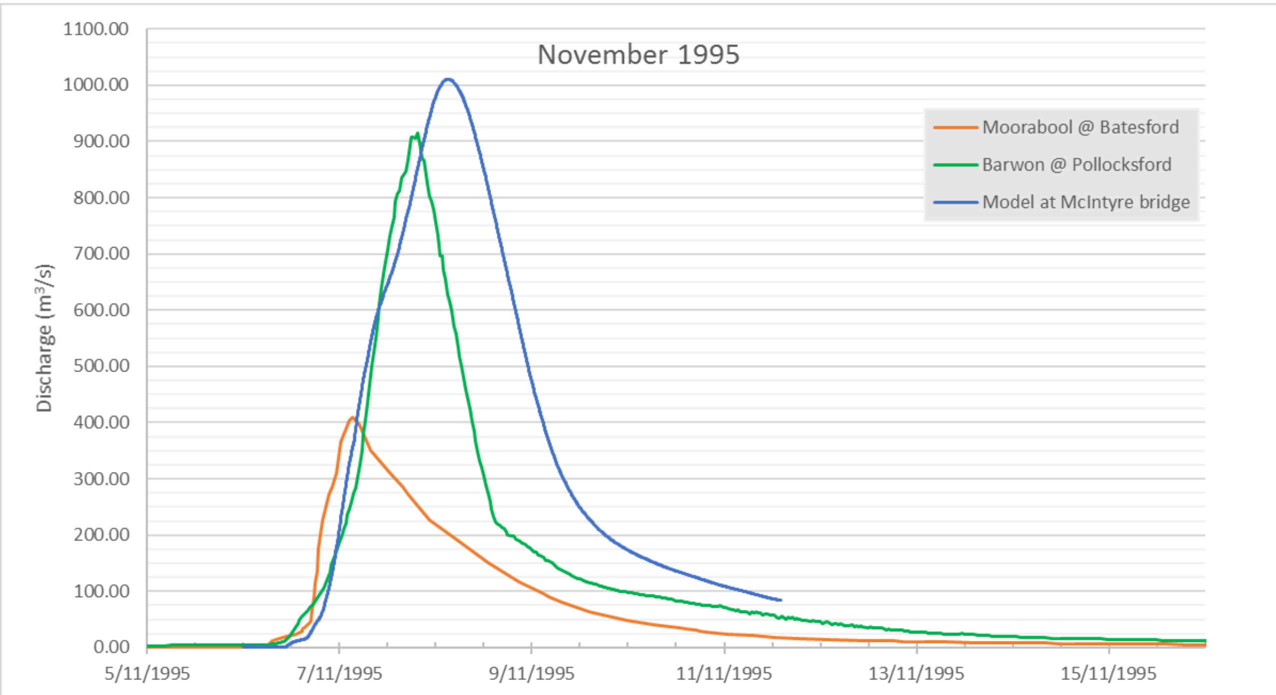


Figure 3-3 November 1995 flood event – streamflow gauges

The shape of the gauged hydrograph at Pollocksford has been queried in the past due to the steep nature of the falling limb and it having no regard for flood hysteresis. Flood hysteresis is rarely considered in rating curves, with a single curve nearly always applied for both the rising and falling limbs. It is known that in some locations hysteresis can result in significantly greater discharges on the falling limb when comparing the same water level on the rising limb.

Having regards to this the CCMA has reproduced the inflow hydrograph at Pollocksford as part of a prior investigation which compared the available gauge hydrograph and a the modelled RORB hydrograph developed by the CMA. Whilst the rising limb of the two-hydrographs match closely, the sustained peak and greater volume of the CMA RORB derived hydrograph is evident. Both scenarios were run as part of the calibration process to determine the effect on flood levels of the change in hydrograph shape and volume at Pollocksford. It is believed that the revised hydrograph provides a more accurate representation of flow at Pollocksford and has therefore been adopted in preference to the gauged record.

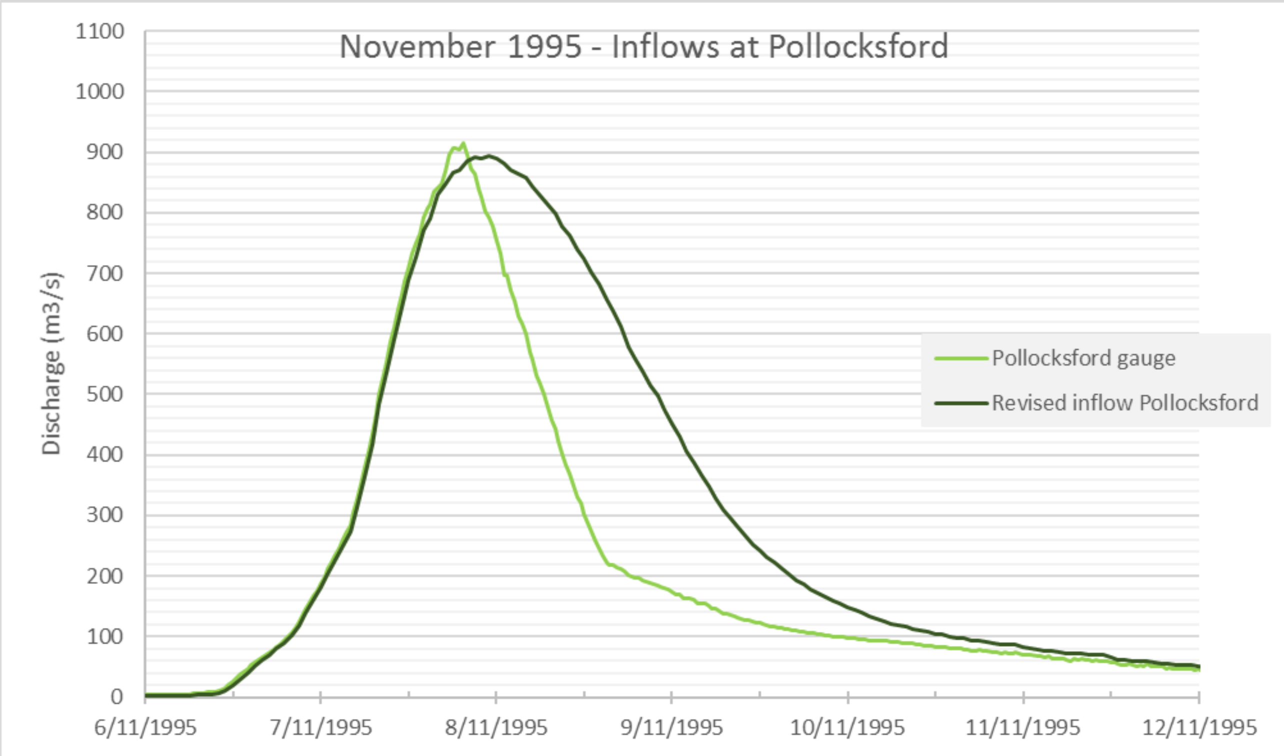


Figure 3-4 Comparison of gauge record and CCMA modelled hydrograph at Pollocksford

For the November 1995 flood a total of 11 flood marks were surveyed. The difference between the model results of the two scenarios and the flood marks are presented in Figure 3-6. These results show two marks upstream of the McIntyre bridge that are overestimated by the model. Calculated levels are between -0.51 and 0.41 m around the surveyed levels, depending on the inflow used at Pollocksford. At the streamflow gauge, the maximum level calculated by the model is 5.25 m AHD reached on November 8th around 4am. The peak level estimated at the McIntyre Bridge gauge location for the event is 5.16 m AHD, at the same time and date. Flood marks further downstream show the model generally calculates levels below the observed marks, with levels 5 cm to 40 cm below the surveyed marks.

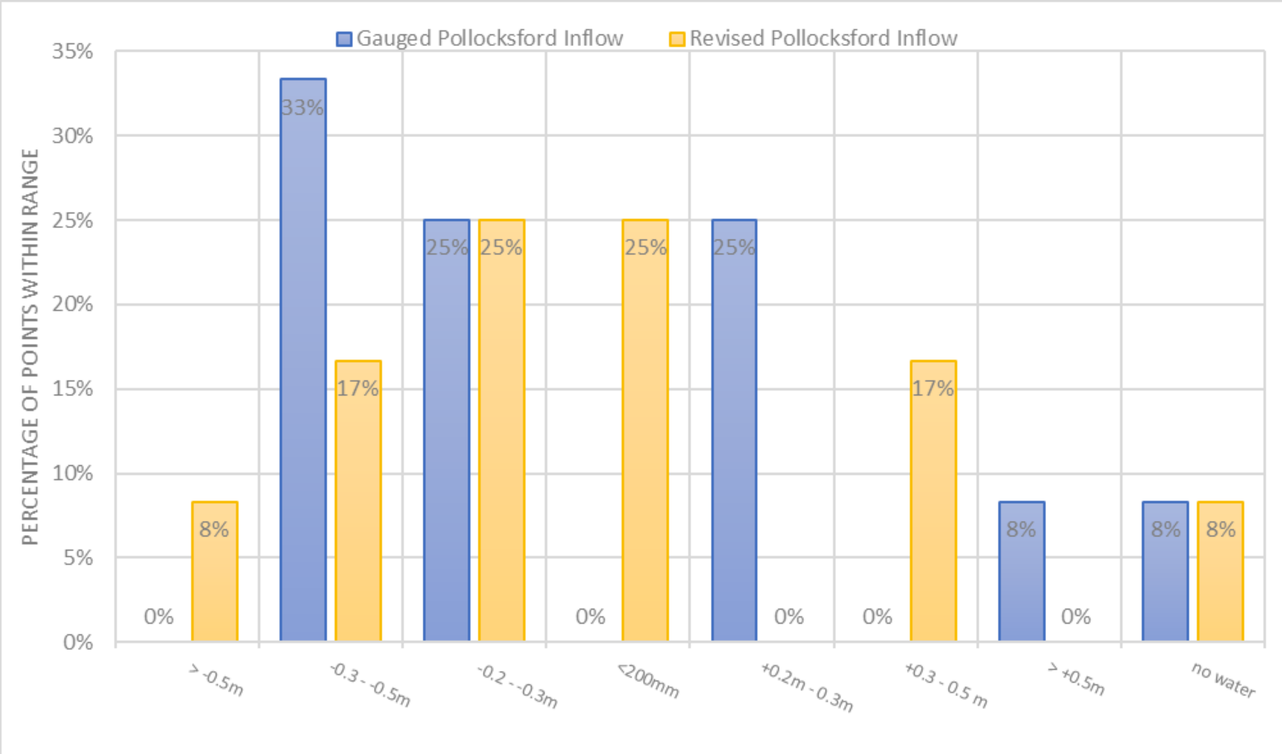


Figure 3-5 Flood marks. Level difference classification (November 1995)

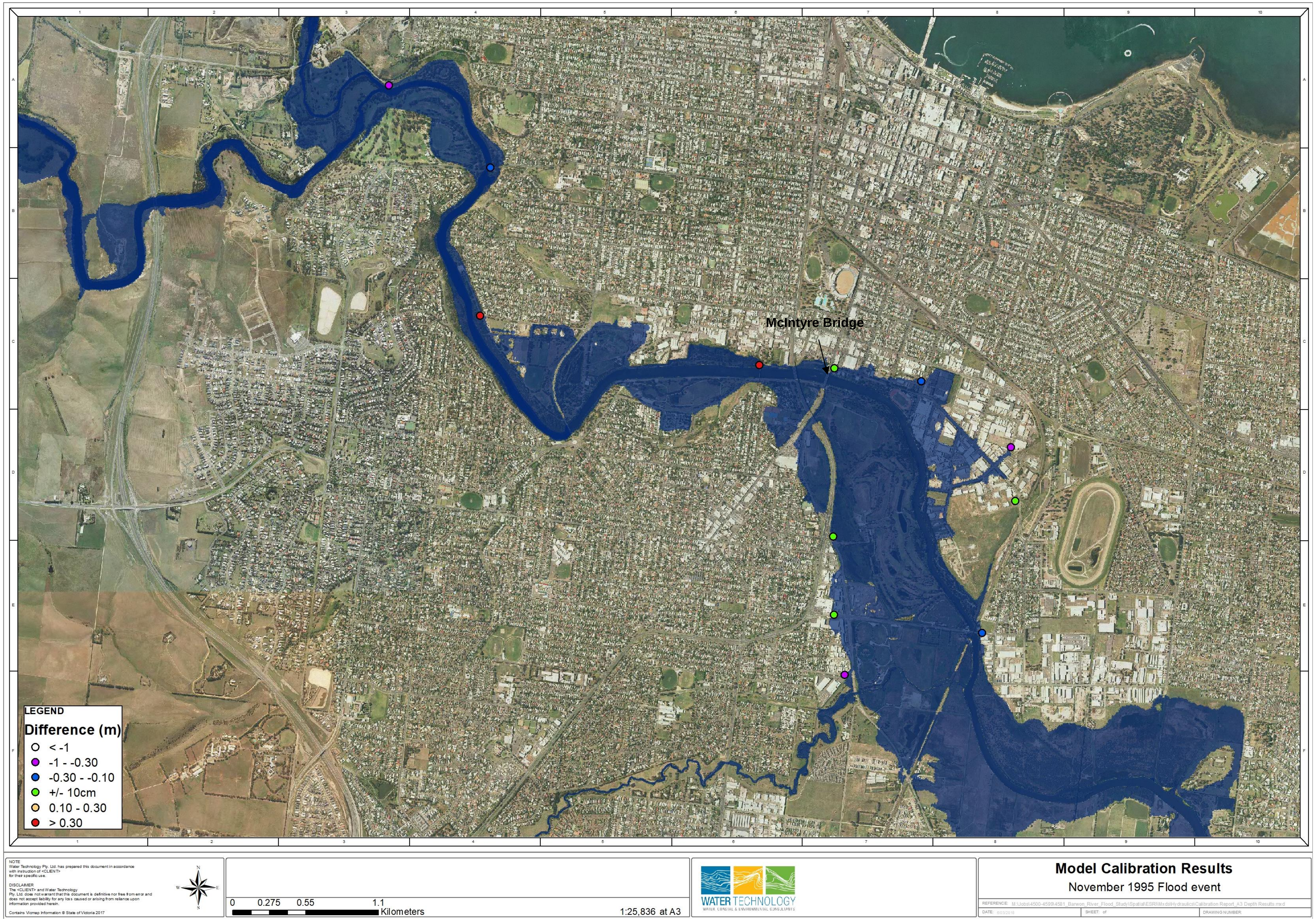
In Figure 3-5, results using the current gauge data indicates water level differences at most of the flood marks are within 300 mm (7/11), and at three locations present a difference greater than 300 mm. When applying the revised hydrograph at Pollocksford, the calculated levels are approximately 7 cm higher, thus improving the classification for several floodmarks, while also worsening the match at some marks. Using the revised inflow hydrograph six flood marks are within 300 mm (5/11), and five present a difference greater than 300 mm.

Table 3-4 Calibrated model flood level difference – November 1995

Mark_ID	Location	FL m AHD	Date	Mark collected by	X	Y	Model results - Difference	Results with revised Pollocksford hydrograph
nov95_1		4.68	8/11/1995	CoGG	269509	5771681	-99	-99.00
nov95_2	Barwon Heads Rd	4.83	8/11/1995	CoGG	268133	5771411	-0.30	-0.10
nov95_3	Swanston Street	5.06	8/11/1995	CoGG	268798	5772583	-0.30	-0.30
nov95_4	Corner of Woods and Dalton Streets	4.95	8/11/1995	CoGG	269477	5772087	-0.34	-0.34
nov95_5	Upstream Queens Bridge	7.48	8/11/1995	CoGG	265547	5774197	0.27	-0.24
nov95_6		4.62	8/11/1995	CoGG	268221	5770370	-0.40	-0.40
nov95_7		4.66	8/11/1995	CoGG	269257	5770686	-0.37	-0.21

Mark_ID	Location	FL m AHD	Date	Mark collected by	X	Y	Model results - Difference	Results with revised Pollocksford hydrograph
nov95_8	Downstream of Barwon bridge	5.1	8/11/1995	CoGG	268142	5772681	-0.12	-0.05
nov95_9		4.63	8/11/1995	CoGG	268140	5770823	-0.28	-0.05
nov95_10	Macintyre Bridge	5.23	8/11/1995	CoGG	267576	5772705	0.24	0.37
nov95_11	Moorabool River confluence	7.9	8/11/1995	CoGG	264781	5774817	0.18	-0.51
nov95_12	Balcombe Road	6.27	8/11/1995	CoGG	265469	5773079	0.66	0.41

Modelled flood extents for the November 1995 were compared to flood extent developed from various sources and available on the Victorian Flood Database. It is understood aerial imagery, flood information and previous modelling were analysed to create the extents. Various degrees of uncertainty are associated with the methods used to create the historic extent layers presented in the map below. Generally, it can be seen there is a very good correlation between the historic flood extent layers and the model results.


McIntyre Bridge
LEGEND
Difference (m)
< -1
-1 - -0.30
-0.30 - -0.10
+/- 10cm
0.10 - 0.30
> 0.30
NOTE
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Contains Vicmap Information © State of Victoria 2017
0 0.275 0.55 1.1
Kilometers
1:25,836 at A3
WATER TECHNOLOGY
Model Calibration Results
November 1995 Flood event

Figure 3-6 Flood map for the November 1995 event extent and flood marks.

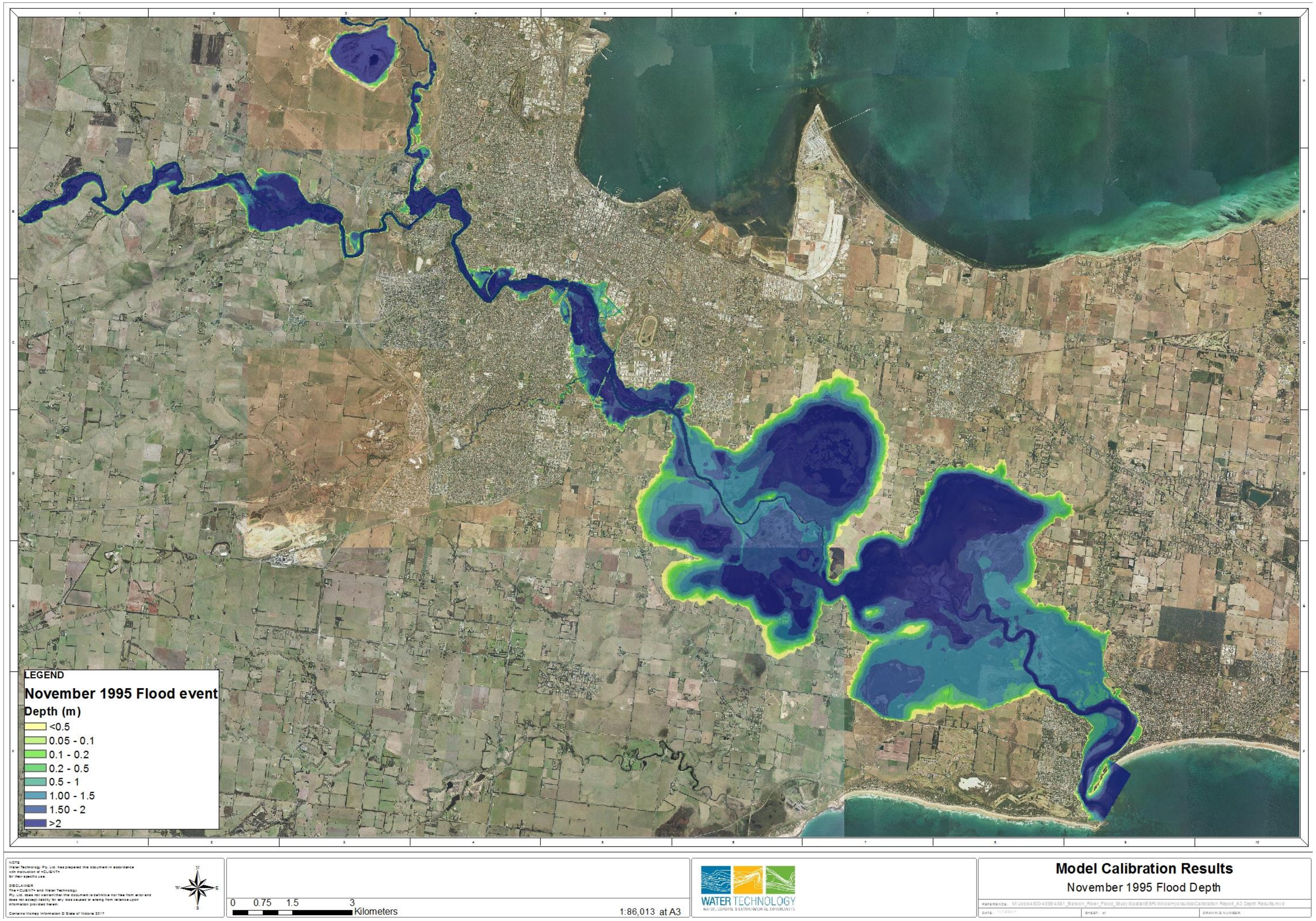

Figure 3-7 Flood extent map for the November 1995 calibration event

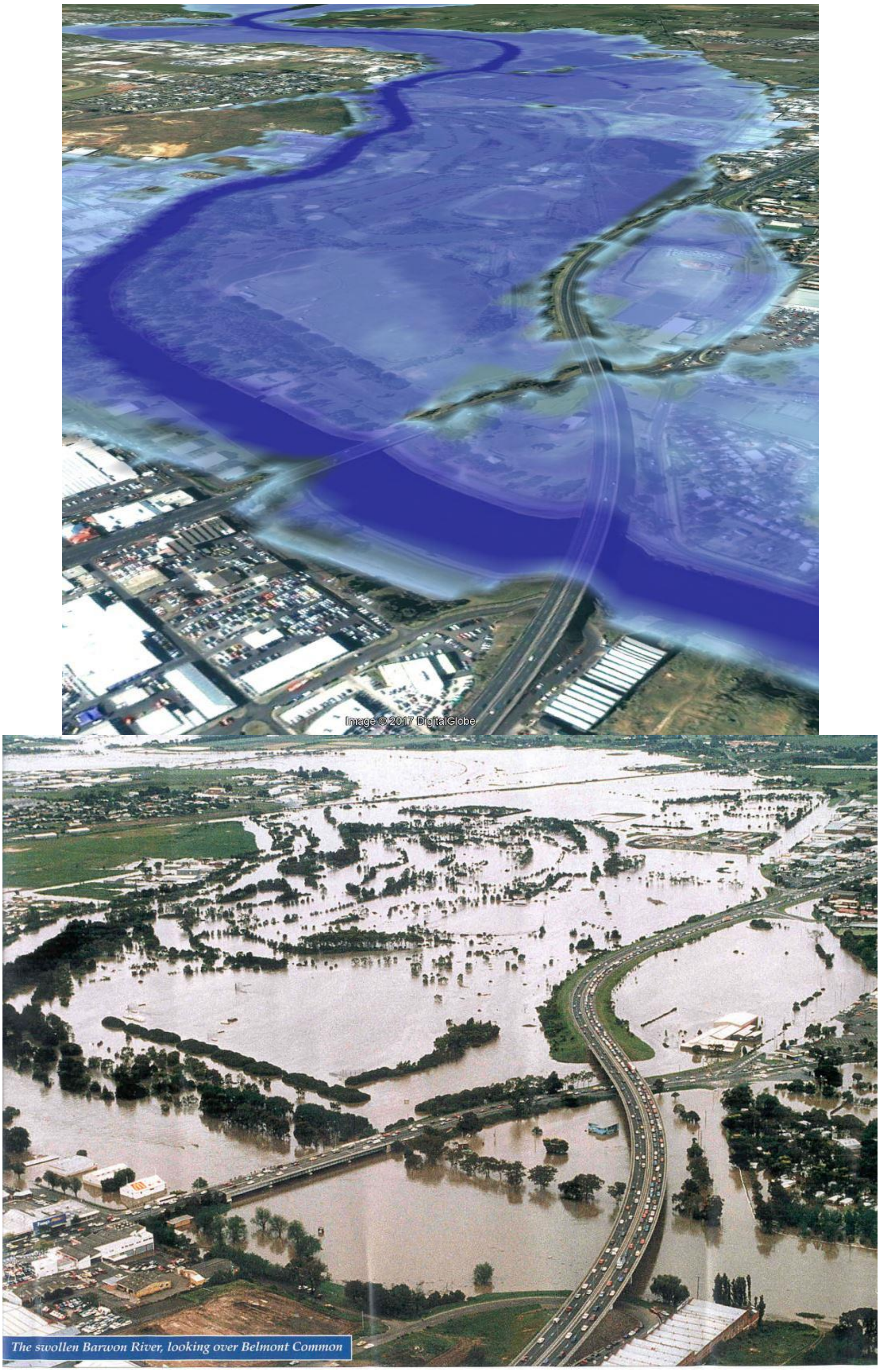

Figure 3-8 Aerial imagery and model results looking at the Barwon River from Belmont Common.

The results show a very good match between observed and calculated peak flood levels at McIntyre Bridge with a difference of only 70 mm. Across the model area flood extents and flood marks are generally well represented by the model. Differences at 8 out of 11 surveyed flood marks are within 370 mm. The model indicates no water at one of the flood marks but given the observed levels in the surrounding area, urban or local runoff could have been responsible for flooding at that location.

Upstream of McIntyre Bridge the results indicate the modelled levels are generally higher than observed. The differences could be due to the surveyed levels being underestimated or could also be related to the uncertainty in the gauged hydrograph at Pollocksford (as discussed earlier). The results upstream of the McIntyre bridge are satisfactory for the other calibration events, which suggests that the there is no uniform bias through that area of the model. The increased levels are isolated only to the November 1995 flood event and so could also be related to the known issues with the rating curve at Pollocksford and determining an accurate hydrograph.

Based on the results presented above the calibration for the November 1995 event in the hydraulic model is considered to be good.

Table 3-5 Modelled vs Recorded Flood Peak

	Flow (m^3/s) @ McIntyre Bridge	Stage Height (m) @ McIntyre Bridge	Time of Peak
Recorded	1111*	5.23	8/11/1995 4:00
Modelled	1010	5.25	8/11/1995 4:00

*Recorded streamflow sourced from GHD 1997 report which was derived from gauge rating at the time.

McIntyre Bridge 1995 Event Rating Curve Review

The hydraulic model results for the 1995 event were used to derive a rating curve at McIntyre Bridge which was compared with previous and current rating curves. Figure 3-9 below shows a plot of the current rating curve (5.0) at McIntyre Bridge against flow extracted from the model at the McIntyre bridge during the 1995 flood event modelling. The plotted curve includes both the rising and falling limb. In addition, the peak flows and water levels calculated by the model for the different calibration events are also marked (and described further in the following sections).

Overall it can be seen that the rating curve correlates well with the rising limb of the modelled hydrograph through the middle and upper flow range of the chart. There is some divergence in the curve at lower flow rates but given the model calibration has focussed on larger events it is possible the modelling is less reliable at lower flow rates. The McIntyre Bridge rating curve is discussed further below in Section 3.4.

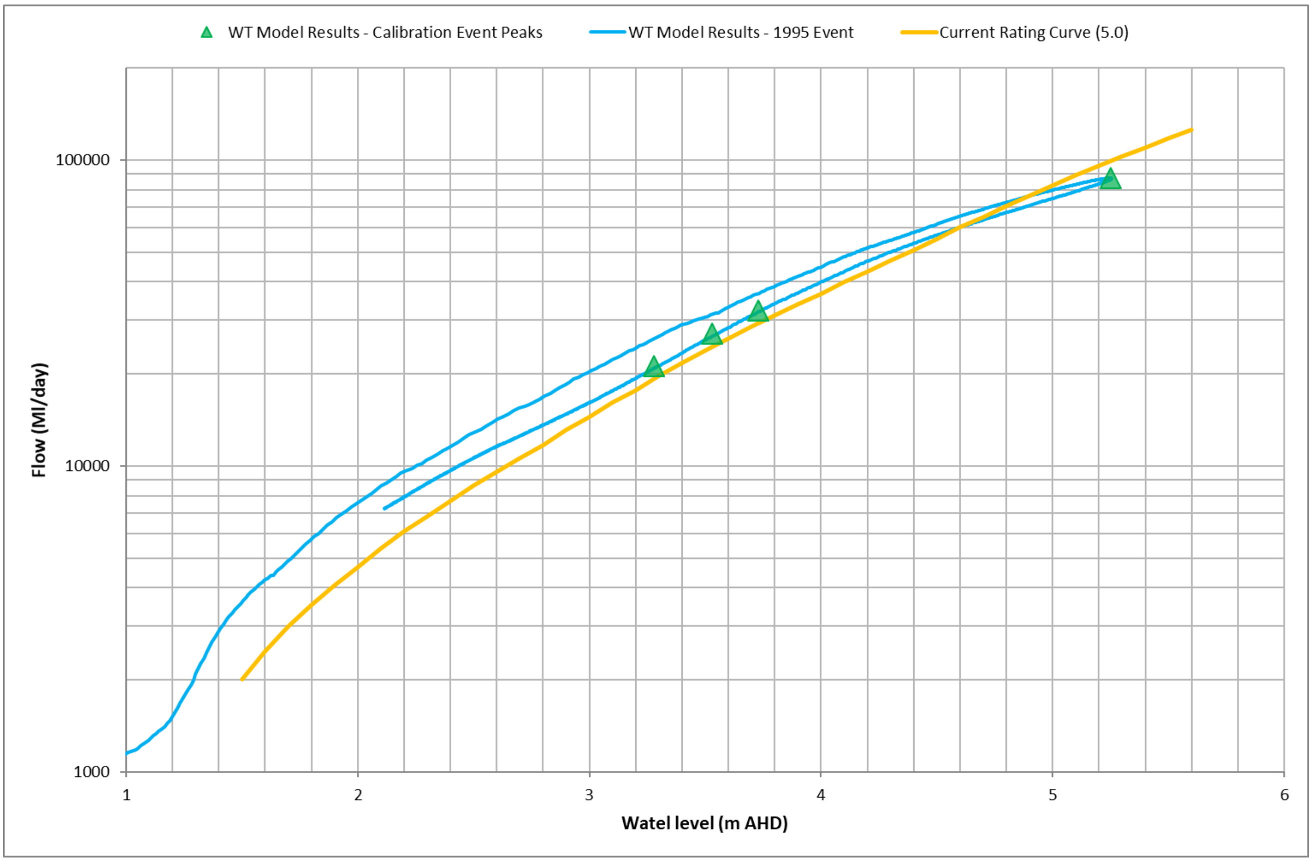

Figure 3-9 Rating curve and model results at McIntyre bridge

3.2.2 April 2001

In April 2001, flows in the Barwon River peaked at 300 m^3/s at McIntyre Bridge following three days of significant rainfall over the majority of the Barwon River catchment from the 21-24th of April 2001. Figure 3-10 shows the distribution of rainfall across the state for the week of 27th April 2001. The map shows significant rainfall in the upper Barwon catchment within the Otway Ranges. This rainfall resulted in minor flooding of the Barwon River through Geelong. Figure 3-11 shows the calculated hydrograph for the Barwon River at Geelong (RORB model) and the observed data. The hydrographs match well in terms of timing and peak flow.

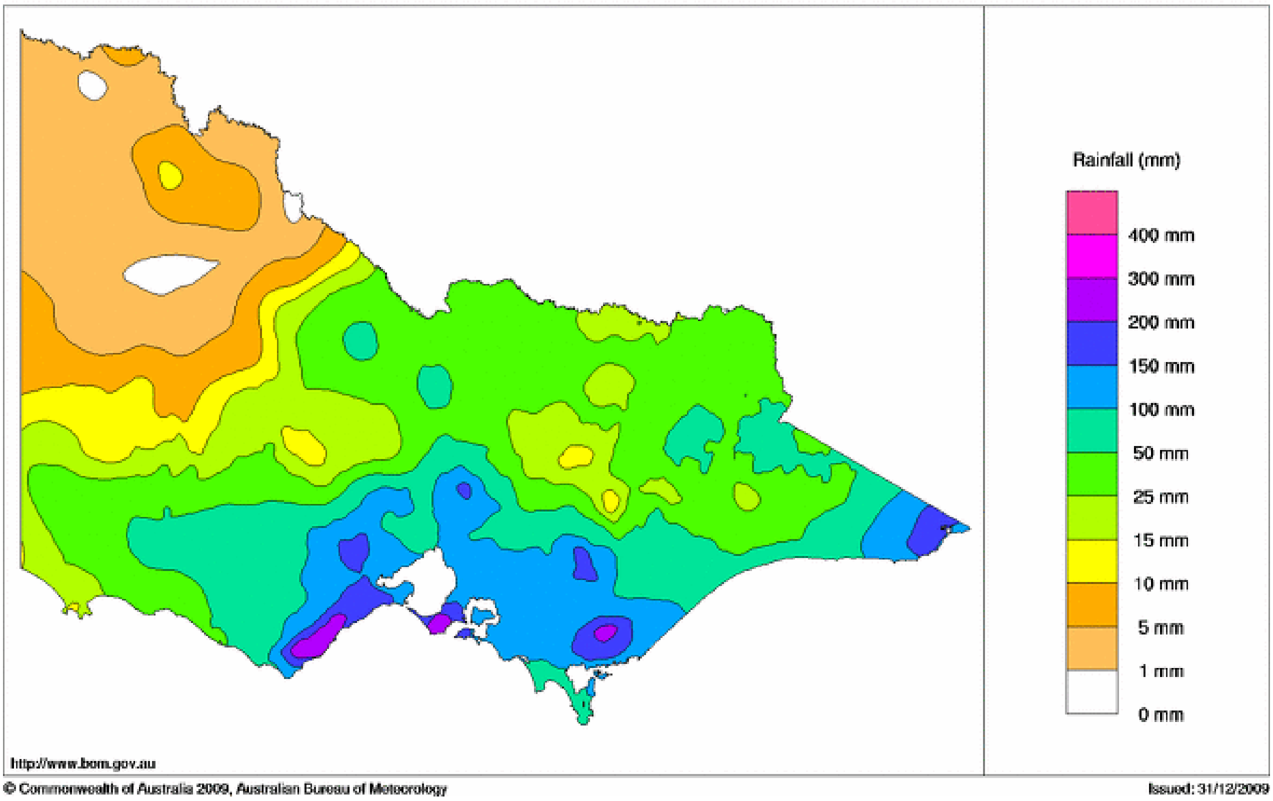

Figure 3-10 Weekly Daily Recorded Rainfall – Week ending 27/04/2001

Table 3-6 April 2001 – Event Catchment Rainfall

Daily Rainfall (mm)/ Station	Apr 20	Apr 21	Apr 22	Apr 23	Apr 24	Apr 25	Total
Forrest (090040)	0.2	-	-	163.0	10.0	3.2	**176.4**
Barwon Downs (090004)	0	5.2	96.6	25.2	5.2	1.8	**134**
Birregurra PO (090008)	0	-	-	98.0	4.0	0	**102**
Winch PO (090167)	0	-	41.8	77.8	10.4	0	**130**
Shelford (087059)	0	3.2	72.8	58.2	18.6	0.8	**153.6**
Grovedale (87163)	0	5.0	47.0	72.0	46.0	0.2	**170.2**
Ocean Grove (087178)	0	1.6	49.0	74.0	34.0	0	**158.6**

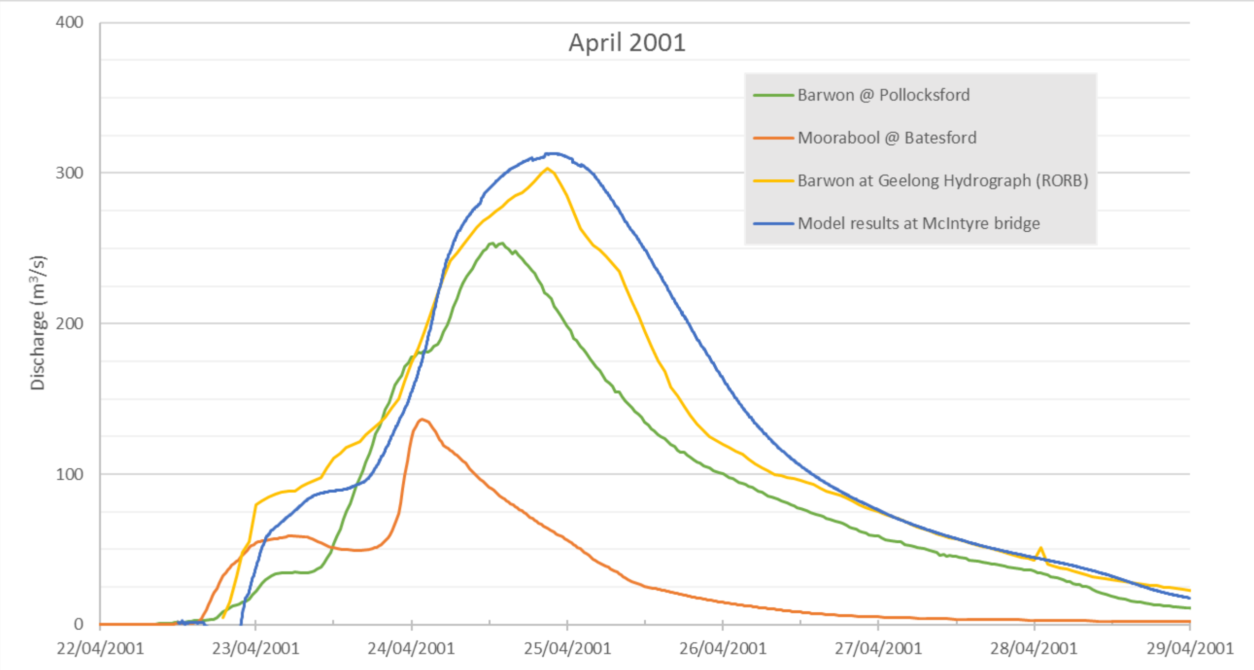

Figure 3-11 April 2001 flood event – streamflow gauges

Eleven flood marks were surveyed following the 2001 flood event in Geelong. These survey marks include a combination of level (to m AHD) and extent markers. The results show that 9 of the 11 survey marks are within 200 mm of the modelled flood levels as shown in Figure 3-12 and Figure 3-13 and Table 3-7. Figure 3-14 shows the modelled flood depth for the April 2001 event.

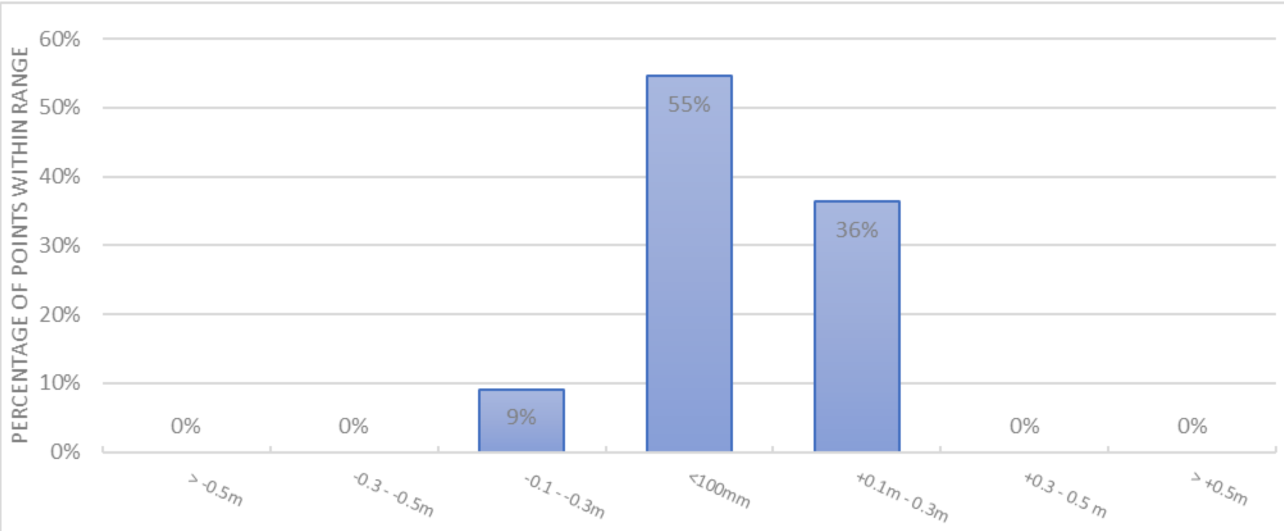

Figure 3-12 Flood marks. Level difference classification (April 2001)

Table 3-7 Modelled Flood Level Difference – April 2001

Mark_ID	Location	FL mAHD	Date	Mark collected by	X	Y	Model results - Difference
Apr2001_1		3.13	24/04/2001	CMA (TJones)	268274	5770787	0.17
Apr2001_2		3.30	24/04/2001	CMA (TJones)	268115	5771841	0.04
Apr2001_3	West Fyans Road	4.07	24/04/2001	CMA (TJones)	265346	5773406	-0.04
Apr2001_4	Balcombe Road	3.94	24/04/2001	CMA (TJones)	265456	5773068	0.03
Apr2001_5	140m d/s Queens Park Bridge	4.29	24/04/2001	CMA (TJones)	265456	5774064	-0.17
Apr2001_6		3.43	24/04/2001	CMA (TJones)	268303	5772598	0.02
Apr2001_7	Macintyre Bridge	3.60	24/04/2001	CMA (TJones)	267605	5772701	-0.04
Apr2001_8	140m d/s Queens Park Bridge	4.19	24/04/2001	CMA (TJones)	265515	5774020	-0.09
Apr2001_9		3.06	24/04/2001	CMA (TJones)	269236	5770692	-0.21
Apr2001_10		3.48	24/04/2001	CMA (TJones)	268083	5772679	0.02
Apr2001_11		3.50	24/04/2001	CMA (TJones)	267833	5772569	0.01

These results are within the satisfactory interval expected for a calibrated hydraulic model. Figure 3-13 shows that all modelled levels are within +/- 210 mm of the surveyed levels. Furthermore, the average difference is +0.07 m.

Table 3-8 Modelled vs Recorded Flood Peak for April 2001 event at McIntyre Bridge

	Flow (m^3/s) @ McIntyre Bridge	Stage Height (m) @ McIntyre Bridge	Time of Peak
Recorded	303 (estimated via routing model)		Not Available
Modelled	322	3.56	24/04/2001 18:15

Whilst limited information is available for the McIntyre Bridge gauge for this event, Table 3-7 shows the modelled and recorded flood peak and timing of the April 2001 event based on the calibrated model and hydrograph produced by the CCMA RORB model. At a surveyed flood mark close to McIntyre Bridge the modelled water level is within 10 mm of the surveyed level indicating an excellent calibration through this area.

Based on the results presented above for the April 2001 flood event, the hydraulic model calibration is considered to be excellent.

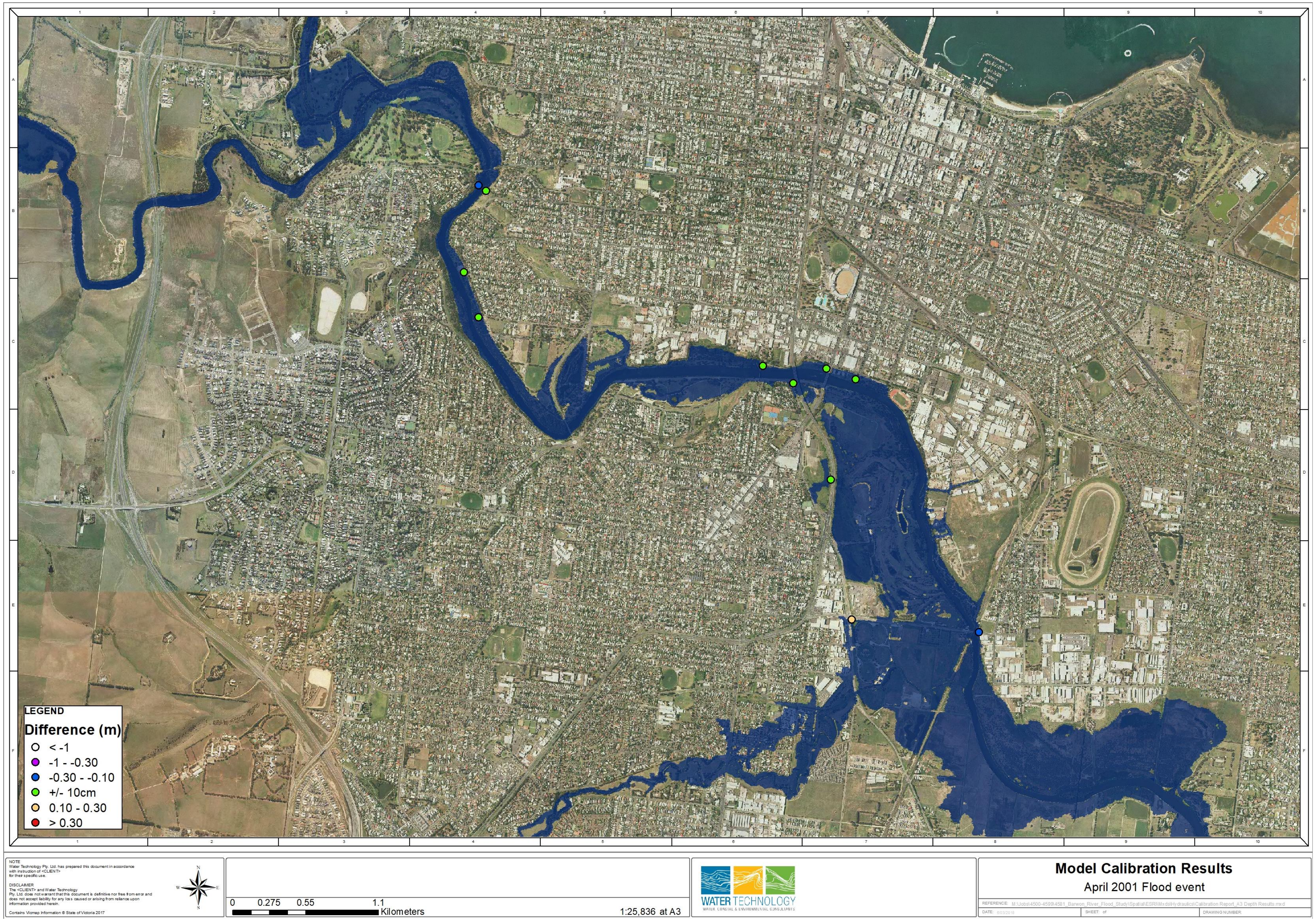

Figure 3-13 Flood map for the April 2001 event extent and flood marks.

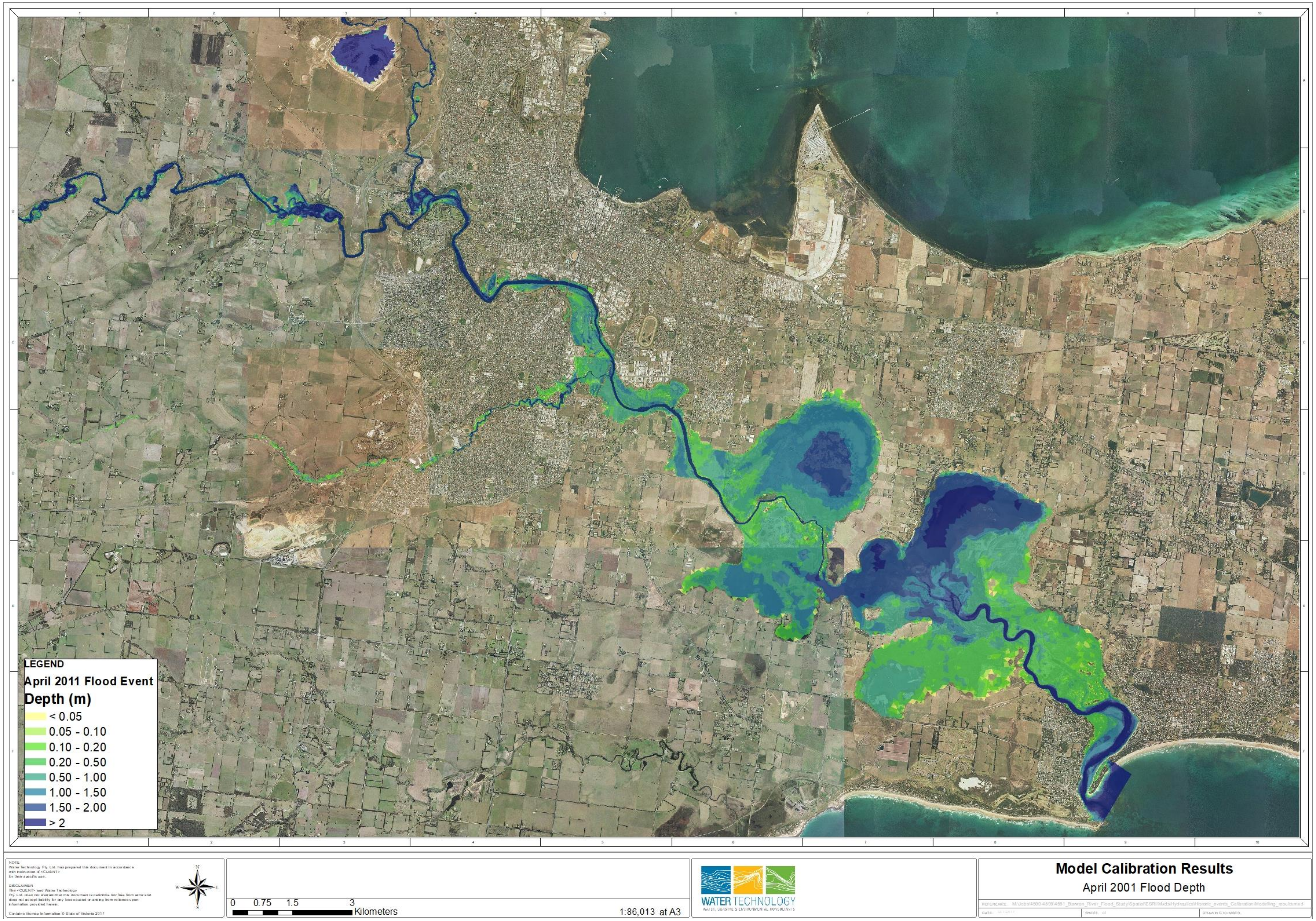

Figure 3-14 April 2001 Modelled Flood Depth

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3.2.3 January 2011

January 2011 saw extreme rainfall across much of the state with widespread flooding across a number of catchments. Moderate flooding occurred in the Barwon River at Geelong. A map of weekly rainfall for the week ending January 15 2011 is shown in Figure 3-15. Daily rainfall totals at different stations across the catchment are shown Table 3-9.

In January 2011 the Barwon River reached a peak flow of between 325 and 375 m^3/s at McIntyre Bridge in Geelong. Streamflow data is incomplete, and the peak flow was unlikely to have been recorded by the gauge. The available observed data indicates a peak flow of 340 m^3/s in the Barwon River at Pollocksford. It is considered unlikely the flow at Geelong was lower than the flow measured upstream due to the input of the Moorabool River and other tributaries. Gauged and modelled hydrographs for the Moorabool and Barwon Rivers are shown in Figure 3-16.

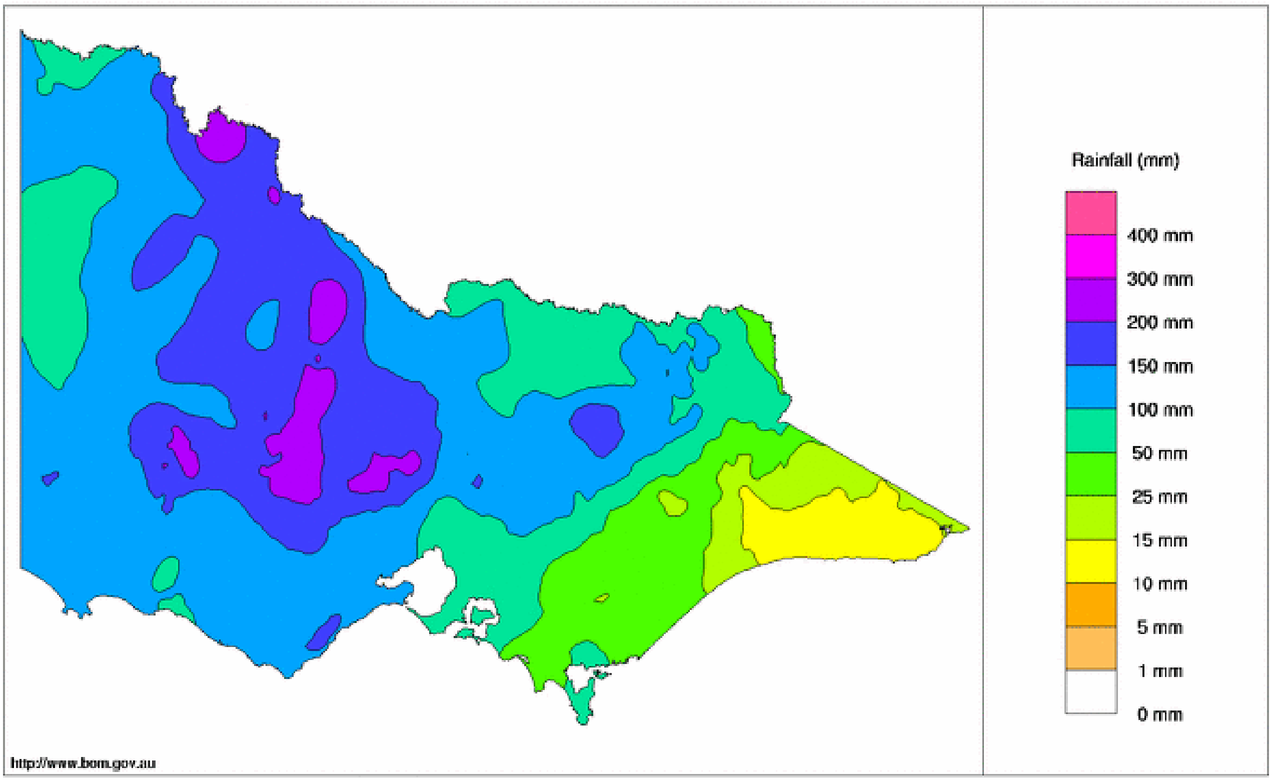

Figure 3-15 Weekly Recorded Daily Rainfall – Week ending 15/01/2011

Table 3-9 January 2011 – Event Catchment Rainfall

Daily Rainfall (mm)/ Station	Jan 10	Jan 11	Jan 12	Jan 13	Jan 14	Jan 15	Total
Forrest (090040)	3.4	23.0	36.8	6.2	51.0	-	**120.4**
Barwon Downs (090004)	3.6	23.0	36.2	2.0	53.2	3.0	**121.0**
Birregurra PO (090008)	13.0	31.0	42.0	5.4	54.0	-	**145.4**
Winch PO (090167)	5.0	25.0	34.0	4.0	44.8	4.6	**117.4**

Daily Rainfall (mm)/ Station	Jan 10	Jan 11	Jan 12	Jan 13	Jan 14	Jan 15	Total
Mt Mercer (89104)	0.6	43.4	42.4	12.0	52.6	4.6	**155.6**
Grovedale (87163)	12.2	21.4	29.0	4.4	48.4	8.0	**123.4**
Ocean Grove (087178)	-	28.6	20.8	4.2	35.8	11.8	**101.2**

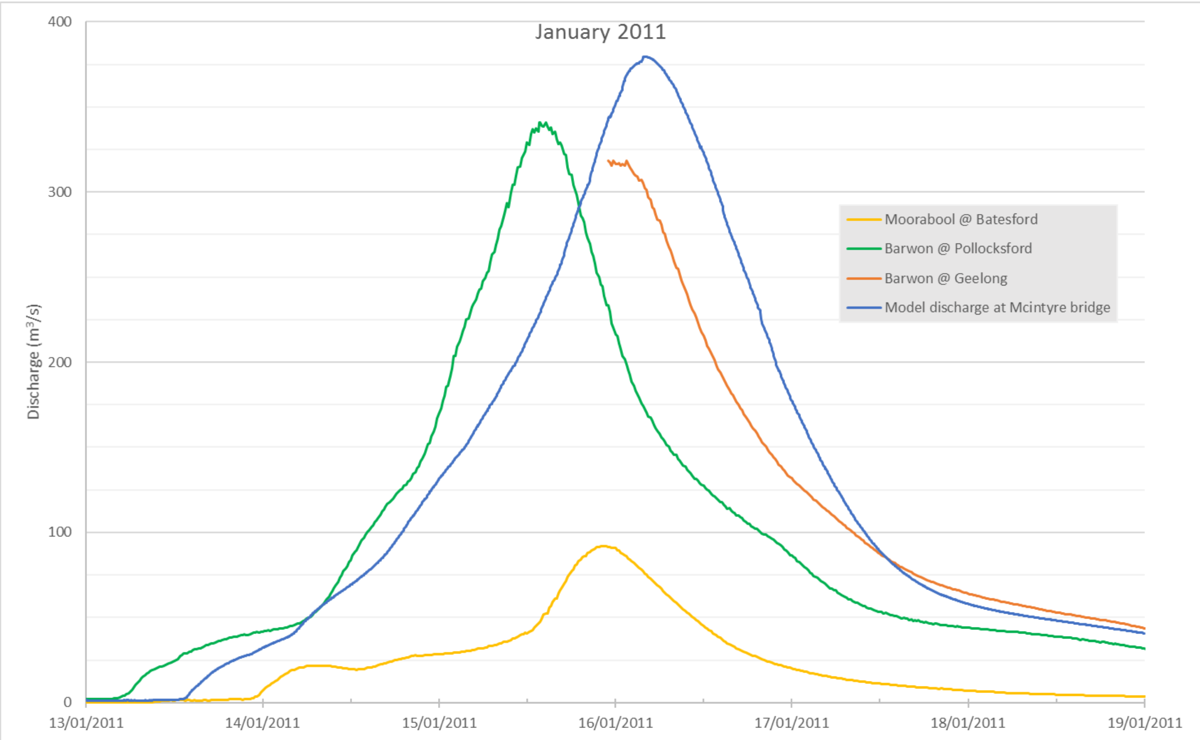

Figure 3-16 January 2011 flood event – streamflow gauges

The recorded water levels at the Barwon River at Geelong gauge were also compared and are shown in Figure 3-17. The peak levels match well, with a relative difference between observed and calculated peak flow of 70 mm. Figure 3-19 shows a map of water level differences between observed and modelled. Figure 3-20 shows a map of flood extent and depths for the modelled January 2011 flood.

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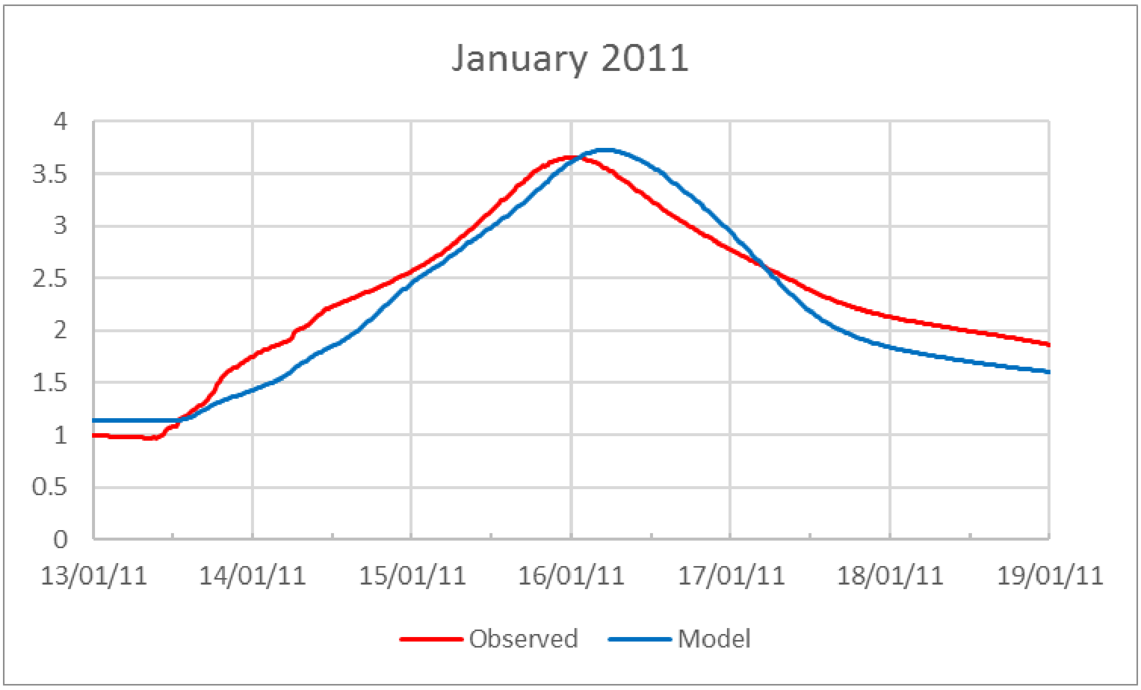

Figure 3-17 Water level comparison at McIntyre bridge, January 2011

A total of eight flood marks were surveyed after the 2011 flood event. Six marks are located around the Moorabool and Barwon River confluence. The modelled levels match the surveyed levels well, all but one are within 150 mm of the observed levels through this area.

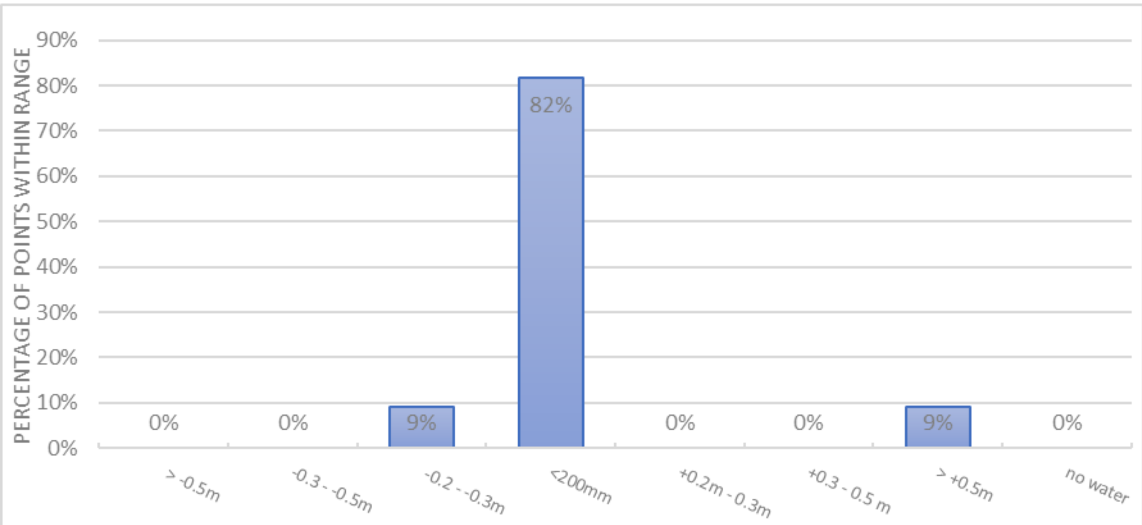

Figure 3-18 Flood marks. Level difference classification (January 2011)

Table 3-10 shows the modelled and recorded peak flow, water level and time of peak at McIntyre Bridge. The comparison is limited due to the incomplete record at the streamflow gauge for this event. The modelled scenario shows a delayed peak of several hours in comparison to the recorded peak, although this needs to be considered in the context of poor and limited gauge data for the event.

Based on the results presented above the calibration for the January 2011 event in the hydraulic model is considered to be good.

Table 3-10 Modelled Flood Level Difference – January 2011

Mark_ID	Location	FL mAHD	Date	Mark collected by	X	Y	Model results - Difference
jan15_1		4.61	15/01/2011	CMA (TJones)	265593	5774209	-0.02
jan15_2		0.00	15/01/2011	CMA (TJones)	264877	5774649	Extent
jan15_3		5.14	15/01/2011	CMA (TJones)	264179	5774948	-0.11
jan15_4		0.00	15/01/2011	CMA (TJones)	268122	5772652	Extent
jan15_5		4.63	15/01/2011	CMA (TJones)	265625	5774305	0.00
jan15_6		4.43	15/01/2011	CMA (TJones)	265448	5774150	0.29
jan15_7		5.14	15/01/2011	CMA (TJones)	264256	5774924	-0.12
jan15_8		0.00	15/01/2011	CMA (TJones)	266162	5772316	Extent
jan15_9		5.05	15/01/2011	CMA (TJones)	264759	5774657	0.14
jan15_10		0.00	15/01/2011	CMA (TJones)	269231	5770699	Extent
jan15_11		0.00	15/01/2011	CMA (TJones)	266580	5772783	Extent
jan15_12	West Fyans Rd	4.25	15/01/2011	CMA (TJones)	265349	5773420	0.10
jan15_13	Macintyre Bridge	3.66	15/01/2011	CMA (TJones)	267605	5772703	0.13
jan15_14		0.00	15/01/2011	CMA (TJones)	266178	5772451	Extent

Table 3-11 Modelled vs Recorded Flood Peak

	Flow (m3/s) @ McIntyre Bridge	Stage Height (m) @ McIntyre Bridge	Time of Peak
Recorded	318 (incomplete)	3.66	16/01/2011 12:00am
Modelled	404	3.79	15/01/2011 9pm

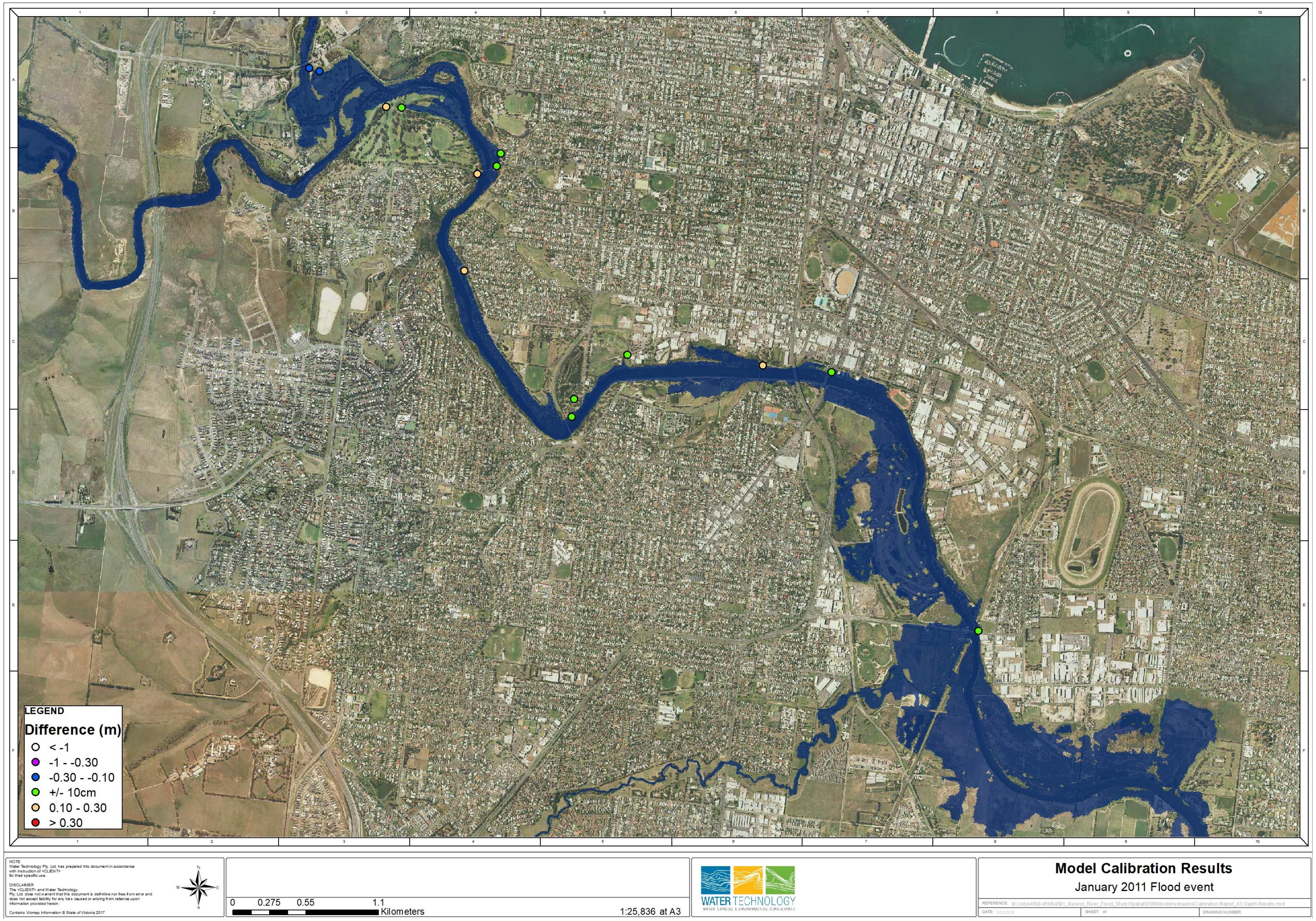

Figure 3-19 Flood map for the January 2011 event extent and flood marks.

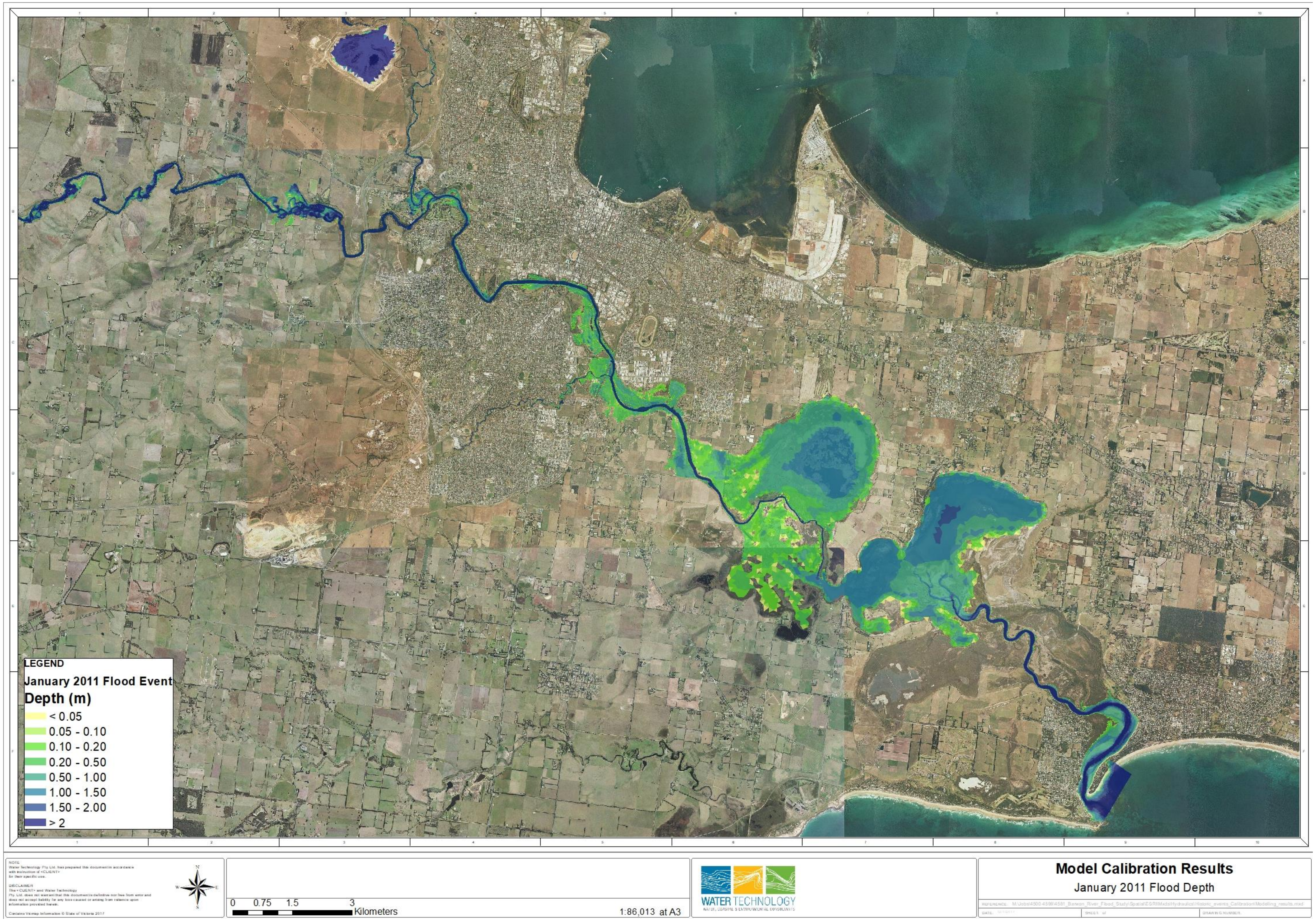

Figure 3-20 January 2011 Modelled Flood Depth

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3.2.4 September 2016

The most recent Barwon River catchment flood occurred in September 2016. The rainfall event which included 50-60 mm over a 3-day period followed several wet months from May – August. Figure 3-21 shows the cumulative rainfall across Victoria for the week ending 15th September 2016. Daily rainfall totals are shown in Table 3-12. The event resulted in minor flooding in the lower Barwon catchment through Geelong. Following this event a total of 33 flood marks were surveyed and have been used to verify the model calibration, giving further confidence in the reliability of the reproduced flood behaviour.

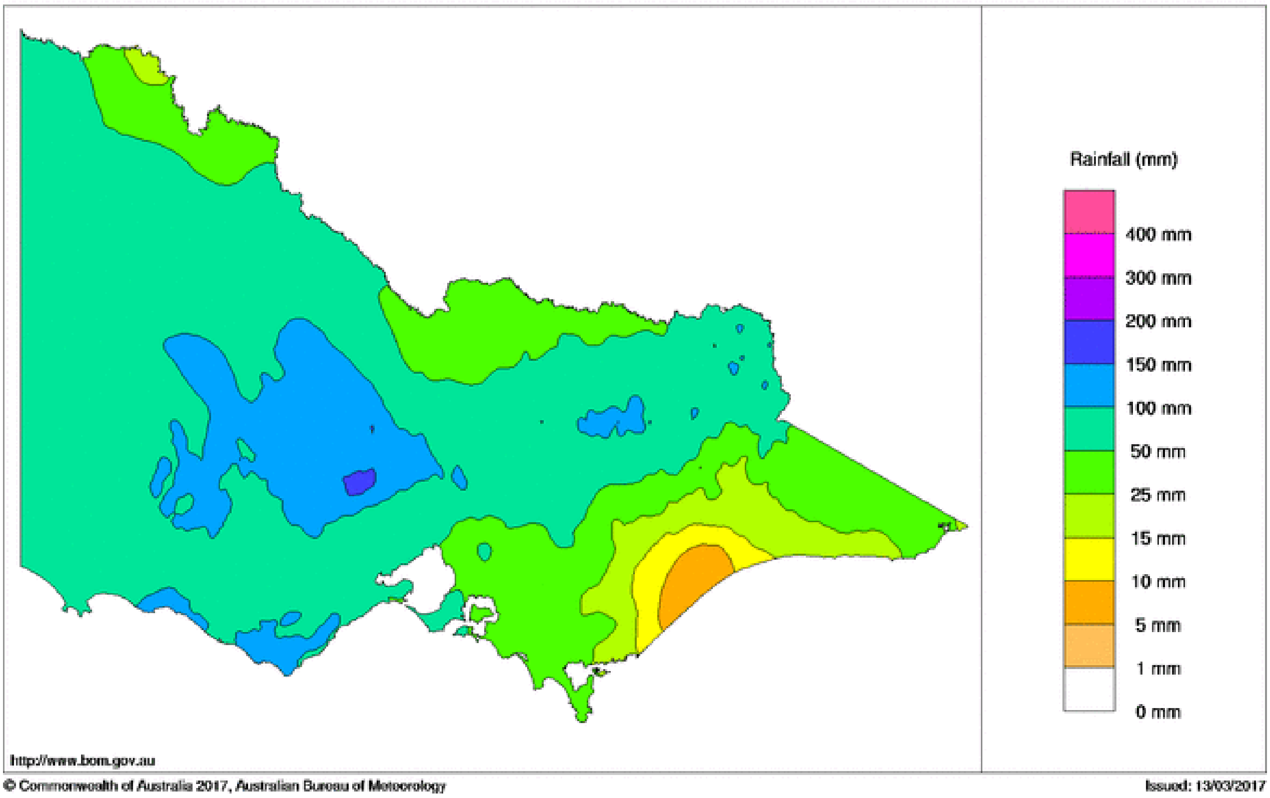

Figure 3-21 Weekly Recorded Daily Rainfall – Week ending 15/09/2016

Table 3-12 September 2016 – Event Catchment Rainfall (mm)

Daily Rainfall (mm)/ Station	Sep 9	Sep 10	Sep 11	Sep 12	Sep 13	Sep 14	Sep 15	Total
Forrest (090040)	35.4	-	-	14.2	7.2	37.2	9.0	**103.0**
Colac (090035)	18.6	4.4	0.2	14.0	11.8	45.8	3.4	**98.2**
Birregurra PO (090008)	21.0	-	-	10.0	9.0	43.0	3.6	**86.6**
Pollocksford (087162)	1.0	0.8	0.2	11.6	1.0	0.8	1.8	**17.2**
Mt Mercer (89104)	11.2	11.4	0.6	7.4	10.6	32.0	1.4	**74.6**
Breakwater (087184)	16.2	3.6	0.8	12.6	7.8	35.0	0.8	**76.8**
Ocean Grove (087178)	9.2	2.6	0.6	-	-	-	45.4	**57.8**

The timing of the calculated hydrograph at the streamflow gauge at McIntyre bridge on the Barwon River, particularly the rising limb, matches the observed flow very well. However, the peak flow is slightly overestimated, with a peak flow of 250 m^3/s instead of 225 m^3/s, as displayed in Figure 3-22.

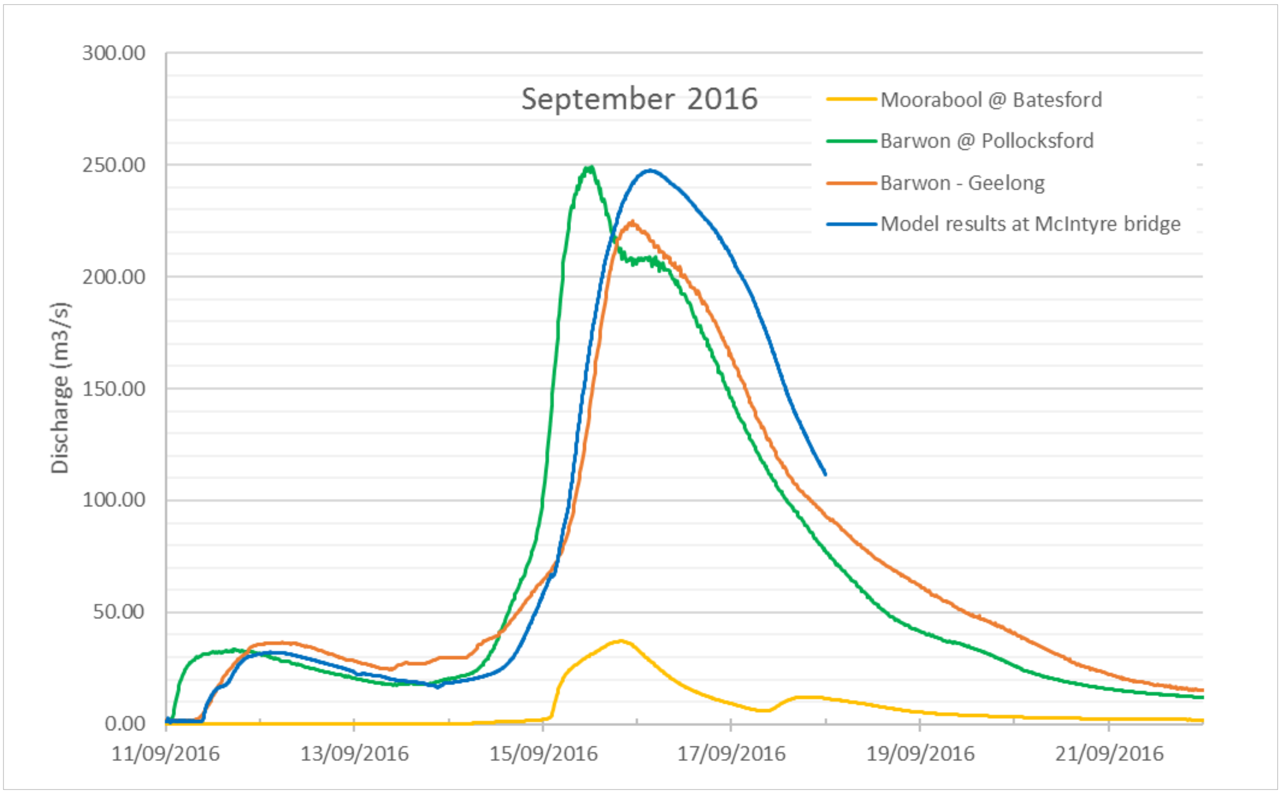

Figure 3-22 September 2016 flood event – streamflow gauges

Water level comparison at the streamflow gauge show the hydrograph and the peak level is well reproduced. The maximum levels calculated and observed show a relative difference of only 0.02 m as shown in the plot below.

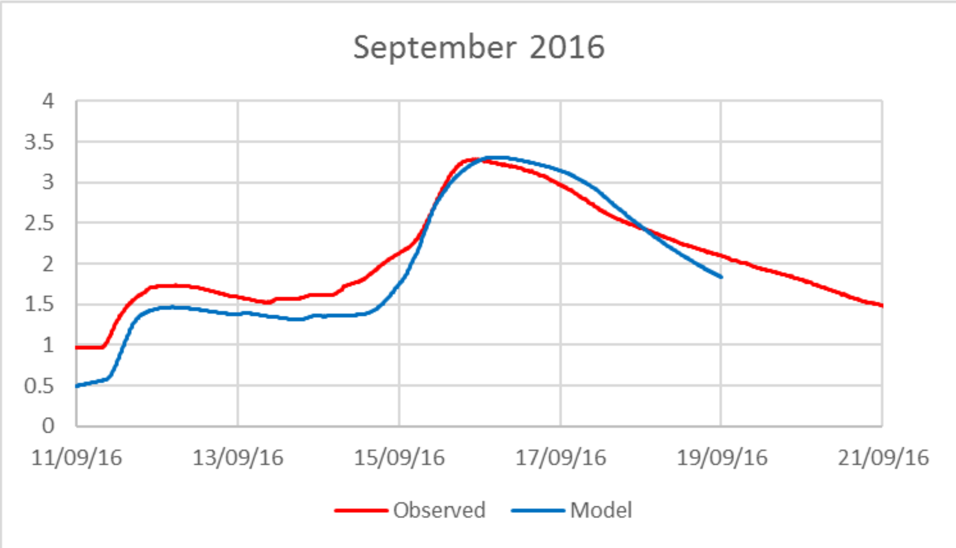

Figure 3-23 Water level comparison at McIntyre bridge, September 2016

Model results in terms of flood marks and calculated water levels match very well. Of the 33 flood marks available, the model is within 200 mm of the observed level at 25 of the survey points. Moreover, the average difference is +40 mm across the 33 surveyed locations.

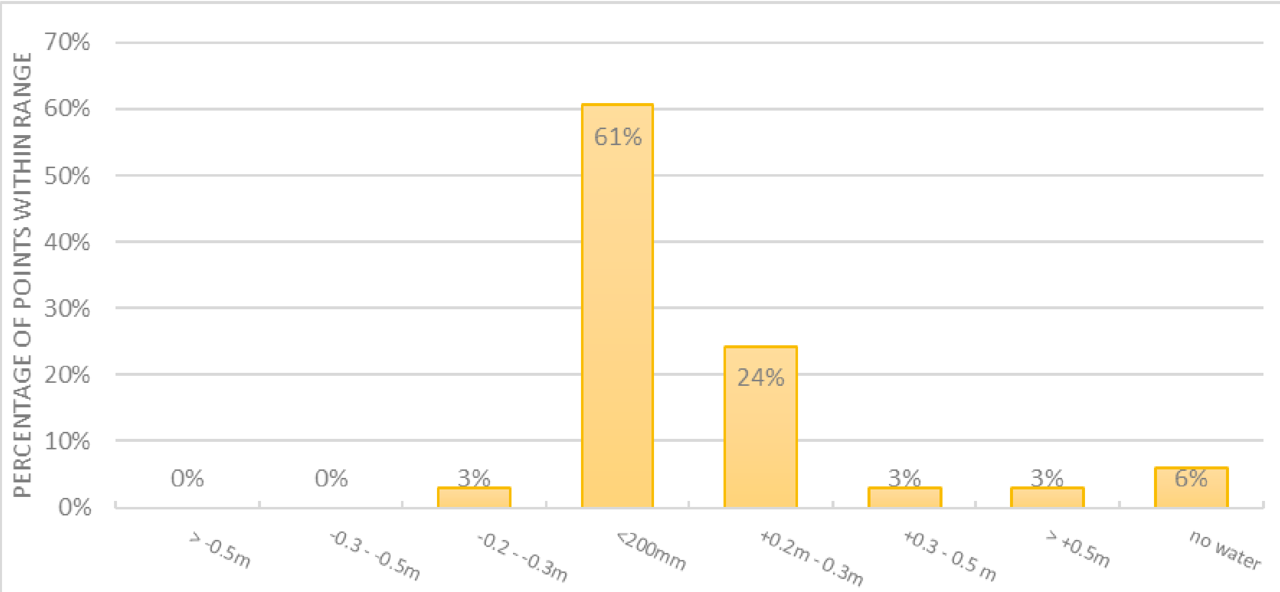

Figure 3-24 Flood marks. Level difference classification (September 2016)

Table 3-13 Modelled vs Recorded Flood Peak

	Flow (m^3/s) @ McIntyre Bridge	Stage Height (m) @ McIntyre Bridge	Time of Peak
Recorded	223	3.29	15/09/2016 11:30pm
Modelled	271	3.36	15/09/2016 9.30pm

Results at the streamflow gauge for the September 2016 flood event are satisfactory both in terms of peak flow and maximum water level. There is a slight delay of four hours between modelled and observed peak, the relative difference in discharge between the model and observation is 18%, the maximum water level in the model is 0.07 m higher than the observed.

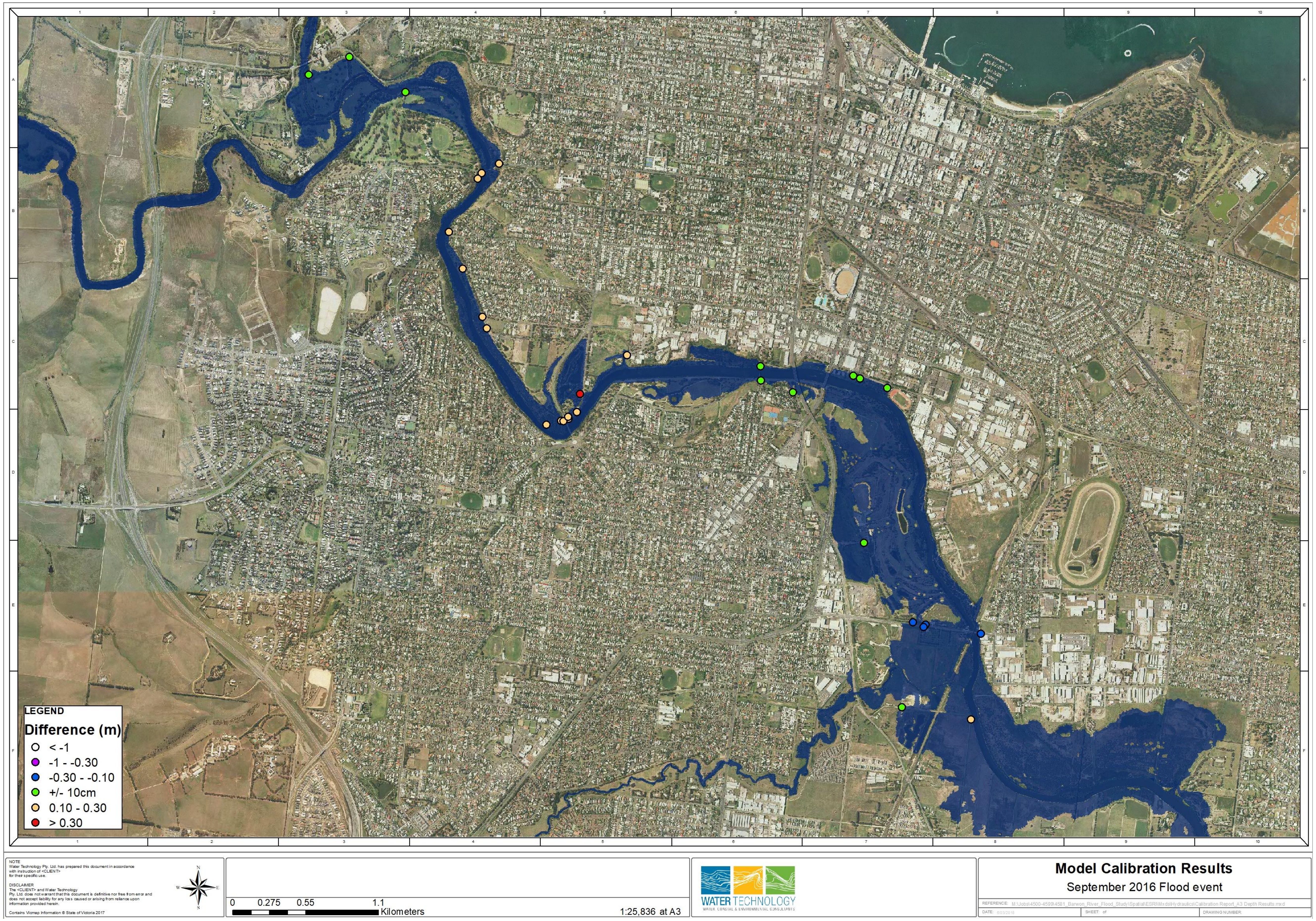

Figure 3-25 Flood map for the September 2016 event, water depths and flood marks.

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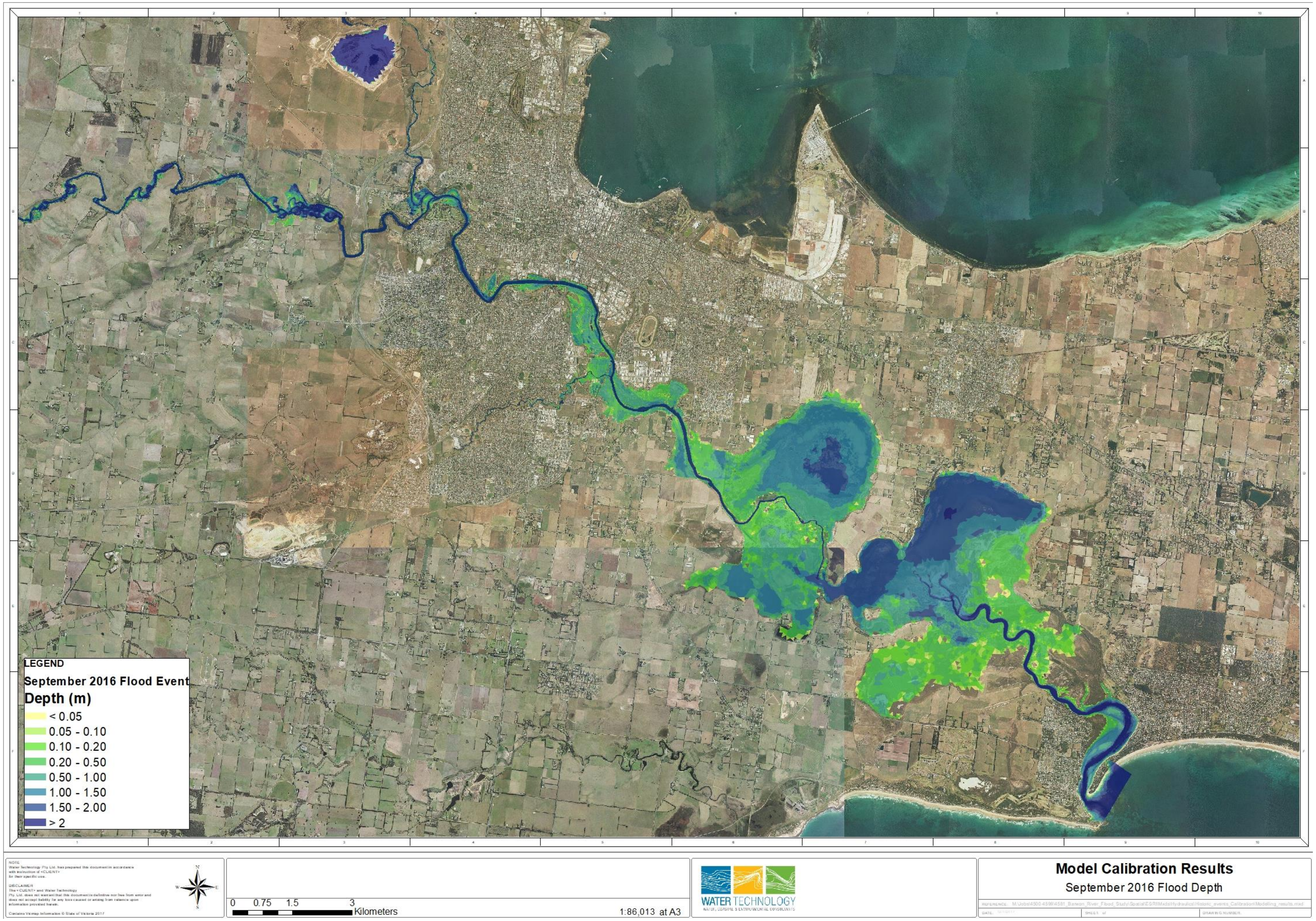

Figure 3-26 September 2016 Modelled Flood Depth

Flood marks located close to the river channel have been placed on a longitudinal profile of the water levels for comparison. This has been undertaken along both the Barwon River and Waurn Ponds Creek. Three markers were surveyed for this event along Waurn Ponds Creek and are shown in Figure 3-27. A very close match can be seen at all three floods marks.

Results along the Barwon River, from the Moorabool River confluence to Waurn Ponds Creek, are presented in Figure 3-28. Again, a very good match to observed levels can be seen at nearly all of the surveyed flood marks

Overall, the results obtained for the September 2016 event are excellent. The model results shown an excellent match to surveyed levels at the historic flood marks. The modelled hydrograph at McIntyre bridge also matches the observations accurately, as shown in Figure 3-22 and Figure 3-23.

Based on the results presented above the calibration for the September 2016 event in the hydraulic model is considered to be good.

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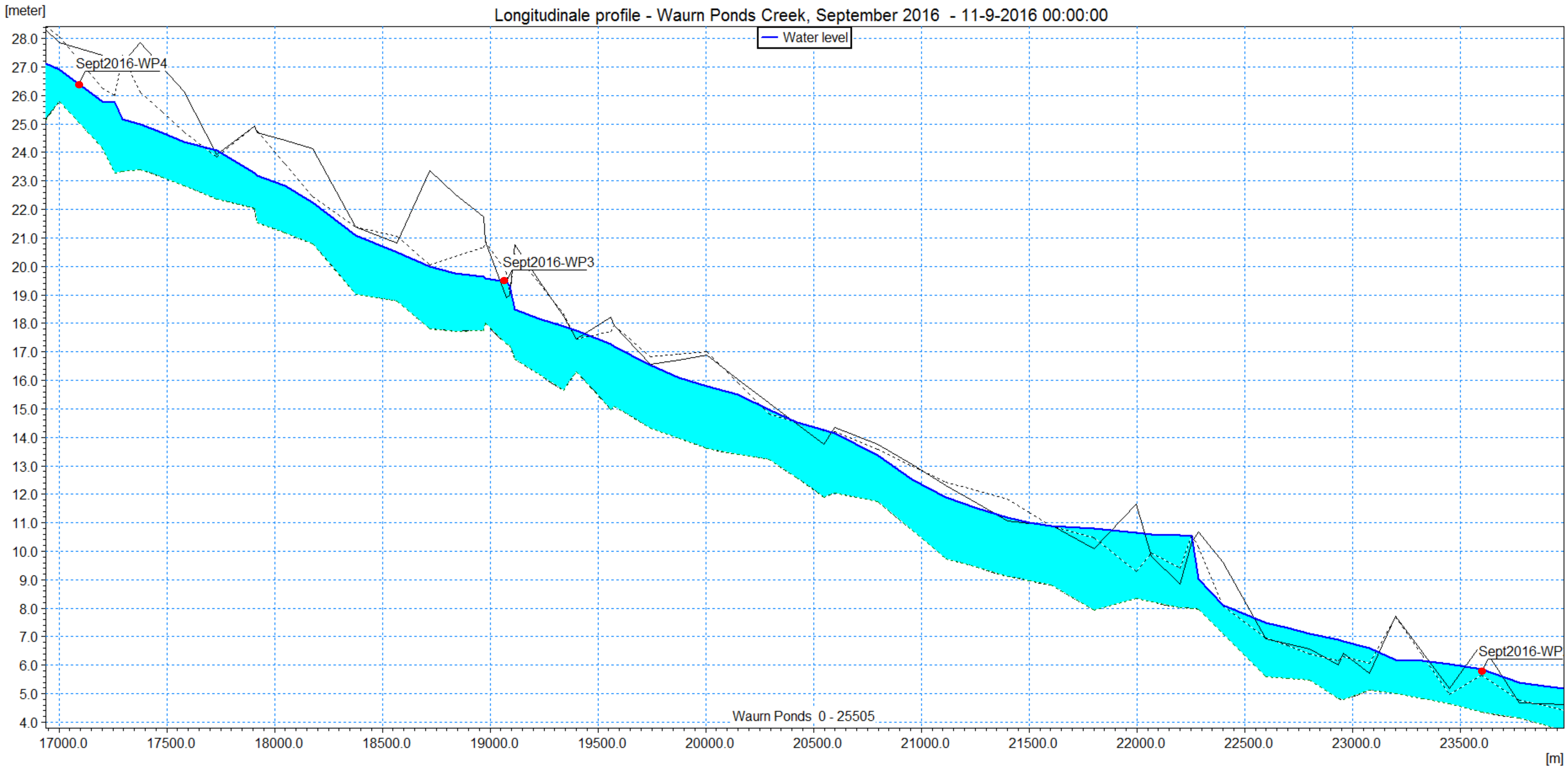

Figure 3-27 Flood marks along Waurn Ponds Creek (September 2016)

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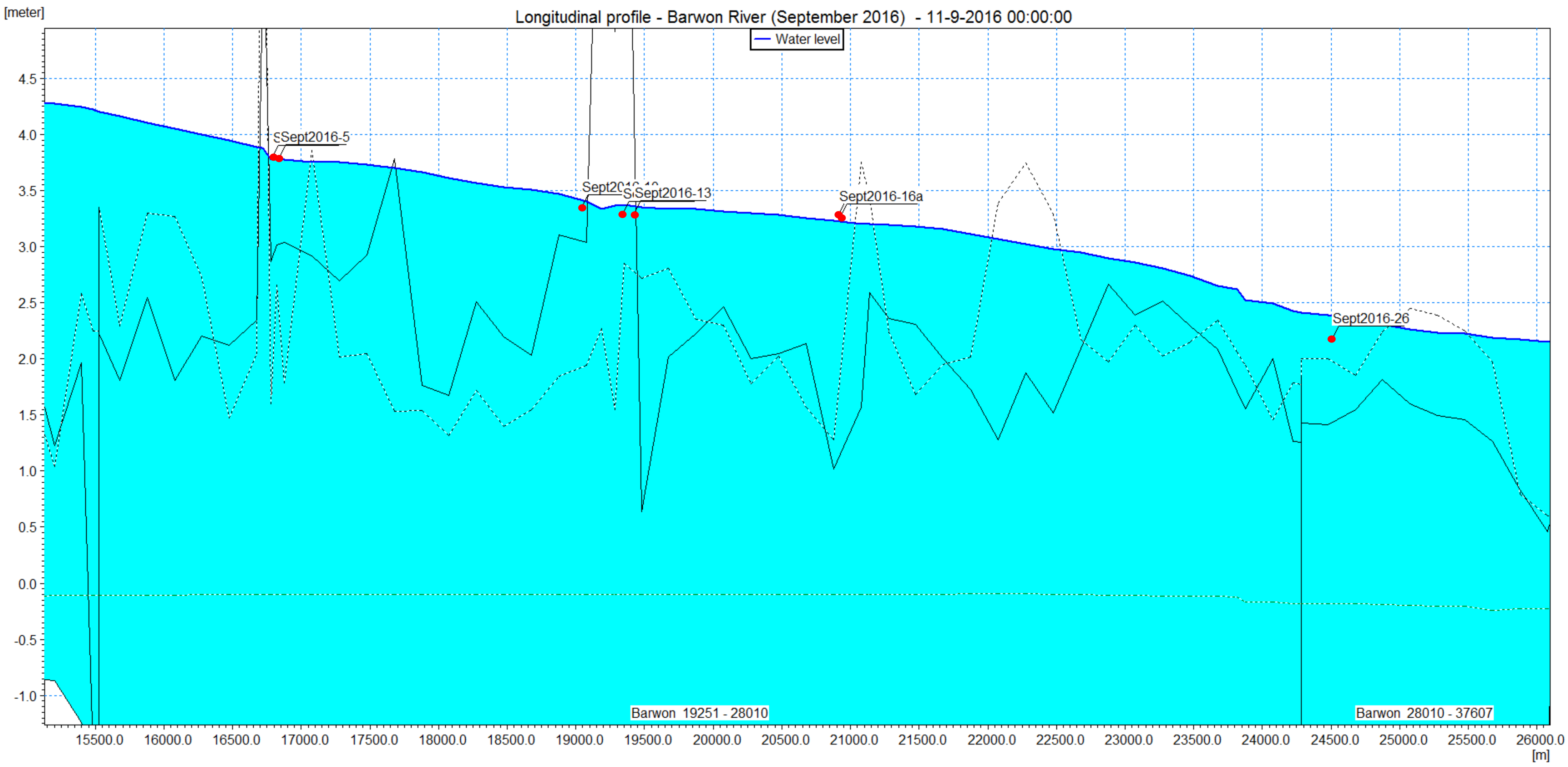

Figure 3-28 Flood marks along Barwon River (September 2016)

Table 3-14 Modelled Flood Level Difference –September 2016

Mark_ID	Location	FL mAHD	Date	Mark collected by	Comment	X	Y	Model results - Difference
1	Carpark Fyansford Common	4.50	17/09/2016	CMA (TJones)	Low round pine post and rail fence. Mark on west post ? cm above NSL.	264174	5774897	-0.17
2	Chain wire fence Fyansford Common	4.42	17/09/2016	CMA (TJones)	Outlet channel high chain mesh fence. Mark on SE corner gate ? cm above NSL	264483	5775032	-0.18
3	Pathway from East carpark Queens Park	3.93	17/09/2016	CMA (TJones)	Low redgum fence south side of path from carpark East bank. Mark ? cm above NSL, ? cm down from top of post.	265613	5774226	0.01
4	Southside Queens park Bridge	3.79	17/09/2016	CMA (TJones)	Redgum post and rail fence, 4th panel up from river. Mark on top rail in middle.	265482	5774154	0.09
5	South side Queens Park Bridge	3.80	17/09/2016	CMA (TJones)	Steel post near staff gauge on power pole. Mark ? cm above NSL.	265452	5774114	0.08
6	End of Camden Rd Newtown	3.65	17/09/2016	CMA (TJones)	Pine square post for snake sign, 20 m north of Camden Rd. Mark 5 cm above NSL, 137.5 cm down from top of post.	265234	5773711	0.17
7	West Fyans Park Newtown	3.64	17/09/2016	CMA (TJones)	West side of access road, pine square post for No Camping sign. Mark 36 cm above NSL, 142.5 cm down top of post.	265337	5773434	0.17
8	Balcombe Road Newtown	3.52	17/09/2016	CMA (TJones)	Green river post and round pine post for Snake sign. Mark on Snake post 29.5 cm above NSL, 161 cm down top of post.	265486	5773070	0.21
9	90m south Balcombe Rd Newtown	3.54	17/09/2016	CMA (TJones)	Pine square post for Change in Gradient sign. Mark 62 cm above NSL, 117.5 cm down from top of post.	265521	5772984	0.16
10	Raised walkway, near old Bird Hide	3.35	21/09/2016	CMA (TJones)	Tree stump on west side of raised walkway. Mark 67 cm down from top of tree stump.	265971	5772256	0.20
11	CCMA sign off walking track, west Shannon Bridge	3.34	21/09/2016	CMA (TJones)	CCMA sign along pathway. Mark 122 cm above NSL, 32 cm down from top of side steel square post.	266081	5772285	0.18
12	25m downstream Shannon Bridge	3.29	17/09/2016	CMA (TJones)	Green river post. Mark riverside 60.5 cm above NSL, 52 cm down from top of post bevel.	266136	5772300	0.21

Mark_ID	Location	FL mAHD	Date	Mark collected by	Comment	X	Y	Model results - Difference
13	150m downstream Shannon Bridge	3.30	17/09/2016	CMA (TJones)	Riverside red seat. Mark on top rail at west side end. Mark 9.3 cm below top of seat back rail.	266199	5772352	0.15
14	Balliang Sanctuary Carpark Newtown	3.19	17/09/2016	CMA (TJones)	Low post and rail fence north side of carpark. 3rd park west of P parking bay. Mark 11cm above NSL, 49cm top of post.	266223	5772487	0.30
15	Bridge Street / Riversdale Road Newtown	3.23	17/09/2016	CMA (TJones)	Silver steel gate along Riversdale Rd, bottom sloping frame. Mark ? cm above NSL.	266578	5772782	0.19
16	McIntyre Bridge North Bank Newtown	3.29	16/09/2016	CMA (TJones)	Telemetry level recorded during event	267586	5772696	0.03
17	Barrabool Rd near High St Belmont	3.26	18/09/2016	CMA (TJones)	On western side of road, White steel Gate support post, 21.4 cm above NSL.	267830	5772500	0.01
18	Corner fence Corio Bay Carpark	3.26	17/09/2016	CMA (TJones)	Low square redgum post and rail fence. Mark on eastern post ? cm above NSL.	268285	5772626	0.00
19	Carpark west side Landy Field Barwon Tce	3.15	17/09/2016	CMA (TJones)	Low pine post and rail fence, west side of carpark. Mark on north post of 3rd set from Barwon Tce, ?cm above NSL.	268543	5772534	0.08
20	Access to Cycle Track Barwon Heads Rd	3.12	18/09/2016	CMA (TJones)	Low timber / steel rail fence. 3rd post south of 2nd foot entrance south of carpark. Mark 25.5 cm above NSL.	267941	5771848	-0.12
21	Wood Street Sth Geelong	3.17	17/09/2016	CMA (TJones)	2nd steel post of chain mesh fence south of Truck Co entry. End of roadside channel. Mark ? cm above NSL.	269247	5771838	-3.17
22	Entrance gate Barwon Valley Golf Club Belmont	3.09	18/09/2016	CMA (TJones)	Steel gate at Golf course carpark. Mark 42.4 cm above NSL near HazChem sign.	268368	5771364	-0.15
23	North side old Breakwater Rd west bank Belmont	2.76	17/09/2016	CMA (TJones)	Steel post for ??? sign. Mark ? cm above NSL.	268832	5770748	-0.21
24	south side old Breakwater Rd West bank Belmont	2.75	17/09/2016	CMA (TJones)	White picket fence entry to Dog Obedience Club. 1st picket pass 2nd post in south entry. Mark ? cm above NSL.	268817	5770730	-0.20
25	South side old Breakwater Rd East bank Belmont	2.85	17/09/2016	CMA (TJones)	Steel post for ??? sign north bank. Mark ? cm above NSL.	269249	5770680	-0.15

3.3 Pollocksford Inflow Hydrograph Review

As part of this study, and complementary to the Inverleigh Flood Study, a discrepancy in the flood hydrograph from the 1995 event at Pollocksford was identified and investigated. The analysis has concluded that the falling limb of the gauged hydrograph for the November 1995 event significantly underestimated the volume of flow at this location. Figure 3-29 below shows the two hydrographs (pre and post consideration for hysteresis) used at the inflow boundary of the model at the Pollocksford gauge as well as the resulting hydrographs in Geelong at McIntyre bridge. As discussed in section 3.2.1, the discrepancy is related to the rating curve at Pollocksford not having consideration for hysteresis which is not uncommon for streamflow gauge rating curves. A single curve is standard practice across Victoria, however it is known that at some locations the rising limb of a flood will operate under a different curve than the falling limb due to flood hysteresis. This can result in flood volumes being significantly underestimated on the falling limb in the gauged hydrograph.

The discrepancy described above had previously been investigated by Corangamite CMA and those learnings have been incorporate into this study. Based on testing both hydrographs, the revised hydrograph was deemed to be a more accurate representation of the hydrograph for the 1995 flood. There is still a level of uncertainty associated with theadopted hydrograph, however it is considered to provide a more realistic estimate of volume.

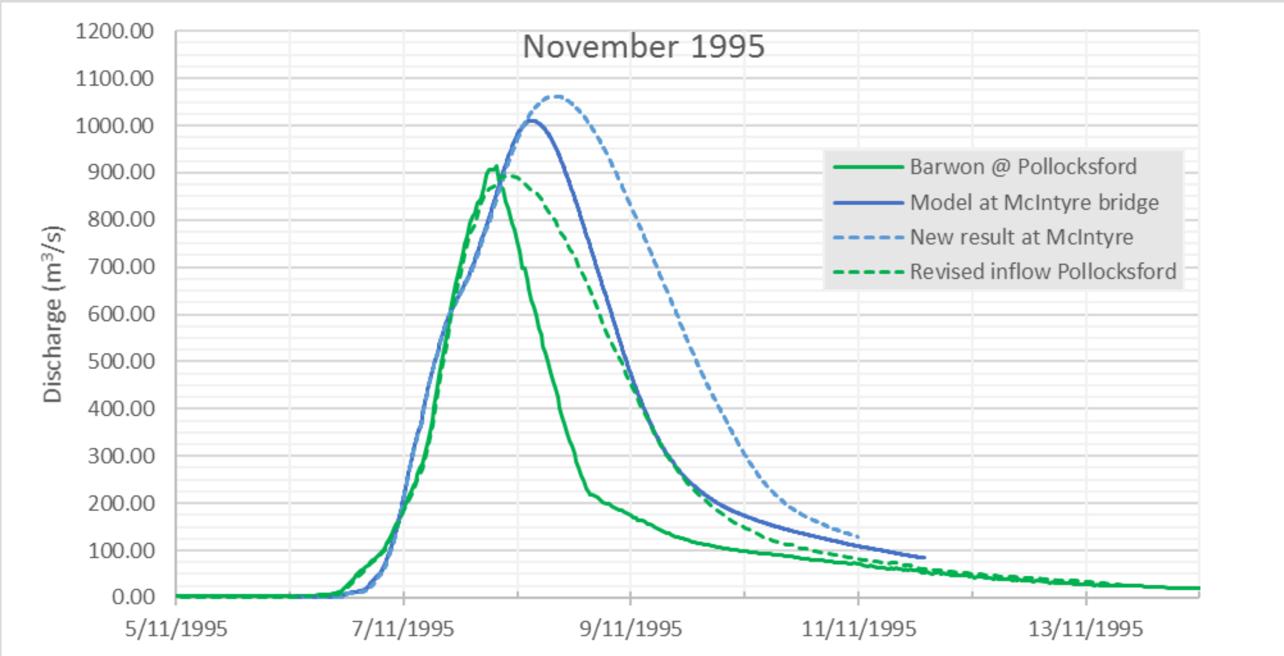

Figure 3-29 Pollocksford inflows and resulting hydrographs at McIntyre bridge, November 1995

3.4 Barwon River at Geelong (McIntyre Bridge) Rating Curve Review

A calibrated hydraulic model is a very useful tool for investigating rating curves at streamflow gauges. Rating curves are most reliable over the range of flows for which accurate discharge measurements are available. This is typically over the lower flow range than for high flows due to the limited occurrence of high flow events that are able to be measured. Subsequently, the higher flow ranges of rating curves are often extrapolated and the uncertainty in the extrapolated section of the curve is considerable. A hydraulic model, which has been calibrated to large flood events, can be used to improve the accuracy of the rating curve for high flows. The hydraulic model is able to explicitly represent the relationship between flow and the complex floodplain geometry that typically exists for large, out-of-bank flows.

The rating curve for the Barwon River at Geelong gauge has been updated on numerous occasions over the years. Several of these rating curves have been plotted below in Figure 3-30, which demonstrates the variability in the stage vs flow relationship across the various rating curves. Also plotted on this figure is the stage-discharge results from the calibrated hydraulic model. The stage discharge relationship from the modelled 1995 calibration event, which is the largest of the modelled events, is included in the plot for both the rising and falling limbs. The current rating curve for Geelong (V5.0) as determined by Ventia, is also plotted. It should be noted that above 70,800 ML/d (4.8 m AHD) the rating table for the gauging station uses extrapolated values and uncertainty in that section of the curve increases accordingly.

Comparing the current rating curve (V5.0) and the modelled 1995 event curve, the following observations can be made:

- for water levels below 3 m AHD, the model results indicate a higher flow capacity with greater discharge values for the same levels. At lower flow rates rating curves typically perform well, with numerous gaugings to develop the relationship. Given the hydraulic model has been calibrated to larger flow events, it is possible the hydraulic model is less accurate than the rating curve for in-bank flows.
- for levels between 3 and 5 m AHD the existing rating curve and model rating curve correlate very closely. The model results indicate marginally higher flow capacity than the rating curve at these levels. It is noted that through this section of the curve, both the existing rating curve and hydraulic model curves are lower than the older GHD curves i.e. predict a lower flow rate for the same water levels.
- for levels above 5 m AHD the rating curve indicates higher flow rates than the model results. The curves begin to diverge beyond 5 m, however both curves don’t extend far above 5 m. It is noted that the current rating curve is extrapolated beyond 4.8 m and uncertainty is greater for that section of the curve.

Based on the analysis above it was concluded that the current rating curve performs well across a wide range of flows and is appropriate for continued adoption. There appears no need for the curve to be modified unless additional information becomes available, such as observed stage-height information from large flood in the future.

Based on the analysis above, and the conclusion that the current rating curve is suitable for adoption, the stage height information collected at Geelong has been re-processed with the current rating (V5.0). Previously peak discharges for historical events were based on the GHD rating curves. This has generally meant that the revised flow estimates for historical flood events are lower than previously estimated.

The flood frequency analysis at the Barwon River at Geelong has also been revised and tested against the revised flows. Further discussion regarding the change in flows resulting from the refitted data has been included in the revised hydrology report which has been submitted with this report.

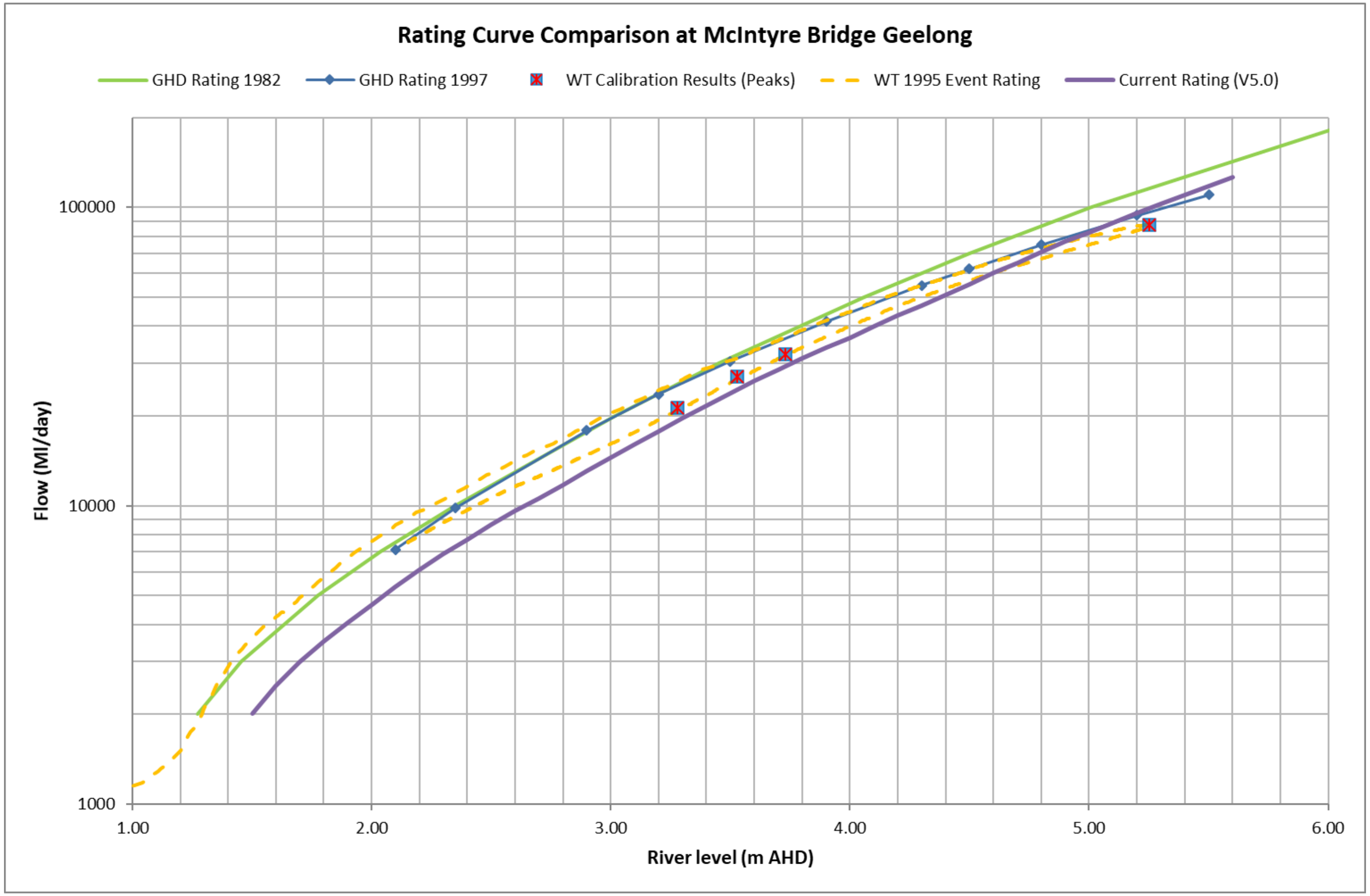

Figure 3-30 Rating Curve Comparison at Barwon River at Geelong (McIntyre Bridge) Gauge

3.5 Hydraulic Model Calibration Summary

The hydraulic model calibration results demonstrate the ability of the model to represent the flood behaviour within Geelong for the November 1995, April 2001, January 2011 and September 2016 flood events. The modelling demonstrates that the events were quite different in nature with November 1995 being a much larger and more damaging flood.

Modelling has identified that the peak flow in the Barwon River in Geelong for the November 1995, April 2001, January 2011 and September 2016 flood events was approximately 1040 m^3/s, 322 m^3/s, 404 m^3/s and 271 m^3/s respectively. These flow estimates represent the flow in the Barwon River and the surrounding floodplain at the Barwon River at Geelong (McIntyre Bridge) gauge.

The model results for the calibration and verification floods replicated the observed flood behaviour through the town quite accurately; this was confirmed by a comparison of modelled to observed flood marks, aerial images as well as previous modelling. The model is considered appropriate for use for design flood modelling and mitigation options investigations.

A review of the current rating curve at Geelong, including comparison to historic and hydraulic model rating curves, has concluded that the current rating curve is appropriate and suitable for continued adoption across the range of flow rates up to the 1% AEP.

4. SUMMARY

The calibration and validation results demonstrated that the Barwon River hydraulic model produces realistic flood behaviour across a range of flood magnitudes and is suitable for use in design modelling. This report has been submitted with the final hydrology report which outlines the hydrological analysis and adopted design flows.

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