

Avon River Regional Flood Mapping – Hydraulics Report



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1. INTRODUCTION

1.1 Overview

Water Technology was commissioned by the Department of Environment, Land, Water and Planning (DELWP) to undertake regional flood mapping for the Avon River. This project includes detailed hydrological and hydraulic modelling of the Avon River and its tributaries including Freestone Creek, Valencia Creek and Blackall Creek, and will take into account the downstream influences of Lake Wellington. This mapping will be used to satisfy a range of business requirements from planning, emergency response, to community awareness and for insurance purposes.

This report details the hydraulic analysis undertaken for the project, including the following components:

- A general description of the methodology used for the hydraulic assessment,
- A description of the model development and schematisation,
- Details of the model calibration and sensitivity analysis, and
- Design flood event modelling.

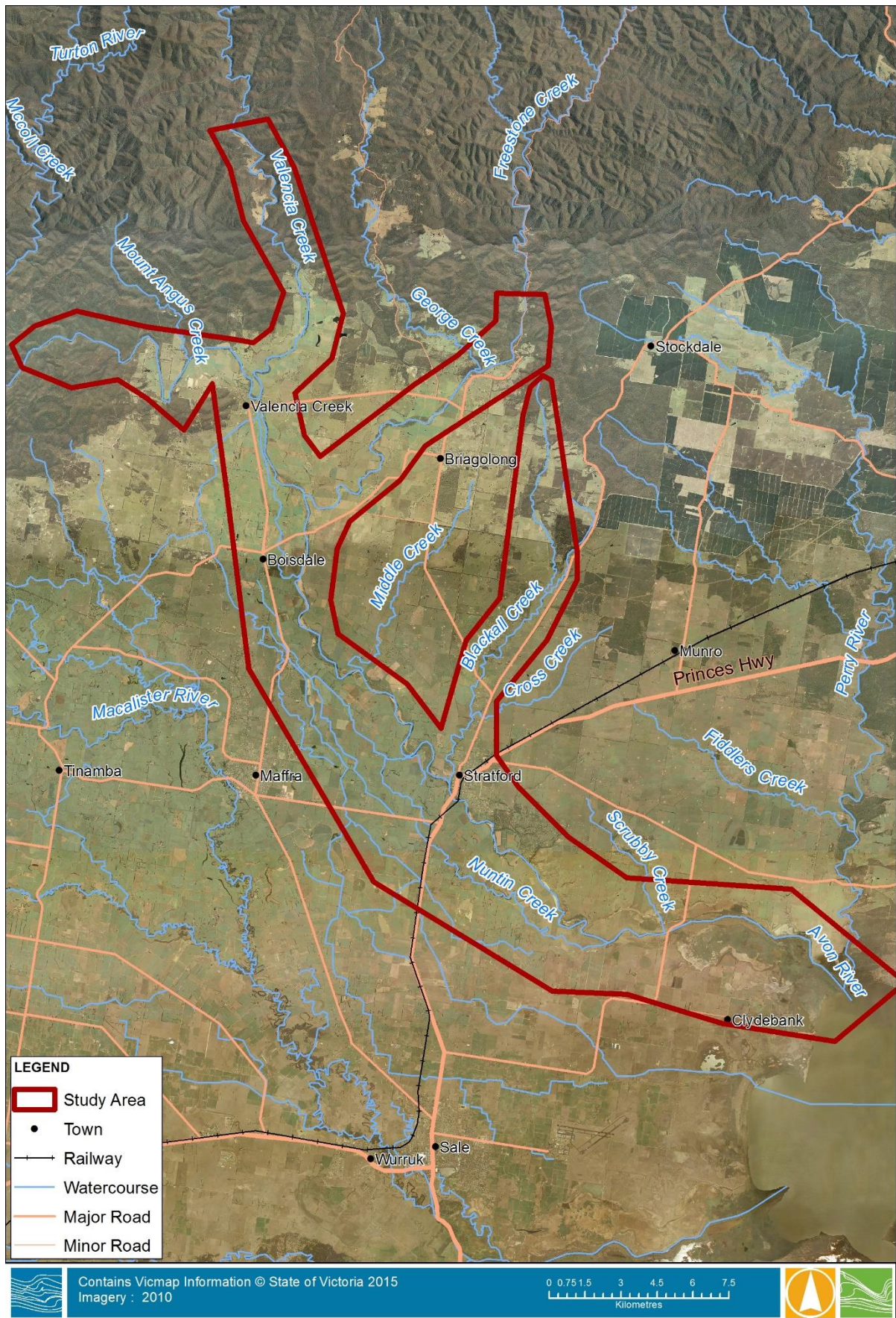
1.2 Available Information

All data received and sent regarding the project has been logged by Water Technology in a Project Data Management Record detailing information about the data. The hydraulic models discussed within this report have been developed based on the previously reported information assembled for the Preliminary Report and the Hydrology Report.

1.3 Study Area

The Avon River rises on the slopes of Mount Wellington in the eastern highlands of the Great Dividing Range and flows south to Lake Wellington and the Gippsland Lakes. The mountainous upper catchment is largely forested, while the lower catchment downstream of the confluence with Valencia Creek has lower relief and primarily agriculture land use (EarthTech, 2006). The floodplain in the lower reaches is traversed by watercourses, swamps and lagoons. Overall, the river descends some 664 m over its 122 km length.

The regional flood mapping area includes approximately 40km of the downstream floodplain of the Avon River catchment, as well as large portions of Freestone Creek, Valencia Creek and Blackall Creek. Key towns within this catchment area include Stratford, Boisdale and Briagolong. The study area and significant watercourses or flood related influences are shown in Figure 1-1.



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05/03/2015

Figure 1-1 Avon River study area

2. PREVIOUS REPORTING

This report should be read in conjunction with the following previous reports:

- Preliminary Report, R01 (Water Technology, 2015a).
- Hydrology Report, R02 (Water technology, 2015b).

2.1 Preliminary Report

The Preliminary Report documented previous flood related information for the study area, including a review of available topographic and structure (bridges and culverts) data. It also outlined the proposed hydrologic and hydraulic modelling scope and methodology.

2.2 Hydrology Report

The final Hydrology Report incorporates the following:

- Flood Frequency Analysis,
- Hydrologic modelling including development and calibration of a RORB rainfall-runoff model,
- Development of design event hydrographs including estimation of the PMF, and
- Comparison with previous studies.

3. HYDRAULIC MODELLING FRAMEWORK

3.1 Overview of the Modelling Approach

A two dimensional (2D) flexible mesh hydraulic model was developed for the study area using MIKE21FM GPU (Mike by DHI). Adopting a flexible mesh modelling approach allowed the hydraulic model to incorporate greater detail in areas of importance, whilst maintaining computational efficiency through a larger element size in less sensitive regions of the modelled area. This allows features within the broader floodplain and the township areas to be resolved in varying detail in the same model whilst maintaining appropriate run times. Model reviews were also undertaken throughout the project, and Appendix B displays the internal hydraulic model review process.

3.2 Hydraulic Model Elements

The hydraulic model framework was required to simulate the flow behaviour across a large portion of the Avon River and its tributaries balancing excessive model simulation times and topographic resolution. The final hydraulic modelling framework comprised of a two dimensional (2D) hydraulic model which is aimed at picking up broad scale floodplain features for large flood events, whilst also providing more refined results in areas of interest.

The hydraulic modelling suite MIKE21 developed by the Danish Hydraulic Institute (DHI) has been applied in this study. The specific module used for this study is MIKE21FM, a state-of-the-art tool for floodplain modelling that applies the dynamic MIKE21FM two-dimensional flexible mesh model systems, while also allowing for the inclusion of one-dimensional elements, and is run with a graphics processing unit (GPU). The GPU allows for greatly accelerated model runs, and represents a recent critical advancement in hydraulic modelling. Further details on the capabilities of the MIKE modelling system can be found at <http://www.dhisoftware.com>.

3.3 Hydraulic Model Limitations

There are numerous contributing factors to the ultimate output uncertainty in a complex hydraulic modelling exercise such as that undertaken for this study. Some of the uncertainties relate to the data inputs, whilst others are dependent on the numerical modelling processes itself. Sources of output uncertainty related to the input data for the hydraulic modelling include:

- Topographic data
- Definition of hydraulic controls/structures
- Observed and estimated design flows for model input
- Observed flows and water levels for model calibration

Sources of uncertainty related to the hydraulic modelling process include:

- Model numerical and computational schemes
- Floating point accuracy of computing resources
- Model schematisation and set-up
- Model parameters such as computational time-steps, surface-friction and other energy-loss parameters

The hydraulic model development process can only address uncertainties arising from model schematisation and set-up, model parameters and definition of hydraulic controls/structures. The remaining aspects are constrained by the available data sources.

There is a wide variation in the magnitude of the impact associated with each source of uncertainty. In order to identify the most significant sources of uncertainty it is possible to consider items as either first or second order magnitude, where second order items are of a significantly smaller magnitude compared to first order items and can generally be ignored or treated with minor consideration. A list of the main sources of the modelling uncertainty and their approximate magnitudes is provided in Table 3-1.

Due to the complexity of the relationships between the input data and modelling outputs, there is no direct correlation between input and output data accuracy, and the error bounds on the data inputs are generally not cumulative. However, there are inferred relationships between model inputs and output accuracy that are typically developed through hydraulic modelling project experience.

Table 3-1 Comparisons of Sources of Uncertainty

Scenario/Data/Process	Order of Accuracy	Approximate Impact on Results
Topographic data	First	Change in floodplain levels/depths ± 0.1 m. The review of the available LiDAR information for Avon found that there was a systematic offset in one of the key datasets (ISC Rivers LiDAR). The dataset was therefore adjusted to correct for this. Channel representation based on LiDAR can often cause underestimation of channel conveyance. Without more detailed survey, this has to be accepted as a model uncertainty.
Definition of hydraulic controls/structures	First	Change in floodplain levels/depths of 0.1 to 0.2 m. The majority of the hydraulic structures in this model are bridges which can have a significant impact on the local water surface level.

Scenario/Data/Process	Order of Accuracy	Approximate Impact on Results
Observed flows for model calibration	First	Flows are dependent on the reliability of the rating curve. The inflows are generally thought to be gauged to a high quality in the Avon River and are likely to be within $\pm 10\%$.
Observed water levels for model calibration	First	Depends on available data, generally ± 0.15 m for observed flood levels. Observed water levels for the 2012 event were pegged from debris lines which may overestimate the actual peak water level. For the 2007 event, the method of identification of water levels is unknown however they are rated as high reliability in the VFD.
Model schematisation and set-up (location of boundaries, mesh resolution)	First	Difficult to quantify, aim for overall accuracy of ± 0.1 m for levels and $\pm 10\%$ for flows in calibration.
Model parameters such as computational time-steps, surface-friction and other energy-loss parameters	First	Difficult to quantify, aim for overall accuracy of ± 0.1 m for levels and $\pm 10\%$ for flows in calibration.
Model numerical and computational schemes	Second	N/A
Floating point accuracy of computing resources	Second	N/A

4. MODEL DEVELOPMENT AND SCHEMATISATION

4.1 Overview

This section defines the scope of the hydraulic analysis, details the hydraulic model scheme and construction including boundary conditions. Hydraulic model calibration, sensitivity tests and flood behaviour are described in Section 5, while design flood events are detailed in Section 6.

4.2 Hydraulic Model Schematisation

4.2.1 Mesh Extent and Resolution

A detailed representation of the ground surface was required to appropriately capture the topographic detail within the hydraulic model. A flexible mesh approach provides high resolution in areas requiring enhanced detail such as the waterway channels, whilst allowing lower resolution in less sensitive areas such as Lake Wellington and the upstream floodplain areas. Spatially varying the resolution allows the model run times to be optimised whilst maintaining element sizes needed to adequately map the study area.

The mesh comprises of triangular and rectangular elements of varying size. The mesh extent and bathymetry used for this study is illustrated in Figure 4-2. The model extends from state forest areas

in the Upper Avon, Freestone and Briagolong catchments to approximately 3.5km downstream from the River's discharge point into Lake Wellington.

The mesh resolution within the townships of Stratford and Boisdale is approximately 15 m² with quadrilateral elements aligned in most areas with the roads and properties. Quadrilateral elements of high resolution were also used to delineate channels and levees. The resolution of the mesh reduces towards the floodplain margin and the Lake Wellington boundary, with a median element size throughout the model of 89m² and a maximum element size of 80 000m². The distribution of mesh element size is shown in Figure 4-1. Triangular elements are used to migrate between quadrilateral sections and areas with different resolutions. An example section of the mesh of the Upper Avon is shown in Figure 4-3, showing the smaller quadrilateral elements in the river, whilst a mixture of larger triangular and quadrilateral elements are used in the broader floodplain.

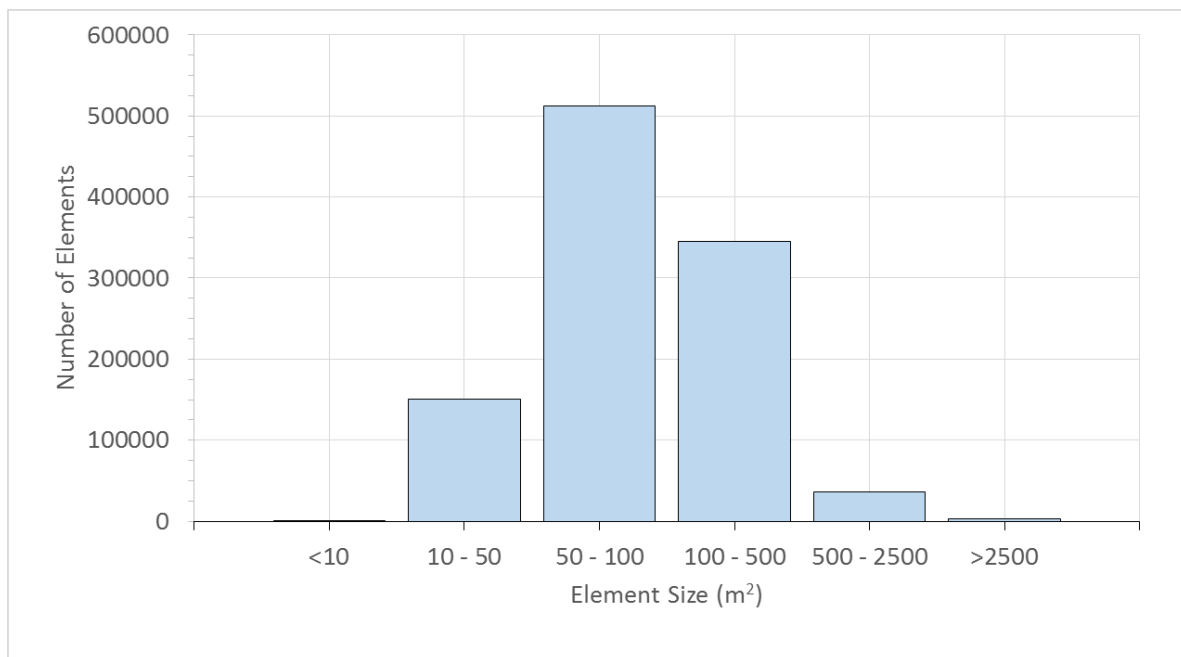


Figure 4-1 Model Mesh Element Size Histogram

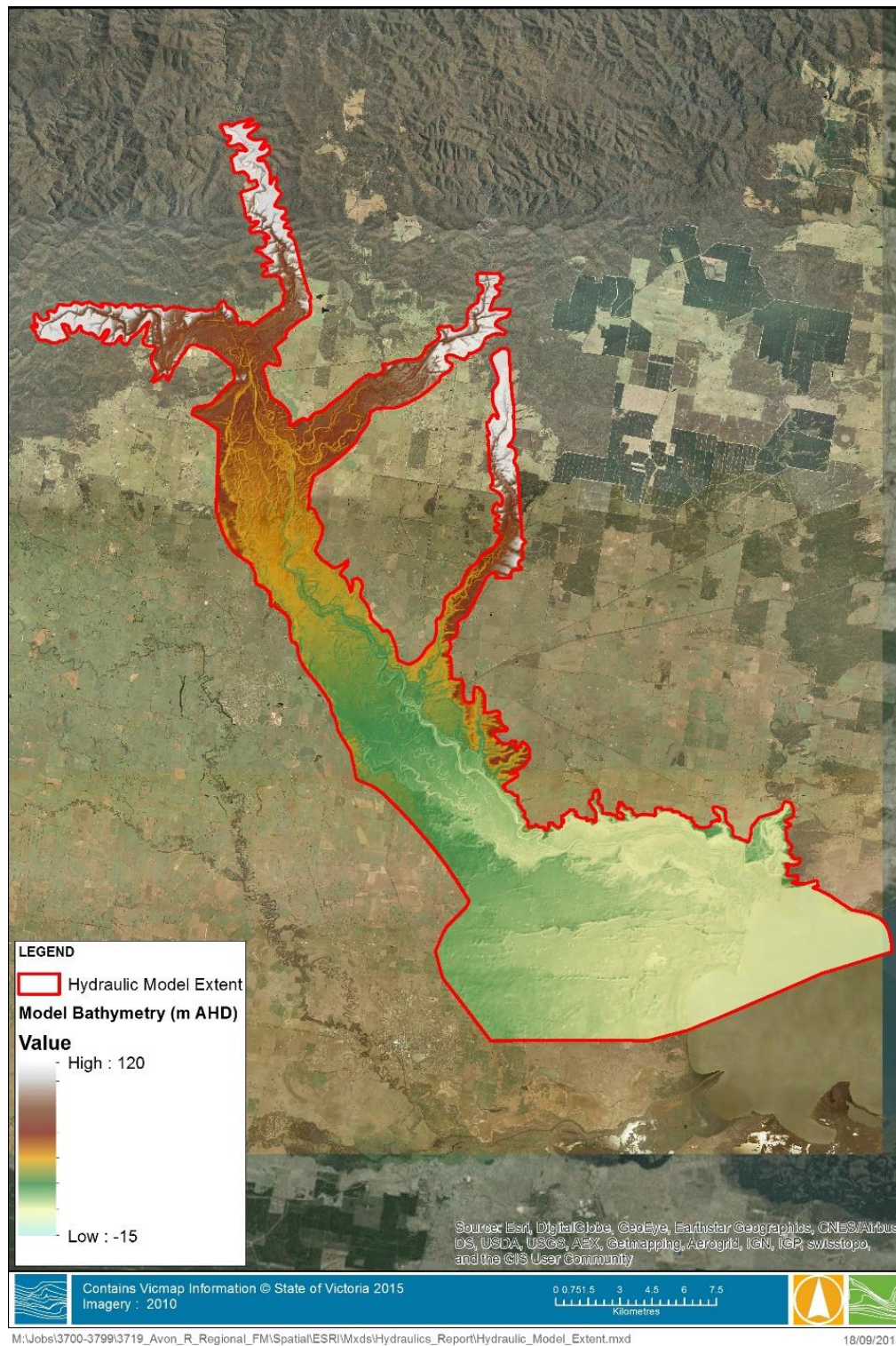


Figure 4-2 Topography generated by the model mesh

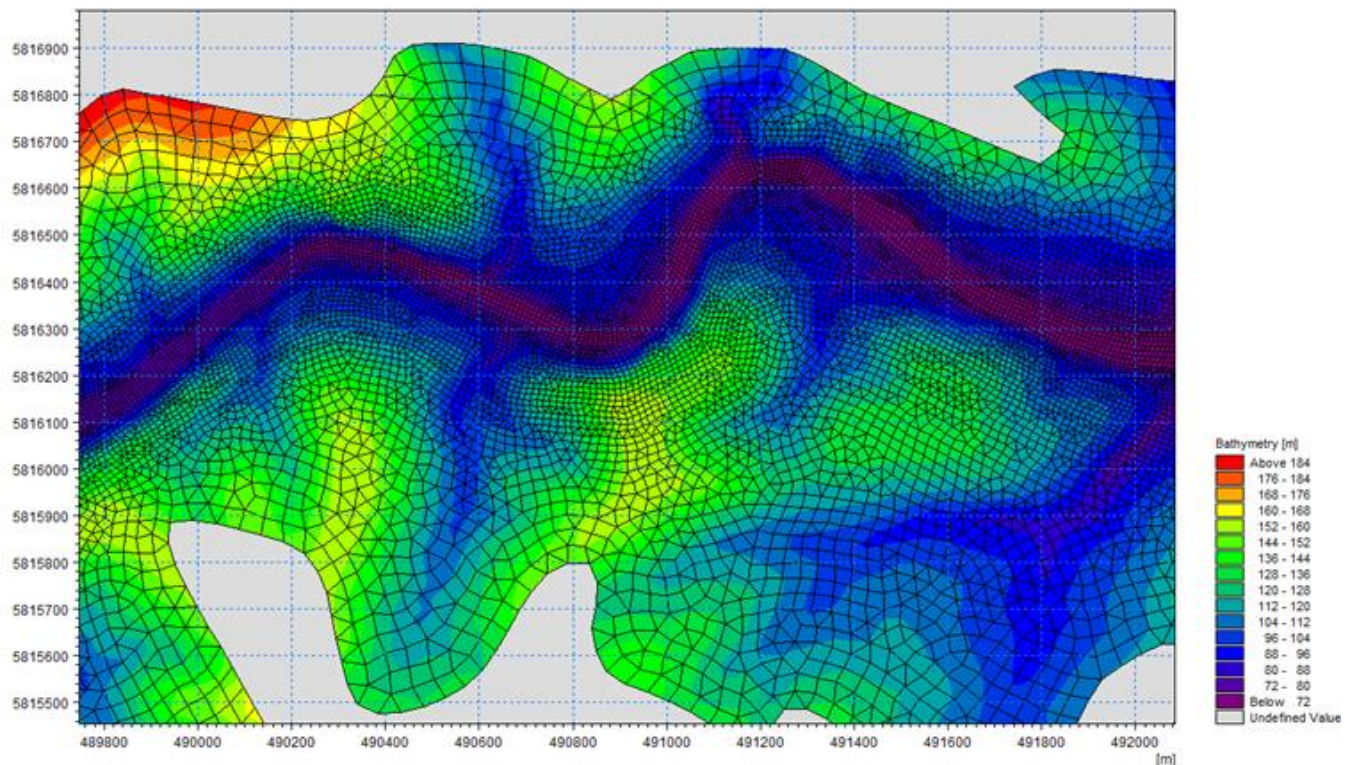


Figure 4-3 Example Mesh of the Upper Avon

4.2.2 Topography

The model topography was based on a mosaic of Index of Stream Condition (ISC) LiDAR, Southern Rural Water (SRW) LiDAR and floodplains LiDAR. This data set was extensively reviewed prior to inclusion in the model (Water Technology, 2015a). This DEM was then sampled at varying resolution using the model mesh, as displayed in Figure 4-3.

4.2.3 Boundary Conditions

There are three key inflow boundaries and one water level boundary controlling the exchange of water into and out of the hydraulic model. These boundaries are identified in Figure 4-4.

Key Inflow Boundaries

Upper Avon River, Valencia Creek and Freestone Creek inflows for the design events and sensitivity testing were provided from the hydrologic model as discussed in the earlier Hydrology Report (Water Technology, 2015b).

Calibration flows for the 2007, 2011 and 2012 historical events were extracted from the Avon River at The Channel gauge (#225224), the Valencia Creek at Gillio Rd gauge (#225223) and the Freestone Creek at Briagolong gauge (#225218), as discussed in the Hydrology Report (Water Technology, 2015b).

The Upper Avon River flows were applied directly to the hydraulic model approximately 2km upstream of the Avon River at The Channel gauge. The Valencia Creek inflows were applied approximately 4km upstream of the Valencia Creek at Gillio Rd gauge and the Freestone Creek inflows were applied approximately 4km upstream of the Freestone Creek at Briagolong gauge.

Baseflow was not considered for inclusion to inflows, as it was found to be insignificant (Water Technology, 2015b).

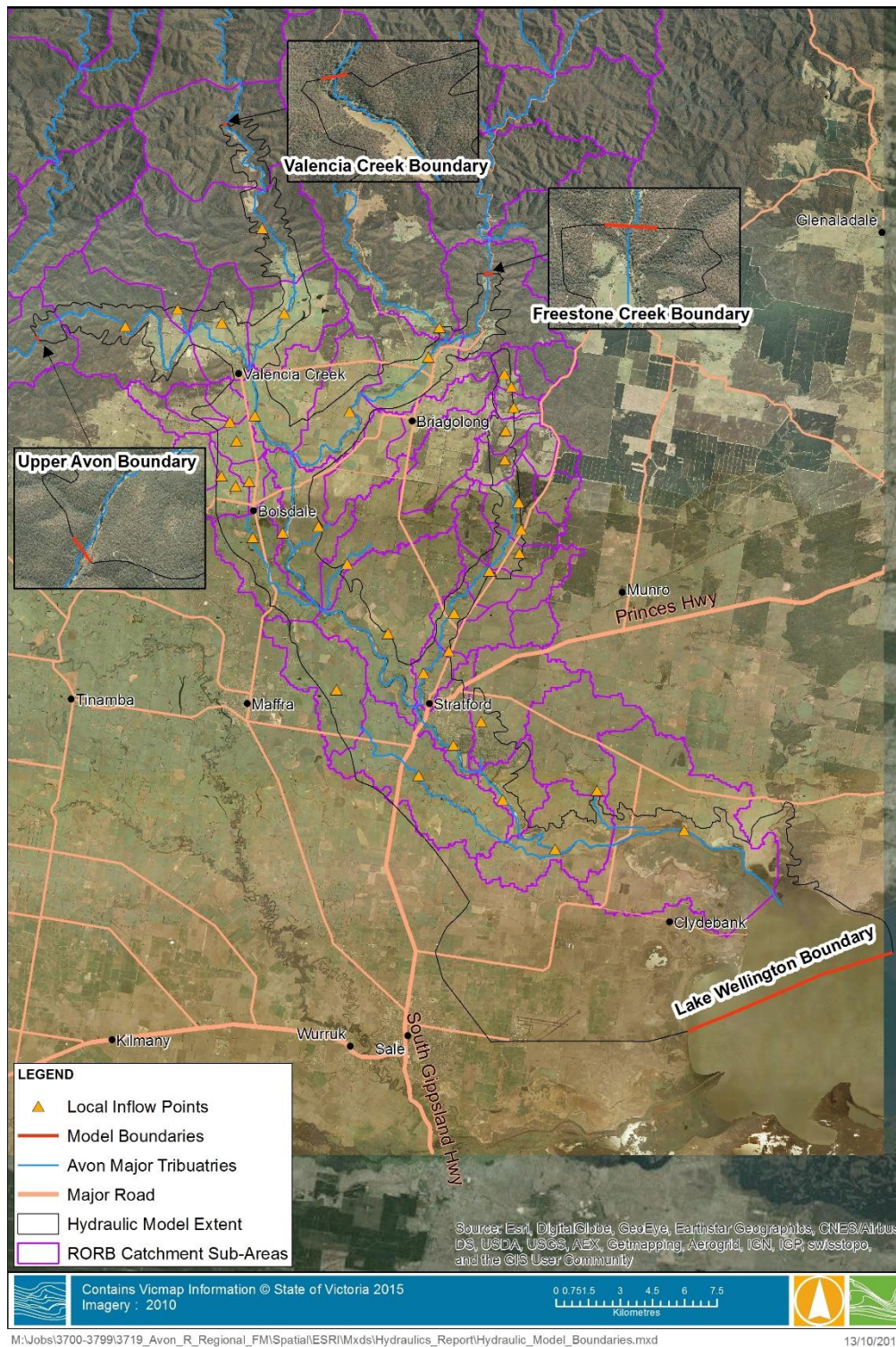


Figure 4-4 Model Boundary Locations

Lake Wellington

For calibration events, water levels for the 2007, 2011 and 2012 historical events were extracted from the Lake Wellington at Bull Bay (#226610) recorded heights, as discussed in the Hydrology Report (Water Technology, 2015b).

For design events and sensitivity testing a steady-state water level boundary was applied to represent tailwater conditions in Lake Wellington.

The dominant forcing mechanism of extreme water levels in Lake Wellington is high river flows. Secondary mechanisms include wind setup and tidal influence. Whilst these secondary mechanisms may be present during a flood, it is unlikely that catchment flooding would occur whilst the water level in Lake Wellington is already high. This would require a flood to occur immediately after another flood. Historic floods on the Avon generally do not have high Lake Wellington levels, which is shown in the calibration events, with the 2007, 2011 and 2012 floods showing approximately 0.40, 0.35 and 0.25m AHD water levels in Lake Wellington at the beginning of each flood, respectively. These calibration levels can be compared to the 10% AEP and 1% AEP Lake Wellington levels of 1.3 and 2.5 m AHD. Sensitivity testing undertaken (see section 5.3.3) show that the water level in Lake Wellington has a minimal impact on the Avon River model, except in the immediate reach upstream of Lake Wellington. It was therefore decided to adopt a 10% AEP flood level in Lake Wellington for the design event simulations as this provides a conservative estimate of Lake Wellington levels during a flood, without the extreme downstream water levels experienced during a 1% AEP flood of Lake Wellington. The Gippsland Lakes are a complex hydraulic system, and it is envisioned that the areas immediately surrounding Lake Wellington would be incorporated into catchment planning via a flood study undertaken on the lake itself, rather than this study which focuses on the Avon River.

These water levels were applied directly to the hydraulic model across approximately 10 km of Lake Wellington.

Local Inflows

Local inflows for the design events, calibration events and sensitivity testing were provided from the hydrologic model as discussed in the earlier Hydrology Report (Water Technology, 2015b).

The local flows were applied directly to the hydraulic model as source points at various locations based on the RORB subareas and are shown in Figure 4-4. As the flows had already been routed in the hydrologic model to the centroid of the hydrologic subcatchments, generally a location near the centroid of the subcatchment was chosen as an inflow location in the hydraulic model, unless the centroid fell outside the model or away from key flow paths. In these cases the source point location was shifted to a more suitable location.

4.2.4 Roughness

Hydraulic roughness within the 2D model was expressed as Manning's n . For the estimation of the floodplain Manning's n , this study assessed land use and vegetation cover. Hydraulic roughness parameters were adopted using industry standard values that represent the channel and floodplain cover, and adjusted as required to calibrate the models. Sensitivity tests were also undertaken on floodplain roughness, as discussed in Section 5.3.1.

Hydraulic roughness values adopted for the 2D hydraulic model are summarised in Table 4-1 and Figure 4-5, which shows the different values adopted for each land use of ground cover. Figure 4-6 is a map of the roughness categories as used in the 2D model. Due to the model sensitivity to roughness values a number of the roughness categories were refined during the calibration process. The final adopted roughness values for each category are shown in the table.

Table 4-1 Roughness Values

Land Use / Topographic Description	Manning's "n"
Valencia Creek stream and bank*	0.015
Road reserve	0.020
Upper Avon River stream and bank*	0.025
General floodplain*	0.040/0.050
Avon River stream and bank*	0.040/0.050
Downstream wetland	0.050
Freestone Creek stream and bank*	0.050
Dense forest	0.10
Built up area	0.20

* modified during the calibration process. Final adopted value shown

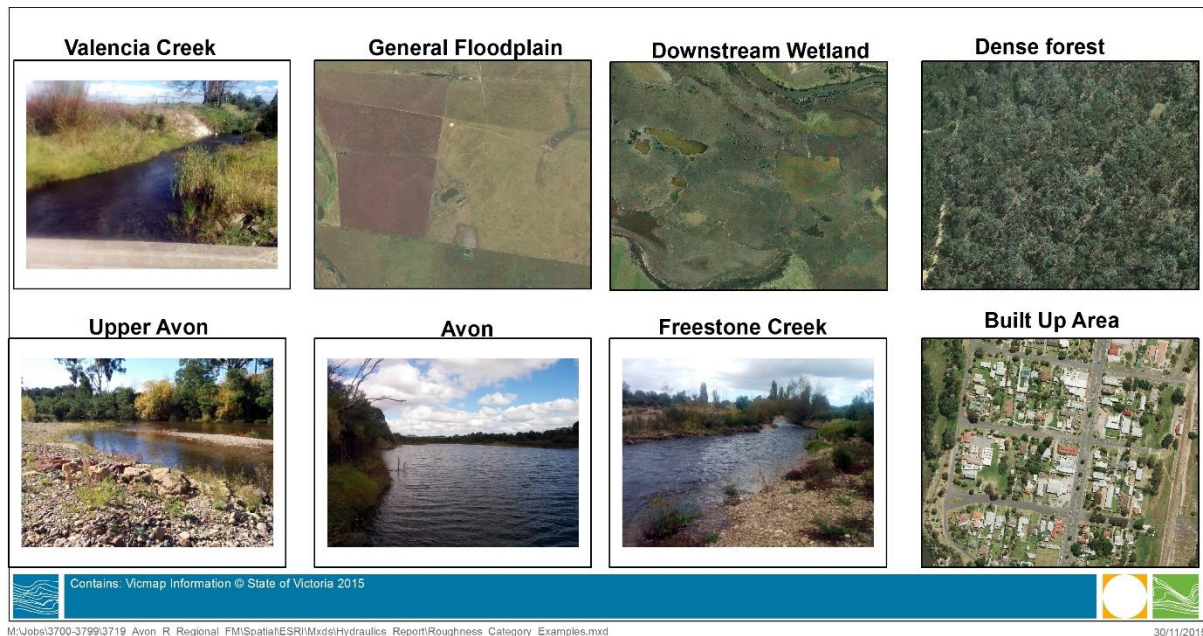


Figure 4-5 Photos showing typical land cover for each roughness category

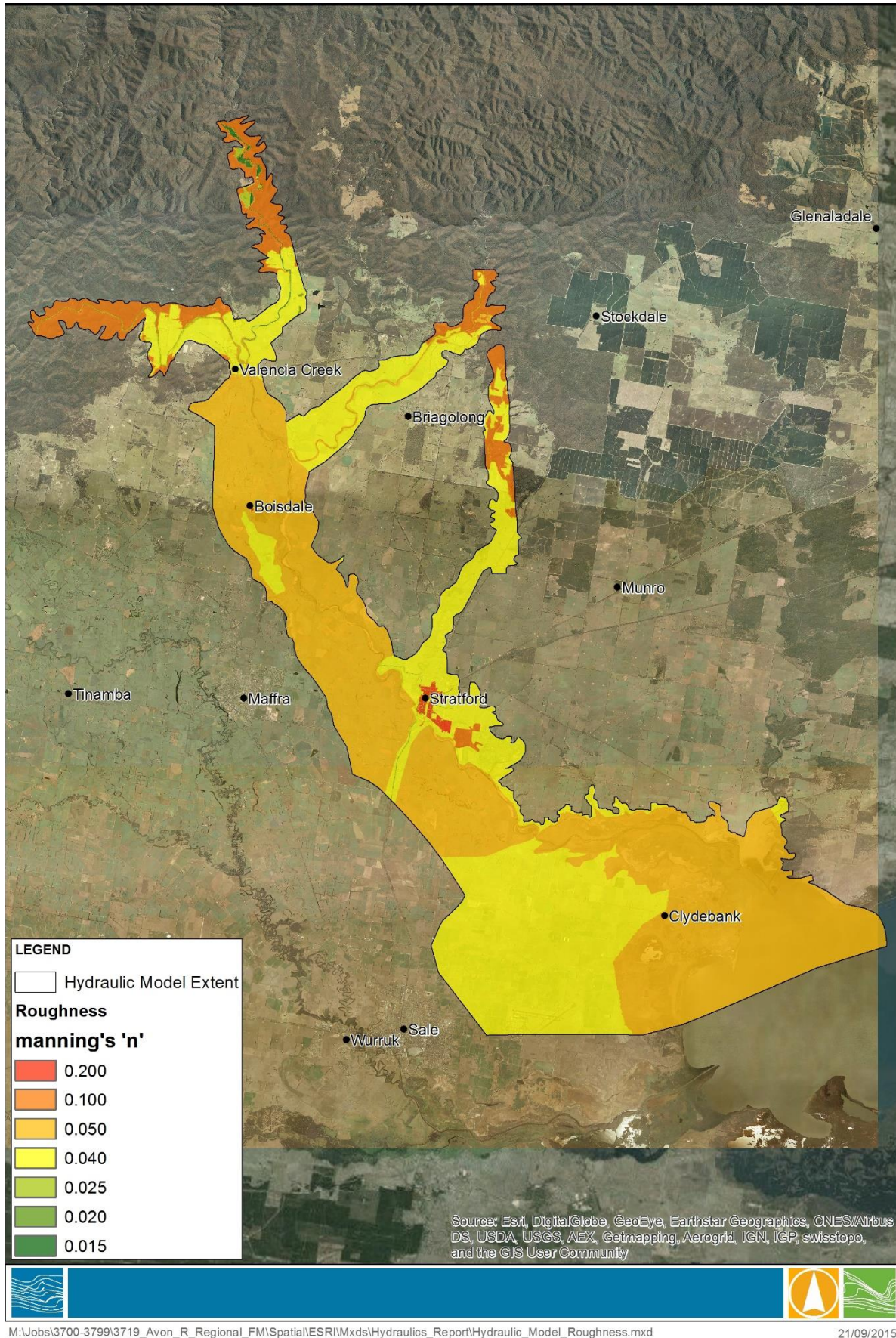


Figure 4-6 Roughness Categories

4.2.5 Hydraulic Structures

Twelve road bridges were explicitly included in the hydraulic model, as shown in Figure 4-7. The road bridges were modelled using a waterway opening cross-section extracted from LiDAR data and a weir crest at the road level, to allow flow both through the waterway opening, and over the bridge deck.

A separate modelling approach was undertaken for the Stratford rail bridge. This bridge has a long span (over 500 m), and is situated in a complex hydraulic location- this area is a key point for riverine breakouts and floodplain flows. The traditional waterway cross-section as adopted for the other bridges would not accurately represent the two-dimensional flow system in this area. Instead, an estimated roughness increase was used as a substitute for the hydraulic energy losses that would occur due to friction losses from the bridge deck and piers.

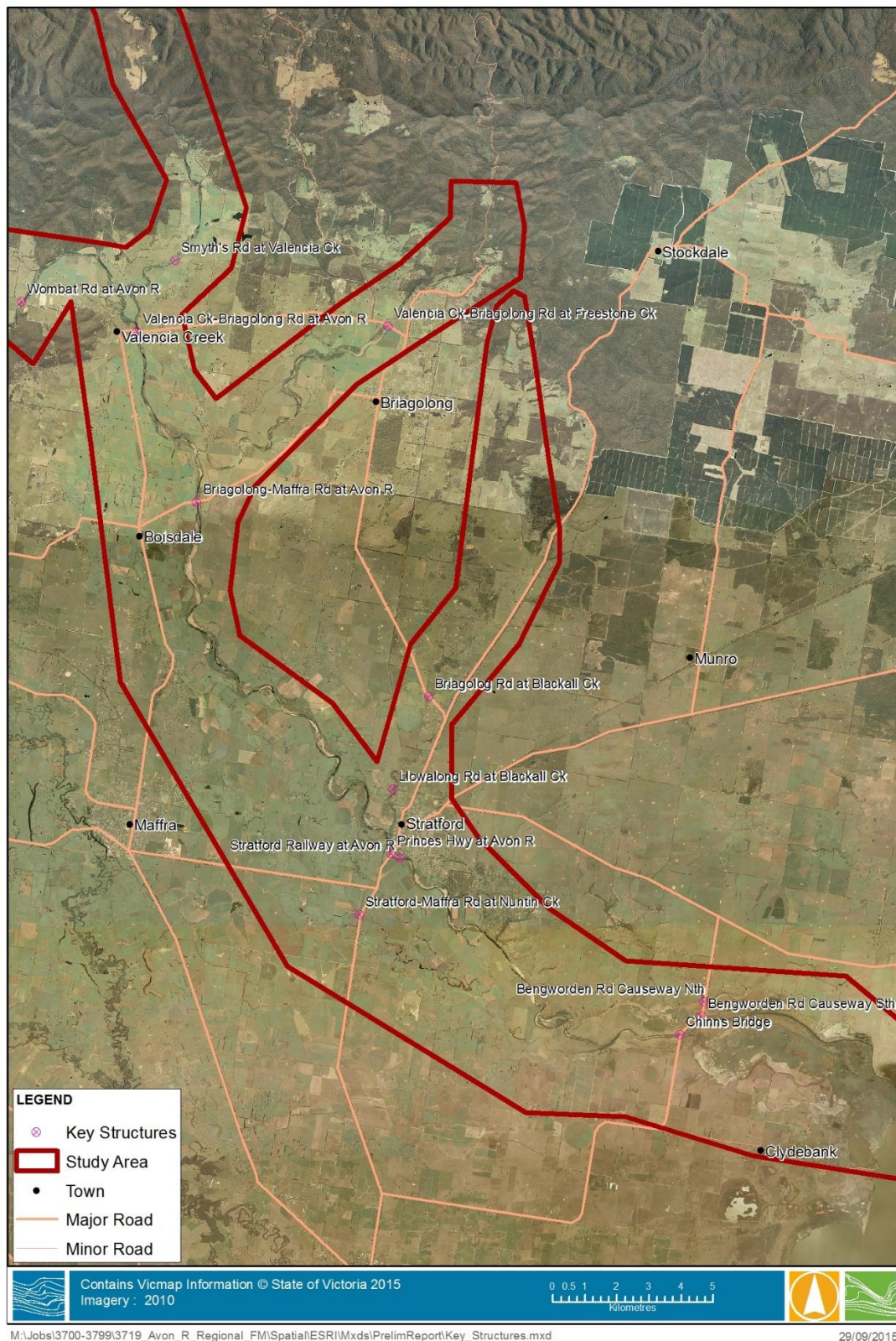


Figure 4-7 Key structures included in the hydraulic model

5. HYDRAULIC MODEL CALIBRATION AND VERIFICATION

5.1 Calibration Approach

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

The calibration process consisted of systematic comparison of observed and modelled flow/flood. This process incorporated comparisons between observed flood levels and flood extents. The models' parameters were adjusted to minimise the differences between the modelled and observed data. The validation process applied the calibrated model parameters to another flood event to assess model performance.

A robust calibration requires the comparison of modelled and observed flood behaviour across a range of flow magnitudes. The following observed data was required for a historical event to be considered in the model calibration:

- Well defined inflows and outflows (boundary conditions).
- Flow and level measurements over time (temporal distribution) at discrete points of interest within and along the river such as effluent points and control structures.
- Flood extent and/or depth measurements (spatial distribution) at multiple times.

The historical flow/flood events used to calibrate/validate the models were chosen on the basis of available observed flood information. The following sections detail the selection of and available data for the calibration/validation events.

The calibration of the model centred on the determination of floodplain and river channel hydraulic roughness values (Manning's n values) to achieve a reasonable agreement between observed and modelled flood levels. Initial Manning's n values were assigned to various land uses based on previous modelling experience, and where necessary to achieve a reasonable agreement, these initial Manning's n values were refined. It was found that slightly different roughness values were required for the stream and wetland areas (particularly the Clydebanks area) for calibration of the different events. Inter-annual and seasonal variability of riparian and wetland vegetation is high, therefore it is reasonable that different vegetation conditions would need to be simulated for the events. Typical roughness values were selected for these areas for design flood modelling. The final values are listed in Section 4.2.4.

5.1.1 Available Observed Flood Data and Calibration/Validation Event Selection

The focus of the model calibration and validation was the general flood behaviour during large flood events, in line with the study's interests (20% AEP to 0.5% AEP events). Hence, the selection of calibration and validation events reflected recent large flood events with adequate available observed flood data suitable for this purpose.

The recent flood events in June 2007 and June 2012 were selected for model calibration, given their relatively large flood magnitude and reasonable abundance of observed flood information. Flood level data was available for the 2012 event from WGCMA flood pegging of observed debris lines after the peak had passed. Flood level data for the June 2007 event was available from the VFD and was rated to high accuracy.

The model was also validated using the August 2011 flood event. This event did not have any available observed flood level data and was smaller than the 2007 and 2012 events. However a comparison with water level and flow data at gauges throughout the catchment was undertaken to provide confidence that the model was capable of accurately simulating flood routing and levels over a wide range of events.

Following discussions with the community during the second round of consultation sessions in December 2015, it was decided to incorporate the April 1990 event into model validation. Whilst the Valencia Creek at Gillio Rd gauge was washed out during this event, and water level records were not available for Lake Wellington, assumptions on flows and levels were made to allow simulation of the flood. This flood is the largest in living memory of the Avon River (estimated as an approximate 1% AEP event), and a large number of flood marks are available in the floodplain on the western side of the Avon River between Stratford and Boisdale. The community noted that flood levels in this floodplain area appeared too low in some areas in draft design event mapping, and the 1990 event was the only flood with quantitative flood levels in this area available to assess those comments further.

The existing floodplain condition is assumed to be representative of all calibration and validation events. However, the Nuntin Levee/spillway area is one location where topography has varied since 1990. A levee was built at this location in the 1990s, however the levee was almost completely scoured out in the July 2007 flood event (Alluvium, 2008), and rebuilt as a spillway. This spillway was then modified in 2014 and replaced with a levee again (Alluvium, 2014). LiDAR captured in 2008 (SRW LiDAR) and 2010 (ISC Rivers LiDAR) in this area, documents the post flood scour conditions before reconstruction of the spillway and conditions after re-construction of the spillway. For the calibration events, the decision was made to utilise the 2008 SRW LiDAR (captured prior to spillway construction) in the model as it is likely to represent the floodplain topography during large floods that manage to cause scour in this region. A sensitivity test was undertaken using the 2010 ISC Rivers LiDAR which captured the re-constructed spillway, and the model was found to be relatively insensitive, even for small events (5% AEP). This is further discussed in Section 5.3.4. For the design events the current level of the levee was included in the model topography.

Table 5-1 displays the peak flows and associated approximate AEP for the model calibration/validation events, and general nature of available observed flood information. Approximately AEP is based on the adopted design peak flows for the Stratford gauging station (225201).

Table 5-1 Hydraulic model calibration/validation events – Peak flows, approximate AEP, and available observed flood information

Event	Peak flow (m ³ /s) and approximate AEP at Stratford		Available flood information	Use
	Peak Flow (m ³ /s)	Approximate AEP (%)		
June 2007	2,156	2.5%	Observed flood marks: 46 Observed flood extent Gauged flows and levels	Calibration
August 2011	889	20%	Gauged flows and levels	Validation
June 2012	1,855	4%	Observed flood levels: 12 Observed flood extent Gauged flows and levels	Calibration
April 1990	2,834	1%	Observed flood marks: 608 Observed flood extent Gauged flows and levels (some missing)	Floodplain Water Level Validation

5.2 Calibration and Validation Results

5.2.1 Gauged Flows and Levels

Modelled water levels and flows at the Stratford gauge and modelled water levels at Clydebank were compared to gauged data for the 2007 and 2012 calibration events and the 2011 validation event. The results are summarised below and in the following figures.

- The modelled results for the June 2007 event had a good match to peak water levels at all gauges (within approximately 0.1 m), and a close match to the peak flow at Stratford (Figure 5-3). The timing of the flood peak was around 1-3 hours early at Stratford and Clydebank. For calibration, peak water level was most accurate when the lower catchment areas around Clydebank had a roughness value of 0.06.
- The June 2012 event also had a very close match of peak water levels (within approximately 0.1 m) at all gauges in the study area, and a close match to the peak flow at Stratford (Figure 5-2). Again, the timing of the rising limb and peak was early at Stratford and Clydebank by 1-3 hours. For calibration, peak water level was most accurate when the lower catchment areas around Clydebank had a roughness value of 0.05, compared to the 2007 event which was calibrated with a roughness of 0.06.
- For the 2011 validation event, the adopted roughness parameters for each of the calibration events were applied to the model and then the 2011 event simulated. The parameter set for the 2012 event with Clydebank roughness of 0.05 was found to produce a slightly better result (Figure 5-3). These roughness parameters were then adopted for calibration events, and they are displayed in Section 4.2.4. Modelled flood levels at Stratford were around 0.3 m higher than measured, probably due to the modelled flow being slightly too high. The modelled rising limb and flood peak were also around 2-3 hours early than measured. Flood levels at Clydebank were around 0.4 m lower than measured values.

The modelled 2011 event exhibits elevated water levels at upstream gauges compared to the 2007 and 2012 calibration events. The 2011 event is the smallest modelled, and smaller events are more sensitive to channel topography and roughness. It is thought that the higher levels in the 2011 event are primarily due to the regional scale model's representation of topography and roughness within the channel. This is considered a limitation of the model, and events smaller than the 10% AEP may overestimate flood levels. However, considering the model's size and resolution, the focus on calibration was accurate estimation of larger flood events and this is thought to have been achieved via the 2007 and 2012 event calibration.

In addition to the main river gauging stations, comparisons were also made between measured and modelled water levels and the timing of peak flows at a low level crossing gauge in the Avon River upstream of Stratford on Valencia Creek-Briagolong Road. Only information for the 2012 flood event was available. The modelled water level at the gauge site shows a good match for the timing of the measured 2012 flood peak, indicating accurate flood routing through the Upper Avon and Valencia Creek tributaries.

The difference in the timing of the modelled and measured rising limb and flood peak at Stratford and Clydebank in the calibration and validation events indicates that the modelled flood routing through the Avon River floodplain is slightly too efficient. However, the timing difference of the flood peak is small (generally between 1 to 3 hours over a 48-56 hour event), and given that the modelled peak water levels and flows are well represented at all sites, the calibration was deemed to be fit for purpose for regional flood mapping.

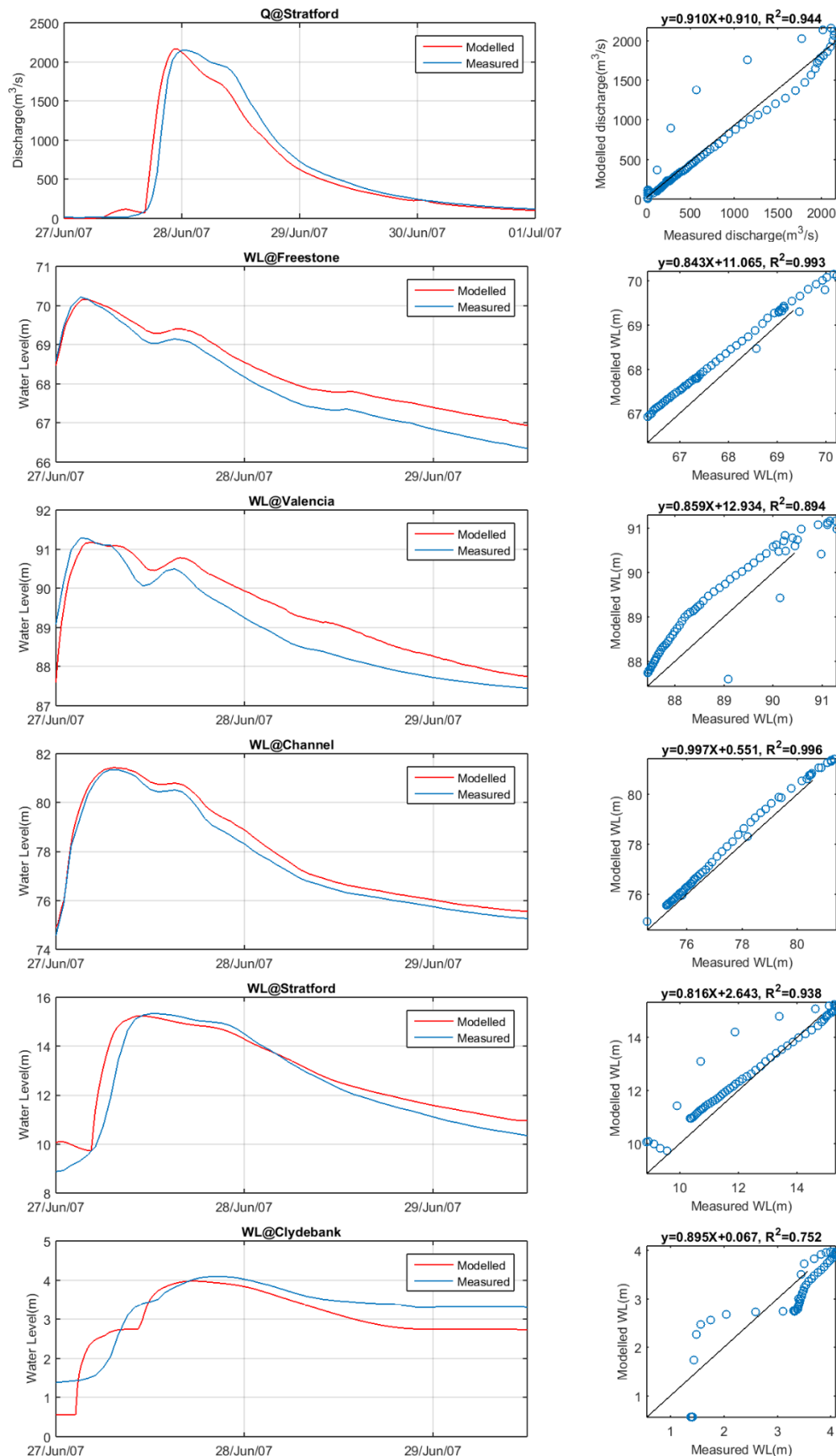


Figure 5-1 Calibration flow and water level results at Stratford and Clydebank gauges, June 2007 event (Clydebank roughness 0.06)

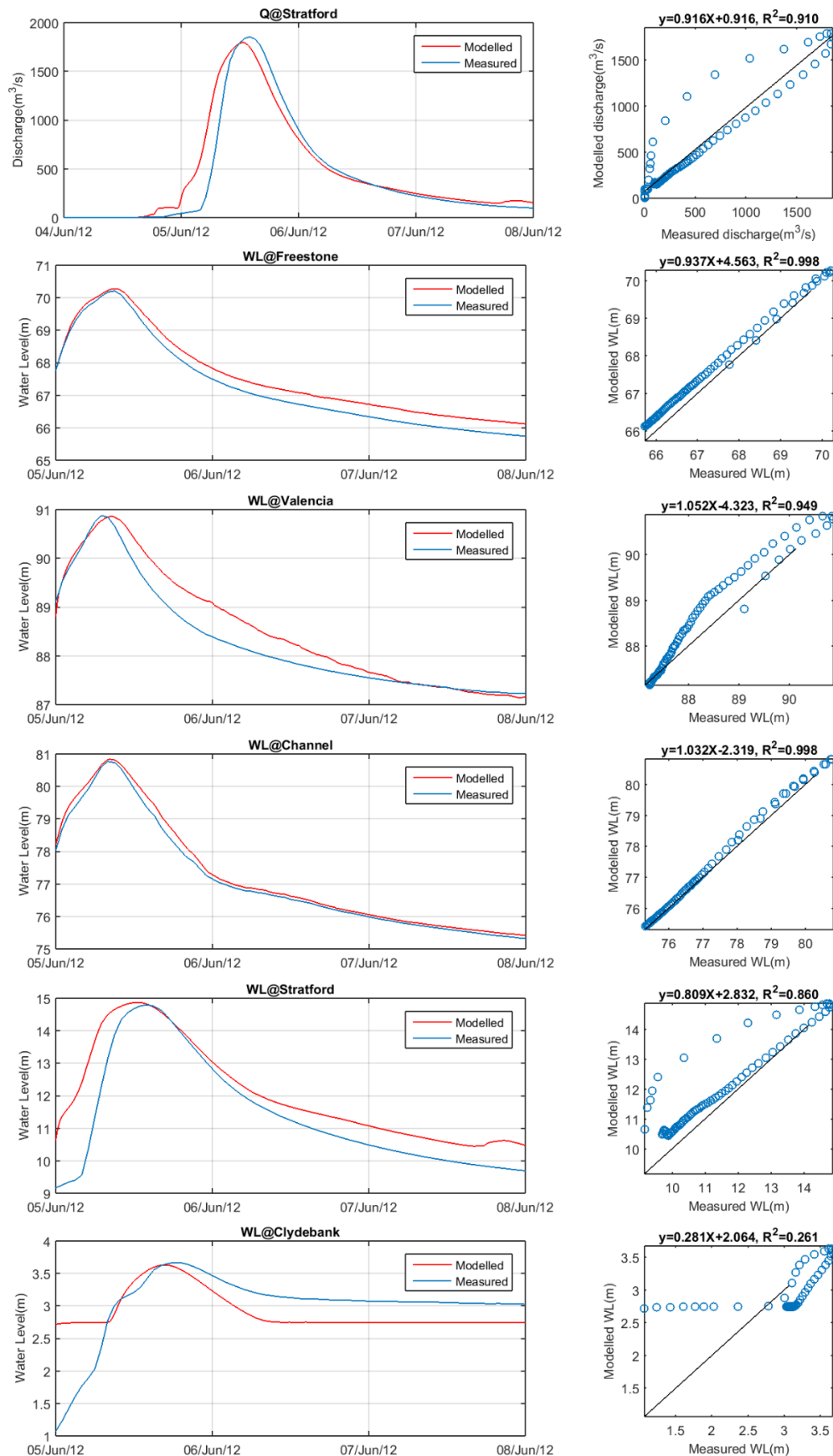


Figure 5-2 Calibration flow and water level results at Stratford and Clydebank gauges, June 2012 event (Clydebank roughness 0.05)

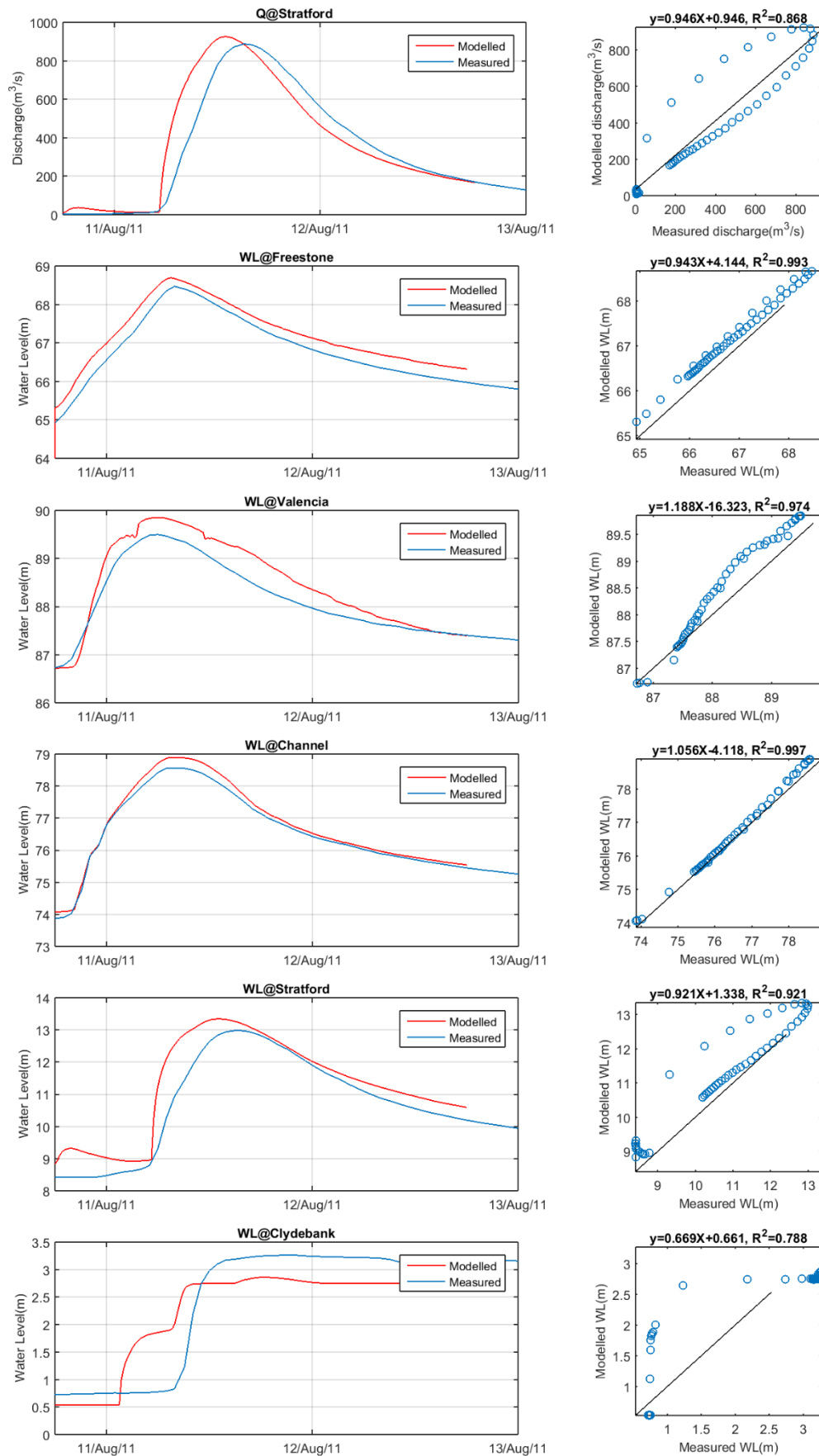


Figure 5-3 Validation flow and water level results at Stratford and Clydebank gauges, August 2011 event (Clydebank roughness 0.05)

5.2.2 Observed Flood Levels and Extents

Apart from river gauges, other observed data was available to verify the calibration and validation events. These include spot levels taken by WGCMA immediately after flooding and digitised flood extents based on aerial imagery. This analysis has been undertaken for the 2007, 2012, and 1990 flood events where sufficient data was available for comparison purposes.

June 2007 Event

Observed flood data for the June 2007 flood event includes 46 surveyed flood marks and a digitised flood extent downstream of Stratford. These flood marks and flood extents were compared to calibrated model results.

Figure 5-5 shows the spatial distribution of these flood marks within the model area. Over 30% of flood marks have less than 200mm difference between measured and modelled results, and over 75% of flood marks are within 600mm. The histogram in Figure 5-4 shows the distribution of difference between the modelled and measured flood marks, with a general trend of modelled water level being lower than measured water level. This discrepancy in the modelled levels and the available post flood survey was not expected given the favourable comparison to the water level gauging stations. This may be associated with the inherent inaccuracies of post event surveyed flood levels, such as estimated peak flood heights and debris lines, and human error; and the inherent model limitations already discussed.

Digitised flood extents are also available for the June 2007 Event. These extents start approximately 1km downstream of Stratford and continue to the Avon River outlet. The digitised and modelled flood extents are very similar, as shown in Figure 5-6.

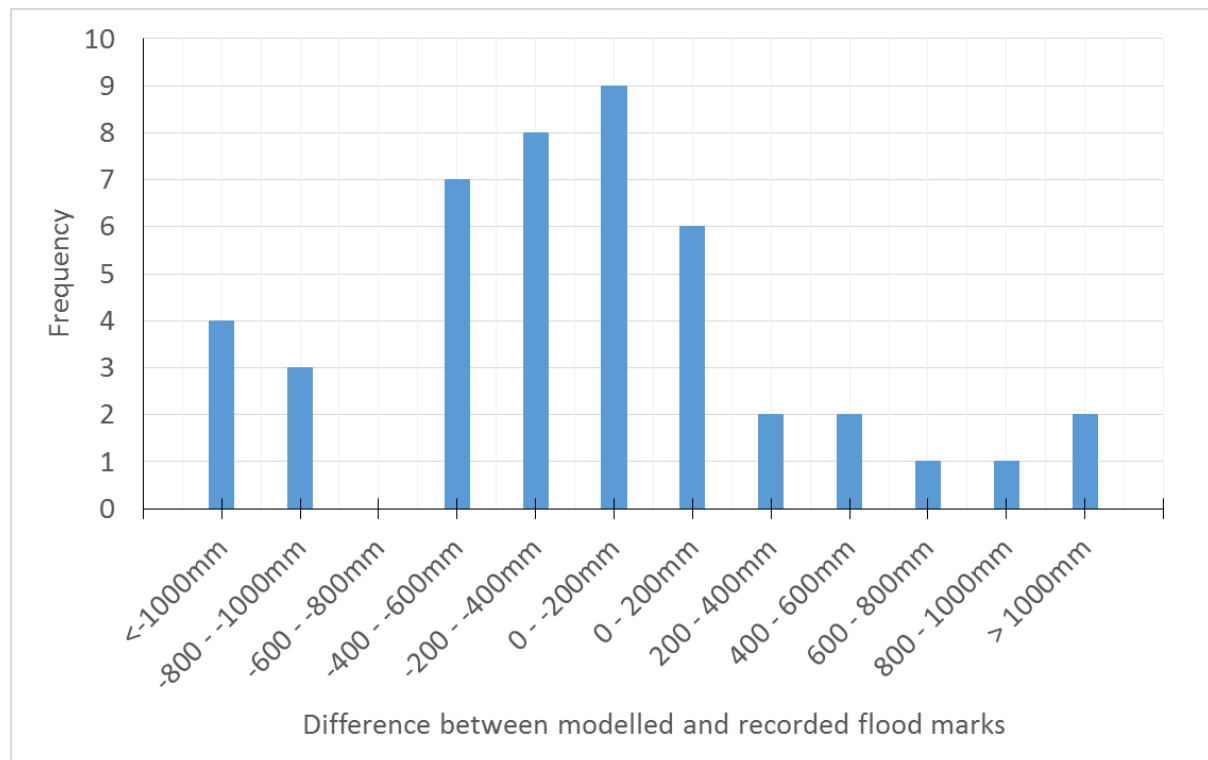


Figure 5-4 Histogram of Modelled and Measured Flood Mark Difference for 2007

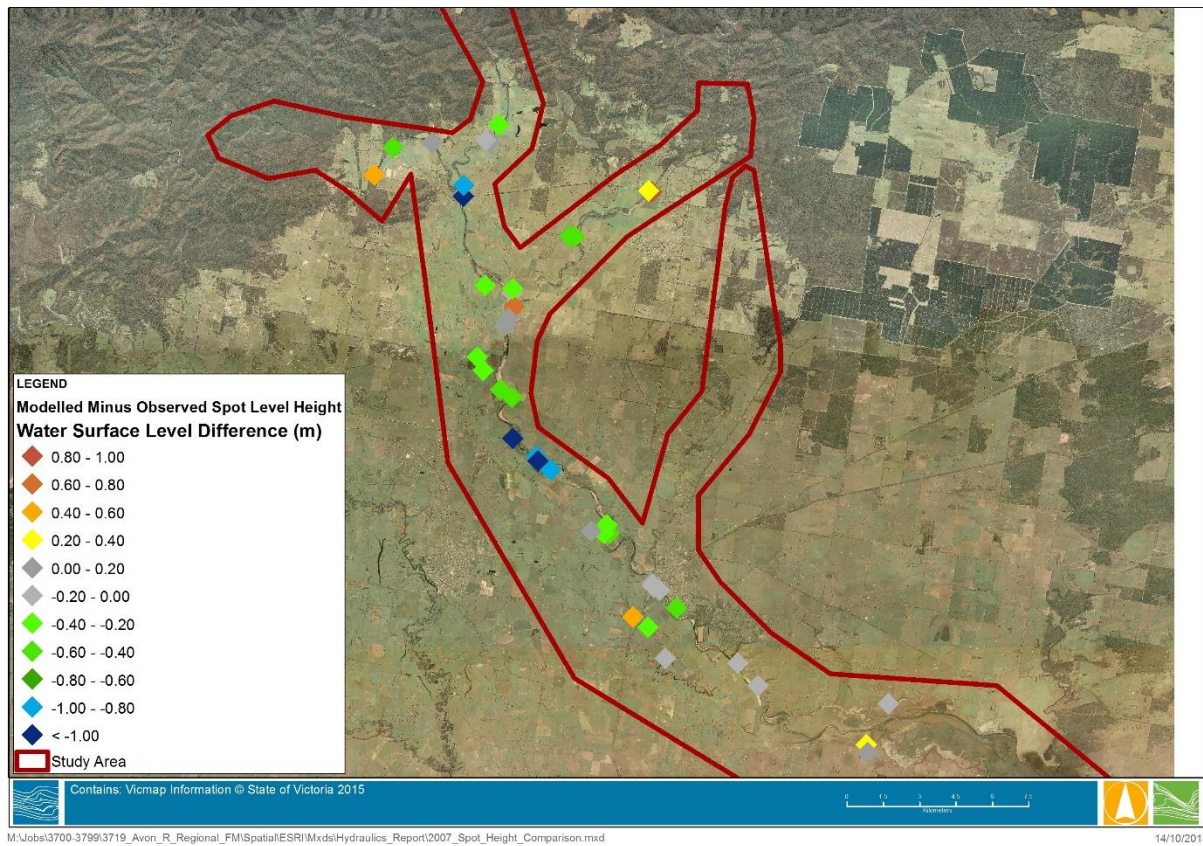


Figure 5-5 June 2007 modelled and observed spot level difference

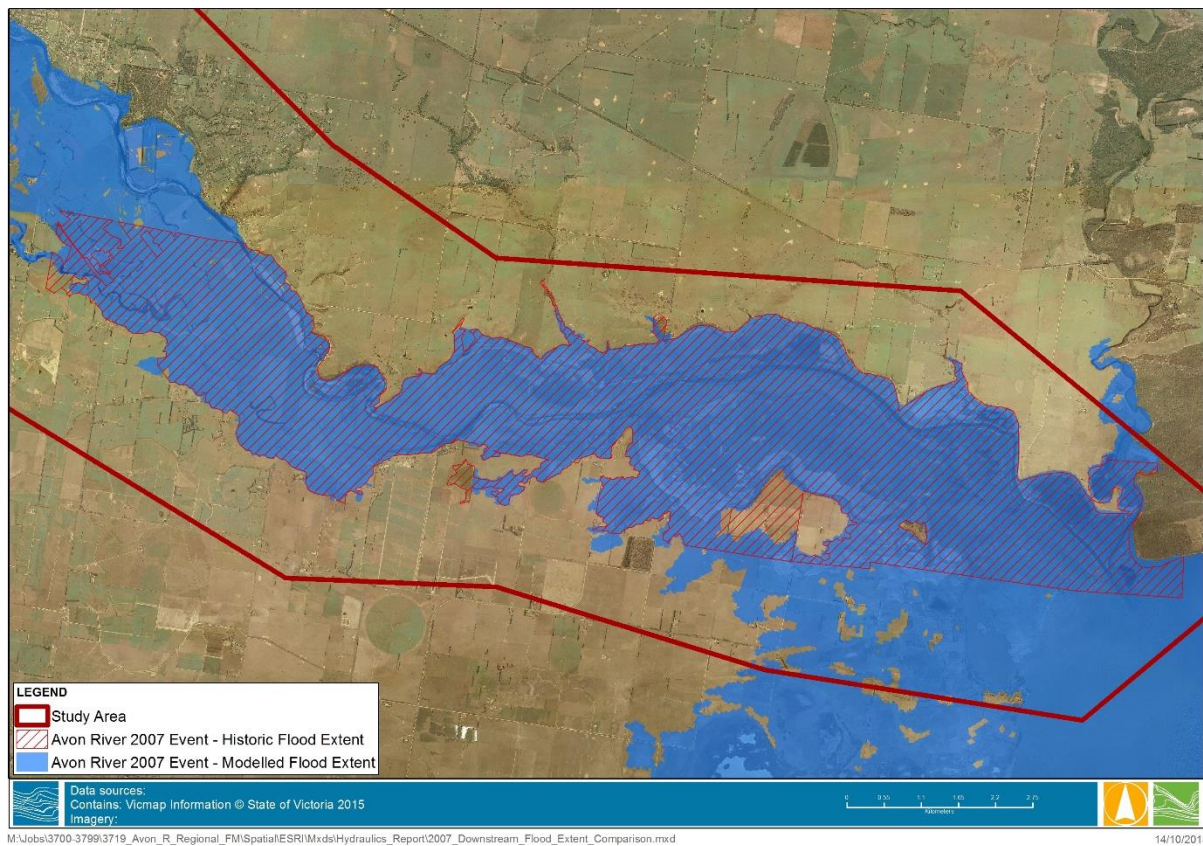


Figure 5-6 June 2007 modelled and observed downstream flood extent

June 2012 Event

Observed flood data for the June 2012 flood event includes 12 surveyed flood marks and a digitised flood extent around Stratford. These flood marks and flood extents were compared to calibrated model results.

Figure 5-8 shows the spatial distribution of these flood marks within the model area. Of the 12 flood marks, nine of them were within 300mm difference between modelled and measured values. The other three flood marks are in relatively small floodplain flow paths that are not picked up within the model topography. The histogram in Figure 5-7 shows the distribution of difference between the modelled and measured flood marks.

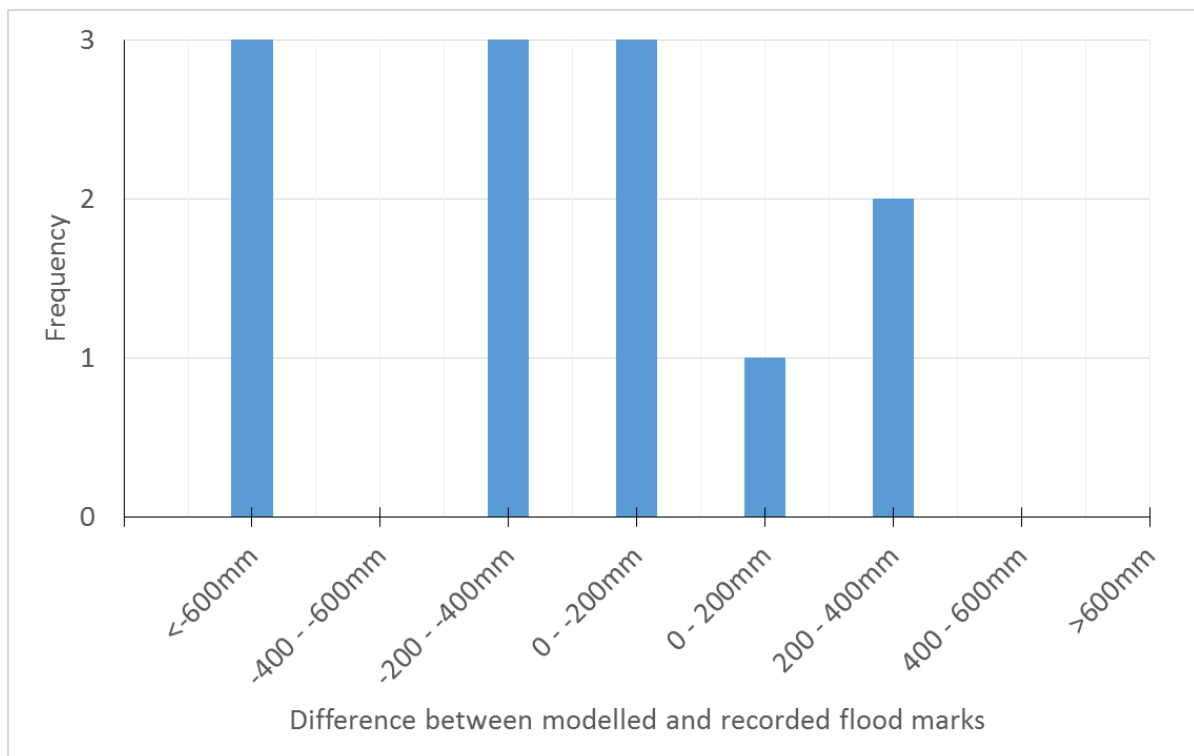


Figure 5-7 Histogram of Modelled and Measured Flood Mark Difference for 2012

Digitised flood extents are also available for the June 2012 Event. These extents start approximately 3 km upstream of Stratford and continue to the Avon River outlet. The digitised and modelled flood extents are very similar in the downstream extent, as shown in Figure 5-9. There are significant differences between the flood extents adjacent to Stratford and the immediate downstream area. The reliability of the digitised flood extents is unknown, as an exact time of capture is not noted in the data. It seems likely that the photos were not captured at the time of peak inundation, as key flow paths are visible, but shallow flow paths only visible around peak flow times are not visible.

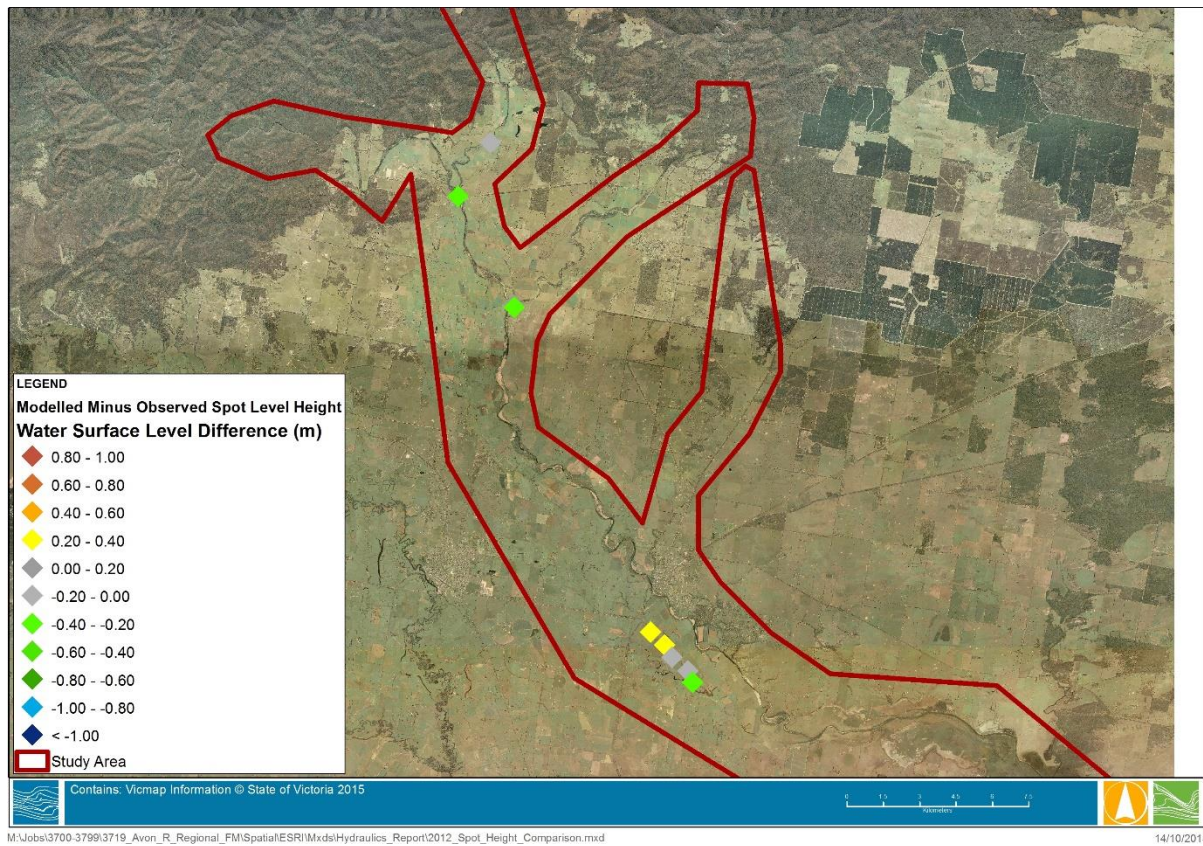


Figure 5-8 June 2012 modelled and observed flood extent and levels

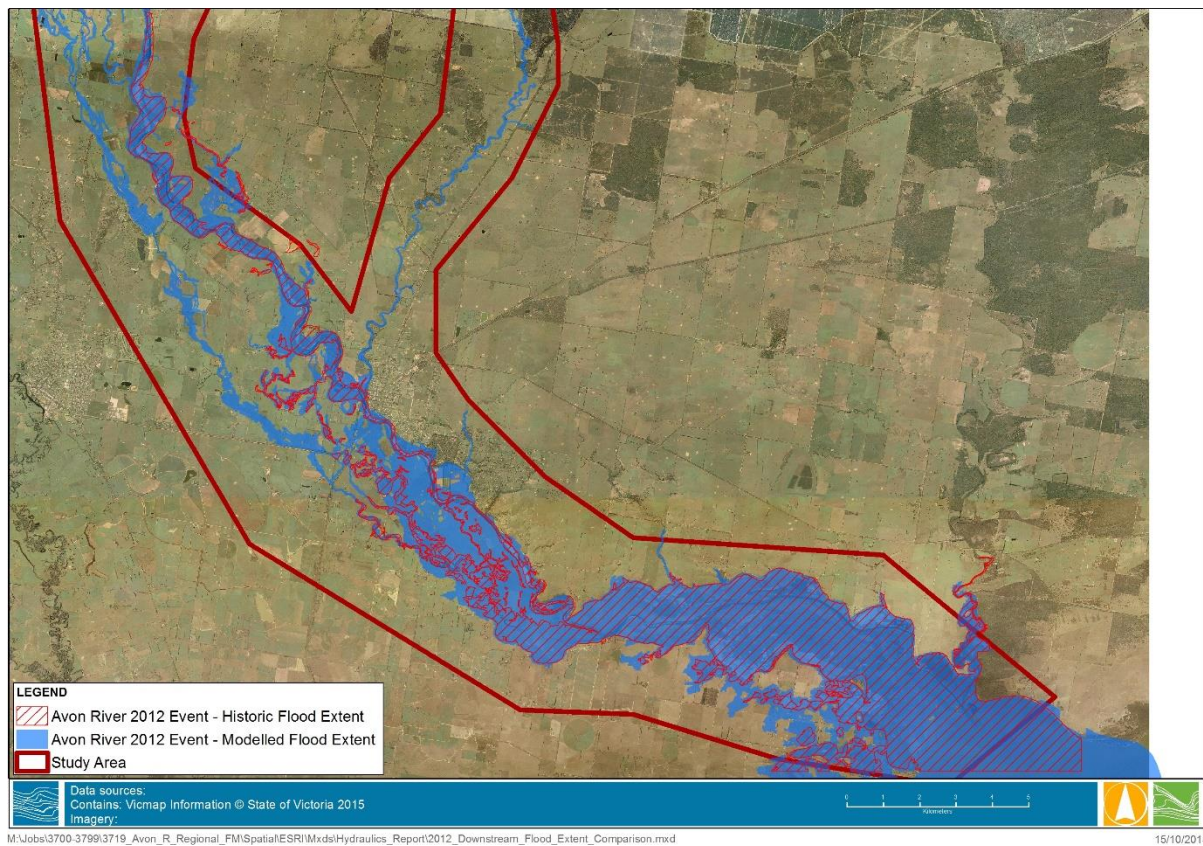


Figure 5-9 June 2012 modelled and observed downstream flood extent

April 1990 Event

Observed flood data for the April 1990 flood event includes 608 surveyed flood marks and a digitised flood extent from Valencia Creek to Stratford. The high number and spatial variation of these flood marks was used to validate water levels in the downstream floodplain, although this comparison is somewhat qualitative as there were no gauged inflows for Valencia Creek for this event and an assumed hydrograph was applied to the model for this boundary.

The 1990 event was tested using a range of roughness values (both river and floodplain) to assess which floodplain roughness (0.05 or 0.04) gave the most accurate water levels in the ungauged Avon floodplain on the western extent of the study area. This area was typically not inundated during the calibration and validation events and therefore its sensitivity to roughness values could not be assessed from the model results for these events.

The 1990 simulation showed that a roughness value of 0.05 resulted in the best fit for water levels, with 34% of flood marks within 200mm of the surveyed level, whilst a roughness of 0.04 resulted in only 17% of values within this range. There was also over 200 flood marks outside of modelled flood extent in both simulations. This is thought to be due to the fact that post-flood surveying also considered small tributaries, which are too minor to be resolved in the regional scale modelling. The histogram in Figure 5-10 shows the distribution of difference between the modelled and measured flood marks for both model runs, whilst Figure 5-11 shows the spatial distribution of these flood marks.

Based on these results it was agreed with the project steering committee to increase the adopted floodplain roughness for simulation of design events.

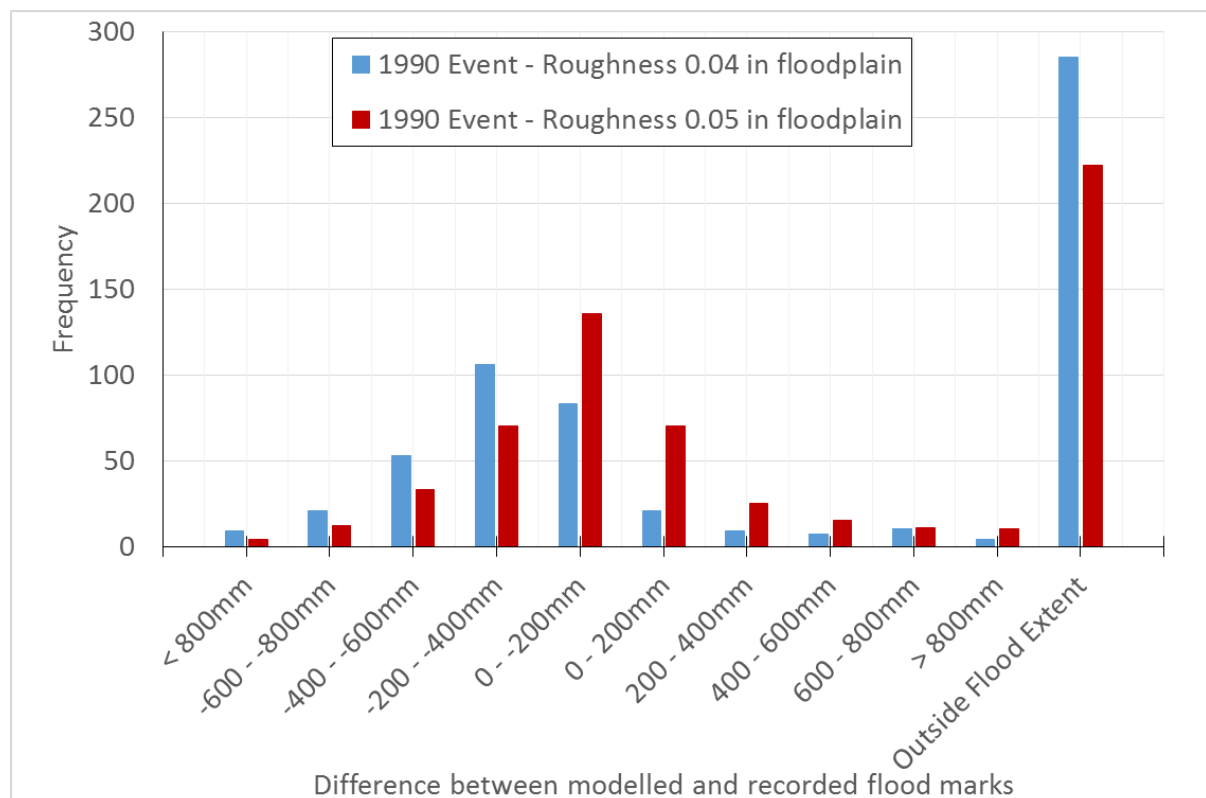


Figure 5-10 Histogram of Modelled and Measured Flood Mark Difference for 1990 Event

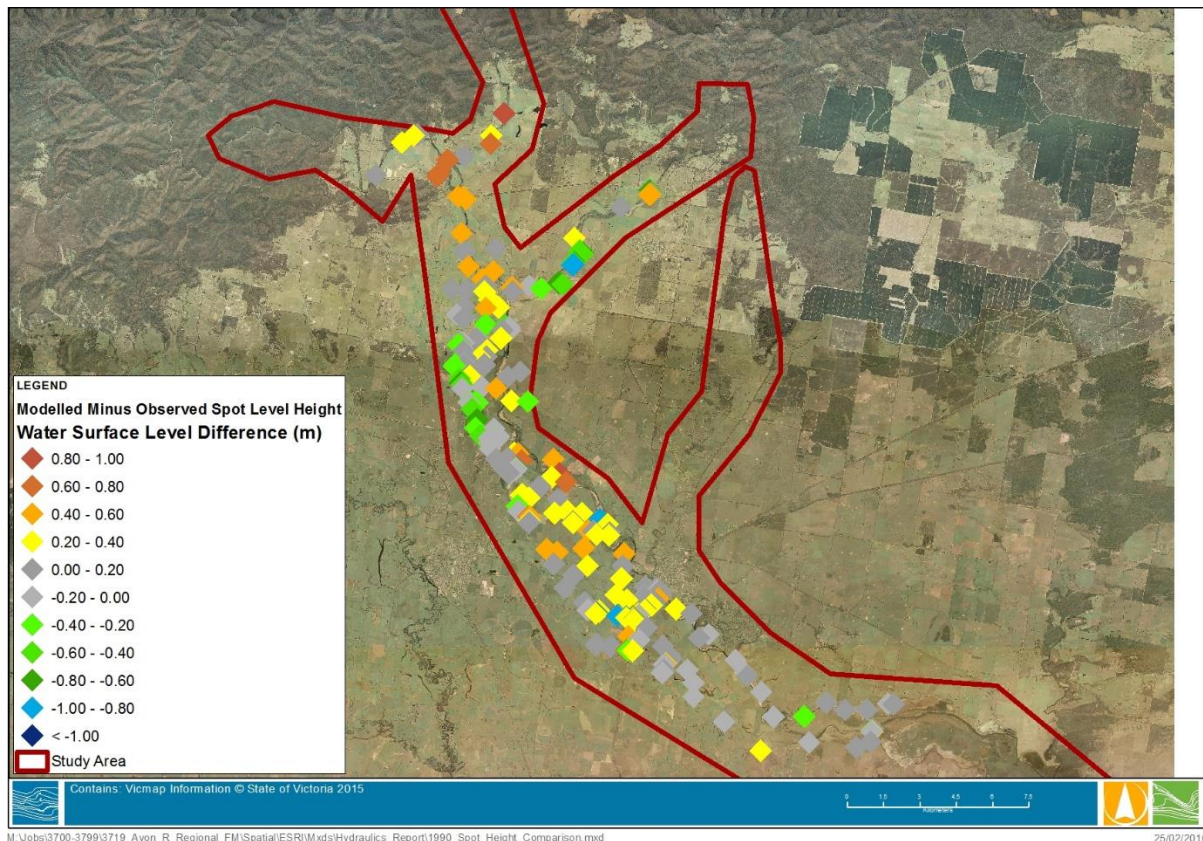


Figure 5-11 April 1990 modelled and observed spot level difference

5.3 Sensitivity Tests

5.3.1 Roughness

Sensitivity to channel and wetland roughness values was tested using the calibration and validation events. Consistent effects were found across the three modelled events, indicating that sensitivity to channel and wetland roughness was independent of event magnitude.

In the Avon River, when roughness was increased from 0.035 to 0.04, flood levels were increased at Stratford and Clydebank by around 0.2-0.3 m, but there was no discernible lag in the timing of the peak. The timing of peak flows in the lower part of the system appears to be largely insensitive to roughness parameters, while peak water levels are quite sensitive.

In Valencia Creek, when roughness was increased from 0.015 to 0.025, flood levels were locally increased by 0.1-0.2 m. This meant a more accurate calibration occurred during the lower roughness case of 0.015. This is considered very low for a natural channel. However, due to the seemingly reliable gauging at Valencia Creek, it was decided to adopt the lower roughness case based on the calibrated water levels.

In Freestone Creek, when roughness was increased from 0.04 to 0.05, flood levels were locally increased by around 0.2 m. There was negligible impact on peak flows, levels and timing at Stratford from altered roughness in Valencia and Freestone Creeks.

In and around Clydebank morass, when roughness was increased from 0.05 to 0.06, flood levels were locally increased by around 0.2 m.

Testing was also undertaken in the Avon River and floodplain between Valencia Creek and Stratford, using the 1990 event validation marks, as discussed in Section 5.2.2. The water level on the floodplain

was found to be sensitive to roughness. The water level in this area was most accurately validated with a roughness of 0.05.

The adopted model roughness parameters are displayed in Section 4.2.4, and are a direct outcome from roughness sensitivity testing.

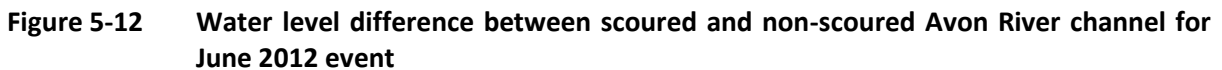
5.3.2 Scour

A consideration during the calibration of this hydraulic model to historic flood events is the scale of channel change that occurs as a result of large floods. The incision of the Avon River channel has created knickpoints in the inflowing tributaries, notably Blackall Creek, Valencia Creek and Freestone Creek which change both the channel slope as well as the hydraulic gradient of these streams. Erosion following European settlement over the last century has resulted in the lower reaches of the Avon comprising of an enlarged sand bed stream which is mobilised during large flood events. A hydraulic modelling study of the lower Snowy River which has a similarly mobile sand bed character upstream of Orbost found that the sand bed could scour during a flood event in the order of metres, which had a significant effect on flood levels and overbank flows.

It is expected that large flood events in the Avon River will generate a channel bed response. Therefore, as well as assessing the impact of channel roughness changes on water levels, a sensitivity test was undertaken for the impact of bed level change on flood levels in the river. To do this, the channel bed elevation was reduced by 0.5m for the entire channel downstream of Valencia Creek / Avon River confluence to replicate a condition where large volumes of sand are mobilised during a flood.

The modelled results showed local reductions in flood level at Stratford of around 0.25 m in the June 2012 event, with impacts of channel bed scour generally confined to the Avon River channel. It was found that changes to floodplain and channel roughness has a more significant impact on flood level than scouring of the channel bed.

Whilst scour is a key mechanism in the movement of sediment in the current geomorphological regime of the Avon River system, it is unlikely to have a major impact to results produced by this study. The impacts of scour fall within the model uncertainties already presented in Section 3.3.



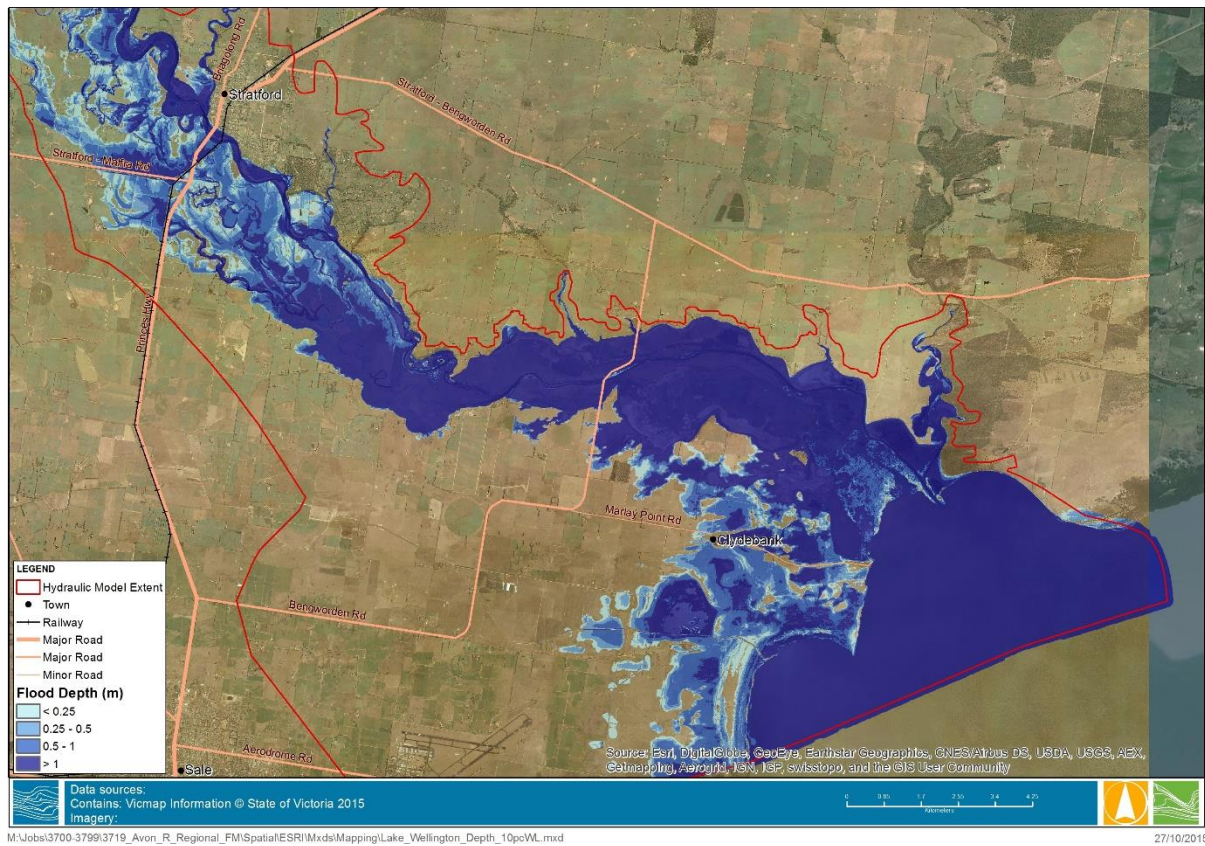


Figure 5-13 1% AEP flood event with 10% AEP Lake Wellington level

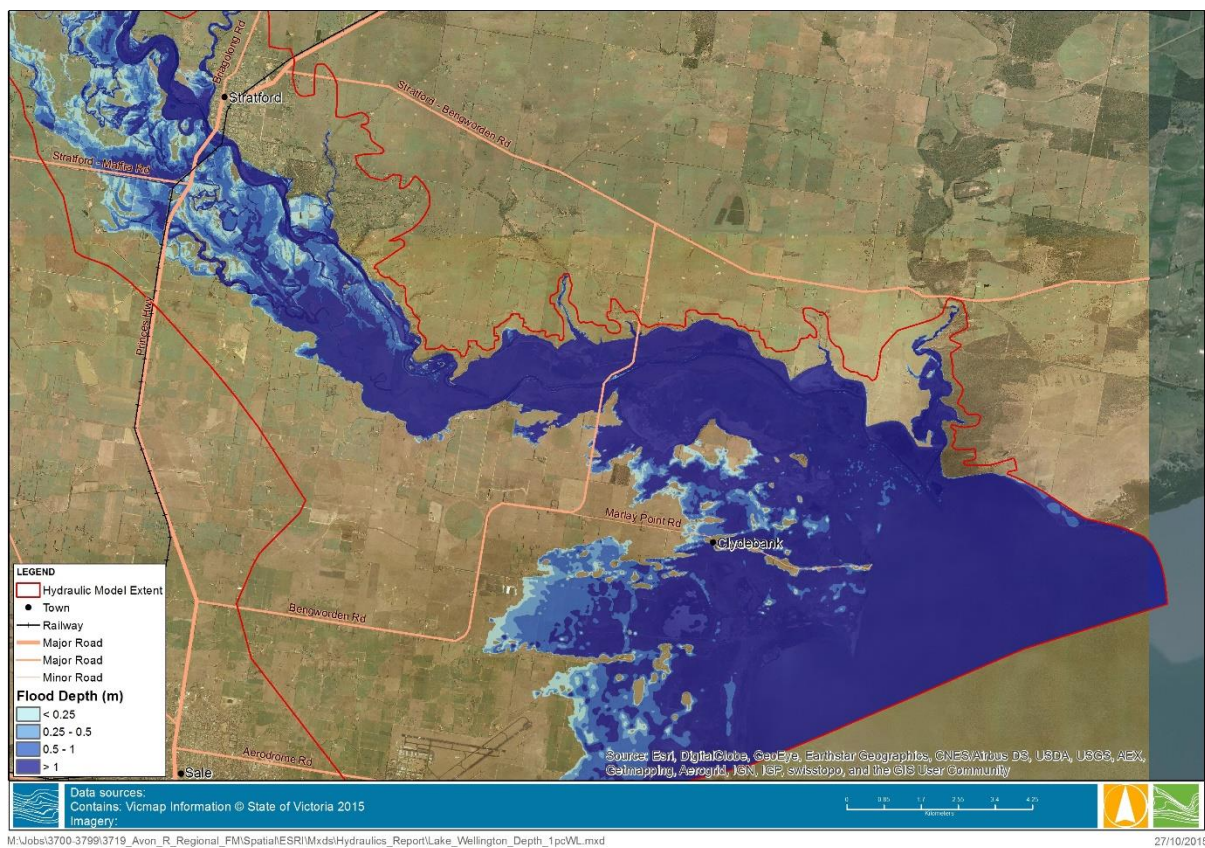


Figure 5-14 1% AEP flood event with 1% AEP Lake Wellington level

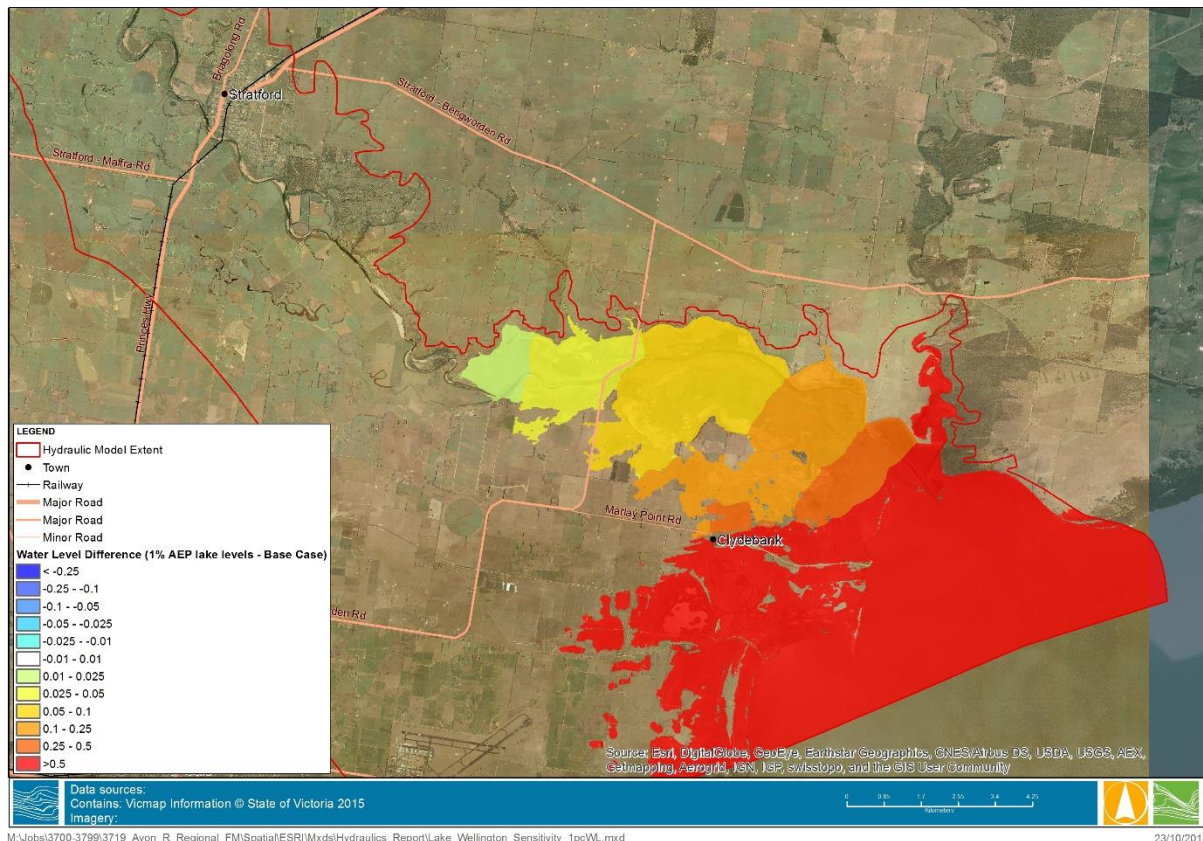


Figure 5-15 Water level difference between 1% AEP and 10% AEP Lake Wellington level for 1% AEP event

5.3.4 Nuntin Levee/Spillway

A significant concern in the downstream area of the Avon River is the possibility of an avulsion developing between the Avon River and Nuntin Creek. This area has undergone significant geomorphic change over the past. The creek entrance was protected with a levee (the Nuntin Levee), which was scoured out by flooding in 2007 and replaced with a spillway, which was then later reconstructed into a levee again in 2014. A sensitivity test was undertaken to compare flood level conditions for the situation where the levee is scoured as per post-2007 flood conditions, to the 2013 conditions with the Nuntin spillway in place at 8.4m AHD. The sensitivity tests applied the 20% AEP flood event, as the structure was designed to be overtopped for floods greater than the 20% AEP event.

The results indicated that the flood level just downstream of the spillway was increased by approximately 0.05 m, and out on the broader Nuntin Creek floodplain, levels were increased by approximately 0.01-0.03 m with the spillway in place. In the Avon River main channel and floodplain, levels were locally decreased by around 0.03 m.

A further sensitivity test was undertaken for the case where the Nuntin levee is at its current height of 9.4m AHD, compared to the previous Nuntin spillway level at 8.4m AHD. The results showed similar, but more extensive, impacts to the previous sensitivity case, with localised increases and decreases on rural properties within the vicinity of the levee.

Based on these results it is considered that the Nuntin levee configuration has a significant impact on flood levels locally, especially during large floods. However, flood levels in the wider floodplain and key townships are not sensitive to the levee height. The current height of the structure at 9.4 m AHD was included in the model DEM for the design flood event modelling.

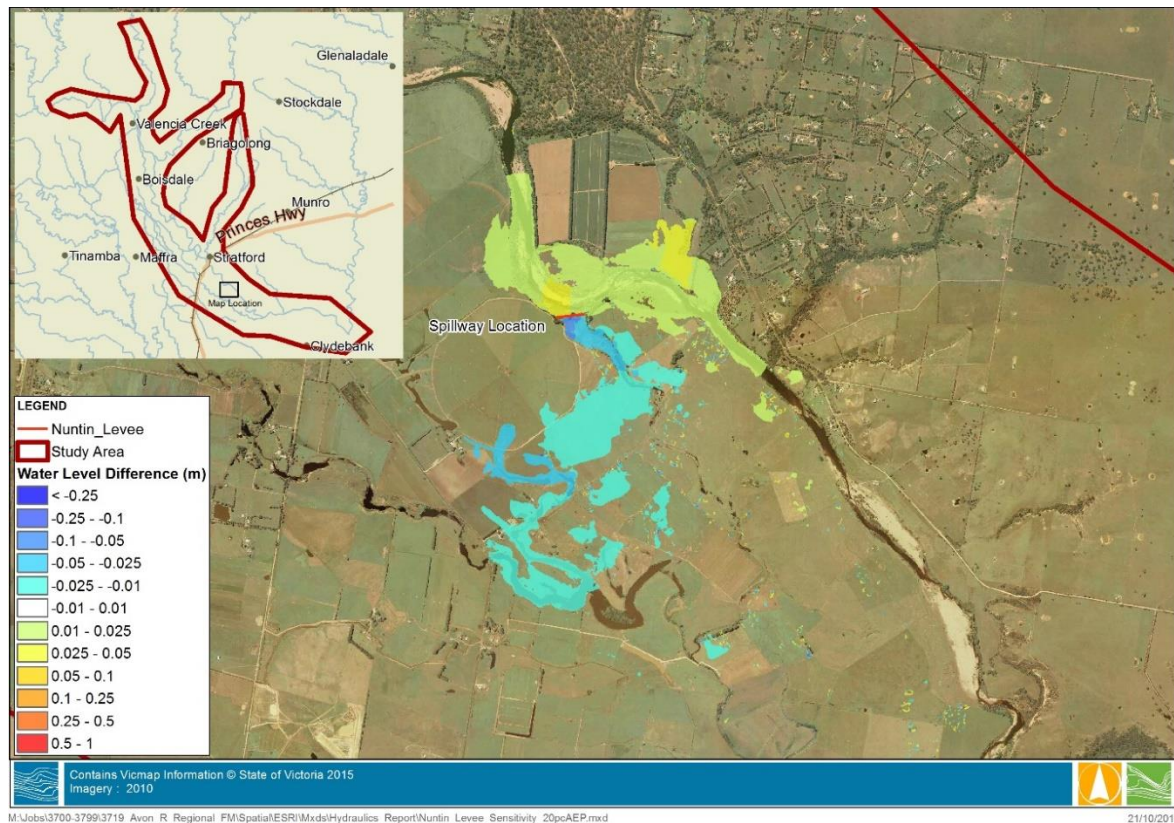


Figure 5-16 Water level difference at Nuntin Creek for a 20% AEP flood event (with and without the Nuntin spillway)

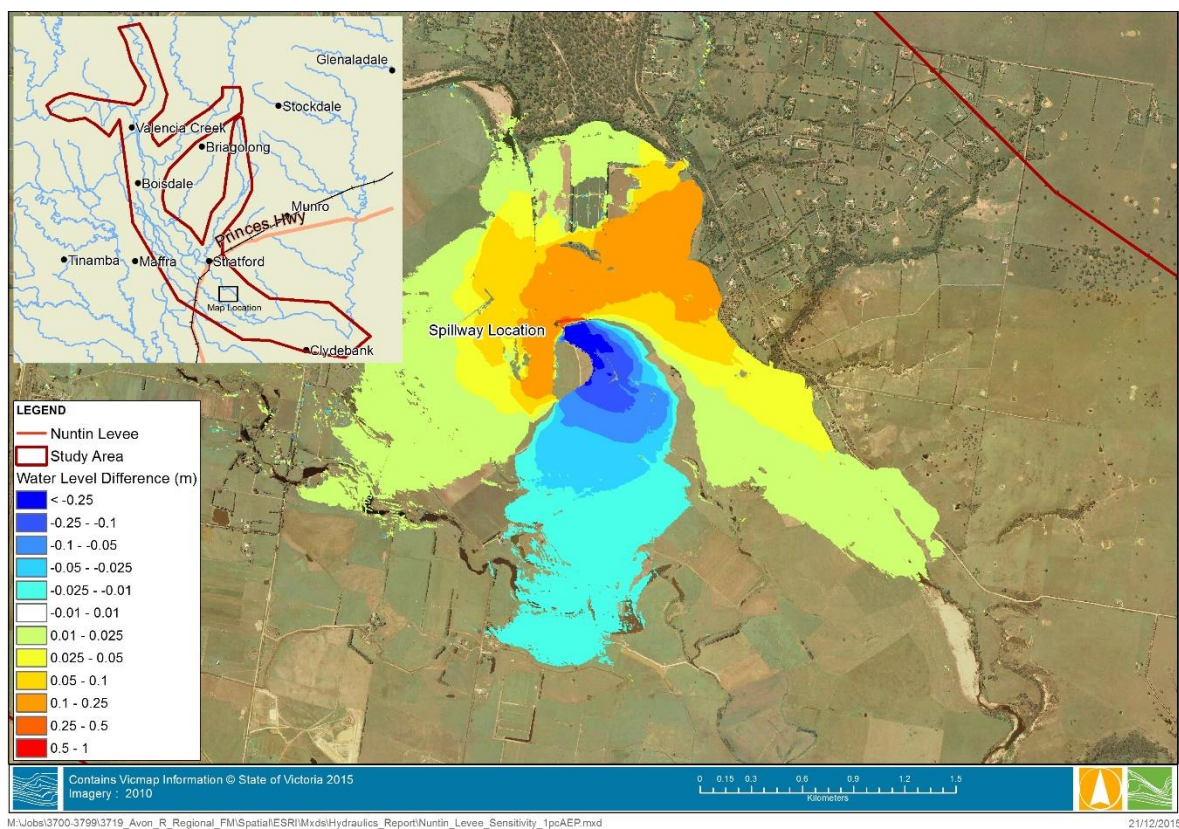


Figure 5-17 Water level difference at Nuntin Creek for a 1% AEP flood event (with Nuntin levee at 9.4m AHD compared to 8.4m AHD)

5.3.5 Structure Blockage

A structure blockage scenario was also assessed to determine the effect partially blocked structures would have on the flooding regime. The Upper Avon catchment is steep and heavily forested, presenting conditions that allow for high debris availability and mobility, and it is likely that during a flood there would be debris transported down the Avon River. However, structures on the river are either low flow weirs or large bridges.

For this structure blockage sensitivity test, ARR Draft Project 11: Blockage of Hydraulic Structures (2014) was consulted. Whilst the Avon catchment was found to have a high risk of debris, the large span of bridge structure across the river suggests there would be limited blockage during flood events.

For structure blockage modelling purposes, a 10% blockage was applied to all bridge structures in the model, as recommended by ARR (2014) for structures with much larger spans than likely debris size. Causeways included in the model were not blocked for this assessment, as it is assumed these structures would be significantly overtopped by the time debris has been transported to their location during a flood event.

Results from the structure blockage show less than 50mm upstream increases in water level, and the impacts are generally confined to within 50m upstream of the structure. These impacts are not thought to be significant in a regional model scale.

5.4 Flood Event Behaviour

The flood behaviour in the study area for each of the calibration events is described in this section. The time series of results was analysed to understand the relative timing of flooding at different locations and how local infrastructure performed for each flood event.

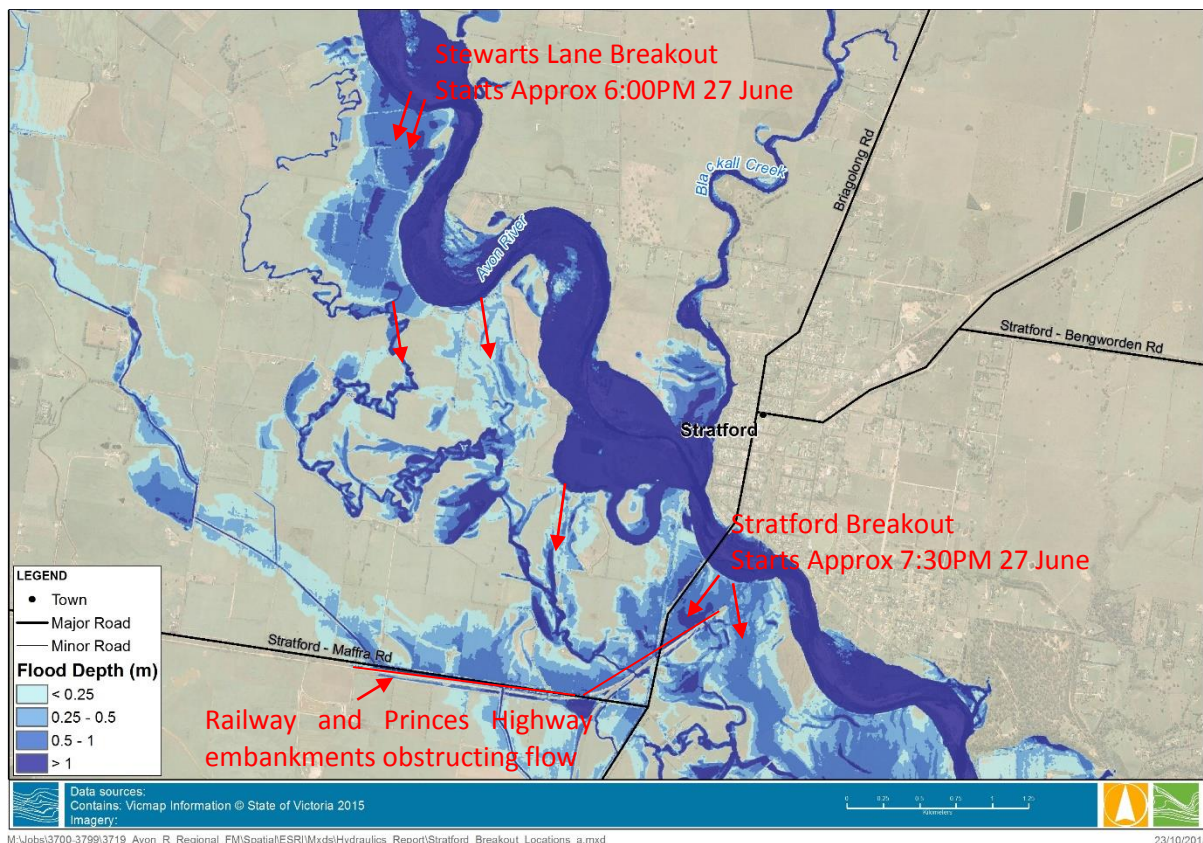
5.4.1 June 2007

The June 2007 event was the largest calibration event modelled. In the 2007 event Blackall Creek was the first significant flow into the model, as it had a much shorter response time than the main tributaries. Blackall Creek did not cause any significant flooding within the catchment, and peaked before the other tributaries reached the confluence of Avon River and Blackall Creek.

In the upper catchment area, the major creek confluences were the primary locations of flooding. Water in the Upper Avon, Valencia Creek and Freestone creeks generally remained confined to channel and other recognised flow paths. Water levels at the Valencia Creek-Avon River confluence peaked at approximately 8:30PM on the 27 June 2007, which is 12 hours after the peak rainfall in the upper catchment. In this area there was not any major flooding apart from existing floodplain channels. Downstream of this, at the Avon River-Freestone Creek confluence there is a significant breakout on the western side of the river that heads towards Boisdale. This breakout first occurred at approximately 6:00PM on the 27 June, which is 9.5 hours after peak rainfall in the upper catchment area. In the event floodwaters from this breakout did not reach Boisdale, as the volumes overtopping the Avon channel were absorbed by a secondary channel immediately east of Boisdale, known as Boisdale Drain 1. Instead, this water inundated agricultural land and joined back to the Avon River approximately 3km downstream of the original breakout. This upstream breakout is shown in Figure 5-20. Rainfall in local catchments also caused some nuisance flooding in the eastern side of the Avon River in the upstream areas around Boisdale.

At approximately 6:00PM on the 27 June 2007 (9.5 hours after peak rainfall in the upper catchment), water first broke out significantly from the Avon River in the lower catchment areas. The first breakout was near Stewarts Lane crossing, approximately 3km upstream of Stratford, as shown in Figure 5-18.

Water from this breakout headed west towards a tributary of Nuntin Creek, and caused flooding in predominately agricultural land. Almost immediately after the first breakout flow, numerous other breakouts around Stratford and downstream of Stratford caused an almost unbroken flow path between Nuntin Creek and the Avon River. Water travelling down Nuntin Creek and its tributaries was obstructed by the raised Princes Highway and railway line embankments. This caused increased water levels upstream of these embankments, as shown in Figure 5-18. This floodplain was almost 2km wide and extends for approximately 10km downstream of Stratford, as shown in Figure 5-19. This floodplain appears to be used for agricultural purposes, based on recent aerial imagery. Water levels peaked at Stratford at approximately 11:00pm on the 27 June, 14.5 hours after peak rainfall in the upper catchment. The land remained inundated for approximately 24 hours, before retreating during the night on 28 June. The township of Stratford sat above the floodwaters and does not experience inundation. Downstream of the confluence of the Avon River and Nuntin Creek, Clydebank wetlands were significantly inundated, and remain so until the model ends on the 1 July 2007, almost four days after inundation first started.



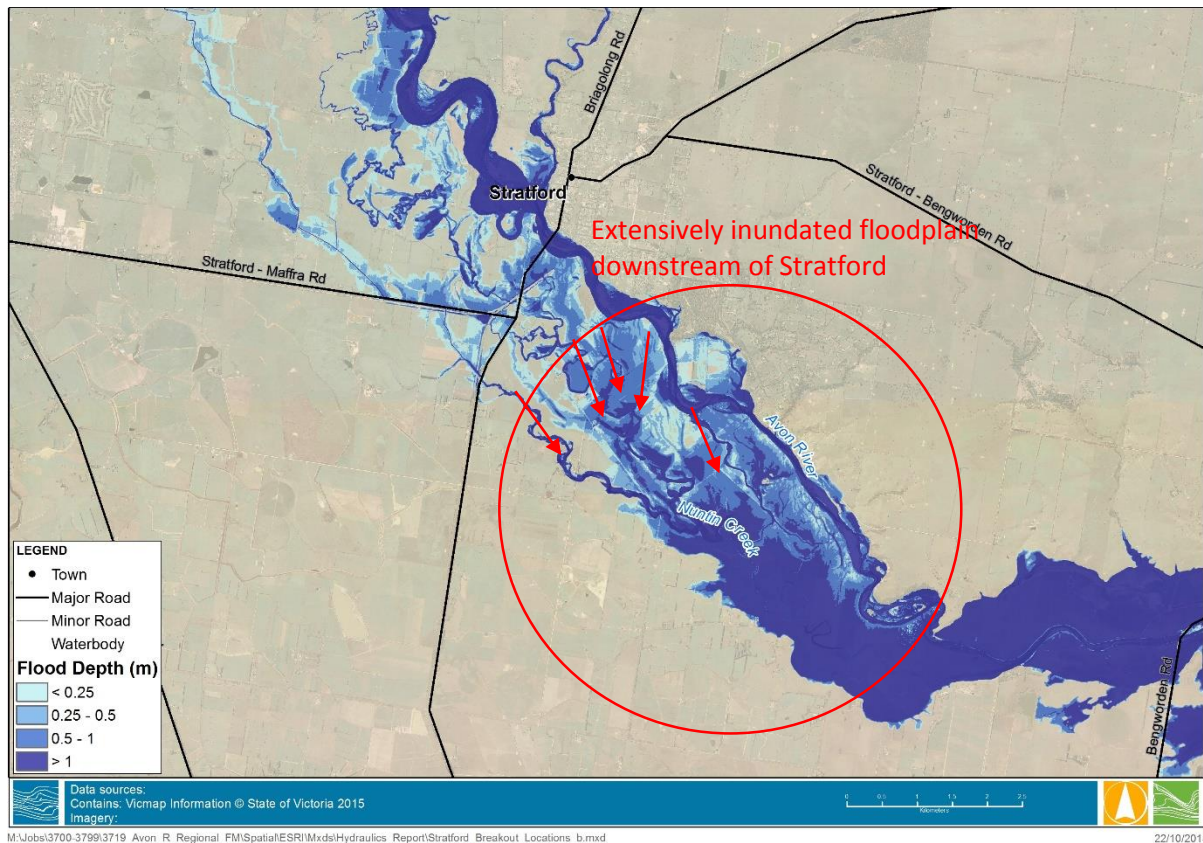


Figure 5-19 Avon River and Nuntin Creek confluence downstream of Stratford in June 2007 flood

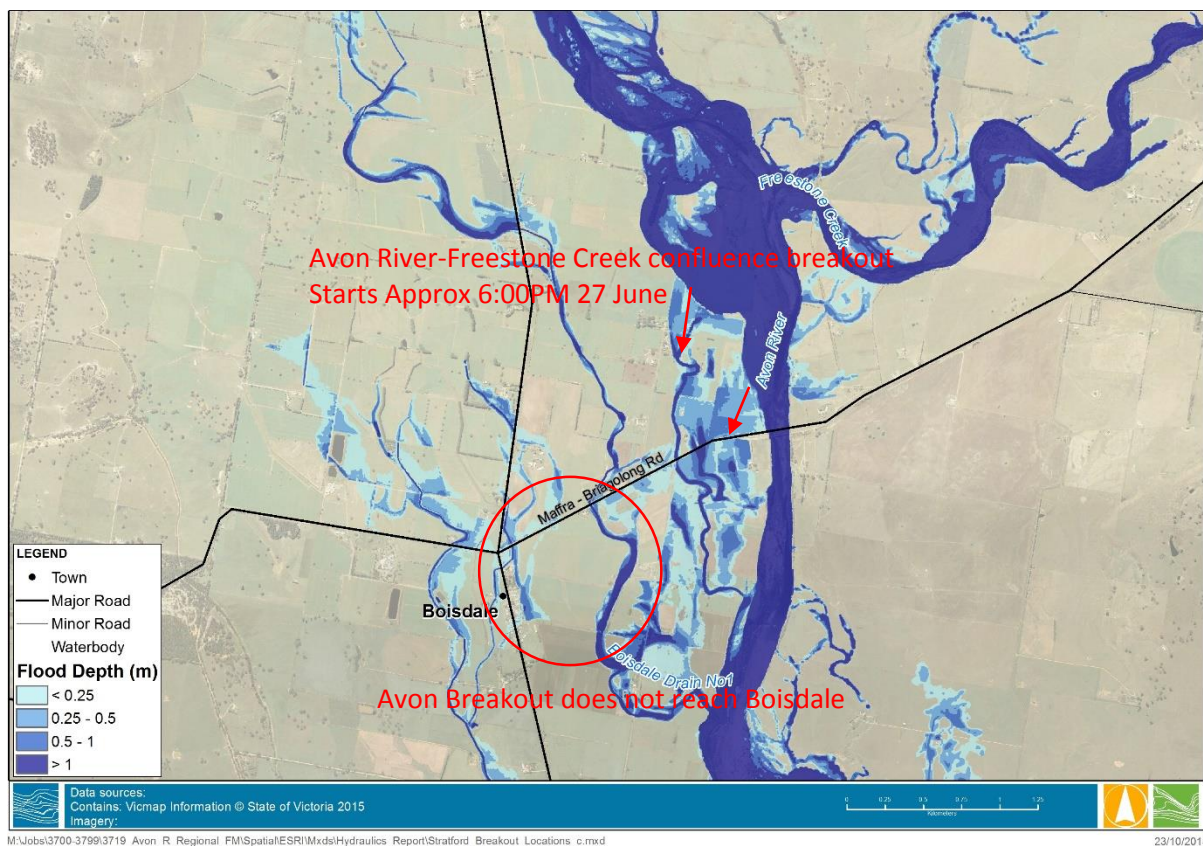


Figure 5-20 Avon River and Freestone Creek confluence near Boisdale in June 2007 flood

5.4.2 August 2011

The August 2011 event was the smallest event modelled. In the 2011 event similar timings were experienced to the 2007 flood, except Avon River flows were kept within channel.

In the upper catchment near Boisdale and around the Stratford area, which are the major locations of breakouts in larger flood events, there was no water that leaves the Avon River channel. At the Avon River-Valencia Creek confluence water levels peaked at approximately 9:30AM on the 11 August, which is approximately 16.5 hours after peak rainfall in the upper catchment. At the Avon River-Freestone Creek confluence water levels peaked at approximately 10:00AM on the 11 August, 17 hours after peak rainfall in the upper catchment. Water levels at Stratford peaked at approximately 1:00PM on the 11 August, 20 hours after peak rainfall in the upper catchment.

Floodplain areas downstream of Stratford near the confluence of Nuntin Creek and the Avon River were heavily inundated as per larger floods, however to a lesser extent than the 2007 and 2012 events.

5.4.3 June 2012

The June 2012 event was smaller than the June 2007 event but larger than the August 2011 event. In the 2007 event Blackall Creek was the first significant flow into the model, this remains the same for the 2012 event. Blackall Creek did not cause any significant flooding within the catchment, and peaked before the other tributaries reached the confluence of Avon River and Blackall Creek.

In the upper catchment area there was no breakouts from the Avon River. The June 2007 event showed a breakout at the Avon River-Freestone Creek confluence, but this was not visible in the June 2012 event. Water levels peaked in the upper catchment area at approximately 10:00AM on 5 June 2012, 17 hours after peak rainfall in the upper catchment.

At approximately 6:30AM on the 5 June 2012, water first broke out significantly from the Avon River, 13.5 hours after peak rainfall in the upper catchment. The first breakout was near Stewarts Lane crossing, approximately 3km upstream of Stratford. Water from this breakout headed west towards a tributary of Nuntin Creek, and caused flooding in predominately agricultural land, as per the 2007 event but of a lesser extent. Almost immediately after the first breakout flow, numerous other breakouts around Stratford and downstream of Stratford caused inundation between Nuntin Creek and the Avon River that extended for approximately 10km downstream of Stratford. The water level peaked at Stratford at approximately 1:00PM on the 5 June 2012, 21 hours after peak rainfall in the upper catchment. This inundation is not as extensive as the June 2007 event, and mainly consisted of swollen existing flow paths rather than the unbroken stretch of water observed in the 2007 model. This land remained inundated for approximately 18 hours, before retreating in the early morning of 6 June.

5.4.4 April 1990

The April 1990 event is the largest event on record, and has the most number of recorded flood marks on the floodplain. However, it is missing key pieces of data, such as the Valencia Creek inflow and Lake Wellington water level. The flood event behaviour will therefore focus on describing the floodplain where levels have been validated from flood marks.

In the upper catchment area the first breakout from the Avon River occurred at approximately 4:00PM on 21 April 1990 upstream of Boisdale. By 7:30PM that day, floodwaters were encroaching Boisdale, and after this the town was extensively inundated.

Downstream of Boisdale there was extensive inundation on the floodplain. Numerous other breakouts between Boisdale and Stratford caused inundation between Nuntin Creek and the Avon River, creating a vast 2km wide floodplain that stretched from upstream of Boisdale to Lake Wellington. This floodplain inundated numerous properties on the western side of the Avon River, and there are very few that remained unaffected from the 1990 flood.

6. DESIGN FLOOD MODELLING

6.1 Overview

This section discusses the application of the hydraulic model to simulate and map flood behaviour (extents, depth, velocities) for a range of flood magnitudes.

Design flood modelling for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP events and PMF event was completed using the hydraulic model parameters determined during the hydraulic model calibration. Whilst not specified in the brief, the 50% AEP was also run to get an approximation for minor flood class events.

The mapping outputs can be used for flood response planning, and land use planning purposes.

6.2 Design Flood Behaviour

Table 6-1 describes the key flood characteristics in the Avon River catchment for each design event. The key aspect to note is that Boisdale is inundated in the 1% AEP and larger flood events. For events larger than a 1% event, the extent of inundation is increased by numerous riverine breakouts upstream of Boisdale. Stratford township remains unaffected by riverine flooding for all design events including the PMF. As inundation of township areas is limited up to the 1% AEP event, in describing the flood behaviour emphasis has been placed on inundation of infrastructure such as roadways.

Table 6-2 to Table 6-6 detail the gauge levels within the catchment during each design event.

Further design flood data, including hydrographs at key locations, result grids, and flood extent data has been provided as part of the project requirements.

Table 6-1 Summary of Flood Behaviour for Various Flood Events

Event	Flood Characteristics	Key roadways inundated
20% AEP	- Flow Remains within channel for most of river - Boisdale unaffected by floodwater from the Avon River - Local catchments start causing some roads to have shallow inundation around Boisdale - Inundation on floodplain downstream of Stratford, initiated by Nuntin Creek spillway	- Bengworden Rd in Clydebank is impassable - Stewarts Lane Avon River crossing is impassable - Valencia Creek-Briagolong Rd Avon River low-level crossing is impassable - Wombat Rd crossing of the Upper Avon is impassable - Smyths Rd crossing of Valencia Creek is impassable - Stratford-Maffra Rd is slightly inundated near Stratford, where the road is low and dips under the railway line - Maffra-Briagolong Rd is impassable in a number of locations downstream of Boisdale - Some shallow inundation on Boisdale-Newry Rd, west of Boisdale - Some shallow inundation on Boisdale-Valencia Creek Rd, north of Boisdale
10% AEP	- Flow Remains within channel for most of river - Boisdale unaffected by floodwater - Inundation on floodplain downstream of Stratford, initiated by Nuntin Creek spillway - Water backs up into the Nuntin system from Nuntin spillway - Small breakout noted just downstream of Stratford, further inundating the Nuntin system	- Stratford-Maffra Rd is impassable near Stratford, where the road is low and dips under the railway line - Local roads around Boisdale are impassable
5% AEP	- Flow Remains within channel for most of upstream section of river - Boisdale unaffected by floodwater, apart from local catchment nuisance flooding - Inundation on floodplain downstream of Stratford, initiated by Nuntin Creek spillway and multiple breakouts just downstream of Stratford - Breakout at Stewarts Lane crossing upstream of Stratford forcing more water into Nuntin system	Princes Highway is inundated at a low point where it crosses under the railway line west of the Avon River at Stratford

Event	Flood Characteristics	Key roadways inundated
	- Inundation extensive in floodplain around Nuntin Creek-Avon River confluence - Flow blockage from Princes Highway and Railway embankment causing ponding behind embankments	
2% AEP	- Flow Remains within channel for most of upstream section of river - Boisdale unaffected by floodwater, apart from local catchment nuisance flooding. A breakout on the Avon River forces water towards Boisdale, but it does not have the volume to reach Boisdale and is absorbed by the drainage system to the east of Boisdale. - Extensive inundation on floodplain downstream of Stratford, with the entire western side of the Avon River exhibiting an unbroken expanse of floodwater between Nuntin Creek and the Avon River between Stratford and the Nuntin Creek-Avon River confluence. - Breakout at Stewarts Lane crossing and just upstream of Princes Highway crossing upstream of Stratford forcing more water into Nuntin system. This flow is obstructed by Princes Highway and Railway line embankments, and combines with local flows to cause inundation behind these embankments	Extensive flooding on the Princes Highway west of the Avon River at Stratford
1% AEP	- Numerous breakouts along Avon River - Boisdale affected by floodwater. A breakout on the Avon River forces water towards Boisdale, which is partially absorbed by the drainage system to the east of Boisdale, but also overtops Boisdale Main drain and causes inundation in the township. Water from this breakout also continues into the downstream Nuntin Creek catchment. - Extensive inundation on floodplain downstream of Stratford, with the entire western side of the Avon River exhibiting an unbroken expanse of floodwater between Nuntin Creek and the Avon River between Stratford and the Nuntin Creek-Avon River confluence. - Breakout at Stewarts Lane crossing and just upstream of Princes Highway crossing upstream of Stratford forcing more water into Nuntin system. This flow is obstructed by Princes Highway and Railway line embankments, and combines with local flows to cause inundation behind these embankments	Some local rural roads on the north side of Stratford become inundated.

Event	Flood Characteristics	Key roadways inundated
0.5% AEP	- Numerous breakouts along Avon River - Boisdale extensively inundated by floodwater. A breakout on the Avon River forces water towards Boisdale, overtops Boisdale Main drain and causes inundation in the township. A breakout from the Avon River near the Valencia Creek confluence also adds additional water to the Boisdale area. - Freestone and Valencia Creeks are also overtopping their banks, with various breakout flows inundating local areas. - Extensive inundation on floodplain on the entire western side of the Avon River with large expanses of floodwater in large sections from the Avon-Valencia Creek confluence to the outlet at Lake Wellington. - Railway line yet to be overtopped and causing extensive obstruction to flow	Valencia Creek - Briagolong bridge over Freestone Creek is impassable
0.2% AEP	- Numerous breakouts along Avon River - Boisdale extensively inundated by floodwater. A breakout on the Avon River forces water towards Boisdale, overtops Boisdale Main drain and causes inundation in the township. - Water is also breaking out on the eastern side of the river in multiple locations, near the Valencia Creek confluence and upstream of Stratford. Stratford remains unaffected. - Freestone and Valencia Creeks are also overtopping their banks, with various breakout flows inundating local areas. - Extensive inundation on floodplain on the entire western side of the Avon River with expanses of floodwater in large sections from the Avon-Valencia Creek confluence to the outlet at Lake Wellington. - Railway line yet to be overtopped and causing extensive obstruction to flow.	
PMF	- Numerous breakouts along Avon River - Boisdale extensively inundated by floodwater. - Freestone and Valencia Creeks are also overtopping their banks, with various breakout flows inundating local areas. - Extensive inundation on floodplain on the entire western side of the Avon River and eastern side of the river upstream of Stratford, with expanses of floodwater	Bushy Park Rd bridge over Freestone Creek is impassable

Event	Flood Characteristics	Key roadways inundated
	in large sections from the Avon-Valencia Creek confluence to the outlet at Lake Wellington. • Stratford unaffected by floodwater. • Railway line partially overtopped and causing extensive obstruction to flow.	

Table 6-2 Avon River at Stratford Gauge Heights for Design Flood Events

Gauge Height ¹ (m)	Flood level at Gauge (m AHD)	Design Flood Event AEP (%)	Design Flood Event ARI (years)
6.9	13.4	20	5
7.7	14.2	10	10
8.4	14.9	5	20
8.7	15.2	2	50
9.0	15.5	1	100
9.1	15.6	0.5	200
9.4	15.8	0.2	500

Table 6-3 Avon River at The Channel Gauge Heights for Design Flood Events

Gauge Height ² (m)	Flood level at Gauge (m AHD)	Design Flood Event AEP (%)	Design Flood Event ARI (years)
6.2	78.2	20	5
7.4	79.4	10	10
8.6	80.6	5	20
9.7	81.7	2	50
10.9	82.9	1	100
11.8	83.8	0.5	200
13.0	85.0	0.2	500

Table 6-4 Avon River at Clydebank Gauge Heights for Design Flood Events

Gauge Height ³ (m)	Flood level at Gauge (m AHD)	Design Flood Event AEP (%)	Design Flood Event ARI (years)
3.1	2.9	20	5
3.4	3.2	10	10
3.8	3.6	5	20
4.1	3.9	2	50
4.4	4.2	1	100
4.7	4.5	0.5	200
5.0	4.8	0.2	500

¹ The Stratford gauge is located adjacent to Stratford on the Avon River. Gauge zero is 6.479m AHD

² The Channel gauge is located upstream of the Avon-Valencia Creek confluence. Gauge zero is 72m AHD

³ The Clydebank gauge is located in the downstream Avon wetlands near Clydebank. Gauge zero is -0.21m AHD

Table 6-5 Freestone Creek at Briagolong Gauge Heights for Design Flood Events

Gauge Height ⁴ (m)	Flood level at Gauge (m AHD)	Design Flood Event AEP (%)	Design Flood Event ARI (years)
5.4	68.6	20	5
6.0	69.2	10	10
6.8	70.0	5	20
7.4	70.6	2	50
8.1	71.3	1	100
8.7	71.9	0.5	200
9.3	72.5	0.2	500

Table 6-6 Valencia Creek at Gillio Rd Gauge Heights for Design Flood Events

Gauge Height ⁵ (m)	Flood level at Gauge (m AHD)	Design Flood Event AEP (%)	Design Flood Event ARI (years)
3.6	89.1	20	5
4.2	89.7	10	10
5.0	90.5	5	20
5.5	91.0	2	50
6.1	91.6	1	100
6.5	92.0	0.5	200
7.1	92.6	0.2	500

6.3 Flood Class Event Behaviour

For this study, minor, moderate and major flood class events have been analysed hydraulically. Hydrologic analysis (Water Technology, 2015b) allowed for magnitude estimations of different flood classes. A more detailed estimate of flood class exceedance probability magnitude can be made with flood levels in the hydraulic model, as shown in Table 6-7.

Table 6-7 Estimated AEP of the Flood Class Events

Gauge Station	Minor		Moderate		Major	
	Water Level (Gauge - m)	Approximate AEP (%) (AEP gauge level)	Water Level (Gauge - m)	Approximate AEP % (AEP gauge level)	Water Level (Gauge - m)	Approximate AEP (%) (AEP gauge level)
Avon River at the Channel	5.0	50% (4.89)	6.9	10 - 20% (7.36 – 6.20)	7.5	10% (7.36)
Avon River at Stratford	4.5	<50% (5.80)	6.0	20% - 50% (6.88 – 5.80)	6.5	20% (6.88)

⁴ The Briagolong gauge is located adjacent to Briagolong on Freestone Creek. Gauge zero is 63.238m AHD

⁵ The Gillio Rd gauge is located upstream of the Valencia Creek area. Gauge zero is 85.481m AHD

6.4 Supplied Model Outputs

The study deliverables provide a comprehensive set of data that support the study outcomes. From the hydraulic model, outputs included:

Grids

Gridded datasets of model results were provided for the following:

- Design events (20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF events) – maximum depth, hazard, velocity and water surface elevation.
- Calibration events (2007, 2011, and 2012 events) – maximum depth, hazard, velocity and water surface elevation.

Vector Data

ERSI shapefiles in VFD format were provided for the following:

- Peak flood extents
- Peak flood depth contours
- Peak flood elevation contours
- Peak flood velocity contours
- Peak flood velocity arrows
- Peak flood hazard contours
- Mapping limits

Data Tables

Data tables in excel CSV format were provided for the following:

- Stage height hydrographs at 12 key locations across the study area for 6 design events (20%, 10%, 5%, 2%, 1% and 0.5% AEP events). The key locations are displayed in Figure 6-1.
- Water surface level profile along the Avon River for 6 design events (20%, 10%, 5%, 2%, 1% and 0.5% AEP events). The long section profile location is shown in Figure 6-1.

Maps

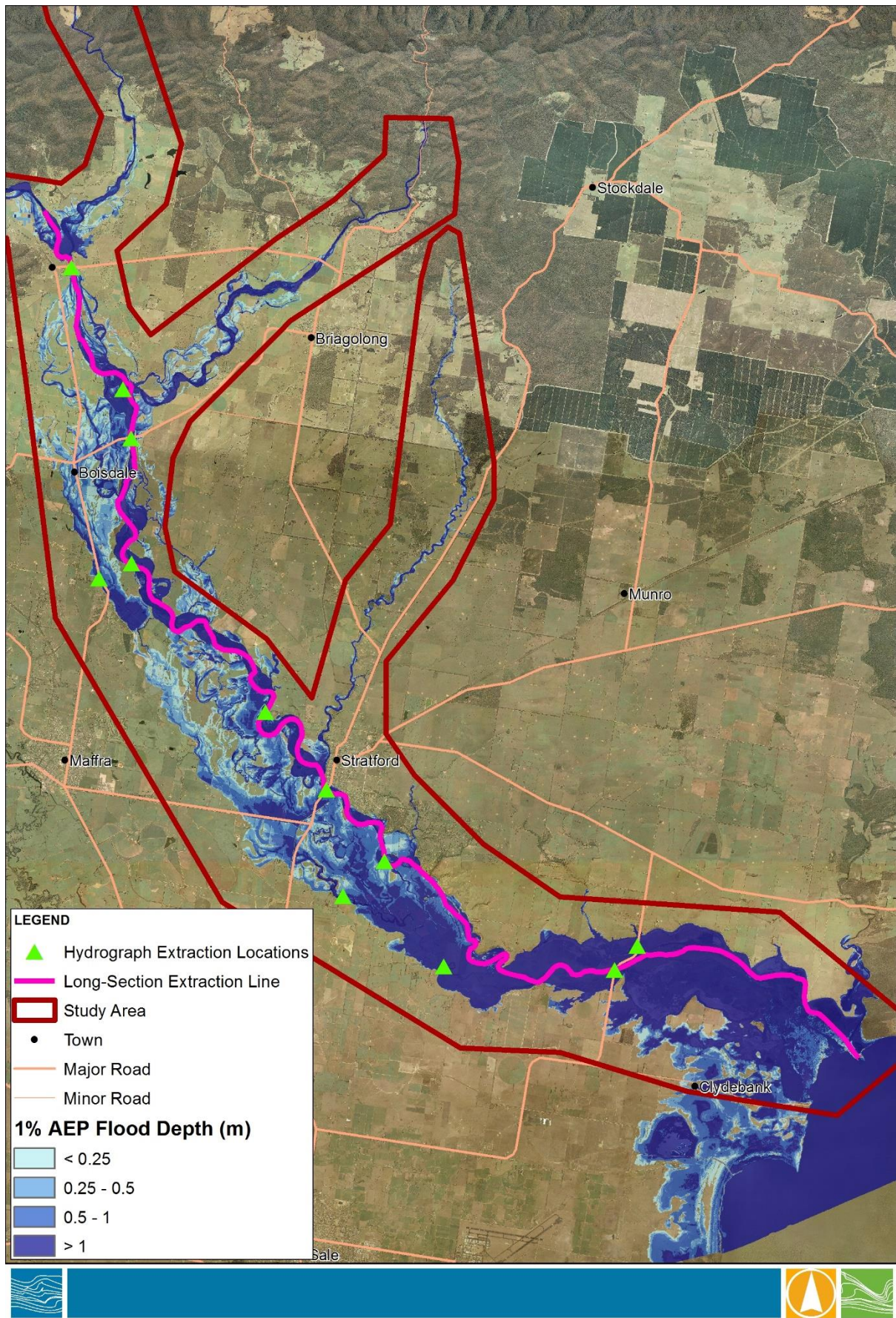
The flood maps have been produced for the following design flood events:

- 10% and 1% AEP events – maximum depth, hazard, velocity and water surface elevation.

Each map includes:

- Flood extent,
- Flood level contour at 1m intervals,
- Depth of inundation,
- Identification of essential services,
- Major Road/street names
- Cadastral base
- Gauge height indication for the Avon River catchment at the five currently active gauges – Avon River at The Channel, Avon River at Stratford, Avon River at Clydebank, Freestone Creek at Briagolong and Valencia Creek at Gillio Road.

Copies of the maps were provided as PDFs. The maps are included in Appendix C of this report.



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28/01/2016

Figure 6-1 Supplied Data Location

7. REFERENCES

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APPENDIX A – CALIBRATION EVENT FLOOD MARK DATA

June 2007 Calibration Event

Location ID	X Co-Ordinate	Y Co-Ordinate	Measured (m AHD)	Modelled (m AHD)	Difference (m)	Comment
1	5808257.08	5808257.08	36.82	36.88	0.06	
2	5809604.75	5809604.75	38.56	38.47	-0.09	
3	5809049.33	5809049.33	37.35	38.14	0.79	Survey seems low compared to LiDAR
4	5808567.94	5808567.94	37.08	37.15	0.07	
5	5811940.63	5811940.63	49.73	49.22	-0.51	
6	5813778.96	5813778.96	62.41	63.29	0.88	Adjacent to flow constriction – model appears high in this area
7	5813819.23	5813819.23	62.02	62.42	0.40	Adjacent to flow constriction – model appears high in this area
8	5811966.57	5811966.57	50.10	49.57	-0.53	Likely picking up local catchment flows not included in model
9	5809792.03	5809792.03	38.42	38.19	-0.23	
10	5813593.47	5813593.47	47.39	46.22	-1.17	Likely picking up local catchment flows not included in model
11	5814051.36	5814051.36	48.50	47.67	-0.83	Decreased model confidence in this location – LiDAR supplemented with 50m DEM
12	5815814.84	5815814.84	54.64	54.72	0.08	
13	5816557.96	5816557.96	57.42	57.12	-0.30	
14	5814473.66	5814473.66	57.47	57.92	0.45	
15	5815611.08	5815611.08	55.57	54.99	-0.58	
16	5814033.05	5814033.05	45.18	47.79	2.61	Steep, highly vegetated area – possibly LiDAR/survey issues.
17	5797672.10	5797672.10	15.22	15.40	0.18	

Location ID	X Co-Ordinate	Y Co-Ordinate	Measured (m AHD)	Modelled (m AHD)	Difference (m)	Comment
18	5797587.42	5797587.42	14.95	14.79	-0.16	
19	5797472.53	5797472.53	14.83	14.78	-0.05	
20	5797347.29	5797347.29	14.40	14.36	-0.04	
21	5796617.59	5796617.59	12.98	12.48	-0.50	
22	5799678.91	5799678.91	19.25	18.66	-0.59	Modelled low, however adjacent flood marks are closer
23	5802862.14	5802862.14	26.50	25.66	-0.84	Model appears low in this area according to flood mark 23, 24, 33 and 34
24	5802679.94	5802679.94	26.44	25.18	-1.26	Model appears low in this area according to flood mark 23, 24, 33 and 34
25	5805308.22	5805308.22	31.29	30.84	-0.45	
26	5815913.47	5815913.47	54.80	54.64	-0.16	
27	5815811.96	5815811.96	51.41	51.50	0.09	
28	5810753.94	5810753.94	40.27	N/A	N/A	No flowpath picked up here – appears to be a local flowpath.
29	5809928.78	5809928.78	38.62	38.32	-0.30	
30	5806966.85	5806966.85	34.14	33.88	-0.26	
31	5806414.78	5806414.78	33.52	33.32	-0.20	
32	5805619.48	5805619.48	31.47	30.96	-0.51	
33	5803613.56	5803613.56	27.86	26.68	-1.18	Model appears low in this area according to flood mark 23, 24, 33 and 34
34	5802312.88	5802312.88	24.88	24.03	-0.85	Model appears low in this area according to flood mark 23, 24, 33 and 34
35	5799703.57	5799703.57	20.10	19.89	-0.21	

Location ID	X Co-Ordinate	Y Co-Ordinate	Measured (m AHD)	Modelled (m AHD)	Difference (m)	Comment
36	5800053.53	5800053.53	20.12	19.77	-0.35	
37	5799784.06	5799784.06	19.56	19.58	0.02	
38	5796255.19	5796255.19	13.03	13.48	0.45	
39	5794355.50	5794355.50	8.08	7.92	-0.16	
40	5793424.19	5793424.19	6.46	6.46	0.00	
41	5792674.06	5792674.06	3.63	3.58	-0.05	
42	5790988.89	5790988.89	3.69	3.95	0.26	
43	5790658.47	5790658.47	3.34	3.35	0.01	
44	5791005.39	5791005.39	3.55	5.22	1.67	Steep terrain, modelled flood extent close
45	5794554.65	5794554.65	9.86	9.68	-0.18	
46	5795826.76	5795826.76	11.98	11.74	-0.24	

June 2012 Calibration Event

Location ID	X Co-Ordinate	Y Co-Ordinate	Measured (m AHD)	Modelled (m AHD)	Difference (m)	Comment
AvoF002	500268.95	5808184.98	35.77	N/A	N/A	Flowpath not in model
AvoF003	500155.91	5808129.62	35.74	N/A	N/A	Flowpath not in model
AvoF001	505757.60	5796281.55	13.10	N/A	N/A	Flowpath not in model
AvoF007	501042.48	5809018.05	38.30	38.03	-0.268	
AvoF005	498733.96	5813596.29	45.83	45.58	-0.244	
AvoF012	508412.39	5793564.25	7.15	6.93	-0.216	
AvoF004	500063.47	5815806.46	54.65	54.58	-0.078	
AvoF011	508202.64	5794036.60	7.90	7.83	-0.068	
AvoF010	507545.83	5794592.32	9.09	9.06	-0.037	
AvoF006	501007.95	5809132.46	38.01	38.02	0.016	
AvoF008	506661.74	5795630.46	11.12	11.34	0.220	
AvoF009	507240.92	5795101.84	10.28	10.55	0.269	

April 1990 Calibration Event

Location ID	X Co-Ordinate	Y Co-Ordinate	Measured (m AHD)	Modelled (m AHD)	Difference (m)
7272	500885.7	5817690	63.05	N/A	N/A
7275	500845.4	5817667	63.05	N/A	N/A
7292	500627	5817030	60.22	59.35	0.875
7293	500614.4	5817027	60.22	59.32	0.896
7298	500910	5816901	59.99	N/A	N/A
7299	500899.4	5816900	59.99	N/A	N/A
7332	497046.2	5816156	53.6	53.51	0.085
7333	497019.4	5816152	53.6	53.51	0.094
7335	500092.4	5816120	55.67	55.35	0.321
7336	500081.5	5816119	55.67	55.28	0.387
7338	496896.8	5816111	53.77	53.57	0.202
7339	496858.4	5816098	53.77	N/A	N/A
7340	500796.8	5816087	57.03	N/A	N/A
7341	500803.4	5816086	57.03	N/A	N/A
7357	496391.5	5815828	55.05	54.66	0.394
7358	496368.4	5815802	55.05	N/A	N/A
7359	497757.5	5815792	51.6	N/A	N/A
7360	500057.2	5815788	55.44	54.79	0.649
7361	500071.4	5815781	55.44	N/A	N/A
7362	497730.4	5815780	51.6	N/A	N/A
7366	499257.4	5815700	52.48	N/A	N/A
7369	499253	5815678	52.48	N/A	N/A
7385	496112.7	5815298	58.17	N/A	N/A
7388	498973.3	5815275	50.52	N/A	N/A
7390	498978.1	5815266	50.52	50.52	0.002
7392	496071.4	5815260	58.17	N/A	N/A
7394	496682.5	5815253	52.49	N/A	N/A
7395	496651.4	5815235	52.49	N/A	N/A
7397	498289.4	5815124	50.25	49.63	0.624
7399	498299.1	5815104	50.25	49.63	0.617
7400	497058.4	5815083	51.32	N/A	N/A
7401	500211.3	5815082	52.51	N/A	N/A
7403	500210.8	5815079	52.51	N/A	N/A
7404	497030.4	5815072	51.32	N/A	N/A
7409	496735	5814881	51.8	N/A	N/A
7410	496707.4	5814857	51.8	N/A	N/A
7428	497931.4	5814587	49.93	49.32	0.615
7433	497931.4	5814565	49.93	49.31	0.623
7441	495340.8	5814517	59.11	N/A	N/A
7442	495315.4	5814507	59.11	58.94	0.167
7447	499620.7	5814460	49.47	N/A	N/A
7448	499674.3	5814446	49.47	N/A	N/A
7450	497870.8	5814432	50.02	49.29	0.727
7453	497735.4	5814401	50.02	N/A	N/A
7466	499503.5	5814157	49.72	N/A	N/A
7468	499540.3	5814137	49.72	N/A	N/A
7483	506596.3	5813861	62.96	N/A	N/A
7485	506639.3	5813856	62.96	63.74	-0.778
7488	506495.3	5813776	62.42	N/A	N/A
7489	506520.3	5813772	62.42	N/A	N/A

7491	506708.3	5813755	62.97	63.51	-0.543
7492	506701.4	5813752	62.97	62.96	0.01
7499	506612.5	5813691	62.63	62.16	0.467
7500	506650.3	5813682	62.63	62.17	0.464
7512	498721.3	5813602	47.59	47.19	0.401
7513	498961.3	5813590	47.75	N/A	N/A
7515	498945.8	5813586	47.75	47.24	0.512
7517	498707.3	5813582	47.59	N/A	N/A
7531	499044.3	5813483	47.16	N/A	N/A
7532	499018.5	5813481	47.16	46.69	0.466
7549	505465.3	5813162	57.14	N/A	N/A
7550	505424.3	5813149	57.14	57.08	0.065
7565	505374.3	5812920	57.54	N/A	N/A
7566	505347.5	5812894	57.54	N/A	N/A
7567	504750.3	5812888	55.45	N/A	N/A
7569	504717	5812878	55.45	54.22	1.233
7574	498459.3	5812694	45.38	N/A	N/A
7576	498460.8	5812680	45.38	N/A	N/A
7581	504710.3	5812649	54.84	N/A	N/A
7582	504668.6	5812639	54.84	N/A	N/A
7587	499834.3	5812441	43.78	N/A	N/A
7588	499810.6	5812412	43.78	N/A	N/A
7599	498872.3	5812088	44.97	44.49	0.485
7600	498881.1	5812077	44.97	N/A	N/A
7602	503334.3	5812033	50.28	N/A	N/A
7603	503314.6	5812012	50.28	N/A	N/A
7604	503532.3	5811950	49.85	N/A	N/A
7605	503512.6	5811890	49.85	49.55	0.304
7606	503338.3	5811886	50.07	N/A	N/A
7608	503326.8	5811866	50.07	N/A	N/A
7616	500251.3	5811498	41.81	N/A	N/A
7618	500255.2	5811466	41.81	41.79	0.015
7620	503737.3	5811365	47.95	48.51	-0.556
7622	498801.3	5811350	42.79	N/A	N/A
7624	498986.3	5811336	43.06	42.98	0.082
7626	498816.4	5811332	42.79	N/A	N/A
7627	499002.3	5811324	43.06	42.96	0.103
7628	503714.7	5811308	47.95	48.51	-0.558
7629	503899.3	5811279	47.85	48.47	-0.615
7630	503872.3	5811223	47.85	48.44	-0.593
7634	498774.3	5810994	41.75	N/A	N/A
7636	498792.2	5810964	41.75	N/A	N/A
7637	497761.3	5810959	41.14	N/A	N/A
7638	497765.6	5810931	41.14	N/A	N/A
7639	503501.3	5810925	46.52	47.17	-0.651
7640	503464.2	5810899	46.52	47.10	-0.577
7641	503479.3	5810811	46.24	47.06	-0.821
7642	503444	5810790	46.24	47.06	-0.825
7643	499136.3	5810717	41.66	N/A	N/A
7644	499151.8	5810713	41.66	41.11	0.55
7652	500169.3	5810525	39.89	N/A	N/A
7653	500166.2	5810510	39.89	39.36	0.528
7659	499540.3	5810283	40.7	N/A	N/A
7660	499572.2	5810256	40.7	N/A	N/A

7662	499682.3	5810231	40.44	N/A	N/A
7663	499705.5	5810215	40.44	39.92	0.519
7664	500998.8	5810166	39.46	N/A	N/A
7665	501012.3	5810165	39.46	N/A	N/A
7667	501061.3	5810132	39.39	N/A	N/A
7668	501039.2	5810122	39.39	N/A	N/A
7670	502893.3	5810069	43.47	44.12	-0.649
7671	502857.9	5810065	43.47	44.08	-0.613
7674	503043.8	5809984	43.95	44.35	-0.402
7675	503065.3	5809974	43.95	N/A	N/A
7677	501649.5	5809936	40.81	40.82	-0.014
7678	499871.2	5809936	39.11	38.91	0.197
7679	501676.3	5809931	40.81	N/A	N/A
7680	499848.3	5809928	39.11	38.95	0.158
7683	500934.2	5809851	39.21	38.80	0.414
7684	500939.3	5809836	39.21	38.80	0.412
7685	501803	5809835	41.3	N/A	N/A
7687	501822.3	5809822	41.3	N/A	N/A
7688	502142.6	5809818	40.99	41.25	-0.262
7689	502163.3	5809812	40.99	N/A	N/A
7690	501047.3	5809802	39.51	N/A	N/A
7691	498468.8	5809786	38.5	38.34	0.165
7692	501061.3	5809782	39.51	N/A	N/A
7693	498406.3	5809758	38.5	N/A	N/A
7694	499103.4	5809754	38.1	N/A	N/A
7695	499067.3	5809739	38.1	37.94	0.156
7698	500966.5	5809705	38.89	38.73	0.165
7699	500968.3	5809699	38.89	38.76	0.127
7700	499815.3	5809697	39.03	38.68	0.346
7701	499838.9	5809677	39.03	38.69	0.345
7708	500032.9	5809353	38.81	38.53	0.284
7709	500005.3	5809348	38.81	38.52	0.29
7712	498960.3	5809099	37.2	37.18	0.017
7713	498994.2	5809094	37.2	N/A	N/A
7715	500396.7	5809041	38.83	38.47	0.358
7716	500382.3	5809035	38.83	38.48	0.35
7722	499853.3	5808998	38.18	37.58	0.6
7723	501019	5808993	38.54	N/A	N/A
7724	499887.4	5808993	38.18	N/A	N/A
7725	501034.3	5808984	38.54	N/A	N/A
7729	498643.3	5808760	35.74	N/A	N/A
7730	498670.9	5808754	35.74	35.84	-0.103
7732	498974.1	5808596	36	35.93	0.067
7733	498942.3	5808592	36	35.89	0.112
7741	499851	5808309	36.39	36.68	-0.29
7742	499834.3	5808307	36.39	36.65	-0.259
7745	500651.3	5808285	37.05	37.54	-0.487
7746	500636.3	5808265	37.05	37.55	-0.499
7748	500829.1	5808244	37.02	36.89	0.13
7750	500825.3	5808234	37.02	36.89	0.133
7753	500837.2	5808200	36.8	36.90	-0.099
7755	500835.3	5808175	36.8	36.89	-0.094
7758	500562.3	5808094	37.21	37.02	0.191
7760	500849.3	5808086	36.77	36.78	-0.01

7763	500829.3	5808080	36.77	N/A	N/A
7764	500534.3	5808078	37.21	37.02	0.186
7776	500837.1	5807815	35.59	N/A	N/A
7777	500813.3	5807787	35.59	N/A	N/A
7778	500497.7	5807783	36.8	36.50	0.298
7782	499475.2	5807767	35.41	35.47	-0.057
7783	500482.3	5807756	36.8	36.50	0.301
7784	499457.3	5807747	35.41	35.40	0.009
7791	498840.6	5807617	34.24	34.31	-0.072
7792	498816.3	5807595	34.24	N/A	N/A
7796	498933.6	5807584	34.32	34.42	-0.104
7800	498905.3	5807566	34.32	34.36	-0.037
7801	498784.1	5807552	34.28	34.19	0.092
7806	498762.3	5807532	34.28	34.16	0.122
7810	498731.5	5807512	33.92	34.13	-0.213
7811	498549.6	5807512	33.2	N/A	N/A
7814	498712.3	5807503	33.92	34.12	-0.203
7815	498523.3	5807488	33.2	N/A	N/A
7824	498448.6	5807398	33.11	N/A	N/A
7830	498431.3	5807378	33.11	N/A	N/A
7841	499948	5807281	35.25	35.22	0.028
7843	499913.3	5807267	35.25	34.94	0.307
7845	498961.9	5807257	34.01	34.05	-0.036
7847	498944.3	5807242	34.01	34.00	0.014
7862	498990.2	5807131	33.96	33.91	0.046
7871	498961.3	5807107	33.96	33.83	0.134
7875	499899.5	5807018	34.58	34.48	0.103
7877	499882.3	5806996	34.58	34.43	0.151
7880	499612.6	5806985	34.89	34.49	0.397
7884	499058.9	5806965	33.88	33.84	0.044
7885	499595.3	5806959	34.89	34.50	0.392
7888	499044.3	5806951	33.88	33.77	0.106
7891	499018.4	5806872	33.63	33.56	0.065
7895	499000.3	5806853	33.63	33.49	0.144
7905	499095.3	5806767	33.39	33.28	0.107
7907	499075.3	5806745	33.39	33.28	0.115
7911	498594.1	5806702	32.74	33.07	-0.331
7912	499810.6	5806694	34.45	34.36	0.09
7913	498982	5806690	33.13	33.15	-0.024
7915	498568.3	5806682	32.74	N/A	N/A
7916	498963.3	5806669	33.13	33.10	0.029
7917	499794.3	5806666	34.45	34.34	0.105
7918	498941.7	5806646	33.1	33.05	0.049
7919	499790.4	5806645	34.4	34.30	0.104
7921	498573.9	5806629	32.66	32.98	-0.319
7923	498914.3	5806622	33.1	N/A	N/A
7924	499766.3	5806611	34.4	34.24	0.159
7925	498545.3	5806609	32.66	32.96	-0.305
7932	499843	5806552	34.12	N/A	N/A
7934	499822.3	5806534	34.12	N/A	N/A
7948	501249.4	5806371	32.27	N/A	N/A
7949	501278.3	5806370	32.27	32.24	0.029
7964	499199.3	5806232	32.45	32.32	0.126
7966	499172	5806222	32.45	32.28	0.168

7970	500802.3	5806198	32.44	N/A	N/A
7971	499201.3	5806194	32.46	32.23	0.228
7973	500780.5	5806190	32.44	32.30	0.138
7974	499176.1	5806190	32.46	32.22	0.238
7987	498767.3	5806081	31.72	32.20	-0.482
7988	498751.7	5806078	31.72	N/A	N/A
8001	498837.3	5805921	31.44	32.09	-0.653
8003	498812.4	5805920	31.49	32.10	-0.606
8012	498888.3	5805834	31.45	31.86	-0.411
8014	498855.5	5805827	31.45	31.87	-0.423
8028	499716.3	5805737	31.56	31.74	-0.179
8029	499691.5	5805736	31.56	31.71	-0.147
8033	500264.6	5805710	32.59	N/A	N/A
8036	500291.3	5805705	32.59	32.12	0.471
8038	498893.3	5805698	31.55	31.73	-0.177
8040	498864.8	5805692	31.55	N/A	N/A
8043	500414.9	5805638	32	N/A	N/A
8044	500428.3	5805626	32	N/A	N/A
8051	500405.5	5805579	31.44	N/A	N/A
8052	500427.3	5805578	31.44	N/A	N/A
8085	500966.3	5805229	31.85	N/A	N/A
8086	500941	5805224	31.85	N/A	N/A
8088	499015.1	5805214	31.38	N/A	N/A
8089	499031.3	5805212	31.38	N/A	N/A
8091	500942.3	5805184	31.69	N/A	N/A
8094	500908.1	5805177	31.69	31.44	0.254
8095	501629.3	5805162	30.41	N/A	N/A
8097	501596.3	5805156	30.41	30.69	-0.282
8100	499163.1	5805139	31.27	31.31	-0.039
8101	499188.3	5805136	31.27	31.25	0.018
8102	499188.3	5805136	30.92	31.25	-0.332
8103	499174.9	5805121	30.92	31.28	-0.359
8104	499503.7	5805111	30.92	31.10	-0.181
8105	499423.8	5805111	30.87	31.12	-0.245
8106	499447.3	5805107	30.87	31.10	-0.23
8109	499526.3	5805095	30.85	31.06	-0.206
8110	499526.3	5805095	30.92	31.06	-0.136
8111	499508.3	5805095	30.85	31.06	-0.215
8112	499188.3	5805083	31.13	31.24	-0.106
8113	499165.5	5805081	31.13	31.31	-0.181
8116	499198.4	5805043	30.85	N/A	N/A
8118	499215.3	5805031	30.85	N/A	N/A
8130	499306.3	5804850	30.48	30.87	-0.392
8131	499280.5	5804844	30.48	30.88	-0.4
8143	501285.3	5804486	29.54	N/A	N/A
8144	501260.5	5804484	29.54	N/A	N/A
8147	501322.3	5804450	29.53	N/A	N/A
8148	501307.4	5804447	29.53	N/A	N/A
8149	499482.6	5804440	29.54	30.03	-0.495
8150	499488.3	5804437	29.54	30.03	-0.491
8153	499505.3	5804396	29.34	30.00	-0.661
8154	499494.3	5804390	29.34	29.99	-0.655
8165	499434.3	5804061	29.38	29.71	-0.33
8166	499426.2	5804054	29.38	29.71	-0.328

8168	500211.3	5804029	29.17	29.35	-0.181
8169	500213	5804023	29.17	29.35	-0.177
8175	500105.3	5803849	29.1	29.28	-0.178
8176	500112	5803829	29.1	29.25	-0.155
8177	499618.3	5803755	28.92	N/A	N/A
8178	499625.8	5803742	28.92	29.38	-0.46
8179	500376.3	5803714	29.11	29.12	-0.014
8180	500389.1	5803705	29.11	29.12	-0.009
8181	499996.3	5803655	29.07	29.16	-0.091
8182	500358.3	5803647	28.83	29.07	-0.237
8183	500001.6	5803642	29.07	29.14	-0.071
8184	500365.6	5803630	28.83	29.00	-0.173
8190	500003.9	5803457	28.98	29.01	-0.026
8193	500959.8	5803312	28.59	N/A	N/A
8194	500960.3	5803307	28.59	N/A	N/A
8195	500045.3	5803211	28.85	28.91	-0.057
8196	500041.5	5803209	28.85	28.91	-0.058
8198	502824.6	5803174	25.96	N/A	N/A
8199	502836.3	5803172	25.96	N/A	N/A
8210	501824.1	5803026	27.14	N/A	N/A
8211	501830.3	5803026	27.14	N/A	N/A
8212	501830.3	5803026	27.17	N/A	N/A
8213	501034.3	5803024	28.68	28.36	0.322
8214	501037.3	5803021	28.68	28.35	0.329
8215	501831.2	5803019	27.17	N/A	N/A
8216	501201.3	5803008	28.22	27.65	0.566
8217	501197	5803005	28.22	27.79	0.427
8221	500786	5802820	28.71	28.67	0.038
8222	500773.3	5802820	28.71	28.67	0.037
8227	500299.9	5802769	28.74	28.72	0.02
8228	502660.3	5802761	25.61	25.16	0.453
8229	500279.3	5802761	28.74	28.72	0.017
8231	502641.4	5802757	25.61	25.16	0.446
8233	501360.3	5802732	27.3	26.56	0.744
8234	501337.9	5802729	27.3	N/A	N/A
8238	501400.3	5802618	27.37	N/A	N/A
8240	501406	5802612	27.37	N/A	N/A
8241	501453.3	5802603	27.2	N/A	N/A
8242	501457.7	5802593	27.2	N/A	N/A
8244	501586.3	5802507	27.13	N/A	N/A
8246	501598.6	5802502	27.13	N/A	N/A
8248	500534.7	5802493	28.74	28.69	0.052
8250	500521.3	5802483	28.74	28.69	0.047
8251	501067.3	5802463	28.71	28.68	0.03
8252	501052.3	5802447	28.72	28.68	0.039
8253	501079.6	5802443	28.71	28.68	0.027
8254	501100.3	5802429	27.29	N/A	N/A
8255	501053.7	5802420	28.72	28.68	0.037
8256	501119.5	5802418	27.29	N/A	N/A
8257	501088.3	5802415	28.4	N/A	N/A
8258	501132.3	5802399	27.14	28.14	-0.998
8259	501122.3	5802386	28.38	28.11	0.272
8260	501143	5802385	27.14	N/A	N/A
8261	501086.6	5802376	28.4	N/A	N/A

8262	501114.8	5802345	28.38	28.51	-0.132
8265	500958.3	5802265	28.44	28.59	-0.149
8266	500959.8	5802254	28.44	N/A	N/A
8267	500960.3	5802219	28.3	N/A	N/A
8268	500912.3	5802219	28.45	N/A	N/A
8269	500966.9	5802214	28.3	N/A	N/A
8270	500777.3	5802205	28.72	28.65	0.069
8271	500929.3	5802205	28.45	28.53	-0.077
8273	500838.3	5802194	28.48	28.55	-0.068
8274	500797.7	5802193	28.72	28.59	0.129
8275	500856.5	5802191	28.48	N/A	N/A
8277	502923.2	5802179	25.19	24.28	0.906
8278	503471.3	5802170	24.32	N/A	N/A
8279	503458.8	5802170	24.32	N/A	N/A
8280	502902.3	5802161	25.19	24.28	0.907
8281	502601.5	5802041	25.24	24.86	0.384
8282	502573.3	5802021	25.24	24.87	0.367
8284	501741.8	5801896	26.12	N/A	N/A
8285	501715.3	5801882	25.56	N/A	N/A
8286	503188.7	5801840	24.62	23.90	0.721
8287	503165.3	5801821	24.62	23.93	0.695
8290	501218.3	5801781	26.86	N/A	N/A
8291	501237	5801779	26.86	N/A	N/A
8293	501824.1	5801753	25.56	N/A	N/A
8295	501633.8	5801730	24.91	N/A	N/A
8296	501126.6	5801718	27.05	N/A	N/A
8297	501596.3	5801717	24.91	N/A	N/A
8298	501113.3	5801717	27.05	N/A	N/A
8301	502115.4	5801641	25.05	24.94	0.106
8302	502071.3	5801638	25.05	25.03	0.024
8306	501777.1	5801482	24.44	N/A	N/A
8307	501744.3	5801478	24.44	N/A	N/A
8311	502906.8	5801432	23.93	N/A	N/A
8312	502867.3	5801422	23.93	N/A	N/A
8314	504478	5801332	22.82	N/A	N/A
8315	504495.3	5801331	22.8	N/A	N/A
8316	504495.3	5801331	22.82	N/A	N/A
8317	504492.1	5801322	22.8	N/A	N/A
8318	501368.5	5801304	24.63	24.34	0.287
8319	501329.3	5801295	24.63	24.37	0.263
8322	501664.4	5801161	24.18	23.88	0.295
8326	501615.3	5801146	24.18	23.92	0.256
8327	502845.7	5801121	22.55	22.52	0.029
8328	502822.3	5801103	22.55	22.46	0.092
8354	501180.6	5800854	22.73	23.02	-0.289
8356	501150.3	5800844	22.73	23.02	-0.287
8362	501227.5	5800644	22.87	22.91	-0.035
8363	503228.5	5800639	22.03	21.67	0.356
8364	501205.3	5800632	22.87	22.91	-0.04
8366	503200.3	5800615	22.03	21.68	0.346
8369	503832.2	5800571	21.84	N/A	N/A
8371	502725.9	5800559	22.22	21.87	0.349
8372	503819.3	5800547	21.84	21.51	0.329
8373	502694.3	5800536	22.22	21.87	0.35

8380	501629.2	5800400	22.7	21.92	0.779
8382	501676.1	5800398	22.3	21.90	0.403
8383	501582.3	5800366	22.7	N/A	N/A
8384	501635.3	5800363	22.3	N/A	N/A
8387	504586	5800281	20.34	21.28	-0.937
8389	504572.3	5800264	20.34	21.21	-0.875
8391	501669.1	5800227	21.83	21.52	0.309
8393	501627.3	5800203	21.83	N/A	N/A
8394	503461.1	5800190	21.25	21.21	0.039
8395	501669.1	5800185	21.47	21.49	-0.017
8397	503433.3	5800174	21.25	21.20	0.051
8399	501631.3	5800155	21.47	21.45	0.024
8401	503479.9	5800150	21.23	21.11	0.116
8403	503458.3	5800135	21.23	20.99	0.244
8406	504889	5800075	20.88	20.51	0.374
8407	504875.3	5800065	20.88	20.53	0.355
8416	504099.9	5799827	20.46	20.04	0.422
8417	504082.3	5799820	20.46	20.01	0.454
8418	504306.6	5799808	20.2	20.06	0.14
8419	504301.3	5799805	20.2	20.06	0.142
8423	504980.3	5799757	19.72	19.55	0.172
8425	504978.3	5799745	19.72	19.63	0.085
8426	504988.3	5799722	19.79	N/A	N/A
8428	504987.7	5799698	19.79	N/A	N/A
8429	504991.3	5799691	19.53	N/A	N/A
8431	504431.1	5799670	20.05	19.85	0.195
8433	504987.6	5799663	19.53	N/A	N/A
8434	504422.3	5799655	20.05	19.83	0.217
8436	504955.3	5799635	19.44	19.22	0.224
8437	504957.1	5799630	19.44	19.21	0.23
8440	505964.7	5799532	18.07	N/A	N/A
8442	505956.3	5799512	18.07	N/A	N/A
8450	506814.9	5799310	17.15	18.51	-1.362
8451	506821.3	5799296	17.15	18.50	-1.35
8455	503343.7	5799179	18.98	N/A	N/A
8456	503331.3	5799157	18.98	N/A	N/A
8457	503914.3	5799106	20.16	19.72	0.441
8458	503891.3	5799088	20.16	19.72	0.441
8459	502383	5799071	19.87	19.37	0.503
8460	502364.3	5799032	19.87	19.33	0.539
8463	502801.1	5798938	19.05	18.62	0.427
8464	502794.3	5798913	19.05	18.60	0.449
8465	505570.1	5798877	17.22	16.80	0.424
8466	505570.3	5798861	17.22	16.78	0.441
8470	502657.9	5798449	18.01	17.88	0.132
8471	502648.3	5798420	18.01	17.87	0.138
8472	504092.8	5798409	17.95	N/A	N/A
8475	504071.3	5798379	17.95	17.71	0.241
8476	505506.7	5798374	17.31	17.18	0.134
8478	502693.1	5798360	17.88	N/A	N/A
8479	505510.3	5798352	17.31	17.13	0.177
8481	502686.3	5798345	17.88	N/A	N/A
8486	503489.3	5797999	16.94	16.86	0.076
8487	503320.2	5797976	17.11	N/A	N/A

8488	503481.3	5797971	16.94	16.78	0.159
8490	503312.3	5797951	17.11	N/A	N/A
8493	505455.1	5797845	16.8	16.59	0.208
8494	505455.3	5797826	16.8	16.59	0.213
8498	506746.8	5797651	15.55	N/A	N/A
8499	506756.3	5797637	15.55	N/A	N/A
8500	506789.1	5797573	15.38	N/A	N/A
8501	506790.3	5797548	15.38	N/A	N/A
8502	506469.7	5797517	16.05	16.08	-0.026
8504	506468.3	5797499	16.05	16.03	0.025
8507	504463.9	5797477	17.04	N/A	N/A
8508	506866.5	5797470	15.06	N/A	N/A
8509	504720	5797468	16.92	N/A	N/A
8510	504446.3	5797454	17.04	N/A	N/A
8511	503106.4	5797452	16.78	16.70	0.076
8512	504711.3	5797447	16.92	N/A	N/A
8513	506869.3	5797436	15.06	15.00	0.06
8514	503102.3	5797411	16.78	N/A	N/A
8515	506948.8	5797407	14.85	14.82	0.034
8516	506945.3	5797377	14.85	14.86	-0.014
8517	507047.5	5797328	14.74	14.62	0.123
8519	504297.1	5797321	15.3	N/A	N/A
8521	507131.9	5797314	14.62	N/A	N/A
8522	507082.7	5797314	14.74	14.60	0.144
8523	507049.3	5797311	14.74	14.61	0.133
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8525	504286.3	5797295	15.3	N/A	N/A
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8528	507088.3	5797288	14.74	14.59	0.148
8529	504567.3	5797286	15.44	N/A	N/A
8534	505241.3	5797168	16.01	15.75	0.263
8535	506411	5797147	15.13	15.14	-0.014
8536	505244.3	5797145	16.01	N/A	N/A
8537	506403.3	5797120	15.13	15.07	0.062
8543	506988.7	5797033	15.15	14.71	0.439
8544	506980.3	5797002	15.15	14.63	0.52
8545	505704	5796974	15.62	15.28	0.337
8546	505702.3	5796943	15.62	15.25	0.372
8548	506833.7	5796899	14.85	14.66	0.188
8549	503951.9	5796876	15.34	15.23	0.107
8550	506821.3	5796871	14.85	14.67	0.18
8551	506854.8	5796862	14.01	N/A	N/A
8552	503932.3	5796847	15.34	15.22	0.118
8553	506845.3	5796837	14.01	N/A	N/A
8554	506723.3	5796822	14.82	14.70	0.122
8555	506703.3	5796782	14.82	14.58	0.242
8556	506735	5796775	14	N/A	N/A
8557	506726.3	5796749	14	13.79	0.213
8560	507730.9	5796614	13.08	12.75	0.328
8561	506420.3	5796597	14.89	14.78	0.111
8562	507713.3	5796586	13.08	12.73	0.346
8563	506403.3	5796574	14.89	14.79	0.098
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8566	504072.3	5796546	14.94	15.06	-0.124
8569	506431.3	5796537	13.68	13.34	0.339
8572	504557.9	5796513	15.34	14.98	0.357
8573	504547.3	5796485	15.34	14.98	0.357
8575	504442.8	5796476	14.94	15.00	-0.064
8577	504420.3	5796452	14.94	15.00	-0.061
8578	504445.1	5796436	14.26	15.01	-0.751
8579	508449.5	5796417	12.33	N/A	N/A
8580	508357.9	5796417	12.43	N/A	N/A
8581	506155	5796410	15.12	14.82	0.295
8583	504417.3	5796406	14.26	14.00	0.262
8584	508351.3	5796401	12.43	12.28	0.147
8585	506141.3	5796382	15.12	14.83	0.294
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8588	508433.3	5796377	12.33	N/A	N/A
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8590	506165.3	5796348	13.66	13.68	-0.021
8593	505277.3	5796334	15.01	14.91	0.1
8594	505281.3	5796326	14.07	14.90	-0.831
8595	505943.6	5796312	15.19	14.81	0.377
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8597	505671.2	5796296	15.02	14.88	0.143
8598	505926.3	5796289	15.19	14.77	0.419
8599	505950.6	5796277	14.05	14.76	-0.709
8600	505661.3	5796271	15.02	14.88	0.14
8601	505673.5	5796258	14.06	14.88	-0.815
8602	505937.3	5796255	14.05	13.93	0.124
8603	505657.3	5796227	14.06	13.82	0.235
8604	505957.7	5796214	14.18	13.85	0.325
8605	505945.3	5796188	14.18	13.94	0.237
8606	506002.3	5796188	13.41	13.22	0.193
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8624	506528.3	5795832	12.38	12.20	0.179
8651	509067.4	5795540	9.82	9.91	-0.093
8652	509062.5	5795531	9.82	9.91	-0.09
8654	505766.3	5795479	13.32	12.93	0.385
8655	505814.3	5795472	12.6	12.27	0.33
8657	505809.7	5795451	12.6	12.32	0.279
8658	505758	5795451	13.32	12.87	0.447
8660	508659.3	5795411	10.63	10.54	0.088
8661	508653.9	5795411	10.63	10.55	0.075
8671	506177.3	5795329	11.54	11.68	-0.145
8674	506178.5	5795300	11.54	11.68	-0.145
8680	509588.4	5795187	9.16	N/A	N/A
8681	509612.2	5795185	9.16	N/A	N/A
8685	504438.1	5795153	13.32	13.23	0.09
8689	504414.3	5795098	13.32	13.23	0.093
8693	507173.3	5795055	10.71	10.64	0.075
8694	505039.3	5795055	13.31	13.17	0.136
8695	507188.4	5795043	10.71	10.57	0.135
8697	505006.3	5795015	13.31	13.18	0.131

8703	505716.3	5794894	11.41	12.28	-0.867
8704	505660.3	5794893	13.31	12.52	0.788
8705	505657	5794879	13.31	12.51	0.796
8706	505925.3	5794877	12.07	11.84	0.231
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8738	510171.1	5794490	8.06	8.12	-0.058
8746	507284.3	5794329	9.75	9.35	0.399
8749	507294	5794318	9.75	9.32	0.429
8752	507230.3	5794307	9.61	9.65	-0.042
8754	507242.3	5794292	9.61	9.63	-0.017
8767	507100.3	5794211	9.5	N/A	N/A
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8778	508166.3	5794075	8.4	8.54	-0.142
8779	507196.3	5794073	9.5	9.49	0.012
8781	508172.4	5794064	8.4	8.52	-0.125
8782	507207.1	5794062	9.5	9.49	0.013
8788	510554.3	5793984	7.31	N/A	N/A
8789	510546.9	5793972	7.31	7.37	-0.062
8790	507146.3	5793960	9.05	9.23	-0.184
8792	507155.5	5793944	9.05	9.22	-0.175
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8798	510822.3	5793896	7.03	N/A	N/A
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8805	510654.9	5793831	7.28	7.21	0.071
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8861	508430.3	5792971	7.6	7.63	-0.034
8866	513919.5	5792736	4.59	4.56	0.033
8869	513925.4	5792714	4.59	4.56	0.033
8871	516479.5	5792698	3.74	N/A	N/A
8873	516700.3	5792684	3.93	3.75	0.184
8876	516477.4	5792673	3.74	3.82	-0.084
8878	516697.4	5792658	3.93	3.74	0.187
8900	515594	5792463	4.29	4.19	0.099
8901	514682.8	5792461	4.39	N/A	N/A
8903	515609.4	5792438	4.29	4.18	0.11
8904	514684.4	5792438	4.39	4.36	0.026
8913	512996.5	5792157	4.52	4.87	-0.351
8914	513001.4	5792146	4.52	4.87	-0.355
8916	511739.3	5792130	5.93	5.96	-0.033
8917	511730.5	5792129	5.93	5.97	-0.036
8927	509716.3	5791937	6.66	6.65	0.006
8928	509696.7	5791933	6.66	6.66	-0.004
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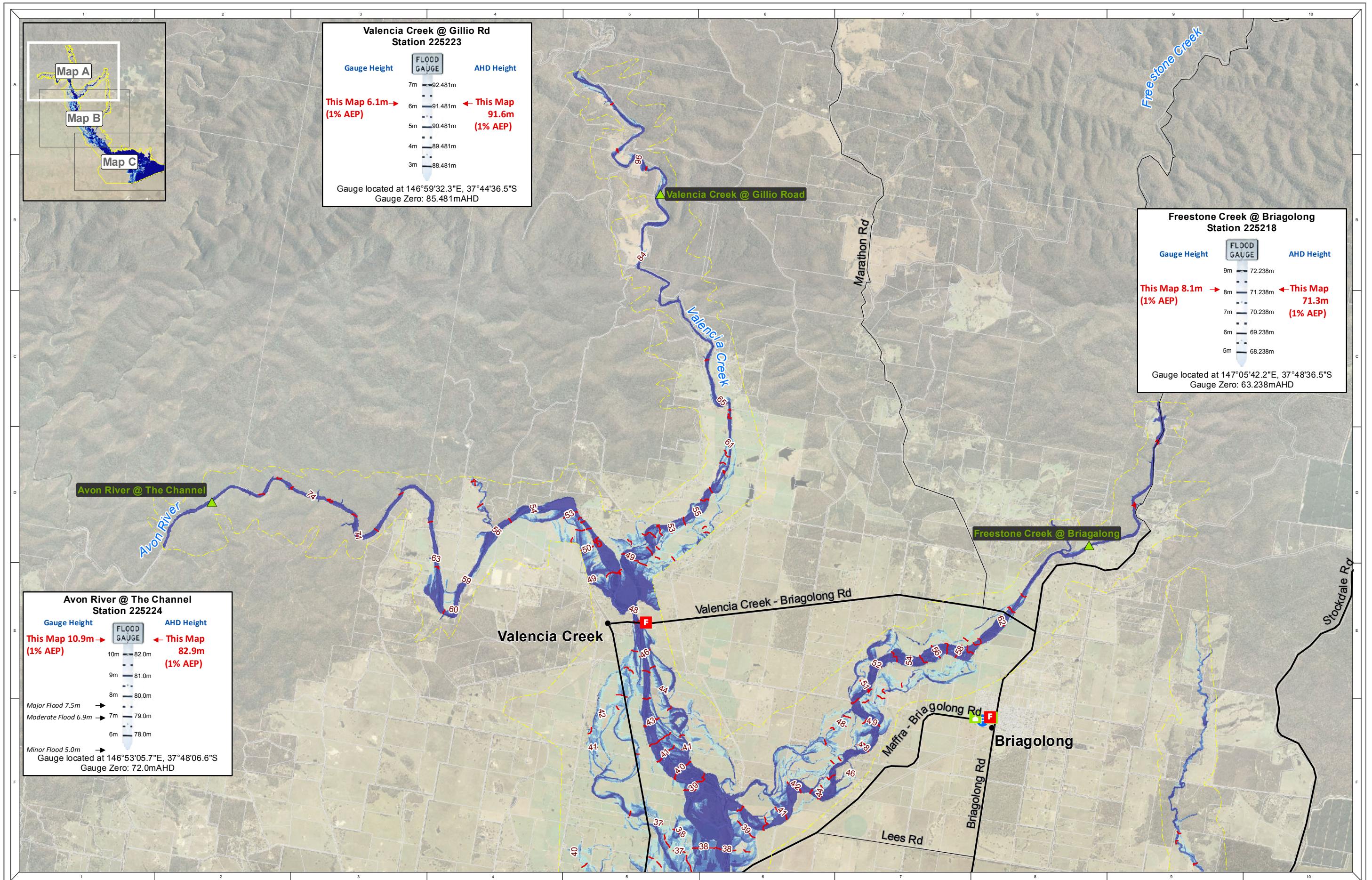
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8948	515786.7	5791566	4.2	N/A	N/A
8949	515807.8	5791552	4.39	4.14	0.245
8950	515783.4	5791545	4.2	4.15	0.055
8951	515783.4	5791545	4.39	4.15	0.245
8952	515783.4	5791545	3.97	4.15	-0.175
8965	515766.6	5791112	4.34	4.26	0.084
8966	515755.4	5791099	4.34	4.26	0.082
8967	513231.3	5791090	5.27	N/A	N/A
8968	513215.4	5791085	5.27	5.34	-0.069
8970	512604.3	5790987	5.66	N/A	N/A
8972	512584.4	5790977	5.66	N/A	N/A
8977	515178.3	5790895	4.35	4.31	0.039
8978	515161.4	5790887	4.35	4.31	0.038
8981	511220.3	5790752	6.2	6.00	0.204
8982	511206.8	5790742	6.2	N/A	N/A

APPENDIX B – MODEL QA SHEET

Modeller:		Reviewer:	
Job Title/Number: 3719-01 Avon River Regional		Date: 10/12/2015	
Model Name: Avon River			
MIKE by DHI Quality Assurance Checklist			
Item	Description	Calibration	Reviewed
MODEL INPUTS			
Client specification / Description of deliverables: Regional Flood Mapping, Other flood intelligence			CLA
Reference data and/or drawings: Nuntin Levee as constructed survey			CLA
Calibration data: AR @ Stratford, AR @ The Channel, AR @ Clydebank, VC @ Gillio Rd, FC @ Briagolong			CLA
Topographic data: LiDAR			CJC
Inflow Data: See hydrology report			KLR
Other inputs: Structures from VicRoads and VicRail			
Model Input Identification Approved - PM Sign:		Date: 1/3/2015	
Model Setup			
MIKE Model Build	Latest model build?	MIKE 2014 FM GPU	CLA
Module Selection	Modules used, Flexible Mesh	FM with GPU	CLA
GPU	Recommended for large FM floodplain models	Yes	CLA
Naming Convention		Avon_Cal_2007_001	CLA
Scenarios and Events		2007, 2012, 2011	CLA
Modelling Log	Using a manual runsheet is recommended for MIKE	Yes	CLA
Domain		As specified in brief	CLA
Element Size	4-5 cells across 2d waterways	~5m in waterways	CLA
Mesh Build Type	SMS with GIS software? Native MIKE mesh?	SMS	CLA
Mesh Reviewed by software	Report mesh analysis	Yes - ok	CLA
Mesh Reviewed manually	Mesh configuration checked internally?	Yes - YZ (13/07/2015)	CLA
2d Timestep	One half to one fifth the 2d cell size	0.01 - 30s (variable)	CLA
1d Timestep	One half to one quarter the 2d cell size	NA	
Structure Checks			
Pipes Flow Direction	Plot Long Section – flow should be downhill	Yes	CLA
Pipes Flow Magnitude	Check flow rates	Yes	CLA
1d Hydrographs	Graph Time series – Hydrographs should be stable	Yes	CLA
Pipe Cover	Minimum cover check	NA	
1d Output Interval	Usually can be greater than 1 minute	NA	
2d Checks			
Topography	Topography dfs2/dfs Check, comparison to survey.	Yes - checked to cross section and between LiDAR sets	
Land Use	Roughness dfs2/dfs Check, modelling of buildings.	Roughness calibrated in channel	CLA
Roughness	Roughness values – Check against recommended values (Chow, 1959; AR&R, 1987)	Yes	CLA
1d-2d Boundaries	MFLOOD schematisation - appropriate number of linked cells?, MFM mesh alignment	Mesh aligned to structures	CLA
Initial Conditions	Initial conditions to encourage stability at start of model	Wet lower catchment	CLA
Downstream Boundary	Visual check for ponding behind boundary	ok	CLA
External Inflow Schematisation	Are inflows working?	Yes	CLA
Internal Inflow Schematisation	Routed or Unrouted flows working, in appropriate locations	Yes	CLA
1d Water Level Lines	Schematisation (bridges/culverts)	ok	CLA
PO Hydrographs Stability	Graph Time Series	Yes	CLA
Water Level Increasing with AEP	Visual inspection	Yes	CLA
2d Output Type	Appropriate outputs being used?	dfsU over domain, dfs1 hydrographs	CLA
2d Output Interval	Consider file size when specifying	30 min	CLA

2d Output Spatial Variation	Consider using output zones	No	CLA
QA Checks			
Instabilities	Check MIKE log files	No	CLA
Final Mass Error	MIKE log files and mass error outputs	-0.49% (2007), -0.98% (2012), -0.02% (2011)	CLA
Warnings Prior to Simulation	Check MIKE log files	ok	CLA
Warnings During Simulation	Check MIKE log files	ok	CLA
Comments			
MODEL OUTPUT VERIFICATION AND VALIDATION			
Outputs may be released if Reviewer is satisfied of the following:			
Output meets/addresses activity objectives. Yes			
Output provides appropriate information for intended purpose Yes Reviewer: Date: 29/10/2015			
Output complies with appropriate acceptance criteria. Yes			
Customer satisfied with output (from preliminary results & discussions) - Validation) yes, refer Peer review report			
Outputs verified & authorised for issue: Yes PM Sign: Date: 14/12/2015			
If required, independent review conducted by : Steering committee			

APPENDIX C – FLOOD MAPS



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Imagery: 2010



- Stream Gauge
- Fire Station
- Police Station
- School/Child Care

- Major Road
- Minor Road
- Cadastre

- AHD Contour (1m)
- Limit of Flood Mapping

- Flood Depth (m)**
- < 0.25
- 0.25 - 0.5
- 0.5 - 1
- > 1

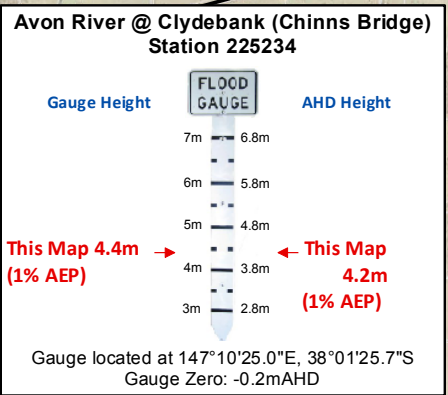
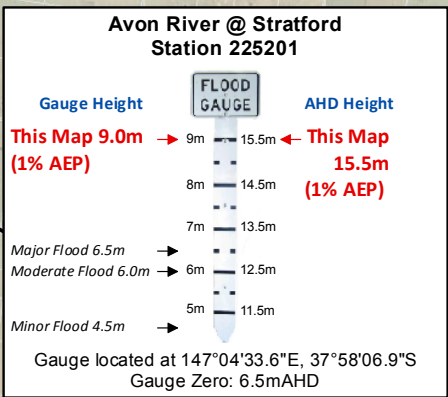
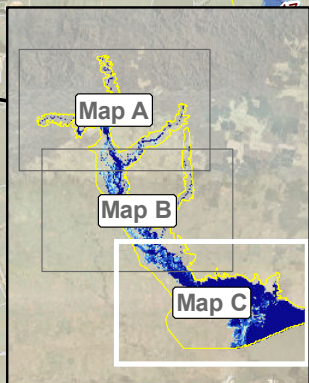
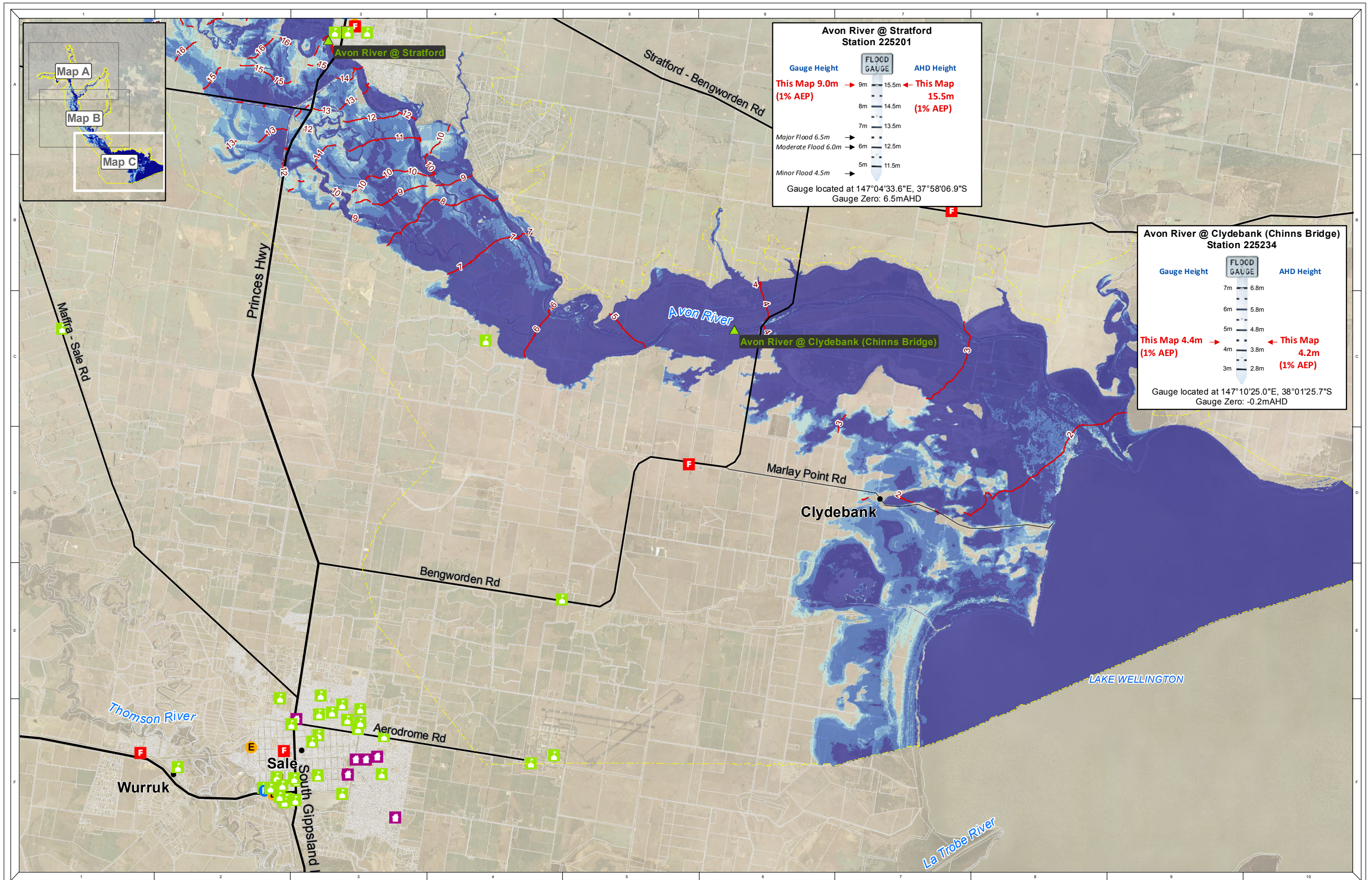
0 0.75 1.5 3 Kilometers 1:75,000 at A3



Avon River Regional Flood Mapping

1% AEP Flood Event - Depth Map

REFERENCE: M:\CORS\37 05 3 769310_AVON_R_REGIONAL_FLOOD_MAPPING\37 19 01_100V_DEPTHMAP_A3-A.MXD
DATE: 08/03/2016 SHEET: 1 of 3 DRAWING NUMBER: A



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Imagery: 2010



- Stream Gauge
- Emergency Services
- Fire Station
- Hospital
- Nursing Home
- Police Station
- School/Child Care
- Highway

- Major Road
- Minor Road
- Cadastre
- AHD Contour (1m)
- Limit of Flood Mapping
- Flood Depth (m)
- 0.25 - 0.5
- 0.5 - 1
- > 1
- < 0.25

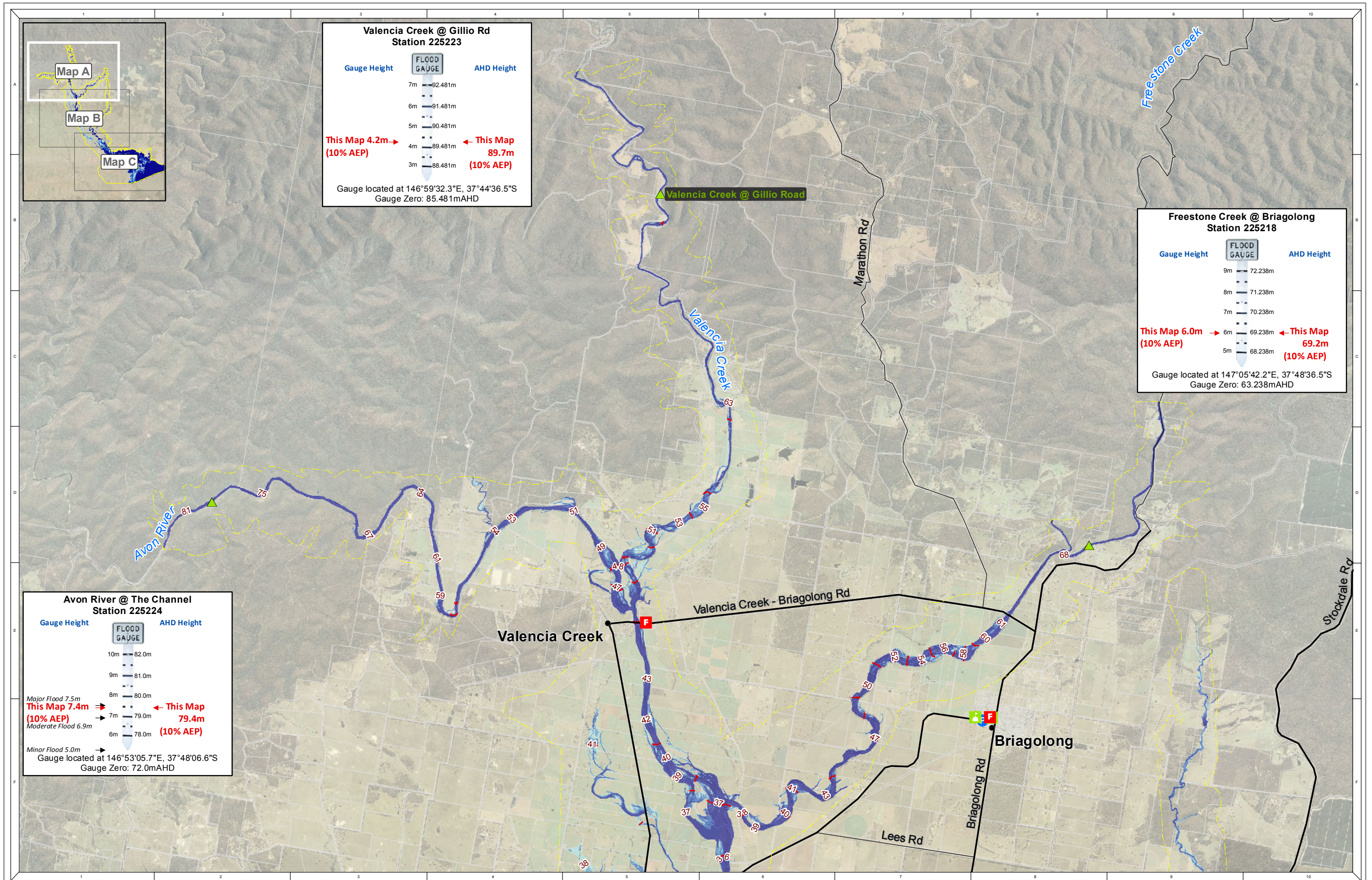
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Avon River Regional Flood Mapping

1% AEP Flood Event - Depth Map

REFERENCE: M:\GIS\3705-3709\3709_AVON_R_REGIONAL_FLOOD_MAPPING\3719-01_100Y_DEPTHMAP_A3-C.MXD
DATE: 08/03/2016 SHEET 3 of 3 DRAWING NUMBER: C



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Imagery: 2010



- Stream Gauge
- Fire Station
- Police Station
- School/Child Care

- Major Road
- Minor Road
- Cadastre

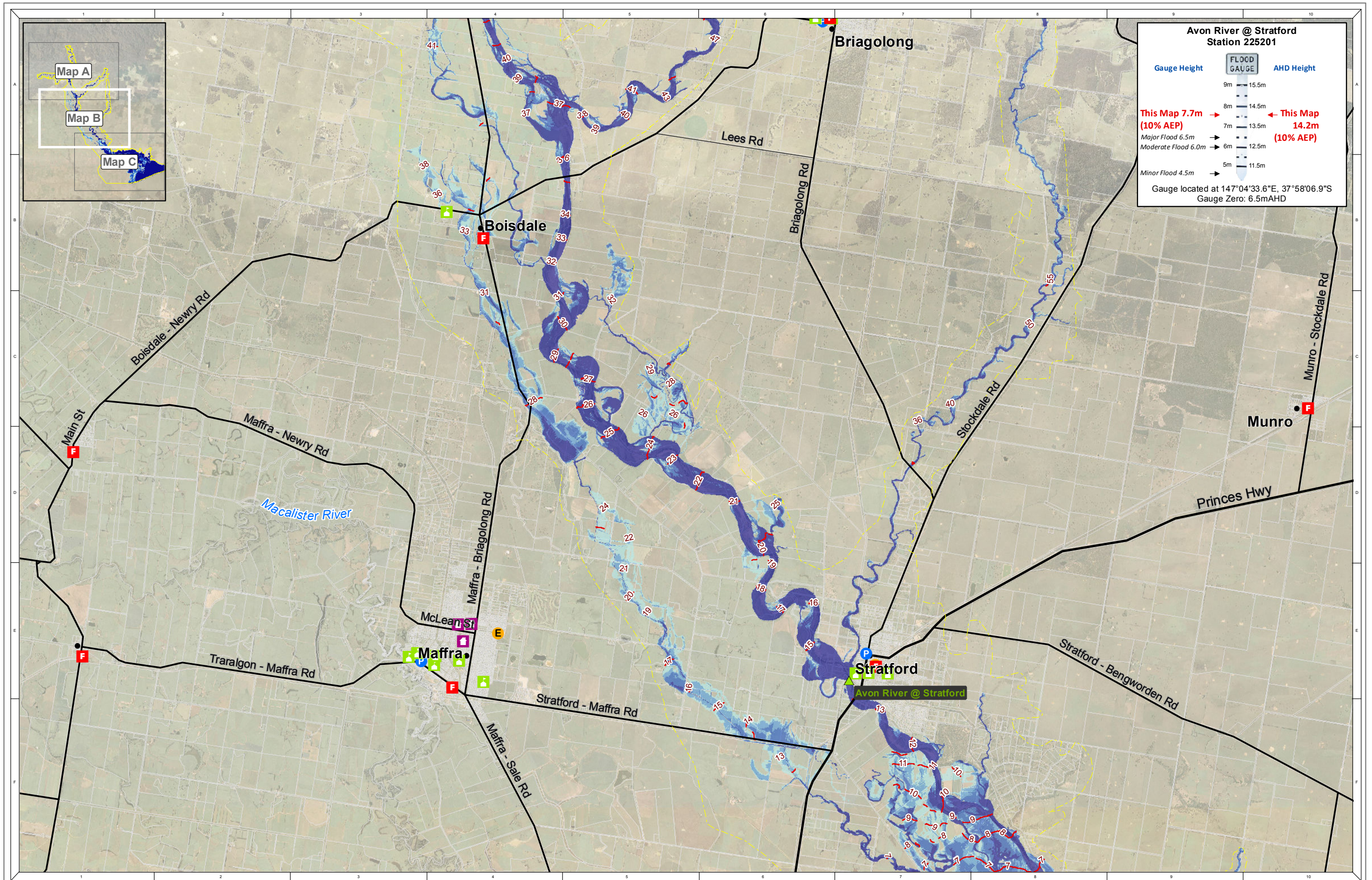
- AHD Contour (1m)
- Limit of Flood Mapping
- Flood Depth (m)
 - < 0.25
 - 0.25 - 0.5
 - 0.5 - 1
 - > 1

0 0.75 1.5 3 Kilometers 1:75,000 at A3



Avon River Regional Flood Mapping 10% AEP Flood Event - Depth Map

REFERENCE: M:\CORS\37 05 3 769310_AVON_R_REGIONAL_FLOOD_MAPPING\37 19 01_10Y_DEPTHMAP_A3.A.MXD
DATE: 08/03/2016 SHEET: 1 of 3 DRAWING NUMBER: A



Avon River @ Stratford Station 225201

Gauge Height	FLOOD GAUGE	AHD Height
9m	15.5m	
8m	14.5m	
7m	13.5m	
6m	12.5m	
5m	11.5m	

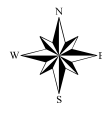
This Map 7.7m (10% AEP) → **This Map 14.2m (10% AEP)**

Major Flood 6.5m →
Moderate Flood 6.0m →
Minor Flood 4.5m →

Gauge located at 147°04'33.6"E, 37°58'06.9"S
Gauge Zero: 6.5mAHD



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Imagery: 2010



- Stream Gauge
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- Highway

- Major Road
- Minor Road
- Cadastre
- AHD Contour (1m)
- Limit of Flood Mapping
- Flood Depth (m)
- 0.25 - 0.5
- 0.5 - 1
- < 0.25
- > 1

0 0.75 1.5 3 Kilometers 1:75,000 at A3

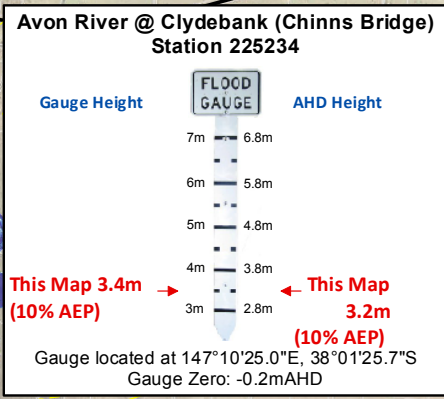
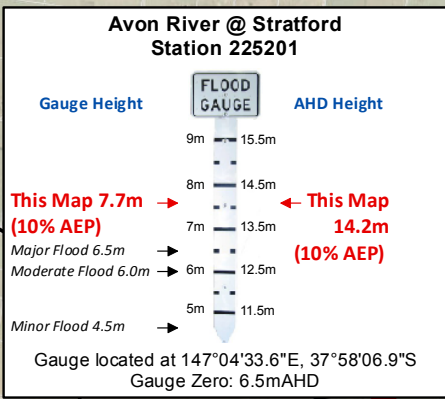
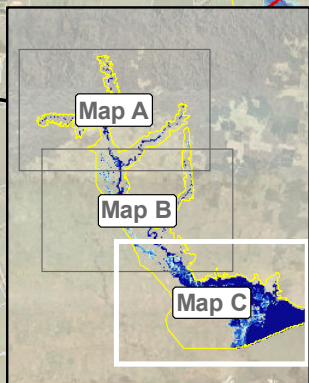
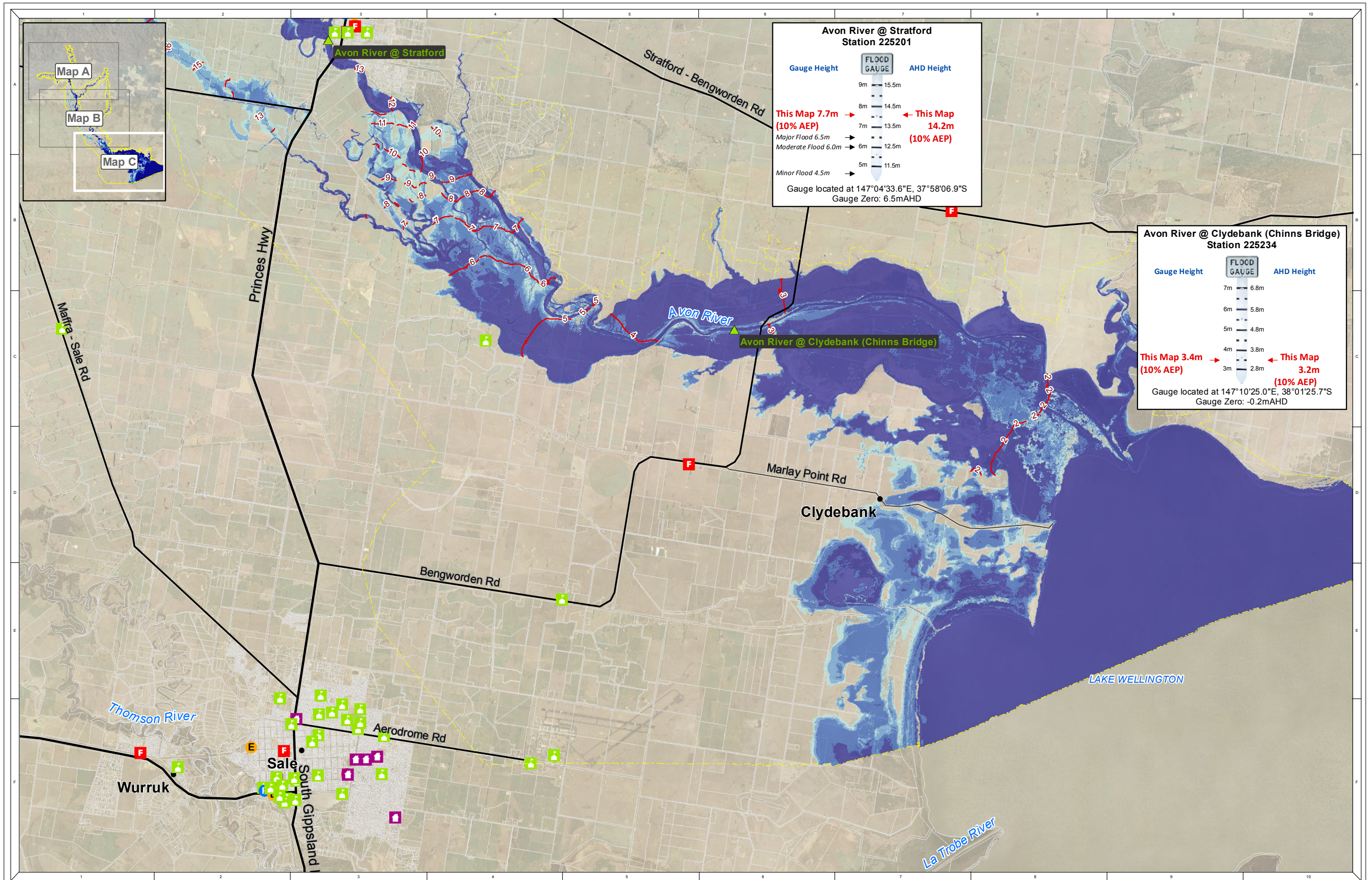


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Water & Planning

Avon River Regional Flood Mapping

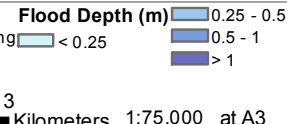
10% AEP Flood Event - Depth Map

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DATE: 08/03/2016 SHEET: 2 of 3 DRAWING NUMBER: B



- Stream Gauge
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- Police Station
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- Highway

- Major Road
- Minor Road
- Cadastre
- AHD Contour (1m)
- Limit of Flood Mapping



Department of
Environment, Land,
Water & Planning

Avon River Regional Flood Mapping
10% AEP Flood Event - Depth Map

REFERENCE: M:\GIS\3705-3706\3706_AVON_R_REGIONAL_FLOOD_MAPPING\3706-10Y_DEPTHMAP_A3.C.MXD
DATE: 08/03/2016 SHEET 3 of 3 DRAWING NUMBER: C

Avon River Regional Flood Mapping – Hydrology Report



June 2015

DOCUMENT STATUS

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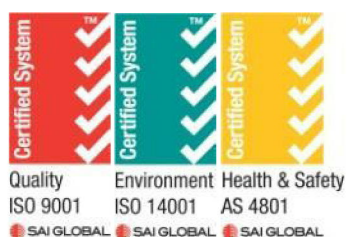
Cover Photo: Avon River, near Clydebank (taken 20/04/2015)

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1. INTRODUCTION

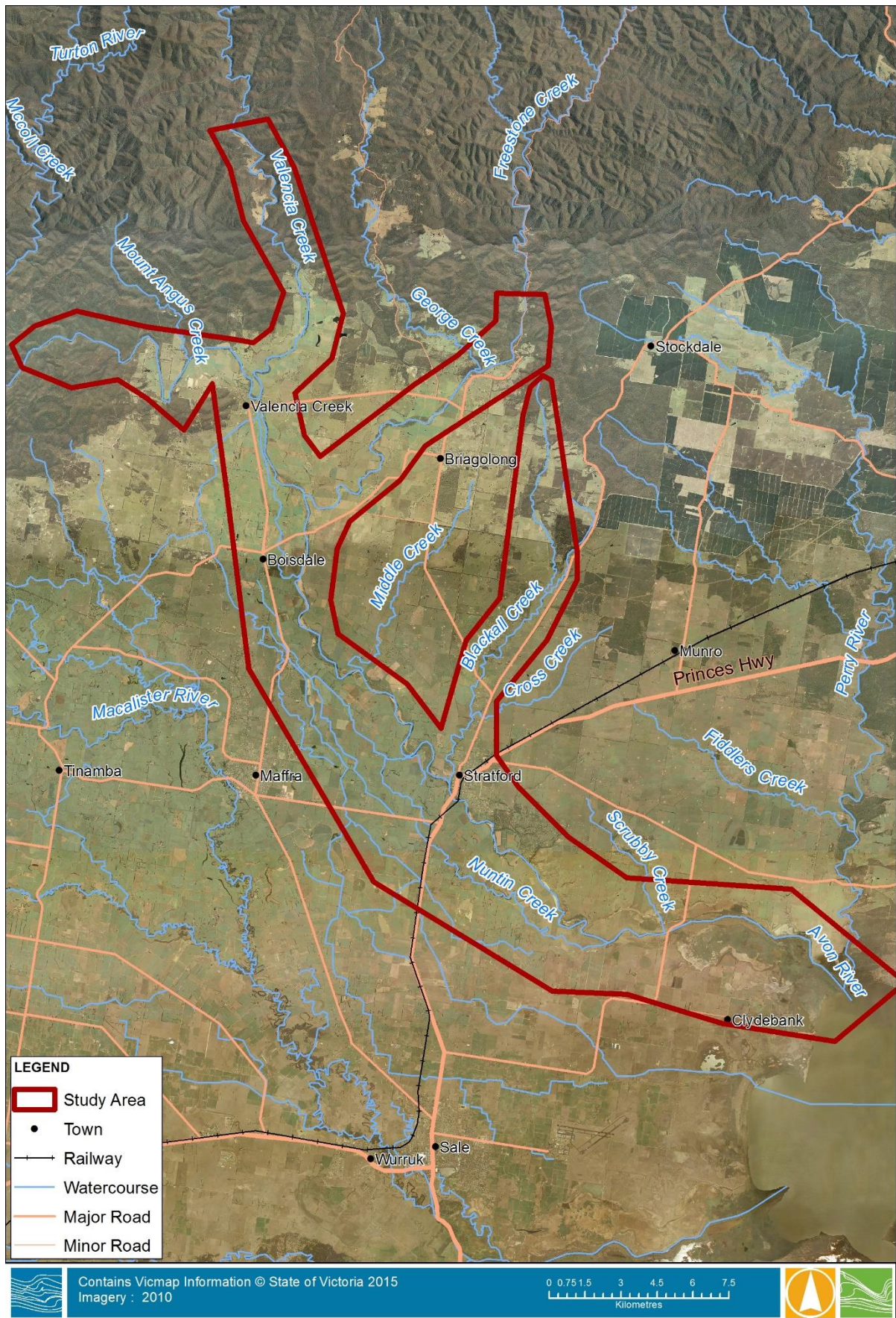
Water Technology was commissioned by the Department of Environment, Land, Water and Planning (DELWP) to undertake regional flood mapping for the Avon River. This project includes detailed hydrological and hydraulic modelling of the Avon River and its tributaries including Freestone Creek, Valencia Creek and Blackall Creek, and will take into account the downstream influences of Lake Wellington. This mapping will be used to satisfy a range of business requirements from planning, emergency response, to community awareness and for insurance purposes.

This report details the hydrological analysis undertaken for the project, and should be read in conjunction with the previous Preliminary Report (Water Technology, 2015).

2. STUDY AREA

The Avon River rises on the slopes of Mount Wellington in the eastern highlands of the Great Dividing Range and flows south to Lake Wellington and the Gippsland Lakes. The mountainous upper catchment is largely forested, while the lower catchment downstream of the confluence with Valencia Creek is generally flatter, with agriculture the primary land use (Earth Tech, 2007). The floodplain in the lower reaches is traversed by watercourses, swamps and lagoons. Overall, the river descends some 664 m over its 122 km length.

Regional mapping will include approximately 40 km of the downstream floodplain of the Avon River catchment, as well as large portions of Freestone Creek, Valencia Creek and Blackall Creek. Key towns within this catchment area include Stratford, Boisdale and Briagolong. The study area and significant watercourses are shown in Figure 2-1.



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Figure 2-1 Avon River study area

3. HYDROLOGY

3.1 Overview

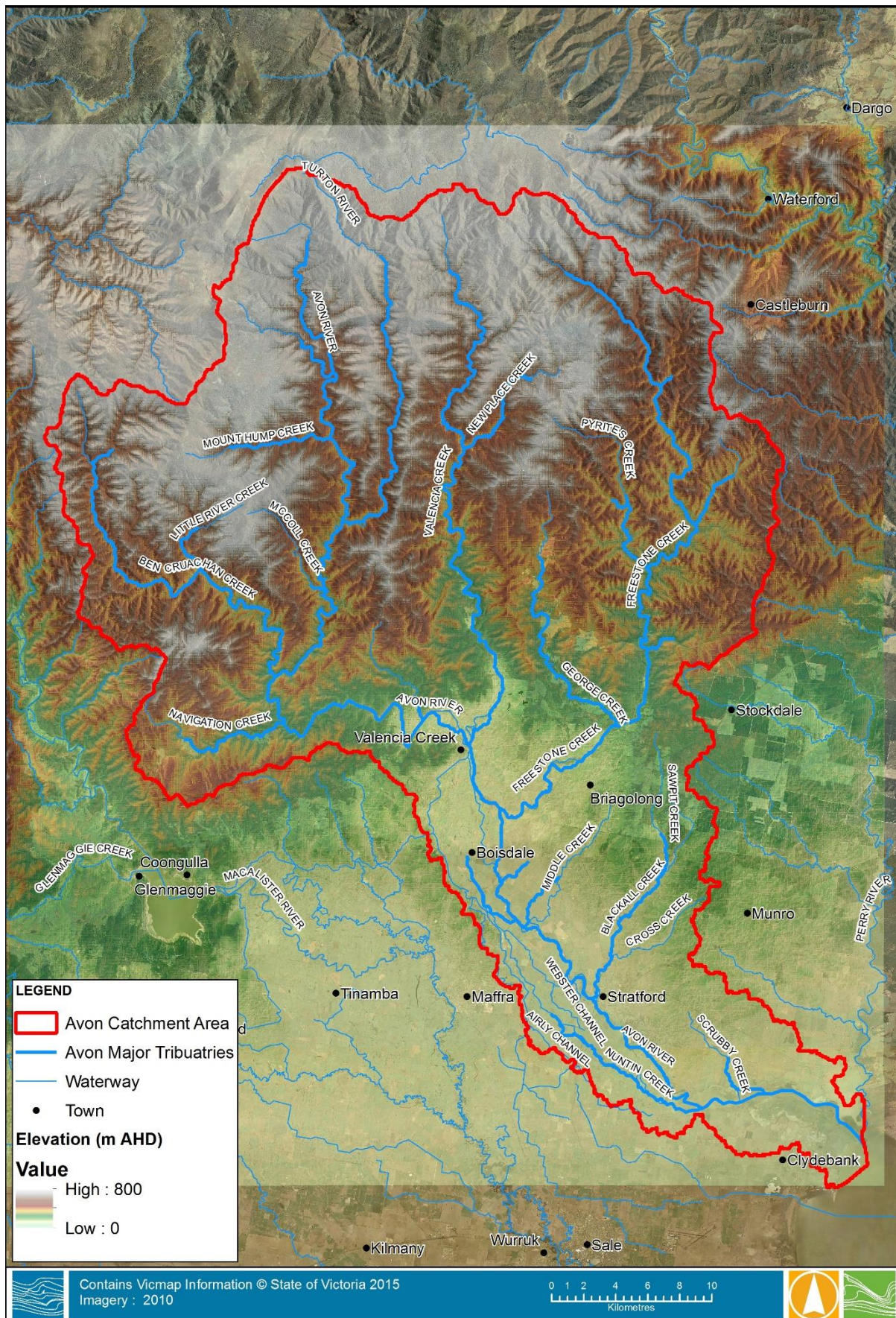
The hydrological analysis for the Avon River consisted of a review of the hydrological context of the study area followed by hydrologic modelling using RORB and flood frequency analysis on gauges with a good period of record. The RORB model was calibrated to three gauged events and parameter sets for design were validated against flood frequency analysis and regional flow estimates.

3.2 Catchment Description

The Avon River catchment has an area of 1,650 km² extending 72 km northward from Lake Wellington to a maximum elevation of 1,615 m AHD at Mount Wellington (Figure 3-1). The river has two main tributaries, Freestone Creek and Valencia Creek. A number of other minor streams feed into the River throughout its course. The Macalister River to the west and Perry River to the east have clearly defined catchments and are unlikely to exchange flows with the Avon River until they reach the downstream outlet at Lake Wellington.

The main stream length from the catchment divide to the mouth is 113 km with an equal area slope of 2.2 m/km. Equal area slope is the averaged slope of a river, and if plotted as a straight line against the real topography will have an equal weighting of topographic error above and below the approximated line. It is commonly used in hydraulic and hydrological formulae. The catchment is much steeper in the ranges upstream of Valencia Creek than in the floodplain.

A steep rainfall gradient exists over the catchment with average annual rainfall reaching 1,910 mm in the headwaters, while at the catchment centroid the average annual rainfall is around 670 mm. Effectively the lower catchment is within the rain shadow of the Australian Alps, part of the Great Dividing Range.



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Figure 3-1 Avon River Catchment

3.3 Design Rainfall Estimates

Design rainfalls were calculated for the 20%, 10%, 5%, 2% and 1% AEP events using the Intensity-Frequency-Duration analysis from Australian Rainfall and Runoff (ARR) (1987). The IFD parameters (Table 3-1) were obtained from the Bureau of Meteorology's IFD program website (www.bom.gov.au/water/designRainfalls/ifd) for the catchment centroid.

Table 3-1 IFD parameters

2yr (50% AEP) 1hr rainfall intensity (mm/hr)	21.87
2yr (50% AEP) 12hr rainfall intensity (mm/hr)	5.48
2yr (50% AEP) 72hr rainfall intensity (mm/hr)	1.7
50yr (2% AEP) 1hr rainfall intensity (mm/hr)	45.47
50yr (2% AEP) 12hr rainfall intensity (mm/hr)	10.07
50yr (2% AEP) 72hr rainfall intensity (mm/hr)	3.24
Skew	0.31
F2	4.24
F50	15.25

Comparisons were made with the new IFDs developed for Project 1 of the ARR Revision Project (<http://www.bom.gov.au/water/designRainfalls/revised-ifd/>). On average the new IFD parameters were around 5% lower than AR&R (1987) (for 1%-10% AEP events), with some AEP/Duration values up to 22% lower.

The 1987 IFD parameters were adopted to be consistent with existing methods for determining areal reduction factors, design losses and hydrologic parameter estimates, which were developed with the older IFD information.

Unfiltered temporal patterns from ARR (1987) for Zone 1 were applied for the design events, as recommended in Hill et al. (1998) for use with their design losses. Rainfall depths were applied uniformly across the catchment.

Areal reduction factors from Siriwardena and Weinmann (1996) were applied to the point design rainfall estimates. These areal reduction factors are recommended for use in Victoria instead of the original ARR values (Hill et al. 1998). These have now been recommended for adoption in the ARR Project 2 Stage 2 report (2013).

3.4 Gauge Review

Five streamflow gauges currently operate in the catchment, while historic data is also available for four other gauges (Table 3-2). Of the currently operating gauges, Valencia Creek at Gillio Road, Avon River at The Channel and Freestone Creek at Briagolong gauges record streamflow at the three largest upstream tributaries that are to be mapped. Downstream gauges at Stratford and Clydebank include 90% and 96% of the Avon River catchment, respectively. The Avon River at Stratford gauge is located in the best location for model calibration, as it is downstream of all large tributaries and has a high quality gauging record. The gauge is also situated adjacent to the township of Stratford, a critical location with respect to flood mapping. The Avon River at The Channel, Valencia Creek at Gillio Road and Freestone Creek at Briagolong gauges were also used to calibrate the hydrologic model. A flood frequency analysis was undertaken at all four of these gauges to verify the design flows generated by the hydrologic model. The hydrologic model is not limited by issues with the stage-discharge relationship at the downstream gauge at Clydebank, which hindered the effectiveness of flood frequency analysis at the gauge, discussed further in Section 3.5.

Table 3-2 Streamflow gauges in Avon River catchment

Gauge No.	Location	Period	Years	Catchment Area (km²)
225223	Valencia Creek @ Gillio Road	1971 - 2015	35	195
225224	Avon River @ The Channel	1972 - 2015	34	554
225201	Avon River @ Stratford	1976 - 2015	38	1485
225218	Freestone Creek @ Briagalong	1967 - 2015	49	309
225234	Avon River @ Clydebank	1977 - 2015	39	1584
225255	Avon River U/S of Valencia Creek Junction	2004 - 2012	9	-
225211	Avon River @ Buxton	1953 - 1972	20	580
225220	Valencia Creek @ Radettis	1967 - 1971	5	233
225205	Avon River @ Valencia Creek	1919 - 1964	46	862

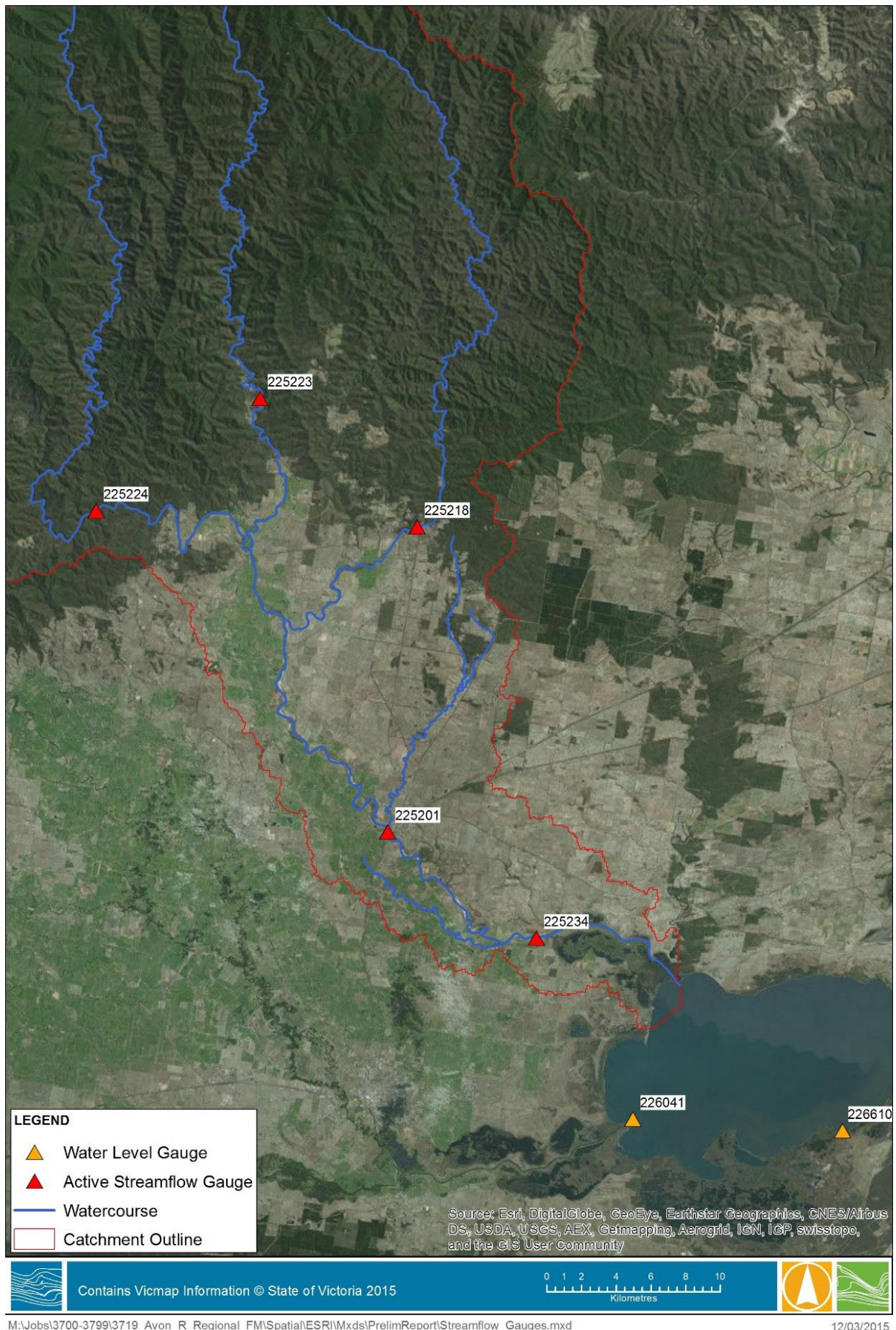


Figure 3-2 Streamflow and water level gauges in the Avon River catchment

3.4.1 Avon River at Stratford

The Avon River at Stratford gauge (225201) has 38 years of instantaneous flow data. The rating for the current gauge is officially considered reliable up to flows of 2,500 m³/s, with a large number of physical gauging measurements showing low scatter for high flow events (greater than 10 m³/s), as shown in Figure 3-3, and the gauged flows are generally lower than the equivalent rating curve estimates. Low flow estimates (less than 10 m³/s) show considerable scatter, likely due to the influence of Lake Wellington and the geomorphologic change of the river since the first gauging in 1908.

Consultations with the current hydrographer of the Avon basin suggest the gauging relationship at Stratford has been evolving for quite some time, likely due to channel change, however this has progressed in a discrete manner and is reflected in the flow estimates for the gauge (Wayne Ross pers. comm., 2015).

The long term water level record (Figure 3-5) was also reviewed and it was found that following the 1990 event, gauged levels were elevated, even during low flow periods, for a number of years. The low flow water level, after suddenly increasing in 1990, showed signs of settling back to pre-1990 levels until 1998 where the low flow level again increased after a major flood. The same trend continued after the 2007 flood. This is indicative of sand accretion in the channel after the 1990 event. The 1990 rating curve had a lower predicted flow for a given water level than the rating curve used in 1998, and the same trend continues between 1998 and later years gauging.

Based on this review, it is considered the flow estimates at the Stratford gauge have a low reliability for low flow conditions, and moderate reliability for high flows.

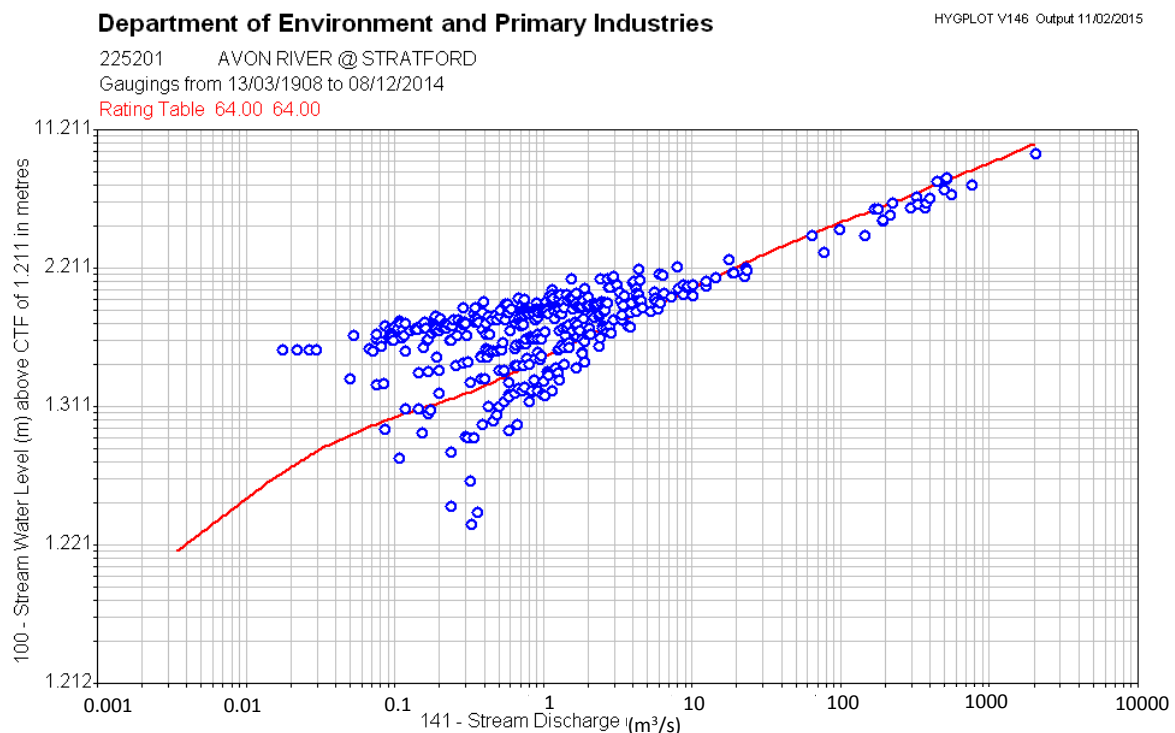


Figure 3-3 Rating Curve for Avon River @ Stratford (225201)

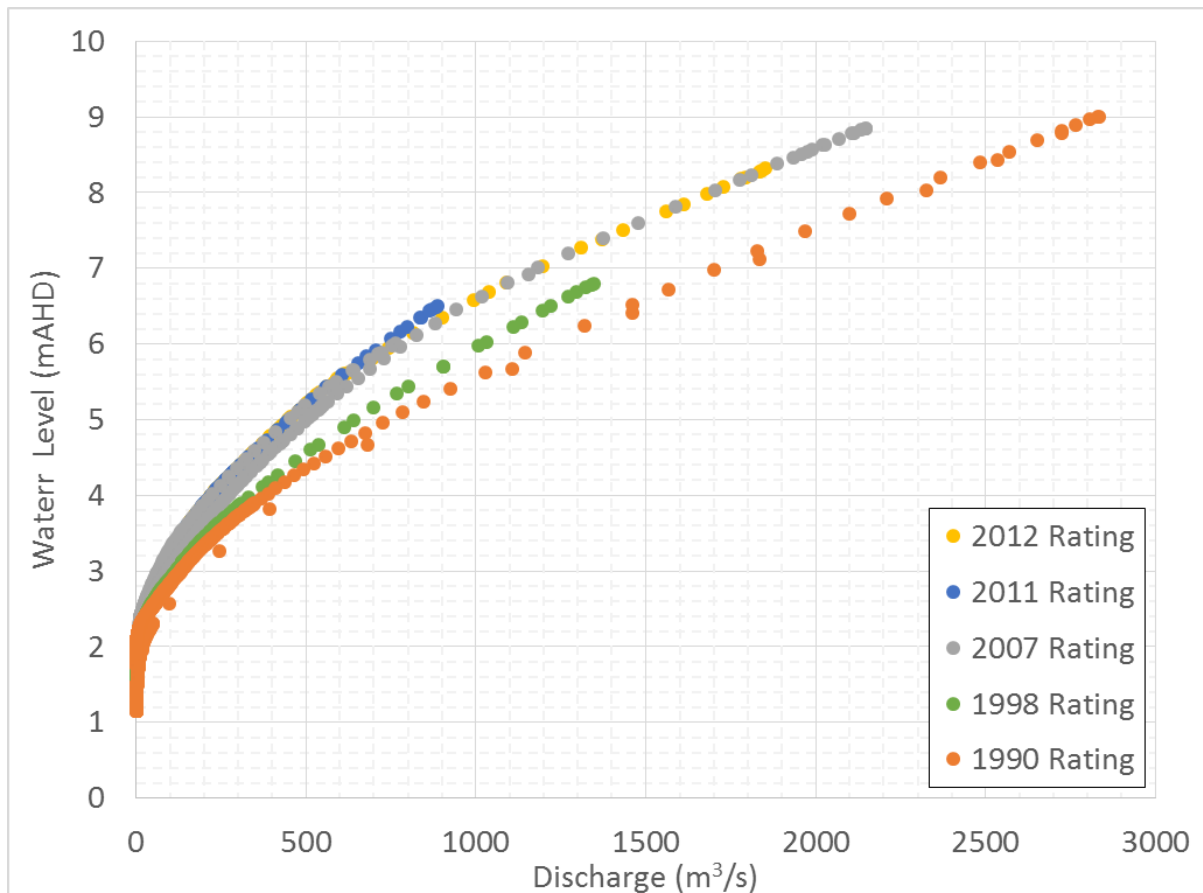


Figure 3-4 Water Level vs. Discharge Plot for Avon River @ Stratford (225201) showing variation in rating curves for selected periods of record

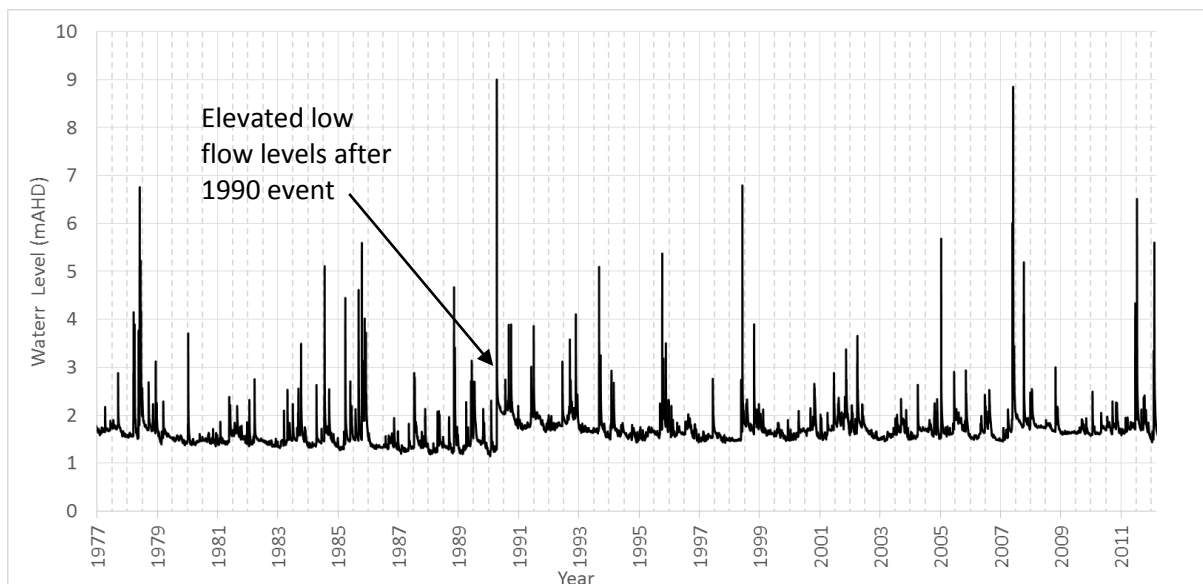


Figure 3-5 Avon River at Stratford Gauge Levels

3.4.2 Avon River at The Channel

The Avon River at The Channel gauge (225224) has 34 years of flow data from 1972-2015. The rating curve at the upper end is based on a small number of high and low flow gauging measurements with low scatter (Figure 3-6), and is therefore expected to be reliable for estimating flows in the upper Avon.

The rating for the current gauge is officially considered reliable up to flows of 360 m³/s, with larger values being extrapolated. However, this extrapolation appears to follow a consistent trend and is considered reliable for calibration, where flows reach up to approximately 1000 m³/s. Without gaugings in this extrapolated region the rating curve was used with caution.

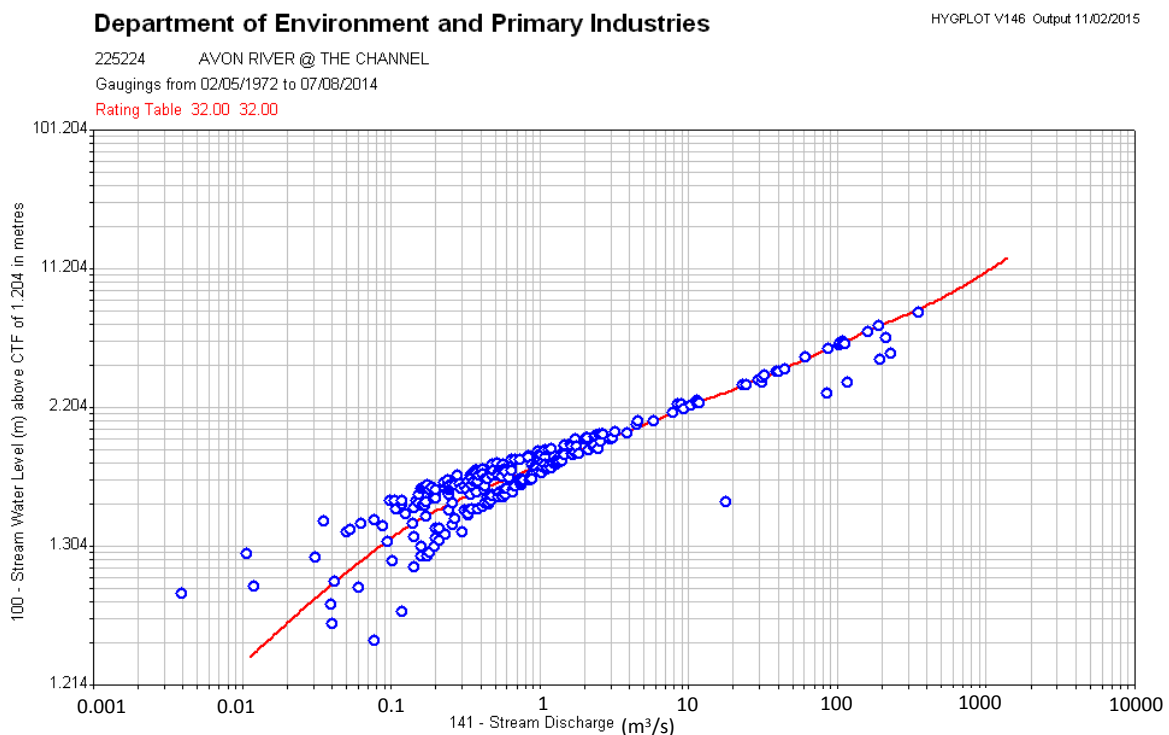


Figure 3-6 Rating Curve for Avon River at The Channel (225224)

3.4.3 Valencia Creek at Gillio Road

The Valencia Creek at Gillio Road gauge (225223) has 35 years of flow data from 1971-2015. The rating curve at the upper end is based on a small number of flow gauging measurements with very little scatter (Figure 3-7), and is therefore expected to be reliable for estimating flows in the Valencia Creek catchment.

The rating for the current gauge is officially considered reliable up to flows of 210 m³/s, with larger values being extrapolated. However, this extrapolation appears to follow a consistent trend and is considered reliable for calibration, where flows reach up to approximately 350 m³/s. Without gaugings in this extrapolated region the rating curve was used with caution.

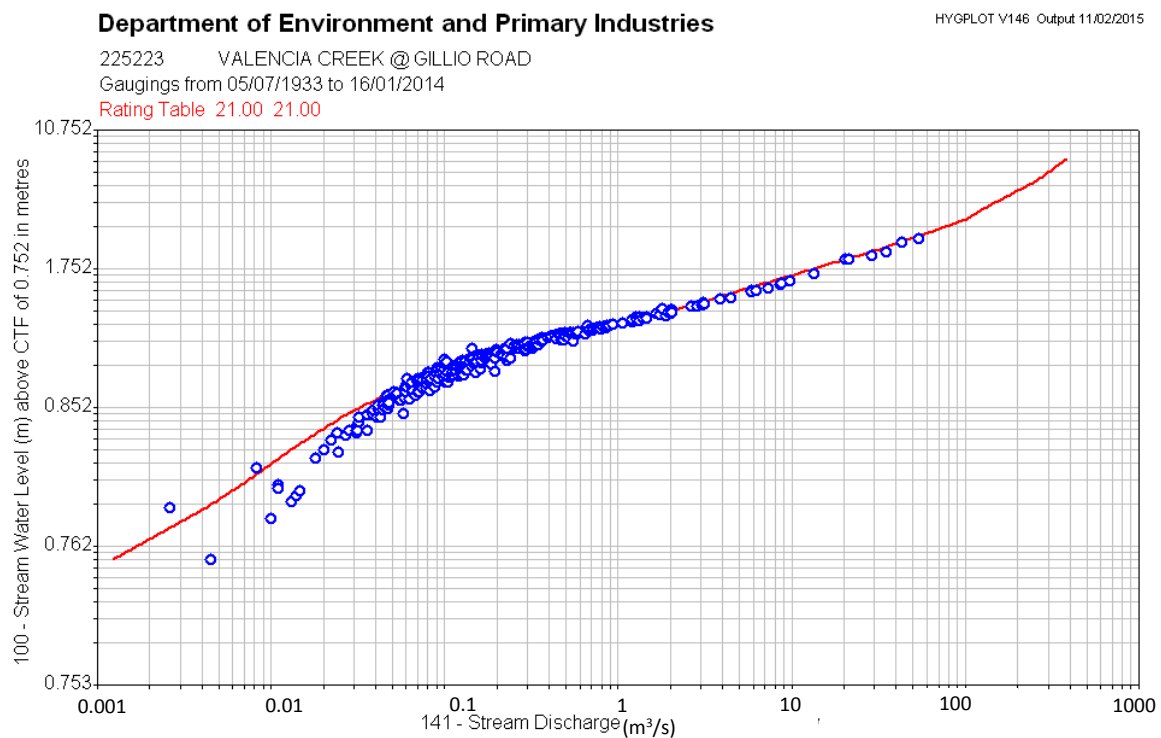


Figure 3-7 Rating Curve for Valencia Creek at Gillio Road (225223)

3.4.4 Freestone Creek at Briagolong

The Freestone Creek at Briagolong gauge (225223) has 49 years of flow data from 1967-2015. The rating curve at the upper end is based on a small number of flow gauging measurements with very little scatter (Figure 3-8), and is therefore expected to be reliable for estimating flows in the Freestone Creek catchment.

The rating for the current gauge is officially considered reliable up to flows of 125 m³/s, with larger values being extrapolated. However, this extrapolation appears to follow a consistent trend and is considered reliable for calibration, where flows reach up to approximately 650 m³/s. Without gaugings in this extrapolated region the rating curve was used with caution.

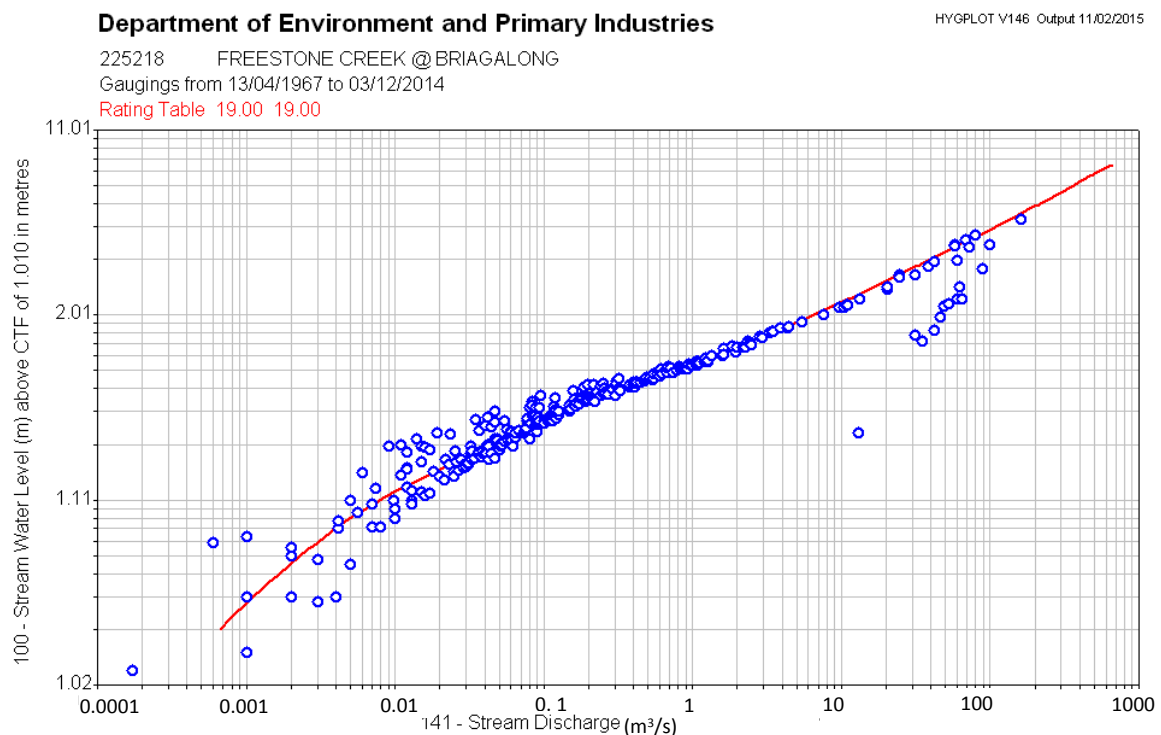


Figure 3-8 Rating Curve for Freestone Creek at Briagolong (225218)

3.4.5 Avon River at Clydebank

The Avon River at Clydebank gauge (225234) has 39 years of flow data from 1977-2015. The rating curve is based on many low flow gauging measurements with considerable scatter (Figure 3-9).

Clydebank does not have high flow readings within the calibration flow range (up to approximately 2000m³/s). The rating curve for Avon River at Clydebank has a highest gauging of 1.725 m (approximately 13m³/s). There are a number of issues associated with stage-discharge relationships at Clydebank. Whilst the gauge is on the Avon River, during high flow events wetlands on either side of the river are activated, causing multiple flow paths across the floodplain separate to the Avon River flow path. Clydebank is also close to the Avon River outlet at Lake Wellington, which has been shown to vary with a number of factors including atmospheric conditions, wind conditions, tides and recent amount of discharge into the lake (Brizga et al., 2013). Due to the uncertainty in the stage-discharge relationship for high flows at Clydebank, the flow values will not be used for calibration. However, downstream water levels will be able to be validated in the hydraulic model based on the recorded Clydebank water levels.

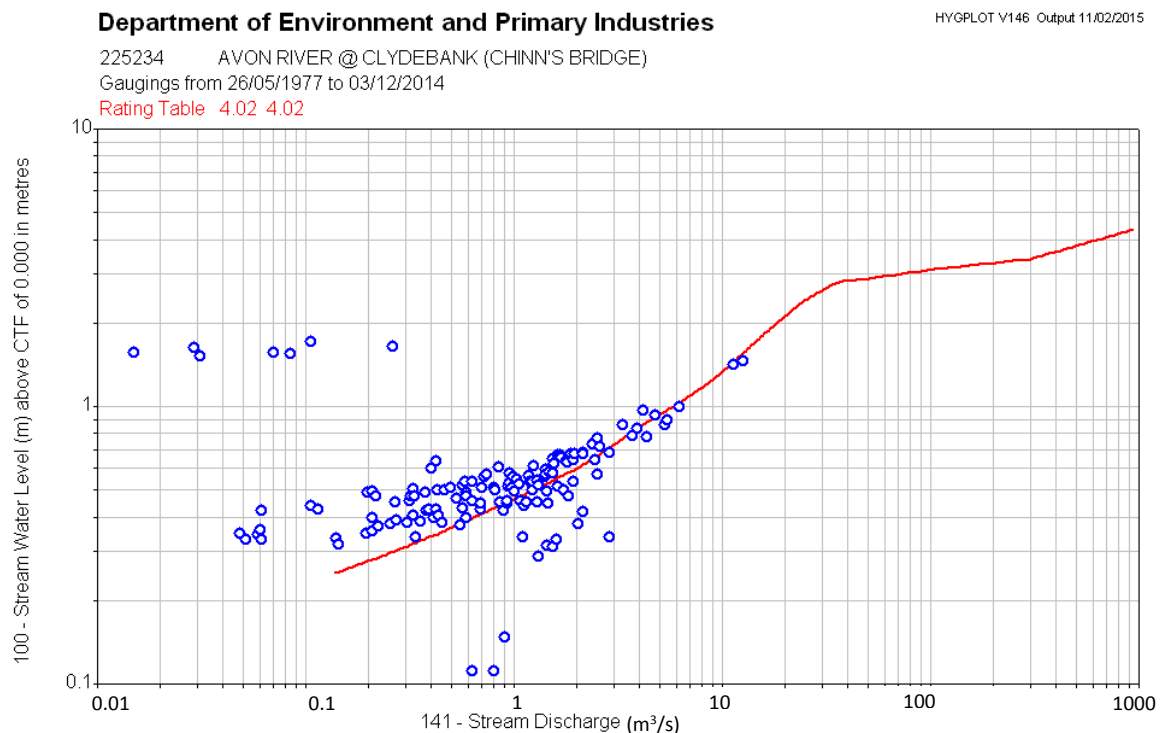


Figure 3-9 Rating Curve for the Avon River at Clydebank (225234)

3.4.6 Lake Wellington at Bull Bay

Water levels in Lake Wellington are recorded at the Bull Bay gauge site (226041), with data available from 1975 to present, with a number of data gaps. As detailed in Brizga et al (2013) the data between 1975 and 1988 was collected by Latrobe Valley Water over the period 1975 to 1988 and was digitised for the Latrobe Environmental Flows project (Brizga et al, 2013). The resolution of the digitised additional data was typically 1-2 hours, with a level resolution of 0.01 m or better. The more recent data is available at 15 minute intervals with a similar level of resolution.

The water level in Lake Wellington is comprised of both tidal and non-tidal components, with the dominant forcing factor being the effect of changes in atmospheric pressure and wind. An example from Brizga et al (2013) of the relative impacts of weather and tides on water levels in Lake Wellington is shown in Figure 3-10.

The observed water level in Lake Wellington has a range of around 0.5 m over the 6 month period shown (Aug 2010 – Jan 2011). The tidal component is at most only ± 0.03 m whereas storm surge is the dominant water level control, raising water levels for extended periods. Over the period shown, the change in water level due to atmospheric changes associated with low pressure weather systems is in the order of 0.5 m. The effect of wind set-up (and set-down) is less pronounced (around ± 0.1 m) and occurs over shorter, daily time scales but has an important role in internal circulation processes such as the mixing and transport of saline water, particularly for shallow areas such as Lake Wellington. Variations in water levels also occur on a seasonal basis, and levels are also affected by the strength of the southern oscillation index.

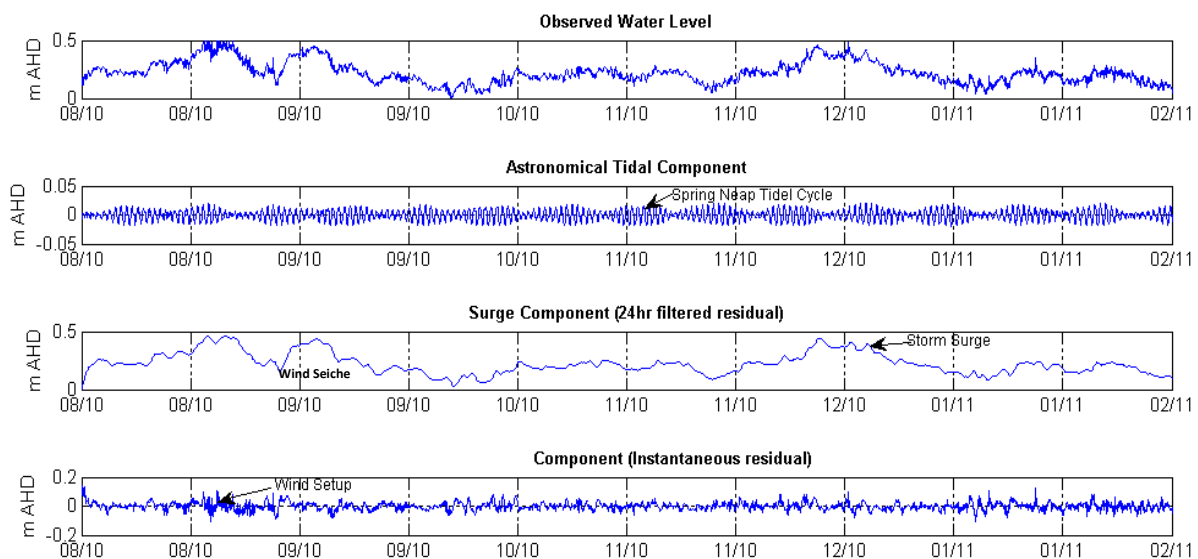


Figure 3-10 Example of relative impacts of weather and tide on water levels in Lake Wellington

3.4.7 Flood Class Levels

The Bureau of Meteorology provides flood forecasting and flood warning services for the Avon River. Flood watches are issued when the combination of forecast rainfall and other hydrological conditions indicate there is a potential risk of flooding. Flood warnings are then issued to advise that flooding is occurring or is expected to occur based on defined criteria. These criteria are the flood classes defined as minor, moderate, or major at specific gauging station locations along the river. On the Avon, flood classes are defined at The Channel and at the Stratford gauge sites.

The definition for different flood classes is summarized in Table 3-3, while the flood class values on the Avon River are detailed in Table 3-4. The height shown for each flood class level is based on the gauge data and is the water level above the gauge zero. At Stratford the gauge zero is 0 m AHD, while at The Channel the gauge zero is 72 m AHD. The flow magnitude associated with the flood class level has been estimated for each site based on the current gauge rating curve.

Table 3-3 Bureau of Meteorology Flood Class Definitions

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

Table 3-4 Flood Classes on the Avon River

Gauge Station	Minor		Moderate		Major	
	Height (m)	Flow (m ³ /s)	Height (m)	Flow (m ³ /s)	Height (m)	Flow (m ³ /s)
Avon River at the Channel	5.00	213	6.90	507*	7.50	604*
Avon River at Stratford	4.50	332	6.00	761	6.50	962

* Flow values for heights above 6.0 m have been extrapolated

3.5 Flood Frequency Analysis

3.5.1 Overview

Flood frequency analysis (FFA) allows the estimation of peak flows of selected Annual Exceedance Probability (AEP) events based on a statistical analysis. FFA was undertaken for the Avon River at The Channel, Avon River at Stratford, Valencia Creek at Gillio Road and Freestone Creek at Briagolong gauges.

Hydrographs extracted from the hydrologic model at the Avon River at The Channel, Freestone Creek at Briagolong and Valencia Creek at Gillio Rd gauges are to be used as direct inflows to the hydraulic model. It was therefore considered Important to validate calibrated losses at these gauges with flood frequency analysis.

The FFA was undertaken on the annual flow series from the gauge records using the analysis program FLIKE, as recommended in the updated ARR guidelines. FLIKE uses a Bayesian approach to parameter fitting (either the Global Probabilistic or Quasi-Newton fitting algorithms) to the records in order to assess the return period of different magnitude flows. There are a number of probability distributions which can be used to undertake an FFA, including the Log Pearson III, Log-Normal, Generalised Pareto, Generalised Extreme Value and Gumbel distributions and a selection of these are applied in the analysis, with the 'best fit' distribution adopted in the final assessment.

The Avon River flow series showed that highest flows have previously occurred in winter and spring (June – October). The flow series analysis therefore assumed that the flow year started in March.

3.5.2 Gauge Relationships

Gauge relationships between each upstream gauge (Avon River at The Channel, Valencia Creek at Gillio Rd and Freestone Creek at Briagolong) and the Stratford Gauge have been developed in order to extend the length of records available for the flood frequency analysis at each site. Generally the Stratford gauge has a reliable historic data, although data was missing for the 1971 flood. The water level at the Stratford gauge is also directly affected by all upstream inflows, and is therefore likely to have a more direct relationship with the upstream gauges than the upstream gauges have with each other. By using the relationship between each upstream gauge and the Stratford gauge, peak flows at the upstream site outside the available gauged record can be estimated and therefore improve the flood frequency analysis estimates.

Figure 3-11, Figure 3-12, and Figure 3-13 shows the relationship between the different upstream sites and the Avon River at Stratford. There is a strong correlation ($R^2 > 0.8$) between each upstream location and the flows at Stratford which is expected given the majority of runoff is generated in the upper catchment.

Annual maximums were used for these relationships under the assumption that large floods in each gauged tributary correlate with large floods at Stratford. Based on hydrologic calibration it has been noted that this is a general trend within the system.

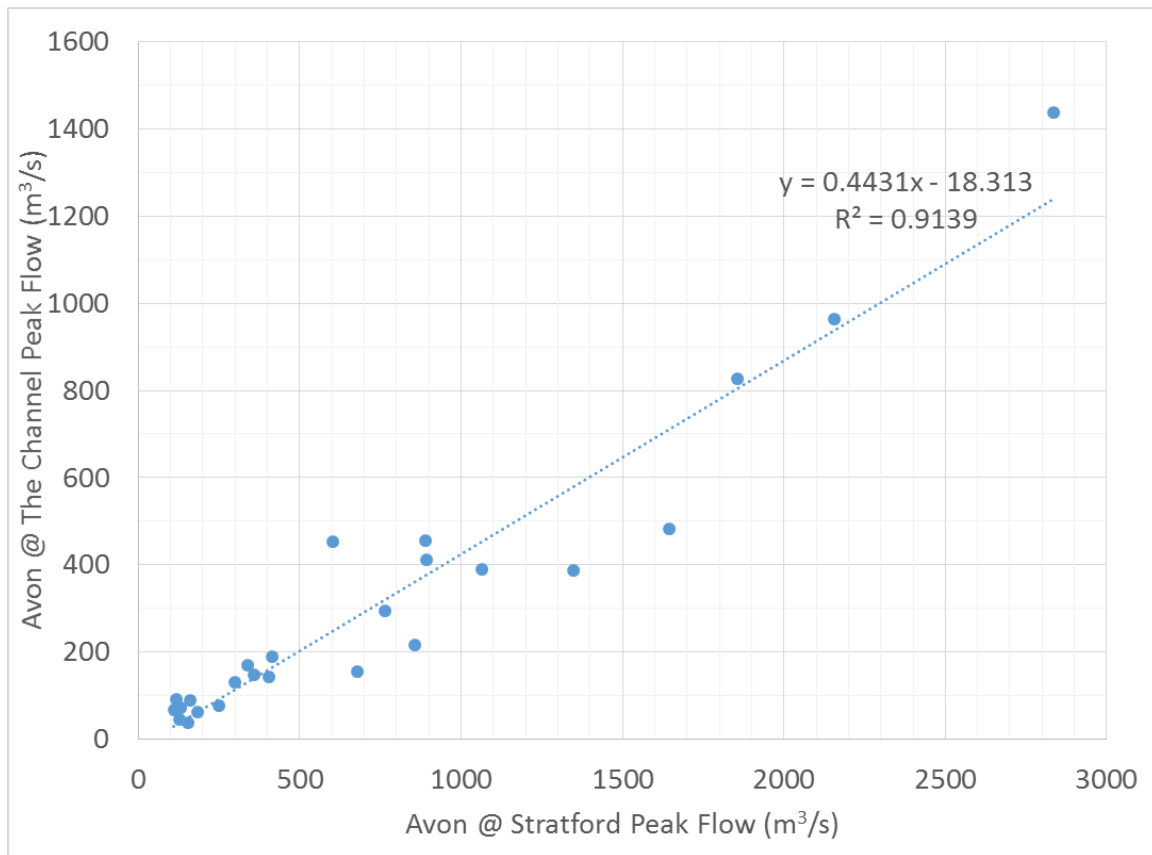


Figure 3-11 Relationship between Avon River at The Channel at Stratford

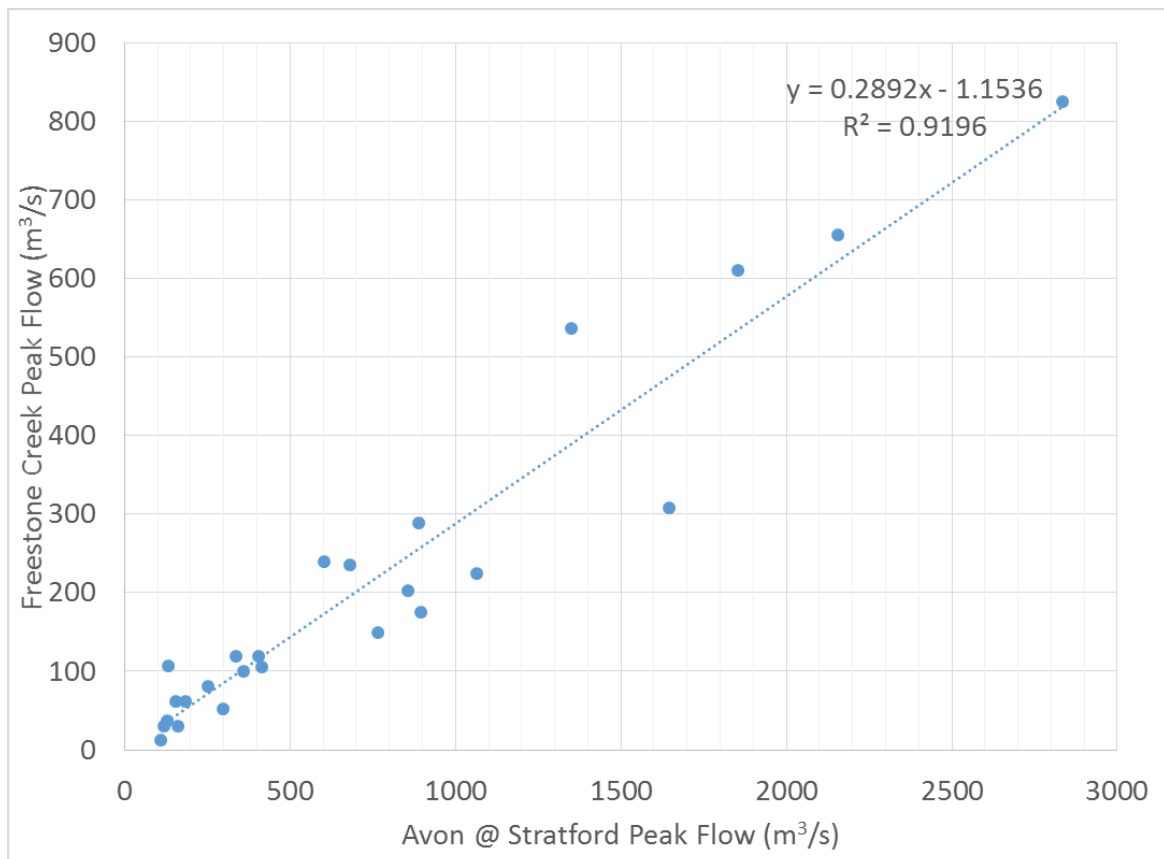


Figure 3-12 Relationship between Freestone Creek at Briagolong and Avon River at Stratford

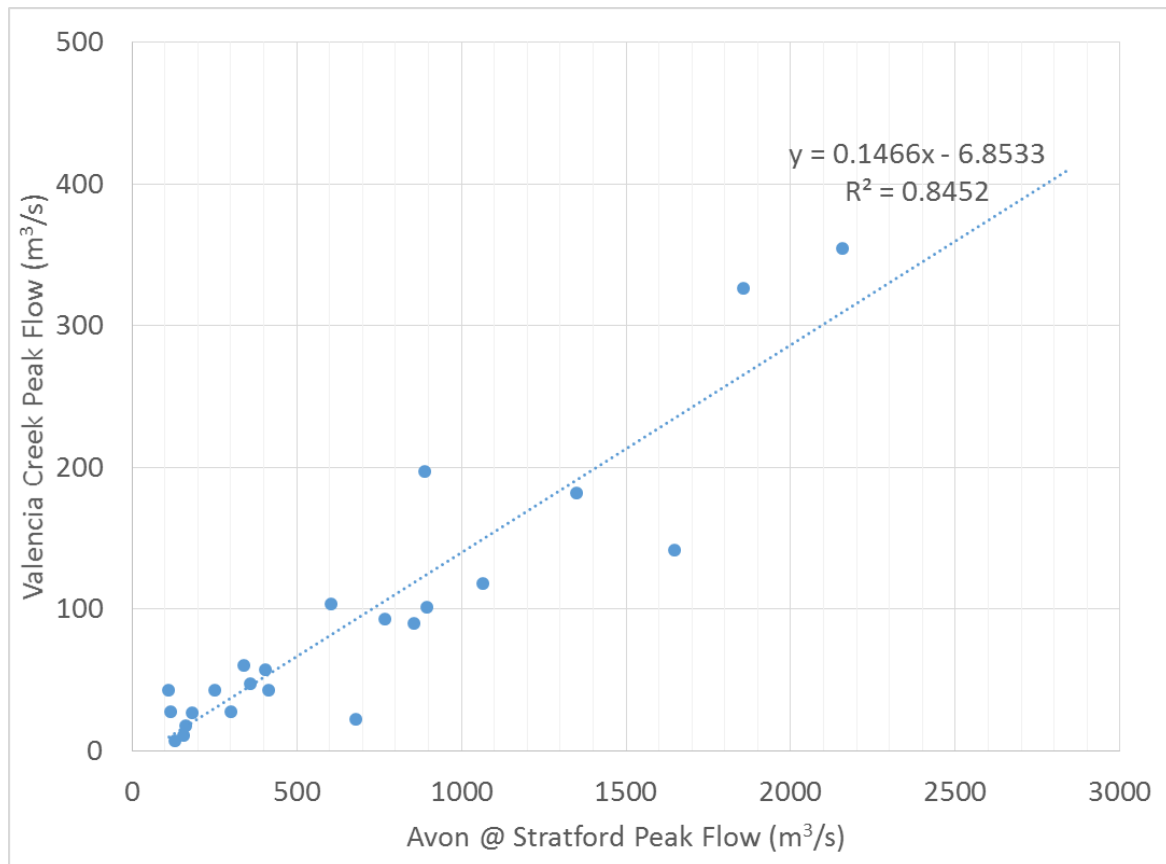


Figure 3-13 Relationship between Valencia Creek at Gillio Rd and Avon River at Stratford

3.5.3 Avon River at Stratford

Annual maximum flows were extracted from the gauge record for Avon River at Stratford (225201) and are listed in Table 3-5. The 1936 and 1950 flood peaks were recovered from historic documents whilst the 1971 flood was estimated based on scaling from Freestone Creek as described in Section 3.5.2.

Table 3-5 Summary of annual peak flows for Avon River at Stratford

Year	Max Flow (m ³ /s)	Year	Max Flow (m ³ /s)	Year	Max Flow (m ³ /s)
1936	2000*	1988	679.9	2002	250.9
1950	1650**	1989	118.5	2003	20.8
1971	2080***	1990	2834.5	2004	27.5
1977	155.1	1991	338.0	2005	603.5
1978	1645.5	1992	413.7	2006	22.4
1979	40.8	1993	766.2	2007	2156.0
1980	358.3	1994	110.9	2008	94.0
1981	54.9	1995	894.6	2009	3.7
1982	129.4	1996	29.5	2010	30.6
1983	298.9	1997	82.4	2011	889.4
1984	856.4	1998	1349.2	2012	1854.8
1985	1064.8	1999	12.3	2013	404.6
1986	13.3	2000	58.6	2014	132.4
1987	161.5	2001	183.7		

*From Strom, 1937

** From Macintyre & Grant, 1950

*** Estimated based on Freestone Creek @ Briagolong Gauge Value

A number of reports of historic flooding were found, however they lacked sufficient quantitative evidence to include in the flood frequency analysis. A censored flood peak threshold was included in the flood frequency analysis based on anecdotal information as summarised in Table 3-6.

Table 3-6 Treatment of historic flood peak threshold (Avon River at Stratford)

Threshold (m ³ /s)	Peaks above threshold	Peaks below threshold
2000	1	111 (1936 flood largest between settlement in 1865 and start of gauging in 1977)

'Censored flood peaks' allow indirect flow estimates to be included as quantitative values in flood frequency estimation. The censored flood peak in Table 3-6 refers to the fact that while we don't know the exact magnitude of the 1936 flood, we do know it was greater than 2000m³/s. We also know that there were no floods bigger than this one between 1865 and 1977, so there is 111 years of unrecorded flows that there was less than 2000m³/s peak flow for the year. The inclusion of this unrecorded data increases the statistical accuracy of flow estimates.

The results of the FFA are shown in Figure 3-14 and Table 3-7. They show a 1% AEP flow estimate of 2,798 m³/s with 5-95% confidence limits of 2,181 to 4,184 m³/s. These confidence limits are considered reasonable based on experience with other FLIKE analyses.

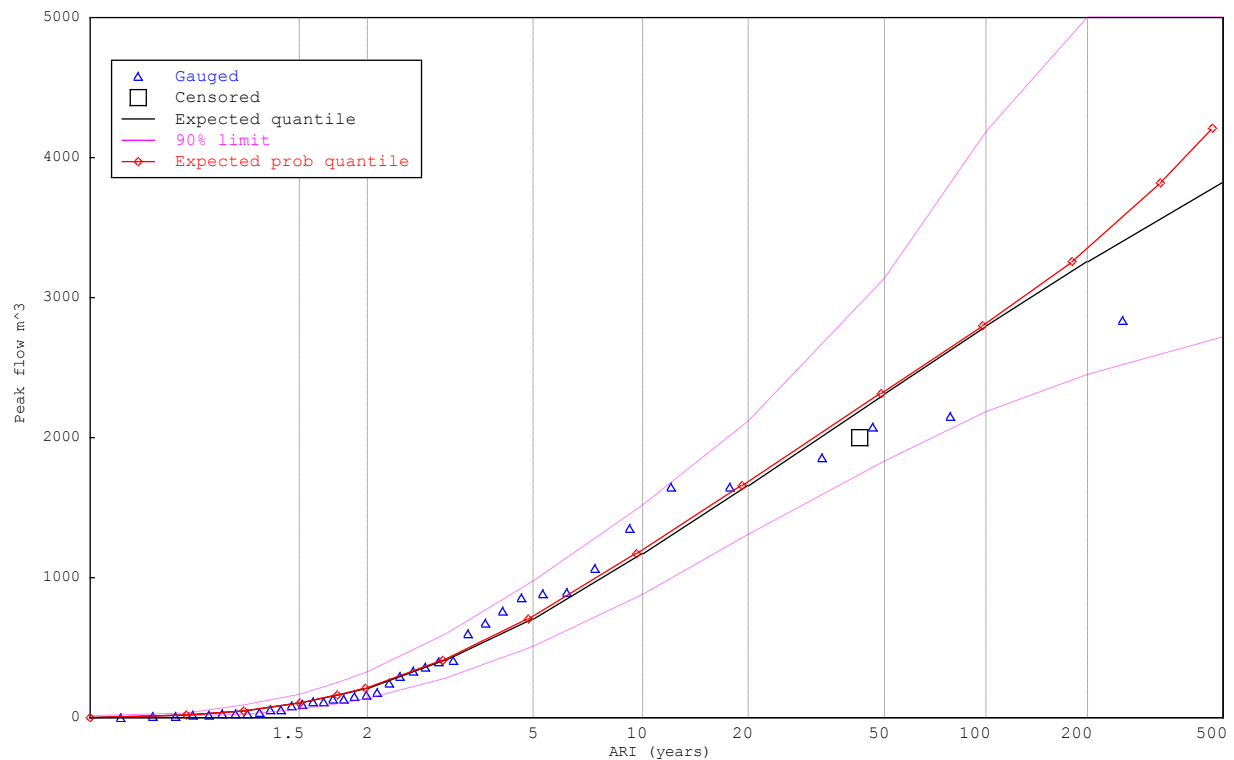


Figure 3-14 Log Pearson III distribution fitted to annual series for Avon River at Stratford (with historic information included)

Table 3-7 FFA Peak Flow Estimates for Avon River at Stratford

AEP	Peak Flow Estimate (m ³ /s)	
	Log Pearson III	5-95% Confidence Limits
20%	709	(501 – 972)
10%	1168	(878 – 1514)
5%	1658	(1301 – 2114)
2%	2316	(1832 – 3132)
1%	2799	(2181 – 4184)
0.5%	3258	(2452 – 5488)
0.2%	3820	(2719 – 7453)

Comparison to Previous Estimates

Estimates of peak flows from previous studies by SKM (2003) and Alluvium (2013) are shown in Figure 3-15.

The SKM (2003) estimate aligns well within the 5% confidence limits of the FFA, with design flow values approximately 20% higher on average. SKM's (2003) flood frequency analysis used a partial series

focussing on small (10% AEP and smaller) events. As the partial series does not have historic information included, has 11 less years of data, and uses older flood frequency techniques, the current analysis is considered more appropriate.

Alluvium's (2013) estimate is also within the 5% confidence limits for the FFA. Alluvium's design flow estimate included a partial and annual series based on flow data between 1976 and 2012. Almost identical flow data is being used between the two analyses, however the FFA has included historic floods. This higher degree of certainty has allowed for lower flow estimates in the larger events.

The current FFA with historic information included is broadly consistent with previous work, however it provides more credible estimates than the previous analyses, as it includes much more gauged data than the 2003 analysis, as well as historical information on flooding prior to gauge records (which was not included in the 2012 analysis). The current analysis also makes use of improved flood frequency methods within FLIKE as recommended by the current Australian Rainfall and Runoff review (Kuczera, 2014).

The current Australian Rainfall and Runoff review has developed a new regional flood frequency estimate (RFFE) which was used to compare Avon River flows to regional methods, called the Australian Regional Flood Frequency Model (ARFF). The ARFF estimates for peak flows were considerably lower than that which was estimated using FLIKE. In this data rich catchment, the FLIKE analysis is considered much more reliable than methods based on regional parameters.

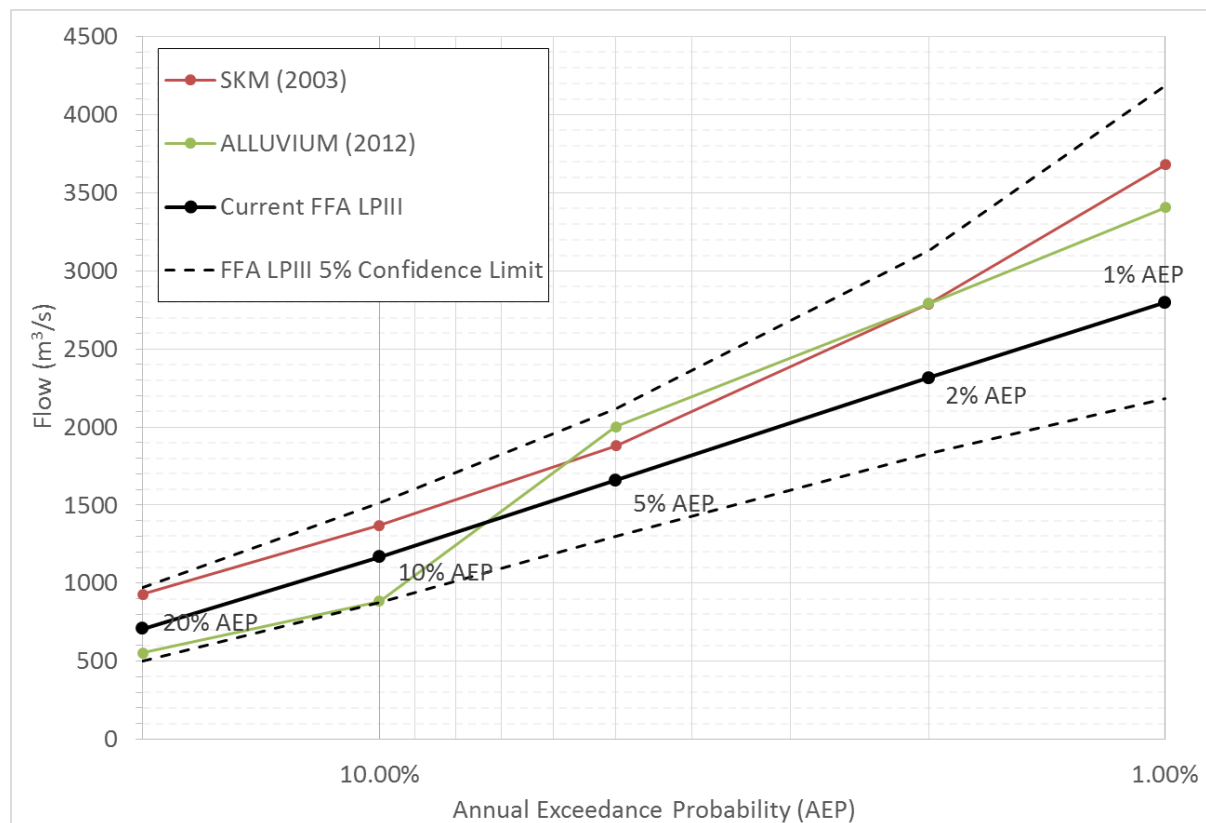


Figure 3-15 Comparison of Peak Flow Estimates

Table 3-8 RFFE Flow Estimates and previous Flood Frequency Estimates for Stratford gauge

AEP	Peak Design Flow (m ³ /s) (SKM, 2003)*	Peak Design Flow (m ³ /s) (Alluvium, 2013)	ARFF Design Flow Estimate		
			Design Estimate (m ³ /s)	Upper Confidence Limit (m ³ /s)	Lower Confidence Limit (m ³ /s)
20%	930	552	241	539	109
10%	1370	884	337	761	150
5%	1880	2001	434	994	189
2%	2790	2793	566	1321	242
1%	3680	3407	666	1565	280

*Results were estimated from the graph provided as a data table was not supplied in report

3.5.4 Avon River at The Channel

Annual maximum flows were extracted from the gauge record for Avon River at The Channel (225224) and are listed in Table 3-9. The 1936, 1950 and 1971 flood peaks were estimated based on scaling from Stratford as described in 3.5.2.

Table 3-9 Summary of annual peak flows for Avon River at The Channel

Year	Max Flow (m ³ /s)	Year	Max Flow (m ³ /s)	Year	Max Flow (m ³ /s)
1936	868*	1985	389.8	2000	30.8
1950	715*	1986	6.4	2001	63.1
1971	905*	1987	90.3	2002	76.7
1973	25.7	1988	155.5	2003	13.8
1974	284.6	1989	91.4	2004	7.3
1975	242.8	1990	1437.7	2005	453.1
1976	263.7	1991	170.7	2006	17.2
1977	38.9	1992	190.9	2007	962.5
1978	483.7	1993	294.0	2008	42.9
1979	34.5	1994	67.6	2009	7.2
1980	147.1	1995	411.6	2010	30.1
1981	18.6	1996	17.8	2011	455.0
1982	46.4	1997	70.3	2012	827.8
1983	131.9	1998	387.0	2013	143.2
1984	217.7	1999	5.3	2014	72.8

* Estimated based on Avon River @ Stratford Flow

A censored flood peak was included in the flood frequency analysis based on anecdotal information as summarised in Table 3-10.

Table 3-10 Treatment of historic flood peak threshold (Avon River at The Channel)

Threshold (m ³ /s)	Peaks above threshold	Peaks below threshold
870	1	105 (1936 flood largest between settlement in 1865 and start of gauging in 1973)

The results of the FFA are shown in Figure 3-16 and Table 3-11. They show a 1% AEP flow estimate of 1,309 m³/s with 5-95% confidence limits of 959 to 2,089 m³/s. These confidence limits are considered reasonable based on experience with other FLIKE analyses.

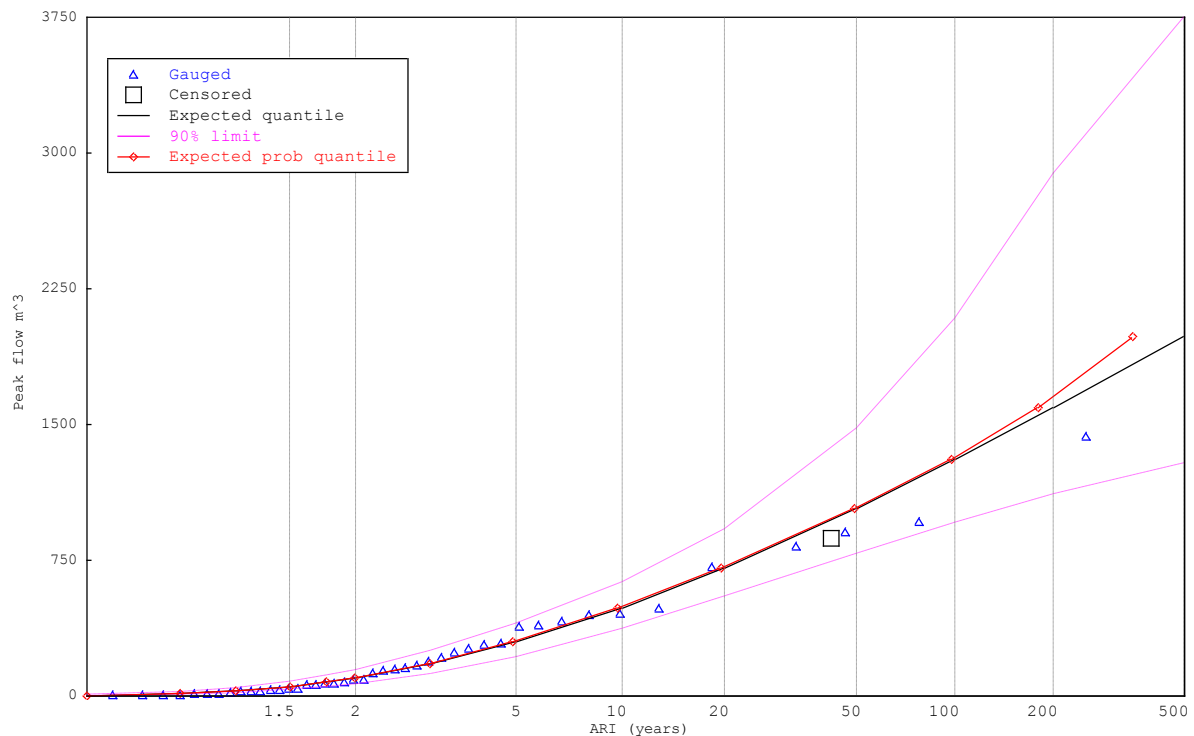


Figure 3-16 Log Pearson III distribution fitted to annual series for Avon River at The Channel (with historic information included)

Table 3-11 FFA Peak Flow Estimates for the Avon River at The Channel

AEP	Peak Flow Estimate (m ³ /s)	
	Log Pearson III	5-95% Confidence Limits
20%	297	(215 – 398)
10%	488	(370 – 631)
5%	709	(549 – 924)
2%	1038	(788 – 1479)
1%	1309	(959 – 2089)
0.5%	1593	(1113 – 2886)
0.2%	1986	(1283 – 4313)

3.5.5 Valencia Creek at Gillio Road

Annual maximum flows were extracted from the gauge record for Valencia Creek at Gillio Road (225223) and are listed in Table 3-12. The 1936, 1950, 1971 and 1990 flood peaks were estimated based on scaling from Stratford as described in Section 3.5.2.

Table 3-12 Summary of annual peak flows Valencia Creek at Gillio Road

Year	Max Flow (m ³ /s)	Year	Max Flow (m ³ /s)	Year	Max Flow (m ³ /s)
1936	286*	1985	117.8	2001	27.0
1950	235*	1986	2.4	2002	43.0
1971	298*	1987	17.9	2003	0.8
1972	0.4	1988	22.5	2004	2.5
1973	6.1	1989	27.5	2005	103.8
1974	122.7	1990	409**	2006	5.9
1975	16.2	1991	60.0	2007	354.7
1976	98.4	1992	42.8	2008	9.0
1977	10.6	1993	93.0	2009	1.3
1978	141.7	1994	43.0	2010	14.9
1979	5.6	1995	101.0	2011	197.1
1980	47.5	1996	2.5	2012	326.7
1981	5.6	1997	9.4	2013	57.3
1982	7.4	1998	181.8	2014	N/A***
1983	27.9	1999	1.4		
1984	90.0	2000	4.5		

* Estimated based on Avon River @ Stratford Flow

** Gauge washed away - estimated based on Avon River @ Stratford Flow

***Not enough data recorded in 2014.

A censored flood peak was included in the flood frequency analysis based on anecdotal information as summarised in Table 3-13.

Table 3-13 Treatment of historic flood peak threshold (Valencia Creek at Gillio Road)

Threshold (m ³ /s)	Peaks above threshold	Peaks below threshold
286	1	104 (1936 flood largest between settlement in 1865 and start of gauging in 1972)

The results of the FFA are shown in Figure 3-18 and Table 3-14. They show a 1% AEP flow estimate of 419 m³/s with 5-95% confidence limits of 316 to 670 m³/s. These confidence limits are considered reasonable based on experience with other FLIKE analyses.

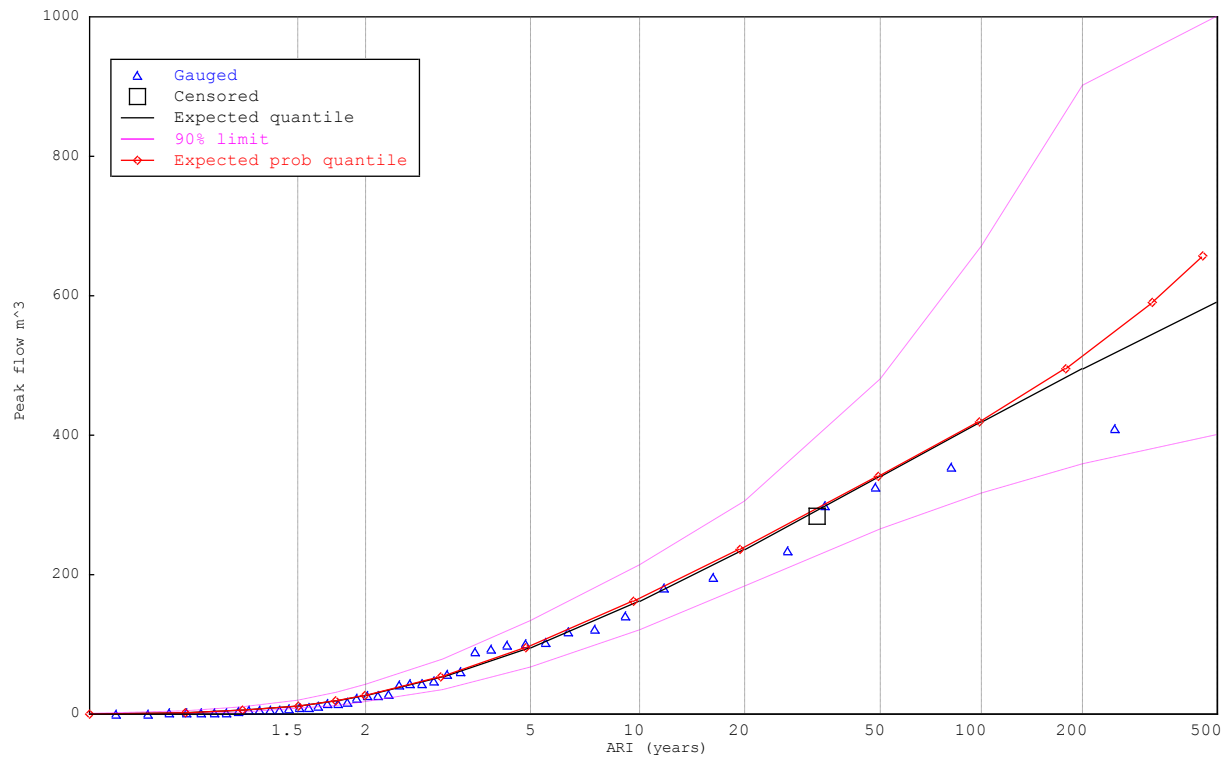


Figure 3-17 Log Pearson III distribution fitted to annual series for Valencia Creek at Gillio Road (with historic information included)

Table 3-14 FFA Peak Flow Estimates for Valencia Creek at Gillio Road

AEP	Peak Flow Estimate (m ³ /s)	
	Log Pearson III	5-95% Confidence Limits
20%	95	(66 – 133)
10%	162	(121 – 213)
5%	237	(184 – 305)
2%	340	(264 – 481)
1%	419	(316 – 670)
0.5%	495	(359 – 902)
0.2%	590	(400 – 1271)

3.5.6 Freestone Creek at Briagolong

Annual maximum flows were extracted from the gauge record for Freestone Creek at Briagolong (225218) and are listed in Table 3-15. The 1936 and 1950 flood peaks were estimated based on scaling from Stratford as described in Section 3.5.2.

Table 3-15 Summary of annual peak flows for Freestone Creek at Briagolong

Year	Max Flow (m ³ /s)	Year	Max Flow (m ³ /s)	Year	Max Flow (m ³ /s)
1936	577*	1983	51.7	2000	29.3
1950	475*	1984	203.2	2001	61.9
1968	54.4	1985	224.9	2002	80.8
1969	212.9	1986	11.3	2003	2.6
1970	337.5	1987	29.8	2004	50.4
1971	600.2	1988	234.9	2005	239.7
1972	0.6	1989	30.6	2006	7.5
1973	14.9	1990	824.9	2007	655.9
1974	169.7	1991	118.6	2008	93.4
1975	78.6	1992	104.8	2009	1.1
1976	108.0	1993	148.7	2010	17.1
1977	61.5	1994	13.0	2011	288.5
1978	308.5	1995	175.6	2012	610.8
1979	3.5	1996	4.9	2013	118.5
1980	99.6	1997	12.3	2014	107.2
1981	23.5	1998	535.8		
1982	36.5	1999	4.8		

* Estimated based on Avon River @ Stratford Flow

A censored flood peak was included in the flood frequency analysis based on anecdotal information as summarised in Table 3-16.

Table 3-16 Treatment of historic flood peak threshold (Freestone Creek at Briagolong)

Threshold (m ³ /s)	Peaks above threshold	Peaks below threshold
577	1	101 (1936 flood largest between settlement in 1865 and start of gauging in 1968)

The results of the FFA are shown in Figure 3-18 and Table 3-17. They show a 1% AEP flow estimate of 781 m³/s with 5-95% confidence limits of 633 to 1,085 m³/s. These confidence limits are considered reasonable based on experience with other FLIKE analyses.

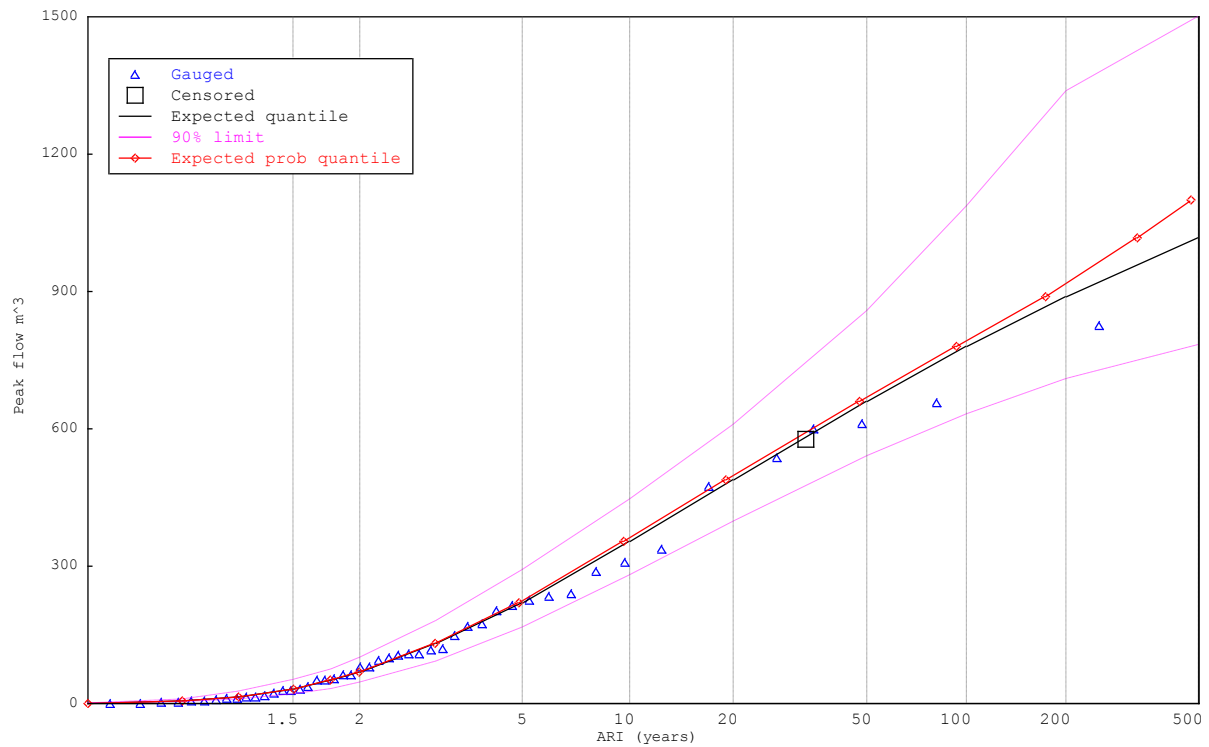


Figure 3-18 Log Pearson III distribution fitted to annual series for Freestone Creek at Briagolong (with historic information included)

Table 3-17 FFA Peak Flow Estimates for Freestone Creek at Briagolong

AEP	Peak Flow Estimate (m³/s)	
	Log Pearson III	5-95% Confidence Limits
20%	221	(166 – 291)
10%	354	(279 – 446)
5%	489	(397 – 608)
2%	661	(541 – 857)
1%	781	(633 – 1085)
0.5%	890	(707 – 1338)
0.2%	1016	(783 – 1698)

3.6 Hydrologic Modelling

3.6.1 Overview

A hydrological model of the catchment was developed for the purpose of extracting design flows to be used as boundary conditions in the Avon River hydraulic model. The rainfall-runoff program, RORB (Version 6) was used for this study.

RORB is a non-linear rainfall runoff and streamflow routing model which is used for calculation of flow hydrographs in drainage and stream networks. The model requires catchments to be divided into subareas, connected by a series of conceptual reach storages. Design storm rainfall is input to the centroid of each subarea. Specified losses are then deducted, and the excess routed through the reach network.

There are four streamflow gauges within the catchment which were used to calibrate the RORB model. The Avon River gauge at Stratford has 38 years of flow records from 1976-2015, covering the 2007, 2011 and 2012 floods and other smaller floods. The Avon River at The Channel, Freestone Creek at Briagolong and Valencia Creek at Gillio Road all have a similar period of record, and rating curves with a similar level of confidence. Parameter selection was based on calibration to all four gauges and comparison to accepted regional methods, and the design flows were validated against the flood frequency analysis. The approach for the selection of routing and loss parameters is outlined in the following sections

3.6.2 RORB Model Development

The ArchHydro tool was used to determine the initial delineation of catchments, sub-catchments and drainage paths of the Avon River for input to the hydrologic model (Figure 3-19). The catchment was split into 82 sub-catchments with areas ranging from 1.6 to 70.4 km². A RORB model was then constructed of the catchment using miRORB (MapInfo RORB tools).

The RORB model was at a resolution adequate to resolve the main drainage paths and sub-catchments, and to provide smooth hydrographs for the hydraulic model. This meant the relatively minor catchments of Blackall Creek and Nuntin Creek generally required much smaller subcatchments than the main streams to be adequately resolved for the hydraulic model. The large variance in subarea size meant that catchment routing parameters could not be expected to remain uniform as in traditional RORB models. 'Interstation areas' were therefore introduced at the downstream end of Blackall Creek, and at Boisdale near Nuntin Creek drain, which allow for scaled catchment routing parameters to be adopted in these catchments with small sub-catchment areas. These areas have adopted the same losses as the calibrated upstream areas.

Interstation areas are also included at each gauge. This allows independent calibration of each gauge.

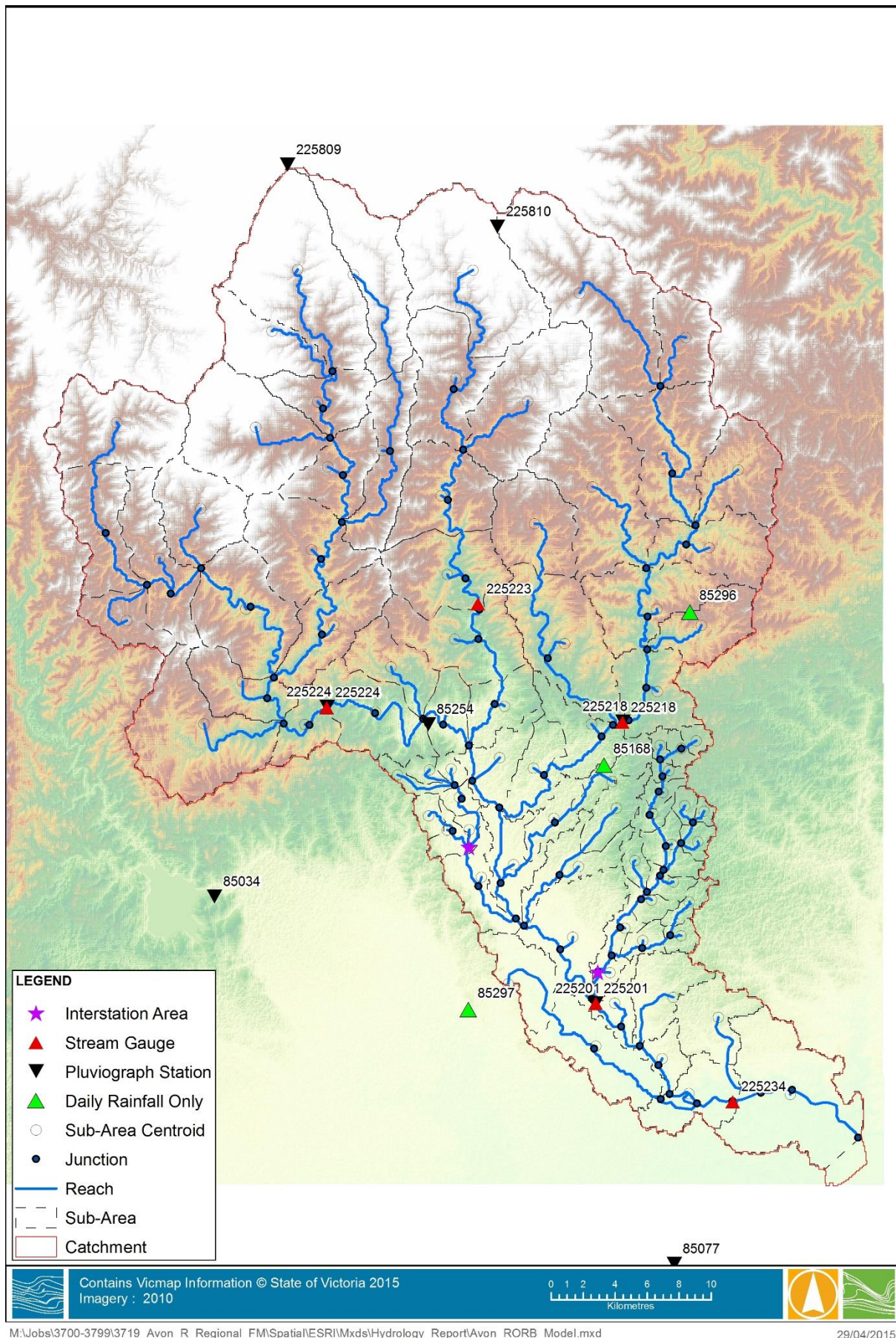


Figure 3-19 RORB Model Structure

3.6.3 Fraction Impervious

The fraction impervious (FI) was included in the hydrologic model by applying a representative FI for each subarea. Aerial imagery suggests that the Avon River catchment has very limited impervious areas. For the RORB model, the upper forested catchment was assumed to have a fraction impervious of 0. The downstream agricultural areas were all assumed to have a fraction impervious of 0.1 and the key townships of Stratford, Briagolong and Boisdale were all assumed to have a fraction impervious of 0.5, as described by Table 3-18.

Table 3-18 Fraction Impervious Designation for Planning Zones

Description	Fraction Impervious (FI)
Agriculture / Floodplain Area	0.1
Forest	0
Township Zone	0.5

3.6.4 Baseflow

Baseflow has been extracted from instantaneous streamflow data at the Stratford gauge using Basejumper (SKM, 2007). Basejumper uses the Lyne and Hollick digital filter to separate a flow series into quick and slow response components. The separated baseflow hydrographs were then compared for all calibration events, as shown below. A baseflow separation parameter of 0.925 was adopted. The baseflow hydrograph for the Avon River at Stratford tends to peak much later than the total flood hydrograph and as such has little impact on the flood peak. The largest difference was seen in the smaller 2011 event where a difference in peak of 1.3% was observed when baseflow was extracted. It is also noted that the baseflow hydrograph has little impact on the hydrograph shape, especially at the start and peak of events. Since it makes such a limited contribution, baseflow was not extracted from the hydrographs for calibration, or added to the design hydrographs.

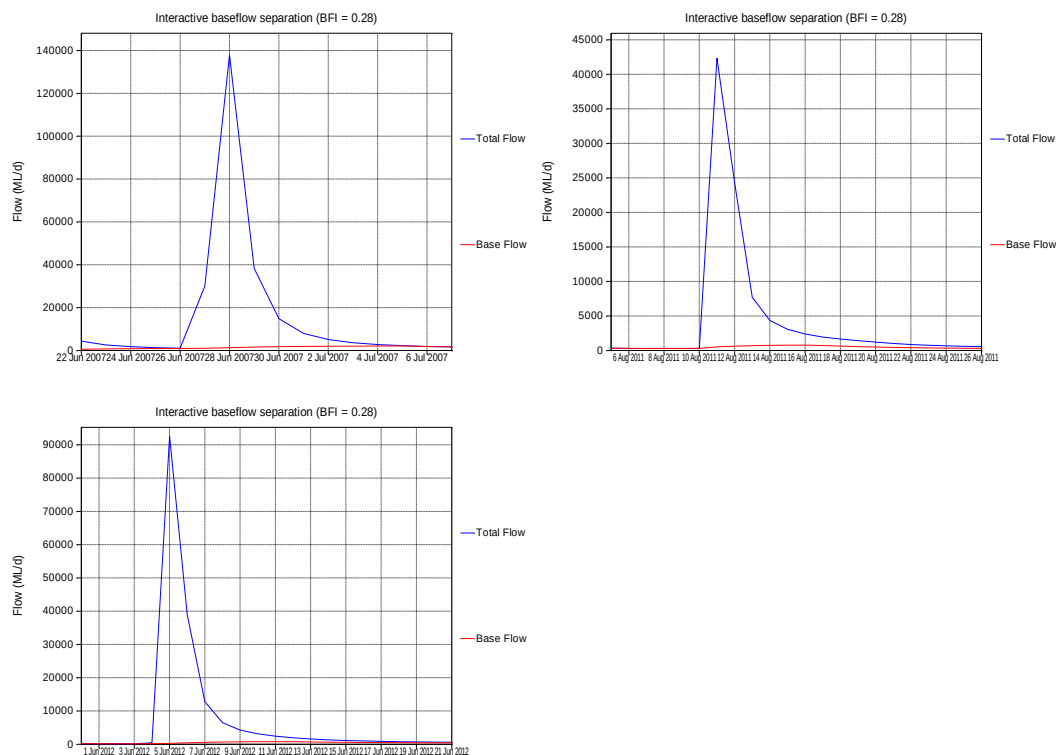


Figure 3-20 Baseflow separation for June 2007, August 2011 and June 2012 calibration events for the Avon River at the Stratford gauge.

3.6.5 Calibration Events

Three recorded events were used for the calibration of the RORB hydrologic model; namely the June 2007, August 2011, and June 2012 floods. Each of these events was represented with a unique temporal and aerial rainfall pattern generated from local rainfall gauge records. The outflow hydrographs from the RORB model were then compared to stream gauges at four locations; Avon River at Stratford, Avon River at The Channel, Valencia Creek at Gillio Road, and Freestone Creek at Briagolong.

The 2007 and 2012 events were moderate to large, with estimated AEPs of approximately 2.5% and 4%, respectively, while the 2011 was a smaller event with an AEP of around 20%. The 2007 event exhibited slightly different behaviour to the other two, with a double peak shaped hydrograph at the gauges and the peak occurring in the Avon comparatively later than at Valencia and Freestone Creeks.

Figure 3-21, Figure 3-23, and Figure 3-25 illustrate the aerial rainfall patterns used in each of the calibration runs. Figure 3-22, Figure 3-24, and Figure 3-26 show the rainfall hyetographs and recorded flows at the four gauges.

The 1990 flood event was not included in the calibration as the river system experienced significant channel change during the event and the Valencia Creek gauge was washed away during this event.

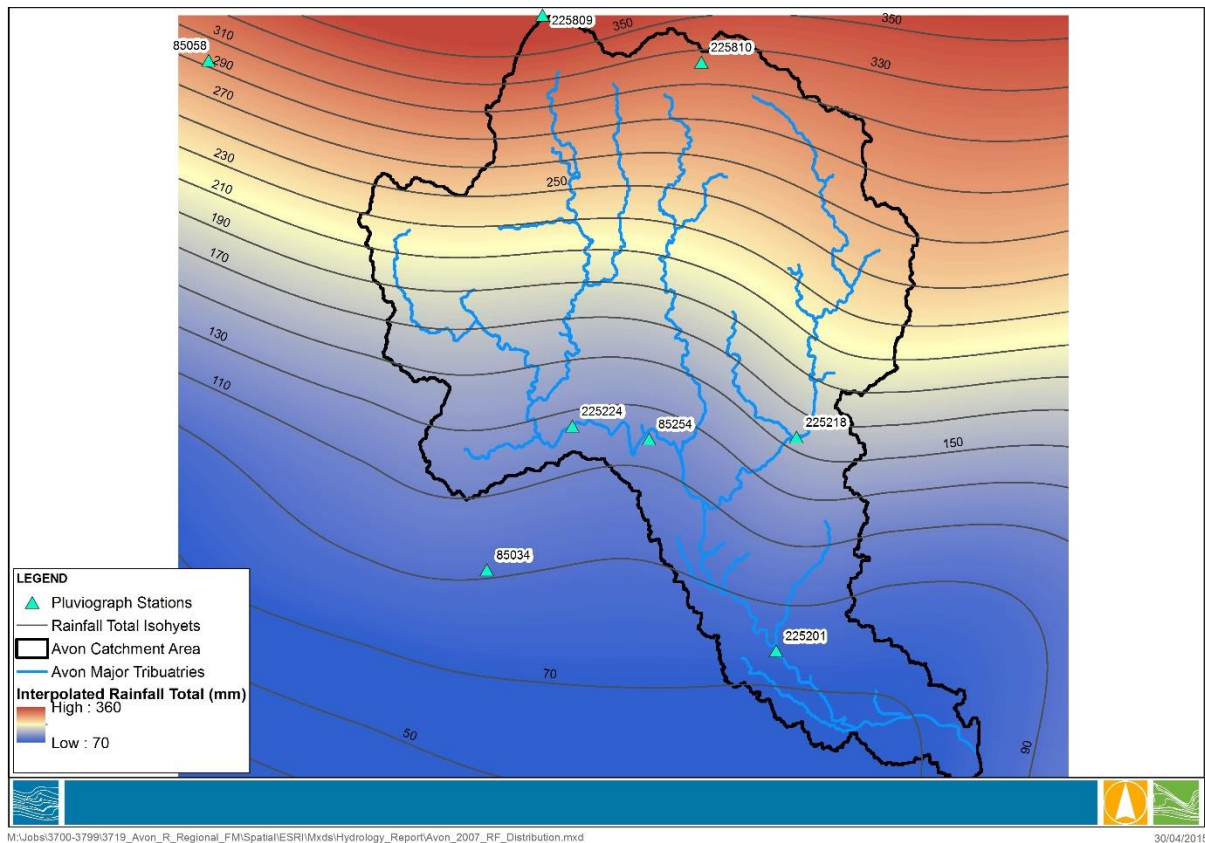


Figure 3-21 Total rainfall across the catchment for the June 2007 calibration event

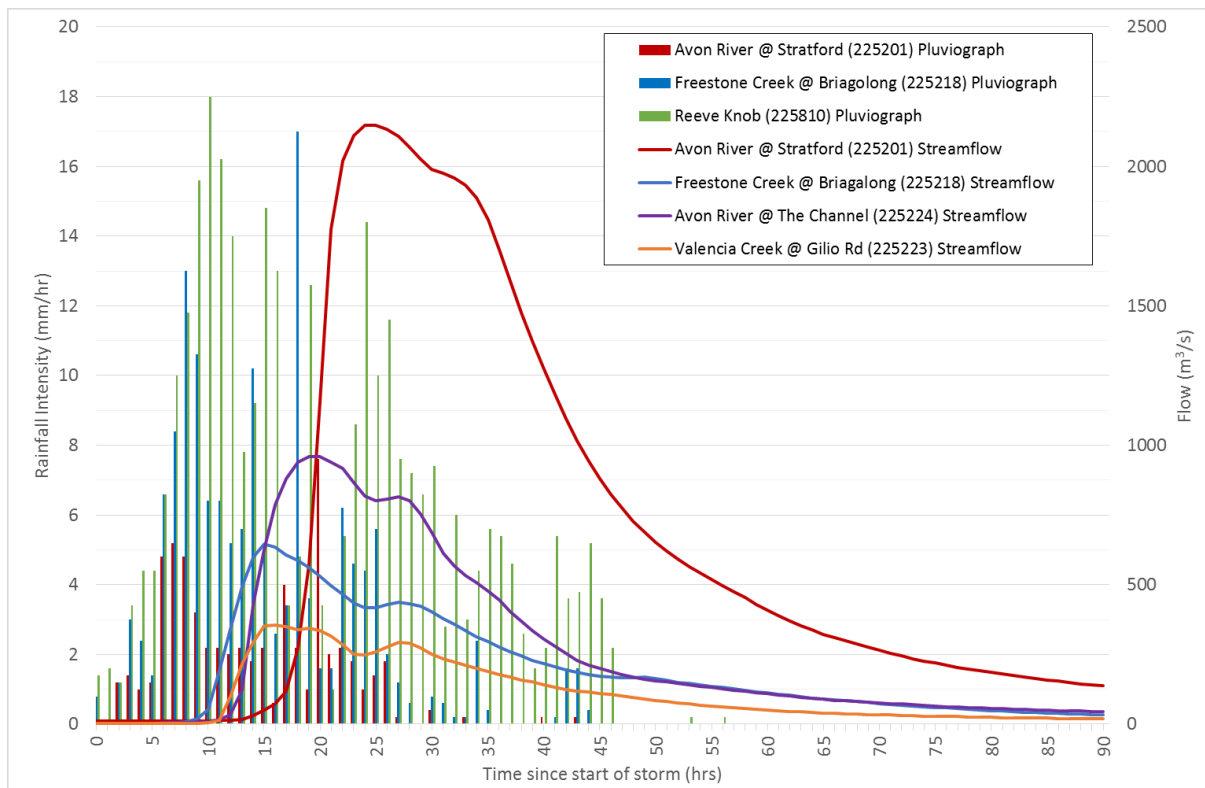


Figure 3-22 Calibration event hyetographs and instantaneous flow hydrographs for the June 2007 calibration event

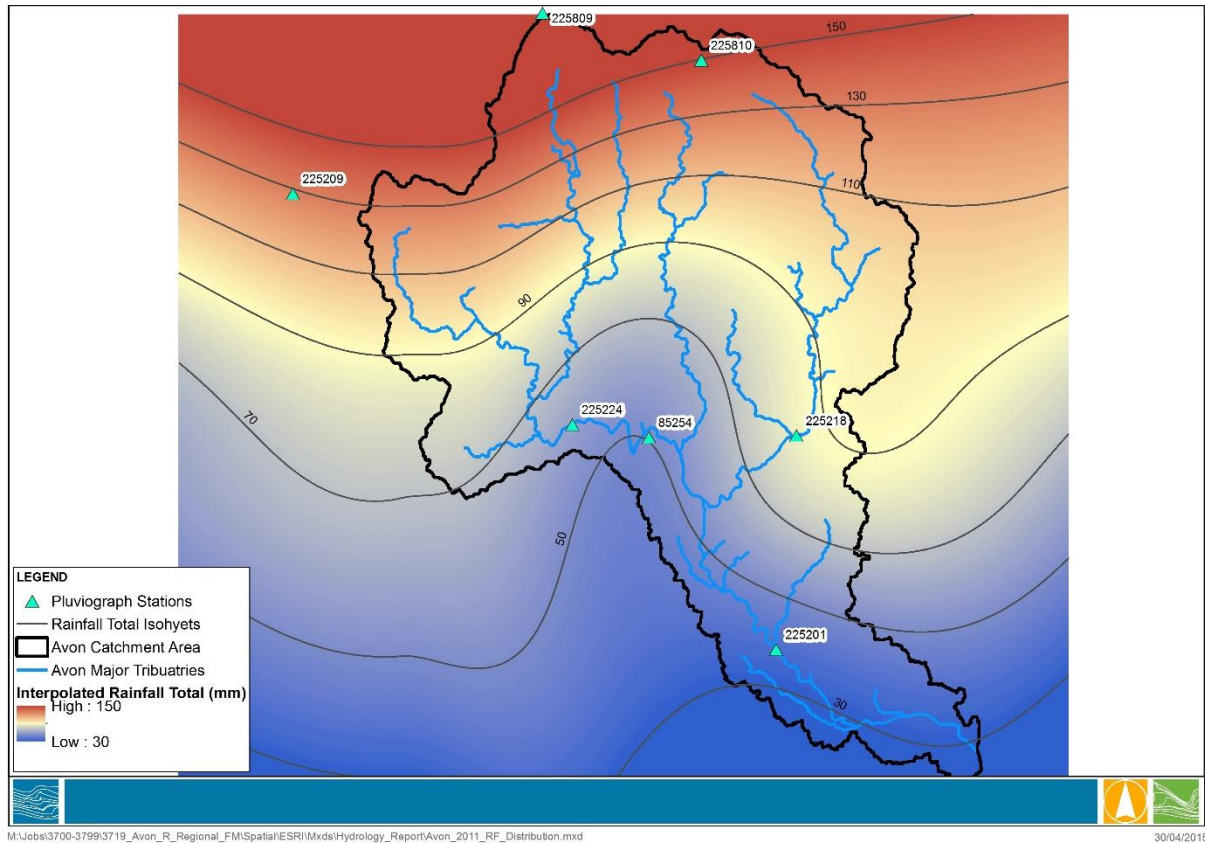


Figure 3-23 Total rainfall across the catchment for the August 2011 calibration event

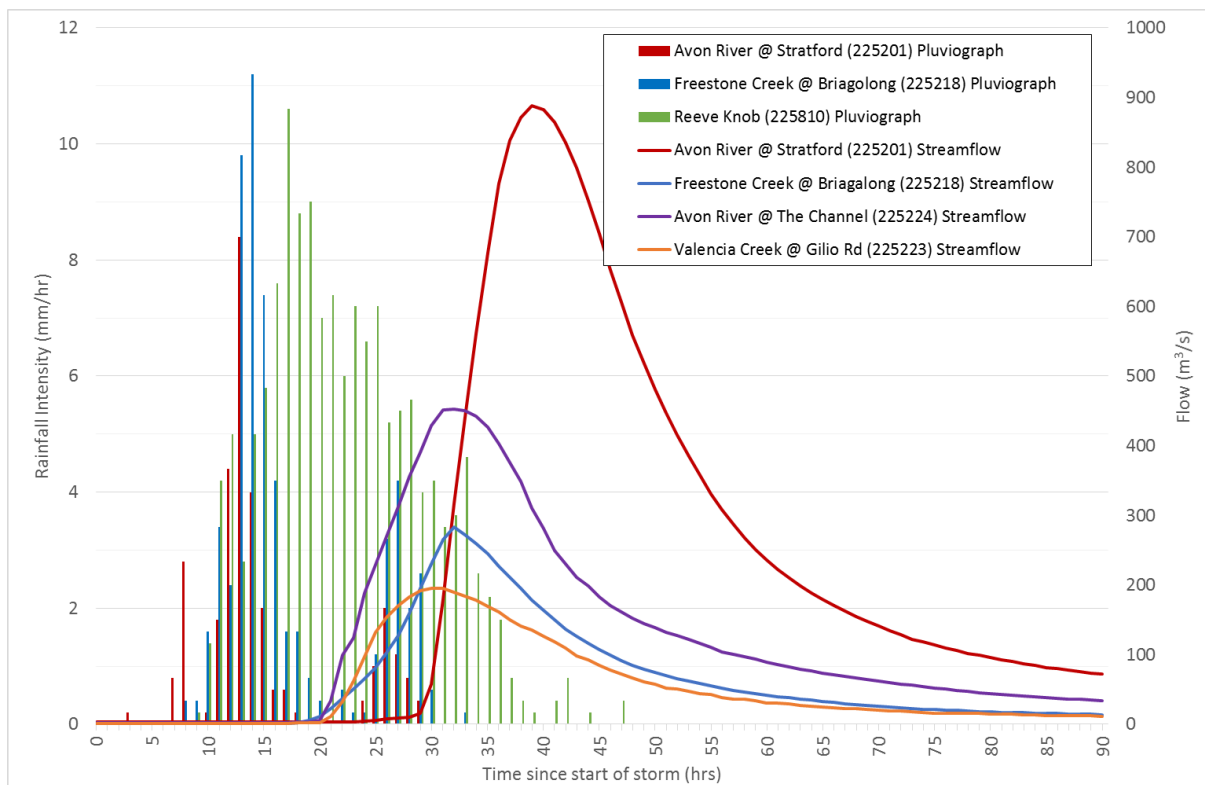


Figure 3-24 Calibration event hyetographs and instantaneous flow hydrographs for the August 2011 calibration event

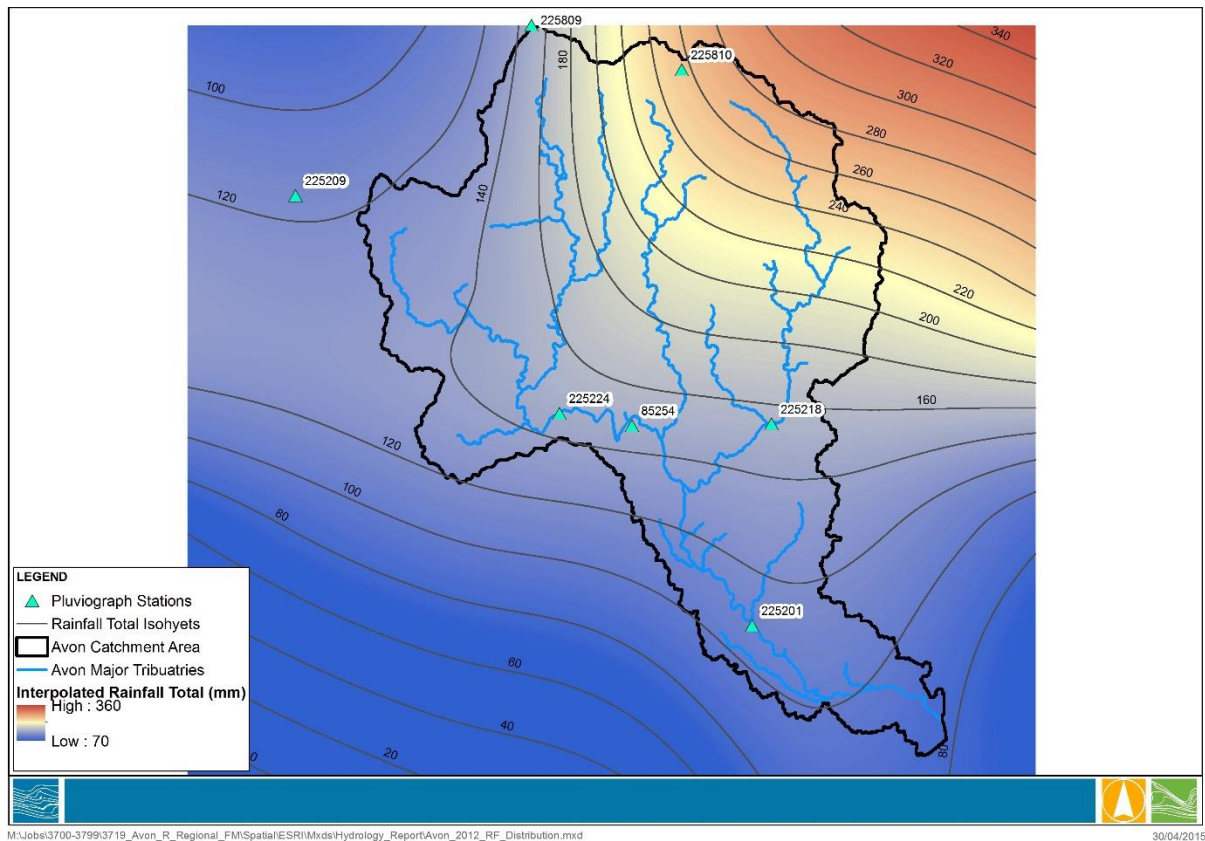


Figure 3-25 Total rainfall across the catchment for the June 2012 calibration event

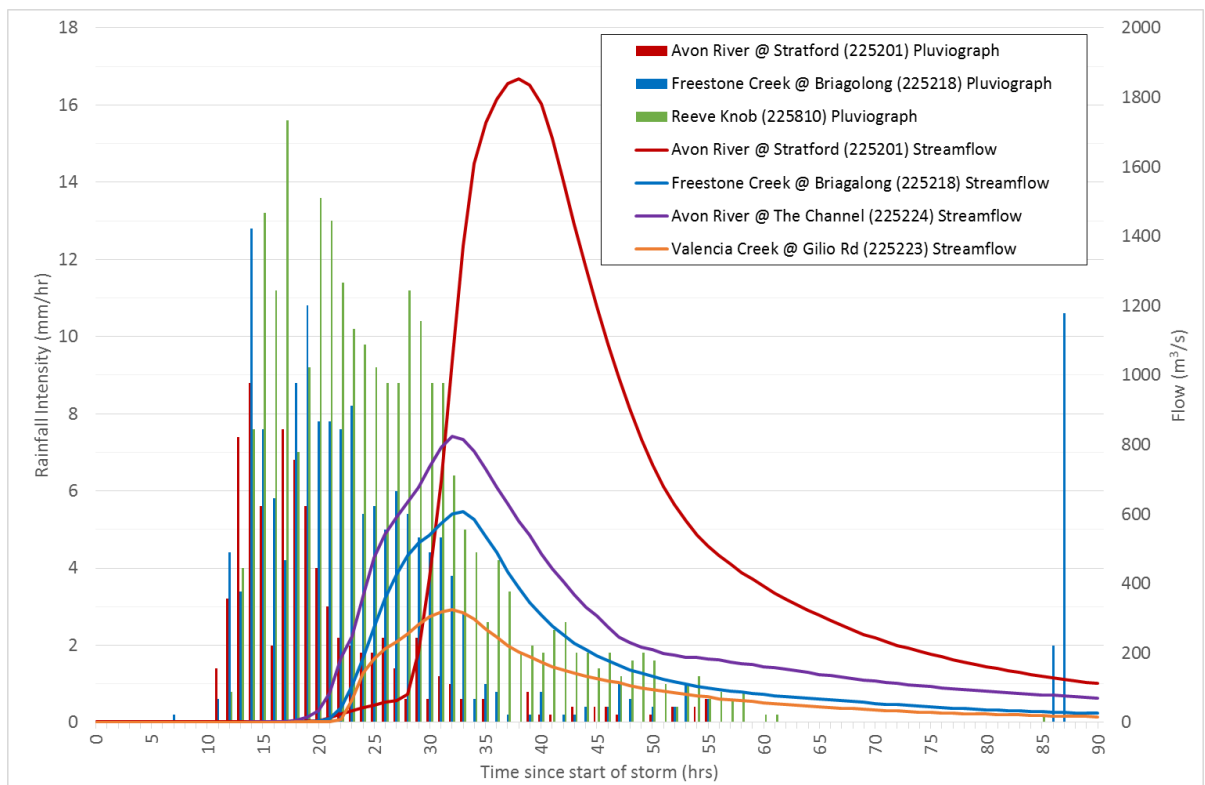


Figure 3-26 Calibration event hyetographs and instantaneous flow hydrographs for the June 2012 calibration event

3.6.6 Calibration of RORB Parameters

The RORB model was run using the initial loss/continuing loss model. The RORB storage and loss parameters – k_c , m , initial loss (IL) and continuing loss (CL) – were fitted for each calibration event to give the best fit to the observed hydrographs. Priority was given to fitting the hydrograph peak and shape, with the volume and timing the secondary priority. The routing parameter k_c was set using a combination of calibration and regional equations. The exponent m was set to 0.8 as per RORB default.

A number of regional equations for the calculation of k_c that are recommended in ARR87 and the RORB manual were used to guide the selection of this parameter (Table 3-19).

Table 3-19 Regional equations for the calculation of k_c

Source	k_c Value					
	Avon River (US of The Channel)	Avon River (US of Stratford)	Valencia Creek	Freestone Creek	Blackall Creek	Nuntin Channel (US of Boisdale)
Aust wide Yu (1989) (Pearse et al 2002)	66					
Vic MAR>800 mm - Eq 3.21 ARR87 (Book V)	44	35	28	38	17	11
Vic MAR<800 mm - Eq 3.22 ARR87 (Book V)	30	21	15	20	8	4
Aust wide Dyer (1994) (Pearse et al 2002)	79					
Victoria data (Pearse et al, 2002)	86					
Default RORB	52	40	31	38	18	11
Scaling from Seaspray Flood Study (Water Technology, in progress)	38					
Scaling from Traralgon Flood Study (Water Technology, in progress)	34					

The final calibrated model parameters for each event are summarised in the following tables. The fit of the RORB modelled hydrographs to the gauged hydrographs for each calibration is shown in Figure 3-27, Figure 3-28, and Figure 3-29.

Table 3-20 RORB Calibration Parameters – Avon River at Stratford

Event	k_c	m	IL (mm)	CL (mm/hr)
2007	20	0.8	50	0.5
2011	20	0.8	40	1.5
2012	25	0.8	50	2

Table 3-21 RORB Calibration Parameters – Avon River at the Channel

Event	k_c	m	IL (mm)	CL (mm/hr)
2007	22	0.8	20	2.2
2011	24	0.8	40	0.8
2012	30	0.8	30	0.1

Table 3-22 RORB Calibration Parameters – Valencia Creek at Gillio Road

Event	k_c	m	IL (mm)	CL (mm/hr)
2007	16	0.8	40	2.0
2011	20	0.8	40	0.0
2012	26	0.8	35	1.9

Table 3-23 RORB Calibration Parameters – Freestone Creek at Briagolong

Event	k_c	m	IL (mm)	CL (mm/hr)
2007	18	0.8	20	2.0
2011	25	0.8	35	0.2
2012	24	0.8	50	0.4

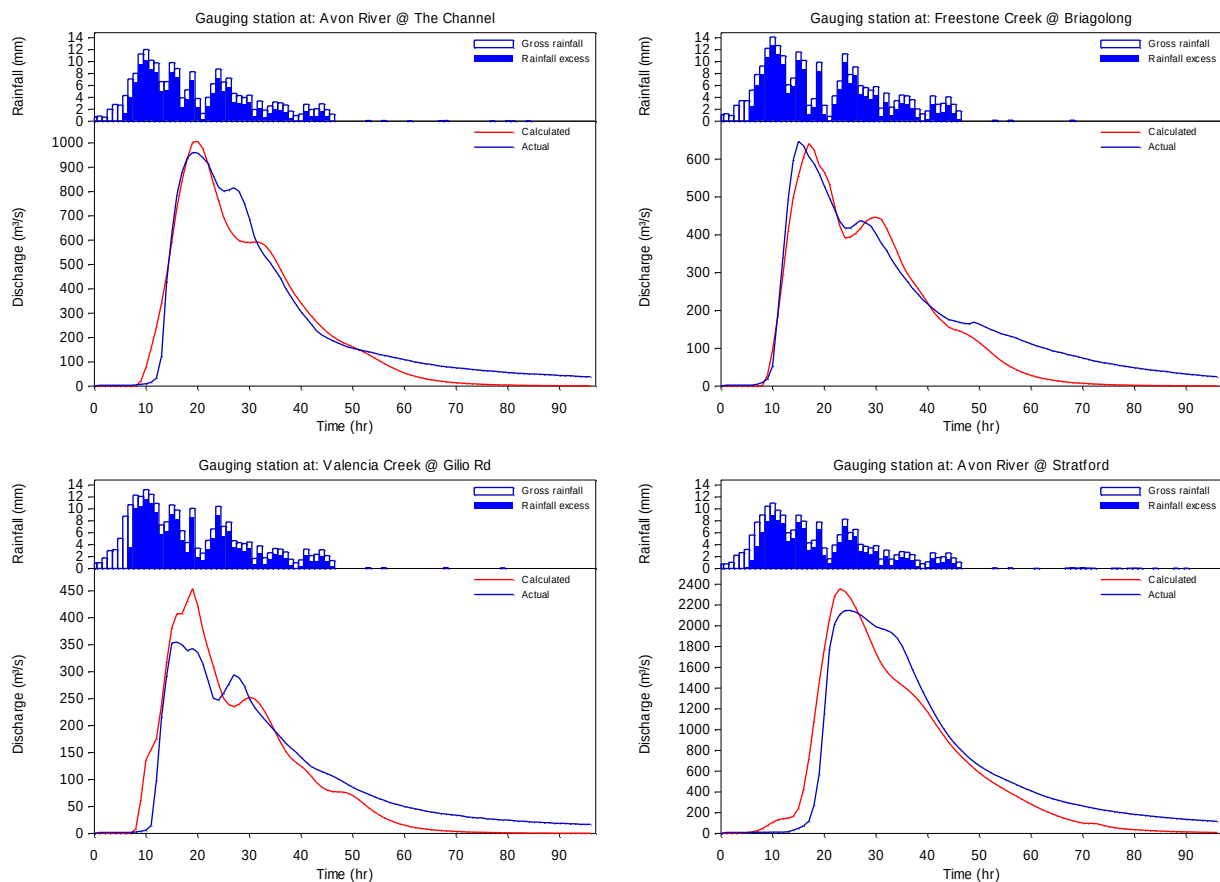


Figure 3-27 Calibration plots for June 2007

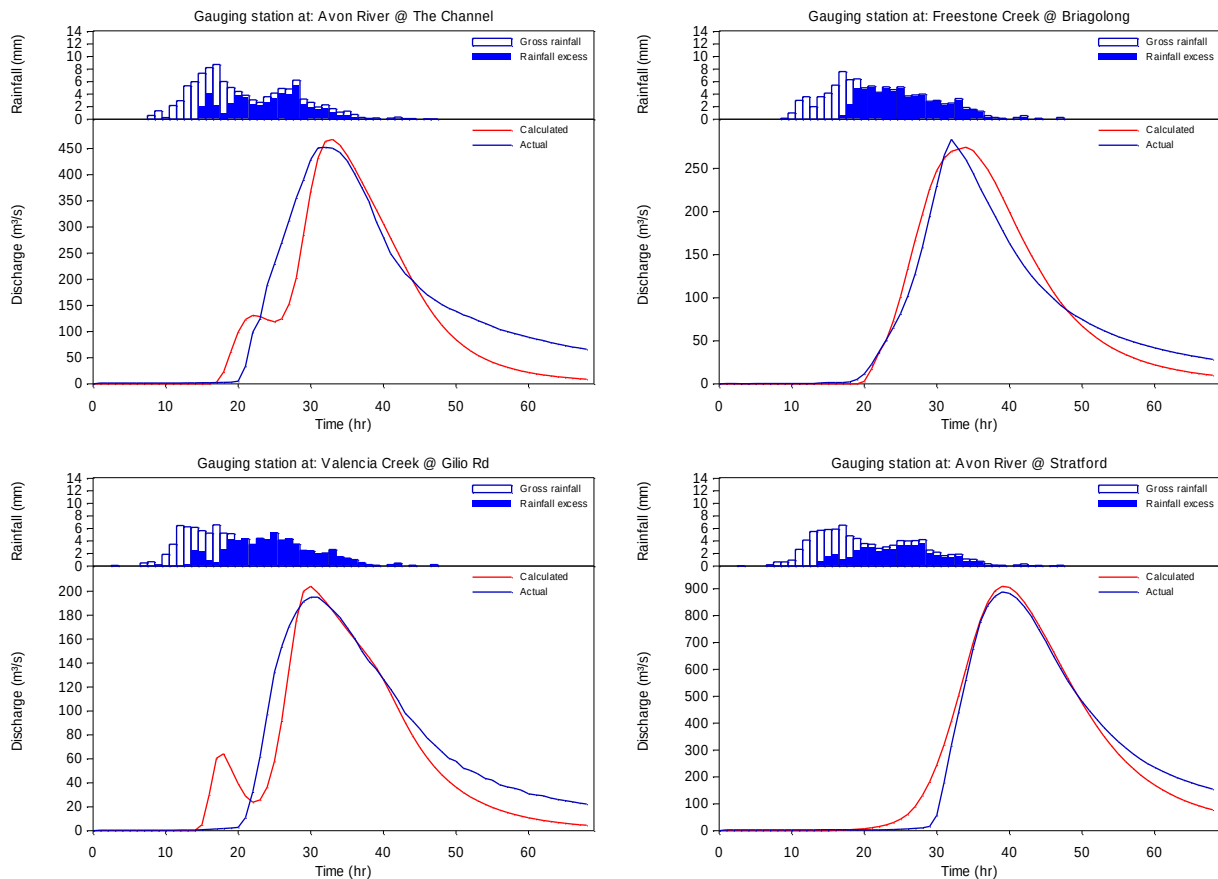


Figure 3-28 Calibration plots for August 2011

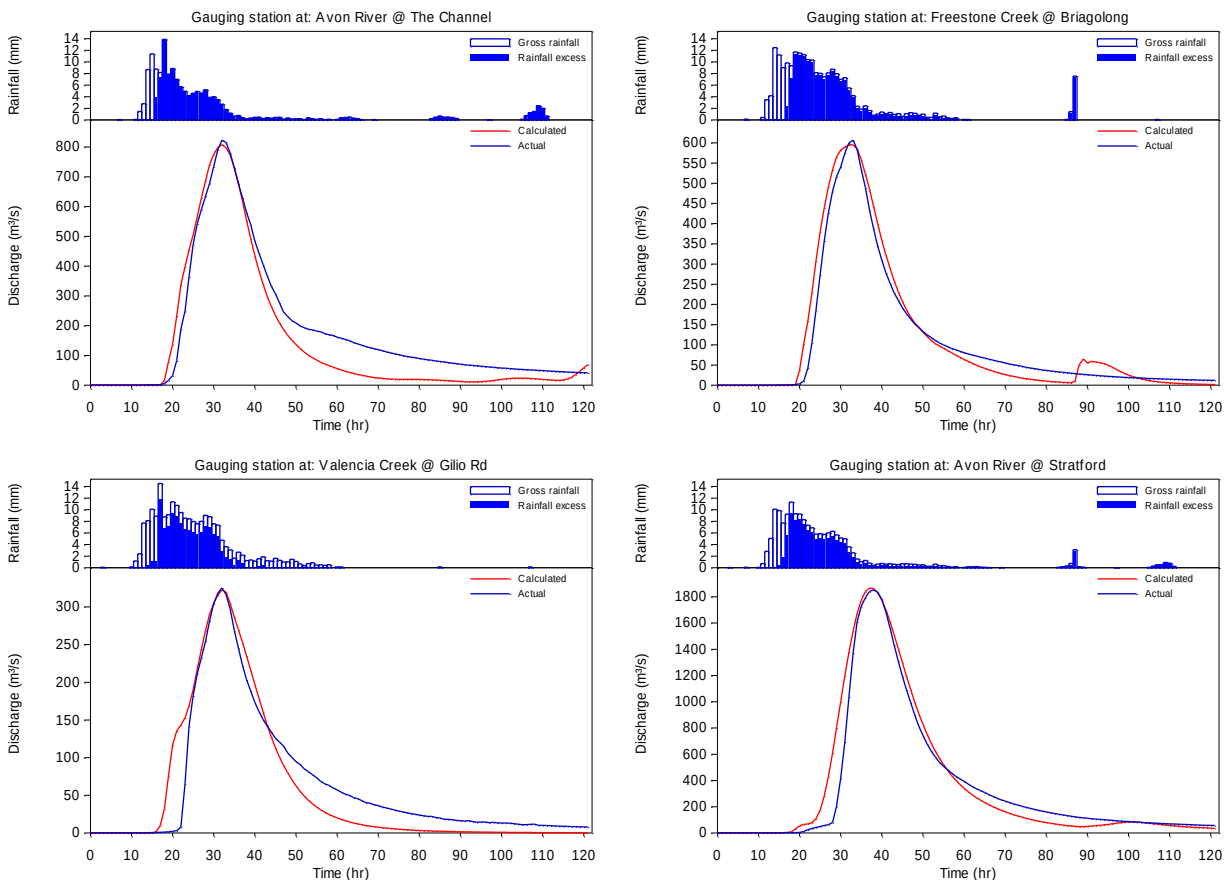


Figure 3-29 Calibration plots for June 2012

The shape and volume of the fitted hydrographs at all four gauges agree well with gauged data. The 2012 and 2011 events were particularly well-matched in shape, timing and volume. The RORB model for these events were able to accurately reproduce flows at all major gauging stations.

In the 2007 event the RORB model predicted the peak of the hydrograph reasonably, with the timing and total flow volume matching well. The modelled peak flow was slightly higher than recorded at the Avon River and Valencia Creek gauges. The shape of the hydrograph at Stratford is also slightly different, with the recorded data showing a pronounced double peak type hydrograph, whereas the RORB model produces a hydrograph with a single main peak and a much smaller secondary peak. Possible reasons for variation in peak flow and hydrograph shape is the routing of the upstream hydrographs. Slight variations on when the Freestone Creek, Valencia Creek and Avon River converge could cause significant differences in peak flows. The peak of Freestone Creek coincided with the Avon peak in the RORB model, however the peaks were slightly different during the real event, which would explain the difference in peak flows. Another explanation could be in the temporal variation of rainfall, as the Avon catchment appears to not register the second peak in rainfall compared to the recorded data.

The k_c values fitted for the calibration events are within the range of those provided by regional equations in Table 3-19. The initial losses tend to be higher than design values and continuing losses tend to be on the low side for the 2011 and 2012 events but reasonable for the 2007 event.

3.6.7 Design Loss Estimates

Design losses were estimated by the design loss prediction equations developed by Hill et al (1998) and (Hill et al. 2014). The losses recommended in AR&R (1987) consistently overestimated peak flows. The Hill et al (1998) losses, in combination with areal reduction factors from Siriwardena and Weinmann (1996), produced peaks that were more consistent with the results of flood frequency analysis.

Hill, et al (1998) calculate initial loss by first calculating the storm initial loss using Equation 1, then the burst initial loss (Equation 2). The burst initial loss varies with storm duration and accounts for the embedded nature of AR&R design rainfalls (Hill et al 1998). The continuing loss is estimated using Equation 3.

Storm initial loss:

$$IL_s = -25.8BFI + 33.8 \quad (1)$$

Burst initial loss:

$$IL_b = IL_s \left\{ 1 - \frac{1}{1 + 142 \frac{\sqrt{\text{duration}}}{MAR}} \right\} \quad (2)$$

Continuing loss:

$$CL = 7.97BFI + 0.00659PET - 6.00 \quad (3)$$

The AR&R Project 6 Stage 3 report (Hill et al. 2014) contains new recommended initial and continuing loss equations, as shown below. No recommendation has been made for the conversion of storm initial loss to burst initial loss.

Storm initial loss:

$$IL_s = 16.7 + 0.141P_{24h}^{2\%} - 0.291MedianAPI \quad (4)$$

Continuing loss:

$$CL = 3.0 \text{ mm/hr} \quad (5)$$

The values of the input parameters to the previous equations are as follows:

- Median API 29 mm
- BFI 0.21
- PET 1,068 mm
- MAR 651 mm
- $P_{24h}^{2\%}$ 167 mm

The design loss estimates produced by both methods are given in Table 3-24. The two methods were found to produce very similar estimates. The Project 6 losses (Hill et al. 2014) are the most consistent with the losses applied to the calibration events. The equations were applied for the whole catchment. Values of initial loss for the upper catchment interstation areas may be higher.

Table 3-24 Design loss parameter estimates

Source	IL _s (mm)	IL _b (mm)	CL (mm/hr)
Hill et al (1996)	28	11-18 (for 9-72 hour events)	2.7
Project 6 Stage 3 Report (Hill et al. 2014)	32	-	3

3.6.8 Design Flood Validation

Various k_c and loss values were compared to the FFA at Stratford (including historical events) to determine the best fit for the design hydrology. The ARR Project 6 Stage 3 Report (Hill et al. 2014) did not find evidence of variation of loss values with AEP, a finding which is consistent with a range of previous studies. Therefore, rather than varying losses to fit the design flows exactly to the FFA, the validation process was aimed at selecting a single set of loss parameters which provided a reasonable fit across the whole range. This approach was justified given the FFA was based on a dataset with 38 years of historical gauged data and historic floods at Stratford.

RORB parameters were tested using k_c and loss values which were output for each calibration event. These were then compared to design loss estimation based on Hill et al (1996, 2014). After comparison, a parameter set was chosen that best matched the flood frequency analysis at each gauge across all events. The selected parameters are displayed in Table 3-25.

In general, design initial losses were required to be high when compared to calibration and other estimates to get the best fit to flood frequency analysis peak flows. These higher design losses are required for accurate validation in this hydrologic analysis, however, the additional floodplain delineation that occurs in two-dimensional hydraulic analysis may show that losses have been overestimated, and if this is the case the hydrologic inflows will be revisited.

Table 3-25 Adopted Design RORB parameters

Location	k_c	Initial Loss (mm)	Continuing Loss (mm/h)
Avon River at Stratford	20	50	1
Avon River at The Channel	22	50	2
Freestone Creek at Briagolong	19	50	1
Valencia Creek at Gillio Rd	18	50	3

Avon River at Stratford

The chosen Avon River k_c of 20 was the same as two calibration events of 2007 and 2011, and marginally lower than 2012 (k_c value of 25). This value is also broadly consistent with regional estimates of k_c values from ARR (1987), which suggest a value of between 21 and 35. Loss parameters are also consistent with calibration values rather than calculated estimates, with the initial loss of 50 mm equivalent to the calibrated 2007 and 2012 values, whilst 2011 had 40 mm. The continuing loss value of 1 mm/hr is slightly lower than 2011 (1.5 mm/hr) and 2012 (2 mm/hr) and slightly higher than that used for 2007 calibration (0.5 mm/hr). The continuing loss values are also lower than that recommended in AR&R (1987). The fit to flood frequency when using these parameters is shown in Figure 3-30 below. These parameter values provide a very close fit to both high and low frequency events. Other tested parameter sets are also displayed in Figure 3-30.

The shape of the hydrographs for selected parameter sets was compared to the 2012 gauged hydrograph to check that the selected k_c value matched hydrograph shape consistent with actual events (Figure 3-31). The comparison shows that the adopted parameters provide a better fit to the hydrograph shape than that of the 2007 calibration event or using ARR loss values.

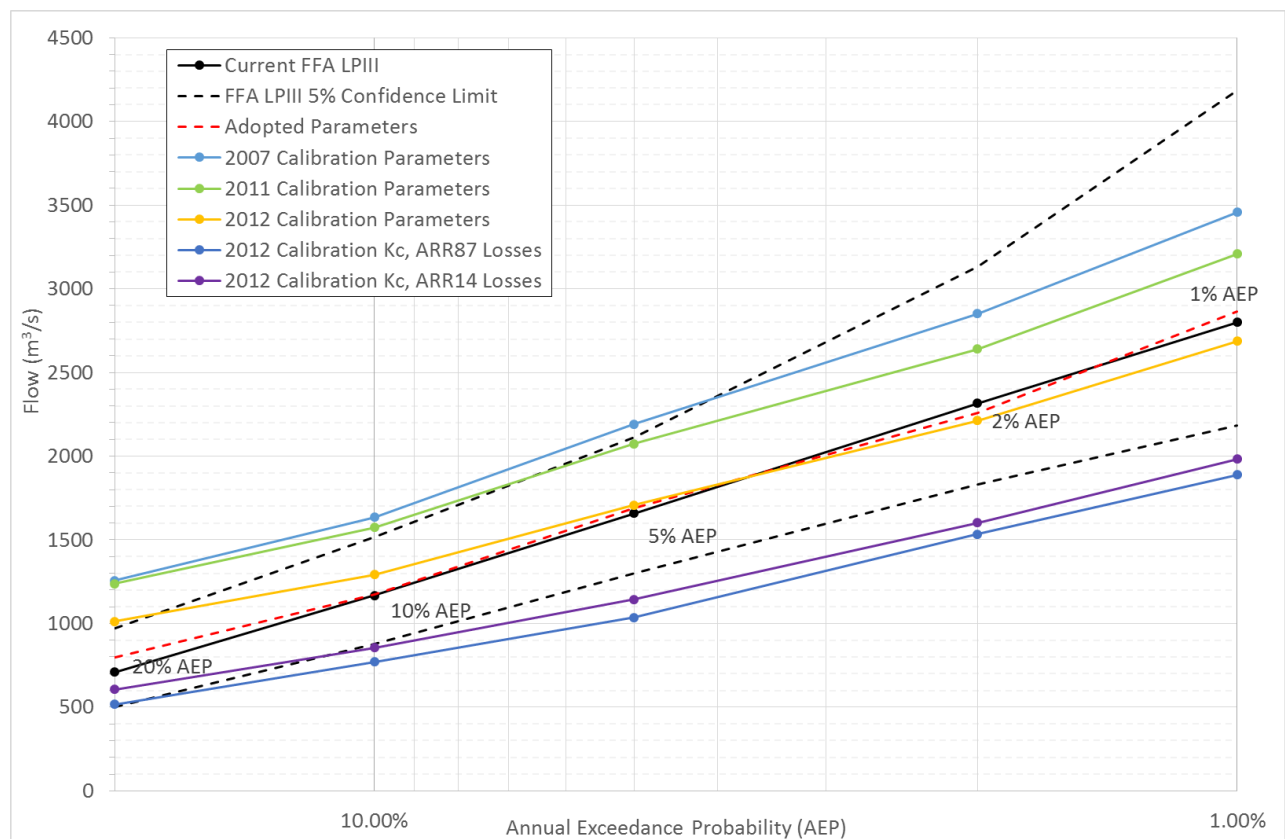


Figure 3-30 RORB peak flow results for various k_c and IL values at Stratford

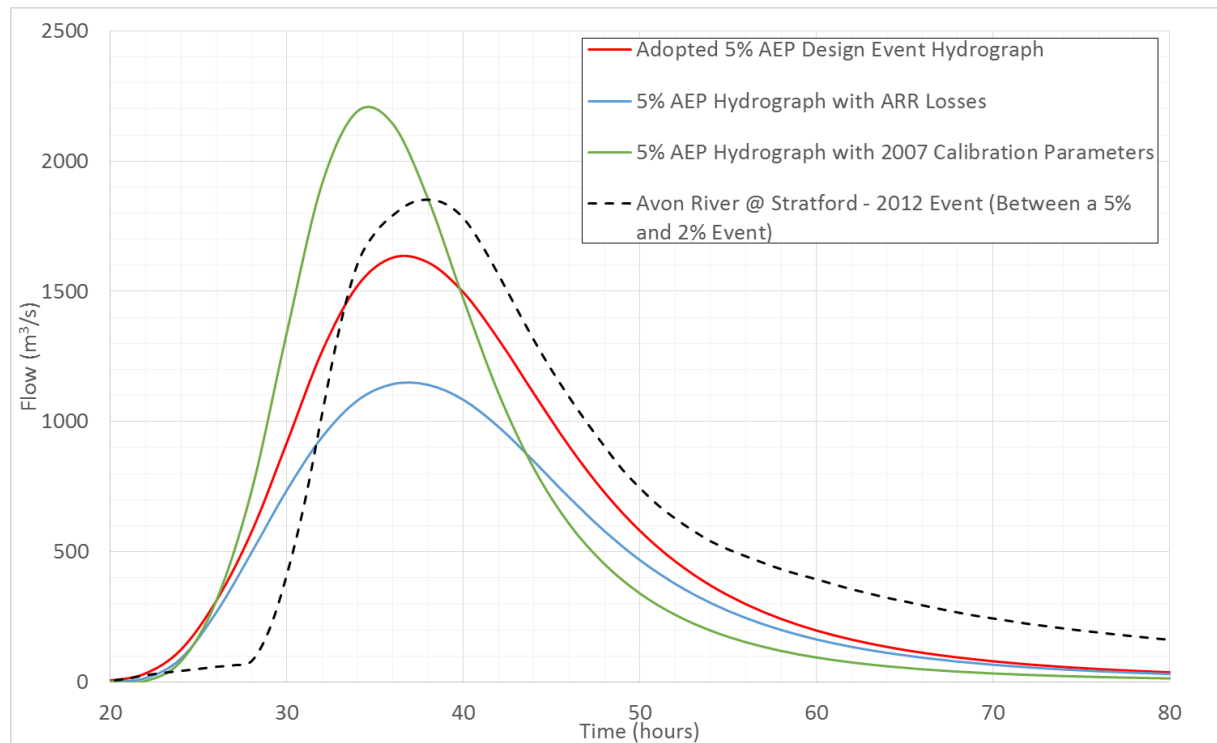


Figure 3-31 Comparison of shape of design hydrographs for selected parameter sets at Stratford

Avon River at The Channel

The chosen Avon River at the Channel k_c of 22 was the same as the 2007 calibration event, and lower than the calibrated 2011 and 2012 events (k_c values of 24 and 30, respectively). This value is also lower than regional estimates of k_c values from AR&R (1987), which suggest a value of between 30 and 44. Loss parameters are also more consistent with calibration values rather than calculated design estimates, with the initial loss of 50 mm higher than the calibrated values (20 mm, 40 mm and 30 mm). The continuing loss value of 2 mm/hr is slightly lower than 2007 value (2.2 mm/hr) and higher than the 2012 and 2011 values (0.8 mm/hr and 0.1 mm/hr). The continuing loss values are lower than that recommended in AR&R (1987). The fit to flood frequency when using these parameters is shown in Figure 3-32 below. These parameter values provide a very close fit to both high and low frequency events. Other tested parameter sets are also displayed in Figure 3-32.

The shape of the hydrographs for selected parameter sets was compared to the 2012 gauged hydrograph to check that the selected k_c value matched produced a hydrograph shape consistent with actual events (Figure 3-33). The comparison shows that the adopted parameters provide a better fit to the hydrograph shape than that of the 2007 calibration event or using AR&R (1987) loss values.

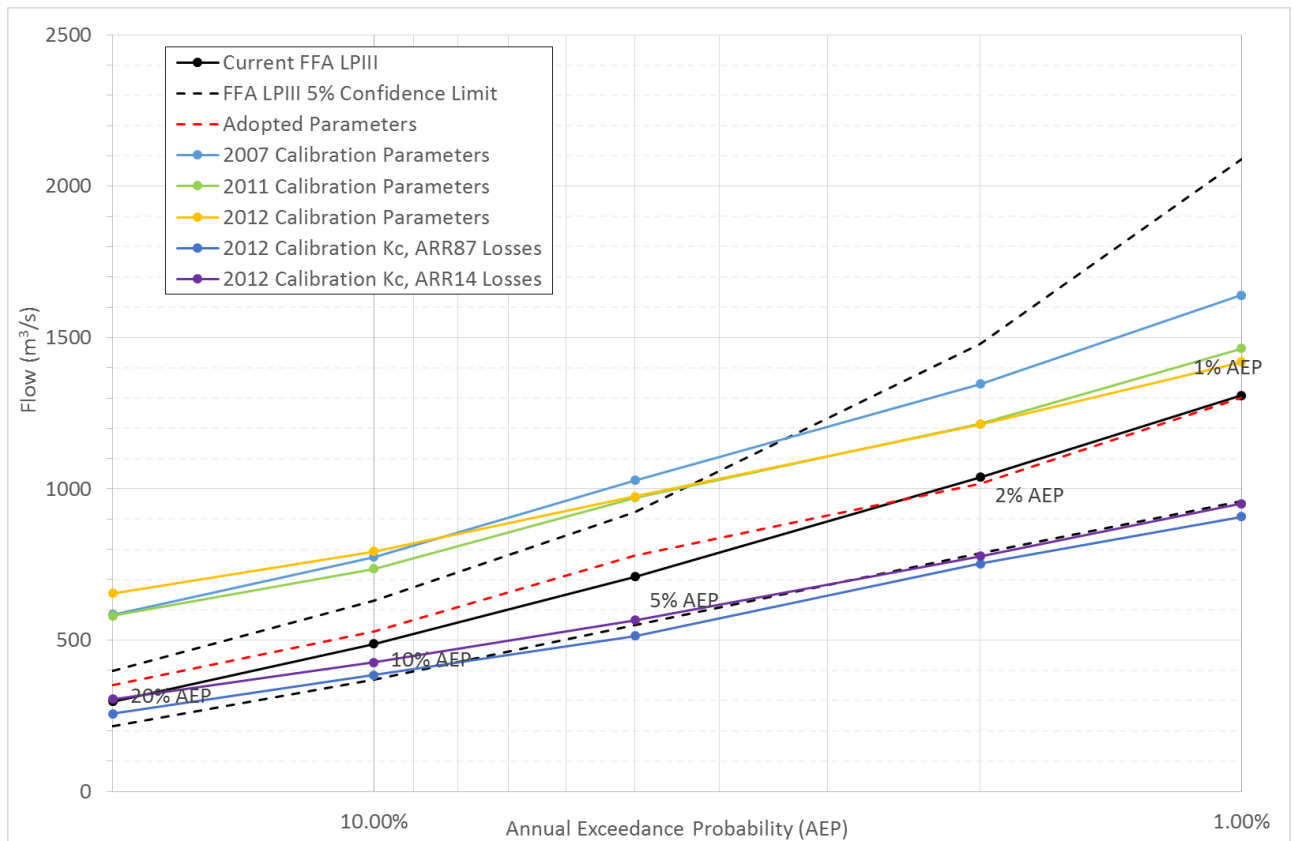


Figure 3-32 RORB peak flow results for various k_c and IL values at The Channel

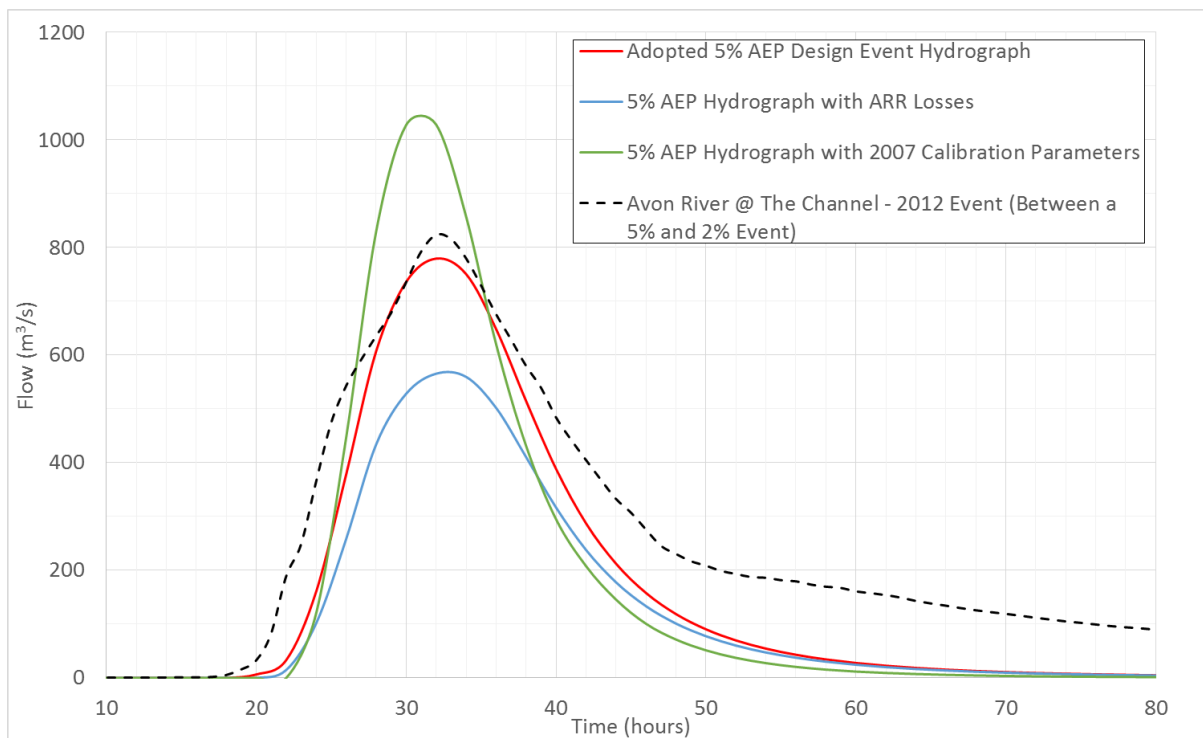


Figure 3-33 Comparison of shape of design hydrographs for selected parameter sets at The Channel

Freestone Creek at Briagolong

The chosen Freestone Creek k_c of 19 is a value in between the calibration event values, which range from 18 to 25. This value is also broadly consistent with regional estimates of k_c values from AR&R (1987), which suggest a value of between 20 and 38. Loss parameters are also consistent with calibration values rather than calculated estimates, with the initial loss of 50 mm equivalent to the calibrated 2012 values, whilst 2011 used 35 mm and 2007 used 20 mm. The continuing loss value of 1 mm/hr is in between the calibrated parameters which range from 0.2 mm/hr to 2 mm/hr. The continuing loss values are also lower than that recommended in AR&R (1987). The fit to flood frequency when using these parameters is shown in Figure 3-34 below. These parameter values provide a very close fit to both high and low frequency events. Other tested parameter sets are also displayed in Figure 3-34.

The shape of the hydrographs for selected parameter sets was compared to the 2012 gauged hydrograph to check that the selected k_c value matched produced a hydrograph shape consistent with actual events (Figure 3-35). The comparison shows that the adopted parameters provide a reasonable fit to hydrograph shape.

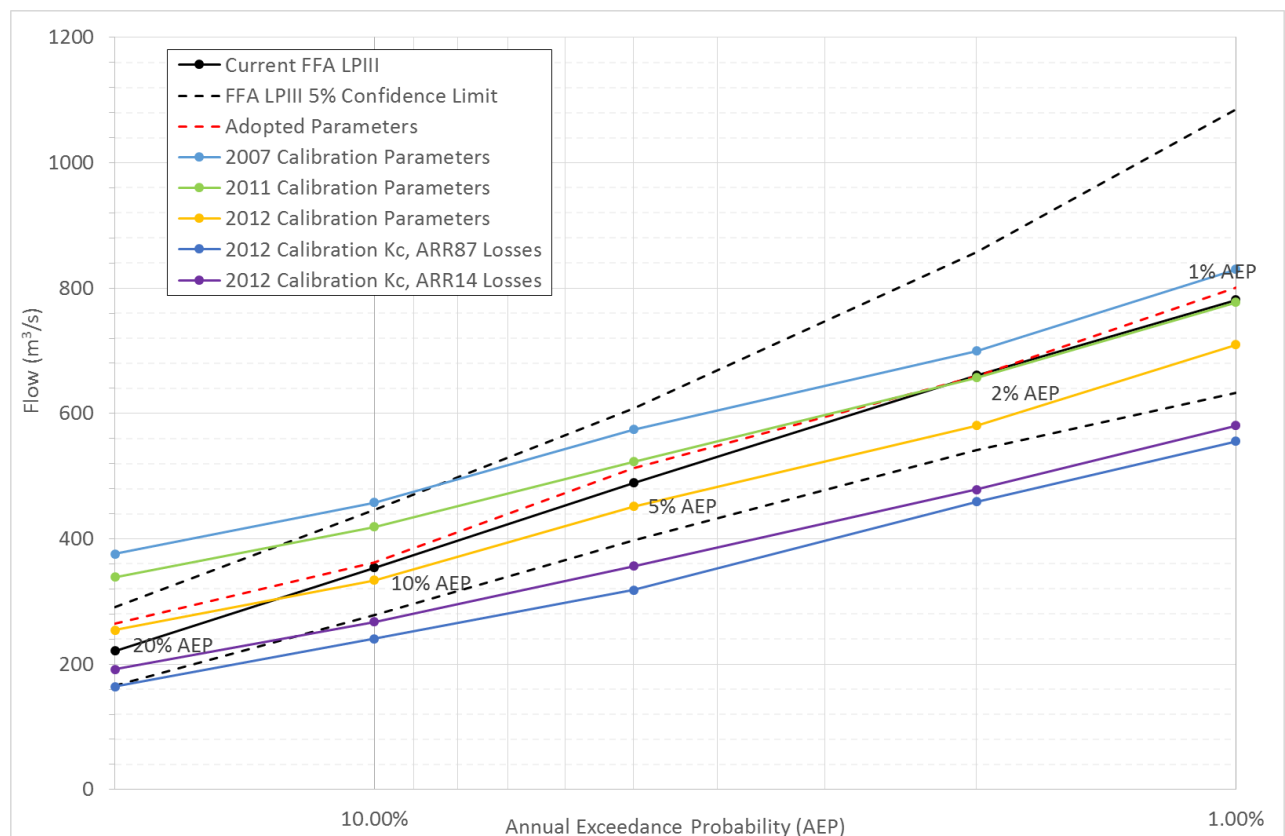


Figure 3-34 RORB peak flow results for various k_c and IL values at Freestone Creek

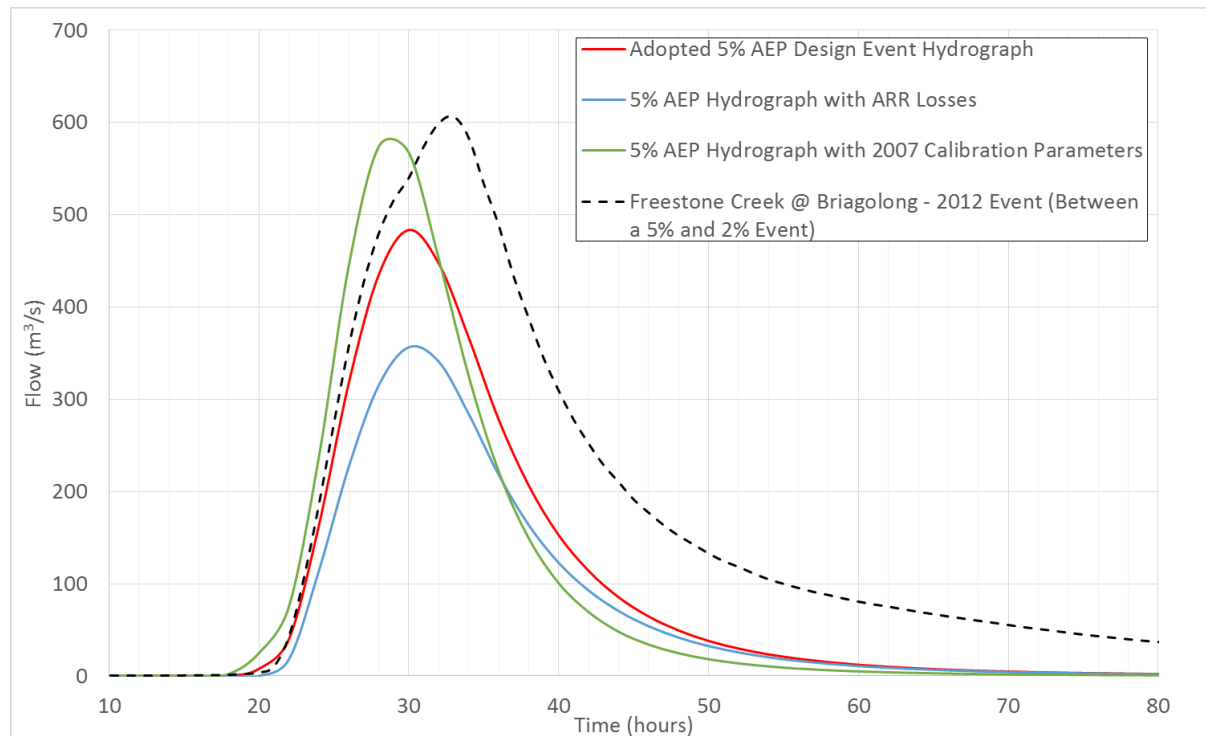


Figure 3-35 Comparison of shape of design hydrographs for selected parameter sets at Freestone Creek

Valencia Creek at Gillio Road

The chosen Valencia Creek k_c of 18 was within the range of 16 to 26 estimated during the calibration events. This value is also consistent with regional estimates of k_c values from ARR (1987), which suggest a value of between 15 and 28. Loss parameters are higher than calibrated values with an initial loss of 50 mm (calibrated values range from 35 to 40 mm) and a continuing loss of 3 mm/hr (calibrated values range from 0 to 2 mm/hr). The fit to flood frequency when using these parameters is shown in Figure 3-36 below. These parameter values provide a very close fit to both high and low frequency events. Other tested parameter sets are also displayed in Figure 3-36.

The shape of the hydrographs for selected parameter sets was compared to the 2012 gauged hydrograph to check that the selected k_c value matched produced a hydrograph shape consistent with actual events (Figure 3-37). The comparison shows that the adopted parameters provide a reasonable better fit to hydrograph shape than other parameter sets.

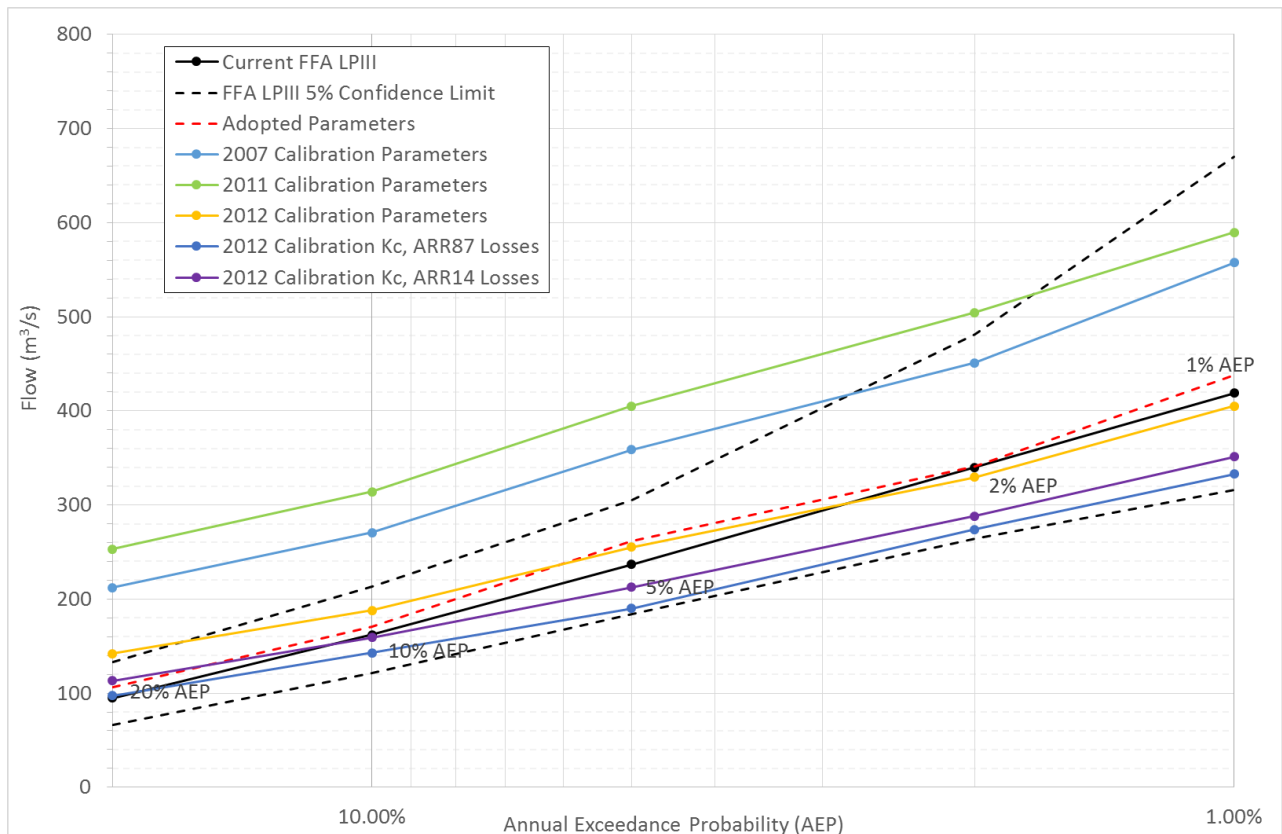


Figure 3-36 RORB peak flow results for various k_c and IL values for Valencia Creek

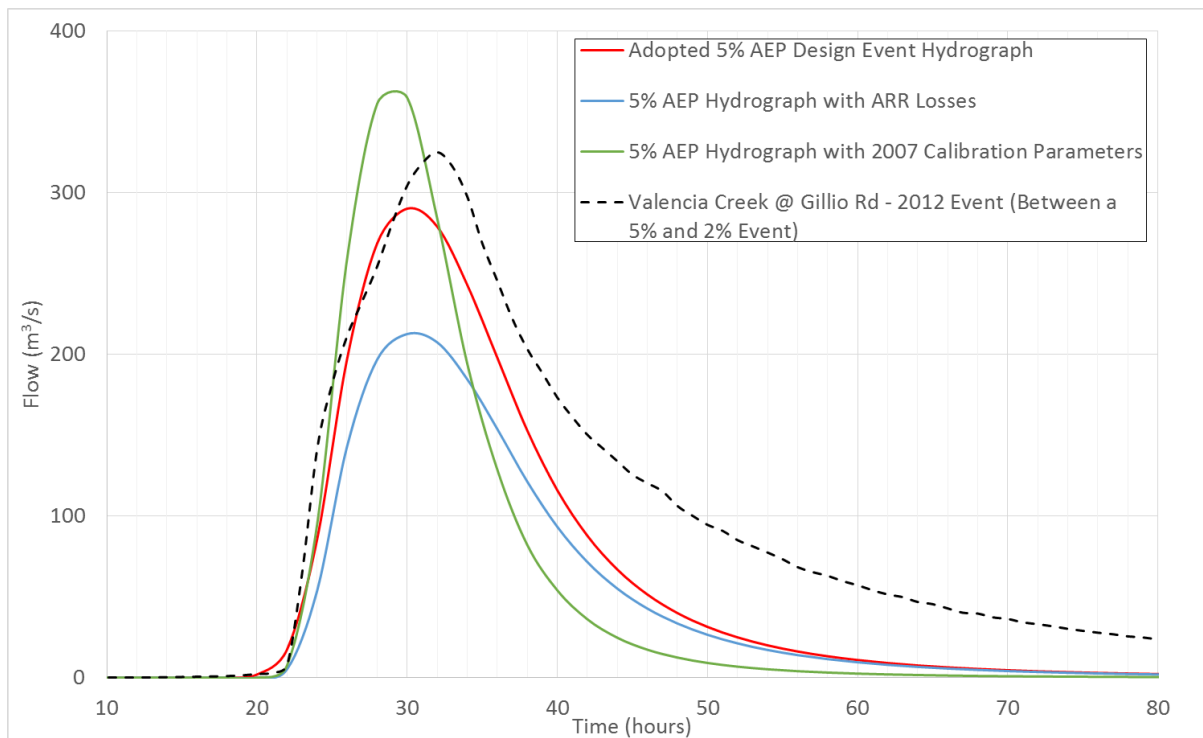


Figure 3-37 Comparison of shape of design hydrographs for selected parameter sets for Valencia Creek

3.7 Design Flows and Hydrographs

The adopted RORB routing and loss parameters summarised in Table 3-25 were found to produce peak flows that were a reasonable match with flood frequency analysis peak flows. The adopted RORB parameters were generally within the range of calibration values. The resulting hydrographs for Avon River at Stratford are shown in Figure 3-38, with peak flows for each of the major tributaries described in Table 3-26.

Table 3-26 Recommended design peak flows

AEP	Design Flow - Stratford (m ³ /s)	Design Flow – The Channel (m ³ /s)	Design Flow – Freestone Creek (m ³ /s)	Design Flow – Valencia Creek (m ³ /s)	Critical Duration (Stratford)
20%	808	350	264	107	36hr
10%	1184	530	363	170	36hr
5%	1703	779	512	262	36hr
2%	2277	1017	659	341	36hr
1%	2883	1301	800	434	36hr
0.5%	3495	1544	919	524	48hr
0.2%	4272	1884	1106	661	48hr

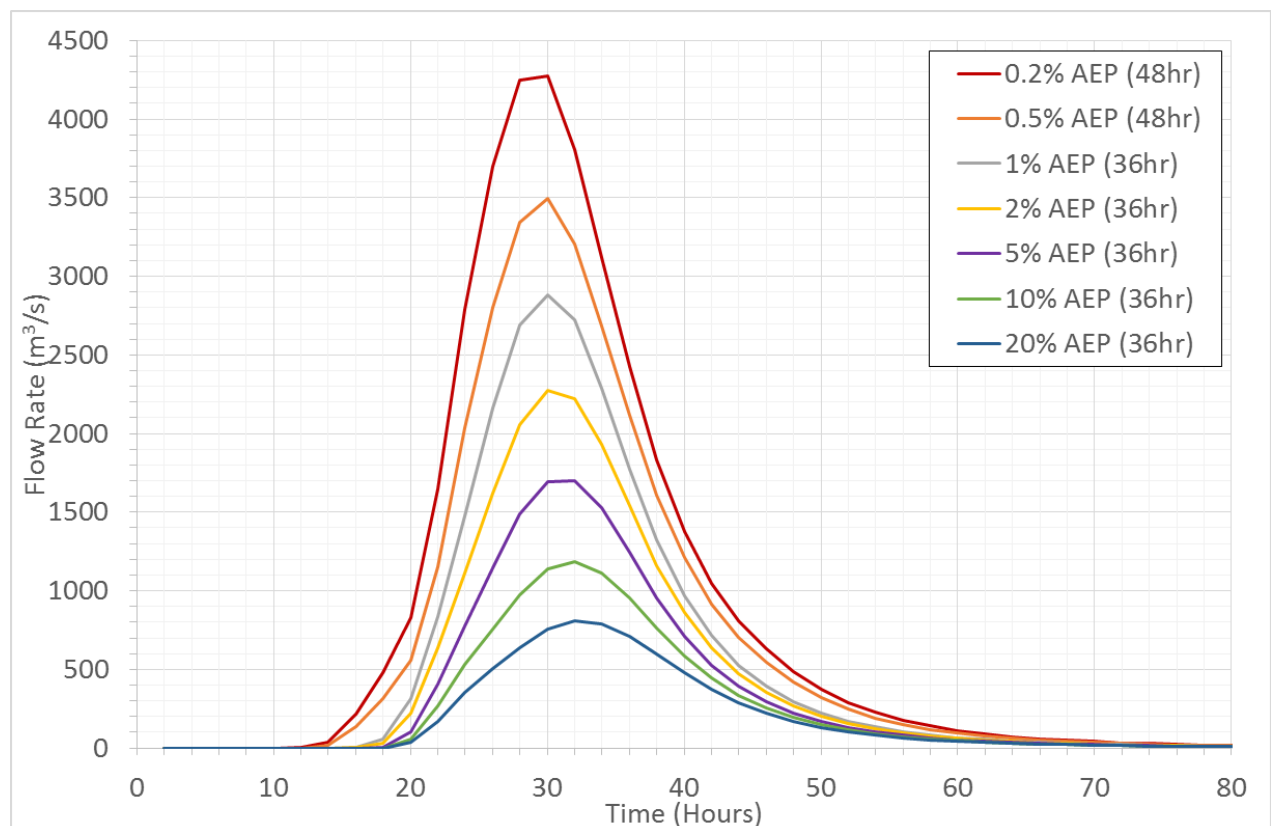


Figure 3-38 Avon River at Stratford design flood hydrographs

3.7.1 Flood Classes

For this study the minor, moderate, and major flood class events will be analysed in the hydraulic model. Details of the flow magnitude associated with these events was summarised previously in Table 3-4. Using the recommended design peak flow estimates, an AEP has been estimated for each flood class event, Table 3-27.

Table 3-27 Estimated AEP of the Flood Class Events

Gauge Station	Minor		Moderate		Major	
	Flow (m ³ /s)	Approximate AEP (%)	Flow (m ³ /s)	Approximate AEP (%)	Flow (m ³ /s)	Approximate AEP (%)
Avon River at the Channel	213	50 – 20%	507	10%	604*	10 – 5%
Avon River at Stratford	332	50 – 20%	761	20%	962	20 – 10%

* Flow values for heights above 6.0 m have been extrapolated

As all AEP events specified in Table 3-27 are being simulated in the hydraulic model, it is proposed that flood class levels will be analysed based on hydraulic modelling undertaken for design events. If major differences are noted between design events when flood class levels lie between these events, additional runs will be undertaken to more accurately approximate the flood class events.

3.8 PMF Estimation

The Probable Maximum Flood (PMF) is the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area. The PMF was estimated through estimation of the Probable Maximum Precipitation (PMP), then application of the PMP to the RORB model to generate PMF flood hydrographs.

3.8.1 Probable Maximum Precipitation Method

The Probable Maximum Precipitation (PMP) is defined by the *Manual for Estimation of Probable Maximum Precipitation* (WMO,1986) as:

"...the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends."

Australian Rainfall and Runoff (AR&R) Book VI recommends the use of generalised methods for estimating the PMP, as recommended by the World Meteorological Organisation (1986). These methods use data from a large number of storms over a wide area and make adjustments for moisture availability and topographic effects. The Generalised Southeast Australia Method (GSAM) is suitable for long duration storms (greater than 24 hours) over catchments of any size in southeast Australia.

3.8.2 Generalised Southeast Australian Method (GSAM)

The Avon River is located in the GSAM coastal zone. PMP rainfall depths were calculated based on the methods outlined in the *Guidebook to the Estimation of Probable Maximum Precipitation: Generalised*

Southeast Australia Method (Bureau of Methodology, 2006). For catchment areas between 1,000 and 40,000 km² in the coastal zone of Victoria the method is valid for durations from 24 to 72 hours.

The GSAM method requires the input of three spatially varying factors. These are the Topographic Adjustment Factor (TAF), the Moisture Adjustment Factor (MAF) and Extreme Precipitable Water (EPW). The MAF is calculated by dividing the seasonal catchment average EPW by the seasonal standard EPW, and has separate values for summer and autumn. The values of these factors for the Avon River study area are:

- Topographic Adjustment Factor (TAF) = 1.575
- Moisture Adjustment Factor (MAF) Summer (Annual) = 0.72
- Moisture Adjustment Factor (MAF) Autumn = 0.67

The area of each catchment was then used to calculate an initial depth for both summer and autumn for a range of durations. These depths were then multiplied by the TAF and MAF to give the final GSAM PMP estimate.

The resulting PMP estimates are given in Table 3-28 below.

Table 3-28 PMP depth estimates (GSAM)

Duration (hours)	Final PMP Estimate (mm)
24	690
36	780
48	840
72	920

The design temporal distributions given in BOM (2006) were adopted.

3.8.3 PMP Spatial Patterns

A uniform spatial pattern was adopted, instead of that given in BOM (2003) and BOM (2006) for both the GSDM and GSAM PMP rainfall. This was because the PMF estimation aims to give a broad-scale map of PMF across the catchment, rather than in a particular location. The GSDM and GSAM spatial pattern aims to give the highest possible flow at a particular point within reason, rather than across the catchment. It is acknowledged that by running only a limited number of durations with a uniform spatial pattern we cannot truly estimate the PMF at every point in the catchment; however it is understood that other factors in the PMP and PMF estimation process provide a conservative PMF that is suitable for planning purposes. The PMF should be reassessed if it is required for dam design or any other design purpose at a particular point in the catchment.

3.8.4 Probable Maximum Flood Estimation

The Probable Maximum Flood (PMF) was modelled by applying the PMP in RORB. The rainfall depth estimates and temporal and spatial patterns calculated above from the GSAM method were adopted.

Since baseflow was found to be a negligible proportion of the calibration events, it was not considered necessary to include baseflow in the PMF modelling.

The PMP rainfall totals, spatial and temporal patterns were input into the RORB model, with the calibrated routing parameters. An initial loss of 0 mm and a continuing loss of 1 mm/hr were adopted as recommended in Australian Rainfall and Runoff Book VI (1998). The resulting PMF peak flows are given in Table 3-29, and the hydrographs are shown in Figure 3-39.

Table 3-29 PMF peak flow estimates

	Design Flow - Stratford (m ³ /s)	Design Flow – The Channel (m ³ /s)	Design Flow – Freestone Creek (m ³ /s)	Design Flow – Valencia Creek (m ³ /s)	Critical Duration (Stratford)
PMF	14,810	5,870	3,164	2,101	24hr

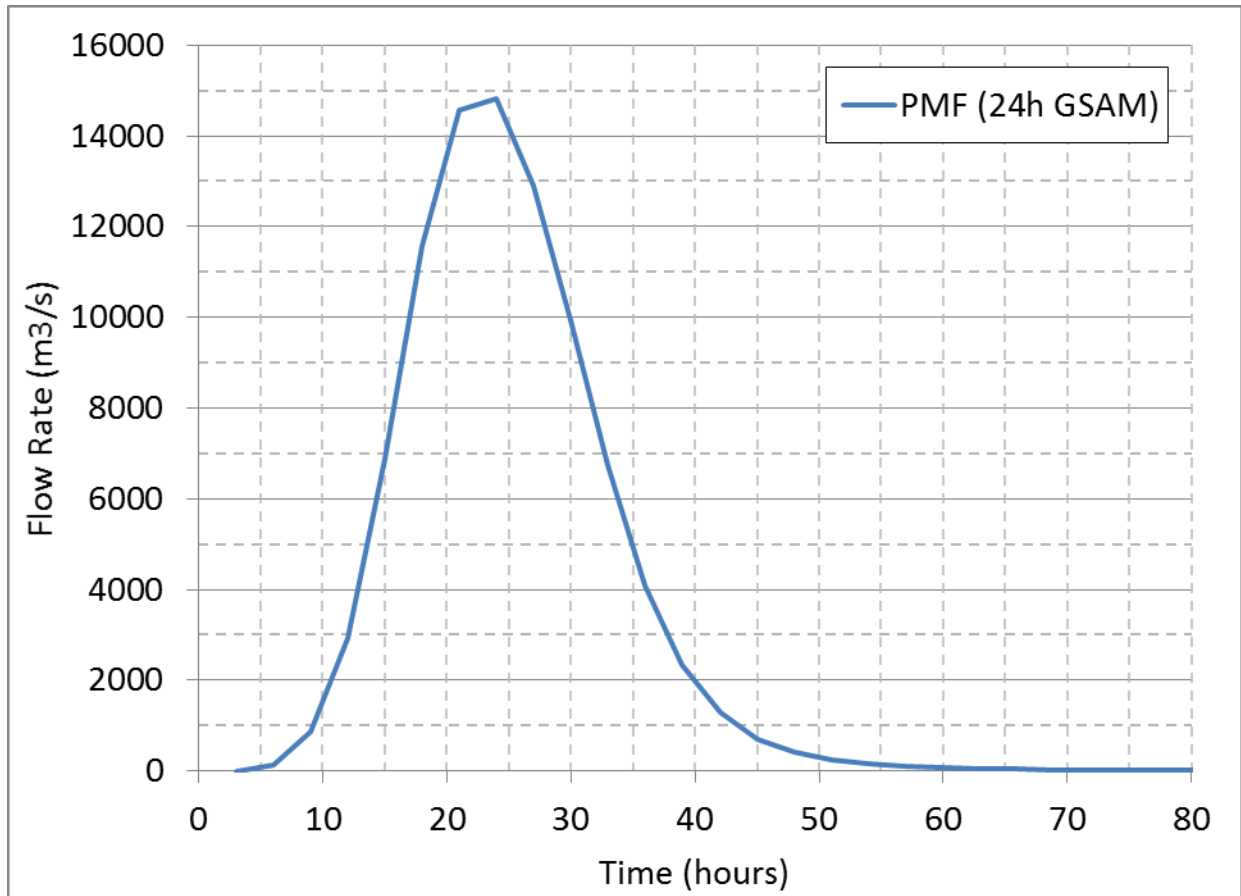


Figure 3-39 Avon River at Stratford PMF hydrograph

3.8.5 Validation

A PMF Estimate for Avon River at Stratford was prepared using the Quick Method of Nathan et al. (1994) to validate the GSAM estimate. This method applies a set of empirical equations to compute a triangular PMF hydrograph. The equations are:

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

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

$$T_p = 0.0001062 A^{-1.057} V^{1.446}$$

$$T_r = V / (1.8 Q_p)$$

Where:

Q_p is peak flow (m³/s)
 A is catchment area (km²)
 V is hydrograph volume (ML)
 T_p is time to peak of hydrograph (h)
 And T_r is base length of hydrograph (h)

The equations are applicable to southeast Australian catchments from 1 to 10,000 km² that do not have large lakes or storages. The resulting PMF peak flow, volume, time to peak and hydrograph length are:

A	1,485 km ²
Q _p	11,607 m ³ /s
V	657,577 ML
T _p	12.2 h
T _r	31.5 h

The quick PMF peak flow is within 22% and volume is within 33% of the RORB PMF results, providing validation that the RORB PMF estimate is appropriate. The RORB PMF estimate is higher, providing a more conservative estimate.

4. CONCLUSION AND NEXT STEPS

Through a process of flood frequency analysis, hydrologic modelling and application of various regional methods, a set of design flood hydrographs have been developed for the Avon River and its tributaries. The hydrological analysis has been based on robust methods and extensive cross-validation due to the relatively high gauge density within the catchment. Validation of the design peak flows against flood frequency analysis and comparison of the design hydrographs against gauged hydrographs gives confidence that they are representative of actual flood risk and appropriate for design.

The next steps in the analysis are:

- Further development and calibration of the hydraulic model
- Sensitivity testing of hydraulic model

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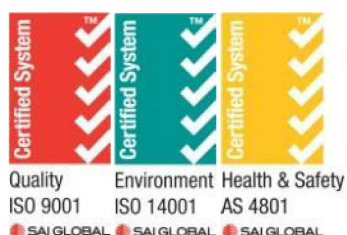
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1. INTRODUCTION

Water Technology was commissioned by the Department of Environment, Land, Water and Planning (DELWP) to undertake regional flood mapping for the Avon River. This project includes detailed hydrological and hydraulic modelling of the Avon River and its tributaries including Freestone Creek, Valencia Creek and Blackall Creek, and will take into account the downstream influences of Lake Wellington. This mapping will be used to satisfy a range of business requirements from planning, emergency response, to community awareness and for insurance purposes.

As part of the preliminary reporting work, the data required for modelling and mapping was collated and reviewed. This report documents the data review findings and identifies gaps in the data. It also outlines the proposed hydrological and hydraulic modelling scope and methodology.

2. STUDY AREA

The Avon River rises on the slopes of Mount Wellington in the eastern highlands of the Great Dividing Range and flows south to Lake Wellington and the Gippsland Lakes. The mountainous upper catchment is largely forested, while the lower catchment downstream of the confluence with Valencia Creek is topographically more subdued and agriculture is the primary land use (EarthTech, 2007). The floodplain in the lower reaches is traversed by watercourses, swamps and lagoons. Overall, the river descends some 664 m over its 122 km length.

Regional mapping will include approximately 40km of the downstream floodplain of the Avon River catchment, as well as large portions of Freestone Creek, Valencia Creek and Blackall Creek. Key towns within this catchment area include Stratford, Boisdale and Briagolong. The study area and significant watercourses or flood related influences are shown in Figure 2-1.

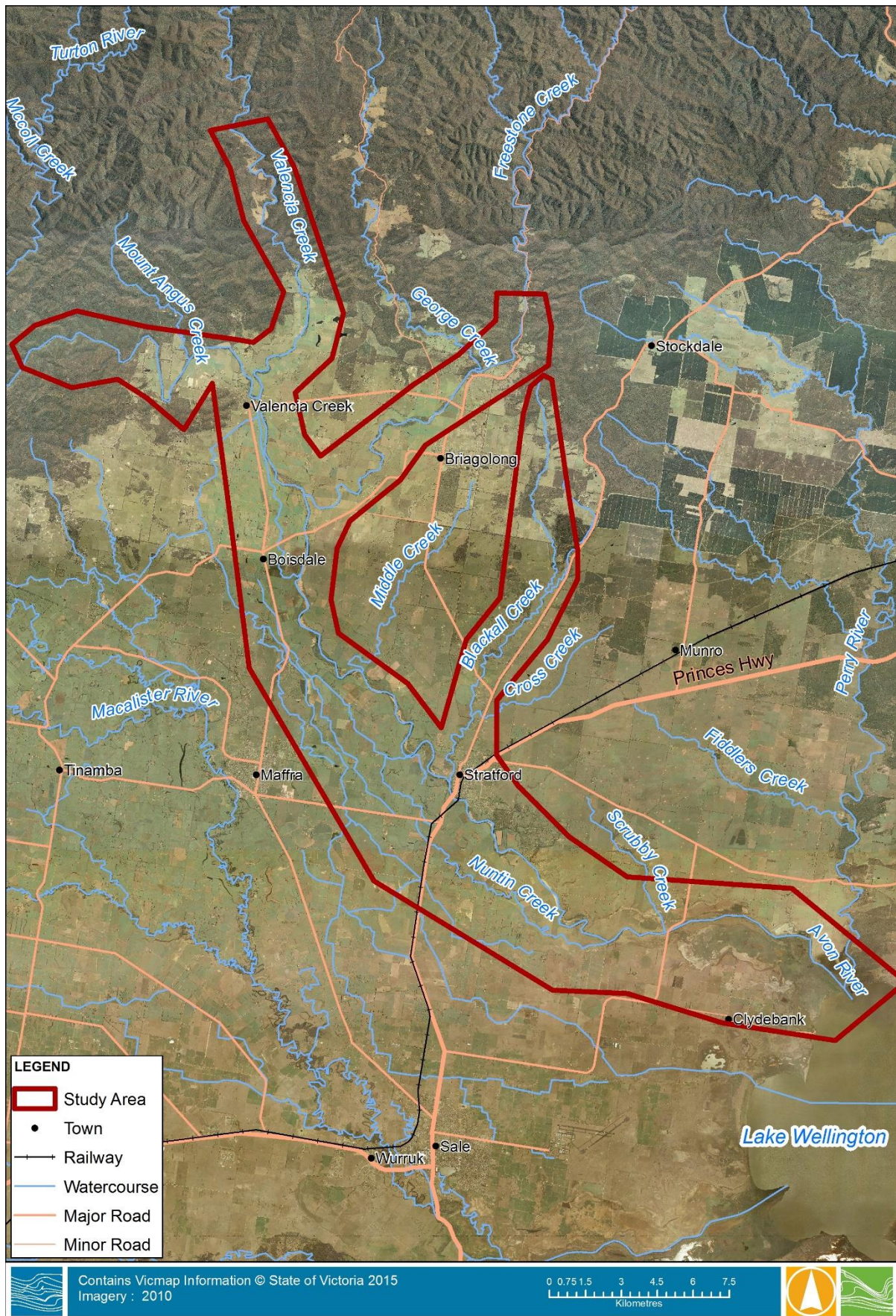


Figure 2-1 Avon River study area

3. PREVIOUS STUDIES

3.1 Flood Related Studies

Due to extreme erosion in the Avon catchment in the past, flood related studies have generally been related to geomorphology, rather than flooding mechanisms and hydraulics. Whilst the river's geomorphology is discussed in Section 3.2, only the flooding components will be discussed in this section.

Early 20th century descriptions of the waterway, such as that by Strom (1937), suggested that flood peaks in the various tributaries coincide more or less with the flood peak in the main stream. This effect is accentuated by the steep grades in the stream in the upper section, compared with the flatter grades of the streams draining the downstream floodplain area. Floods were noted to have a rapid rise, high peak of short duration, and rapid fall. Macintyre & Grant (1950) also noted tendency for the Avon River to exhibit 'flashy' and violent flows immediately after rain falls in its catchment area.

Alluvium (2008b) noted the Avon River experiences flashier flows than other comparable systems. Brizga (1990) also noted flood regimes in the Avon and Freestone rivers are significantly more variable than other flood regimes in the same climatic zone.

Extreme flooding in 1990 prompted an investigation by Sherrard (1990), which includes a detailed description of the 1990 flood with interviews of land owners, aerial photography, survey and cross sections. A similar report from East and West Gippsland Catchment Management Authorities (2007) after the 2007 flood showed significant areas of erosion and overbank flows. Alluvium (2008b) noted that Wombat Flat is the first major overbank flow location, with water then able to exhibit overbank flows at a number of locations in the lower catchment.

Erskine et al. (1990) noted that the existing channel capacity is very large in the heavily eroded and incised Avon River, and in many places overbank flows are unlikely, even in large events. Geomorphic effects of the 1990 flood were not as great as those experienced in previously recorded major flood events, and it is suggested that *'the Avon River is now better able to accommodate large floods'* (Erskine, et al, 1990).

SKM (2003) developed a water balance model to investigate Clydebank Morass. This model uses the Boughton conceptual model to generate surface runoff volumes, which assumes a finite amount of rainfall can be absorbed by the soil moisture store, and extra water is generated as runoff. Irrigation, evapotranspiration and groundwater were also taken into account. The design hydrology was verified with a flood frequency analysis of the Avon River based on 21 years of data at the Stratford gauge. This study is focussed on the extreme downstream sections of the Avon River at Clydebank Morass, and mainly focuses on high frequency events.

Hydraulic modelling of the reach was undertaken by Earthtech (2007) for the purpose of environmental flow studies. The catchment was split into a number of reaches, and separate one dimensional steady state HEC RAS models were developed for each reach. Topography was based on cross-section surveys throughout the catchment. The one dimensional model was aimed at analysing environmental flow conditions, but is not capable of being adapted to flood mapping purposes.

A refined one dimensional model was developed by Alluvium (2008a) to allow for a hydraulic analysis of the lower reaches of the Avon (downstream of Stratford) to aid design of Nuntin spillway. Hydrology for this model was adapted from SKM's (2003) updated water balance model.

With the addition of LiDAR, Alluvium (2013b) was able to perform two dimensional hydraulic modelling of the Nuntin Spillway and downstream Avon reach with XPSWMM software. Hydrology for the model was generated using a partial and annual series analysis at the Avon River at Stratford gauge. This allowed determination of 1 year to 100 year Annual Recurrence Interval (ARI) flows for the Avon River downstream of Stratford.

3.2 Geomorphology Related Studies

Following severe river widening in the 1936 flood, the State Rivers and Water Supply Commission undertook a report on erosion of the alluvial part of the Avon River, downstream of Valencia Creek. This reach has been subject to ongoing adjustments in its planform and channel dimensions since the area was settled. At the time of European settlement (around the 1840s) the river at Boisdale was reported to be 20-40 m wide with scrub and trees on both banks (Strom, 1937). In the course of settlement most of the riparian vegetation was cleared and the banks began to erode in the 1893 flood. Due to enlargement of the channel, a greater proportion of floodwaters now flowed down the channel than before European settlement. Strom (1937) reported that even in the large flood of 1936 (the third-largest flood since European settlement), overflow from the channel occurred in only a few locations in the Boisdale reach. The channel continued to widen and deepen over subsequent floods, and it was estimated that 2000 acres of land had been eroded by 1937. The ongoing erosion of the river was attributed to the high flood velocity in the already-enlarged channel, along with the friable nature of the bank material, the cleared banks, and possibly a fall in base level at Lake Wellington associated with the opening of a permanent entrance to the Gippsland Lakes (Strom, 1937).

The reported dramatic river change prompted an investigation of the metamorphosis of the Avon River by Brizga (1990). She found that the Avon River upstream of Weirs Crossing was already incised and actively migrating at the time of European settlement, and subsequent channel change was characterised by an increase in meander wavelength coupled with some increase in the degree of incision. Dramatic channel metamorphosis was confined to the reach between Weirs Crossing and Redbank, and involved channel incision and increased lateral migration. This metamorphosis was attributed to the crossing of intrinsic threshold due to the input of sediment from the incised reaches upstream, as well as the clearing of vegetation from channel banks (Brizga, 1990). Downstream of Redbank, the previously navigable channel has become filled with sand eroded from the channel further upstream (Brizga, 1990).

Popular perceptions that the entire alluvial section of the Avon River had enlarged due to human intervention have resulted in intensive management due both to a perceived duty to right the wrongs of European settlement and an economic imperative to minimise the “loss” of productive land (Finlayson et al., 1995). However, the total loss of land was probably overestimated in early studies (e.g. Strom, 1937), as the pre-European dimensions of the channel were underestimated, and recently reworked bare land was assumed to be unproductive.

Pre-1950, interventions were generally limited to localised protective works at the major road and rail bridges and near Stratford (Alluvium, 2013a). In 1951 the Avon River Improvement Trust was established and widespread restoration works including concrete block and timber groynes were installed. Subsequent floods continued to produce extensive erosion, including the 1971 flood, which washed away the old Princes Highway Bridge. The 1990 flood was the largest on record but resulted in a surprisingly small amount of channel change (Sherrard, 1990). This was thought to be because the Avon River has reached a critical channel size such that vegetation can establish on in-channel features and the stream power of floods is dissipated over its large channel boundary. If so, the channel is likely to continue to recover, although meander migration will be ongoing, resulting in localised bank erosion (Alluvium, 2013a).

The build-up of sand in the lower reach is still considered a problem, as it increases the risk of an avulsion at the Nuntin Spillway (formerly Nuntin levee) into the lower end of Nuntin Creek. In the 2007 flood, the Nuntin levee was completely scoured out. The Nuntin Creek strategy (Alluvium 2008a) was developed and implemented with the aim of preventing avulsion and encouraging deposition on the floodplain. The strategy included the replacement of the levee with a spillway with its crest at natural bank height, and substantial revegetation along scour paths, to encourage deposition on the floodplain. This was further modified after flooding in 2012, with rock piling and a higher crest.

A geomorphic review in 2013 (Alluvium 2013a) identified the following ongoing risks:

- Further deepening and widening of the Avon River in the vicinity of the Freestone Creek confluence, and in the lower reach of Freestone Creek
- Ongoing meander migration resulting in channel widening
- Ongoing sediment transport into the lower reaches continuing to increase the risk of development of the Nuntin avulsion.

4. DATA AVAILABILITY

4.1 Digital Elevation Models and Survey

4.1.1 Available LiDAR

Aerial LiDAR (Light Detection and Ranging) survey is available for the Avon study area from three different sources:

- 2007-08 Southern Rural Water LiDAR Project
- 2009-10 Victorian State Wide Rivers LiDAR Project - West Gippsland CMA
- 2009-10 Floodplains Stage 1 LiDAR Project

Key metadata for the three digital elevation models (DEMs) is given in Table 4-1, and their extents are shown in Figure 4-1. The Floodplains LiDAR only covers two small parts of the study area at Briagolong and Stratford. The Rivers LiDAR covers most of the study area but only for a 1-2km wide corridor along watercourses. The Southern Rural Water (SRW) LiDAR has a more complete coverage of the study area downstream of the Valencia and Avon confluence but does not capture Freestone and Blackall Creeks.

Table 4-1 Key metadata for LiDAR datasets

Dataset	Source	Date of Capture	Vertical accuracy (1 sigma)	Resolution
2007-08 SRW LiDAR	LiDAR	Jul 2008-Aug 2008	0.10 m	1 m
2009-10 Rivers LiDAR	LiDAR	Feb-Nov 2010	0.20 m	1 m
2009-10 Floodplains LiDAR	LiDAR	Dec 2010-Feb2011	0.10 m	1 m

As the SRW DEM is rated to a higher accuracy and has greater coverage within the study area it has been used as the primary dataset for modelling, supplemented by the Stratford section of the Floodplains LiDAR and upstream sections of the Rivers LiDAR (see section 4.1.2 of this report for further details).

A coarse (~90 m resolution) DEM is available from Geoscience Australia for the whole Avon River catchment for catchment delineation purposes.

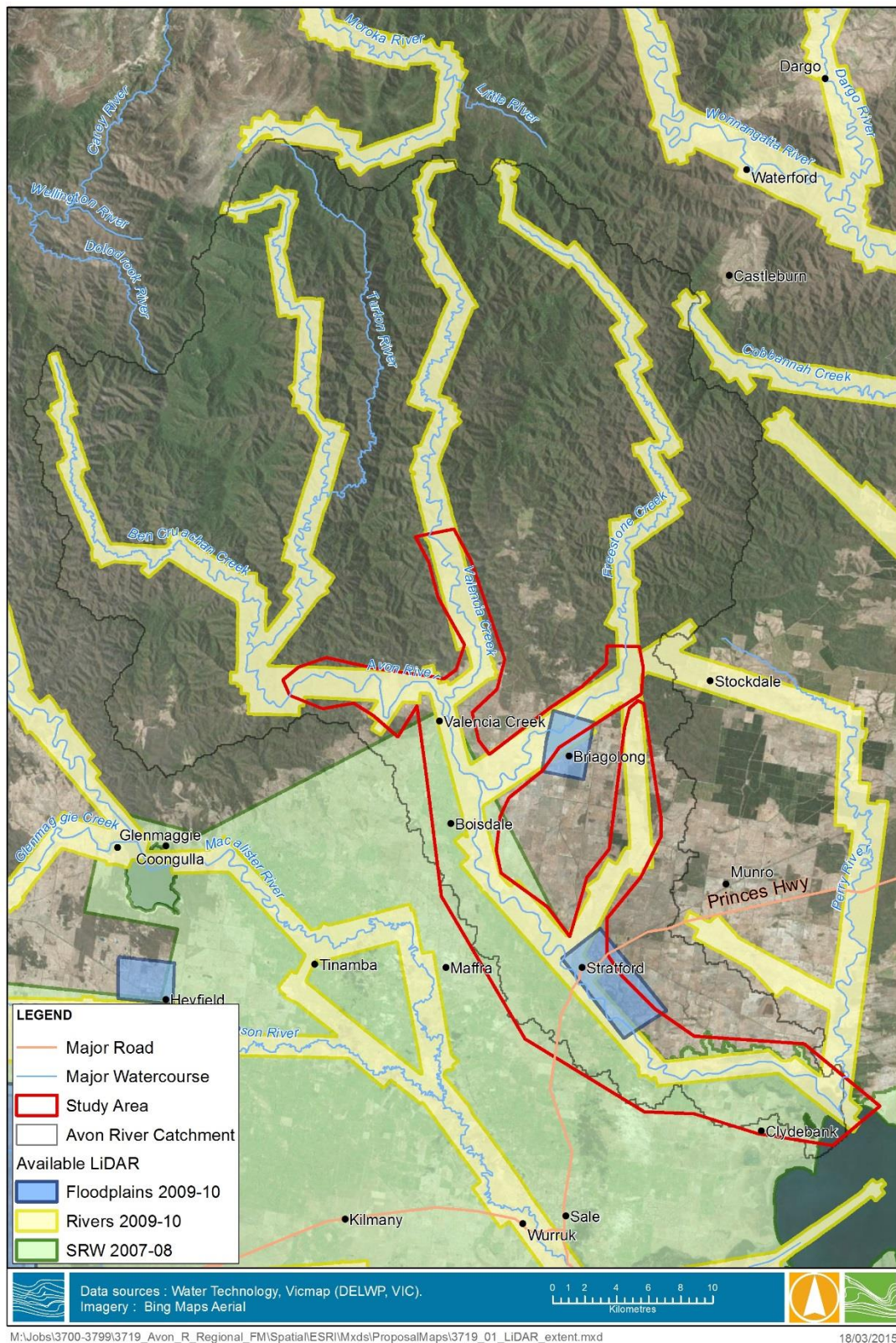


Figure 4-1 LiDAR extents

4.1.2 LiDAR Verification

LiDAR Comparison

A comparison of the SRW and Rivers LiDAR datasets where they overlap is shown in Figure 4-2. The difference shown represents the River LiDAR minus the SRW LiDAR data. A systematic vertical offset is discernible between the two datasets in flat floodplain areas. In these areas, the Rivers LiDAR is consistently ~0.20 m higher than the SRW LiDAR.

A similar comparison between the SRW and Floodplains LiDAR datasets revealed a good agreement between the two datasets with a mean difference of ~0.03 m.

In the absence of any topographic survey data to use for verifying the LiDAR datasets, a comparison with the AHD elevations of 14 survey benchmarks (third-order) throughout the study area was completed. The location of the benchmarks is shown in Figure 4-3 and the results of this comparison are shown in Table 4-2. The comparison showed that the Rivers LiDAR was on average 0.234 m higher than the survey benchmarks, the SRW LiDAR was 0.054 m higher on average and the Floodplains LiDAR was 0.025m higher on average. The comparisons indicate that the Rivers LiDAR has a positive vertical offset from AHD of around 0.2 m which should be corrected before use of the data for the hydraulic modelling.

Cross Section Verification

Cross-sections of the Avon River, Freestone Creek and Valencia Creek were surveyed as part of Earthtech's (2007) *Environmental Flow Determination for the Avon River* one-dimensional HEC-RAS modelling. These cross-sections capture the river channel, and can be compared to the LiDAR within the channel during development of the hydraulic model. As LiDAR cannot penetrate below the water surface any areas where water was present in the channel will not be accurately resolved in the LiDAR.

After comparison of the LiDAR and cross-section data, it was determined that the channel was represented in enough detail for hydraulic modelling based on LiDAR data. A typical comparison between cross section data and LiDAR data is shown in Figure 4-4 at Redbank, a section of the Avon River downstream of Stratford.

Typically, the Avon River main channel is over 100m wide and has a large flow capacity. Only a small portion of this channel is activated during non-flood conditions. Water is generally considered a barrier to LiDAR survey, but the large channel capacity of the Avon minimises the effects of this issue. In the floods that are being modelled, it is considered unlikely that the low-flow channel will cause considerable impact to the total channel capacity and hydraulic modelling results.

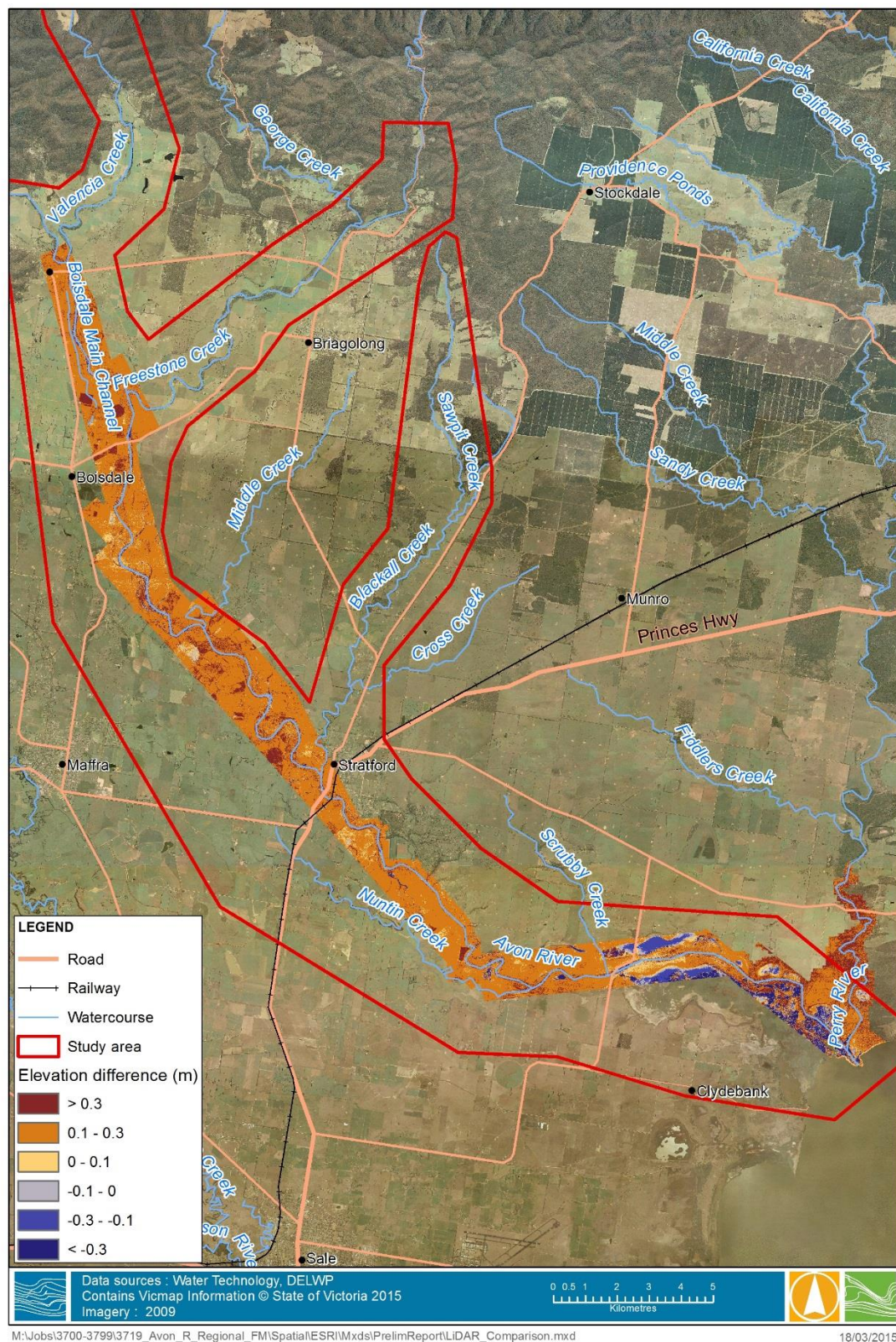


Figure 4-2 LiDAR comparison – Rivers DEM minus SRW DEM

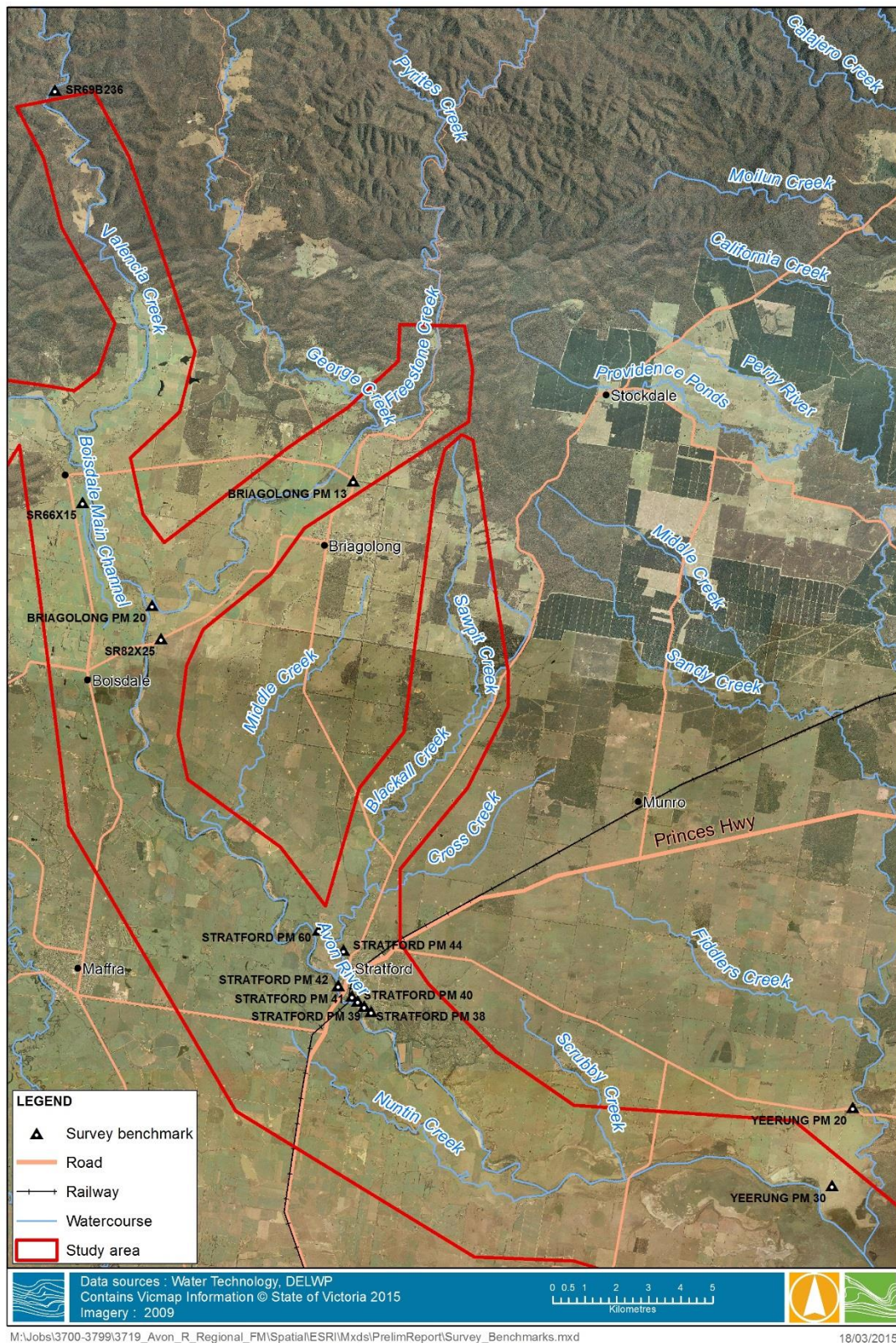


Figure 4-3 Location of survey benchmarks

Table 4-2 Comparison of survey benchmark elevations minus LiDAR elevations

Benchmark Name	AHD	Rivers LiDAR	Difference	SRW LiDAR	Difference	Floodplains LiDAR	Difference
BRIAGOLONG PM 13	68.551	68.732	-0.181				
BRIAGOLONG PM 20	38.964	39.095	-0.131	38.975	-0.011		
SR66X15	45.567	45.960	-0.393	45.780	-0.213		
SR69B236	111.881	111.988	-0.107				
SR82X25	38.069	38.458	-0.389	38.310	-0.241		
STRATFORD PM 38	18.261	18.423	-0.162	18.423	-0.162	18.28	-0.019
STRATFORD PM 39	19.991	20.133	-0.142	20.025	-0.034	20.01	-0.019
STRATFORD PM 40	18.904	19.037	-0.133	18.905	-0.001	18.86	0.044
STRATFORD PM 41	18.897	19.222	-0.325	19.056	-0.159	19.03	-0.133
STRATFORD PM 42	19.281	19.481	-0.200	19.268	0.013	19.21	0.071
STRATFORD PM 44	23.916	24.177	-0.261			24.01	-0.094
STRATFORD PM 60	23.731	23.893	-0.162	23.743	-0.012		
YEERUNG PM 20	11.851	12.530	-0.679				
YEERUNG PM 30	8.601	8.608	-0.007	8.320	0.281		
Average Difference:			-0.234		-0.054		-0.025

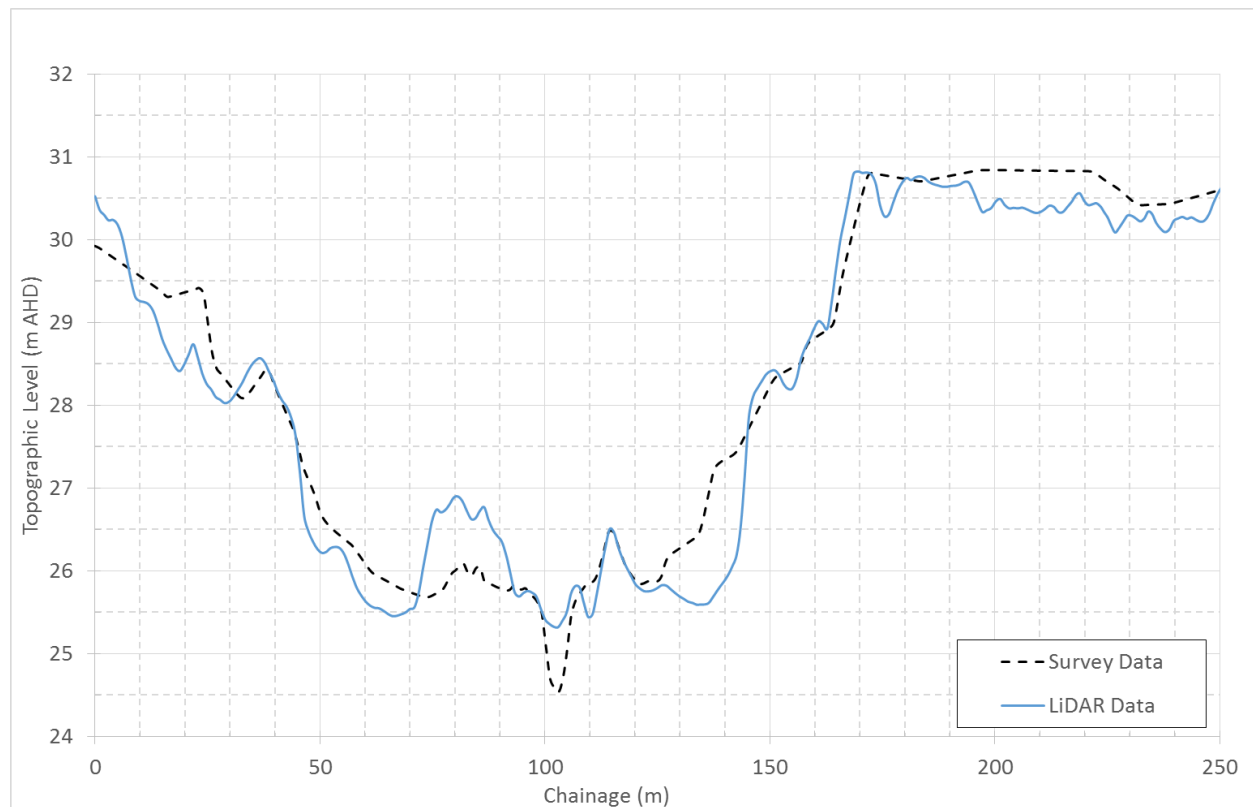


Figure 4-4 Cross Section at Redbank with Lidar and Survey Comparison

4.1.3 Digital Elevation Model Development

As previously discussed in Section 4.1.1, there are three LiDAR datasets that will be combined to produce a Digital Elevation Model (DEM) of the model area; known as Rivers LiDAR, SRW LiDAR and Floodplains LiDAR, respectively. Of these datasets, analysis showed that the highest vertical accuracy and a good agreement with benchmarks and each other exists in the SRW and Floodplains LiDAR. It was therefore decided to preferentially use this LiDAR, which covers the Avon River downstream from Valencia Creek to Lake Wellington.

The remaining areas including the Avon River upstream of Valencia Creek, Valencia Creek, Freestone Creek and Blackall Creek will all be covered using Rivers LiDAR. As previously discussed in Section 4.1.2, Rivers LiDAR was found to be consistently offset vertically by +0.2 m compared to survey marks and other LiDAR datasets. Therefore, in the regions where Rivers LiDAR is being utilised it will be reduced by 0.2 m.

There are also areas in the model that are not covered by LiDAR datasets. These are generally in topographically high areas that would not normally be affected by floodwaters. Initial testing will be undertaken to see if water reaches any of these uncaptured areas, and if so, coarse topographic data from Geoscience Australia will be supplemented into these areas.

Manual smoothing will be required for transitions between the datasets to ensure the model hydraulics are not impacted by the change in source DEM. A summary of the datasets that will be used in the DEM preparation is shown in Figure 4-5.

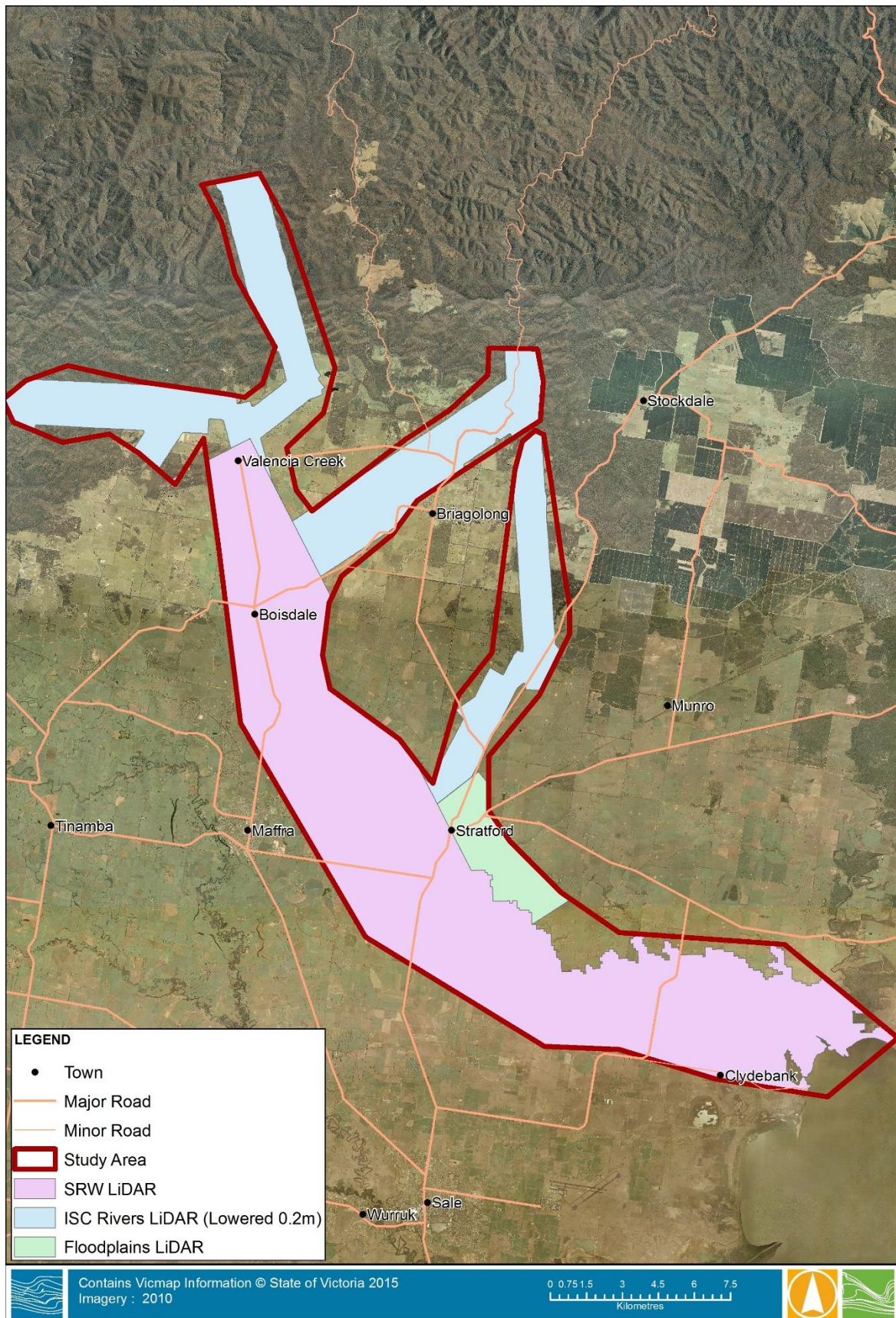


Figure 4-5 Model DEM Preparation Plan

4.2 Hydrological Data

4.2.1 Rainfall Data

The average annual rainfall varies throughout the catchment, reaching 1910 mm at the headwaters and as low as 600 mm near its outlet to Lake Wellington. At the catchment centroid the average annual rainfall is approximately 670 mm.

Numerous daily rainfall sites are in operation in and around the catchment. Key stations, including current stations and stations operating over the 2007, 2011 and 2012 floods, are listed in Table 4-3.

Table 4-3 Daily rainfall stations around Avon River catchment

Gauge No.	Location	Period	Years	Distance from catchment centroid (km)
85054	Maffra Shire Hall	1879 - 1968	82	29
85020	Clydebank	1884 - 2009	121	37
85130	Newry	1885 - 1930	42	19
85012	Boisdale	1886 - 1954	51	18
85090	Valencia Creek (Bulgar Park)	1887 - 1974	86	8
85055	Maffra Forestry Office	1899 - 1996	92	25
85083	Tinamba West	1905 - 1950	46	24
85035	Glenmaggie (The Laurels)	1905 - 1957	53	26
85016	Bushy Park	1905 - 1983	79	14
85203	Licola (RWC)	1906 - 2002	56	34
85211	Glenmaggie (Cheynes)	1906 - 1919	11	25
85027	Fernbank	1908 - 1967	59	33
85080	The Heart	1922 - 1956	35	44
85088	Valencia Creek	1938 - 1986	48	9
85034	Glenmaggie Weir	1938 - 2015	78	25
85104	Cobbannah	1952 - 1955	4	22
85167	Meerlieu (Springvale West)	1968 - 2015	48	45
85165	Fernbank (Towri)	1968 - 2010	41	35
85168	Briagolong	1968 - 2015	48	13
85171	Culloden (Estoppey)	1968 - 1979	12	11
85166	Stratford	1968 - 2015	47	26
85254	Valencia Creek (Little Plain)	1974 - 2015	42	8
85286	Stringybark Creek	1989 - 2002	14	28
85296	Mount Moornapa	1994 - 2015	22	13
85297	Maffra	1993 - 2012	20	25
85276	Avon River @ The Channel	2000 - 2015	16	11
84118	Wonnangatta River @ Waterford	2000 - 2015	16	32
85304	Mount Wellington	2002 - 2015	14	30
85303	Reeves Knob	2002 - 2015	14	23
85306	Licola	2010 - 2015	6	34

Pluviograph (sub-daily rainfall) stations in and around the Avon River catchment that captured the 2007, 2011 and 2012 calibration events are listed in Table 4-4. The 2007 event was not captured by East Sale Airport and the Macalister River @ Licola gauges. The 2011 event was not captured by Glenmaggie Weir and Glencairn gauges. The 2012 event was not captured by East Sale Airport, Glenmaggie Weir and Glencairn gauges. Fortunately, these missed events do not cause significant model issues as the pluviograph density is still considered high for use in model calibration.

Table 4-4 Pluviograph stations around Avon River catchment

Gauge No.	Location	Period	Years	Distance from catchment centroid
85072	East Sale Airport	1943 - 2015	73	44
85034	Glenmaggie Weir	1957 - 2015	57	24
84125	Crooked River	1972 - 2015	42	41
85278	Aberfeldy (Lily Creek (Larommi))	1983- 2015	23	53
85254	Valencia Creek (Little Plain)	1984 - 2015	30	8
225209 (DELWP)	Macalister River @ Licola	1992 - 2015	24	35
225224 (DELWP)	Avon River @ The Channel	1992 - 2015	24	11
225201 (DELWP)	Avon River @ Stratford	1993 - 2015	23	27
225218 (DELWP)	Freestone Creek @ Briagalong	1995 - 2015	21	12
225809 (DELWP)	Avon River @ Mount Wellington	1997 - 2014	18	29
225810 (DELWP)	Avon River @ Reeve Knob	1997 - 2014	18	23
85058	Glencairn (Barkly River (Glenview))	2003 – 2015	11	45

4.2.2 Streamflow Data

Gauge Locations

Five streamflow gauges currently operate in the catchment, while historic data is also available for four other gauges (Table 4-5). Of the currently operating gauges, Valencia Creek at Gillio Road, Avon River at The Channel and Freestone Creek at Briagalong gauges record streamflow at three largest upstream tributaries that are to be mapped – the Avon River, Valencia Creek and Freestone Creek. Downstream gauges at Stratford and Clydebank include 90% and 96% of the Avon River catchment, respectively. Of the five currently operating gauges, all of them recorded data during the 2007, 2011 and 2012 calibration events. The currently available streamflow gauges are shown in Figure 4-7.

Table 4-5 Streamflow gauges in Avon River catchment

Gauge No.	Location	Period	Years	Catchment Area (km ²)
225223	Valencia Creek @ Gillio Road	1971 - 2015	35	195
225224	Avon River @ The Channel	1972 - 2015	34	554

Gauge No.	Location	Period	Years	Catchment Area (km ²)
225201	Avon River @ Stratford	1976 - 2015	38	1485
225218	Freestone Creek @ Briagalong	1967 - 2015	49	309
225234	Avon River @ Clydebank	1977 - 2015	39	1584
225255	Avon River U/S of Valencia Creek Junction	2004 - 2012	9	-
225211	Avon River @ Buxton	1953 - 1972	20	580
225220	Valencia Creek @ Radettis	1967 - 1971	5	233
225205	Avon River @ Valencia Creek	1919 - 1964	46	862

Rating Curves

Streamflow data in the catchment consists of five gauges, as discussed in Section 4.2.2. Of these gauges, the model will be primarily calibrated to the Avon River @ Stratford (225201) gauge. This gauge was found to have a number of high flow gaugings and has been consistently gauged throughout its 38 year gauging period. Consultations with the current hydrographer of the Avon basin suggest the gauging relationship at Stratford has been evolving for quite some time, likely due to channel change, however this has progressed in a distinguishable manner and is reflected in the flow estimates for the gauge (Wayne Ross pers. comm., 2015).

Upstream gauging stations are the Freestone Creek @ Briagalong, Valencia Creek @ Gillio Road and Avon River @ The Channel are also considered reliable. They have a number of high flow gaugings and little scatter.

However, the downstream gauge at Clydebank does not appear to have any high flow readings within the calibration flow range (up to approximately 185000 ML/day). The rating curve for Avon River @ Clydebank, also known locally as the Chinns Bridge gauge, is shown in Figure 4-8, with a highest gauging of 1.725 m (approximately 1050 ML/day). There are a number of issues associated with stage-discharge relationships at Clydebank. Whilst the gauge is on the Avon River, during high flow events wetlands on either side of the river are activated, causing multiple flow paths across the floodplain separate to the Avon River flow path. Clydebank is also close to the Avon River outlet at Lake Wellington, which has been shown to vary with a number of factors including atmospheric conditions, wind conditions, tides and recent amount of discharge into the lake (Brizga et al., 2013). Due to the uncertainty in the stage-discharge relationship for high flows at Clydebank, and the relative reliability of the Stratford gauge, the Stratford gauge was chosen as the primary gauge for downstream calibration of the hydrologic and hydraulic models with the Clydebank gauge acting as secondary validation point where required.

4.2.3 Water Level Data

Two water level gauges operate in Lake Wellington (Table 4-6). The Light Pile was installed in 2013 as part of an environmental flows monitoring program for the lower Latrobe River, and does not have data available for the selected calibration events. Bull Bay has a long record of data, including recorded data for the calibration events. Bull Bay water elevations will be used in the modelling as a downstream boundary.

Table 4-6 Water level gauges in Lake Wellington

Gauge No.	Location	Period	Years
226041	Lake Wellington @ Bull Bay	1975 - 2015	31
226610	Lake Wellington @ Light Pile	2013 - 2015	2

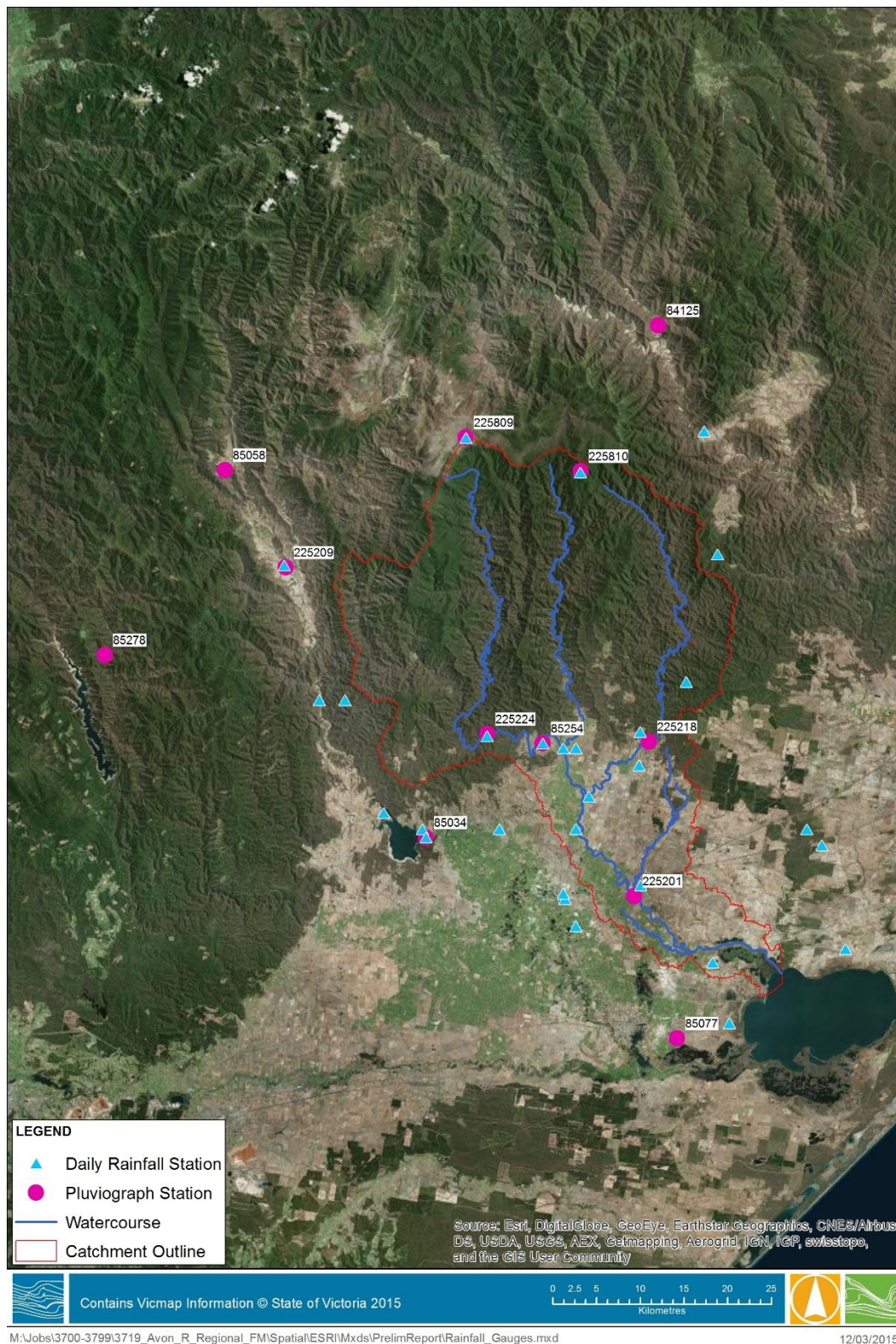


Figure 4-6 Rainfall stations in and around the Avon River catchment



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12/03/2015

Figure 4-7 Streamflow and water level gauges in the Avon River catchment

Department of Environment and Primary Industries

HYGPLOT V146 Output 11/02/2015

225234 AVON RIVER @ CLYDEBANK (CHINN'S BRIDGE)
Gaugings from 26/05/1977 to 03/12/2014

Rating Table 4.02 4.02

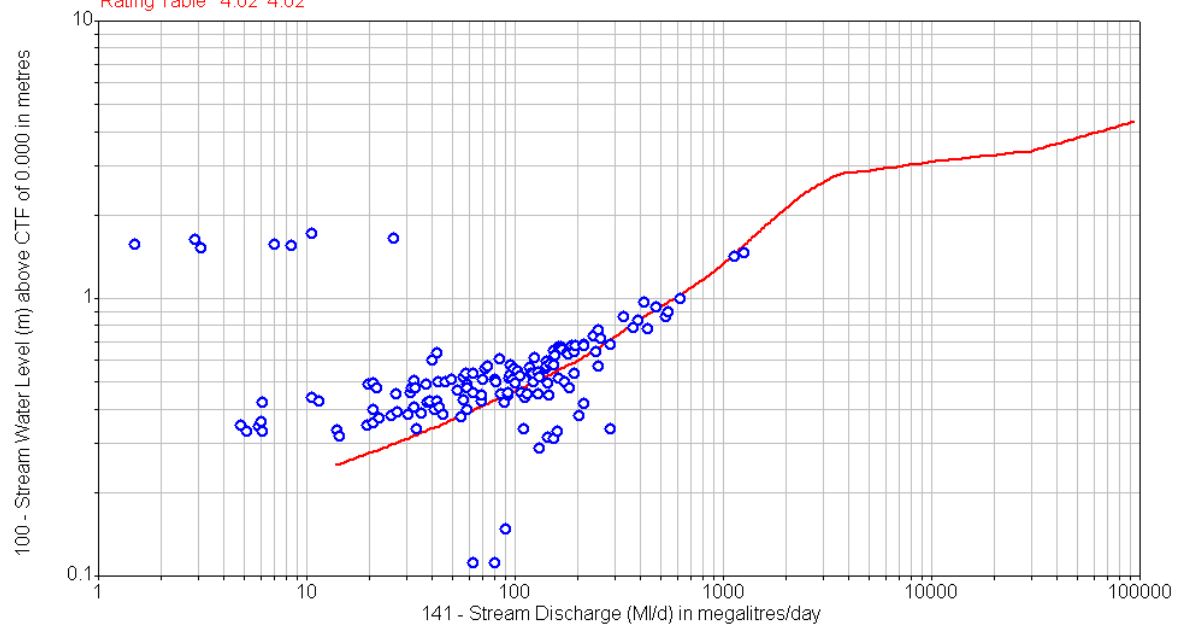


Figure 4-8 Avon River @ Clydebanks (225234) gaugings with rating curve plot

4.3 Hydraulic Structures

At the regional scale, hydraulic structures of interest are those that have the potential to impact the wider flood extent. These have been generally limited to bridges and weir crossings. The following structures are those that have been identified for incorporation to the hydraulic model.

4.3.1 Road / Rail Crossings

The resolution of the model allows for key bridge and rail crossings of the waterways to be included. Data on these bridges has been provided by VicRoads, whilst railway track information has currently been accessed from VicTrack. Weir crossings for vehicles and large railway culverts were also measured and photographed during a site visit on the 20/04/15. Locations of key structures are shown in Figure 4-9 and details of the structures are listed in Table 4-7.

4.3.2 Irrigation Channels

A network of open irrigation channels bisect the Avon floodplain, the most significant of which are located between downstream stretches of the Avon and Macalister rivers. Key irrigation channels in this area include Airly Channel, Webster Channel, the Boisdale Drains and Nuntin Creek.

The channel banks of these and other major irrigation channels which are known to impact on flooding will be sampled from the LiDAR and specifically incorporated into the hydraulic model. Due to the size of the study area and the impact of some minor structures during large floods, not all irrigation channel banks will be incorporated into the hydraulic model. It is encouraged that if there is any particular infrastructure that is of interest or has known flood impacts, that these be raised with the study team so they can be incorporated into the modelling.

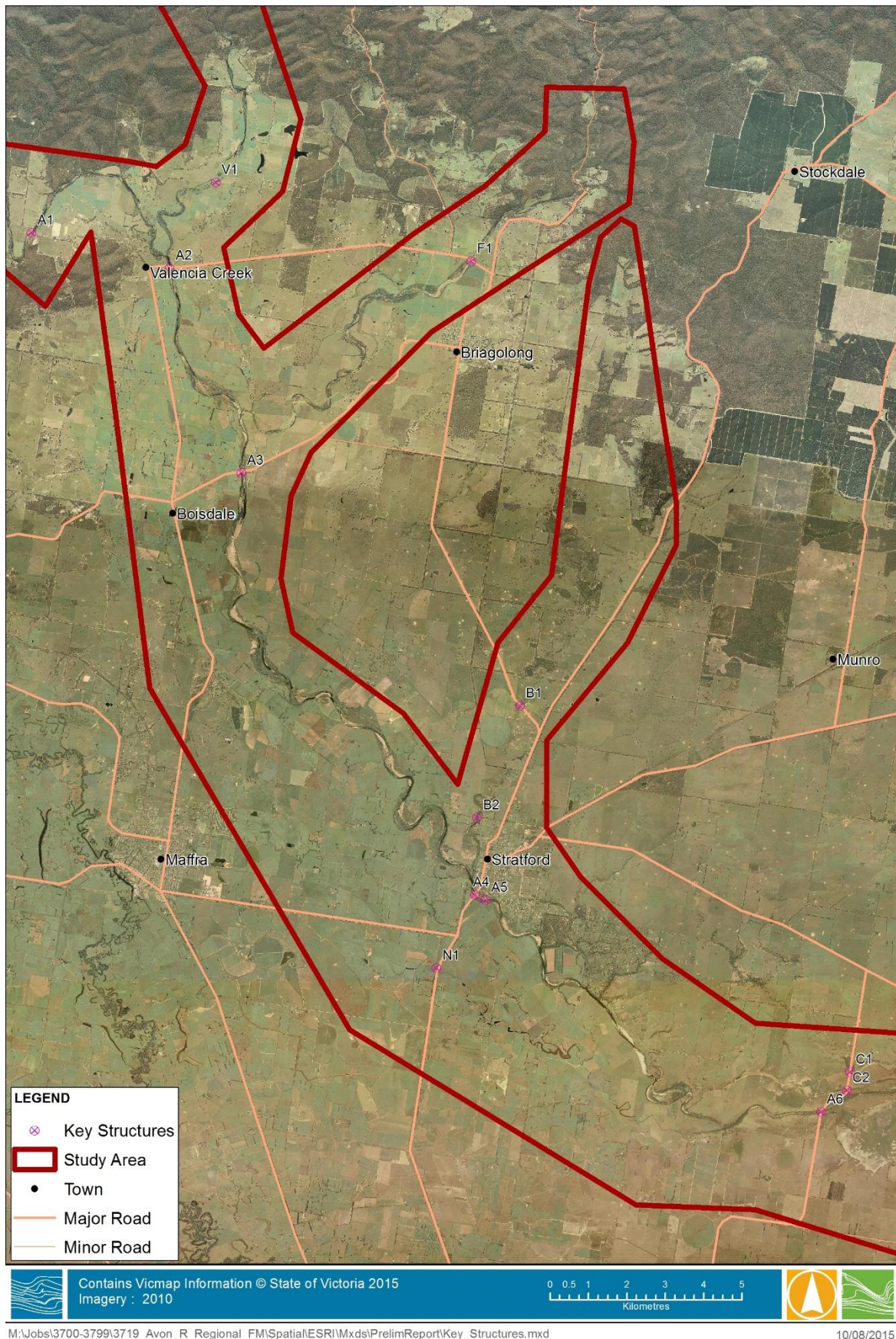


Figure 4-9 Key structures within study area

Table 4-7 Key details for surveyed bridges and culverts

Culvert ref.	Type	Description	Notes
A1	Causeway	3 span road crossing.	Known locally as Wombat Crossing. Crosses Avon River on Wombat Road.
A2	Causeway	Single span road crossing.	Just downstream of Valencia Creek and Avon River confluence. Crosses Avon River on Valencia Creek – Briagolong Road.
A3	Bridge	6 span road crossing with guard fence.	Known as Bushy Park Bridge. Crosses the Avon River on Maffra – Briagolong Road.
A4	Bridge	9 span road crossing with guard fence.	Princes Highway crossing of the Avon River. Stratford at Avon streamflow gauge is just upstream. Key township of Stratford is located on eastern side of bridge.
A5	Bridge	12 span rail crossing. There are also a number of openings and culverts along the elevated railway that leads to the bridge.	Railway bridge crossing of the Avon River. Has been extensively modified over time to keep up with erosion and scour issues.
A6	Bridge	7 span road crossing with guard fence.	Known locally as Chinns Bridge. Crosses Avon River on Bengworden Road. Avon River at Clydebank gauge is just upstream.
B1	Bridge	Single span road bridge with guard fence	Briagolong Road crossing of Blackall Creek.
B2	Bridge	5 span road bridge with guard fence.	Llowalong Road crossing of Blackall Creek.
C1	Bridge	Two lane road bridge.	Bengworden Road crossing of wetlands to the north of Avon River.
C2	Bridge	Two lane road bridge.	Bengworden Road crossing of wetlands to the north of Avon River.
F1	Bridge	5 span road bridge with guard fence.	Known as Delta Bridge. Crosses Freestone Creek at Valencia Creek – Briagolong Road.
F2	Bridge	6 span road bridge with guard fence.	Known as Nobles Bridge. Crosses Freestone Creek at Bushy Park.
N1	Bridge	Rail bridge with seven piers.	Rail crossing of Nuntin Creek.
V1	Causeway	Single span road crossing.	Known as Smythe's Bridge. Crosses Valencia Creek at Smythe's Road.

4.3.3 Levees

Constructed levees are not a key feature of the Avon River channel. The Nuntin Creek spillway, formerly Nuntin Creek levee, is the only large man-made levee that will be included in the model based on crest survey taken in 2013 (Alluvium, 2013b). The spillway has been modified a number of times,

and consideration will be taken in the hydraulic model calibration as to the configuration of the levee at the time of calibration.

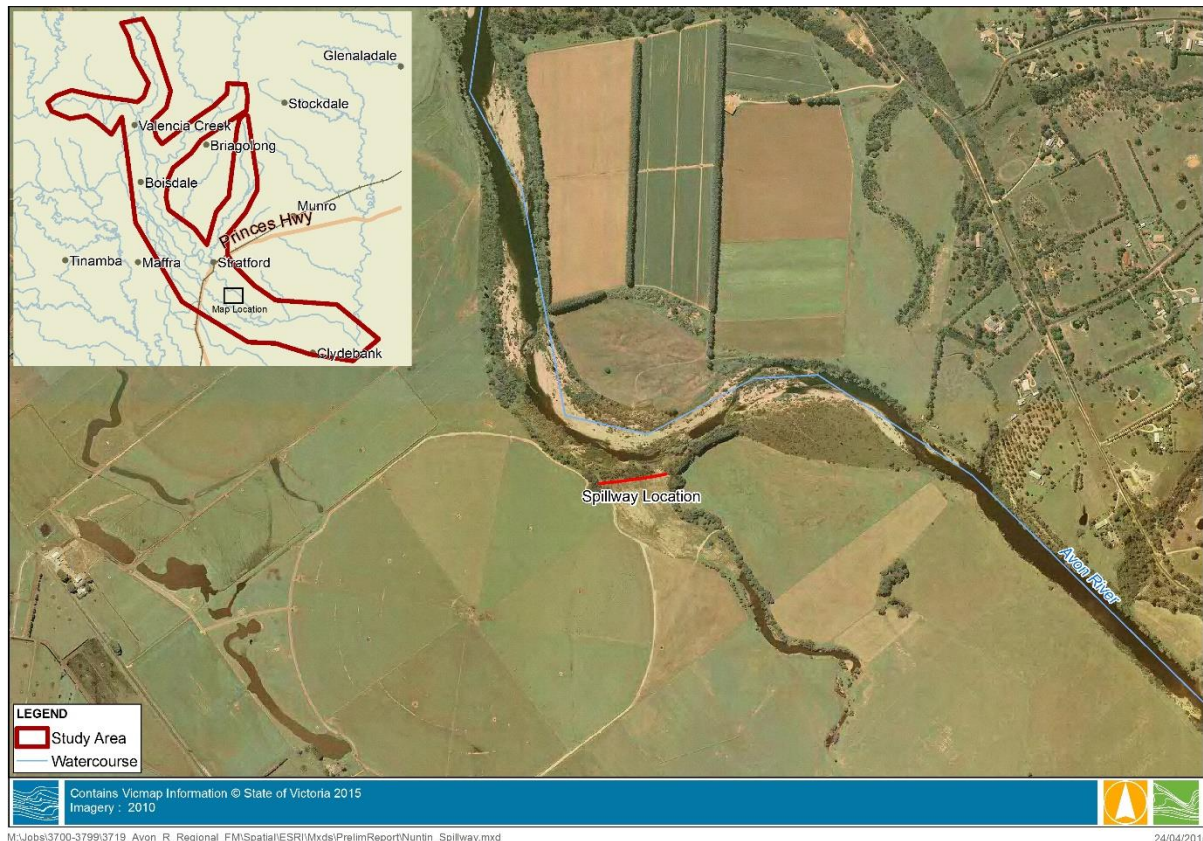


Figure 4-10 Location of Nuntin Creek Spillway (formerly Nuntin Creek Levee)

4.4 Flood Records

4.4.1 Historic Flood Information

Significant historic flood events have been compiled from available sources and are listed in Table 4-8. The largest flood on record at the Avon River at Stratford, Avon River at The Channel and the Freestone Creek at Briagalong gauges, was the April 1990 flood. Information is available for the 1990 event, including digitised flood extent, surveyed flood levels, floor levels and numerous flood photographs. After performing a flood frequency analysis on all available gauges in the catchment, this flood was estimated as between a 1% and 2% Annual Exceedance Probability (AEP). Another large flood occurred in the Avon catchment in June 2007, which also has available data including spot heights, digitised flood extents and scaled aerial photography. This 2007 event was estimated around a 4% AEP event. Data is also available for the 1936, 1978 and 2012 floods which were all significant flooding events.

Table 4-8 Historic flood events

Event	Description	Data available
1870	Severe flood (Strom, 1937)	
1893	Big flood (Strom, 1937)	
1916	Big flood (Strom, 1937)	
1935	Big flood (Strom, 1937)	

Event	Description	Data available
1936	Major flood, higher than all recorded floods except 1990 and 2007 at Stratford. Caused extensive damage to bridges, irrigation channels and river protection works, and washed away 40 acres of land on the Boisdale Flats (Strom, 1937).	Spot heights of flood level from Valencia Creek to Stratford. Peak flow rate estimated at 70000 cusecs (2000 m ³ /s) (Strom, 1937).
March and April 1950	Large floods, extensive damage to land and damage at two places to constructed water channels (Macintyre & Grant, 1950).	Peak flow estimated at 58500 cusecs (1650 m ³ /s) (Macintyre & Grant, 1950)
1971	No major flooding occurred between the 1950s and 1971. Excessive damage not recorded in the 1971 flood. (Ian Drummond and Associates, 1993).	
May 1978	Moderate flood.	Digitised flood extents downstream of Stratford.
April 1990	Major flood, highest recorded on gauges within catchment. Probably the highest flood since European settlement.	Spot heights of flood level from upstream of Valencia Creek to Clydebank. Digitised flood extents downstream of Stratford.
1998	Major flood.	
June 2007	Intense low pressure system caused major flooding, with many roads impassable and properties inundated. Second largest flood on record.	Spot heights of flood level from upstream of Valencia Creek to Clydebank. Digitised flood extents downstream of Stratford. Scaled aerial photography downstream of Lake Wellington.
August 2011	Major flood.	
June 2012	Major flood.	Digitised flood extents downstream of Stratford.

Historic flood data recorded in the Victorian Flood Database (VFD) is summarised in Figure 4-11, Figure 4-12, Figure 4-13, Figure 4-14 and Figure 4-15 below.



Figure 4-11 1936 flood information in VFD



Figure 4-12 May 1978 flood information in VFD

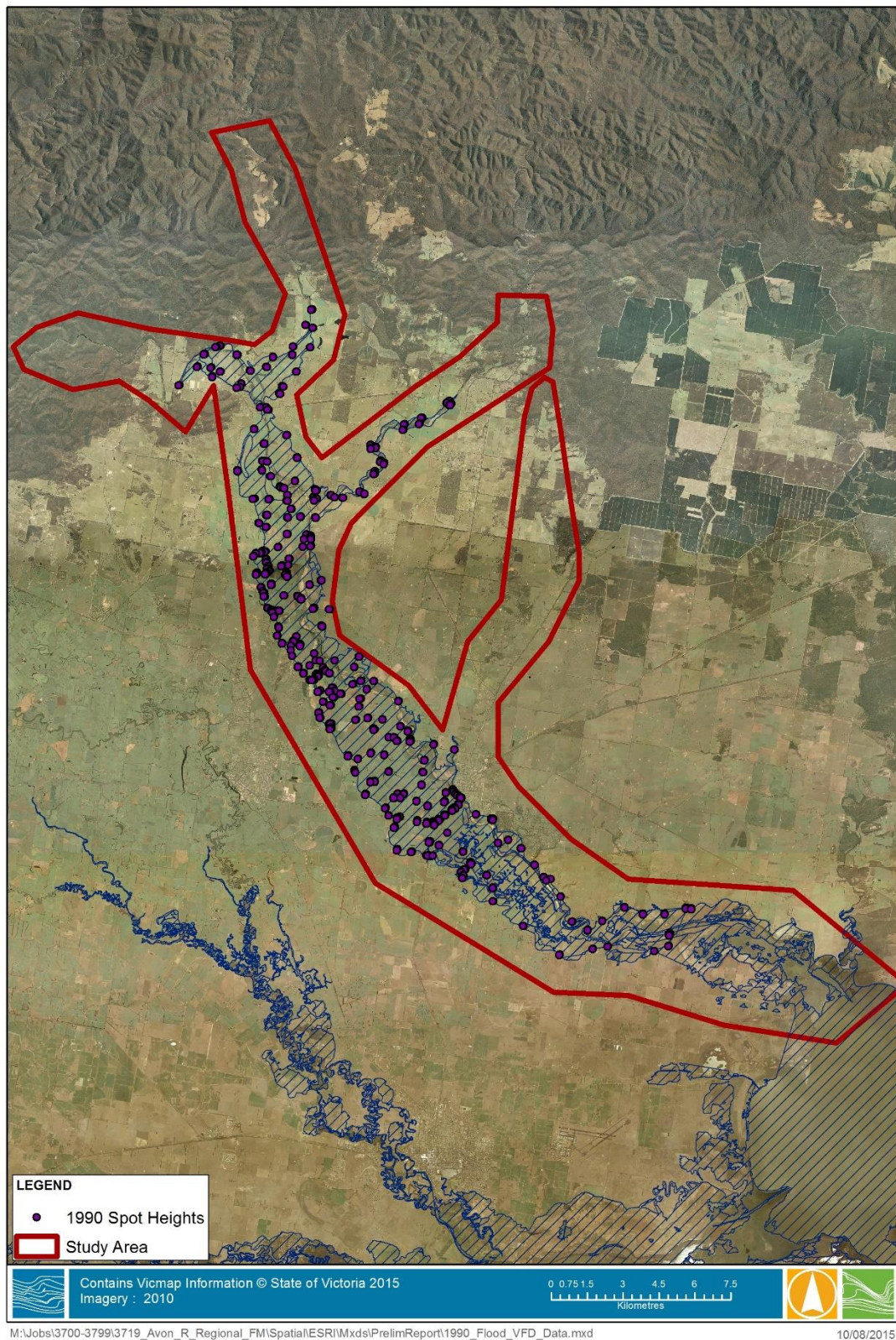


Figure 4-13 April 1990 flood information in VFD



Figure 4-14 June 2007 flood information in VFD

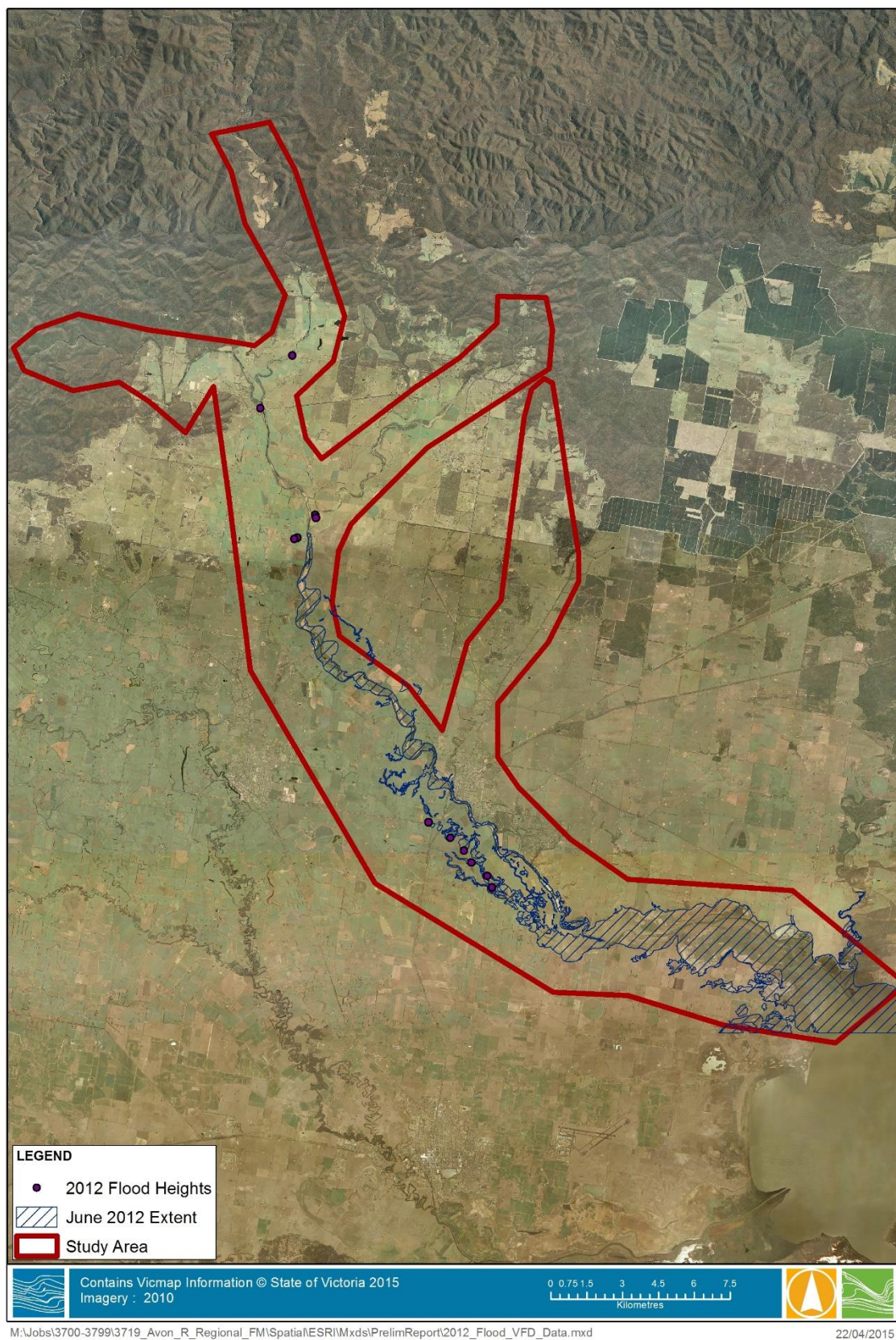


Figure 4-15 June 2012 information in VFD

4.4.2 Imagery

Georeferenced aerial photography was available for the June 2007 flood event downstream of Stratford to Lake Wellington, shown in Figure 4-16. This imagery was taken near the time of peak flooding and will be used to validate flood extents in this region when modelling the 2007 calibration event.

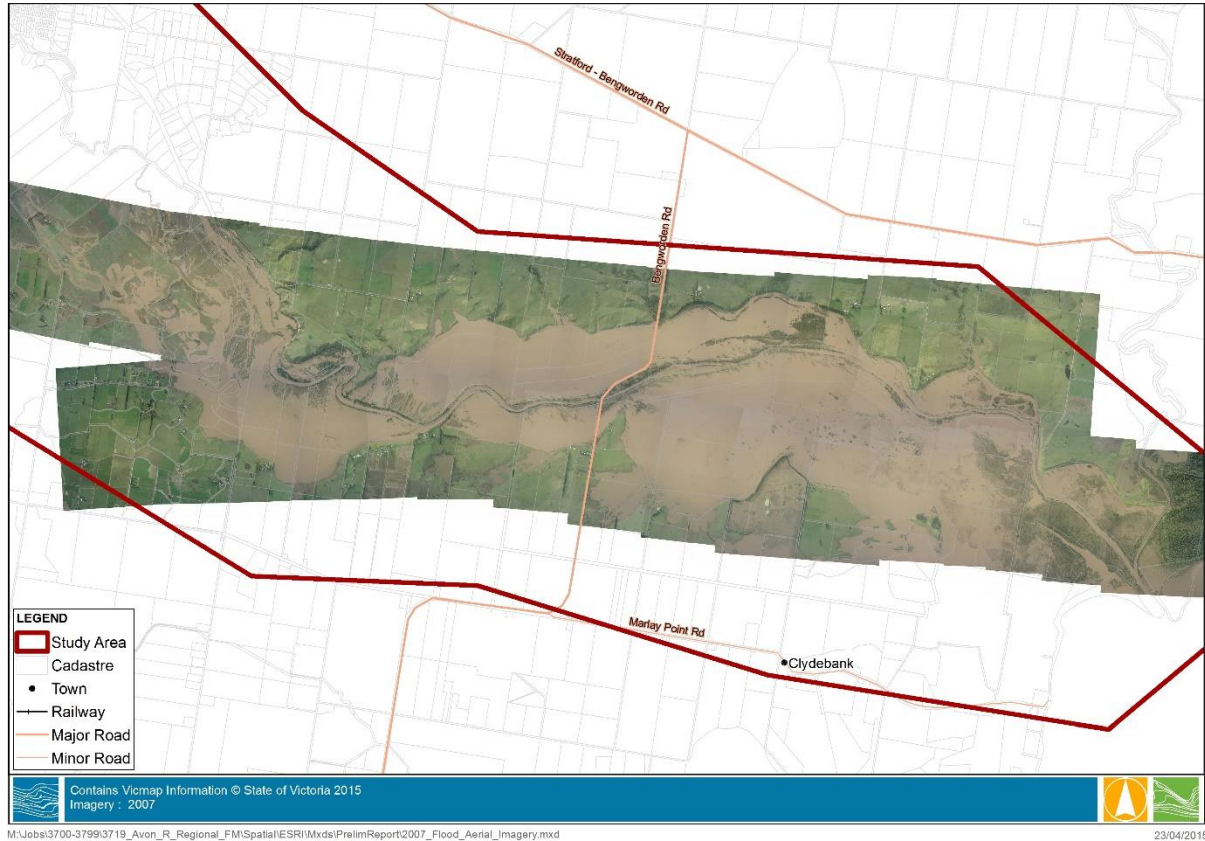


Figure 4-16 June 2007 flood aerial imagery

5. PROJECT STAKEHOLDER COMMUNICATION

Water Technology's approach to engagement and consultation is directly in-line with the project brief and includes:

- Monthly meetings with DELWP to discuss issues and progress of project (assumed to occur in Melbourne). Water Technology recommends that these meetings be held in the first week of each month following the progress report (last week of the month).
- Four project steering committee meetings to be held in Traralgon to discuss progress, approaches to technical challenges, agency knowledge, and project results.
- Two community meetings to capture local knowledge at the start of the project and another one late in the study to communicate outcomes and seek feedback.

It was discussed at the inception meeting that we would hold the community consultation meetings in two locations (Boisdale and Stratford). These meetings will be targeted at key individuals with an interest in flooding and strong local knowledge. Information regarding the study will be disseminated to the general public via local news and website articles.

Water Technology will prepare agendas and minutes for the monthly and steering committee meetings. We will also facilitate the community meetings, however we believe these should be led by DELWP and the West Gippsland Catchment Management Authority.

6. HYDROLOGIC MODELLING APPROACH

Hydrologic modelling will be undertaken to quantify the catchment generated flows in the Avon River and its tributaries at the hydraulic model boundaries.

6.1 Flood Frequency Analysis

A flood frequency analysis (FFA) allows the estimation of peak flows of selected Annual Exceedance Probability (AEP) based on a statistical analysis. An FFA will be undertaken for the Avon River at The Channel, Avon River at Stratford, Valencia Creek at Gillio Road and Freestone Creek at Briagolong gauges in order to estimate the return periods of peak flow at the gauge for verification of the RORB model.

FLIKE software will be used to perform the FFA. FLIKE uses a Bayesian approach to parameter fitting (either the Global Probabilistic or Quasi-Newton fitting algorithms) to the records in order to assess the return period of different magnitude flows. There are a number of probability distributions which can be used to undertake an FFA. Australian Rainfall and Runoff (AR&R) recommends the 'Log Pearson III' distribution for general use, however it suggests awareness of other types of distributions that might provide a better fit. FLIKE also allows a Log-Normal, Generalised Pareto, Generalised Extreme Value (GEV) and Gumbel distribution to be fitted.

6.2 Hydrologic Modelling

6.2.1 Options Available

Two options were initially considered for the hydrologic modelling approach. These options were to adapt the Bureau of Meteorology's (BOM) existing URBS model of the Avon River, or develop a new model of the catchment using RORB. After enquiring with BOM it was determined that the current official position is to not distribute existing hydrologic models including any documentation. Therefore, it was decided to build a new model using RORB hydrologic modelling software.

6.2.2 Model Build / Development

A RORB hydrological model will be developed of the entire Avon River catchment to the River entrance at Lake Wellington, which includes the hydraulic model extent. ESRI's ArcHydro will be used to delineate the catchment, with a minimum of 3 to 5 sub-areas schematised upstream of any required streamflow hydrograph. Print locations will be included at all locations where flow is required such as at tributaries, streamflow gauges and model boundaries.

The RORB model will be at a resolution adequate to resolve the main drainage paths and sub-catchments, and to provide smooth hydrographs for the hydraulic model. This means the relatively minor catchments of Blackall Creek and Nuntin Creek will require much smaller subcatchments than the main streams to be adequately resolved for the hydraulic model. The large variance in subarea size means that catchment routing parameters cannot be expected to remain uniform as in traditional RORB models. 'Interstation areas' will therefore be introduced at the downstream end of Blackall Creek, and at Boisdale near Nuntin Creek drain, which will allow for scaled catchment routing parameters to be adopted in these catchments with small sub-catchment areas. These areas will adopt the same losses as the calibrated upstream areas.

6.2.3 Model Calibration

The model will be calibrated to the 2007, 2011, and 2012 flood events. Gauged information is available at all gauges for all three events. Local daily rainfall gauges will be used to construct a spatial pattern of rainfall for the calibration events, and local sub-daily rainfall gauges will be used as temporal patterns. Model parameters kc , m , *initial loss* (IL) and *continuing loss* (CL) will then be developed for each event by calibrating to the available streamflow gauge. The kc and m will most likely be consistent across events with the losses varied to represent different antecedent conditions.

The hydrologic model will be calibrated to the four major gauges in the catchment, Avon River at The Channel, Valencia Creek at Gillio Road, Freestone Creek at Briagolong and Avon River at Stratford.

As the hydraulic model is not as geographically extensive as the hydrologic model, the focus of calibration will be at the Avon River at Stratford. Measured flows at the other three major gauges will be applied directly to the model. The hydraulic model can also be validated against the Avon River at Clydebank water level, numerous flood marks and flood extent data.

The relatively high saturation of good quality data within the catchment means that joint calibration between the hydraulic and hydrologic models is initially unnecessary, however can be investigated if adequate calibration is unable to be achieved.

6.2.4 Hydrological Design Modelling

Design rainfalls will be input into the calibrated RORB hydrologic model to produce design flows throughout the catchment. It is proposed the current IFD curves from AR&R (1987) be utilised for design rainfalls. Presently, the new IFDs developed for Project 1 of the Australian Rainfall and Runoff Revision Project are not recommended to be used in practice until the revised AR&R manual is finalised. The revised IFD curves will be modelled, however, as part of a sensitivity analysis.

RORB model design parameters (kc , m , IL , CL) will be adopted from the calibration results, and compared to previous regional modelling studies as well as values from Australian Rainfall and Runoff and the RORB kc prediction equations.

A number of estimation techniques will be tested for design losses, with the flows at Avon River at Stratford compared to the various methods:

- Hill *et al.*
- Australian Rainfall and Runoff
- Other models from nearby catchments
- Losses from calibration events

Verification of design flows will be undertaken by comparison to flood frequency analysis results at various gauges in the study area, for the Avon River, Valencia Creek and Freestone Creek. Further verification of design flows will be undertaken using regional prediction equations and methods such as the Australian Regional Flood Frequency Method.

All critical durations will be simulated in the hydraulic model and results enveloped for the final design event mapping.

The final adopted design model parameters will be utilised to produce hydrographs at all hydraulic model boundaries for the PMF, 0.2%, 0.5%, 1%, 2%, 5%, 10% and 20% AEP flood events.

The probable maximum flood (PMF) discharge will be estimated using the rapid assessment method developed by Nathan *et. al.* (1994).

7. HYDRAULIC MODELLING APPROACH

7.1.1 Overview

For the hydraulic modelling we propose to use a MIKE21 Flexible Mesh model to assess the impacts from riverine flooding.

The flexible mesh model will have a variable mesh resolution across the model domain. The advantage of the flexible mesh model is that it can be refined to accurately represent small topographic features in areas of interest without having to alter the size of the grid elements in other locations. This allows greater detail with less impact on model runs times. The flexible mesh model can also include direct rainfall as well as the more standard point source inflows.

The model will predominantly be a 2D model with hydraulic structures including large culverts and bridges modelled in 1D. The selection of the 2D model extent is a compromise between geographical coverage, topographic data coverage and model grid resolution.

Preliminary testing during this review has indicated that in the township areas and other locations of specific interest a fine mesh element size can be used (3-5 m). In other areas the mesh resolution will be increased up to 10-20 m depending on the location and the requirements to resolve specific topographic features. Mesh resolutions will be refined during the model development to optimise model run times.

The model's inflow boundaries will include the key upstream inflows from the Avon River, Valencia Creek, Freestone Creek and Blackall Creek. Point source inflows will also be included for other smaller tributaries within the catchment. These inflows will use hydrographs generated from the RORB model for the Avon River and its tributaries. The model's downstream boundary at Lake Wellington will use a time series water level boundary condition. Sensitivity analysis will be undertaken on the downstream boundary during design events assess the model's sensitivity to Lake Wellington water levels.

Hydraulic roughness parameters will be adopted using industry standard values that represent the creek and floodplain vegetated condition, and will be adjusted as required to calibrate the models. Sensitivity analysis will be performed on hydraulic roughness to assess the model's sensitivity to the adopted parameters.

A 2D roughness map will be developed including appropriate roughness values for residential/commercial/industrial properties, roads and car parks, waterways, public open space, dense vegetation and sparse vegetation.

7.1.2 Mesh Schematisation

The use of flexible mesh requires extra considerations compared to grid based modelling. The mesh must be fine enough in areas to pick up key features, but also coarse enough to allow reasonable model run times. Numerous mesh sizes and distributions will be tested during hydraulic model development stages. Key features that will be incorporated into the mesh include:

- Rivers – the river must be represented adequately. The Avon and main tributaries being mapped will have refined mesh along their length to ensure adequate model representation. Quadrangular elements will be used as they are best suited to uni-directional flow. Channels will also be included as breaklines in the topography where necessary, to ensure the mesh is picking up the invert of the channel. Breaklines will mostly be used in the upper catchment where riparian vegetation has impeded accurate LiDAR topography generation.
- Levees – the mesh will be refined around any identified levees to ensure their current peak elevation is represented in the model. Levee crests will also be included in the model as

breaklines in the mesh, to ensure the peak topographic level of the levee is included in the model.

- Roads and rail – main road and rail crossings will have a refined mesh around them.
- Bridges and large culverts – any bridges and large culverts incorporated into the model will have refined mesh near their outlets and inlets to ensure model performance around these structures.
- Populated areas – populated areas for the Avon catchment include Stratford, northern Briagalong and Boisdale, and the mesh will be refined in these areas to enhance model accuracy.
- Floodplain / Agricultural land – mesh will generally be at approximately 10 – 20 m intervals. A triangular mesh will be incorporated in the floodplain as it is more suited to the multi-directional and low velocity flows associated with floodplain hydraulics.

A flexible mesh has recently been developed for the Seaspray flood study and is shown in Figure 7-1. A mixture between quadrangular and triangular elements and refined mesh around key areas of interest is visible. This Seaspray model comprises 164000 elements and each simulation take approximately 3 hrs to run for a 48 hour duration flood event. The Avon River study area mesh will be much larger in size and result output, however the mesh element size across much of the floodplain will be correspondingly larger, and it is therefore estimated that it will take less than 12 hours to run simulations.

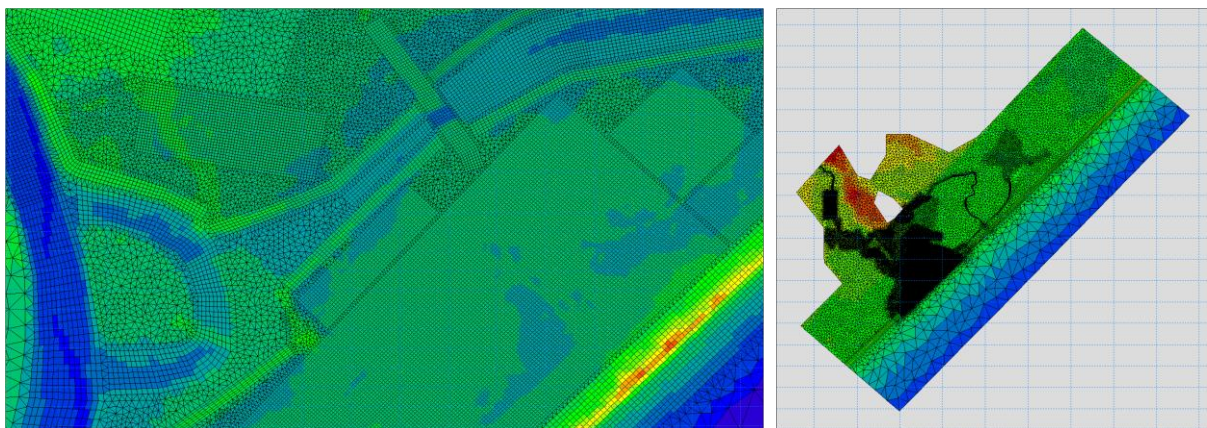


Figure 7-1 Example Hydrodynamic Model Domain and Mesh from Seaspray

7.1.3 Lake Wellington Water Levels

To assess flooding impacts from Lake Wellington, a water level boundary conditions will be applied as a downstream boundary to the Avon River model.

Previous modelling of Gippsland Lakes including Lake Wellington (Grayson, et al, 2004) was undertaken, which resulted in estimated water levels for the 5% AEP, 2% AEP and 1% AEP events.

For this study, it is proposed that boundary conditions for each AEP initially be adopted based on the reported AEP levels, using interpolation where necessary. A sensitivity test on Lake Wellington levels will also be undertaken to further understand the impact downstream boundary water levels have on the model.

Gauged water level data from Bull Bay (226041) will be applied for the calibration events.

7.1.4 River Morphology

River morphology is also a consideration for the Avon River model hydraulics. Detailed assessments of the channel were undertaken pre and post flood in 1990, which shows the level of impact a large flood can have on the existing channel.

Sensitivity testing will be undertaken with respect to the river morphology, by modifying the topography in certain regions to simulate that which may occur in a large flood. The exact extent of the sensitivity tests will be refined based on the outcomes of the model calibration.

Initial calibration runs will be based on the existing topography discussed in Section 4.1.

8. ADVANTAGES AND LIMITATIONS OF THE PROPOSED METHODOLOGY

The proposed method aims at delivering on all expected project outputs using industry best practice. This methodology and its outputs will still have limitations that will be discussed in the hydrology and hydraulic report outputs.

9. FLOOD BEHAVIOUR AND INTELLIGENCE OUTPUTS

All model scenarios (historic and design) will be processed and formatted in line with the VFD specification for flood extents, depths, water surface elevation, flood velocities and velocity x depth. Water level hydrographs and water level profiles will also be produced.

The flood intelligence will be written up and presented in a format that is similar to that of a Municipal Flood Emergency Plan (MFEP) so that VICSES can use the study report to copy valuable flood intelligence into MFEP. For this, focus will be given to timings and duration of depths, as the Avon River lends is known to be a flashy system that cuts off numerous access routes.

All results will be mapped, providing standard flood study outputs. All maps will be provided in pdf format. An online mapping portal will also be established, that allows stakeholders to view and comment on the maps.

10. DATA GAPS

The data collated to date is sufficient to begin the hydrology analysis and begin construction of the hydraulic model. Further information regarding hydraulic structures and sites of interest is currently being collated and will be required to complete hydraulic model development.

A large amount of information, including existing reports, imagery and VFD data has already been provided by WGCMA and DELWP. VicRoads has also provided details on important bridge structures in the catchment. Further information will be required to ensure the best results are achieved by this study. Table 10-1 lists the outstanding data that has been requested. It is acknowledged that the list is extensive and not all data may be available, and hence the relevant impact of each request on the study results has been indicated. It would be greatly appreciated that if a dataset or piece of information can't be retrieved, or the source department can't resource the data request, that the study team be notified and we will identify a suitable solution to work around the data gap.

Table 10-1 Outstanding data requests

Description	Source	Impact on Study
Nuntin spillway area photogrammetry	WGCMA	Required for accurate representation of the existing conditions at the Nuntin spillway
Details of railway crossings	VicTrack	For incorporation into the hydraulic model

Water level measurements at two unreported sites in the catchment	Wellington Shire Council	Useful additional flood level data information
Anecdotal flood information	All	For calibration
Rapid Impact Assessments	SES, Councils	For calibration
Field Survey	CMA, Council, VicRoads	For incorporation into the hydraulic model

We appreciate any effort people go to in sourcing the requested data and we will make best possible use of it. However if data or information is received late, the study team may not be able to rebuild the model or recalibrate results given time and budget constraints. Therefore it is imperative that these data requests be actioned quickly to make the best use of everyone's time.

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Avon River Regional Flood Mapping - Project Report



February 2016

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EXECUTIVE SUMMARY

This report details the input data, approach and outcomes for the Avon River Regional Flood Mapping study.

The study has been initiated by the Department of Environment Land Water and Planning (DELWP) in order to define the extent and characteristics of flooding in the Avon River catchment so that future planning decisions may be soundly based and measures may be put in place to minimise risk to the community.

The study provides information on flood behaviour and flood intelligence across the Avon River catchment. The study involved a rigorous technical analysis of the drivers for flooding, which provided confidence in the use of this information to guide emergency management and future floodplain management in the catchment.

Community consultation was undertaken at various stages of the study, primarily in order to gather data and accounts of flooding and to benchmark the outputs of the calibration and preliminary design event mapping. The flood information provided by residents was invaluable in the development of the study outcomes.

A hydrologic analysis of the Avon River and tributaries was undertaken to determine design flood hydrographs for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% annual exceedance probability (AEP) flood events in the Avon catchment as well as the probably maximum flood (PMF). A rigorous approach has been applied to test and validate the design flows by utilising a number of hydrologic approaches including Flood Frequency Analysis, and development of a detailed hydrologic (RORB) model. The adopted design flood inflows for the study are listed in Table 1.

Table 1 Design peak flows at major waterways

AEP	Avon River at Stratford (m ³ /s)	Avon River at The Channel (m ³ /s)	Freestone Creek (m ³ /s)	Valencia Creek (m ³ /s)
20%	808	350	264	107
10%	1184	530	363	170
5%	1703	779	512	262
2%	2277	1017	659	341
1%	2883	1301	800	434
0.5%	3495	1544	919	524
0.2%	4272	1884	1106	661

To place the design peak flows in a historical context, the approximate AEP (and Average Recurrence Interval, ARI) of significant historical flood events are provided in Table 2. The April 1990 event is the largest gauged event recorded at all streamflow gauges in the catchment, except at Valencia Creek where the gauge was washed away during the event. Since the 1990 event, large events have occurred in 2007 and 2012 which are the 2nd and 3rd largest gauged events in the catchment.

Table 2 Avon River, Approximate AEP/ARIs for significant historical flood events

Historical event (year)	Approximate AEP/ARI (based at Stratford)
April 1990	1% / 100 years
June 2007	2.5% / 40 years
June 2012	4% / 25 years

A digital elevation model (DEM) was developed from LiDAR survey. Using the DEM, a hydraulic model was established to simulate flood behaviour within the study area. Flood behaviour was assessed for flooding originating from tributaries as well as local catchment runoff within the floodplain. The hydraulic model was calibrated to three historic flood events (June 2007, June 2012 and August 2011) while the April 1990 event was used to further validate flood depths and extents across the floodplain. There was a good level of data available for the calibration events which enabled a high level of model calibration to be achieved.

Flood maps for the 1% AEP and 10% AEP design flood events and output data for all events have been produced. The relationship between flood magnitude (i.e. the AEP of an event) to gauge heights on the Avon River at The Channel, Avon River at Stratford, Avon River at Clydebank, Freestone Creek at Briagolong and Valencia Creek at Gillio Rd gauge have also been established. This information will assist VicSES, Council and community members in planning for and responding to flood situations.

The model resolution of this study is suitable to inform land use planning and flood insurance pricing at a property scale. The timing of the flood peak and associated data is suitable to inform emergency response services.

ACKNOWLEDGEMENTS

Numerous organisations and individuals have contributed both time and valuable information to the Avon River Regional Flood Mapping study. The study team acknowledges the contributions made by these groups and individuals, in particular:

- (Department of Environment Land Water and Planning & Project Manager)
- (West Gippsland CMA)
- (Thiess/Ventia Hydrographic Services)

The study team also wishes to thank all those stakeholders and members of the public who participated in the steering group and community information sessions and provided valuable records (including historic photos) and discussed their experiences and views on flooding in the Avon River catchment.

GLOSSARY OF TERMS

Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded; it would be fairly rare but it would be of extreme magnitude.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. A 10 year ARI flood is expected to be exceeded on average once every 10 years. A 100 year ARI flood is expected to be exceeded on average once every 100 years. The AEP is the ARI expressed as a percentage.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Design flood	A design flood is a probabilistic or statistical estimate, being generally based on some form of probability analysis of flood or rainfall data. An average recurrence interval or exceedance probability is attributed to the estimate.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from elevated sea levels and/or waves overtopping coastline defences.
Flood frequency analysis	A statistical analysis of observed flood magnitudes to determine the probability of a given flood magnitude.
Flood hazard	Potential risk to life and limb caused by flooding. Flood hazard combines the flood depth and velocity.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Flood storages	Those parts of the floodplain that are important for the temporary storage, of floodwaters during the passage of a flood.
Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.

Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Intensity frequency duration (IFD) analysis	Statistical analysis of rainfall, describing the rainfall intensity (mm/hr), frequency (probability measured by the AEP), duration (hrs). This analysis is used to generate design rainfall estimates.
LiDAR	Spot land surface heights collected via aerial light detection and ranging (LiDAR) survey. The spot heights are converted to a gridded digital elevation model dataset for use in modelling and mapping.
MIKE FLOOD	A hydraulic modelling tool used in this study to simulate the flow of flood water through the floodplain. The model uses numerical equations to describe the water movement.
Peak flow	The maximum discharge occurring during a flood event.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Average Recurrence Interval.
Probable Maximum Flood	The flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area.
RORB	A hydrological modelling tool used in this study to calculate the runoff generated from historic and design rainfall events.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Topography	A surface which defines the ground level of a chosen area.

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1. INTRODUCTION

1.1 Overview

The Department of Environment Land Water and Planning (DELWP) commissioned Water Technology to undertake the Avon River Regional Flood Mapping Study. This study involved detailed hydrological and hydraulic modelling of approximately 40km of the downstream floodplain of the Avon River catchment, as well as large portions of Freestone Creek, Valencia Creek and Blackall Creek and took into account the downstream influences of Lake Wellington.

The objective of the Avon River Regional Flood Mapping Study was to define the extent and characteristics of flooding in the Avon River catchment so that emergency management and future planning decisions may be soundly based and measures may be put in place to minimise risk to the community.

The study addressed the following aspects:

- Examine contributing factors to flood events within the Avon River catchment including the main tributaries;
- Assess the sensitivity of flood mechanisms to a range of conditions, including floodplain and channel roughness, Nuntin levee failure, Lake Wellington water levels, channel scour and structure blockage;
- Determine flood levels and extents for a range of flood modelling scenarios within the study area;
- Provide detailed flood intelligence outputs.

1.2 Study Catchment and Floodplain

The Avon River rises on the slopes of Mount Wellington in the eastern highlands of the Great Dividing Range and flows south to Lake Wellington and the Gippsland Lakes. The mountainous upper catchment is largely forested, while the lower catchment downstream of the confluence with Valencia Creek is topographically more subdued and agriculture is the primary land use (EarthTech, 2007). The floodplain in the lower reaches is traversed by watercourses, swamps and lagoons. Overall, the river descends some 664 m over its 122 km length.

There are four major sub-catchments comprising:

- Valencia Creek catchment, just to the east of the Upper Avon River, with its headwaters in the Victorian Alps, part of the Great Dividing Range;
- Freestone Creek catchment, with its headwaters also in the Victorian Alps, before passing through the Briagolong area;
- Blackall Creek, which rises to the north east of Stratford and past the southern side of Briagolong;
- Avon River with its headwaters in the Avon Wilderness Park in the Victorian Alps. This is the primary tributary. After reaching the floodplain from the mountainous upper catchment, the River meets Valencia Creek and Freestone Creek. It then passes Boisdale, Stratford and Blackall Creek, before finally discharging into Lake Wellington.

Key towns within this catchment area include Stratford, Boisdale and Briagolong. Figure 1-1 provides an overview of the hydrologic catchment extent for the Avon River. This includes the upstream tributary catchments.

Apart from the township areas of Stratford, Boisdale and Briagolong, land use across the lower catchment is primarily agricultural. The upper catchment upstream of Valencia Creek is almost completely forested, with a large part of the catchment encompassing the Avon Wilderness Park.

The study area for the purposes of flood modelling and mapping for this project covers a 40 km reach of the Avon River and floodplain and including the lower sections of Freestone Creek, Valencia Creek and Blackall Creek. The study area is shown in Figure 1-2.

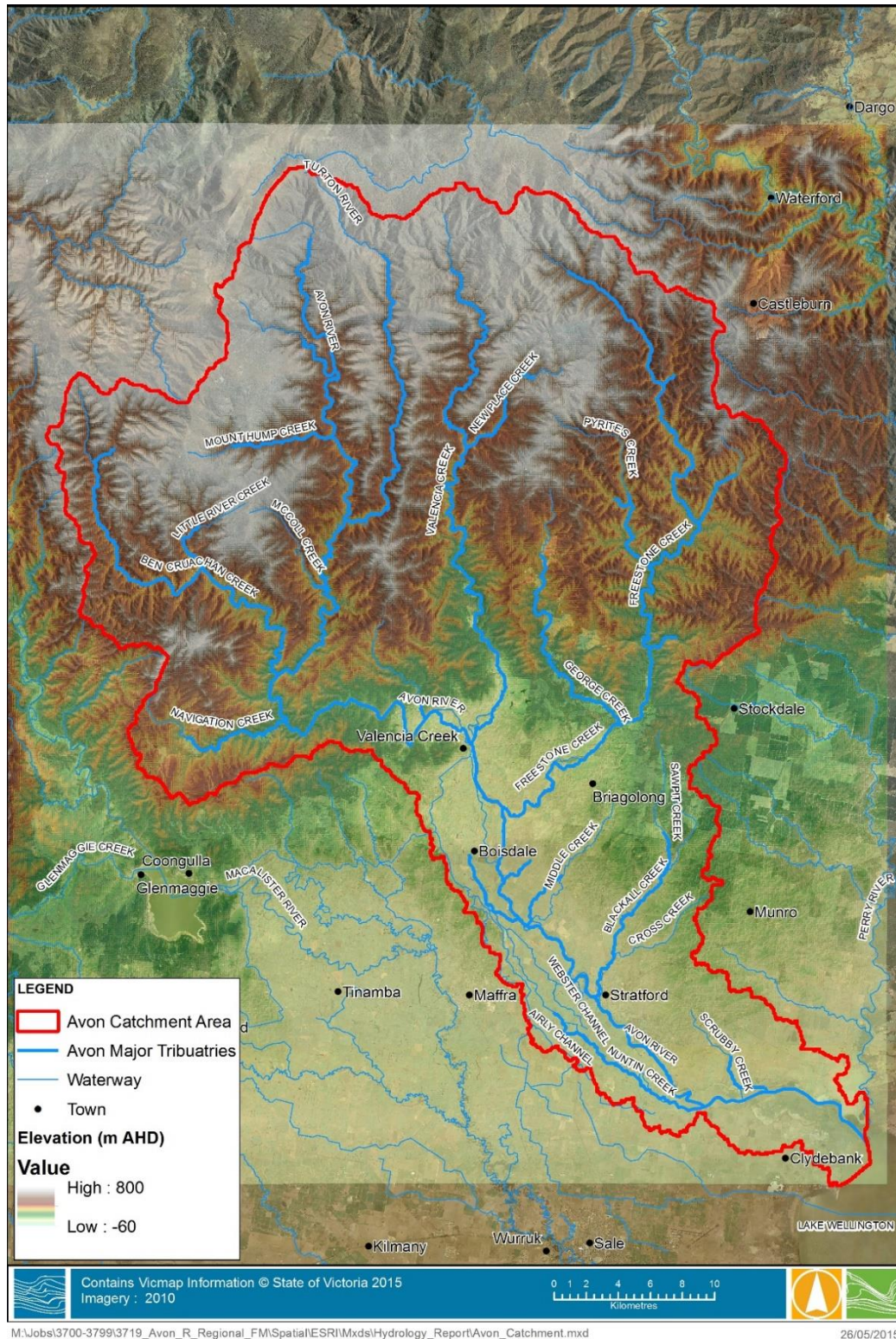


Figure 1-1 Avon River catchment extent including waterways

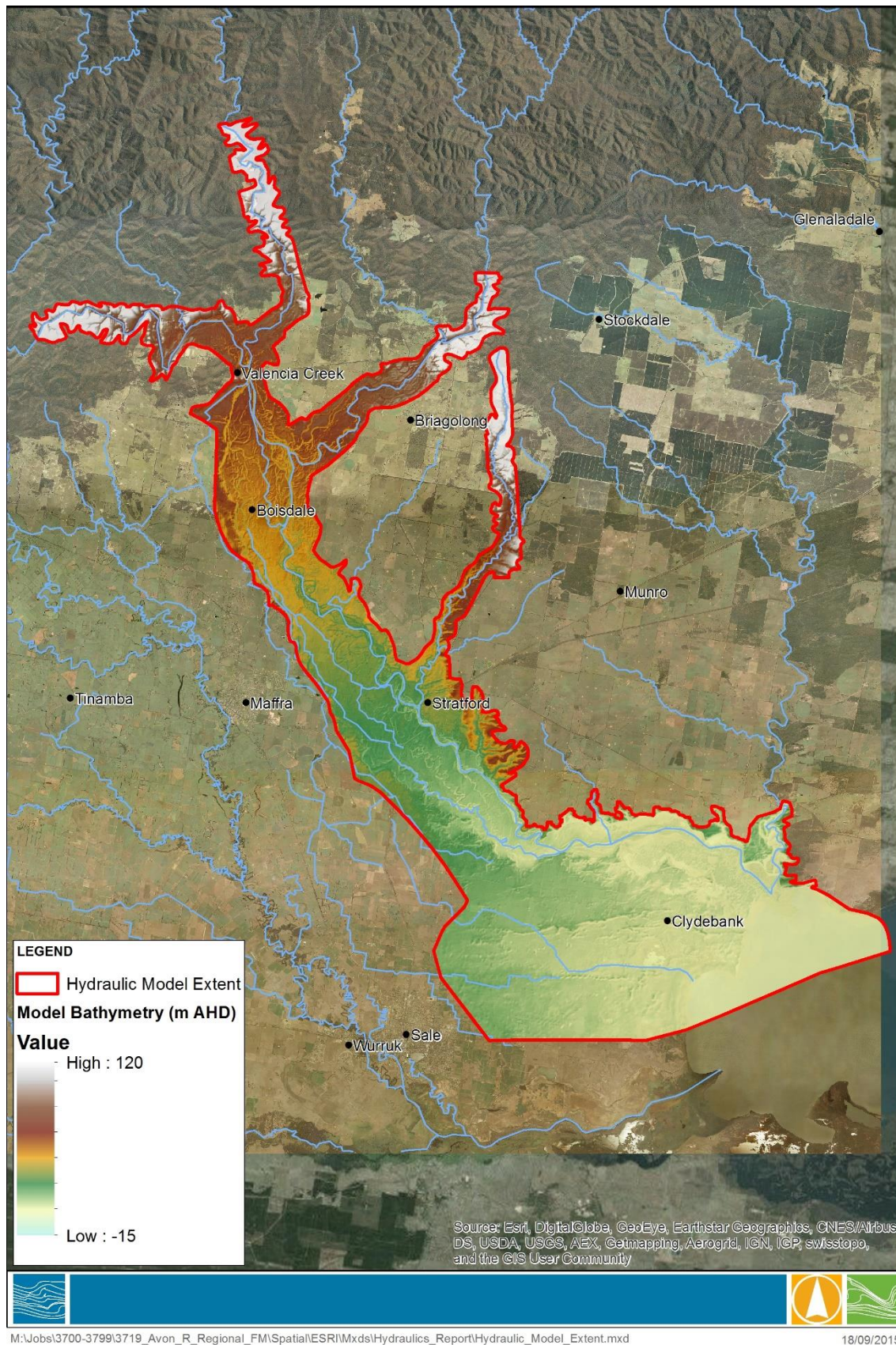


Figure 1-2 Study Area

1.3 Supporting Documents

A number of reports were prepared at each stage of the study. These reports were produced separate standalone volumes, and a summary of each is provided in Table 1-1. In addition to these documents, flood intelligence outputs and GIS layers have been provided for each of the design flood events.

Table 1-1 Supporting documents

Report	Document Number	Title	Summary
1	R01	Preliminary Report	Review of flood related information for the study area, a review of available topographic and structure data (bridges and culvert information), and verification of topographic data. The report also provided a proposed outline of the hydrologic analysis and hydraulic modelling methodology
2	R02	Hydrology Report	Hydrologic modelling and analysis report, summarising results of flood frequency analysis, RORB modelling, estimation of design event, and probable maximum flood hydrographs
3	R03	Hydraulics Report	Hydraulic modelling report providing details of hydraulic model construction and calibration, sensitivity tests, and results of design event simulations.

2. DATA REVIEW

On inception of the project a detailed review was undertaken of all available flood related information as well as topographic data, structure information, and hydrological data. Details of this review are provided in Report 1, while a short overview is provided herein.

2.1 Flood Related Studies

The Avon River has a long history of flooding, with historic flood events recorded since 1870. Early 20th century descriptions of the Avon River waterway, such as that by Strom (1937), suggested that flood peaks in the various tributaries coincide more or less with the flood peak in the main stream. This effect is accentuated by the steep grades in the stream in the upper section, compared with the flatter grades of the streams draining the downstream floodplain area. Floods were noted to have a rapid rise, high peak of short duration, and rapid fall. Macintyre & Grant (1950) also noted tendency for the Avon River to exhibit 'flashy' and violent flows immediately after rain falls in its catchment area.

Alluvium (2008b) noted the Avon River experiences flashier flows than other comparable systems. Brizga (1990) also noted flood regimes in the Avon and Freestone rivers are significantly more variable than other flood regimes in the same climatic zone.

Extreme flooding in 1990 prompted an investigation by Sherrard (1990), which includes a detailed description of the 1990 flood with interviews of land owners, aerial photography, survey and cross sections. A similar report from East and West Gippsland Catchment Management Authorities (2007) after the 2007 flood showed significant areas of erosion and overbank flows. Alluvium (2008b) noted that Wombat Flat is the first major overbank flow location, with water then able to exhibit overbank flows at a number of locations in the lower catchment.

Erskine et al. (1990) noted that the existing channel capacity is very large in the heavily eroded and incised Avon River, and in many places overbank flows are unlikely, even in large events. Geomorphic effects of the 1990 flood were not as great as those experienced in previously recorded major flood events, and it is suggested that '*the Avon River is now better able to accommodate large floods*' (Erskine, et al, 1990).

The largest flood on record at the Avon River at Stratford, Avon River at The Channel and the Freestone Creek at Briagalong gauges, was the April 1990 flood which based on flood frequency analysis of all available gauges in the catchment, has an estimated Annual Exceedance Probability (AEP) of approximately 1%. More recently, other significant floods occurred in the Avon catchment in June 2007, and June 2012.

2.2 Geomorphology Related Studies

Following severe river widening in the 1936 flood, the State Rivers and Water Supply Commission undertook a report on erosion of the alluvial part of the Avon River, downstream of Valencia Creek. This reach has been subject to ongoing adjustments in its planform and channel dimensions since the area was settled. At the time of European settlement (around the 1840s) the river at Boisdale was reported to be 20-40 m wide with scrub and trees on both banks (Strom, 1937). In the course of settlement most of the riparian vegetation was cleared and the banks began to erode in the 1893 flood. Due to enlargement of the channel, a greater proportion of floodwaters now flowed down the channel than before European settlement. Strom (1937) reported that even in the large flood of 1936 (the third-largest flood since European settlement), overflow from the channel occurred in only a few locations in the Boisdale reach. The channel continued to widen and deepen over subsequent floods, and it was estimated that 2000 acres of land had been eroded by 1937. The ongoing erosion of the river was attributed to the high flood velocity in the already-enlarged channel, along with the friable

nature of the bank material, the cleared banks, and possibly a fall in base level at Lake Wellington associated with the opening of a permanent entrance to the Gippsland Lakes (Strom, 1937).

The reported dramatic river change prompted an investigation of the metamorphosis of the Avon River by Brizga (1990). She found that the Avon River upstream of Weirs Crossing was already incised and actively migrating at the time of European settlement, and subsequent channel change was characterised by an increase in meander wavelength coupled with some increase in the degree of incision. Dramatic channel metamorphosis was confined to the reach between Weirs Crossing and Redbank, and involved channel incision and increased lateral migration. This metamorphosis was attributed to the crossing of intrinsic threshold due to the input of sediment from the incised reaches upstream, as well as the clearing of vegetation from channel banks (Brizga, 1990). Downstream of Redbank, the previously navigable channel has become filled with sand eroded from the channel further upstream (Brizga, 1990).

Popular perceptions that the entire alluvial section of the Avon River had enlarged due to human intervention have resulted in intensive management due both to a perceived duty to right the wrongs of European settlement and an economic imperative to minimise the “loss” of productive land (Finlayson et al., 1995). However, the total loss of land was probably overestimated in early studies (e.g. Strom, 1937), as the pre-European dimensions of the channel were underestimated, and recently reworked bare land was assumed to be unproductive.

Pre-1950, interventions were generally limited to localised protective works at the major road and rail bridges and near Stratford (Alluvium, 2013a). In 1951 the Avon River Improvement Trust was established and widespread restoration works including concrete block and timber groynes were installed. Subsequent floods continued to produce extensive erosion, including the 1971 flood, which washed away the old Princes Highway Bridge. The 1990 flood was the largest on record but resulted in a surprisingly small amount of channel change (Sherrard, 1990). This was thought to be because the Avon River has reached a critical channel size such that vegetation can establish on in-channel features and the stream power of floods is dissipated over its large channel boundary. If so, the channel is likely to continue to recover, although meander migration will be ongoing, resulting in localised bank erosion (Alluvium, 2013a).

The build-up of sand in the lower reach is still considered a problem, as it increases the risk of an avulsion at the Nuntin levee into the lower end of Nuntin Creek. In the 2007 flood, the Nuntin levee was completely scoured out. The Nuntin Creek strategy (Alluvium 2008a) was developed and implemented with the aim of preventing avulsion and encouraging deposition on the floodplain. The strategy included the replacement of the levee with a spillway with its crest at natural bank height, and substantial revegetation along scour paths, to encourage deposition on the floodplain.

A geomorphic review in 2013 (Alluvium 2013a) identified the following ongoing risks:

- Further deepening and widening of the Avon River in the vicinity of the Freestone Creek confluence, and in the lower reach of Freestone Creek
- Ongoing meander migration resulting in channel widening
- Ongoing sediment transport into the lower reaches continuing to increase the risk of development of the Nuntin avulsion

Flooding in June 2012 led to damage and scour of the spillway, and a levee was re-instated at the spillway location (Alluvium, 2014). The current levee consists of pile fields, a bund wall and rock beaching, and its height is aimed at prevent any scour or channel diversion into Nuntin Creek.

2.3 Historic Flood Information

The largest flood on record at the Avon River at Stratford, Avon River at The Channel and the Freestone Creek at Briagalong gauges, was the April 1990 flood. Information is available for the 1990 event,

including digitised flood extent, surveyed flood levels, floor levels and numerous flood photographs. After performing a flood frequency analysis on all available gauges in the catchment, this flood was estimated as between a 1% and 2% Annual Exceedance Probability (AEP). Another large flood occurred in the Avon catchment in June 2007, which also has available data including spot heights, digitised flood extents and scaled aerial photography. This 2007 event was estimated around a 4% AEP event. Data is also available for the 1936, 1978 and 2012 floods which were all significant flooding events.

2.4 Topographic Data

2.4.1 Available Datasets

Available topographic data for this study included three LiDAR datasets, captured between 2007 and 2010:

- 2007-08 Southern Rural Water (SRW) LiDAR Project
- 2009-10 Victorian State Wide Rivers LiDAR Project - West Gippsland CMA
- 2009-10 Floodplains Stage 1 LiDAR Project

Vertical accuracy of the datasets, verification of topographic data against survey benchmarks, and comparison of cross-sections determined from field survey and LiDAR provided guidance on the suitability of the data for use in the hydrologic and hydraulic modelling.

Details of each of the topographic data sets are provided in Report 1.

2.4.2 Data Verification

The accuracy of the hydraulic modelling relies to a large degree on the accuracy of the topographic datasets. Therefore a detailed verification process was undertaken for the LiDAR by comparison of each dataset and using the field survey information.

A comparison of the SRW and Rivers LiDAR datasets indicated a systematic vertical offset between the two datasets in flat floodplain areas. In these areas, the Rivers LiDAR is consistently ~0.20 m higher than the SRW LiDAR. A similar comparison between the SRW and Floodplains LiDAR datasets revealed a good agreement between the two datasets with a mean difference of ~0.03 m.

In the absence of any topographic survey data to use for verifying the LiDAR datasets, a comparison with the AHD elevations of 14 survey benchmarks (third-order) throughout the study area was completed. The results of this comparison showed that the Rivers LiDAR was on average 0.234 m higher than the survey benchmarks, the SRW LiDAR was 0.054 m higher on average and the Floodplains LiDAR was 0.025m higher on average. The comparisons indicate that the Rivers LiDAR has a positive vertical offset from AHD of around 0.2 m which was corrected before use of the data for the hydraulic modelling.

2.4.3 DEM Development

Due to the large study extent it was necessary to combine the three LiDAR datasets to produce a Digital Elevation Model (DEM) of the model area. As noted previously, the highest vertical accuracy and a good agreement with benchmarks exist in the SRW and Floodplains LiDAR. It was therefore decided to preferentially use this LiDAR, which covers the Avon River downstream from Valencia Creek to Lake Wellington.

The remaining areas including the Avon River upstream of Valencia Creek, Valencia Creek, Freestone Creek and Blackall Creek were covered using Rivers LiDAR. As the Rivers LiDAR was found to be consistently offset vertically by +0.2 m compared to survey marks and other LiDAR datasets in the regions where Rivers LiDAR is being utilised it was adjusted vertically by -0.2 m.

Manual smoothing was undertaken for transitions between the datasets to ensure the model hydraulics are not impacted by the change in source DEM. A summary of the datasets that were used in the DEM preparation is shown in Figure 2-1.

2.5 Structure Information

At the regional scale, hydraulic structures of interest are those that have the potential to impact the wider flood extent. These have been generally limited to bridges and weir crossings. The following structures are those that have been identified for incorporation to the hydraulic model.

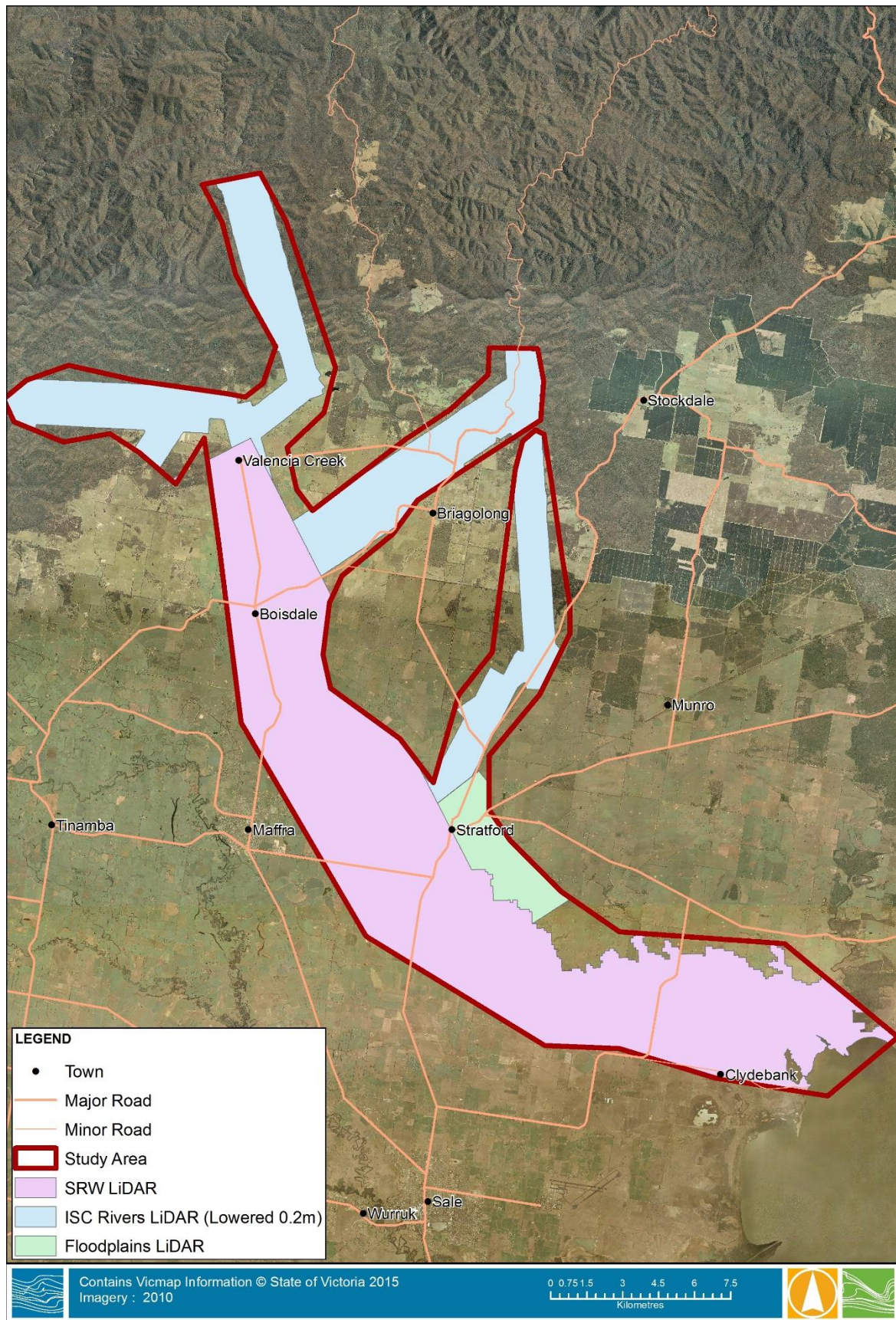
2.5.1 Road / Rail Crossings

The resolution of the model allows for key bridge and rail crossings of the waterways to be included. Data on these bridges has been provided by VicRoads, whilst railway track information has been accessed from VicTrack. Weir crossings for vehicles and large railway culverts were also measured and photographed during a site visit on the 20/04/15. Locations of key structures are shown in Figure 2-2 and details of the structures are listed in Report 3, the hydraulics report.

2.5.2 Irrigation Channels

A network of open irrigation channels bisect the Avon floodplain, the most significant of which are located between downstream stretches of the Avon and Macalister rivers. Key irrigation channels in this area include Airly Channel, Webster Channel, the Boisdale Drains and Nuntin Creek.

The channel banks of these and other major irrigation channels which are known to impact on flooding were sampled from the LiDAR and specifically incorporated into the hydraulic model. Due to the size of the study area and the impact of some minor structures during large floods, not all irrigation channel banks are incorporated into the hydraulic model.



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27/04/2015

Figure 2-1 Model DEM Preparation Plan

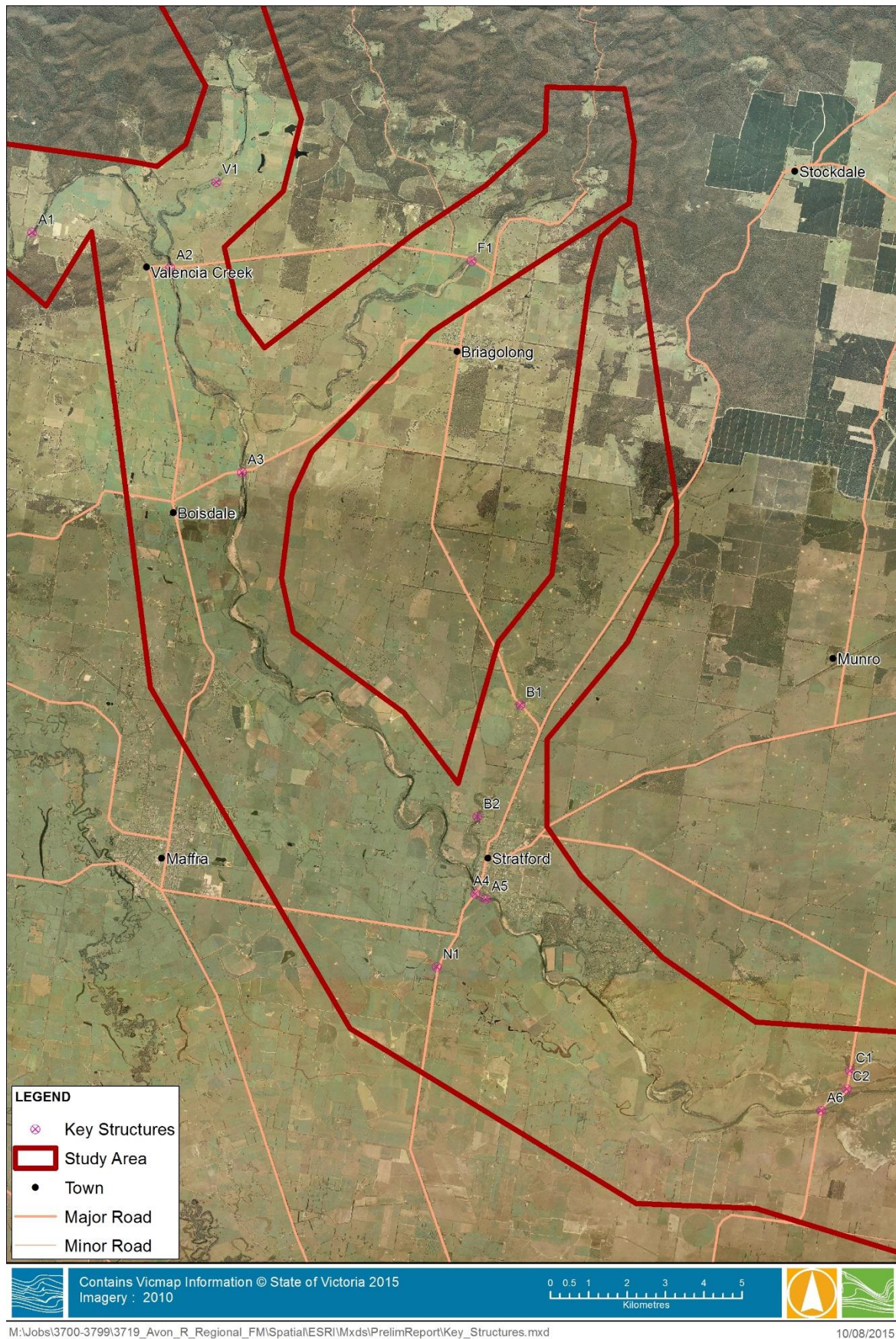


Figure 2-2 Key structures within study area

2.5.3 Levees

Constructed levees are not a key feature of the Avon River channel. The Nuntin Creek spillway, formerly Nuntin Creek levee, is the only large man-made levee that has been included in the model based on crest survey taken in 2014 (Alluvium, 2014). The spillway has been modified a number of times, and consideration was taken in the hydraulic model calibration as to the configuration of the levee at the time of calibration.

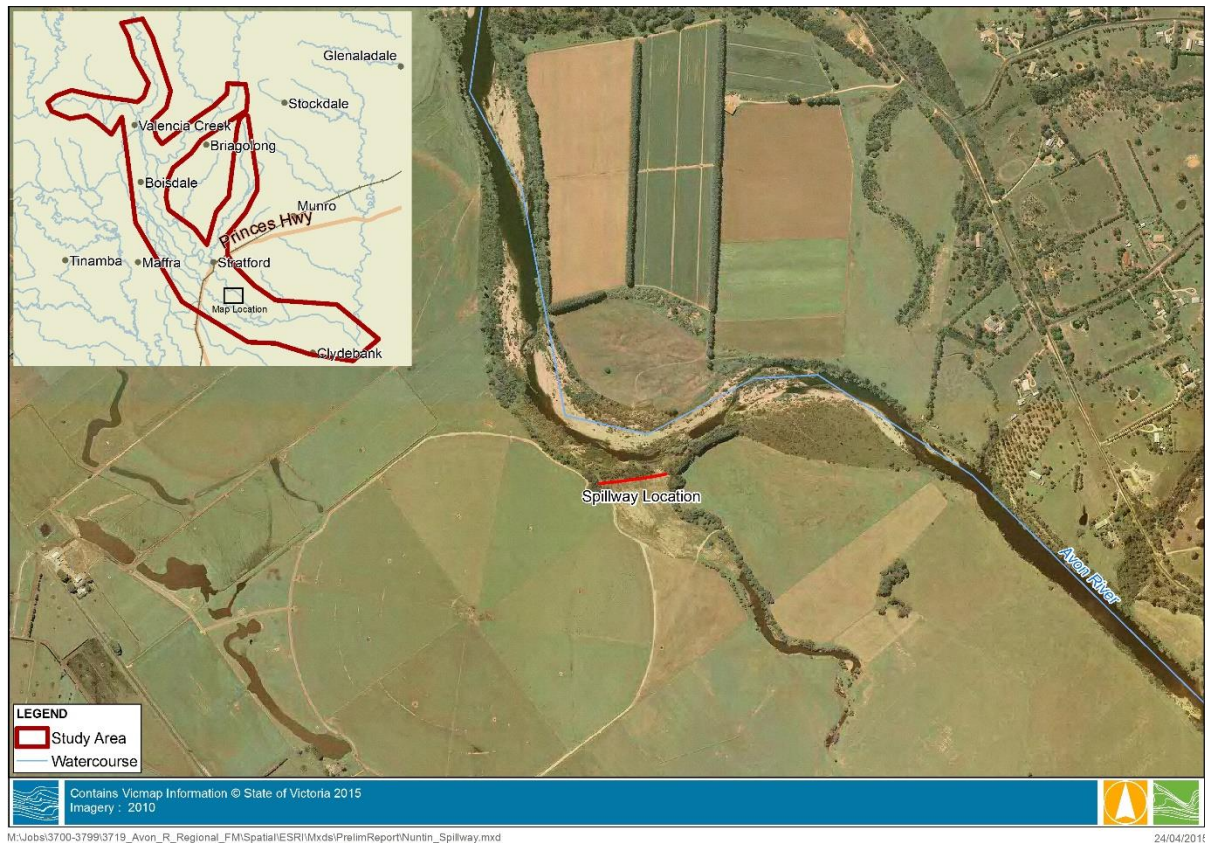


Figure 2-3 Location of Nuntin Creek Spillway (formerly Nuntin Creek Levee)

2.6 Hydrological Data

Hydrological data required for the study included streamflow, rainfall, and water level information.

2.6.1 Rainfall Data

The average annual rainfall varies throughout the catchment, reaching 1910 mm at the headwaters and as low as 600 mm near its outlet to Lake Wellington. At the catchment centroid the average annual rainfall is approximately 670 mm.

Numerous daily rainfall sites are in operation in and around the catchment. Key stations, including current stations and stations operating over the 2007, 2011 and 2012 floods, are listed in Table 2-1.

Table 2-1 Daily rainfall stations around Avon River catchment

Gauge No.	Location	Period	Years	Distance from catchment centroid (km)
85054	Maffra Shire Hall	1879 - 1968	82	29
85020	Clydebank	1884 - 2009	121	37
85130	Newry	1885 - 1930	42	19
85012	Boisdale	1886 - 1954	51	18
85090	Valencia Creek (Bulgar Park)	1887 - 1974	86	8
85055	Maffra Forestry Office	1899 - 1996	92	25
85083	Tinamba West	1905 - 1950	46	24
85035	Glenmaggie (The Laurels)	1905 - 1957	53	26
85016	Bushy Park	1905 - 1983	79	14
85203	Licola (RWC)	1906 - 2002	56	34
85211	Glenmaggie (Cheynes)	1906 - 1919	11	25
85027	Fernbank	1908 - 1967	59	33
85080	The Heart	1922 - 1956	35	44
85088	Valencia Creek	1938 - 1986	48	9
85034	Glenmaggie Weir	1938 - 2015	78	25
85104	Cobbannah	1952 - 1955	4	22
85167	Meerlieu (Springvale West)	1968 - 2015	48	45
85165	Fernbank (Towri)	1968 - 2010	41	35
85168	Briagolong	1968 - 2015	48	13
85171	Culloden (Estoppey)	1968 - 1979	12	11
85166	Stratford	1968 - 2015	47	26
85254	Valencia Creek (Little Plain)	1974 - 2015	42	8
85286	Stringybark Creek	1989 - 2002	14	28
85296	Mount Moornapa	1994 - 2015	22	13
85297	Maffra	1993 - 2012	20	25
85276	Avon River @ The Channel	2000 - 2015	16	11
84118	Wonnangatta River @ Waterford	2000 - 2015	16	32
85304	Mount Wellington	2002 - 2015	14	30
85303	Reeves Knob	2002 - 2015	14	23
85306	Licola	2010 - 2015	6	34

Pluviograph (sub-daily rainfall) stations in and around the Avon River catchment that captured the 2007, 2011 and 2012 calibration events are listed in Table 2-2. The 2007 event was not captured by East Sale Airport and the Macalister River @ Licola gauges. The 2011 event was not captured by Glenmaggie Weir and Glencairn gauges. The 2012 event was not captured by East Sale Airport, Glenmaggie Weir and Glencairn gauges. Fortunately, these missed events do not cause significant model issues as the pluviograph density is still considered high for use in model calibration.

Table 2-2 Pluviograph stations around Avon River catchment

Gauge No.	Location	Period	Years	Distance from catchment centroid
85072	East Sale Airport	1943 - 2015	73	44
85034	Glenmaggie Weir	1957 - 2015	57	24
84125	Crooked River	1972 - 2015	42	41
85278	Aberfeldy (Lily Creek (Larommi))	1983- 2015	23	53
85254	Valencia Creek (Little Plain)	1984 - 2015	30	8
225209 (DELWP)	Macalister River @ Licola	1992 - 2015	24	35
225224 (DELWP)	Avon River @ The Channel	1992 - 2015	24	11
225201 (DELWP)	Avon River @ Stratford	1993 - 2015	23	27
225218 (DELWP)	Freestone Creek @ Briagalong	1995 - 2015	21	12
225809 (DELWP)	Avon River @ Mount Wellington	1997 - 2014	18	29
225810 (DELWP)	Avon River @ Reeve Knob	1997 - 2014	18	23
85058	Glencairn (Barkly River (Glenview))	2003 – 2015	11	45

2.6.2 Streamflow Data

Gauge Locations

Five streamflow gauges currently operate in the catchment, while historic data is also available for four other gauges (Table 2-3). Of the currently operating gauges, Valencia Creek at Gillio Road, Avon River at The Channel and Freestone Creek at Briagalong gauges record streamflow at three largest upstream tributaries that are to be mapped – the Avon River, Valencia Creek and Freestone Creek. Downstream gauges at Stratford and Clydebank include 90% and 96% of the Avon River catchment, respectively. Of the five currently operating gauges, all of them recorded data during the 2007, 2011 and 2012 calibration events. The 1990 event was captured at four of the gauges, however the Valencia Creek at Gillio Road gauge was washed out. The currently available streamflow gauges are shown in Figure 2-5.

Table 2-3 Streamflow gauges in Avon River catchment

Gauge No.	Location	Period	Years	Catchment Area (km ²)
225223	Valencia Creek @ Gillio Road	1971 - 2015	35	195
225224	Avon River @ The Channel	1972 - 2015	34	554
225201	Avon River @ Stratford	1976 - 2015	38	1485
225218	Freestone Creek @ Briagalong	1967 - 2015	49	309
225234	Avon River @ Clydebank	1977 - 2015	39	1584

Gauge No.	Location	Period	Years	Catchment Area (km ²)
225255	Avon River U/S of Valencia Creek Junction	2004 - 2012	9	-
225211	Avon River @ Buxton	1953 - 1972	20	580
225220	Valencia Creek @ Radettis	1967 - 1971	5	233
225205	Avon River @ Valencia Creek	1919 - 1964	46	862

Rating Curves

Streamflow data in the catchment consists of five gauges. An important gauge for the model calibration is the Avon River @ Stratford (225201) gauge. This gauge was found to have a number of high flow gaugings¹ and has been consistently gauged throughout its 38 year gauging period. Consultations with the current hydrographer of the Avon basin suggest the gauging relationship at Stratford has been evolving for quite some time, likely due to channel change, however this has progressed in a distinguishable manner and is reflected in the flow estimates for the gauge (Wayne Ross pers. comm., 2015).

Upstream gauging stations are the Freestone Creek @ Briagolong, Valencia Creek @ Gillio Road and Avon River @ The Channel are also considered reliable. They have a number of high flow gaugings and little scatter.

However, the downstream gauge at Clydebank does not appear to have any high flow readings within the calibration flow range (up to approximately 2100 m³/s). There are a number of issues associated with stage-discharge relationships at Clydebank. Whilst the gauge is on the Avon River, during high flow events wetlands on either side of the river are activated, causing multiple flow paths across the floodplain separate to the Avon River flow path. Clydebank is also close to the Avon River outlet at Lake Wellington, which has been shown to vary with a number of factors including atmospheric conditions, wind conditions, tides and recent amount of discharge into the lake (Brizga et al., 2013).

2.6.3 Water Level Data

Two water level gauges operate in Lake Wellington (Table 2-4). The Light Pile was installed in 2013 as part of an environmental flows monitoring program for the lower Latrobe River, and does not have data available for the selected calibration events. Bull Bay has a long record of data, including recorded data for the calibration events. The 1990 event was not captured by the Bull Bay gauge, as data is missing from this time period. Bull Bay water elevations will be used in the modelling as a downstream boundary.

Table 2-4 Water level gauges in Lake Wellington

Gauge No.	Location	Period	Years
226041	Lake Wellington @ Bull Bay	1975 - 2015	31
226610	Lake Wellington @ Light Pile	2013 - 2015	2

¹ Gaugings are physical measurements of flow rate in the river undertaken by measuring the flow velocity and depth at a number of locations across the width of the river. High flow gaugings are measurements undertaken when the river level is high, such as during flood events.

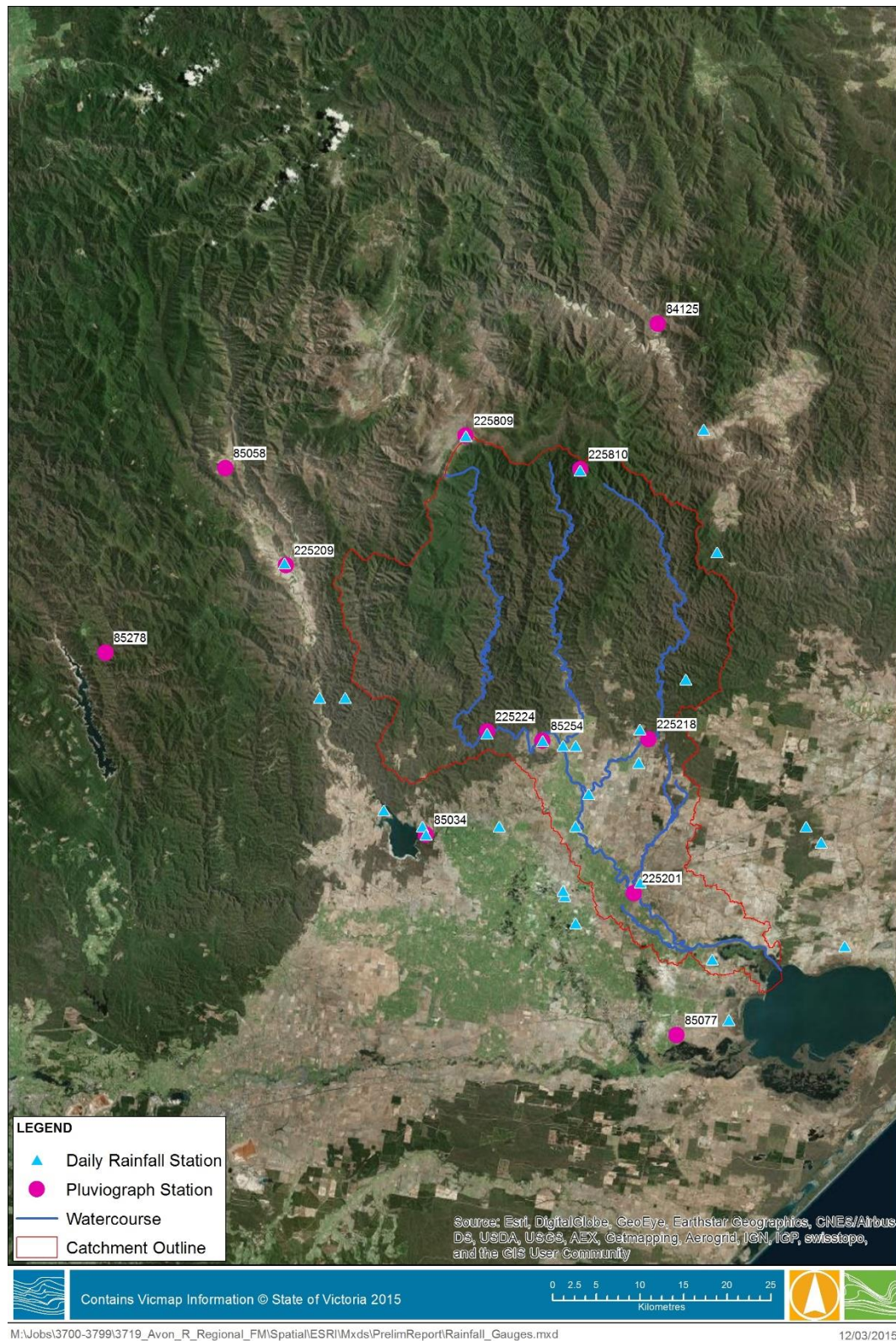


Figure 2-4 Rainfall stations in and around the Avon River catchment

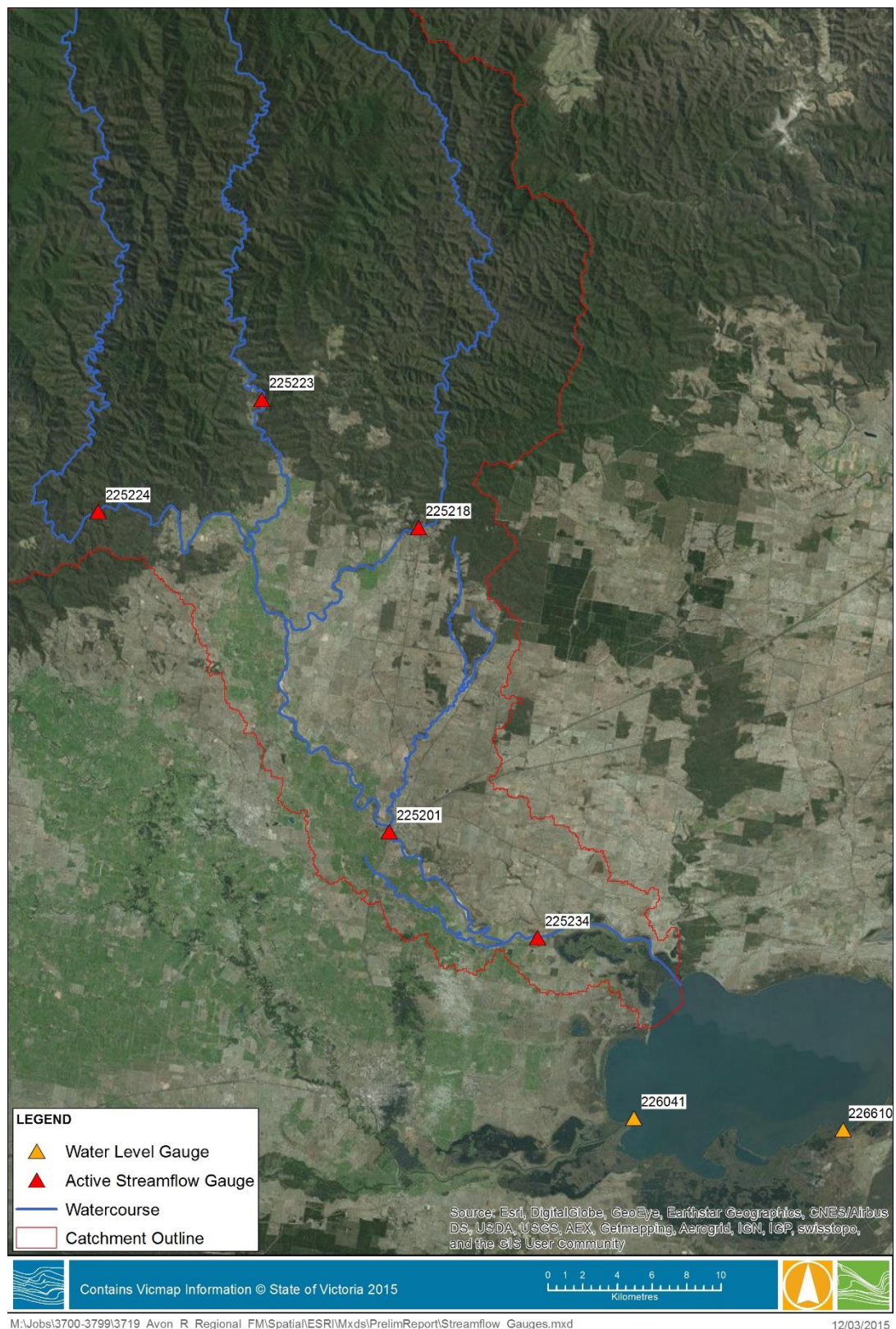


Figure 2-5 Streamflow and water level gauges in the Avon River catchment

3. PROJECT CONSULTATION

3.1 Overview

An important element of the flood mapping study was the active engagement of residents in the study area. This engagement was developed over the course of the study through community consultation sessions and meetings with a Steering Committee. The aims of the community consultation were as follows:

- To raise awareness of the study and to identify key community concerns; and
- To provide information to the community and seek their feedback/input regarding the study outcomes including the existing flood behaviour and proposed flood mapping extents.

3.2 Steering Committee

The flood mapping study was led by a Steering Committee consisting of representatives from Department of Environment Land Water and Planning (DELWP), West Gippsland Catchment Management Authority (WGCMA), Wellington Shire Council (WSC) and Victorian State Emergency Service (VicSES).

The Steering Committee met on three occasions at key points throughout the study, to review and manage the development of the study.

3.3 Community Consultation

The main aim of the community engagement process was to provide information regarding the development of the study and to seek feedback, both verbally and through the use of online methods. All community meetings were supported by media releases to local papers and meeting notices.

The public consultation process was coordinated by DELWP. The following community meetings were held as part of the consultation process:

- Initial community meeting, 30th June and 1st July 2015 in Boisdale and Stratford – The first public meeting was held to outline the objectives of the study to the community and to receive any flood information the community may be able to provide;
- Second community meeting, 8th and 9th December 2015 – This meeting presented the results of the flood modelling. Community feedback was sought on the flood modelling results.

The community provided knowledge of a range of previous floods. An especially large range of data from the 1990 flood was provided, and could be compared to the 1% AEP event due to the similarity in magnitude.

4. FLOOD BEHAVIOUR

4.1 Overview

Flooding in the Avon catchment usually occurs due to widespread and prolonged rainfall. Apart from numerous rural properties, the primary township affected by floodwater is Boisdale. Stratford and Briagolong generally remain unaffected by floodwaters.

The flood behaviour associated with catchment flooding mechanisms has been assessed using a range of industry standard approaches and tools:

- Hydrological analysis – this involves the analysis of the magnitude of previous flood events in the catchment, the development of a rainfall-runoff model for the entire Avon River catchment, and the prediction of the likelihood of future flood events of a given magnitude,
- Hydraulic analysis – the physical understanding of what a given flood event may look like in the lower Avon catchment was assessed through a hydraulic analysis. A hydraulic model was used to predict the extent of flooding, flood depths and flow velocities for a range of possible future flood events.

The different flood mechanism and the results of the hydrologic and hydraulic analysis for the study area are discussed in detail in the following sections. Detailed reports are also provided in Report 2 & 3.

4.2 Hydrology

4.2.1 Streamflow Gauging

There are a number of streamflow gauge stations available for use in flood frequency analysis and calibration data for the hydrologic and hydraulic models. Of these gauges, the Avon River at Stratford, Avon River at the Channel, Freestone Creek at Briagolong and Valencia Creek at Gillio Rd were all deemed suitable for flood frequency analysis and calibration purposes. A detailed analysis of each gauge was undertaken and is presented in the Section 3.4 of Report 2, the Hydrology report.

4.2.2 Flood Frequency Analysis

A flood frequency analysis was used to estimate the magnitude of flood events at the four selected gauges in terms of a probability of occurrence. This allows the quantification of previous flood events and also enables the estimation of the frequency of future flood events.

The flood frequency analysis was based on an annual series of maximum flows at each gauge for the full record of data. Historic flood peaks were also included based on flood information received for each of the gauges and relationships between the gauges. Further details are provided in Section 3.5 of Report 2. The design flows resulting from the flood frequency analysis at each gauge are given in Table 4-1, Table 4-2, Table 4-3 and Table 4-4. Given the reasonable length of record and the good fit of the Log Pearson III distribution, these peak design flows are considered to be a good predictor of flood probability (assuming no on-going or future climate trends).

Table 4-1 FFA Peak Flow Estimates for Avon River at Stratford

AEP	Peak Flow Estimate (m ³ /s)	
	Log Pearson III	5-95% Confidence Limits
20%	709	(501 – 972)
10%	1168	(878 – 1514)
5%	1658	(1301 – 2114)
2%	2316	(1832 – 3132)
1%	2799	(2181 – 4184)
0.5%	3258	(2452 – 5488)
0.2%	3820	(2719 – 7453)

Table 4-2 FFA Peak Flow Estimates for the Avon River at The Channel

AEP	Peak Flow Estimate (m ³ /s)	
	Log Pearson III	5-95% Confidence Limits
20%	297	(215 – 398)
10%	488	(370 – 631)
5%	709	(549 – 924)
2%	1038	(788 – 1479)
1%	1309	(959 – 2089)
0.5%	1593	(1113 – 2886)
0.2%	1986	(1283 – 4313)

Table 4-3 FFA Peak Flow Estimates for Valencia Creek at Gillio Road

AEP	Peak Flow Estimate (m ³ /s)	
	Log Pearson III	5-95% Confidence Limits
20%	95	(66 – 133)
10%	162	(121 – 213)
5%	237	(184 – 305)
2%	340	(264 – 481)
1%	419	(316 – 670)
0.5%	495	(359 – 902)
0.2%	590	(400 – 1271)

Table 4-4 FFA Peak Flow Estimates for Freestone Creek at Briagolong

AEP	Peak Flow Estimate (m ³ /s)	
	Log Pearson III	5-95% Confidence Limits
20%	221	(166 – 291)
10%	354	(279 – 446)
5%	489	(397 – 608)
2%	661	(541 – 857)
1%	781	(633 – 1085)
0.5%	890	(707 – 1338)
0.2%	1016	(783 – 1698)

4.2.3 Hydrologic Modelling

A hydrological model of the catchment was developed for the purpose of extracting design flows to be used as boundary conditions in the Avon River hydraulic model. The rainfall-runoff program, RORB (Version 6) was used for this study.

RORB is a non-linear rainfall runoff and streamflow routing model which is used for calculation of flow hydrographs in drainage and stream networks. The model requires catchments to be divided into subareas, connected by a series of conceptual reach storages. Design storm rainfall is input to the centroid of each subarea. Specified losses are then deducted, and the excess routed through the reach network. The RORB model layout is shown in Figure 4-1.

There are four streamflow gauges within the catchment which were used to calibrate the RORB model. The Avon River gauge at Stratford has 38 years of flow records from 1976-2015, covering the 2007, 2011 and 2012 floods and other smaller floods. The Avon River at The Channel, Freestone Creek at Briagolong and Valencia Creek at Gillio Road all have a similar period of record, and rating curves with a similar level of confidence. Parameter selection was based on calibration to all four gauges and comparison to accepted regional methods, and the design flows were validated against the flood frequency analysis.

Design flow hydrographs were developed using the calibrated routing parameters, and loss parameters adjusted to reconcile the flood peak to the flood frequency analysis. The critical storm duration for design events ranged from 36 hours to 48 hours. The adopted peak design flows are provided in Table 4-5.

Table 4-5 Adopted Peak Flows for the Avon River catchment

AEP	Design Flow - Stratford (m ³ /s)	Design Flow – The Channel (m ³ /s)	Design Flow – Freestone Creek (m ³ /s)	Design Flow – Valencia Creek (m ³ /s)	Critical Duration (Stratford)
20%	808	350	264	107	36hr
10%	1184	530	363	170	36hr
5%	1703	779	512	262	36hr
2%	2277	1017	659	341	36hr
1%	2883	1301	800	434	36hr
0.5%	3495	1544	919	524	48hr
0.2%	4272	1884	1106	661	48hr

4.2.4 Probable Maximum Flood

The Probable Maximum Flood (PMF) was modelled by applying the Probable Maximum Precipitation (PMP) in RORB. The rainfall depth estimates and temporal and spatial patterns calculated from the Generalised Southeast Australian Method (GSAM) were adopted.

The PMP rainfall totals, spatial and temporal patterns were input into the RORB model, with the calibrated routing parameters. An initial loss of 0 mm and a continuing loss of 1 mm/hr were adopted as recommended in Australian Rainfall and Runoff Book VI (1998). The resulting PMF peak flows are given in Table 4-6.

Table 4-6 PMF peak flow estimates

	Design Flow - Stratford (m ³ /s)	Design Flow – The Channel (m ³ /s)	Design Flow – Freestone Creek (m ³ /s)	Design Flow – Valencia Creek (m ³ /s)	Critical Duration (Stratford)
PMF	14810	5870	3164	2101	24hr

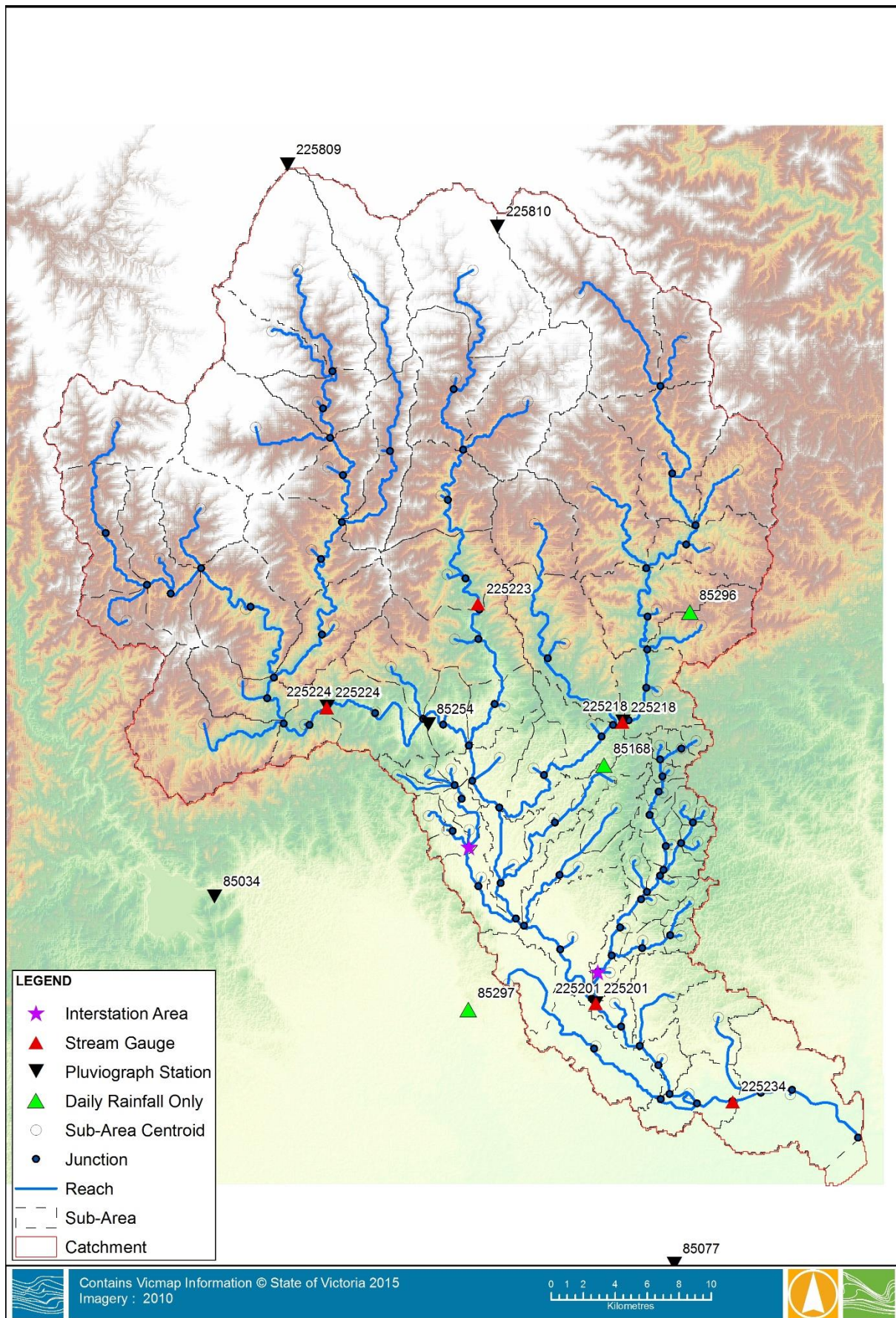


Figure 4-1 RORB Model Structure

4.3 Hydraulics

4.3.1 Overview

This section discusses the application of the hydraulic model to simulate flood behaviour (extents, depth, velocities) for a range of flood magnitudes.

The hydrologic analysis previously discussed, provided flood inflow hydrographs for the hydraulic model. These inflow hydrographs were routed through the calibrated hydraulic model. This enabled the modelling of flood depths, extents and velocities over a range of flood magnitudes. It also provided a tool for understanding the flood behaviour across the study area.

A detailed description of the hydraulic model setup, calibration, validation, sensitivity tests and design event simulation is provided in Report 3. This section summaries the general model development and key outcomes from the hydraulic modelling investigation.

4.3.2 Hydraulic Modelling

A two dimensional (2D) flexible mesh hydraulic model was developed for the study area using MIKE21FM GPU (Mike by DHI). MIKE21FM two-dimensional flexible mesh model systems is a 2D state-of-the-art tool for floodplain modelling which is run with a graphics processing unit (GPU). The GPU allows for greatly accelerated model runs, and represents a recent critical advancement in hydraulic modelling. Further details on the capabilities of the MIKE modelling system can be found at <http://www.dhisoftware.com>.

Adopting a flexible mesh modelling approach allowed the hydraulic model to incorporate greater detail in areas of importance, whilst maintaining computational efficiency through a larger element size in less sensitive regions of the modelled area. This allows features within the broader floodplain and the township areas (Stratford, Boisdale, and Briagolong) to be resolved in varying detail in the same model whilst maintaining appropriate run times.

The model extent covered the full study area, as shown in Figure 1-2, and inflows were included from all tributaries (Upper Avon River, Valencia Creek, and Freestone Creek), as well as runoff from Blackhall Creek and the floodplain itself. Water levels in Lake Wellington provided the downstream boundary of the model. Topography data was provided by LiDAR survey.

The modelling process involved the following stages:

- Model setup and calibration,
- Validation and sensitivity tests,
- Design flood simulations,

The calibration, validation, and sensitivity assessments are an iterative investigative process and all outcomes from these stages inform the final design flood simulations.

4.3.3 Understanding Flood Behaviour

Table 4-7 describes the key flood characteristics in the Avon River catchment for each design event. The key aspect to note is that Boisdale is inundated in the 1% AEP and larger flood events. For events larger than a 1% event, the extent of inundation is increased by numerous riverine breakouts upstream of Boisdale. Stratford township remains unaffected by riverine flooding for all design events including the PMF.

Table 4-7 Summary of Flood Behaviour for Various Flood Events

Event	Flood Characteristics	Key roadways inundated
20% AEP	- Flow Remains within channel for most of river - Boisdale unaffected by floodwater from the Avon River - Local catchments start causing some roads to have shallow inundation around Boisdale - Inundation on floodplain downstream of Stratford, initiated by Nuntin Creek spillway	- Bengworden Rd in Clydebank is impassable - Stewarts Lane Avon River crossing is impassable - Valencia Creek-Briagolong Rd Avon River low-level crossing is impassable - Wombat Rd crossing of the Upper Avon is impassable - Smyths Rd crossing of Valencia Creek is impassable - Stratford-Maffra Rd is slightly inundated near Stratford, where the road is low and dips under the railway line - Maffra-Briagolong Rd is impassable in a number of locations downstream of Boisdale - Some shallow inundation on Boisdale-Newry Rd, west of Boisdale - Some shallow inundation on Boisdale-Valencia Creek Rd, north of Boisdale
10% AEP	- Flow Remains within channel for most of river - Boisdale unaffected by floodwater - Inundation on floodplain downstream of Stratford, initiated by Nuntin Creek spillway - Water backs up into the Nuntin system from Nuntin spillway - Small breakout noted just downstream of Stratford, further inundating the Nuntin system	- Stratford-Maffra Rd is impassable near Stratford, where the road is low and dips under the railway line - Local roads around Boisdale are impassable
5% AEP	- Flow Remains within channel for most of upstream section of river - Boisdale unaffected by floodwater, apart from local catchment nuisance flooding - Inundation on floodplain downstream of Stratford, initiated by Nuntin Creek spillway and multiple breakouts just downstream of Stratford	Princes Highway is inundated at a low point where it crosses under the railway line west of the Avon River at Stratford

Event	Flood Characteristics	Key roadways inundated
	- Breakout at Stewarts Lane crossing upstream of Stratford forcing more water into Nuntin system - Inundation extensive in floodplain around Nuntin Creek-Avon River confluence - Flow blockage from Princes Highway and Railway embankment causing ponding behind embankments	
2% AEP	- Flow Remains within channel for most of upstream section of river - Boisdale unaffected by floodwater, apart from local catchment nuisance flooding. A breakout on the Avon River forces water towards Boisdale, but it does not have the volume to reach Boisdale and is absorbed by the drainage system to the east of Boisdale. - Extensive inundation on floodplain downstream of Stratford, with the entire western side of the Avon River exhibiting an unbroken expanse of floodwater between Nuntin Creek and the Avon River between Stratford and the Nuntin Creek-Avon River confluence. - Breakout at Stewarts Lane crossing and just upstream of Princes Highway crossing upstream of Stratford forcing more water into Nuntin system. This flow is obstructed by Princes Highway and Railway line embankments, and combines with local flows to cause inundation behind these embankments	Extensive flooding on the Princes Highway west of the Avon River at Stratford
1% AEP	- Numerous breakouts along Avon River - Boisdale affected by floodwater. A breakout on the Avon River forces water towards Boisdale, which is partially absorbed by the drainage system to the east of Boisdale, but also overtops Boisdale Main drain and causes inundation in the township. Water from this breakout also continues into the downstream Nuntin Creek catchment. - Extensive inundation on floodplain downstream of Stratford, with the entire western side of the Avon River exhibiting an unbroken	Some local rural roads on the north side of Stratford become inundated.

Event	Flood Characteristics	Key roadways inundated
	expanse of floodwater between Nuntin Creek and the Avon River between Stratford and the Nuntin Creek-Avon River confluence. Breakout at Stewarts Lane crossing and just upstream of Princes Highway crossing upstream of Stratford forcing more water into Nuntin system. This flow is obstructed by Princes Highway and Railway line embankments, and combines with local flows to cause inundation behind these embankments	
0.5% AEP	- Numerous breakouts along Avon River - Boisdale extensively inundated by floodwater. A breakout on the Avon River forces water towards Boisdale, overtops Boisdale Main drain and causes inundation in the township. A breakout from the Avon River near the Valencia Creek confluence also adds additional water to the Boisdale area. - Freestone and Valencia Creeks are also overtopping their banks, with various breakout flows inundating local areas. - Extensive inundation on floodplain on the entire western side of the Avon River with large expanses of floodwater in large sections from the Avon-Valencia Creek confluence to the outlet at Lake Wellington. - Railway line yet to be overtopped and causing extensive obstruction to flow	Valencia Creek - Briagolong bridge over Freestone Creek is impassable
0.2% AEP	- Numerous breakouts along Avon River - Boisdale extensively inundated by floodwater. A breakout on the Avon River forces water towards Boisdale, overtops Boisdale Main drain and causes inundation in the township. - Water is also breaking out on the eastern side of the river in multiple locations, near the Valencia Creek confluence and upstream of Stratford. Stratford remains unaffected. - Freestone and Valencia Creeks are also overtopping their banks, with various breakout flows inundating local areas.	

Event	Flood Characteristics	Key roadways inundated
	• Extensive inundation on floodplain on the entire western side of the Avon River with expanses of floodwater in large sections from the Avon-Valencia Creek confluence to the outlet at Lake Wellington. • Railway line yet to be overtopped and causing extensive obstruction to flow.	
PMF	• Numerous breakouts along Avon River • Boisdale extensively inundated by floodwater. • Freestone and Valencia Creeks are also overtopping their banks, with various breakout flows inundating local areas. • Extensive inundation on floodplain on the entire western side of the Avon River and eastern side of the river upstream of Stratford, with expanses of floodwater in large sections from the Avon-Valencia Creek confluence to the outlet at Lake Wellington. • Stratford unaffected by floodwater. • Railway line partially overtopped and causing extensive obstruction to flow.	• Bushy Park Rd bridge over Freestone Creek is impassable

5. FLOOD BEHAVIOUR AND INTELLIGENCE OUTPUTS

5.1 Overview

The flood behaviour and intelligence outputs developed as part of the Avon River Regional Flood Mapping Study are described in this section. Flood Response Inundation Mapping.

5.2 Model Result Outputs

The model result data including grids and extents have been provided in specified Victorian Flood Database (VFD) format for each flood event. The following result components were generated:

- Flood level, flood depth, flood velocity and flood hazard grids
- Flood elevation contours
- Flood extent data
- Hydrographs at key locations
- Long-section of river water levels

Details are provided of the study outputs for emergency response, and land use planning mapping including:

- Data sets: grids and shapefiles (ESRI/VFD format), Data tables (Excel csv/xlsx format)

5.2.1 Data Sets

The following datasets have been provided. All GIS files were provided in ESRI VFD format or Excel csv/xlsx format. A summary of the datasets is provided below and shown in Figure 5-1.

Grids

Gridded datasets of model results were provided for the following:

- Design events (20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF events) – maximum depth, hazard, velocity and water surface elevation.
- Calibration events (1990, 2007, 2011, and 2012 events) – maximum depth and water surface elevation.
- Model Topography

The hydraulic analysis provides regular grid of flood elevations across the hydraulic model study area. The flood extent was defined by converting the 2m flood elevations grid to an extent polygon. The extent is smoothed to remove the sharp edges of the grid cells for cartographic / presentation purposes.

Flood depths were classified for mapping using the following classifications:

- 0 m to 0.25 m
- 0.25 m to 0.5 m
- 0.5 m to 1.0 m
- Greater than 1.0 m

Vector Data

ESRI shapefiles in VFD format were provided for the following:

- Peak flood extents

- Peak flood elevation contours
- Mapping limits

Data Tables

Data tables in excel CSV format were provided for the following:

- Stage height hydrographs at 12 key locations across the study area for 6 design events (20%, 10%, 5%, 2%, 1% and 0.5% AEP events). The key locations are displayed in Figure 5-1.
- Water surface level profile along the Avon River for 6 design events (20%, 10%, 5%, 2%, 1% and 0.5% AEP events). The long section profile location is shown in Figure 5-1.

5.2.2 Maps

The flood response inundation maps have been produced for the following design flood events:

- 10% and 1% AEP events – maximum depth.

Each map includes:

- Flood extent,
- Flood level contour at 1m intervals,
- Depth of inundation,
- Identification of essential services,
- Major Road/street names
- Cadastral base
- Gauge height indication for the Avon River catchment at the five currently active gauges – Avon River at The Channel, Avon River at Stratford, Avon River at Clydebank, Freestone Creek at Briagolong and Valencia Creek at Gillio Road.

Copies of the maps were provided as PDFs, and in Appendix C of Report 3. A mapping limits layer has been provided in the vector data. This data generally shows the model extent. However, in some small areas, near the Avon River – Valencia Creek Confluence, 50m SRTM data was used for the modelling due to a lack of any other topographic data source. Modelling in these areas has a much lower confidence, and was therefore excluded from the model result extents.

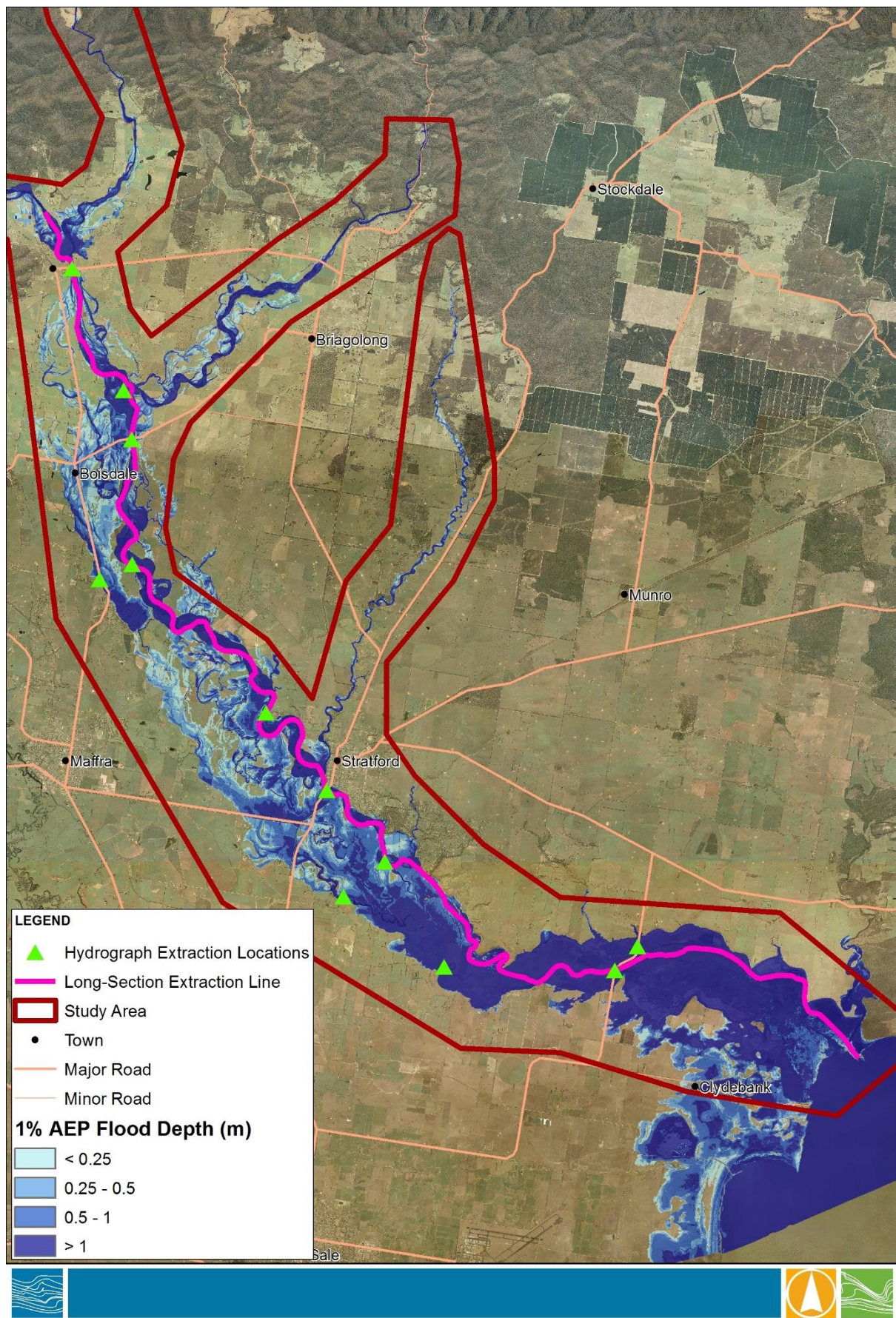


Figure 5-1 Supplied Data Location

5.3 Gauge Height Relationships

For each design flood event the model results were interpreted to provide information on the relationship between the flood level at each of the gauges on the Avon River and the equivalent design flood magnitude (in % AEP and ARI (years)). Table 5-1, Table 5-2, Table 5-3, Table 5-4 and Table 5-5 results of the assessment.

Table 5-1 Avon River at Stratford Gauge Heights for Design Flood Events

Gauge Height ² (m)	Flood level at Gauge (m AHD)	Design Flood Event AEP (%)	Design Flood Event ARI (years)
6.9	13.4	20	5
7.7	14.2	10	10
8.4	14.9	5	20
8.7	15.2	2	50
9.0	15.5	1	100
9.1	15.6	0.5	200
9.4	15.8	0.2	500

Table 5-2 Avon River at The Channel Gauge Heights for Design Flood Events

Gauge Height ³ (m)	Flood level at Gauge (m AHD)	Design Flood Event AEP (%)	Design Flood Event ARI (years)
6.2	78.2	20	5
7.4	79.4	10	10
8.6	80.6	5	20
9.7	81.7	2	50
10.9	82.9	1	100
11.8	83.8	0.5	200
13.0	85.0	0.2	500

² The Stratford gauge is located adjacent to Stratford on the Avon River. Gauge zero is 6.479m AHD

³ The Channel gauge is located upstream of the Avon-Valencia Creek confluence. Gauge zero is 72m AHD

Table 5-3 Avon River at Clydebank Gauge Heights for Design Flood Events

Gauge Height ⁴ (m)	Flood level at Gauge (m AHD)	Design Flood Event AEP (%)	Design Flood Event ARI (years)
3.1	2.9	20	5
3.4	3.2	10	10
3.8	3.6	5	20
4.1	3.9	2	50
4.4	4.2	1	100
4.7	4.5	0.5	200
5.0	4.8	0.2	500

Table 5-4 Freestone Creek at Briagolong Gauge Heights for Design Flood Events

Gauge Height ⁵ (m)	Flood level at Gauge (m AHD)	Design Flood Event AEP (%)	Design Flood Event ARI (years)
5.4	68.6	20	5
6.0	69.2	10	10
6.8	70.0	5	20
7.4	70.6	2	50
8.1	71.3	1	100
8.7	71.9	0.5	200
9.3	72.5	0.2	500

Table 5-5 Valencia Creek at Gillio Rd Gauge Heights for Design Flood Events

Gauge Height ⁶ (m)	Flood level at Gauge (m AHD)	Design Flood Event AEP (%)	Design Flood Event ARI (years)
3.6	89.1	20	5
4.2	89.7	10	10
5.0	90.5	5	20
5.5	91.0	2	50
6.1	91.6	1	100
6.5	92.0	0.5	200
7.1	92.6	0.2	500

⁴ The Clydebank gauge is located in the downstream Avon wetlands near Clydebank. Gauge zero is -0.21m AHD

⁵ The Briagolong gauge is located adjacent to Briagolong on Freestone Creek. Gauge zero is 63.238m AHD

⁶ The Gillio Rd gauge is located upstream of the Valencia Creek area. Gauge zero is 85.481m AHD

5.4 Study Deliverables

The study deliverables provide a comprehensive set of data that support the study outcomes. The deliverables are supplied on a study USB and consist of background data and outputs as listed below:

- Digital copies of study reports in PDF format.
- Digital copies of the maps (PDF format)
- GIS datasets for the model results (ArcGIS VFD format and Excel csv format)
- Digital elevation models

There is a readme.txt file on the USB that describes the directory structure of the data contained on the USB.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Overview

The Avon River Regional Flood mapping Study provides a comprehensive analysis and review of flood risk in the Avon River catchment. The study has involved:

- Collection and review of a range of data relevant to the definition of flooding within the study area.
- A rigorous hydrologic analysis to develop robust design flood estimates for the study.
- Development of a detailed hydraulic model that is capable of predicting flood impacts across the entire floodplain under a range of conditions.
- Design and calibration model result outputs.

6.2 Key Outcomes

In undertaking this study a number of important aspects of flood risk relevant to the Avon catchment have become apparent. These are summarised as follows.

Avon Hydrology – flooding in the Avon catchment is primarily a function of sustained, high intensity rainfall events in the mountainous upper catchment over a period of 24 – 48 hours. Generally when the Avon River is in flood, its main tributaries of Freestone Creek and Valencia Creek are also in flood.

Hydraulic Characteristics of the Avon River – Overbank flows are common in the lower catchment, however significant flooding does not occur to any of the major townships in floods less than a 1% AEP event. In the 1% AEP event and larger Boisdale is at a high risk of flooding through the township. As the magnitude of a flood event increases the increase in flow results in an increase in depth and velocity and flood extent, especially on the lower floodplain to the west of the Avon River.

6.3 Learnings & Recommendations

6.3.1 Learnings

Based on the study process and outcomes the following learnings are noted for future Regional Flood Studies:

- The involvement of local hydrographers with experience in stream flow gauging and an understanding of the history of gauging stations provides an invaluable resource to the study team,
- The issues with the Nuntin Levee/Spillway highlighted the importance of “as constructed” data being available for major infrastructure such as levees.
- Local community networks such as Landcare are an important resource for accessing community based information on a catchment. In the future it is suggested a sign-in sheet be utilised at community meetings and where possible, key community sources of information be noted.

6.3.2 Recommendations

With regard to the study outcomes, the following recommendations are provided:

- DELWP gauge records should be updated to reflect the correct gauge zeros; Avon River at Stratford (#225201) gauge zero is 6.479m AHD, whilst Avon River at Clydebank (#225234) gauge zero is -0.21m AHD.

- The low-level crossing on Bengworden Rd in Clydebank should include flood warning signage and road should be closed during flood events. At present it appears to not have a management plan during floods. Automated warning lights should be considered for this frequently inundated road.
- The WGCMA and Wellington Shire Council adopt the determined design flood levels and proceed to incorporate them into planning scheme amendments.
- The Wellington Shire Council and WGCMA continue to engage the community in the treatment of flood risks through regular flood awareness programs such as the VICSES FloodSafe program, starting with the development of a local flood guide.
- Avon River at Stratford (#225201) gauge high flow ratings are sensitive to the downstream impacts of the Stratford bridges.
- The catchment flooding is sensitive to rainfall in the upper catchment area, and would therefore be sensitive to any increase in rainfall due to climate change.
- Sea level rise due to climate change in Lake Wellington would cause an increase in flooding in the lower catchment (downstream of Stratford).

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