Avon River Regional Flood Mapping - Project Report

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Telephone
Fax
ACN No.
ABN No.

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.

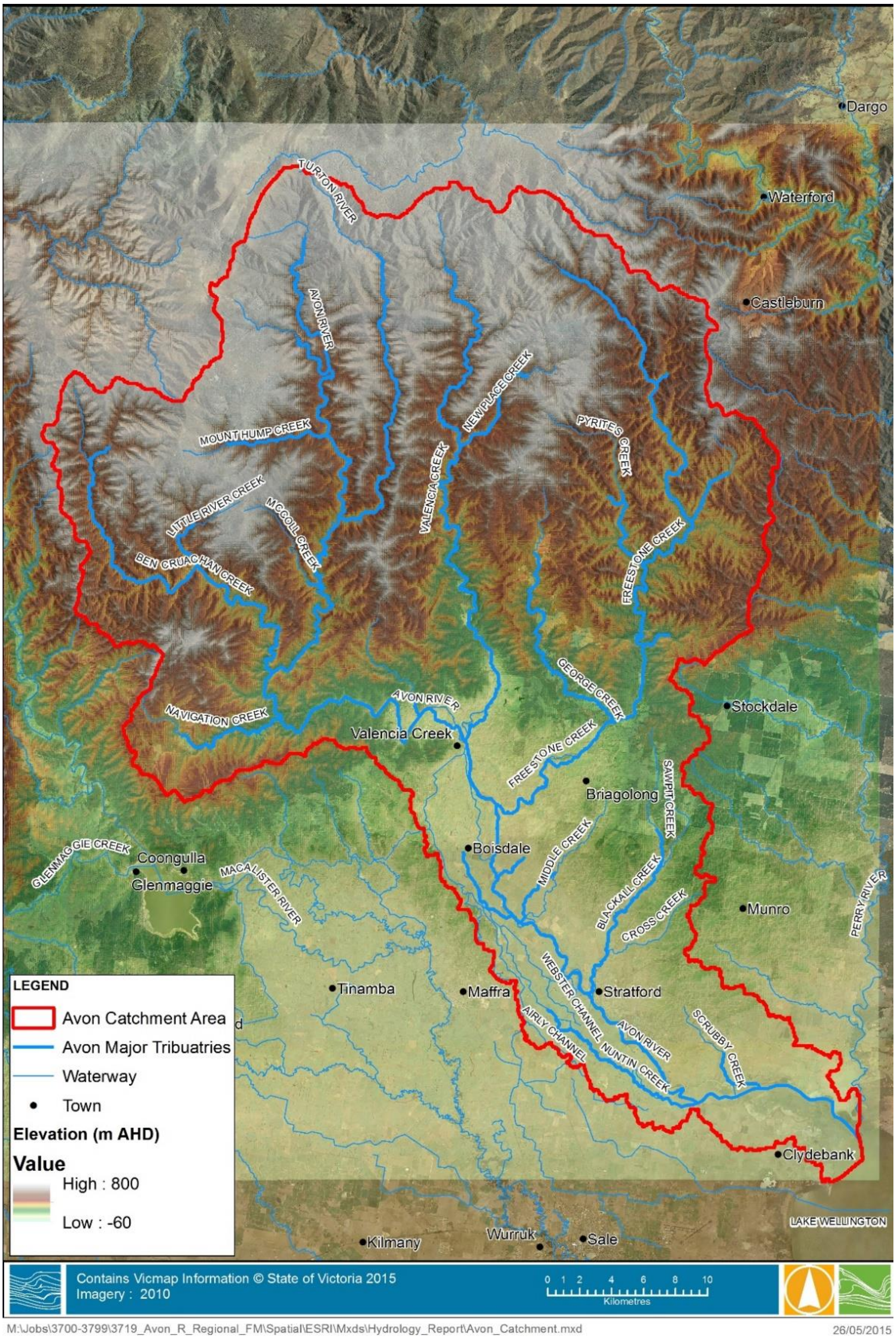

Figure 1-1 Avon River catchment extent including waterways

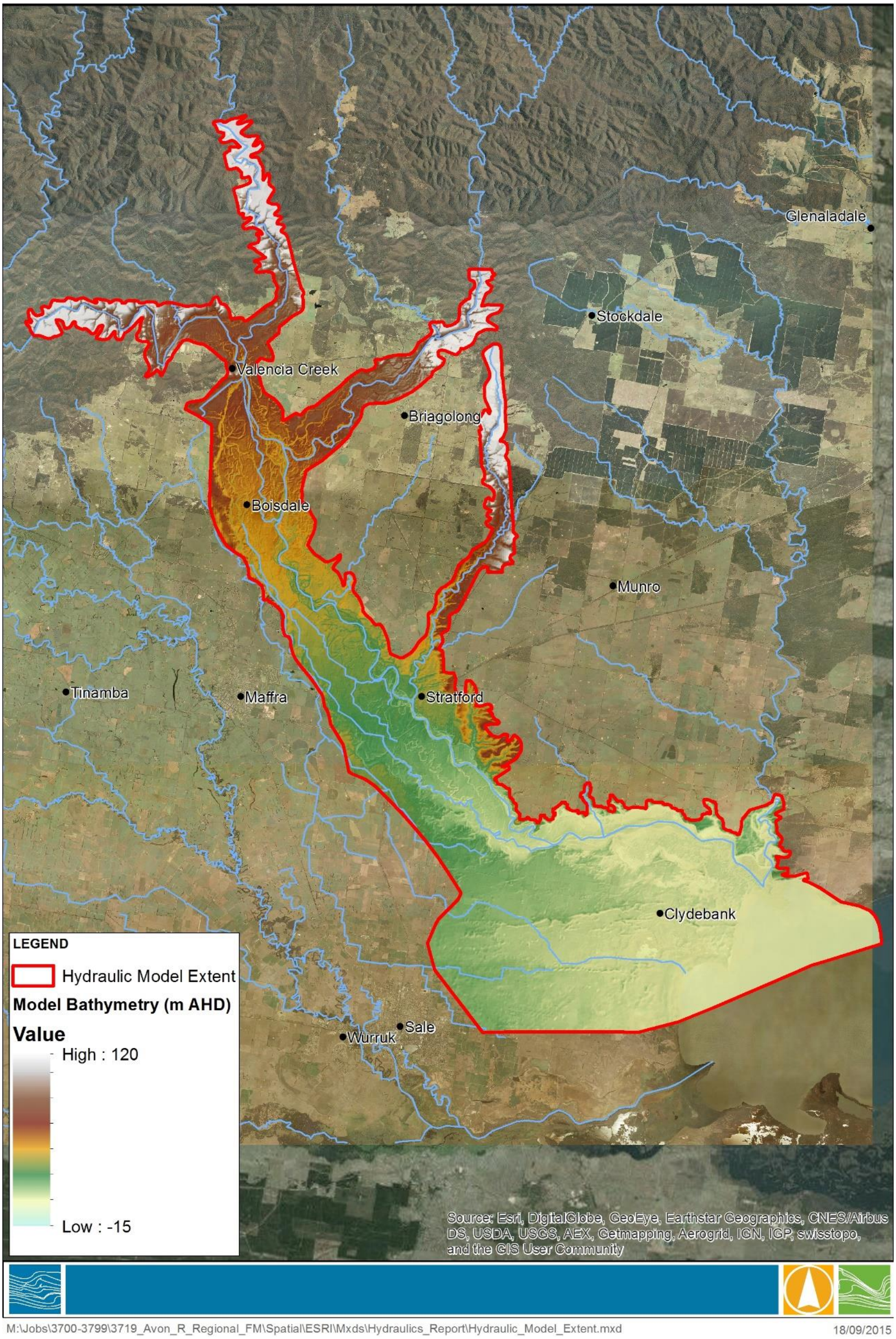

Figure 1-2 Study Area

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.

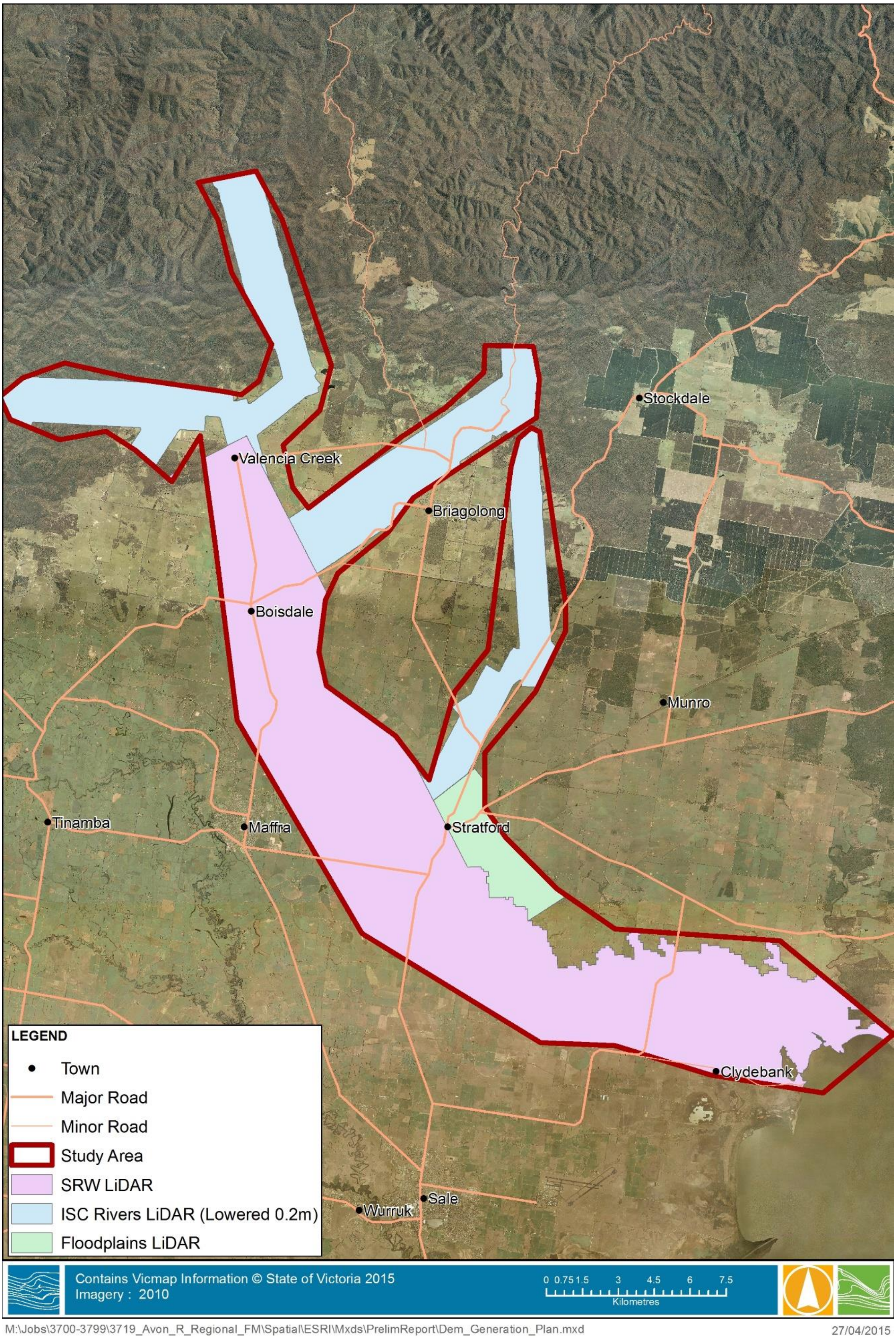

Figure 2-1 Model DEM Preparation Plan

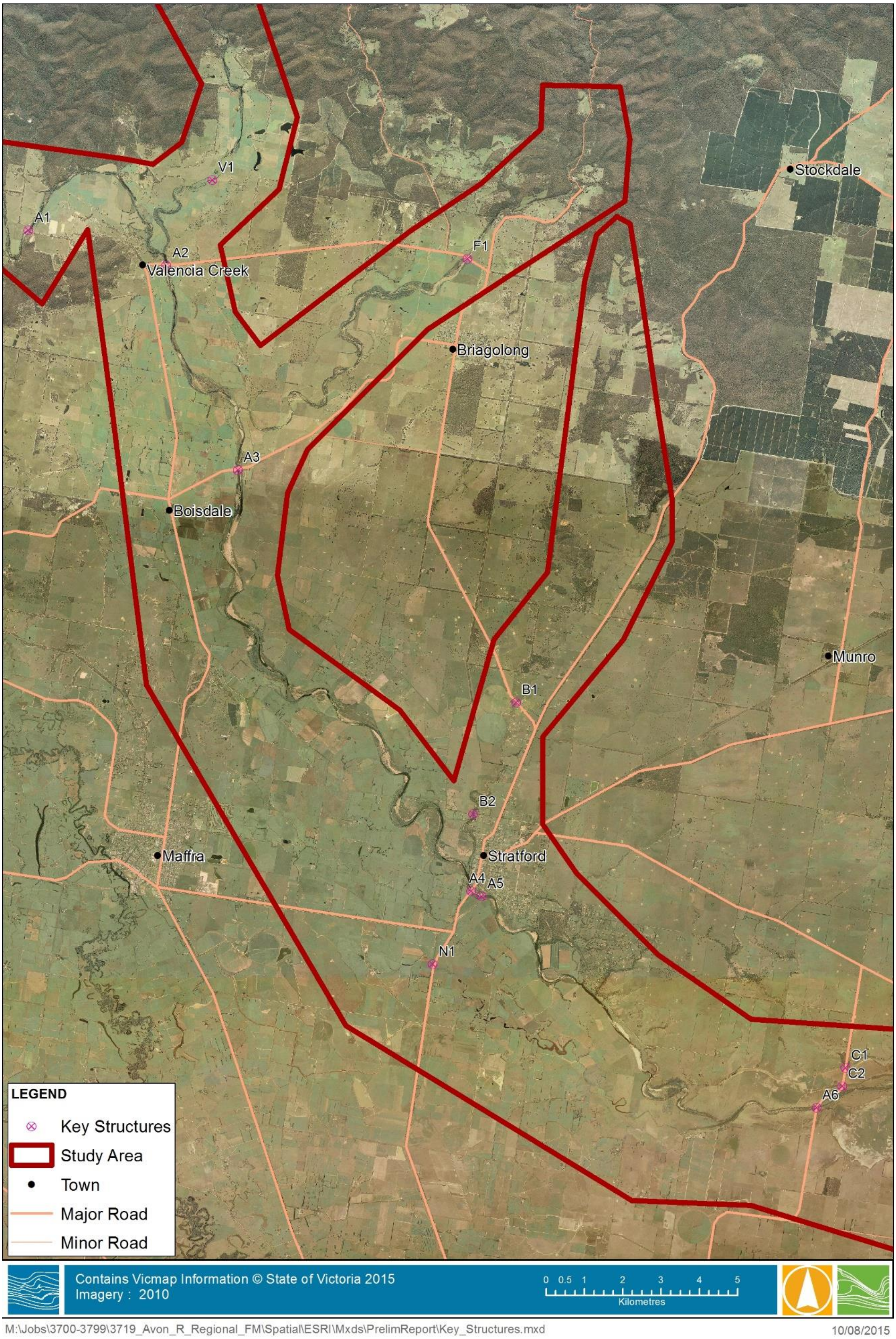

Figure 2-2 Key structures within study area

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.

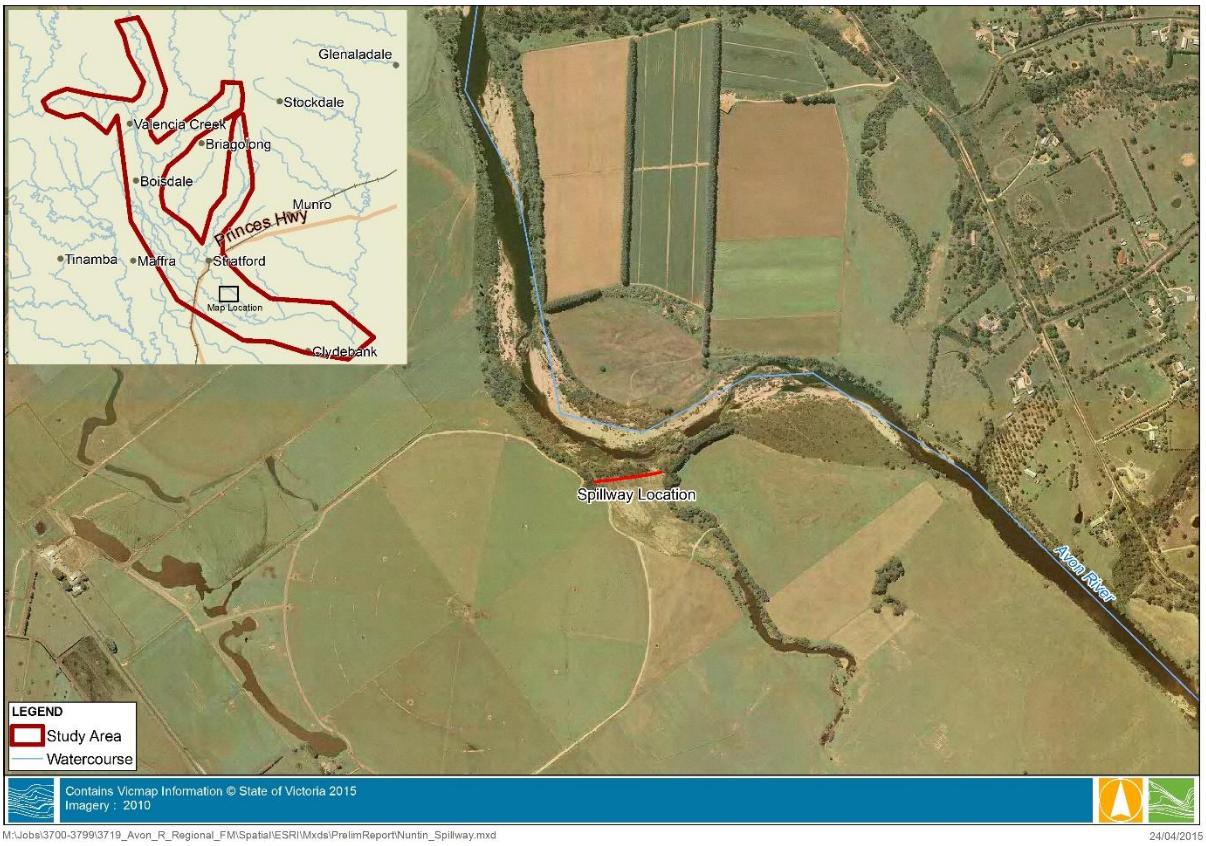

Figure 2-3 Location of Nuntin Creek Spillway (formerly Nuntin Creek Levee)

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 gaugings[1] 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 m^3/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 undertake when the river level is high, such as during flood events.

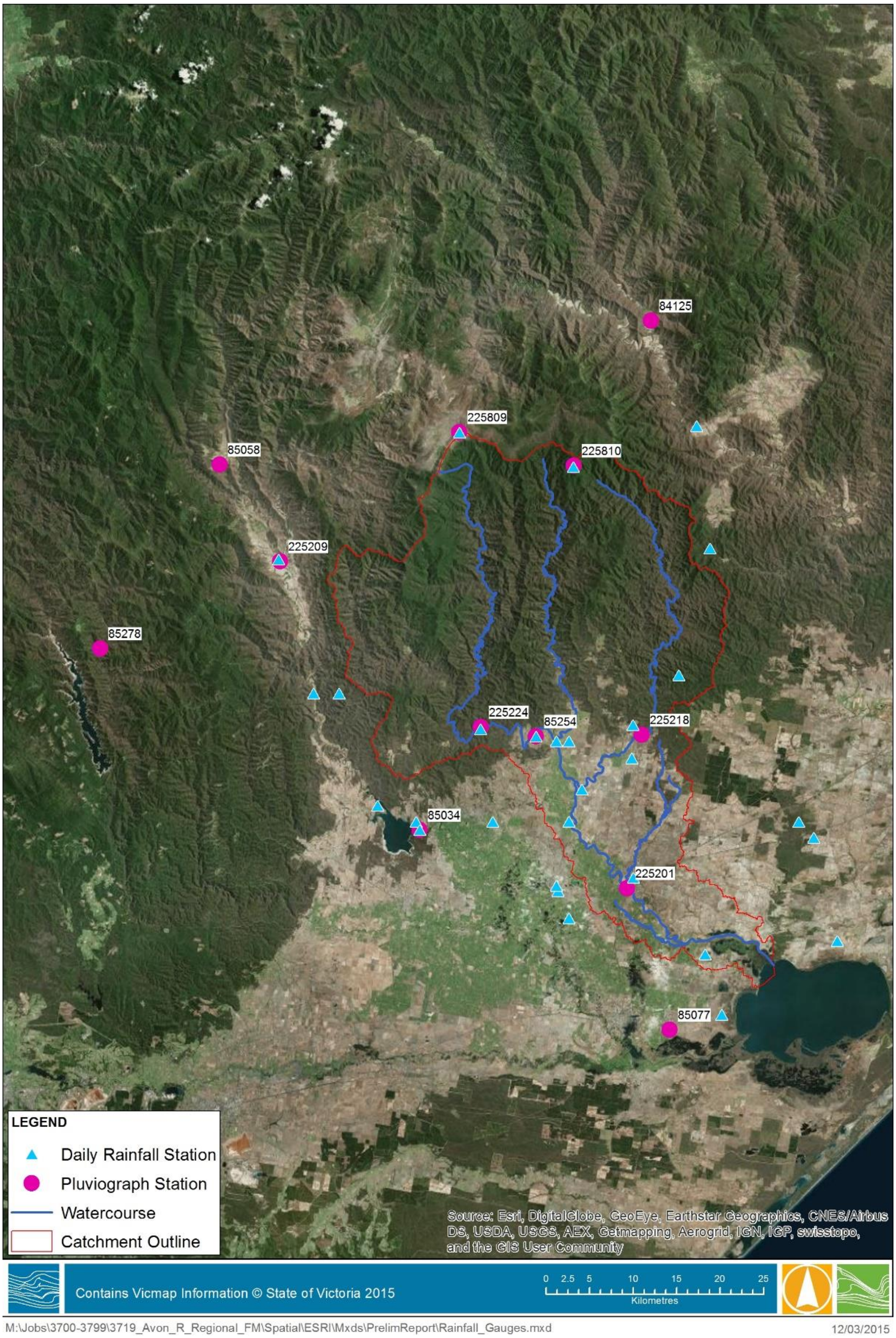

Figure 2-4 Rainfall stations in and around the Avon River catchment

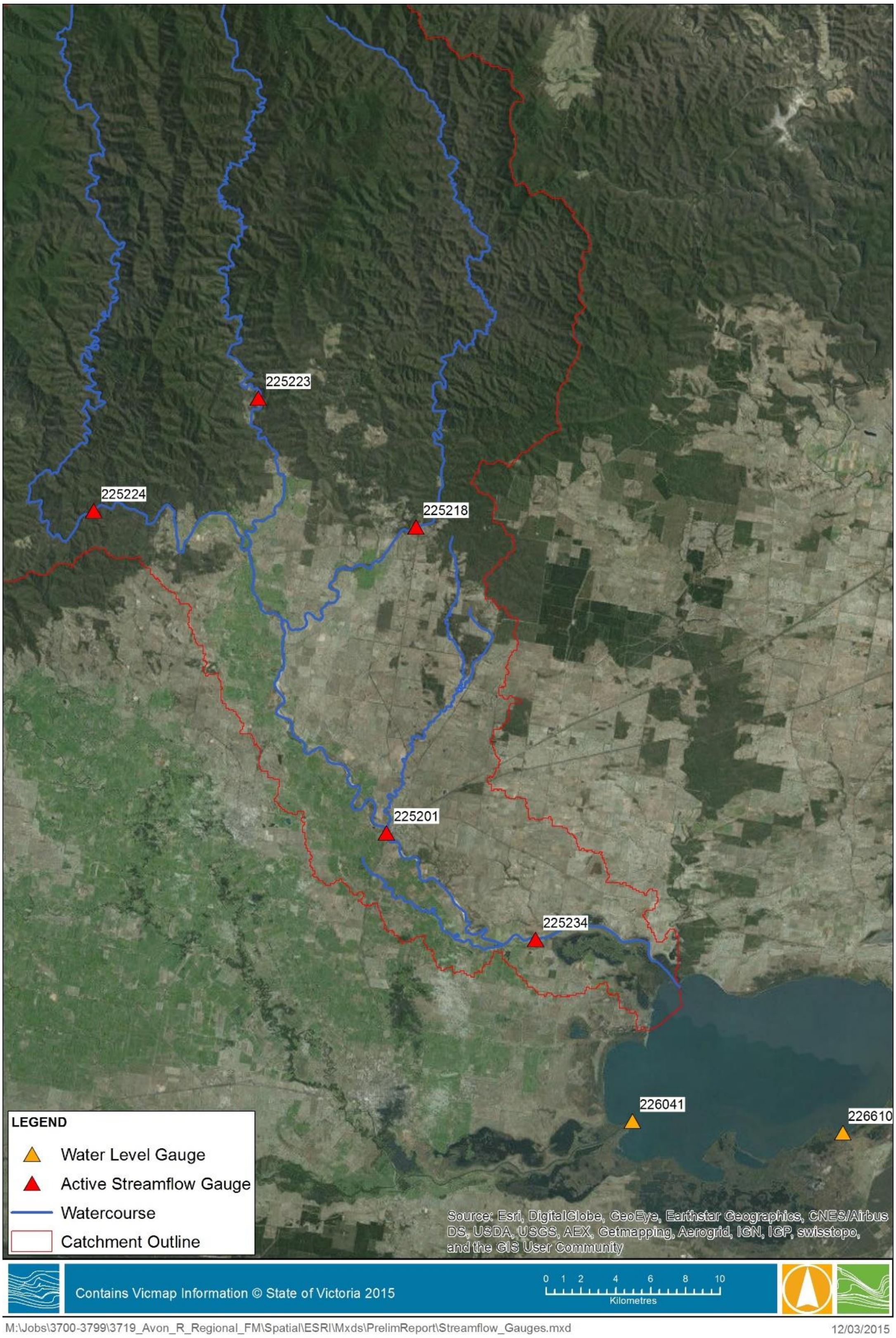

Figure 2-5 Streamflow and water level gauges in the Avon River catchment

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

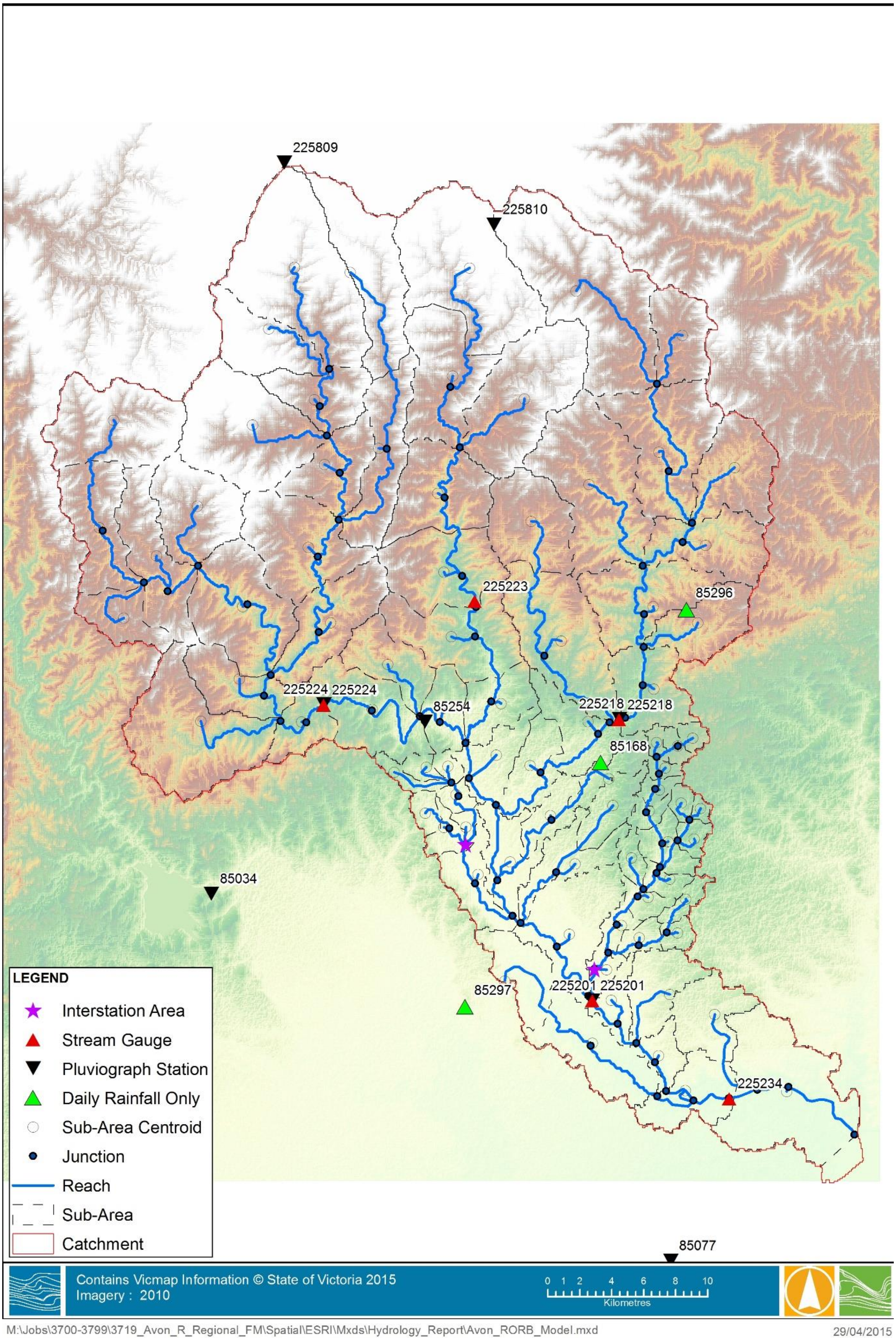

Figure 4-1 RORB Model Structure

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

ERSI 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.

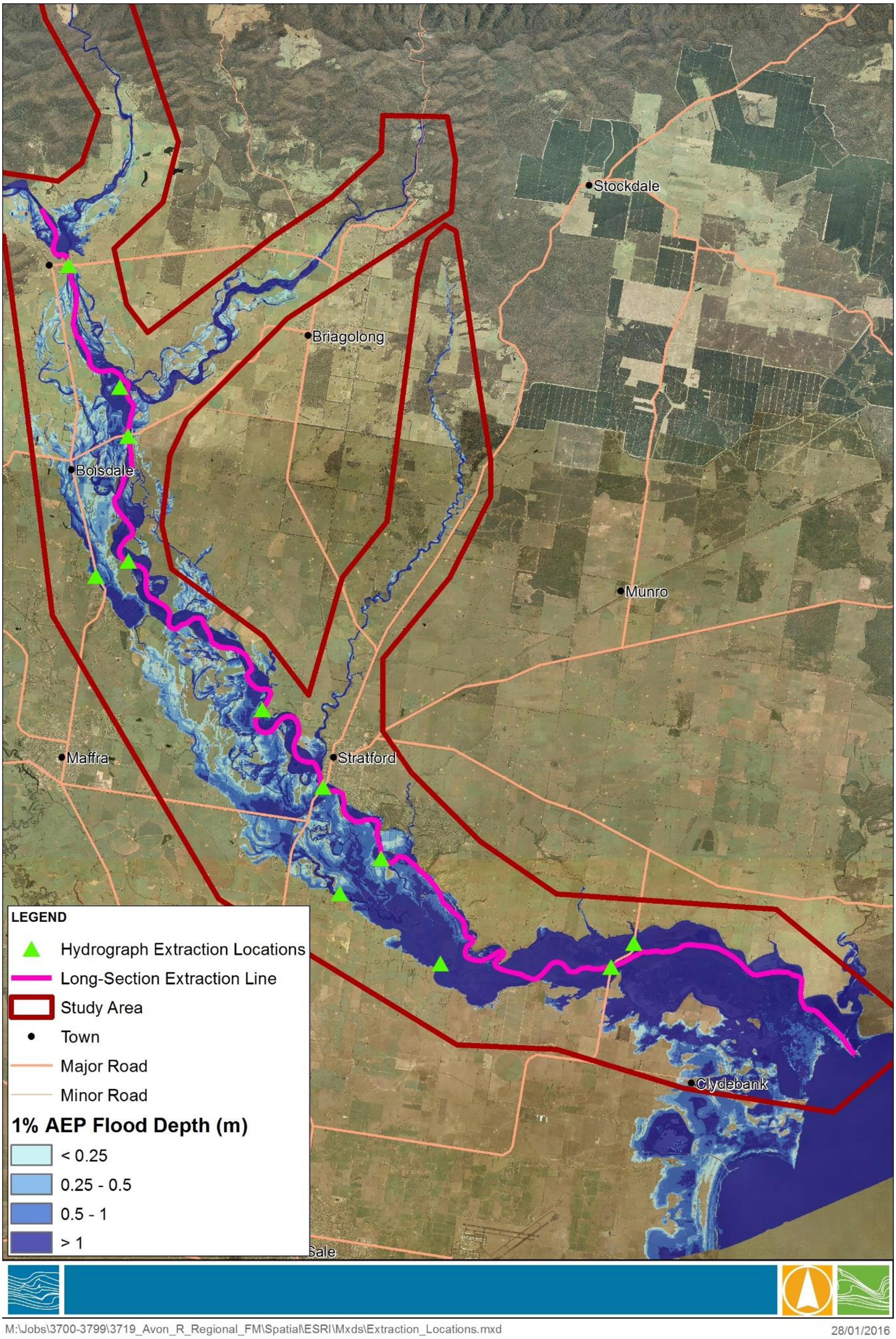

Figure 5-1 Supplied Data Location

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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