Avon River Regional Flood Mapping – Preliminary Report

April 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.

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.

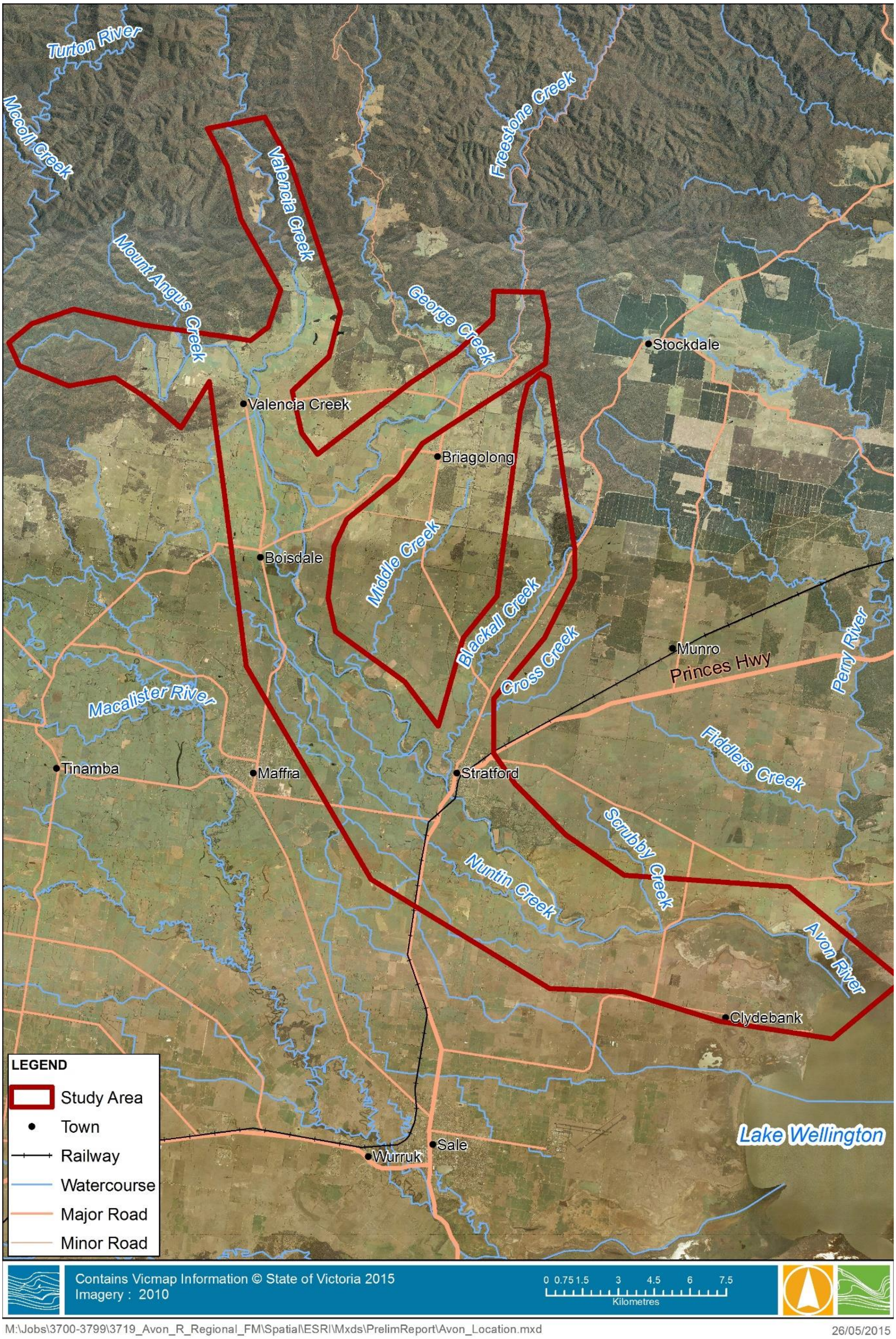

Figure 2-1 Avon River study area

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.

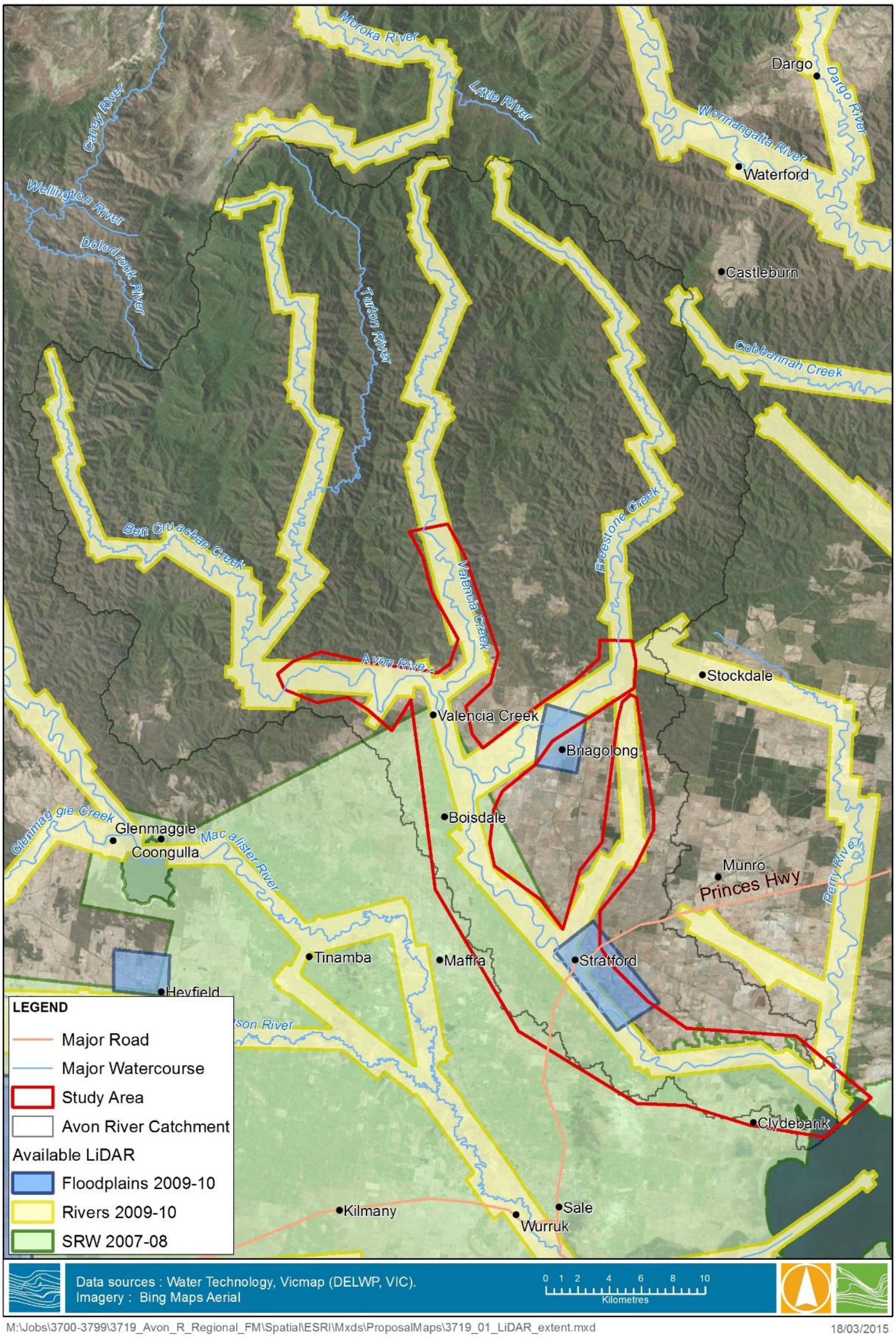

Figure 4-1 LiDAR extents

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.

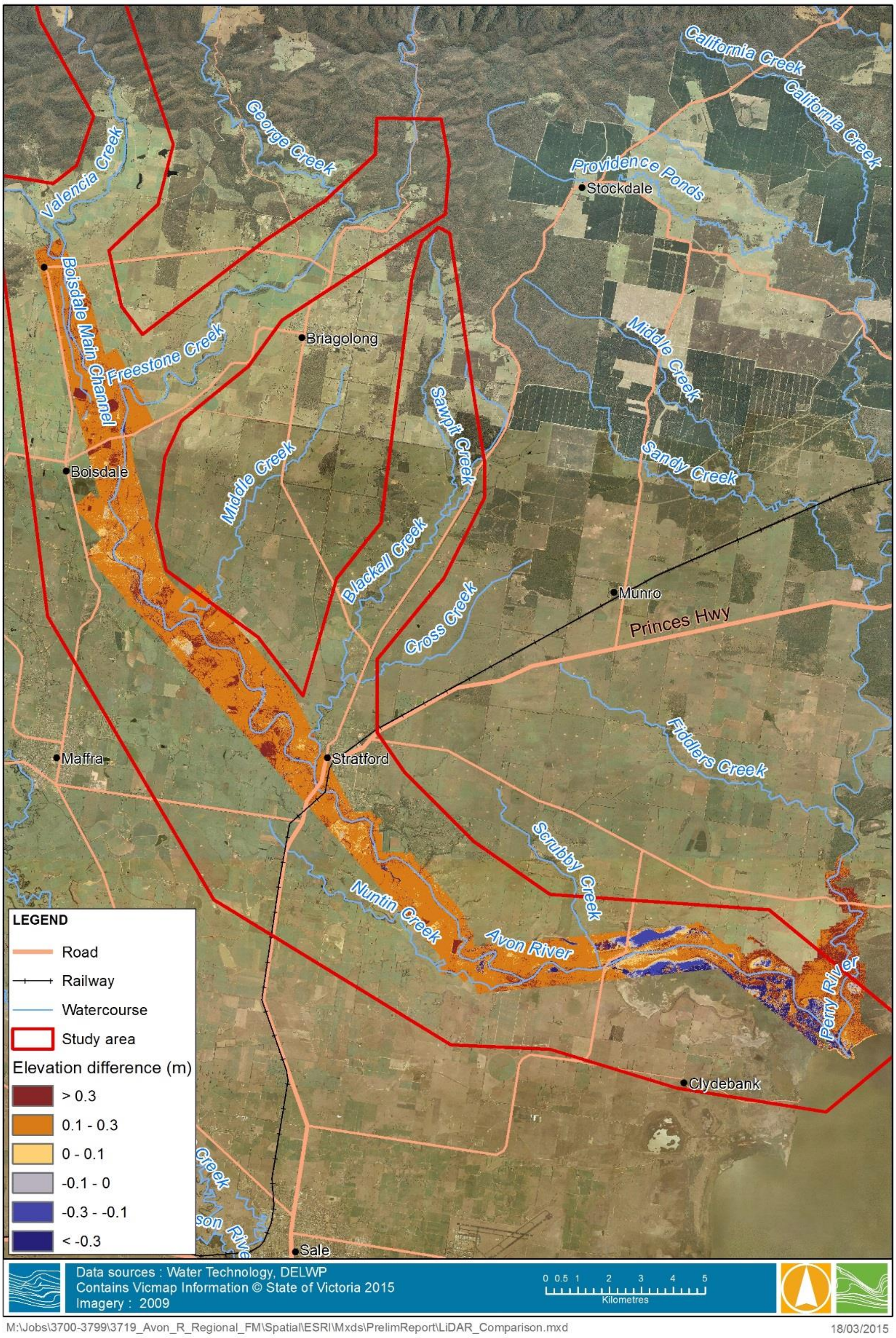

Figure 4-2 LiDAR comparison – Rivers DEM minus SRW DEM

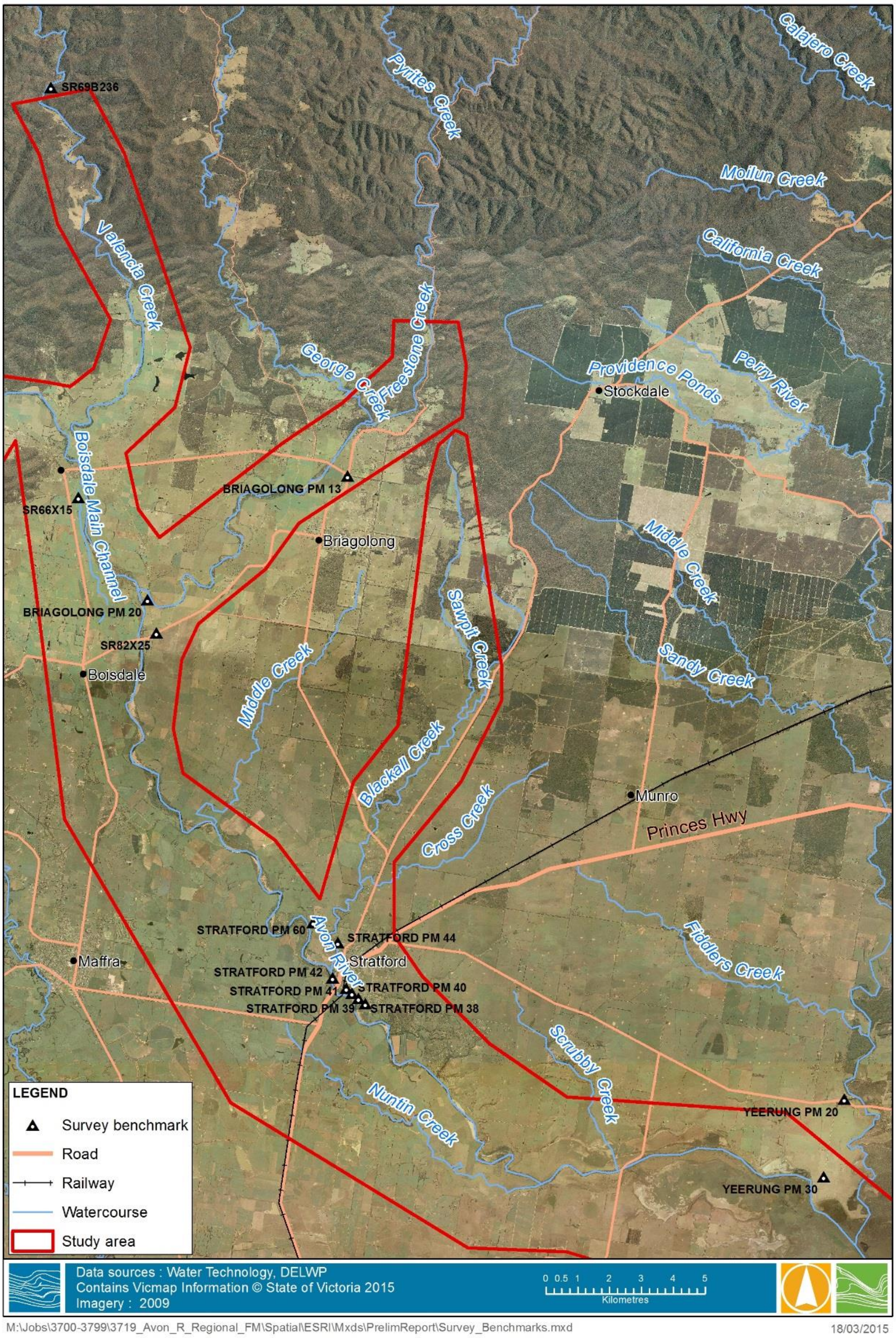

Figure 4-3 Location of survey benchmarks

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**

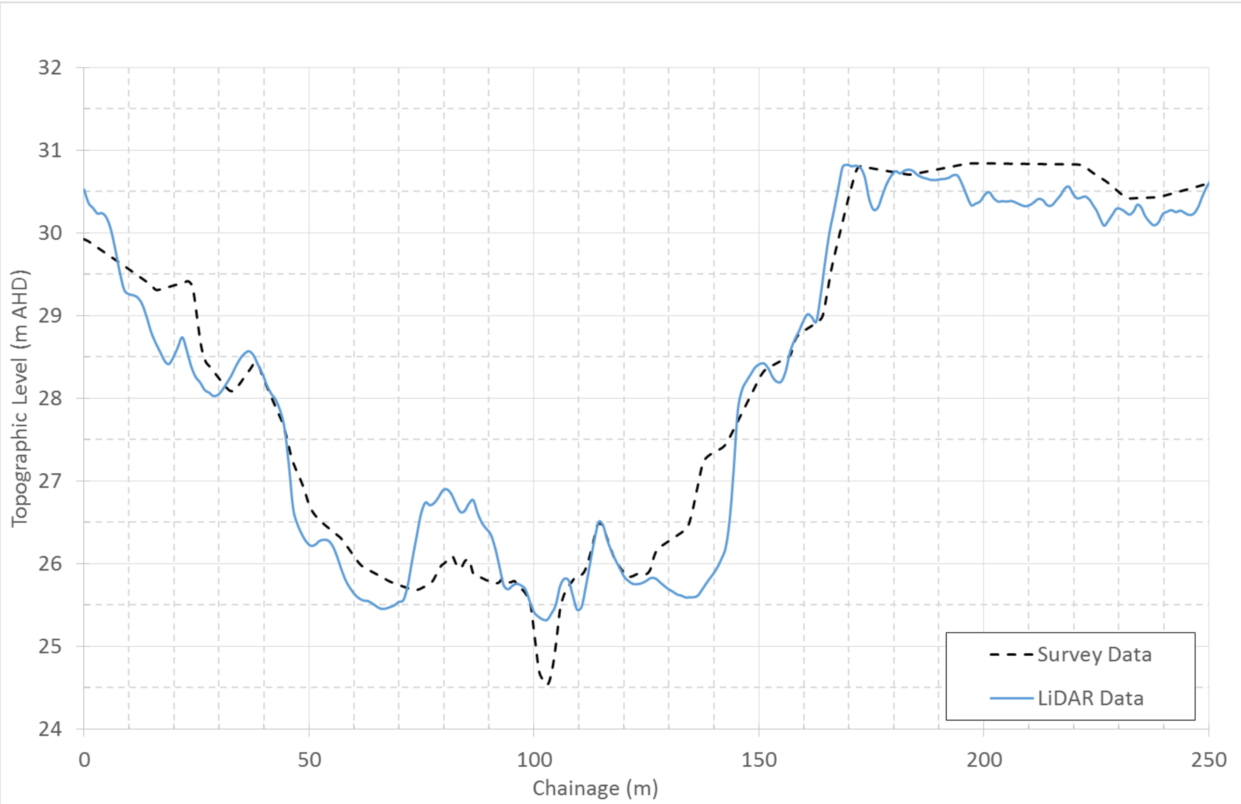

Figure 4-4 Cross Section at Redbank with Lidar and Survey Comparison

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.

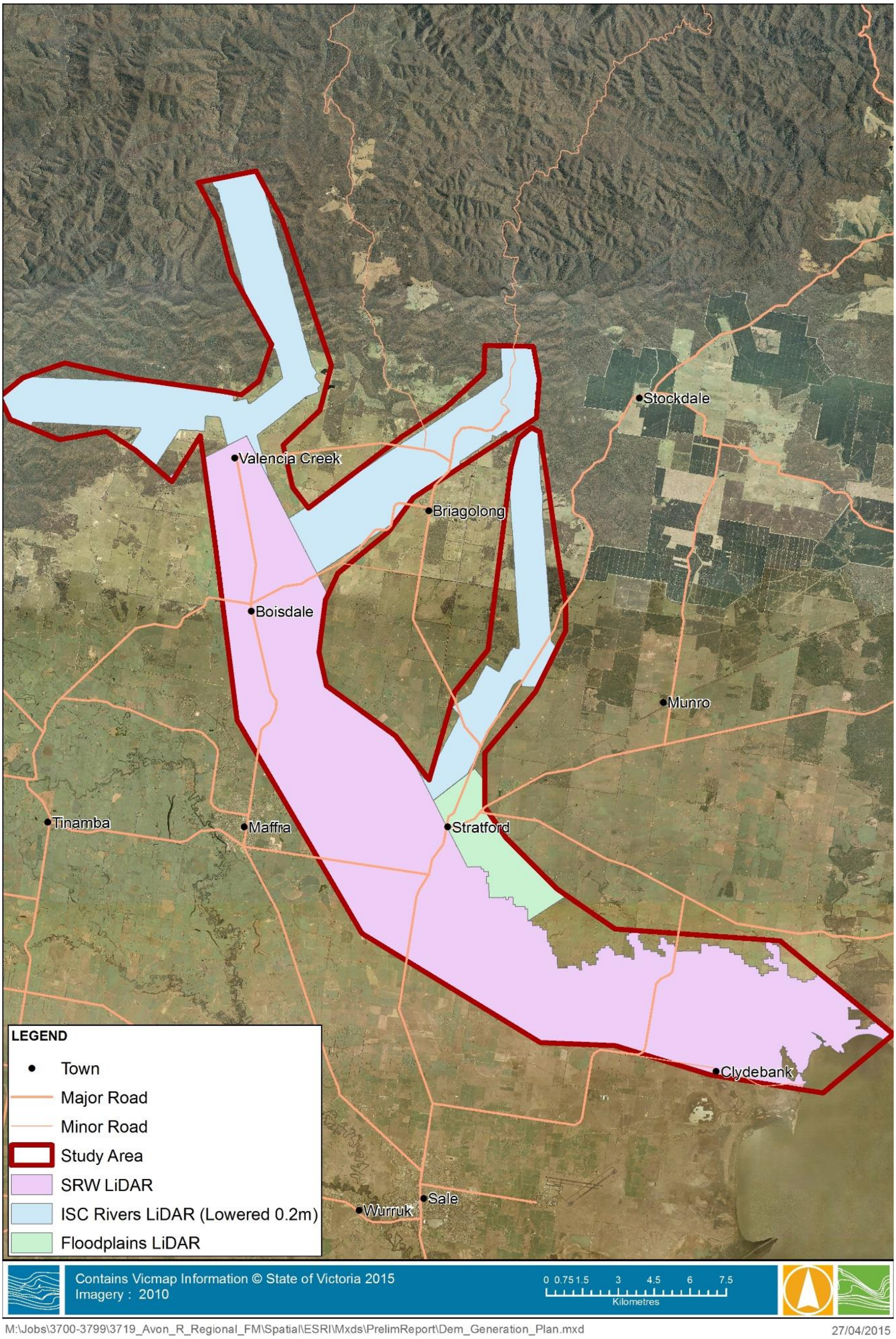

Figure 4-5 Model DEM Preparation Plan

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 @ 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 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

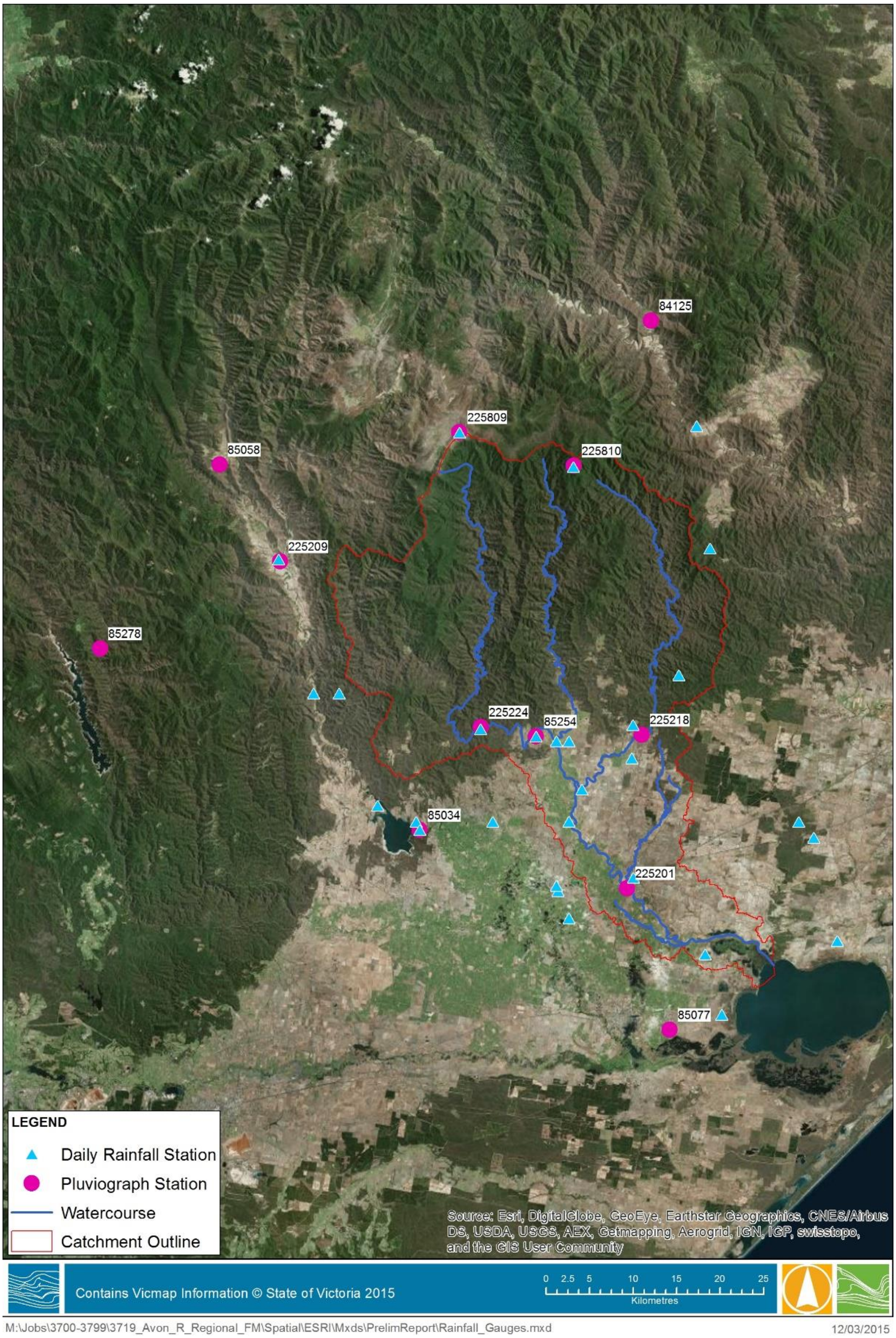

Figure 4-6 Rainfall stations in and around the Avon River catchment

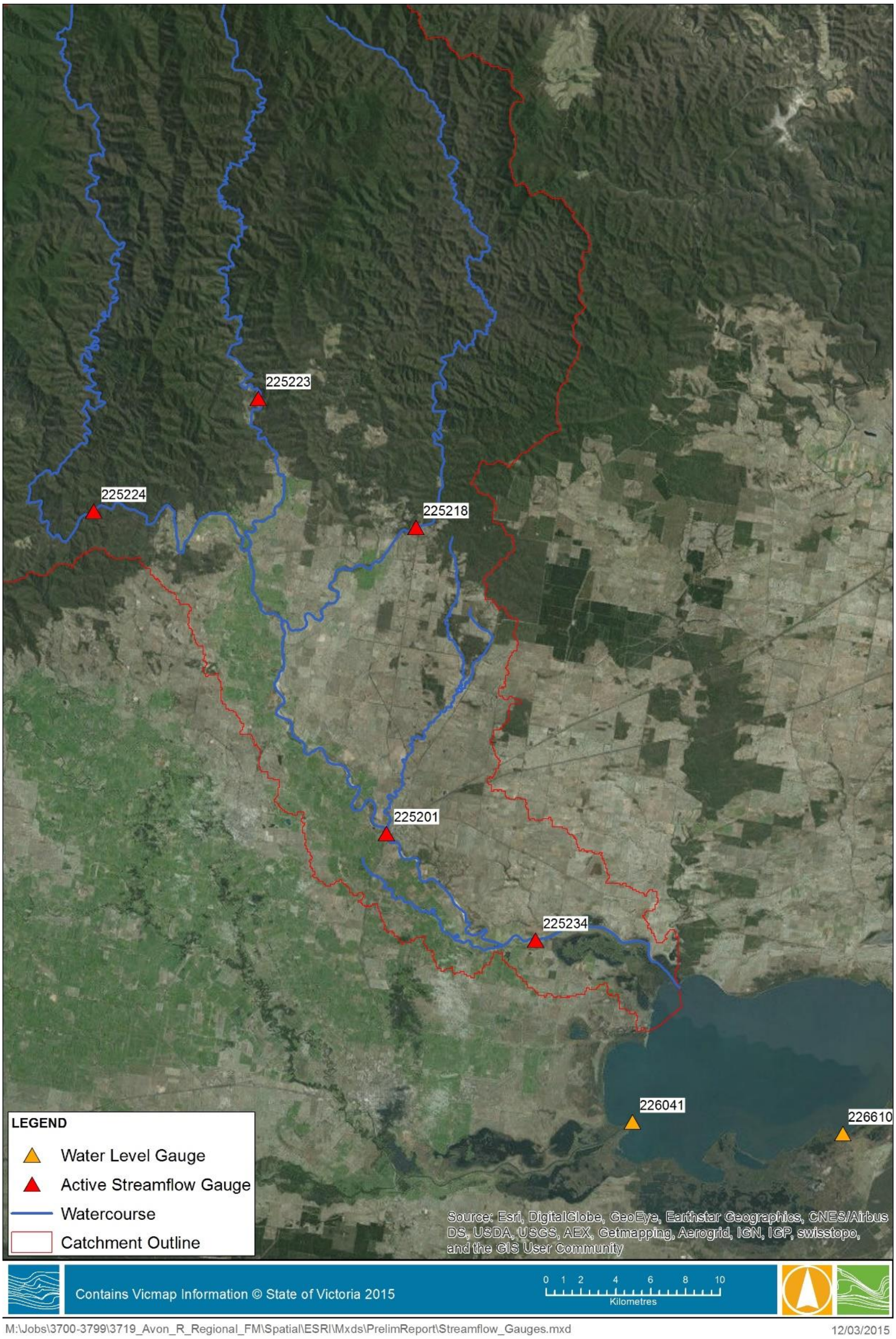

Figure 4-7 Streamflow and water level gauges in the Avon River catchment

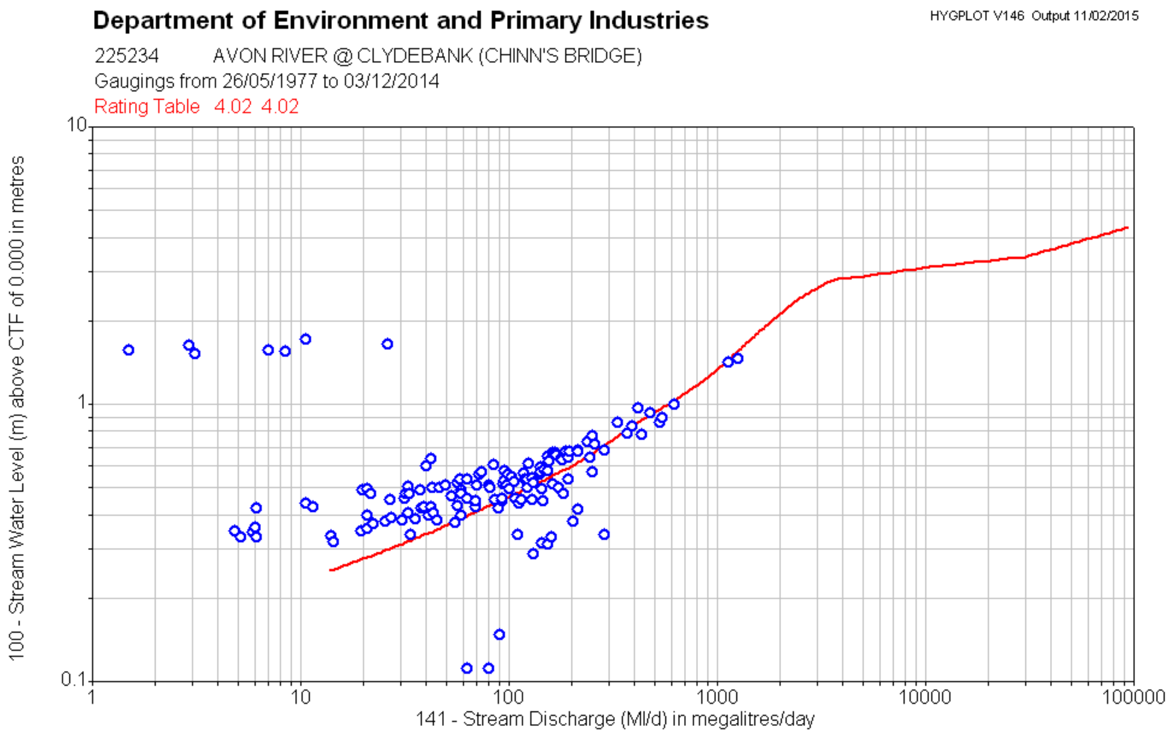

Figure 4-8 **Avon River @ Clydebank (225234) gaugings with rating curve plot**

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.

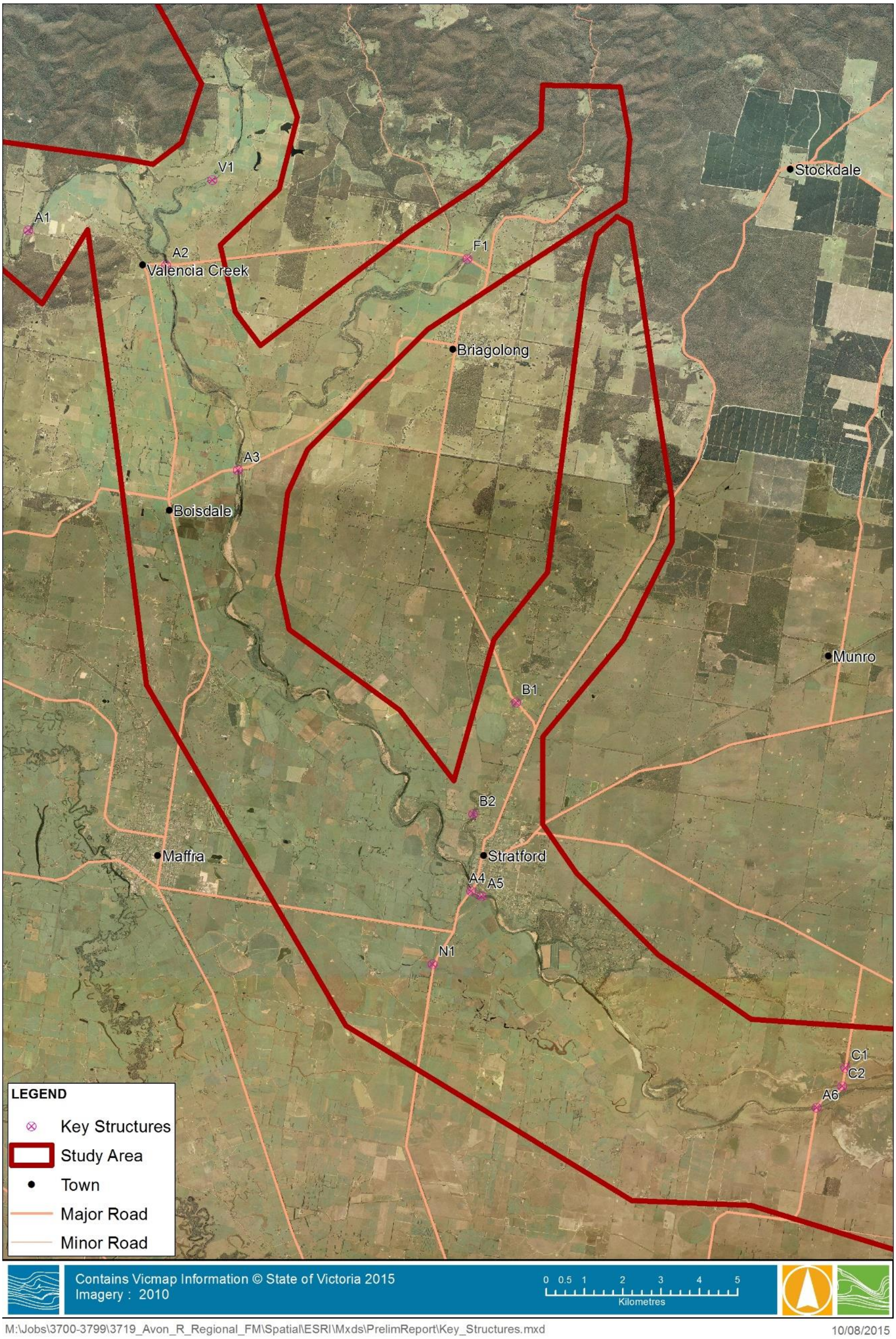

Figure 4-9 Key structures within study area

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.

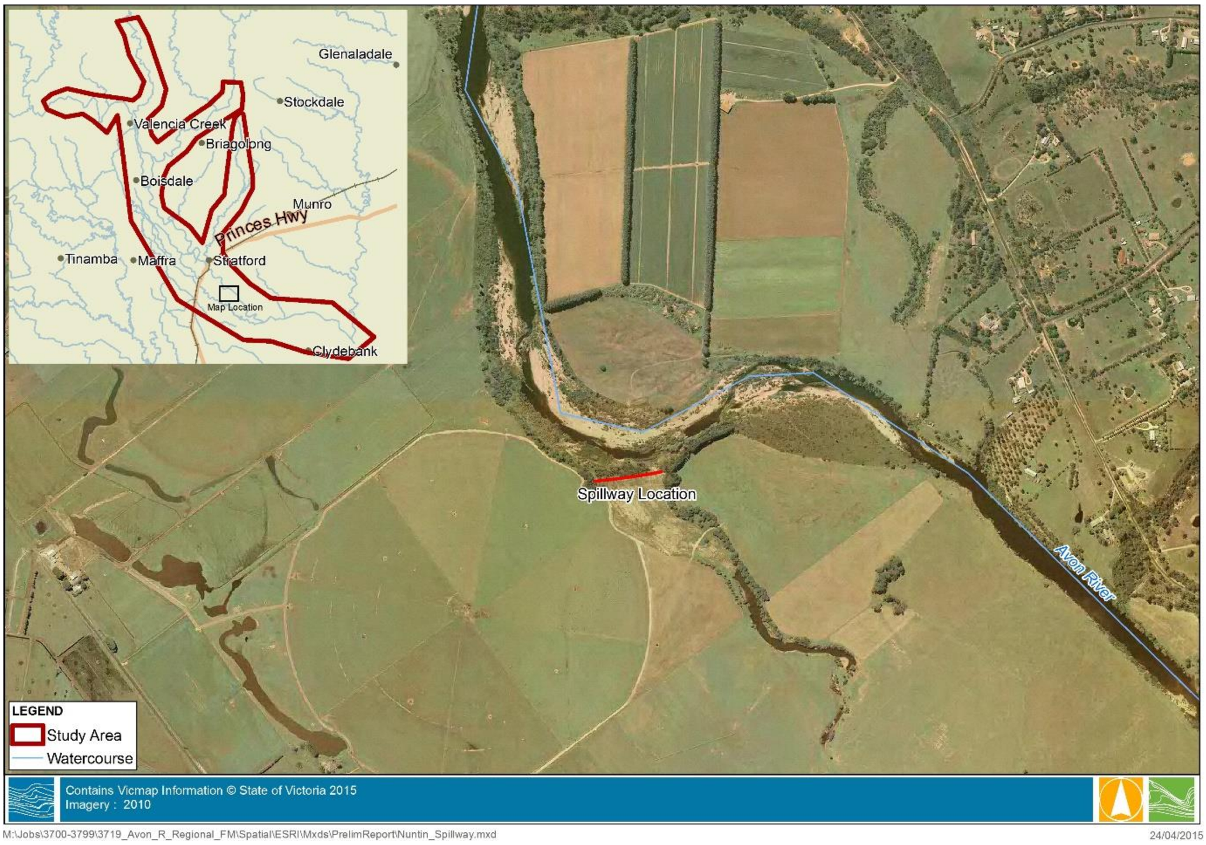

Figure 4-10 Location of Nuntin Creek Spillway (formerly Nuntin Creek Levee)

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 Asscociates, 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.

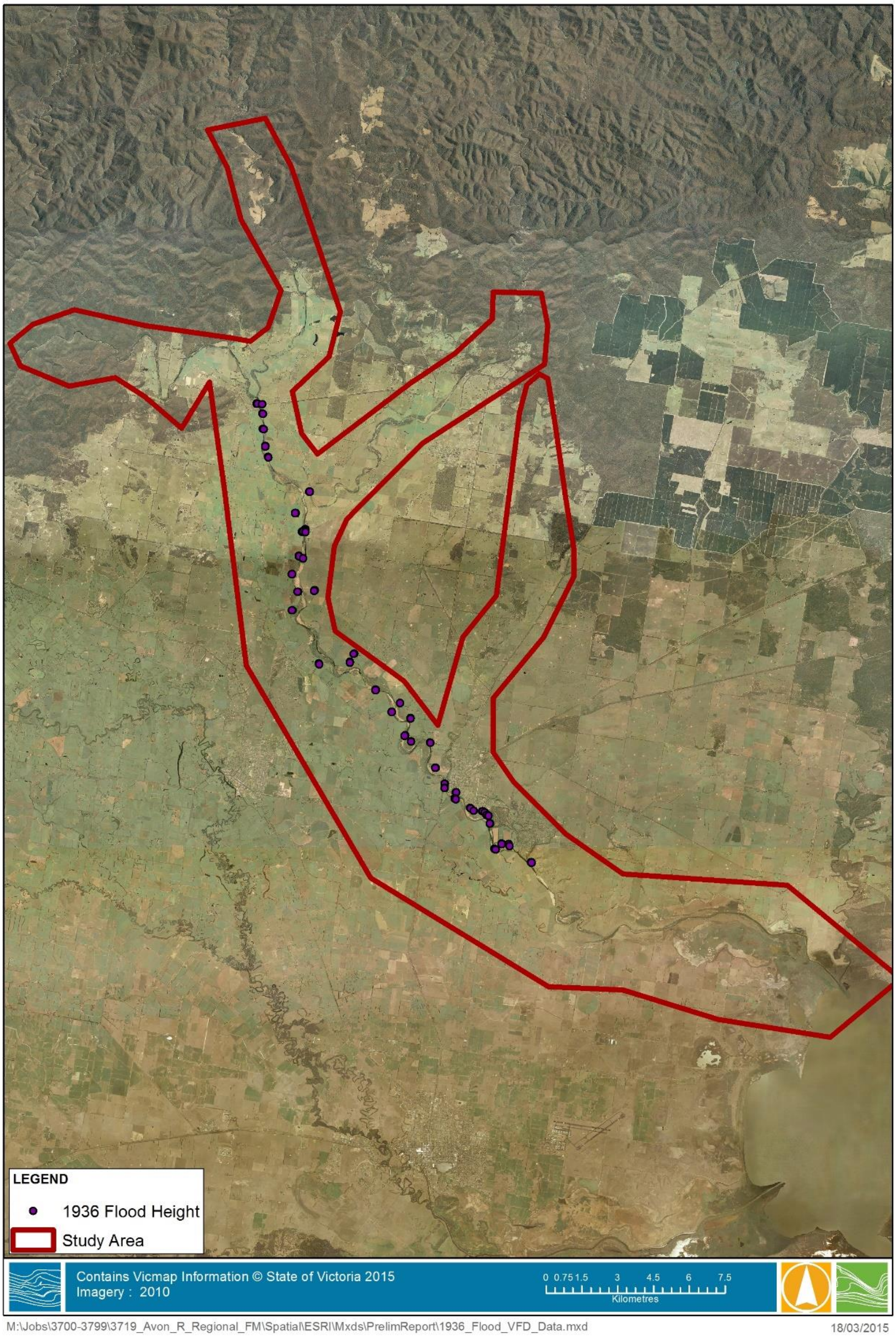

Figure 4-11 1936 flood information in VFD

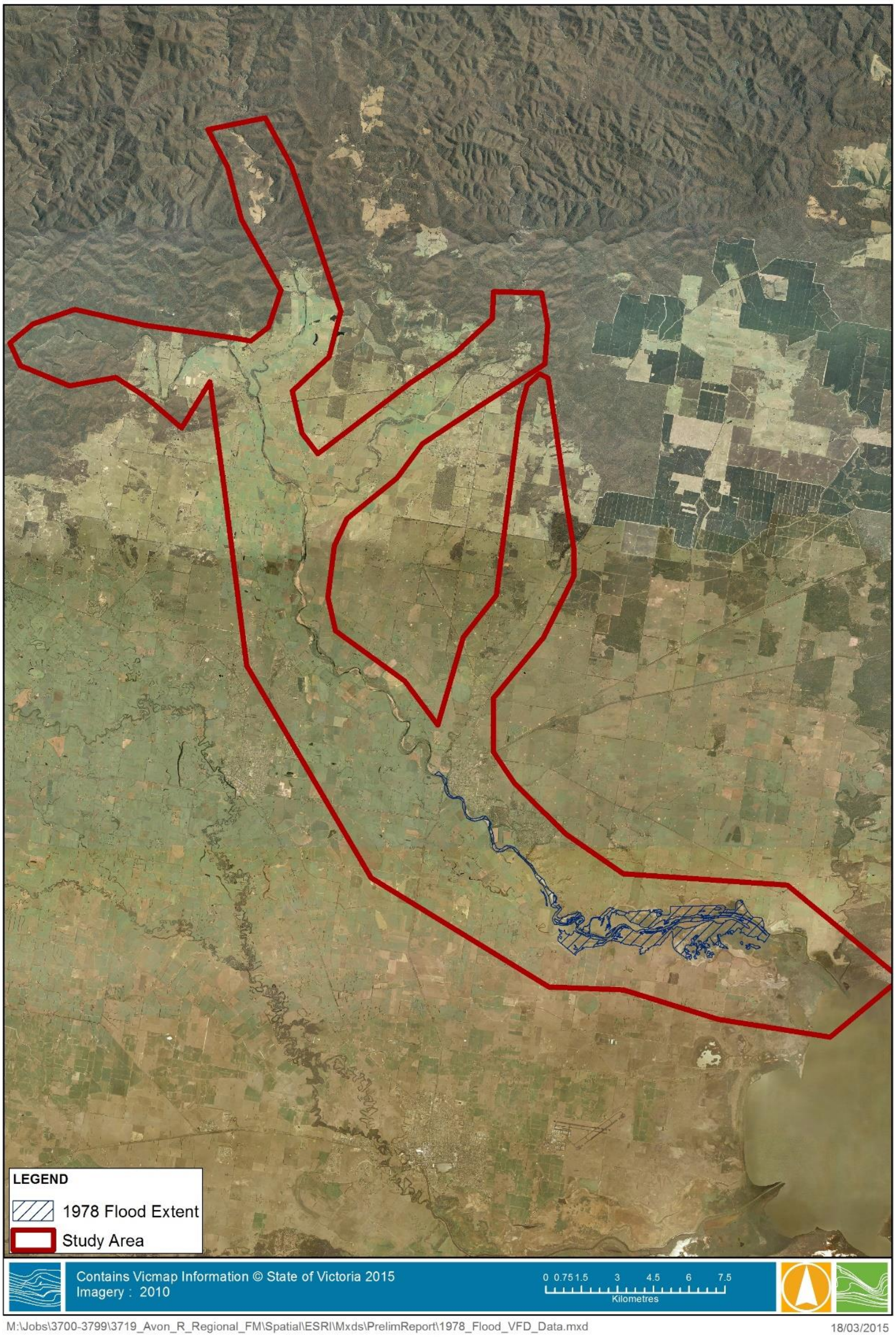

Figure 4-12 May 1978 flood information in VFD

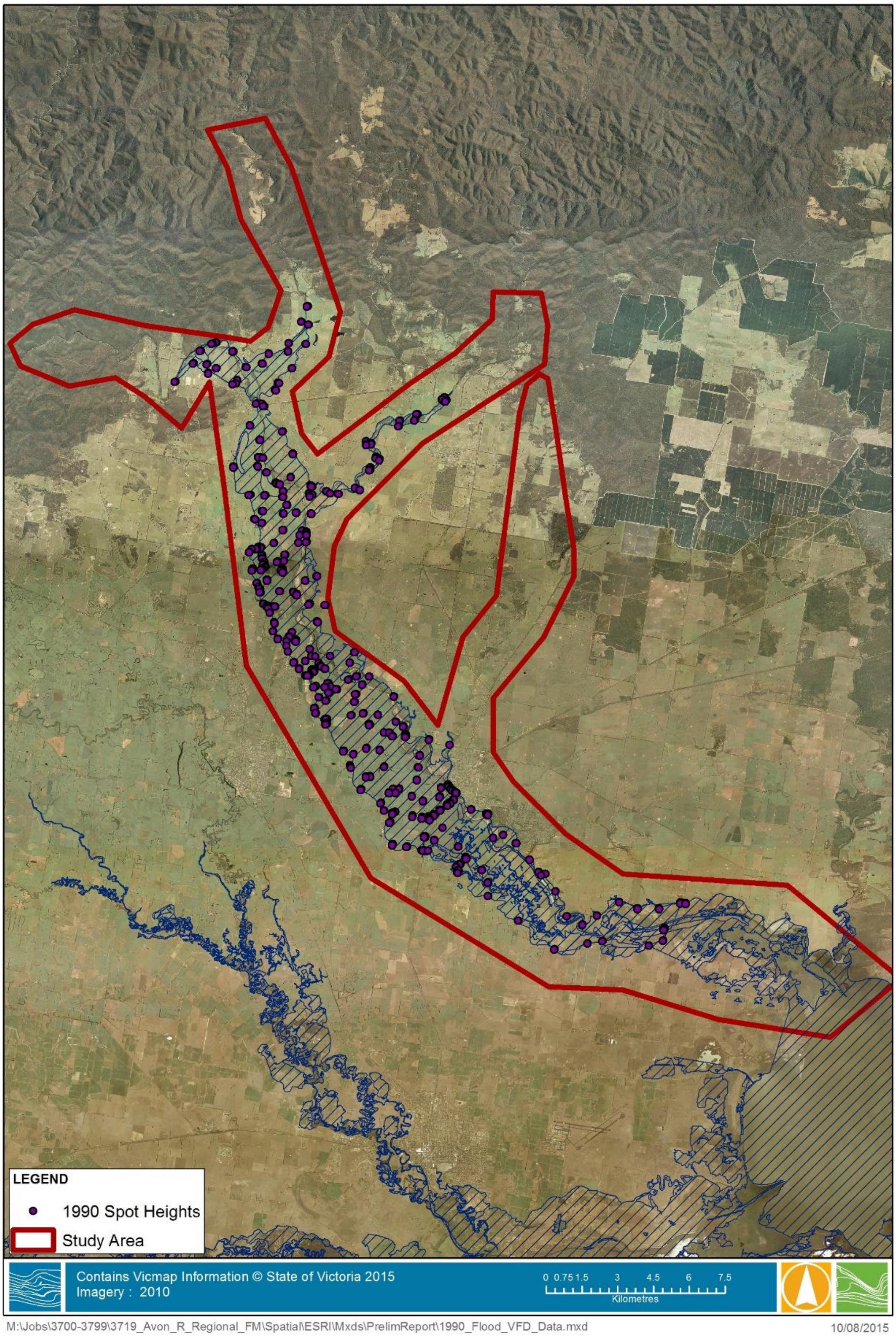

Figure 4-13 April 1990 flood information in VFD

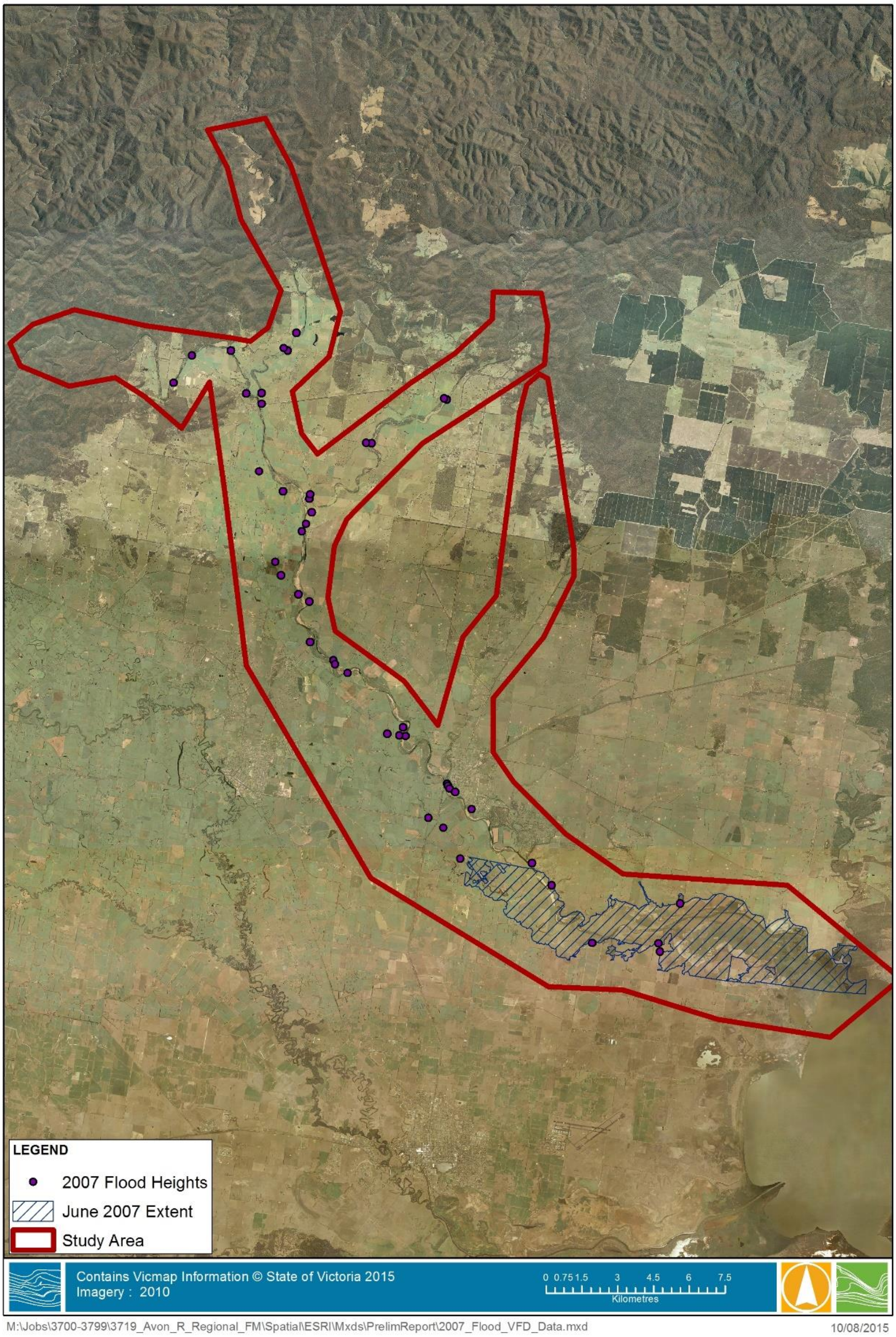

Figure 4-14 June 2007 flood information in VFD

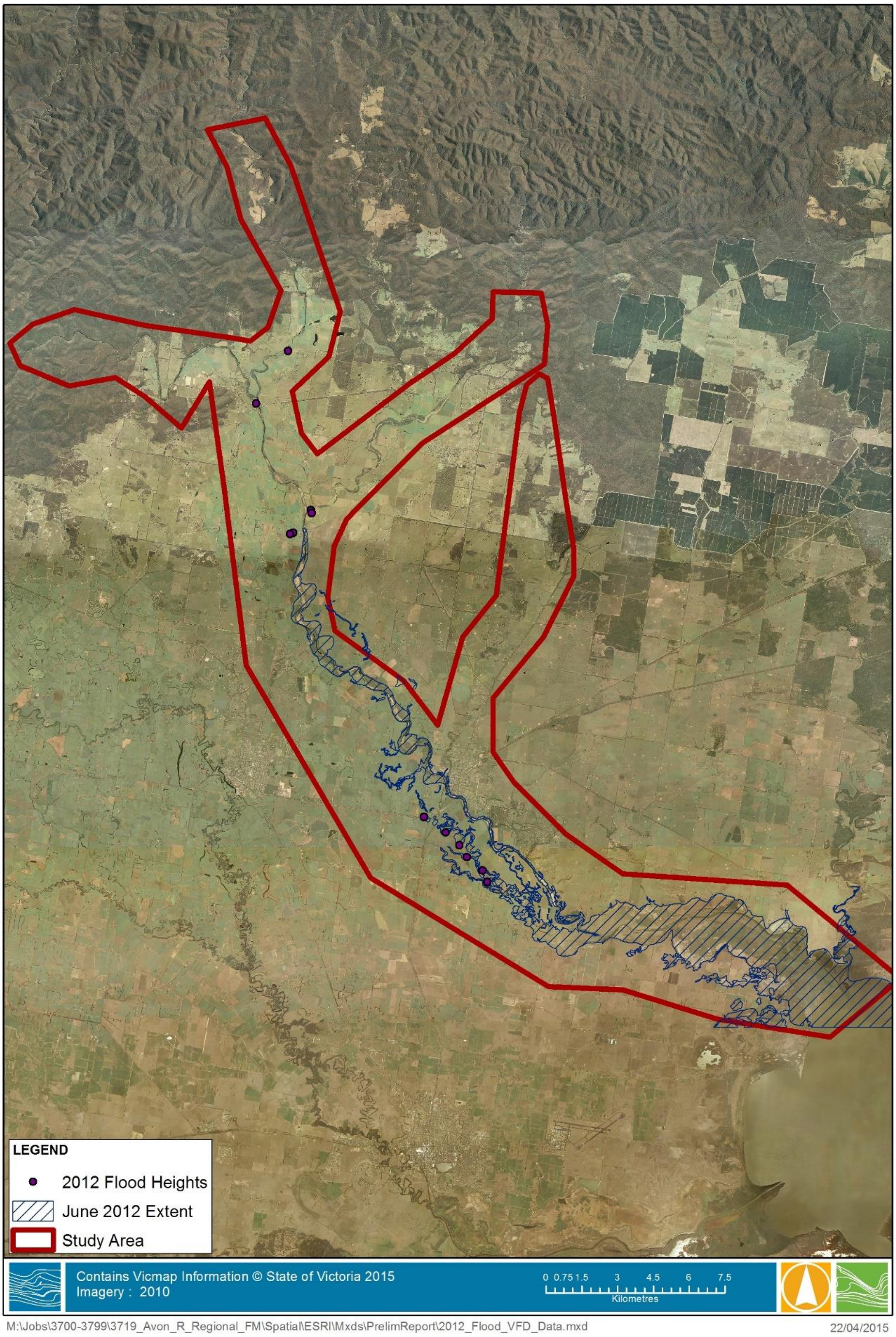

Figure 4-15 June 2012 information in VFD

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.

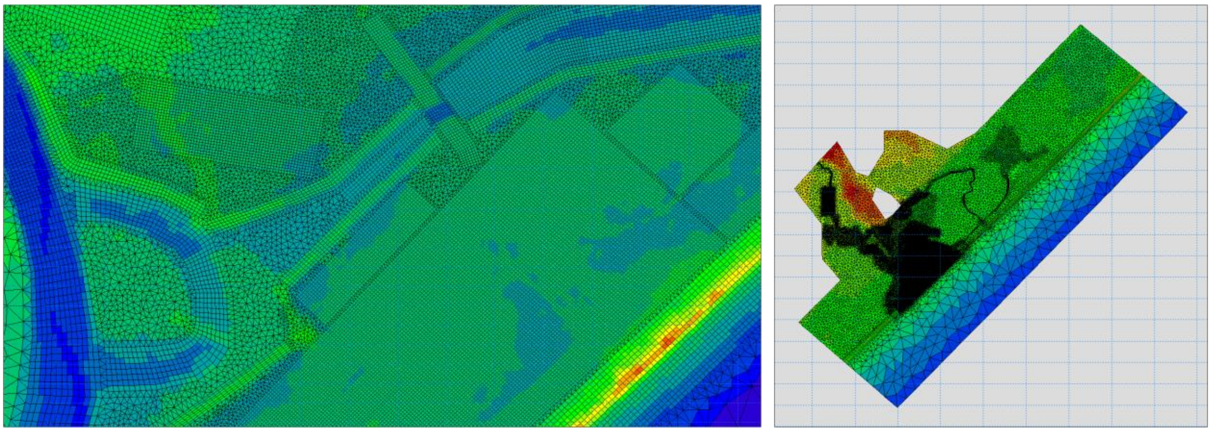

Figure 7-1 Example Hydrodynamic Model Domain and Mesh from Seaspray

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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