Flood Study Report

St Marys Flood Risk Investigation

Break O'Day Council

09 February 2018

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1 INTRODUCTION AND PROJECT BACKGROUND

Break O'Day Council (BODC) engaged Water Technology to undertake the St Marys Flood Risk Management Study. The objective of the study is to provide flood mapping and flood intelligence for St Marys' major waterways based on best practice modelling and utilising knowledge from recent flood events. Mapping will be used to update flood intelligence for emergency response, and to guide future development of the township.

St Marys is a small rural town located near the eastern coastline of Tasmania. St Marys Rivulet flows through the township as do two small tributaries – Newmans Creek and St Patricks Creek. The catchment upstream of St Marys is predominately farmland and bush with some areas of rural and low density residential properties within and around the township. The township was subject to three significant flood events in 2016 with the January 2016 event being the largest and two smaller events occurring in June and November.

This document forms the interim flood study report for the St Marys Flood Risk Management Study and outlines the following:

- Details regarding the development of both the hydrologic and hydraulic models
- Hydraulic flood modelling of St Marys for three historic events which occurred in January, June and November of 2016.
- Calibration and validation of the hydrologic and hydraulic modelling for the three calibration events.
- Design hydrologic and hydraulic modelling for a range of design events
- Summary of flood intelligence
- Climate change scenario modelling
- Flood, hazard and flood function mapping for the full range of design flood events.

FIGURE 1-1 FLOODING IN ST MARYS DURING THE JANUARY 2016 EVENT (PHOTO COURTESY OF NIGEL GEORGE)

2 AVAILABLE DATA

2.1 Overview

This section identifies and briefly reviews relevant available data and information collated. Sources of background data and information collated included:

- Rainfall and streamflow data
- Historic flood information
- Survey and Topographic Data
- Previous studies and investigations
- Site visit and community consultation summary

2.2 Rainfall and Streamflow gauges

Both streamflow and rainfall gauge records were available within the catchment areas up and downstream of St Marys. A single streamflow gauge was available approximately 10km downstream of St Marys on the Break O'Day River at Killymoon Bridge. There is a good concentration of daily rainfall gauges around St Marys with the two closest sub daily gauges located at Upper Scamander (15km north) and Fingal (19km south-west).

The available streamflow, sub daily and daily gauges is shown in Figure 2-1. Further information regarding the available historic rainfall and streamflow data is provided in Section 3.2 (Model Calibration)

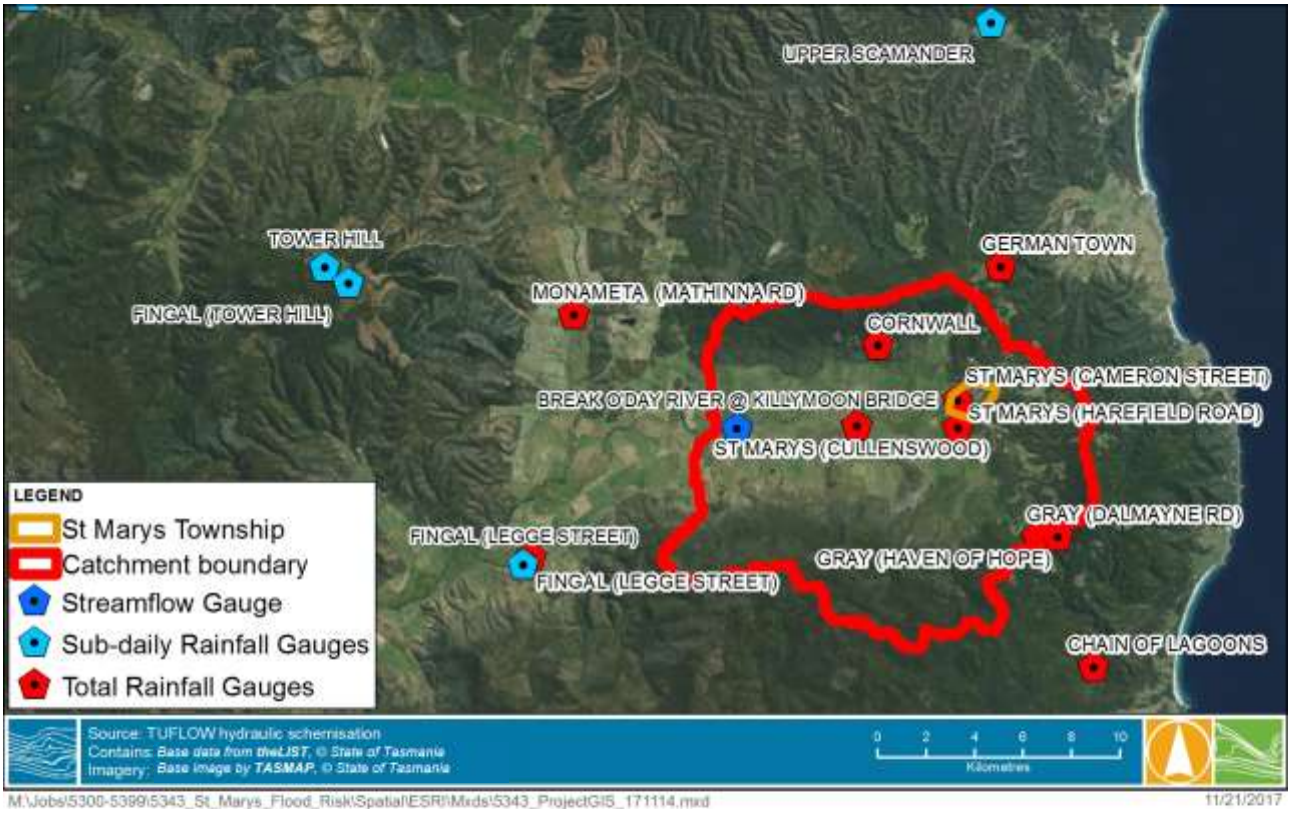

FIGURE 2-1 RAINFALL AND STREAMFLOW GAUGES

2.3 Historic Flood Information

As discussed in Section 1, St Marys witnessed three significant flood events in 2016, during January, June and November. Given how recent these events were and the amount of community appreciation of their significance they were chosen for the model calibration and verification process. The three events varied considerably in terms of magnitude. Calibrating the model using a range of historic events ensures the model can perform well across a range of event magnitudes.

Unfortunately, the streamflow record on the Break O'Day River at Killymoon Bridge indicates poor data quality for each of these three events however the streamflow record was still useful in calibrating the hydrological model.

Other historic flood information included:

- A large amount of photos of historic flood events were provides by the community. The photos were primarily of the three events that occurred in 2016. The data was vital in helping to calibrate and validate the modelling of the historic events.
- Verbal anecdotal reports, notes and comments on draft flood mapping provided during the community consultation sessions (and described further below).
- Anecdotal reports from Council staff who were present during some of the events of 2016 and assisted with management during the event and clean-up after the event.
- Some flood images from the media taken during the events in 2016.

The above information sourced from the community is discussed in more detail in Section 3 (Calibration Section), with the data used in validating the modelling of the three historic events.

2.4 Survey and Topographic Data

2.4.1 LiDAR

Detailed and accurate topographic data provides the basis for any hydraulic model. For the present study a LiDAR dataset of the study area was provided by Break O'Day Council. The LiDAR was captured in 2012 as part of the St Marys DEM project. The LiDAR data was converted to 2 m grid resolution, which was determined as a suitable size to accurately represent the key hydraulic features. The model DEM is shown in Figure 2-2.

In order to validate the vertical accuracy of the LiDAR and ensure it was fit for modelling purposes it was compared to a surveyed transect along Main Road near the intersection with The Flat. The transect consisted of a 100 metre line surveyed at 5 metre intervals. When compared to the LiDAR it was shown that on average the LiDAR was within 70 mm of the surveyed points. This is considered acceptable and within the reported error bands of the LiDAR. The LiDAR was therefore deemed appropriate for use in this project and did not require any modifications to address vertical bias.

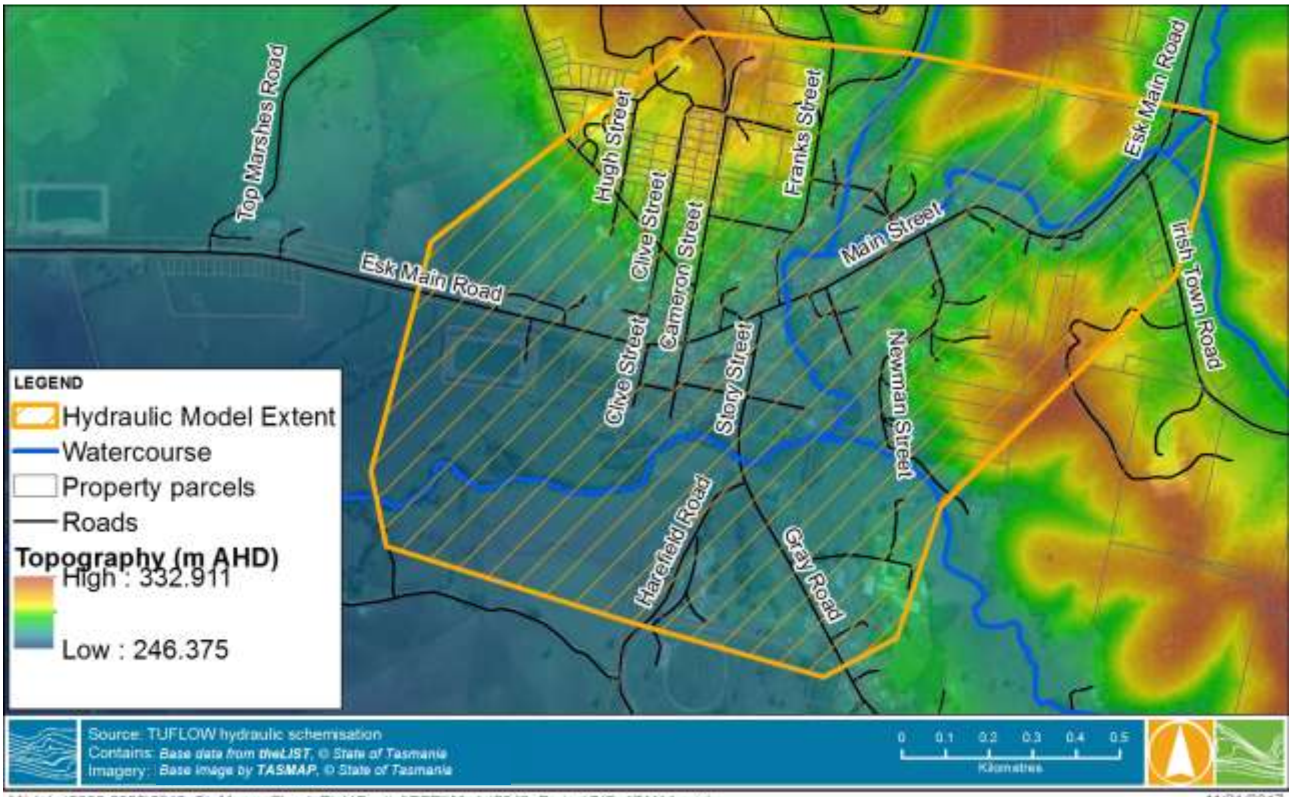

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FIGURE 2-2 TUFLOW MODEL TOPOGRAPHY

2.4.2 Channel Cross Section Survey

Seven cross sections which cover the floodplain and channel of the St Marys Rivulet were surveyed in October 2017. LiDAR cannot penetrate below water surfaces and so these cross sections were used to assess the depth of channel below the surface represented in the LiDAR. The cross-sections were then used to better represent the channel bathymetry and flow conveyance of the channel in the hydraulic model. This was achieved by “stamping in” the surveyed channel invert through the deeper pools along the rivulet which weren’t captured by the LiDAR data. The location of the seven surveyed channel cross section locations are shown in Figure 2-3.

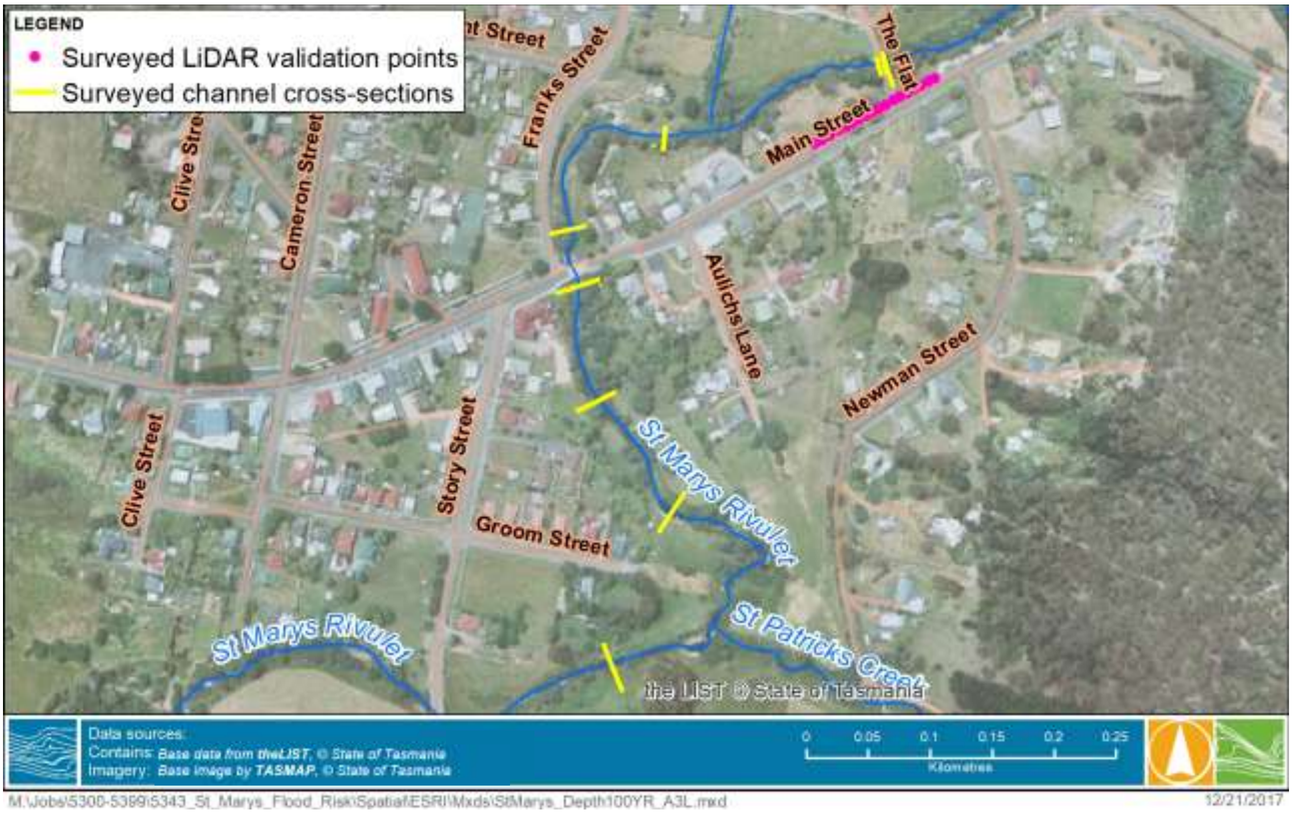

FIGURE 2-3 LOCATION OF SURVEYED CROSS-SECTIONS AND LIDAR VALIDATION POINTS

2.4.3 Key Drainage Infrastructure

Key drainage infrastructure data around the St Marys township was collected from existing plans and survey as well as during a site visit undertaken in September 2017 (discussed below). A summary of the key drainage infrastructure is shown in Table 2-1 and the locations of these structures are shown in Figure 2-4. It should be noted that the local stormwater drainage network was not assessed or included as part of this investigation.

TABLE 2-1 SUMMARY OF KEY HYDRAULIC STRUCTURES

Structure ID (as per Figure 2-4)	Location	Structure Type
1	Storey Street Road Bridge (over St Marys Rivulet)	Road bridge (two cells)
1a	Storey Street – additional floodplain culverts	Box culvert – 2700mm wide x 800mm high
1b	Storey Street – additional floodplain culverts	Pipe culverts x 2 – 900mm diameter
2	St Patricks Creek Pedestrian Bridge	Wooden, pedestrian bridge
3	Main Street Road Bridge (over St Marys Rivulet)	Clear span road bridge
4	Pedestrian Bridge (over St Marys Rivulet)	Pedestrian bridge

Structure ID (as per Figure 2-4)	Location	Structure Type
5	The Flat Road Bridge (over Newmans Creek)	Clear Span Road Bridge
6	The Flat Road Bridge (over St Marys Rivulet Creek)	Clear Span Road Bridge
7	Esk Highway Bridge (over St Marys Rivulet Creek)	Clear Span Road Bridge

FIGURE 2-4 KEY DRAINAGE INFRASTRUCTURE IDENTIFIED DURING THE SITE VISIT

2.5 Site Visit and Community Consultation

A site visit was completed by the study team on 28th September 2017. The township area and upstream catchments were visited, and all key hydraulic structures were photographed and measured. The visit also allowed an assessment of land use and roughness to be made which is a key input of the hydraulic model.

Extensive community consultation has been undertaken since the project commenced and has consisted of the following:

- A public meeting held on 28th September 2017 to introduce the study and gather local flood information.
- A stall at the monthly market held on 2nd December 2017 where draft flood maps were presented and the objectives and findings of the study were discussed with community members.
- A public workshop held on 2nd December 2017 to present the result of the calibration and design modelling and seek feedback on the modelling completed to date. The workshop also involved discussing options

to improve flood risk in St Marys. A large number of potential management options were discussed and recorded.

- A river walk undertaken on 2nd December with several residents to discuss key areas of concern related to flood management and ideas to be discussed regarding improving flood risk. The walk involved walking St Marys Rivulet from Groom St to upstream of The Flat Bridge with key areas of concern discussed along the way.
- A number of media advertisements and articles in the local newspaper and on the Council website.
- An online mapping portal which presents the modelling results and allows community members to leave comments regarding the results.
- Residents have been provided with relevant email addresses of Council and project team contacts and have submitted large numbers of historic flood photos and anecdotal reports.

The community consultation has achieved the following objectives:

- Introduce the study to the community including key outcomes and benefits.
- Allowed an extensive amount of local flood information to be gathered and shared.
- Allowed the community to suggest and discuss options for the ongoing management and mitigation of flood risk in St Marys.

Additional community consultation will be undertaken in coming weeks to present the final outputs of the study including final design flood maps and the results of flood mitigation modelling.

3 MODEL DEVELOPMENT AND CALIBRATION

3.1 Overview

The model development and calibration methodology is described below in two main components; hydrology and hydraulics. Hydrologic modelling was completed in RORB, while the hydraulic modelling utilised TUFLOW. RORB is an industry standard rainfall and runoff modelling packaged used widely throughout Australia and was used to determine flows into St Marys, TUFLOW is also widely used and a benchmarked 1D and 2D hydraulic modelling package. TUFLOW was used to determine flood levels, depths and velocities across the township.

The hydrologic and hydraulic modelling components were completed in tandem due to the limited and poor quality streamflow gauge data available. Whilst there was limited recorded streamflow or water level data to calibrate the model, there was significant amounts of anecdotal information and flood photos of the three flood events which occurred in 2016. This information was used to validate the results in the hydraulic model and to inform the hydrologic modelling. This tandem approach is commonly used on ungauged catchments and aims to reduce uncertainty as much as it practical in the modelling results.

3.2 Hydrology

3.2.1 RORB Model Structure and Parameters

3.2.1.1 Overview

A RORB model was constructed to determine historic and design flood flows through the study area. The RORB analysis aimed to represent the rainfall runoff processes occurring across the catchment and define a range of potential flows that reach St Marys via St Marys Rivulet and the two smaller tributaries. A schematic of the RORB model is shown in Figure 3-1

The RORB model included multiple detailed inputs to ensure accurate results, these included:

- Sub-catchments and reach delineation.
- Fraction impervious.
- Rainfall depth information.
- Rainfall losses.
- Rainfall temporal patterns.
- Rainfall spatial patterns.
- Kc – key routing parameter.
- m – degree of catchment non-linearity

Each of these inputs are discussed in the following sections. A summary of the RORB modelling process is shown in Figure 3-1.

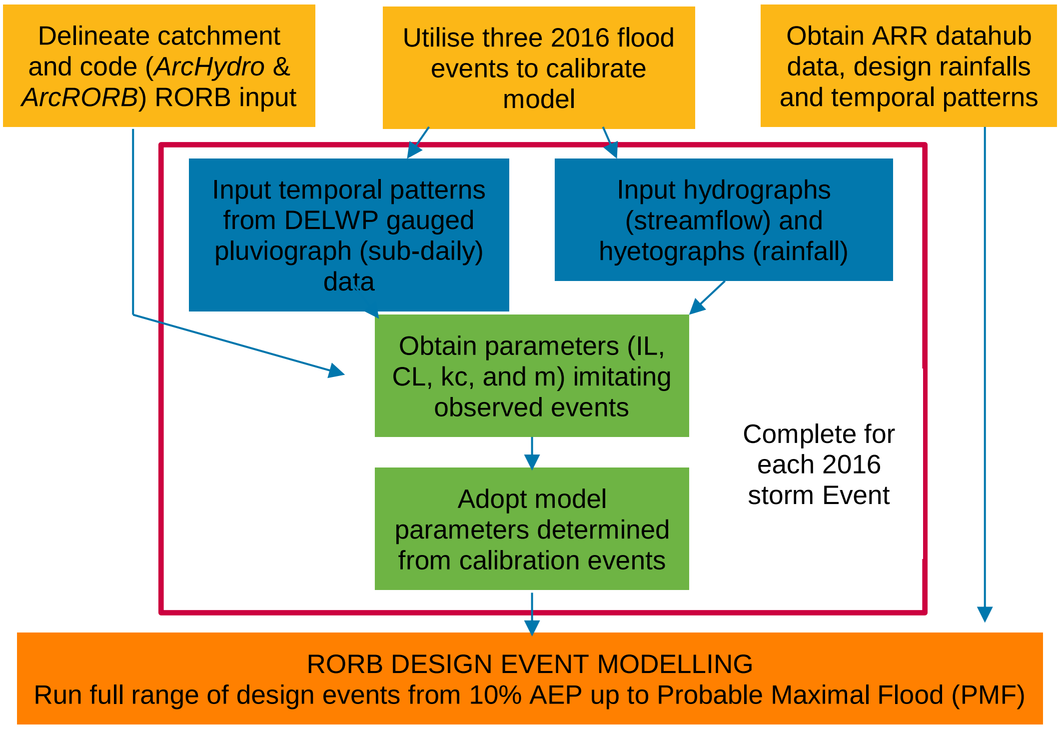

FIGURE 3-1 RORB HYDROLOGICAL ANALYSIS OVERVIEW

3.2.1.2 Catchment delineation

A catchment delineation was undertaken using the available topographic datasets. This included a detailed Light Distance and Ranging (LiDAR) topographic dataset resampled to a 1 metre resolution Digital Elevation Model (DEM). The 1 m DEM was used to determine the catchment area upstream of St Marys using ESRI's *ArcHydro for ArcGIS*. Catchment boundaries were also manually checked to ensure consistent shape and size.

Based on the *Boyd (1985)* calculation a minimum of 9 sub-areas are required over the catchment (see Equation 2-1), however due to the catchment area, shape, location of St Marys and a downstream streamflow gauge; 37 sub-areas were created. The catchment was also separated into two interstation areas, up and downstream of St Marys. Using interstation areas allows for different kc and loss values to be selected within each area. In this case the area upstream of St Marys has much smaller subareas and a therefore a different kc value is required.

The RORB manual stipulates that a minimum of five upstream subareas are needed to extract a flow from RORB so it was ensured that at least 5 subareas were located upstream of each of the three key tributaries flowing into St Marys.

The final catchment delineation is shown in Figure 3-2, highlighting the study area and two interstation areas.

EQUATION 2-1 BOYD (1985) SUB-CATCHMENT DELINEATION CALCULATION:

$$S_{min} = 5.20(A)^{0.1} = 5.20(182.12)^{0.1} = 8.75 \sim 9.0$$

$$S_{min} = 8.75 \sim 9.0$$

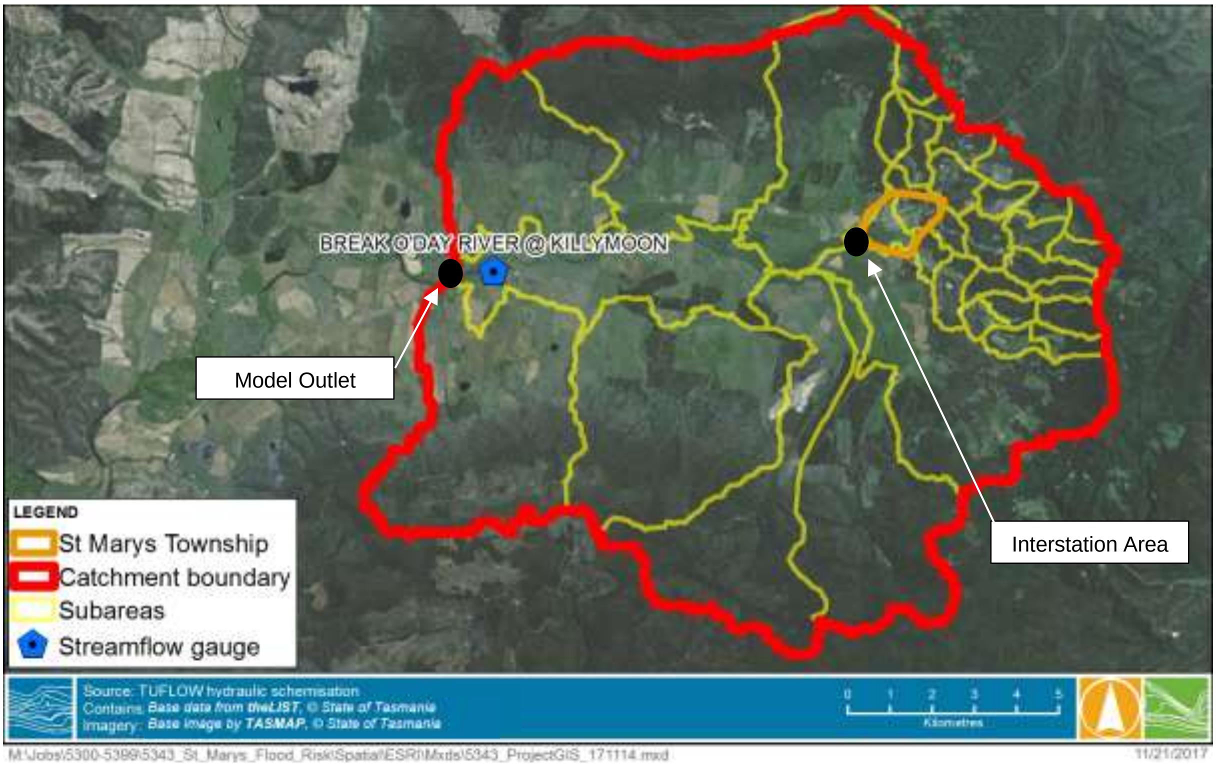

FIGURE 3-2 RORB MODEL BOUNDARY WITH DELINEATED SUBAREAS

3.2.1.3 Reaches and Nodes

The catchment and drainage line delineation were converted to RORB reaches and nodes using ArcRORB. Nodes were placed at sub-area centroids and junctions between any two reaches. These were connected via reaches, each with an ArcGIS calculated length and slope.

Each RORB model reach was classified into one of five different reach types (1 = natural, 2 = excavated & unlined, 3 = lined channel or pipe, 4 = drowned reach, 5 = dummy reach). Most reaches within the St Marys catchment were classified as "Natural" due to their open grassed areas and natural waterways, a small number of short, modified sections of St Marys Rivulet and Newmans Creek which were classed as excavated and unlined.

The RORB model subarea and reach delineation is shown in Figure 3-3.

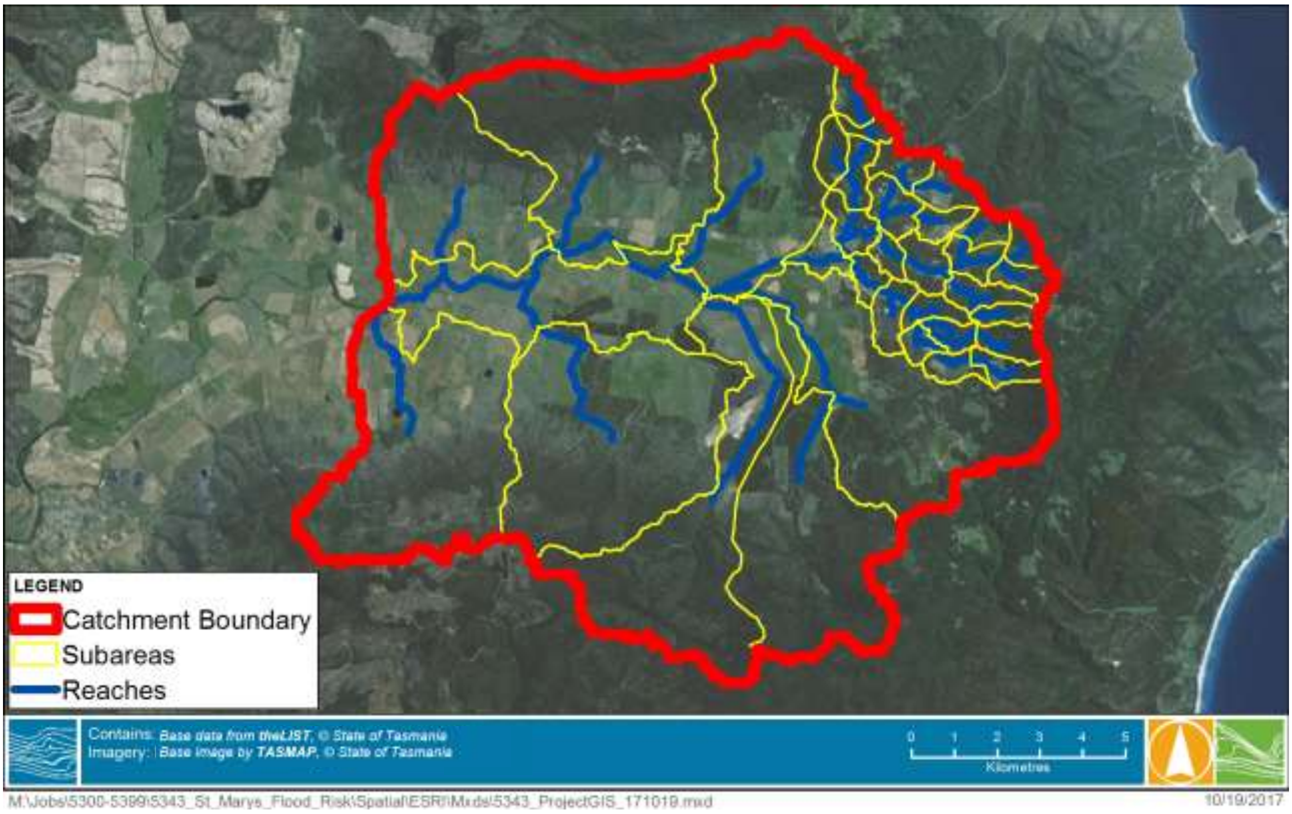

FIGURE 3-3 RORB REACHES AND SUBAREAS

3.2.1.4 Fraction Impervious (FI)

The estimated proportion of impervious surface within each sub-area was determined using land use planning (zoning) maps and modified based on aerial imagery and land cover mapping. Adopted FI values were based on relevant industry guidelines. Specific values were allocated to each zone and are shown in Table 3-1. An area weighted fraction impervious for each sub-area was calculated, as shown in Figure 3-4.

TABLE 3-1 ADOPTED FRACTION IMPERVIOUS VALUES

Land use	Adopted FI[1]
10.0 General Residential	0.75
12.0/13.0/14.0 Low Density, Rural and Environmental Residential	0.2
16.0 Village	0.55
17.0 Community Purpose	0.75
18.0/19.0/26.0 Recreation/Open Space/Rural Resource	0.1
20.0/25.0 Local Business/General Industrial	0.9
28.0 Utilities	0.75
29.0 Environmental Management	0.0

[1] Melbourne Water – Table 1: Effective Impervious values for source nodes: MUSIC Guidelines (2016)

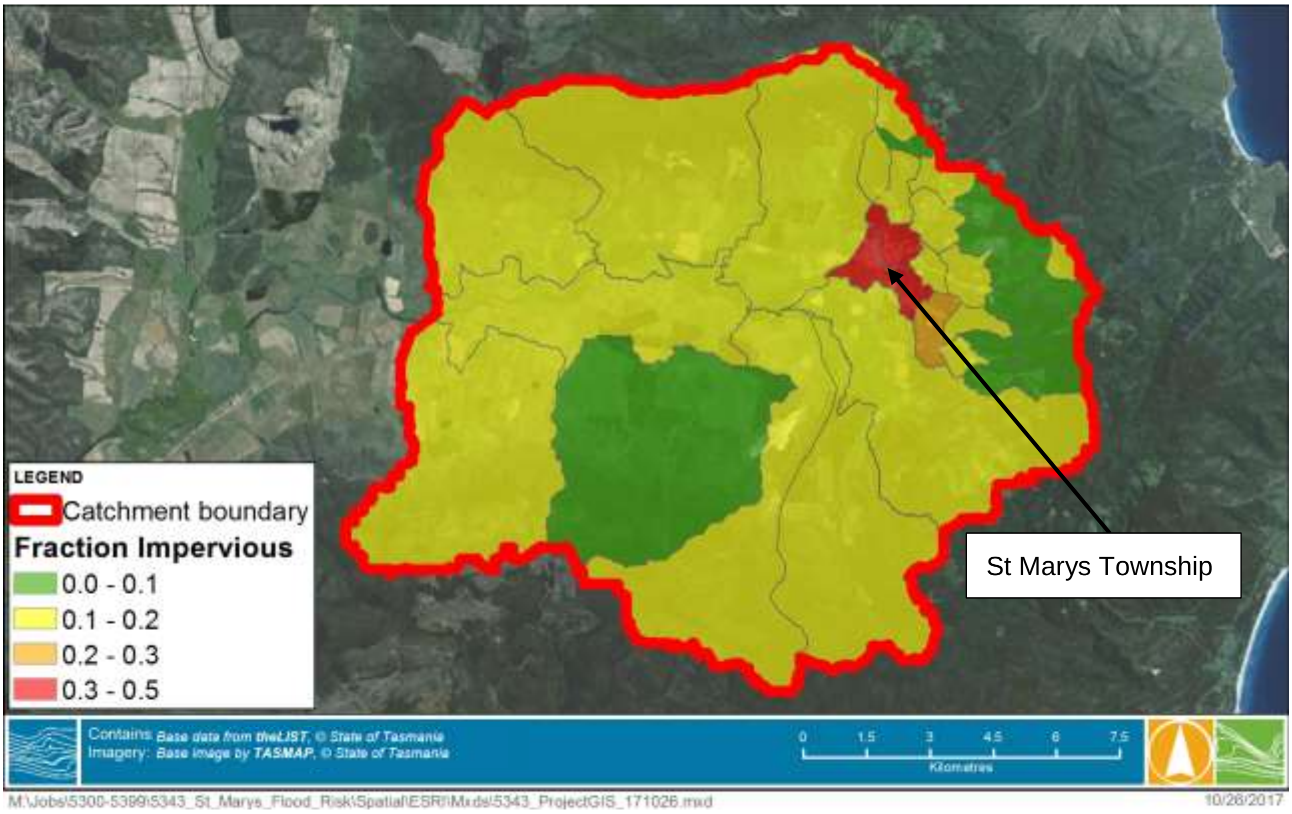

FIGURE 3-4 FRACTION IMPERVIOUS MAP

3.2.1.5 Rainfall Depths and Losses

Rainfall depths for historic events were based on recorded daily rainfalls for all active gauges within and around the study area. Daily totals were sourced from the Bureau of Meteorology (BoM) website and used to generate a spatial pattern of rainfall across the catchment for each event. Gauges which had a good quality data record for the period of each event were utilised in the analysis, while gauges which had poor quality or missing data were omitted. Rainfall event depths between gauges were determined used an Inverse Distance Weighted (IDW) interpolation, resulting in a grid covering the entire catchment area, which was used to determine a mean rainfall depth for each of the RORB subareas for each event. Design event depths were determined using the ARR 2016 methodology.

The loss model chosen for the modelled catchment was an initial and continuing loss model. This model was chosen because it is a predominantly rural/forested catchment. The catchment is likely to have high rainfall losses at the beginning of an event when the ground is dry, which will then reduce to a smaller loss rate over the remainder of the event.

3.2.1.6 RORB kc and m

'kc' is the RORB model routing parameter and can be estimated using empirical equations that generally represent a wide range of fitted data for Australian catchments and dictates the attenuation and storage along reach models. In gauged catchments, as is this one, the kc value is the major routing parameters used to calibrate the RORB model, where peak flow and timing is fitted to streamflow data.

The RORB model kc value was initially estimated using a range of prediction equations as shown below in Table 3-2. These equations use either catchment area or D_{av} (the average flow distance in the channel network of sub area inflows) and have been developed using different data sets (or subsets of the same data set). The parameter selected for design is based on consistency of prediction and resulting flows.

TABLE 3-2 VARIOUS 'KC' CALCULATED VALUES

Method	Equation	kc	
		Upstream of St Marys	Downstream of St Marys
Victoria (Mean Annual Rainfall >800mm)	$kc = 2.57A\hat{}0.45$	10.81	25.10
Victoria (Mean Annual Rainfall <800mm)	$kc = 0.49 * A^{0.65}$	3.90	13.18
Victorian based data (Pearse et al, 2002)	$kc = 1.25 * \mathrm{D_{av}}$	6.63	12.74
Australian based data (Dyer, 1994)	$kc = 1.14 * \mathrm{D_{av}}$	6.05	11.62
Australian based data (Yu, 1989)	$kc = 0.96 * \mathrm{D_{av}}$	5.10	9.78
West Tas (HEC)	$kc = 0.86A\hat{}0.57$	5.30	15.43

Based on the regional prediction equations, several 'kc' values were initially trialled, with calibration to the gauge records used to refine the 'kc' value for each of the selected calibration events. This is discussed further in Section 3.2.2,

The RORB 'm' value is typically set at 0.8. This value remains unchanged and is an acceptable value for the degree of non-linearity of catchment response (Australian Rainfall and Runoff, 1987)[2]. There are alternate methods for determining m, such as Weeks (1980),[3] which uses multiple calibration events to select 'kc' and m. However, if retaining a value of 0.8 is possible it is best left unchanged.

3.2.2 RORB Calibration

3.2.2.1 Overview

As discussed in Section 2.3, the January, June and November 2016 flood events were chosen for calibration of the RORB and TUFLOW models. Initially, the RORB model was calibrated for these events at the Killymoon gauge, downstream of St Marys, comparing modelled and observed hydrographs at the Killymoon gauge. The focus of the RORB model calibration was the determination of RORB parameters: kc, initial loss and continuing loss.

Additional validation was completed by testing the initial flow estimates in the TUFLOW hydraulic model and comparing to available flood photos and anecdotal reports of flood behaviour. The results of the hydraulic modelling informed modifications to the parameters in the RORB model. Given the very poor quality of the streamflow gauge data testing the resulting flows in the hydraulic model was vital to ensure it reproduced appropriate flood magnitudes at St Marys.

3.2.2.2 Recorded streamflow data

As discussed in Section 2.2, only one streamflow gauge was available for calibration, the St Marys Rivulet at Killymoon, located approximately 10 kilometres downstream of St Marys. Across all chosen calibration events the data quality codes show the streamflow data is of poor quality. Nonetheless the records were still useful in understanding catchment response and timing, and therefore helping to determine reasonable routing parameters for the RORB model across the three events.

The streamflow records indicate peak flows of 474 m^3/s, 495 m^3/s and 374 m^3/s were recorded for the January, June and November 2016 events respectively. Interestingly, while the June event resulted in the largest

[2] AR&R, 1987 – Australian Rainfall and Runoff
[3] Weeks, W. D. (1980). Using the Laurenson model: traps for young players. Hydrology and Water Resources Symposium, Adelaide, Institution of Engineers Australia

recorded flow at Killymoon it is the January event which was the largest flood event in St Marys. This is likely to be due to the distance between the Killymoon gauge and St Marys with a large catchment area contributing between them.

3.2.2.3 Temporal Rainfall Patterns

3.2.2.3.1 OVERVIEW

Temporal rainfall patterns represent how rainfall falls over time, and are a key input into a RORB model. Inaccurate temporal data due to limited or poor quality pluviograph data can skew RORB results significantly, severely impacting the output hydrographs and uncertainty of the modelling. Temporal rainfall patterns are derived from sub-daily rainfall gauges. As detailed in Section 2.2, two gauges, Fungal (92012) and Upper Scamander (92130), were available to be used as the basis for calibration temporal rainfall patterns. The gauge records for these gauges were compared across the January and June 2016 events, while no comparison could be made for November 2016 due to the Scamander gauge ceasing operation in August 2016.

3.2.2.3.2 JANUARY 2016

Rainfall data from the Scamander and Fingal sub-daily gauges were compared to the daily rainfall record and anecdotal observations at St Marys. The peak intensity and total accumulated rainfalls are shown in Table 3-3 and are represented in Figure 3-5 and Figure 3-6. The total cumulative rainfall recorded at the gauge for this event occurred across a 4 day period.

Table 3-3 shows the total cumulative rainfall recorded by the Scamander pluviograph gauge is less than that of the daily rainfall gauges in and around St Marys captured for the January event as shown in Figure 3-11.

The presence of large rainfall bursts in the early hours of the 29th January 2017 in the gauge record and a review of historic RADAR imagery of the event indicated that the Scamander pluviograph graph much better represented the magnitude and timing of the event than the Fingal gauge and was therefore adopted in the modelling. This assumption is validated by anecdotal reports that the largest rainfall bursts occurred in the early hours of the 29th January. It is estimated that the largest rainfall burst consisted of approximately 100mm in just a 2 hour period. When comparing to design IFD rainfall depths this equates to approximately a 0.2% AEP or 1 in 500 year ARI storm event.

Table 3-3 Comparison Of pluviograph data for the January 2016 event

Gauge	Peak Rainfall Intensity (mm/hr) and time/date	Total Cumulative Rainfall (mm)
Scamander Pluviograph Gauge (92130)	40.4 mm/hr @ 1/29/2016 7:00	137.8
Fingal Pluviograph Gauge (92012)	50 mm/hr @ 1/29/2016 9:30	156.2

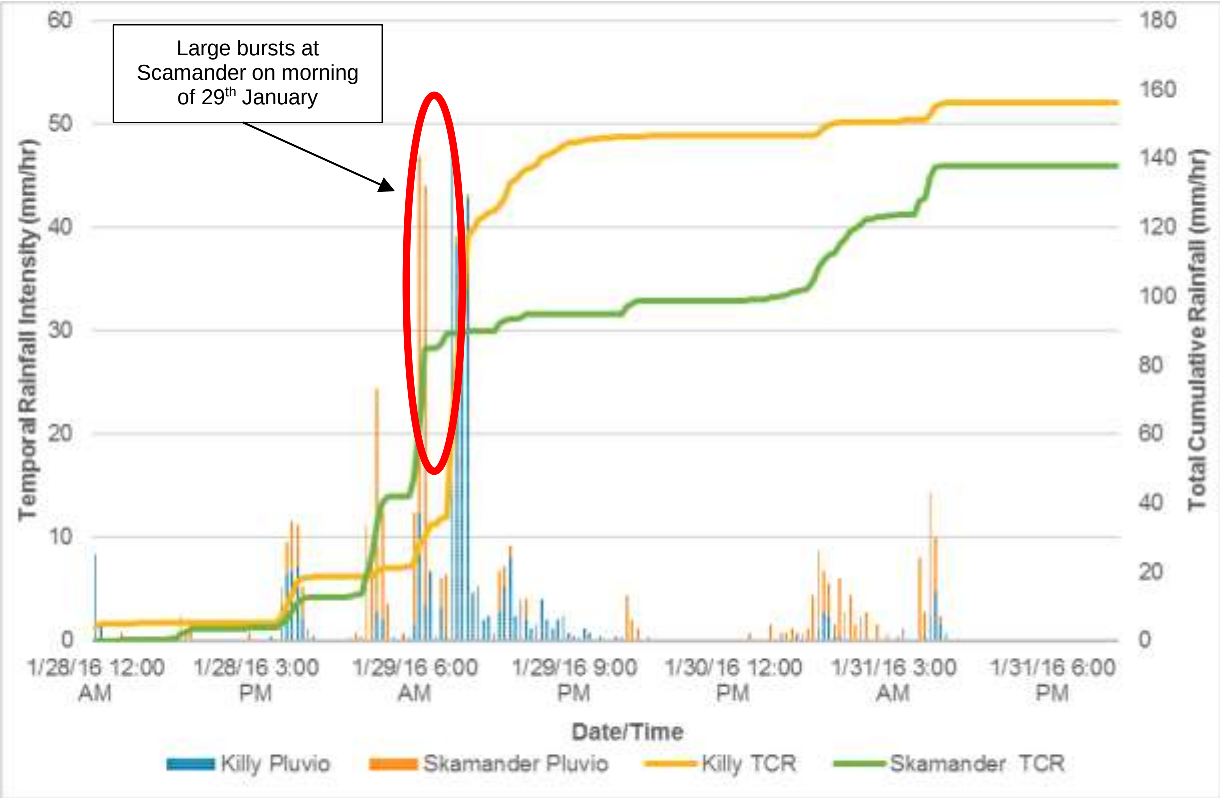

FIGURE 3-5 TEMPORAL RAINFALL INTENSITY AND TOTAL CUMULATIVE RAINFALL FOR JANUARY 2016

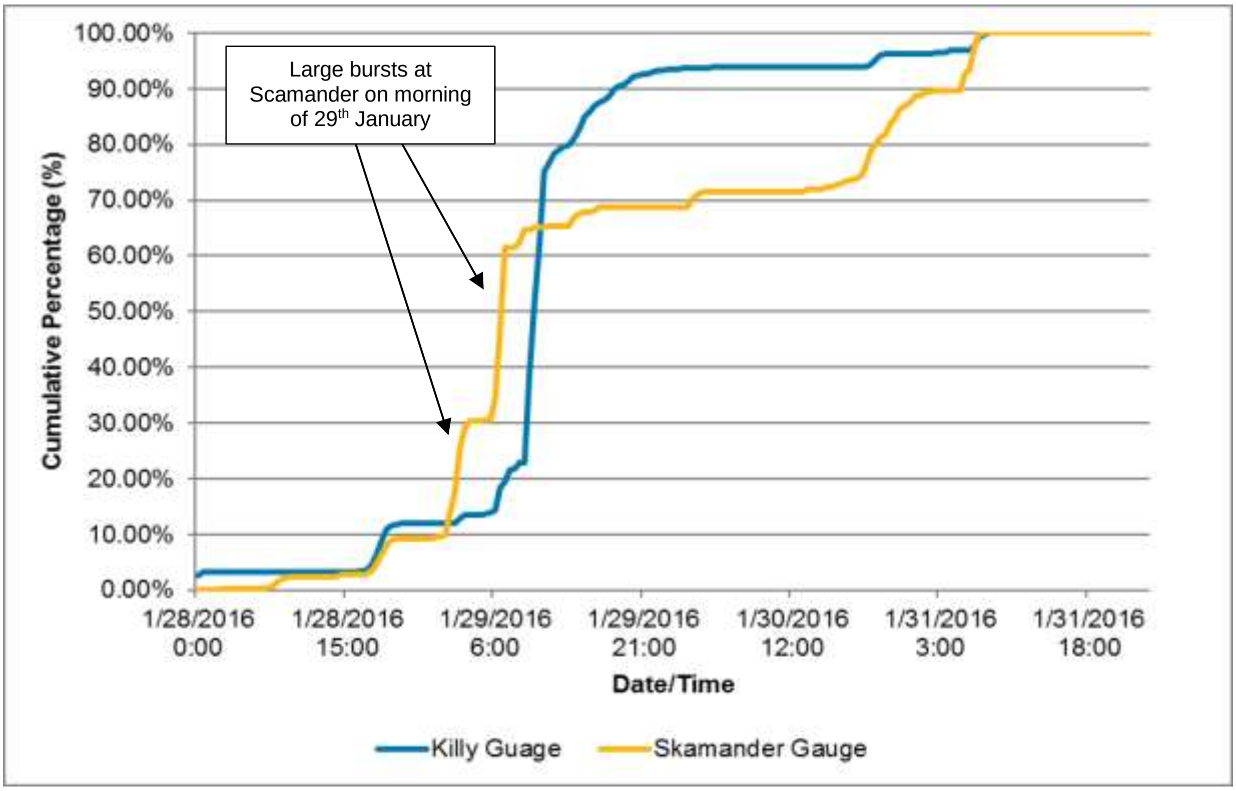

FIGURE 3-6 CUMULATIVE RAINFALL PERCENTAGE FOR JANUARY 2016

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3.2.2.3.3 JUNE 2016

Similar to the January 2016 event, the Fingal and Scamander sub-daily rainfall records were compared for the June 2016 event. Table 3-4 shows the peak rainfall intensity and total cumulative rainfall total for each event, while Figure 3-8 provides a comparison between the sub-daily rainfall records over the duration of the event. The total cumulative rainfall recorded at both gauges occurred over a two day period. The variation of larger and concentrated rainfall bursts in the Scamander gauge record again better represented the event at St Marys and so was adopted for this event. This was determined by extensive testing in the RORB model with both the Fingal and Scamander temporal patterns and a review of historic RADAR data which showed the event moved from north-south passing over both Scamander and St Marys.

TABLE 3-4 COMPARISON OF PLUVIOGRAPH DATA FOR THE JUNE 2016 EVENT

Pluviograph	Peak Rainfall Intensity (mm/hr) and time/date	Total Cumulative Rainfall (mm)
Scamander Pluviograph Gauge (92130)	14.0 @ 6/5/2016 22:30	171.8
Fingal Pluviograph Gauge (92012)	12.0 @ 6/6/2016 7:00	153.4

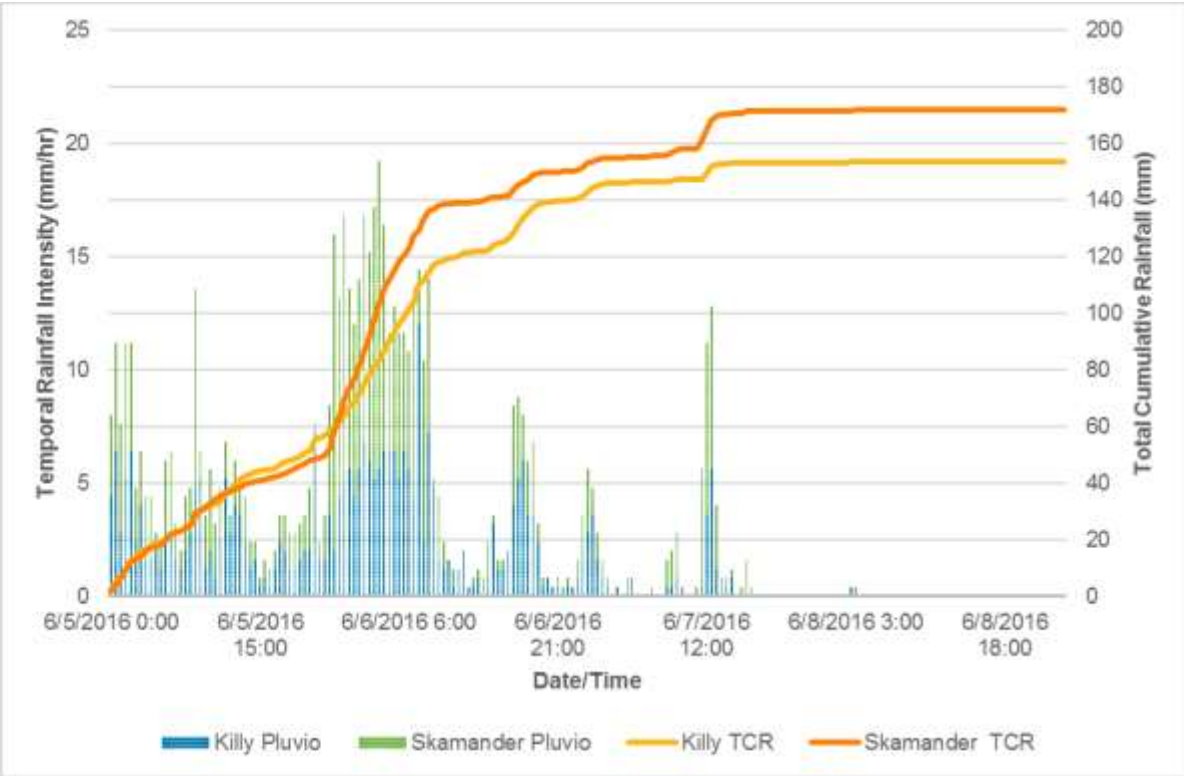

FIGURE 3-7 TEMPORAL RAINFALL INTENSITY AND TOTAL CUMULATIVE RAINFALL FOR JUNE 2016

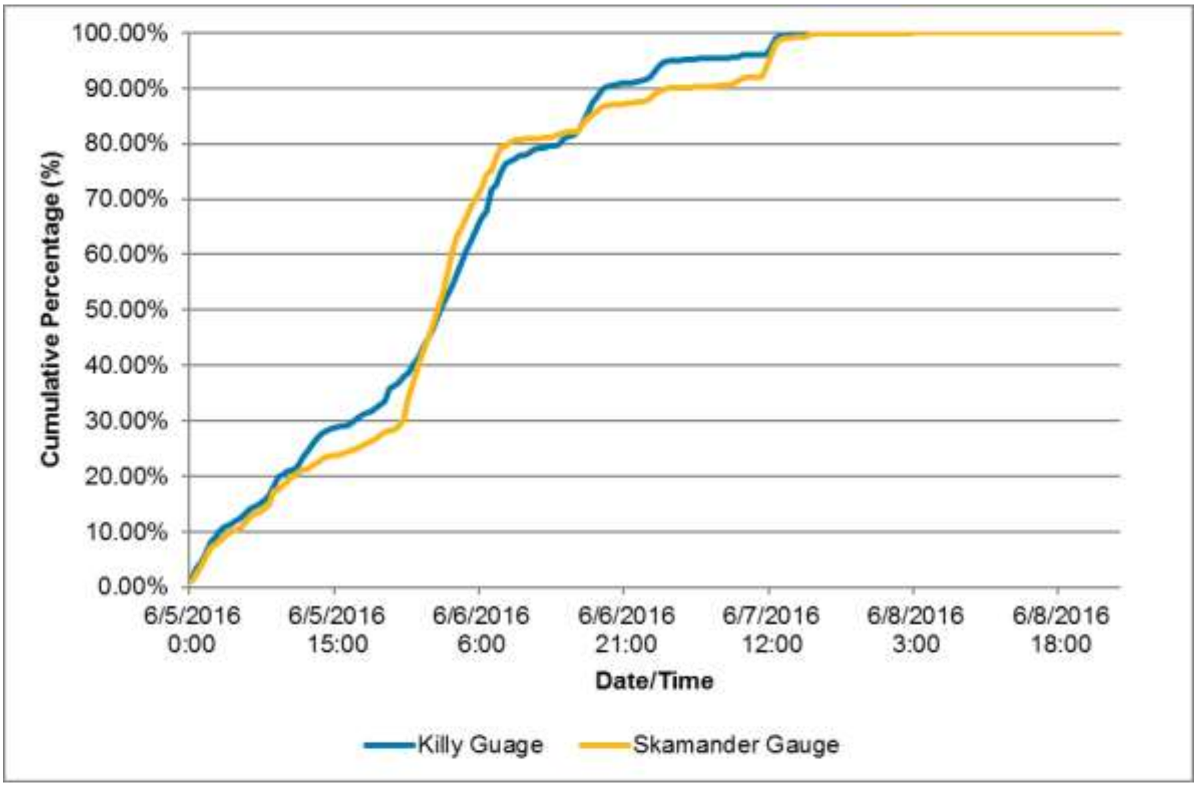

FIGURE 3-8 CUMULATIVE RAINFALL PERCENTAGE FOR JUN 2016

3.2.2.3.4 NOVEMBER 2016

The Scamander Pluviograph gauge has been inactive since August 2016 and did not record the November 2016 event. The Fingal gauge record was therefore used and showed peak rainfall intensity bursts of 10 mm/hr occurring at 2:42 am and 3:18 am on the 13th of November as shown in Figure 3-9 and Figure 3-10 below. The total cumulative rainfall recorded at the gauge was 48 mm over a 4 day period. The bulk of the rainfall fell with a sustained rainfall intensity over a 24 hour period.

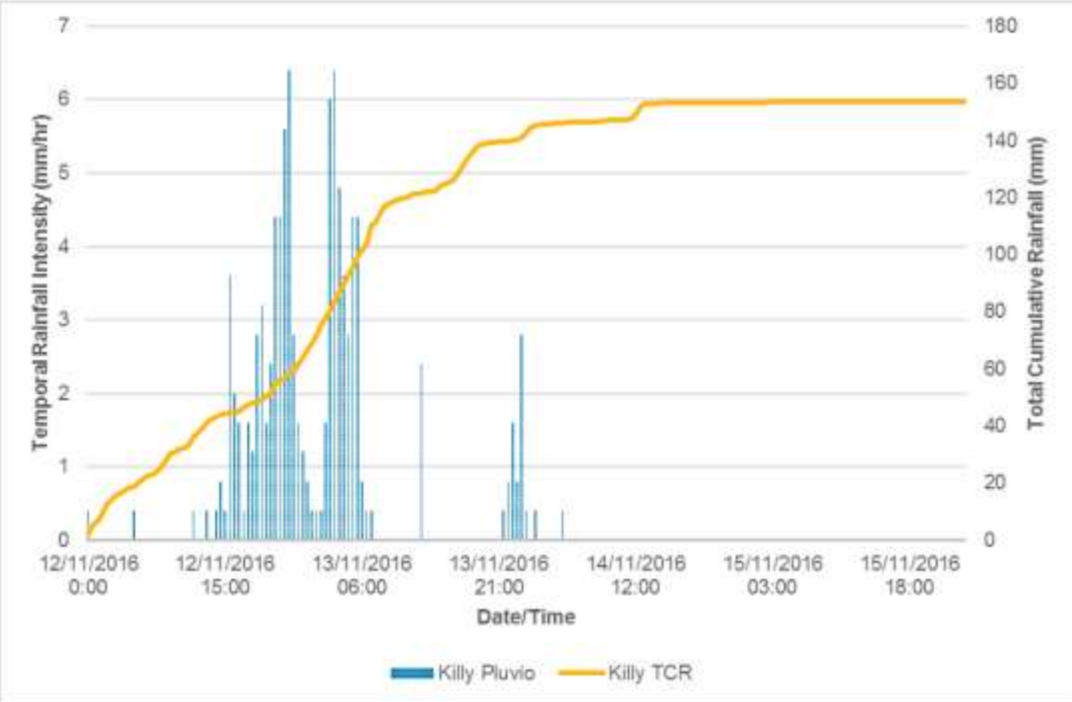

FIGURE 3-9 TEMPORAL RAINFALL INTENSITY AND TOTAL CUMULATIVE RAINFALL FOR NOV 2016

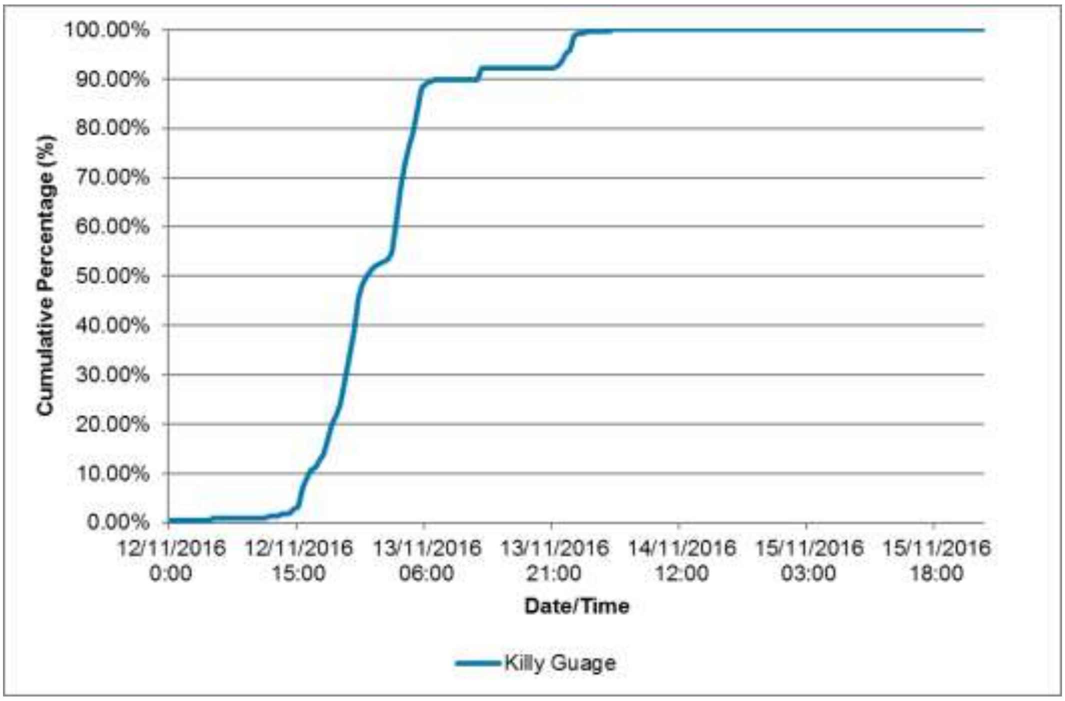

FIGURE 3-10 CUMULATIVE RAINFALL PERCENTAGE FOR NOV 2016

3.2.2.4 Daily Rainfall totals

The interpolated rainfall totals for the January 2016, June 2016 and September 2016 events are shown in Figure 3-11, Figure 3-12, and Figure 3-13 respectively. The topography surrounding St Marys and proximity the coast results in large rainfall totals in the catchment areas upstream of St Marys.

Of the three events, the largest falls were recorded in January 2016 with 529 mm recorded at the St Marys township gauge. The June and November events recorded to the largest falls south of St Marys at the Gray gauge with 312 mm and 264 mm recorded in June and November respectively.

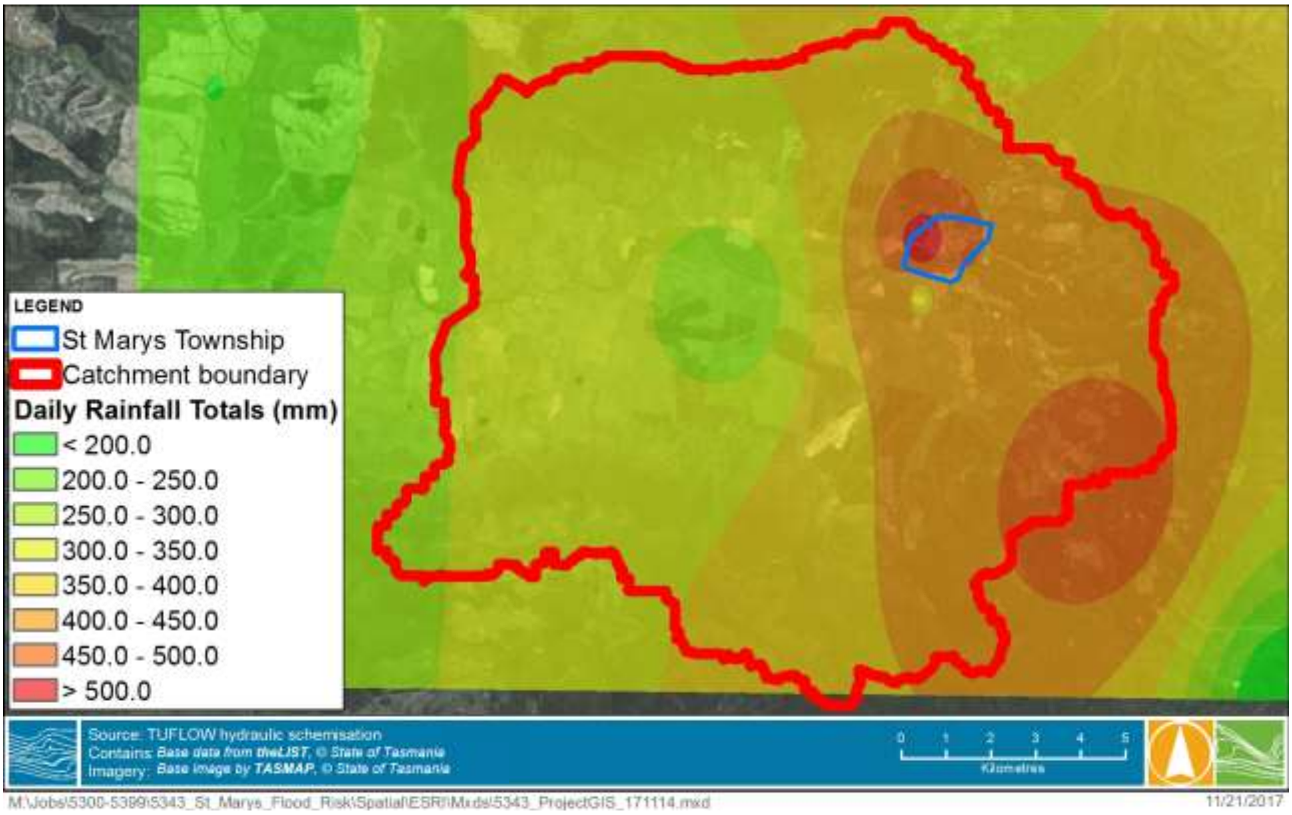

FIGURE 3-11 JANUARY 2016 SPATIAL PATTERN OF RAINFALLS (4 DAY TOTAL)

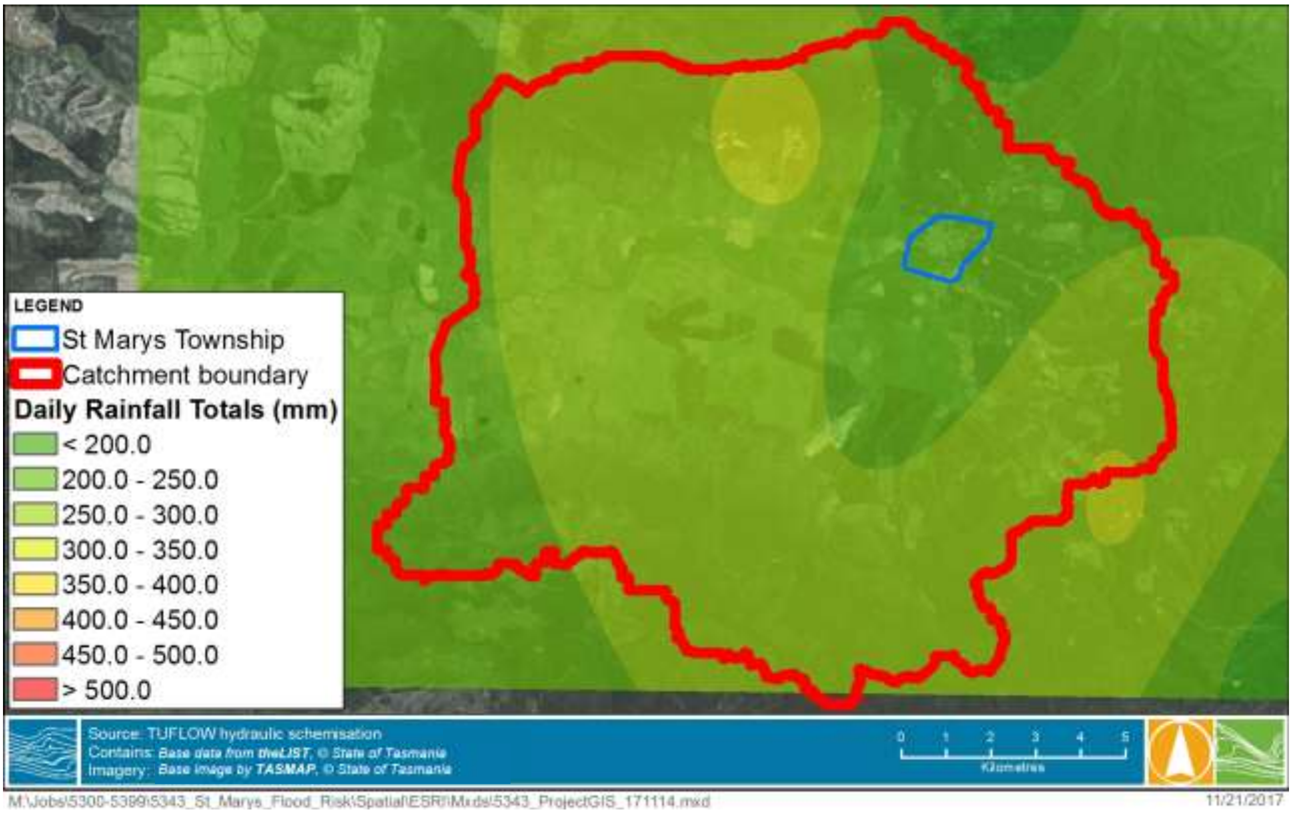

FIGURE 3-12 JUNE 2016 SPATIAL PATTERN OF RAINFALL (2 DAY TOTAL)

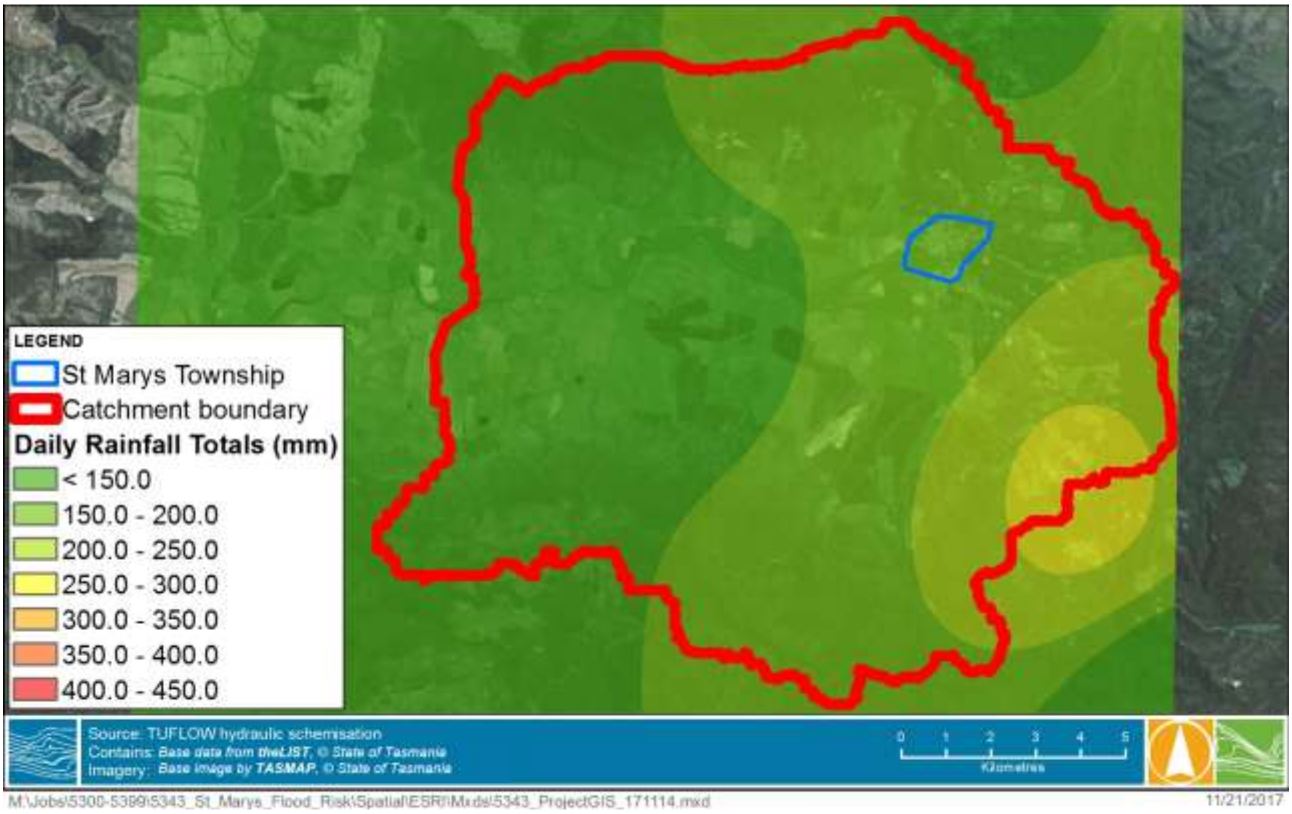

FIGURE 3-13 NOVEMBER 2016 SPATIAL PATTERN OF RAINFALL (4 DAY TOTAL)

3.2.3 Calibration Results

Calibration of the RORB model across the three events was challenging due to the quality of the streamflow and rainfall data. Calibration of the model required manipulation of the key routing parameter, kc and rainfall loss values across the catchment. Initial hydraulic model runs were also completed to determine the likely range of peak flows at St Marys for each calibration event. The determined peak flows were 200-240 m^3/s for the January 2016 event and 60-80 m^3/s for the June and September events.

January 2016 Event

The adopted parameters for the January 2016 event are shown in Table 3-5. These values resulted in a good representation of the hydrograph at Killymoon as shown in Table 3-6 and Figure 3-14. The calculated peak discharge is 492.3 m^3/s at the gauge is 4.2% greater than the gauged value of 472.5 m^3/s and the timing of the peak flow was also within 1 hour of that observed, both of these are considered to represent a good match. The calculated event volume was 6,020 ML greater (22%) than that observed, indicating the adopted loss values could be higher.

As an additional form of validation, a comparison was made between the modelled peak flow at St Marys with preliminary hydraulic modelling which indicated that the peak discharge was approximately 220 – 240.0 m^3/s for this event. This compared closely to the modelled peak flow of 232.1 m^3/s further validating the flow estimates. The modelled hydrographs at both Killymoon and St Marys for the January 2016 event are shown in Figure 3-14.

The January 2016 flow estimates were further verified by running them through the hydraulic model and comparing to observed flood behaviour, this is discussed further in Section 3.3.6.

TABLE 3-5 CALIBRATED PARAMETERS

Gauging Stations	kc	Initial Losses	Continuing Losses	m
Interstation	4.50	30.0	1.8	0.8
Gauge	24.00	35.0	2.0	0.8
Outlet	24.00	35.0	2.0	0.8

TABLE 3-6 GAUGING STATION RESULTS

	Hydrograph		Error	
	Calculated	Actual	Abs	Percent (%)
Peak discharge, m^3/s	492.3	472.5	19.8	4.2
Time to peak, hr	13.5	12.5	1.0	-
Volume, ML	33,000	26,900	6,020	22.4

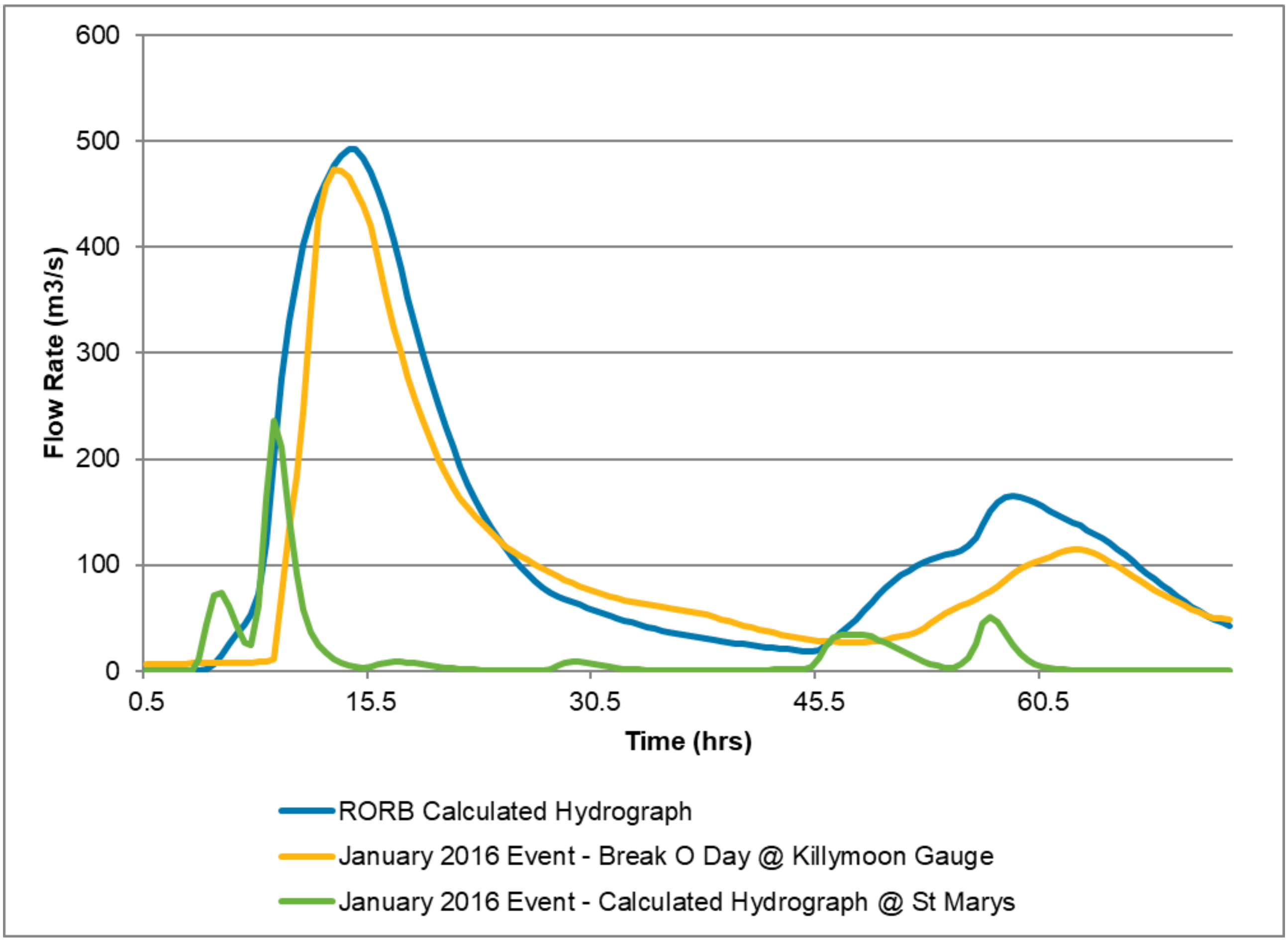

FIGURE 3-14 CALCULATED AND ACTUAL PRINTED HYDROGRAPHS FOR JANUARY 2016

3.2.3.1 June 2016 Event

The June 2016 event was modelled utilising similar Kc values to that adopted for January 2016, and a good calibration was achieved. The St Marys interstation area kc remained at 4.5, resulting in a calculated peak discharge of 468.1 m^3/s, matching closely with the gauged peak flow of 494.6 m^3/s. The modelled event timing was within 1 hour of that observed and the modelled event volume was 5,890 ML (18.1%) higher than that observed.

Much lower losses were adopted (initial loss – 5 mm, continuing loss 0.25 mm), indicating a wet catchment at the start of the event. This is considered reasonable given the large amount of rain that occurred in the months prior and a large rainfall event occurred week prior to the June event.

The adopted model calibration inputs are shown in Table 3-7 with results shown in Table 3-8.

Similar to January 2016, a comparison was made between the RORB modelled peak flow at St Marys with that determined during the preliminary hydraulic modelling. The preliminary hydraulic modelling indicated the peak discharge was approximately 60 – 80 m^3/s for June 2016, this compares closely to the modelled peak flow of 68.5 m^3/s further validating the flow estimates. The modelled hydrographs at both Killymoon and St Marys for the June 2016 event are shown in Figure 3-15.

As with the January event the June flow estimates were further verified by running them through the hydraulic model and comparing to observed flood behaviour, which is discussed in Section 3.3.6.

TABLE 3-7 CALIBRATED PARAMETERS

Gauging Stations	kc	Initial Losses	Continuing Losses	m
Interstation	4.50	5.0	0.25	0.8
Gauge	22.00	5.0	0.25	0.8
Outlet	22.00	5.0	0.25	0.8

TABLE 3-8 GAUGING STATION RESULTS

	Hydrograph		Error	
	Calculated	Actual	Abs	Percent
Peak discharge, m^3/s	468.1	494.6	-26.5	-5.4
Time to peak, h	33.5	34	-0.5	-
Volume, ML	38,500	32,600	5,890	18.1

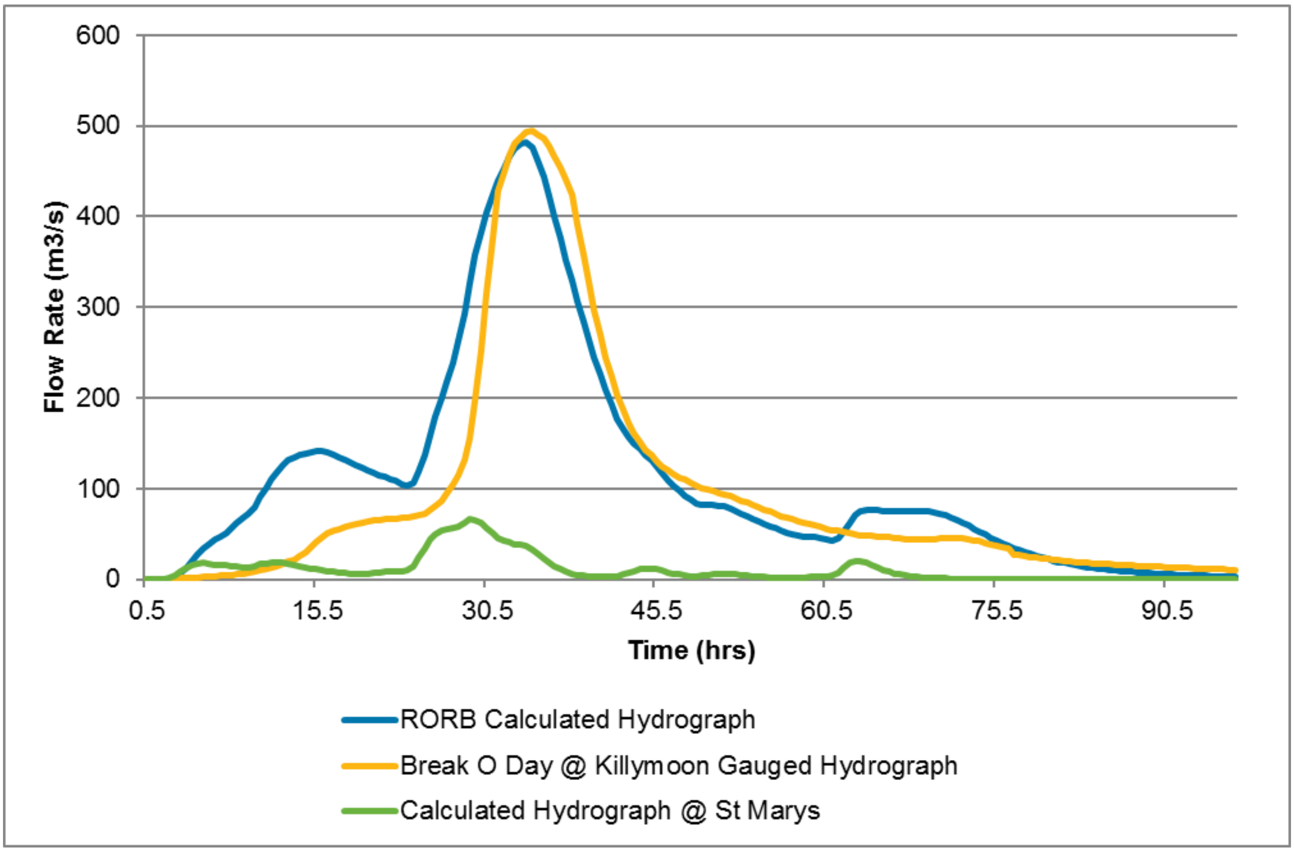

FIGURE 3-15 CALCULATED AND ACTUAL PRINTED HYDROGRAPHS FOR JUNE 2016

3.2.3.2 November 2016 Event

The November 2016 event was the third calibration event and a good calibration was also achieved for this event. A Kc value of 4.5 was again adopted for the St Marys interstation area. A peak flow of 359.8 m^3/s was modelled at the Killymoon gauge, matching closely with the gauged peak of 374.4 m^3/s. The low adopted continuing loss values again indicate a wet catchment which correlates with the regular and significant rainfall which occurred throughout 2016. The timing of the modelled peak flow matched within 2 hours of that observed, with the event volume 3,570 ML above that observed.

The modelled calibration parameters are shown in Table 3-9 with results shown in Table 3-10.

A comparison was made between the RORB modelled peak flow at St Marys with preliminary hydraulic modelling which indicated that the peak discharge was approximately 80 – 100 m^3/s for this event. This compares closely to the modelled peak flow of 83.3 m^3/s further validating the flow estimates. The modelled hydrographs at both Killymoon and St Marys for the June 2016 event are shown in Figure 3-16.

As with the January and June events the November flow estimates were further verified by running them through the hydraulic model and comparing to observed flood behaviour, this is discussed in Section 3.3.6.

TABLE 3-9 CALIBRATED PARAMETERS

Gauging Stations	kc	Initial Losses	Continuing Losses	m
Interstation	4.50	35.0	0.25	0.8
Gauge	24.00	35.0	0.25	0.8
Outlet	24.00	35.0	0.25	0.8

TABLE 3-10 GAUGING STATION RESULTS

	Hydrograph		Error	
	Calculated	Actual	Abs	Percent
Peak discharge, m^3/s	359.8	374.4	-14.6	-3.9
Time to peak, h	32.0	34.0	-2.0	-5.9
Volume, ML	21,800	18,300	3,570	19.5

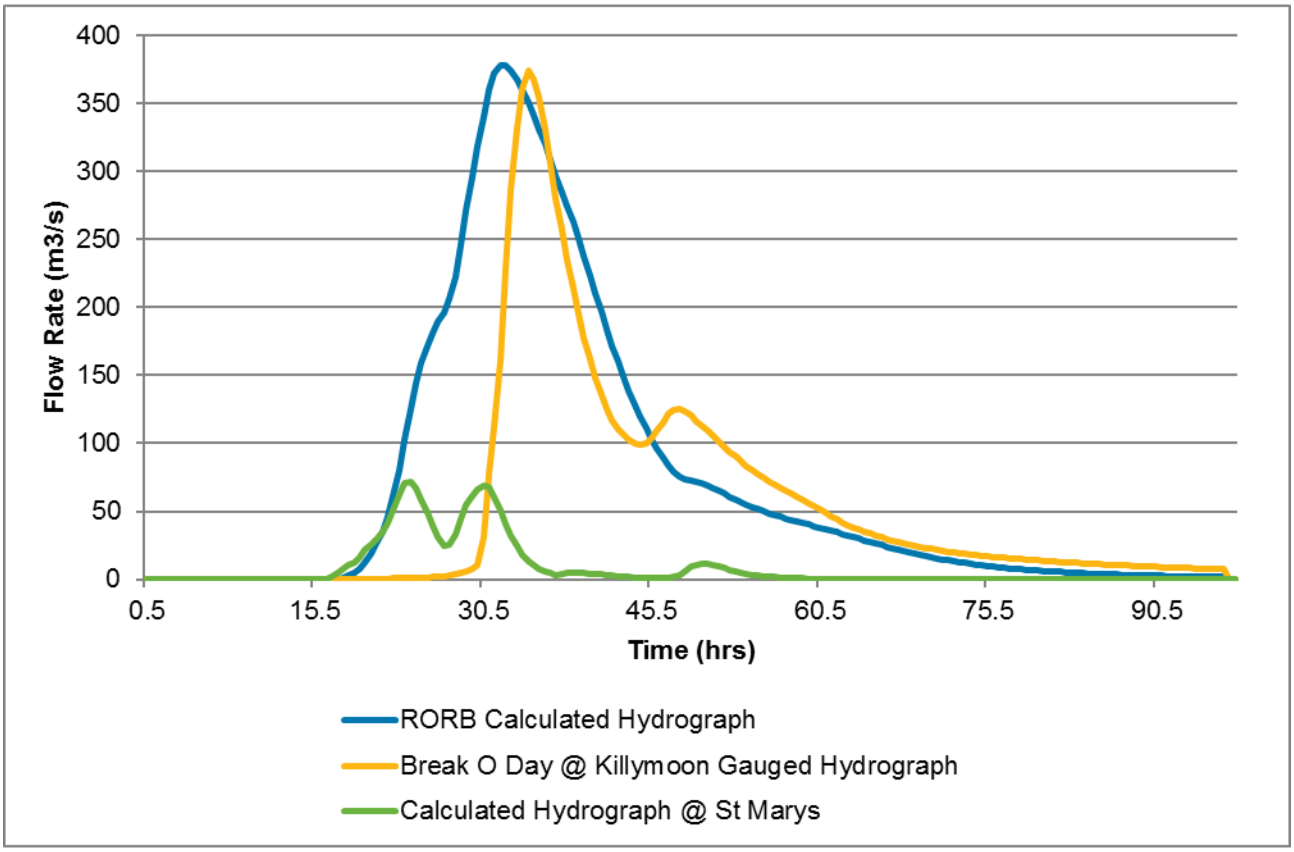

FIGURE 3-16 CALCULATED AND ACTUAL PRINTED HYDROGRAPHS FOR NOVEMBER 2016

3.2.4 Hydrology Summary

The hydrological analysis has involved the development of a RORB model and the calibration of the model using three events that occurred in January, June and November of 2016. The analysis required temporal rainfall data, daily rainfall data and streamflow data to generate storm files mirroring the storm events.

Kc, initial losses and continuing loss parameters were determined for each event. The quality of data from the pluviograph and streamflow gauges caused challenges in the modelling, however, after extensive analysis a very good calibration was achieved across the three events. Based on the calibration process detailed in this report the model is considered suitable to be used for design modelling.

The estimated peak flows at St Marys and the corresponding calibration inputs for the three calibration events are shown in Table 3-11.

TABLE 3-11 PEAK FLOWS AT THE ST MARYS TOWNSHIP

Flood Events	Calculated Flow Rate (m^3/s)	kc (St Marys interstation area)	Initial Loss	Continuing Loss
January 2016	236.6	4.5	30.0	1.80
June 2016	68.5	4.5	5.0	0.25
November 2016	83.2	4.5	35.0	0.25

3.3 Hydraulic Modelling

3.3.1 Overview

Hydraulic modelling undertaken as part of this project covers the St Marys township from the intersection of the Esk Highway and Irish Town Road in the north to downstream of St Marys township in the south, as shown in Figure 3-17. A detailed combined 1D-2D hydraulic modelling approach was adopted, consisting of the following components:

- One dimensional (1D) hydraulic model of key hydraulic structures; and,
- Two dimensional (2D) hydraulic model of some hydraulic structures, key waterways and the broader floodplain.

The hydraulic modelling suite TUFLOW was used in this study. TUFLOW is a widely used hydraulic model that is suitable for the analysis of flood behaviour in rural and urban area. TUFLOW has five main inputs:

- Topography and drainage infrastructure data;
- Inflow data (based on catchment hydrology);
- Roughness; and,
- Boundary conditions.

This section of the report defines the scope of the hydraulic analysis, details the hydraulic model construction, and discusses the modelling and validation of the three historic events.

FIGURE 3-17 TUFLOW HYDRAULIC MODEL EXTENT

3.3.2 Boundary Conditions

3.3.2.1 Model Inflows

Inflow boundary conditions were extracted from the RORB model (as detailed in Section 3.2.1) at three key tributaries entering St Marys township – St Marys Rivulet, St Patricks Creek and Newmans Creek. These were modelled as source-area boundary types whereby the inflows are applied across a small polygon placed across the waterway. The hydraulic model inflow locations are shown in Figure 3-18.

3.3.2.2 Model Outflows

The hydraulic model outflow is achieved by a downstream boundary located across the St Marys rivulet floodplain downstream of the township. The outflow was modelled as a Discharge/Water Level (QH) boundary, whereby the model determines a rating curve based on the model topography, slope and roughness.

FIGURE 3-18 TUFLOW MODEL BOUNDARIES

3.3.3 Topography Extent and Resolution

As discussed in Section 2.4, the model topography was based on LiDAR data captured in 2012 as part of the St Marys DEM project. The LiDAR data was converted 2m grid resolution, which was determined as a suitable size to accurately represent the key hydraulic features. The model DEM is shown in Figure 3-19.

A key consideration in establishing an appropriate grid resolution for the 2D hydraulic model was to ensure waterway channel capacity was well represented whilst enabling fast model run times. A 2 metre grid resolution for St Marys township was adopted and considered sufficient to represent all the key tributaries and floodplain flood behaviour with reasonable run-times. This was considered a fairly fine grid resolution for a riverine flood study.

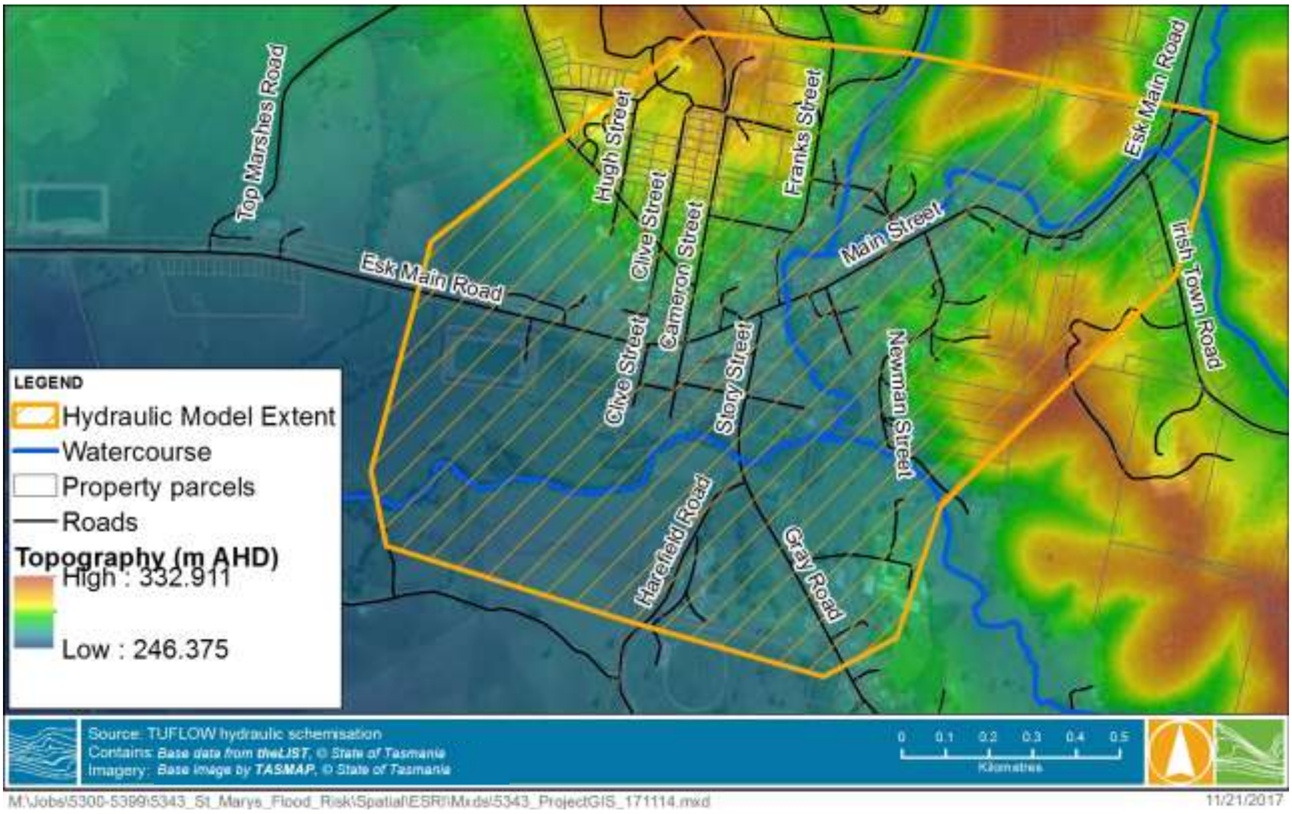

FIGURE 3-19 TUFLOW MODEL TOPOGRAPHY

3.3.4 Hydraulic Roughness

Hydraulic roughness was determined initially using planning layers and then modified based on land cover mapping, aerial imagery and observations from the site visit. Table 3-12 shows the Manning's 'n' roughness values adopted for each land use, with the values adopted in the hydraulic model are shown in Figure 3-20. The adopted roughness' were based on standard industry accepted values as outlined in Australian Rainfall and Runoff[4].

TABLE 3-12 MANNING'S VALUE "N" FOR THE TUFLOW MODEL AREA

Land Type	Manning's Value (n)
Residential – Urban (higher density)	0.200
Residential – Rural (lower density)	0.060
Open Space or Pasture	0.040
Open Space or Waterway – moderate vegetation	0.060
Open Space or Waterway – heavy vegetation	0.090
Open water body	0.030
Sealed Road	0.025
Unsealed Road	0.035

[4] Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2016, Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia

Land Type	Manning's Value (n)
Dense Bushland	0.100

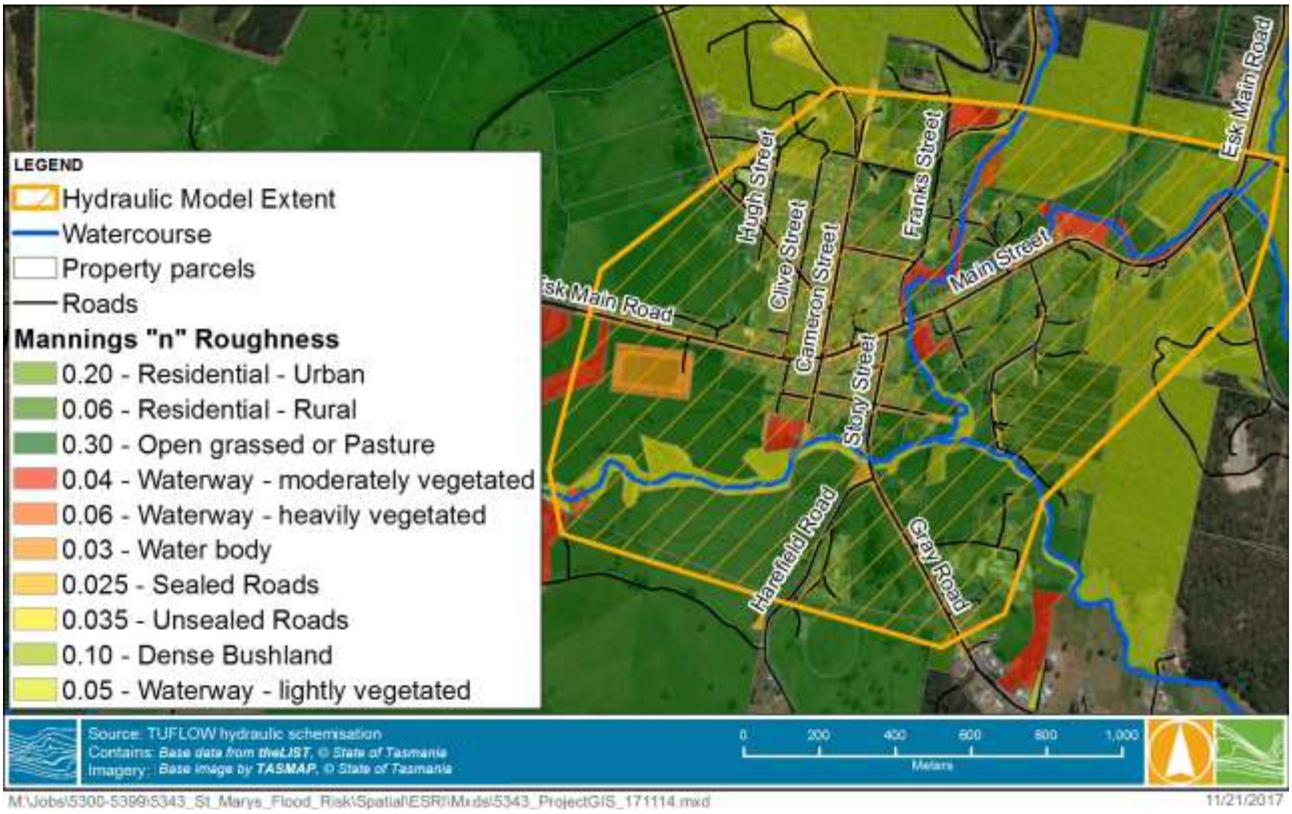

FIGURE 3-20 MANNINGS "N" ROUGHNESS

3.3.5 Hydraulic Structures

There were seven key hydraulic structures within the hydraulic boundary varying in capacity and type (i.e. bridges and culverts). Four open span bridges traversed St Marys Rivulet and a single open span bridge on Newmans Creek. The large bridge located along Storey Street also contained culverts on either side of the bridge, providing additional capacity and allowing nearby properties to drain. Smaller structures were represented in 1D, whilst larger structures were represented using 2D layered flow constrictions. Both methods are appropriate modelling techniques and ensure the capacity and hydraulic behaviour of each structure was accurately represented.

Figure 3-21 shows the location of the modelled structures. Data for each of the structures was a determined from a combination of original plans, recent survey and information gathered form the site visit undertaken in September 2017.

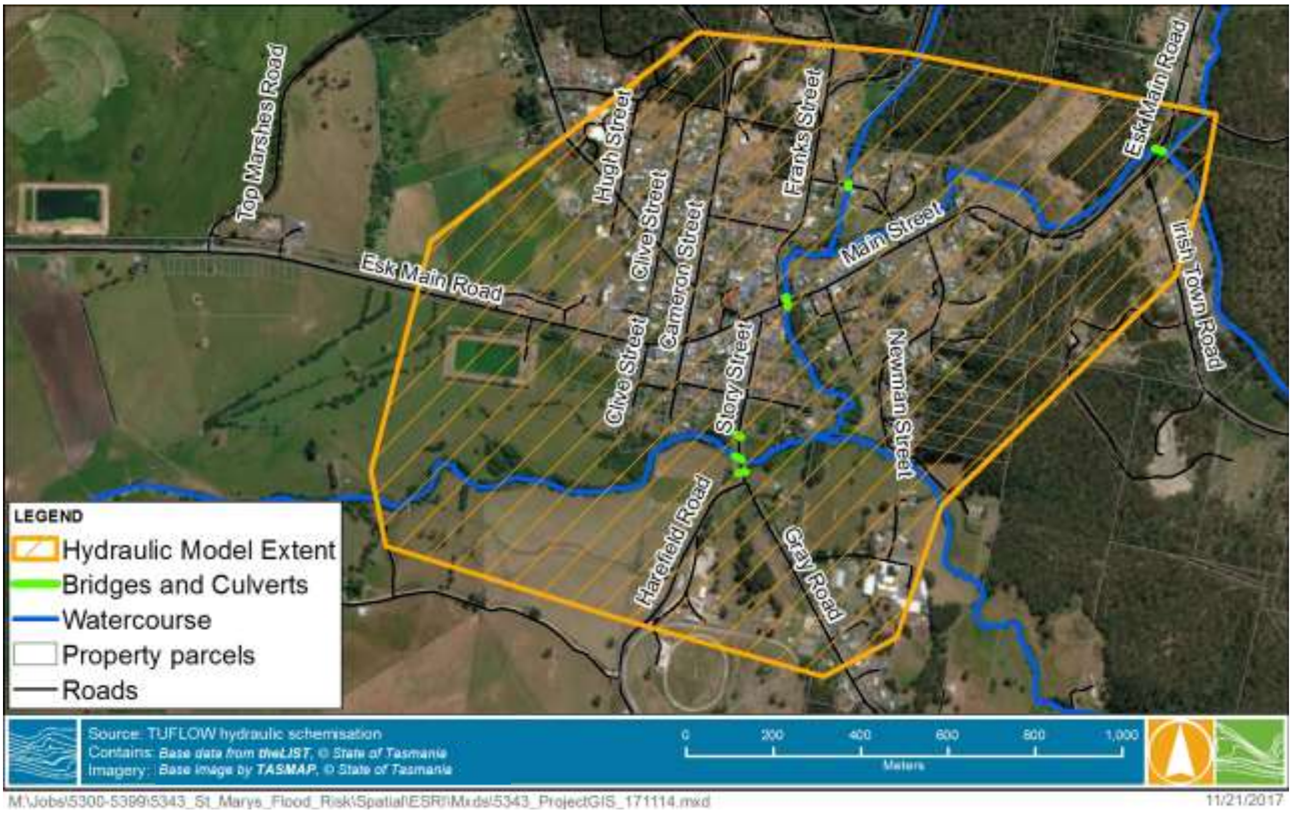

FIGURE 3-21 LOCATION OF KEY HYDRAULIC STRUCTURES

3.3.6 TUFLOW Validation

3.3.6.1 Overview

The three 2016 flood events were modelled in the TUFLOW model, and the results validated using the information available. This largely considered of photos taken during and after the event and anecdotal reports. The process showed the model is producing accurate flood behaviour across a range of magnitude events and is appropriate to be used for design modelling.

3.3.6.2 January 2016

Information available for the January 2016 event included a range of photos and anecdotal reports which were largely collated during the community meeting and site visit undertaken in September 2017. Key observed flood behaviour is summarised in Figure 3-22 below.

Model results for January 2016 are shown in Figure 3-22 and direct comparisons are made against the observed behaviour, Figure 3-23 compares the model results and available photos of the event. Direct comparisons are made in Figure 3-25 below between the model results and photos of the event. It can be generally seen that there is a strong correlation between the model results and the observed behaviour in terms of inundation extent, depth and key behaviour such as breakouts and overtopping of roads and bridges. It should be noted that the flood photos are unlikely to have been taken at the peak of the event but nonetheless they allow a good comparison to be made between model results and observed flooding.

It also needs to be noted that there were significant input data limitations and extensive number of iterations were required to match to observed behaviour. Given the data limitations the resulting model validation of the January 2016 event is very good.

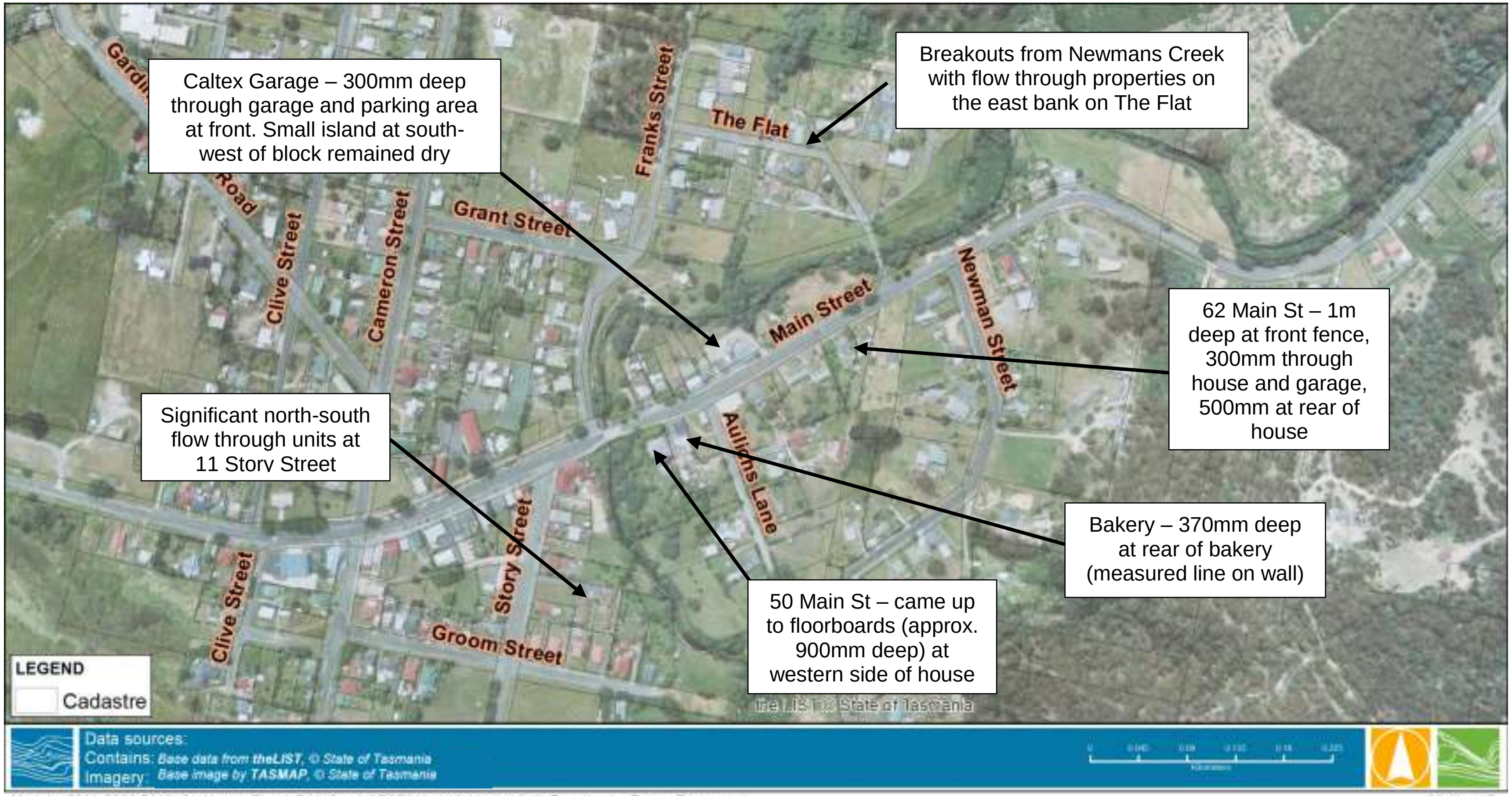

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FIGURE 3-22 JANUARY 2016 EVENT – KEY OBSERVED FLOOD BEHAVIOUR

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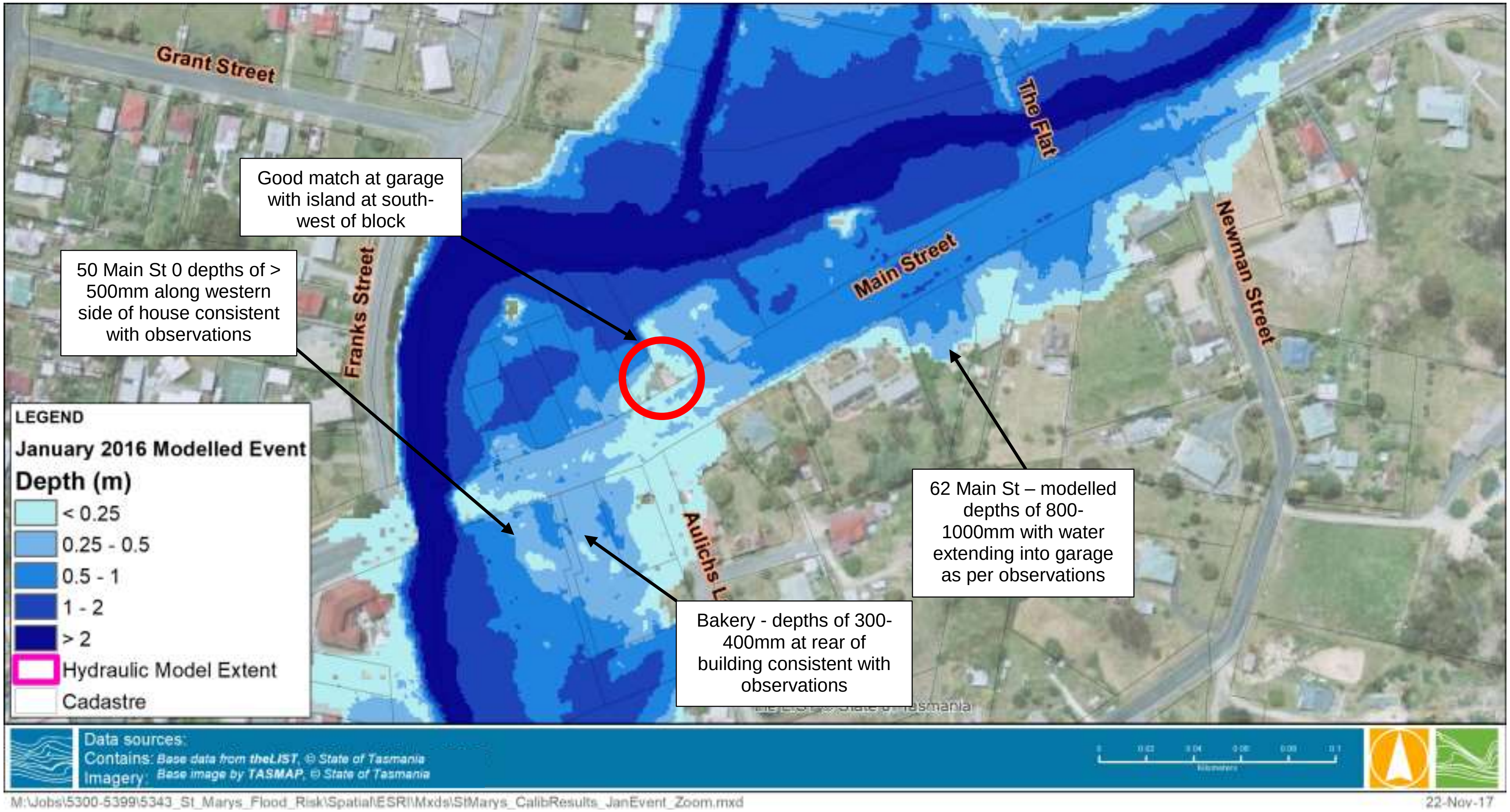

FIGURE 3-23 MODELLED JANUARY 2016 EVENT ZOOM VIEW – COMPARISON TO OBSERVED FLOODING

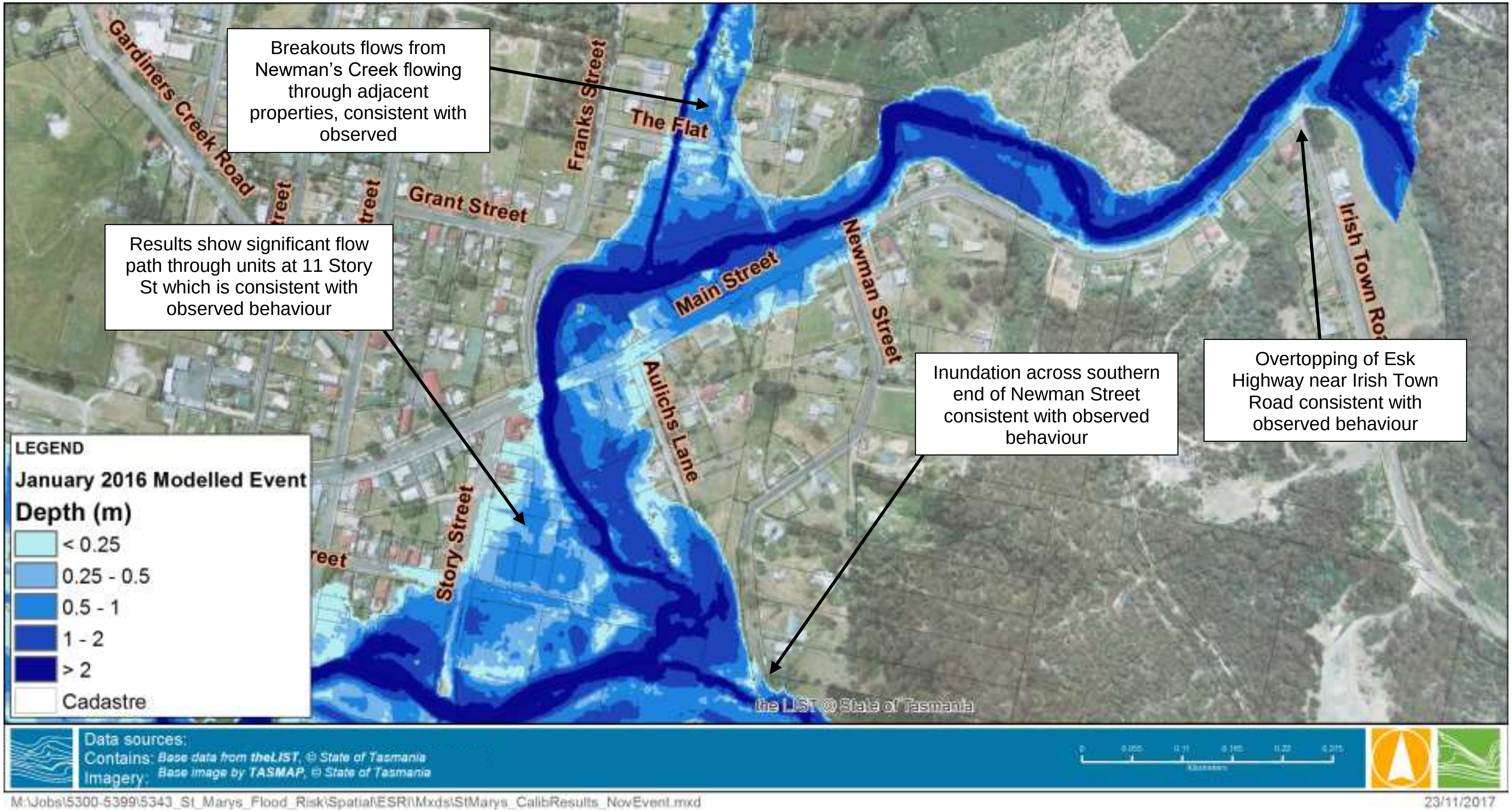

FIGURE 3-24 MODELLED JANUARY 2016 EVENT – COMPARISON TO OBSERVED FLOODING

FIGURE 3-25 MODELLED JANUARY 2016 EVENT – COMPARISON TO FLOOD IMAGERY

FIGURE 3-26 MODELLED JANUARY 2016 EVENT – COMPARISON TO FLOOD IMAGERY

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3.3.6.3 June 2016

There was considerably less available information for the June 2016 event than January 2016, which was unsurprising given it was a much smaller flood event. Available information included several photos and anecdotal reports collated during the community meeting and site visit undertaken in September 2017. Key observed flood behaviour is summarised in Figure 3-27 below.

Model results for the June 2016 event are shown in Figure 3-28 and direct comparisons are made against the observed behaviour, Figure 3-29 compares the modelling results and available photos of the event. Generally, there is a strong correlation between the model results and the observed behaviour in terms of inundation extent, depths and key behaviour such as the shallow overtopping of Main Street in the vicinity of The Flat Bridge over St Marys Rivulet.

Given the input data limitations and quality the model validation of the June 2016 event is considered very good.

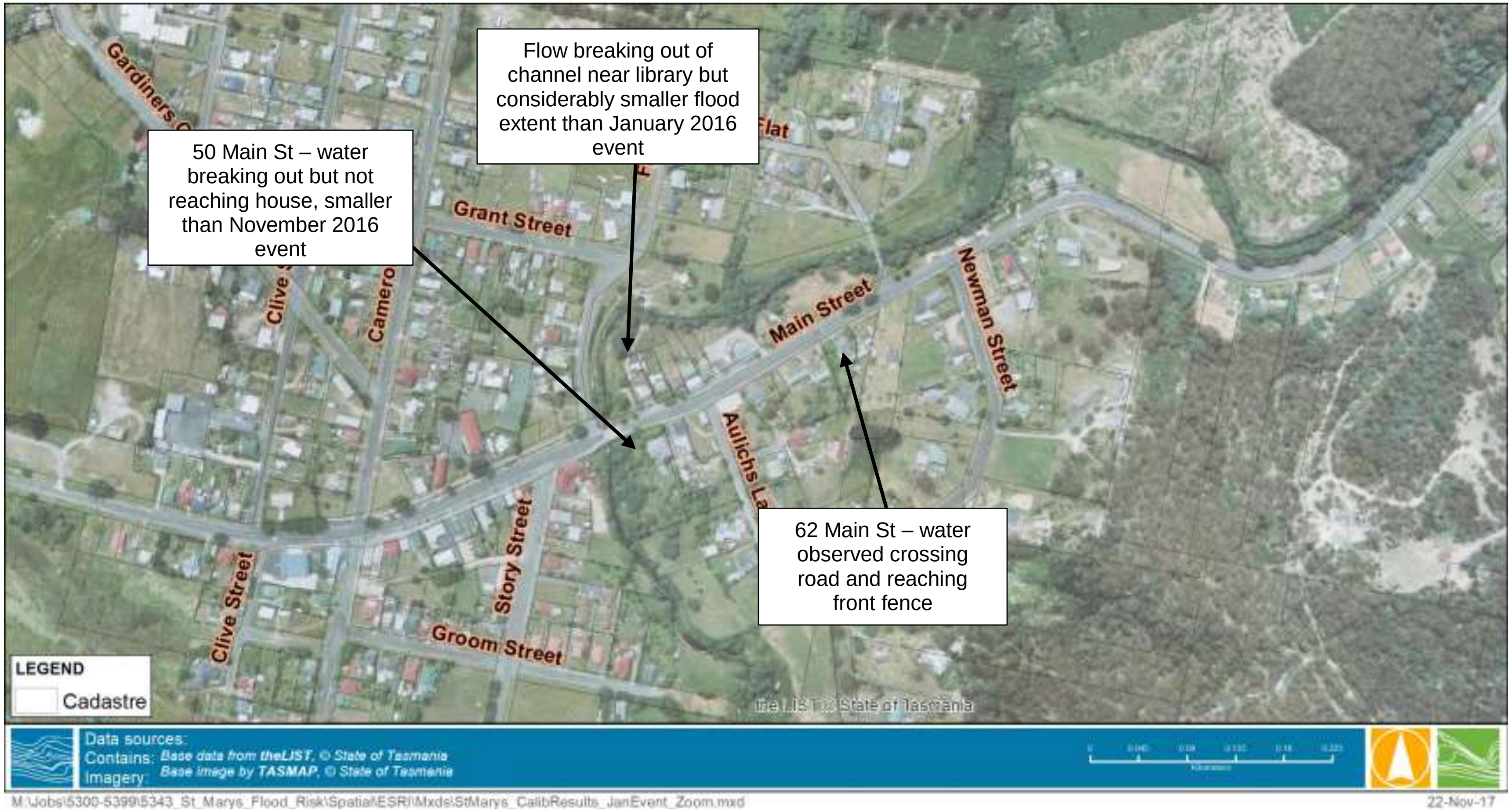

FIGURE 3-27 JUNE 2016 EVENT – KEY OBSERVED FLOOD BEHAVIOUR

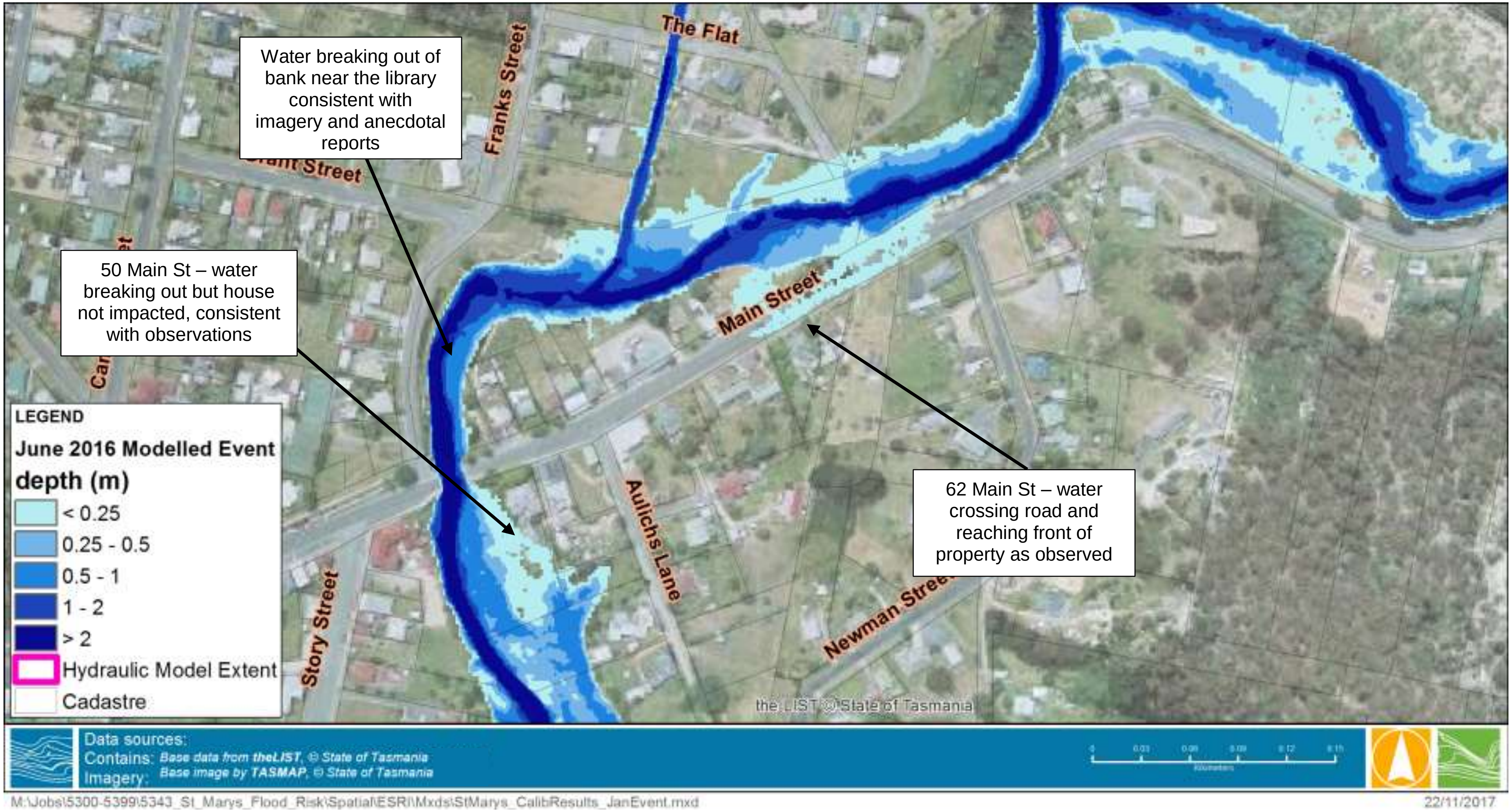

FIGURE 3-28 MODELLED JUNE 2016 EVENT – COMPARISON TO OBSERVED FLOODING

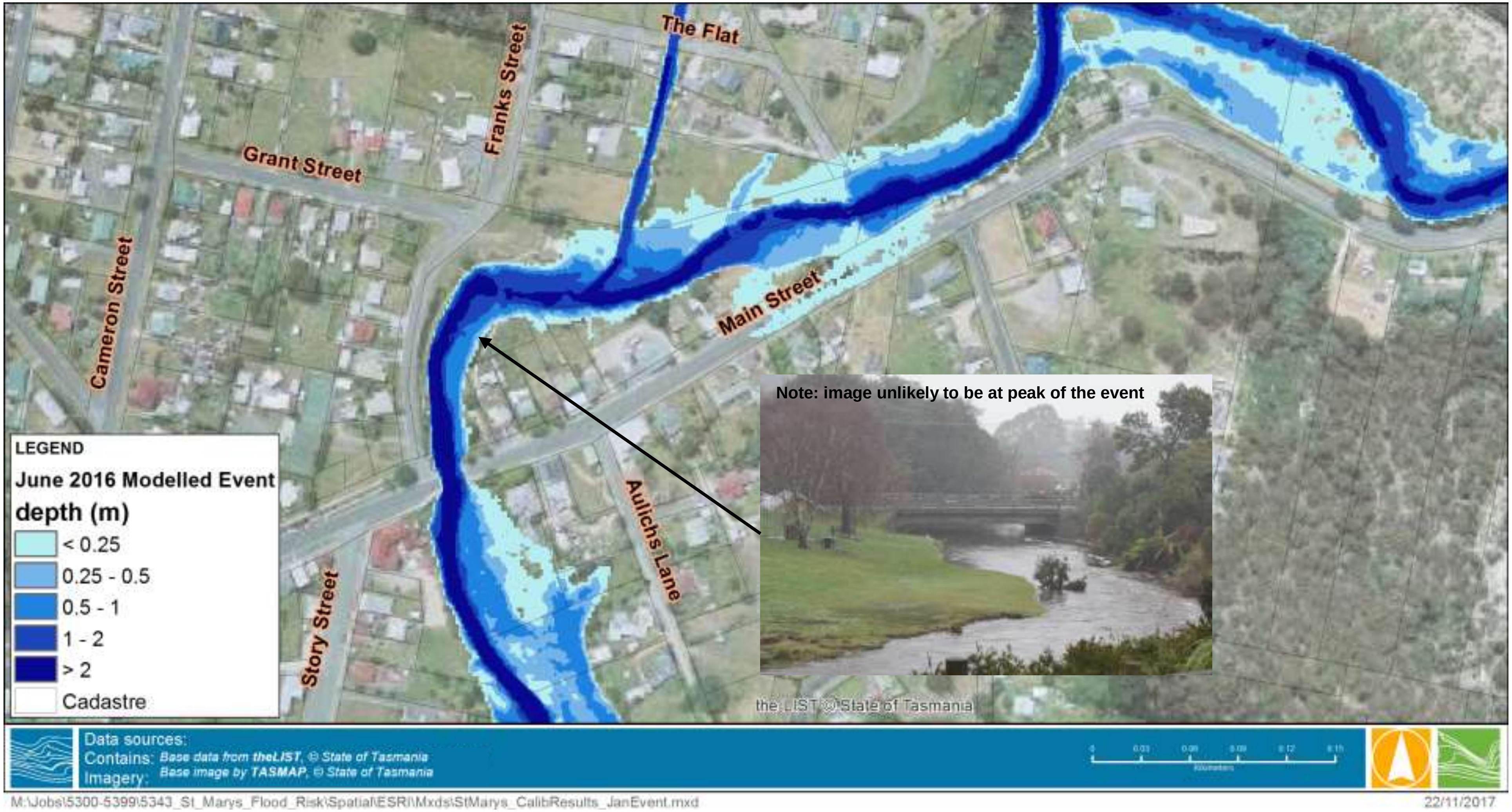

FIGURE 3-29 MODELLED JUNE 2016 EVENT – COMPARISON TO IMAGERY

3.3.6.4 November 2016

There was also less information for the November 2016 event than January 2016, available information mainly comprised anecdotal reports and a couple of flood photos collated during the community meeting and site visit. Key observed flood behaviour from anecdotal reports and imagery is summarised in Figure 3-30 below.

The modelling results for the November 2016 event are shown in Figure 3-31 and direct comparisons are made against the observed behaviour. Figure 3-32 compares the model results and available photos of the event. It can be seen that there is a strong correlation between the model results and the observed behaviour in terms of inundation extent, flood depths and key behaviour such as the shallow overtopping of Main Street in the vicinity of The Flat Bridge over St Marys Rivulet. The model results show the November 2016 flood extent is slightly larger than the June 2016 event which is consistent with anecdotal reports.

It should be noted that some of the input data, particularly relating to the temporal pattern of rainfall was of poor quality. Considerable testing was undertaken to improve the validation of the model with several iterations undertaken. Overall the validation of the November 2016 event is considered to be very good.

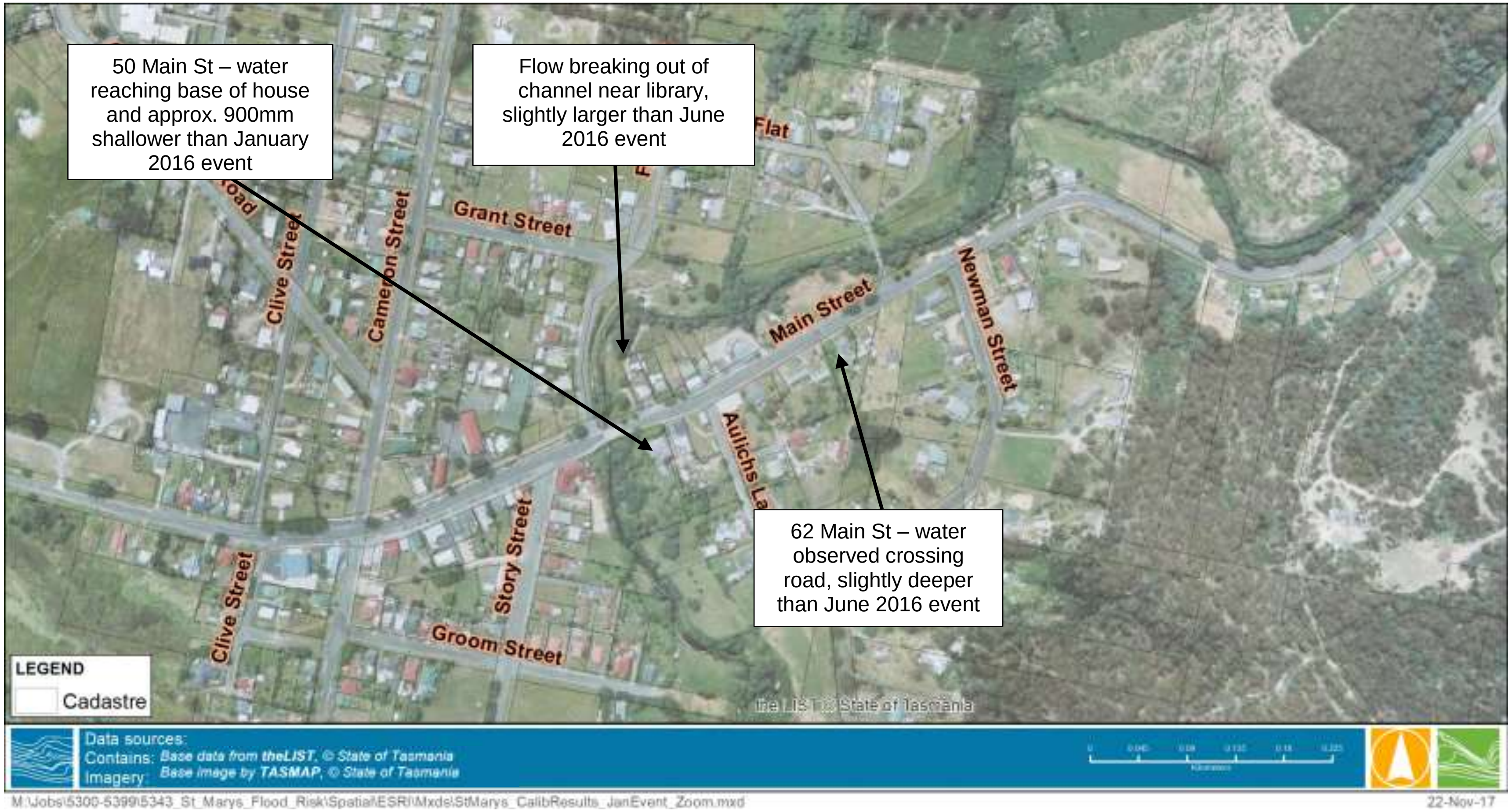

FIGURE 3-30 NOVEMBER 2016 EVENT – KEY OBSERVED FLOOD BEHAVIOUR

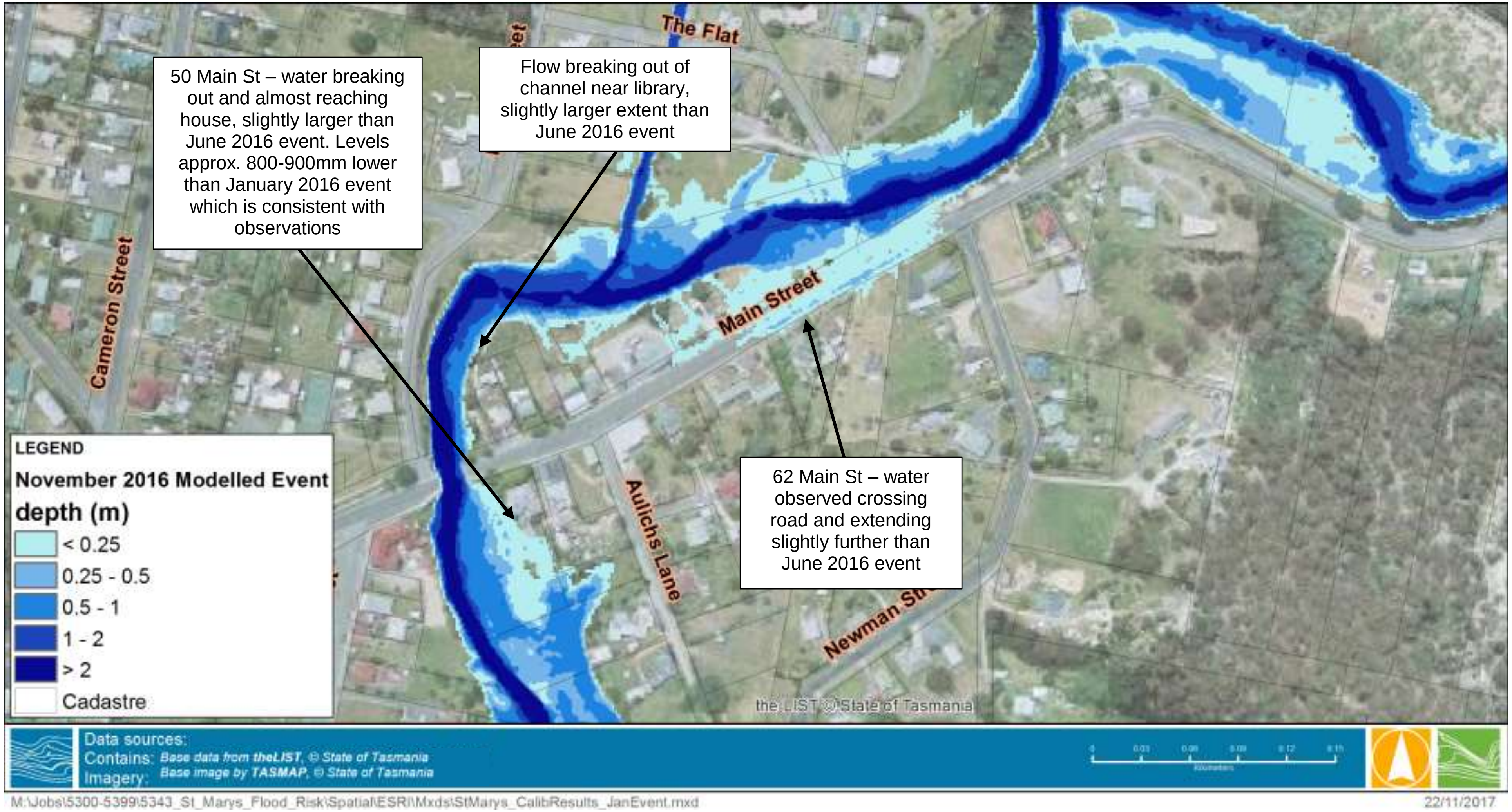

FIGURE 3-31 MODELLED NOVEMBER 2016 EVENT – COMPARISON TO OBSERVED FLOODING

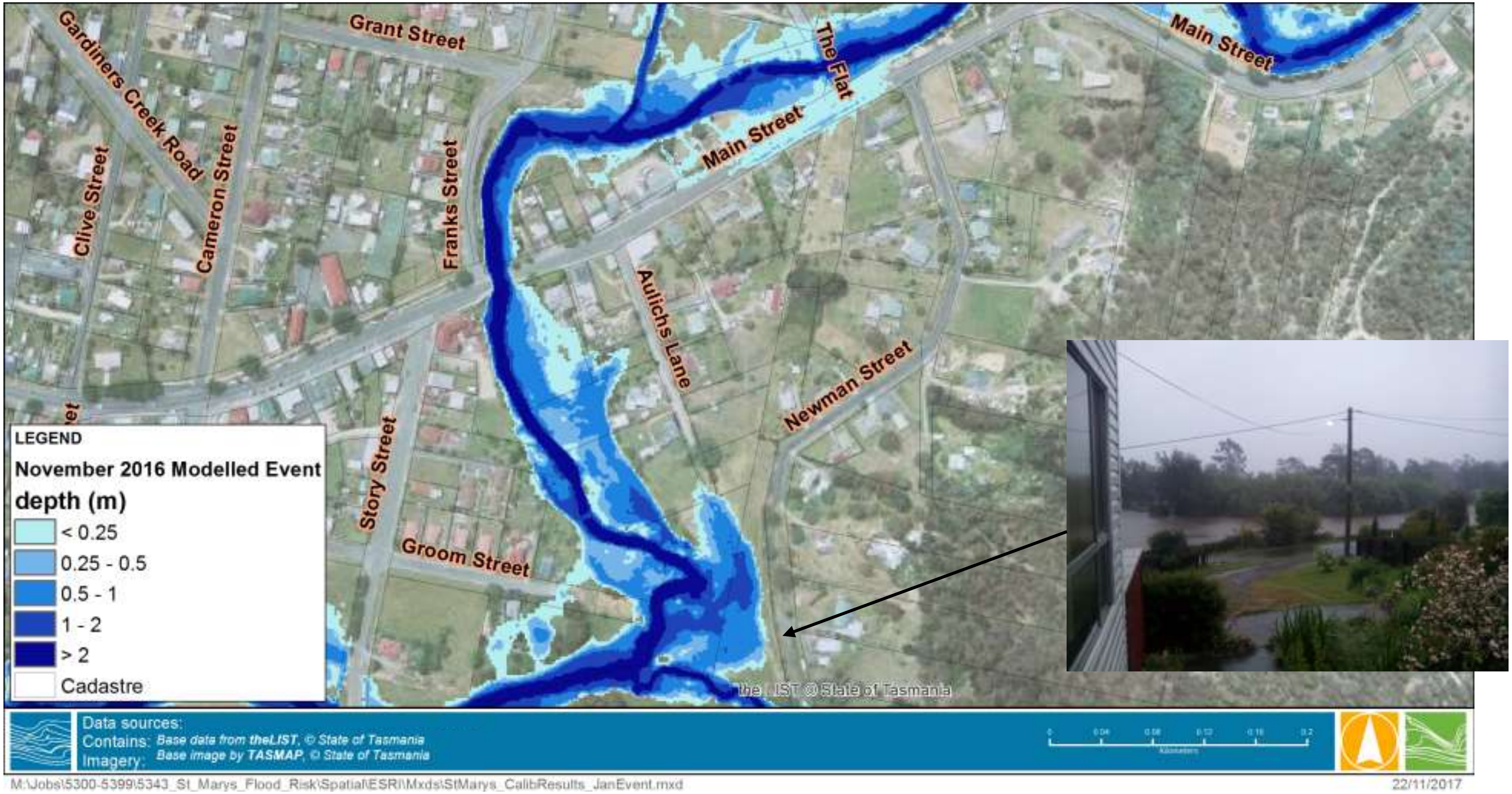

FIGURE 3-32 MODELLED NOVEMBER 2016 EVENT – COMPARISON TO FLOOD IMAGERY

3.4 Model Calibration Summary

The model calibration has demonstrated that the hydrologic and hydraulic models have produced accurate flood behaviour across a range of historic flood events. Based on this the models were deemed suitable for the purpose of modelling the full range of design events and assessing mitigation options.

The peak flow estimate for the three calibration events in the key watercourses flowing into St Marys are shown in Table 4-5 below.

TABLE 3-13 CALIBRATION MODELLING FLOW SUMMARY

Event	St Marys Rivulet (Main St Bridge)	St Marys Rivulet (Esk Highway Bridge)	Newmans Creek	St Patricks Creek
January 2016	237	185	63.0	101
June 2016	68.5	50.7	16.1	26.4
November 2016	83.2	63.4	19.6	31.5

4 DESIGN MODELLING

4.1 Design Hydrology

4.1.1 Overview

The design hydrology was based on a Monte Carlo approach and consistent with methods described in Australian Rainfall and Runoff 2016. The Monte Carlo analysis was used to determine the design peak flows on the St Marys Rivulet at St Marys. The RORB model was then run using an ensemble approach, with objective of determining which ensemble temporal pattern produced peak flows most closely matching the results of the Monte Carlo simulation for each AEP. The flow chart outlined in Figure 4-1 demonstrates the modelling process.

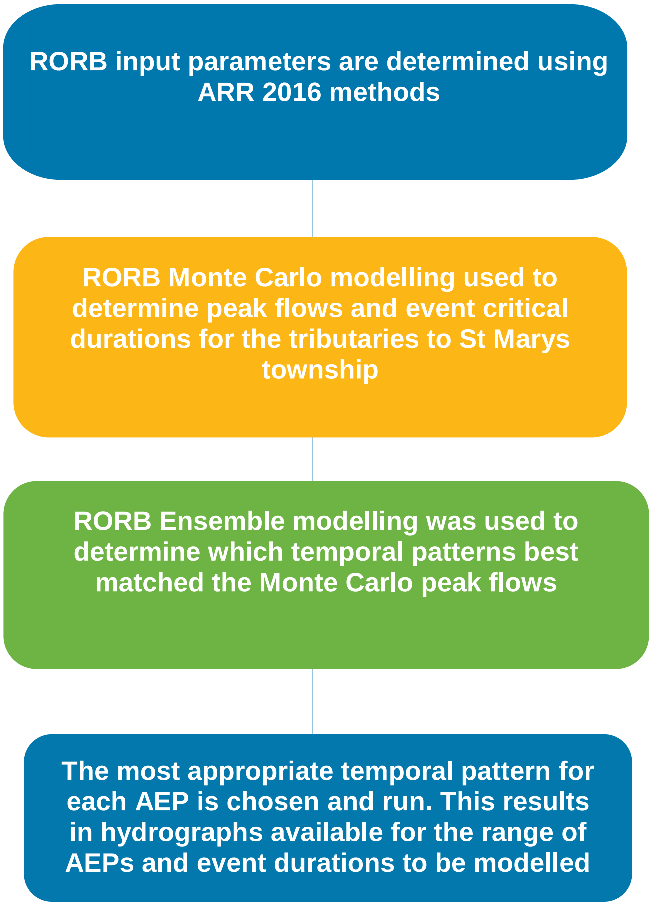

FIGURE 4-1 DESIGN MODELLING PROCESS DIAGRAM

4.1.2 Rainfall Depths

Rainfall depths for St Marys catchment were determined with the use of the Australian Rainfall and Runoff (2016) recommendations. Areal reduction factors and temporal patterns were sourced from the ARR data hub[5], while the intensity frequency duration (IFD) rainfall depths were sourced from the Bureau of Meteorology (BoM) online IFD tool[6]. Both data sets were based on the coordinates of the catchment centroid.

Rainfall depths for rare events (less than 0.5% AEP) are only supplied for storm durations greater than 24 hours. Therefore, the required points were extrapolated for durations from 15min to 12 hours based on the average percentage increase across the events from 24 to 168 hours. For example, the average percentage depth increase from the 1% AEP to the 0.5% AEP was 15%. This 15% increase was applied to durations from 15mins to 12 hours for the 0.5% AEP. This method was continued through all AEPs.

4.1.3 Rainfall Losses

An initial loss and continuing loss model was used in RORB, similar to that adopted during the calibration modelling. Catchment losses vary considerably depending on catchment antecedent conditions. Losses for the catchment were determined using methods described in ARR 2016, Book 5, Chapter 3, this included estimates recorded via the ARR2016 Data Hub, regional estimates and equations based estimates.

The ARR Data Hub determined initial loss and continuing loss parameters to be 44.0 mm and 0.7 mm/hr respectively. The study area is located within Region 3 of the loss prediction equations, shown in Figure 4-2.

[5] http://data.arr-software.org/
[6] http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016

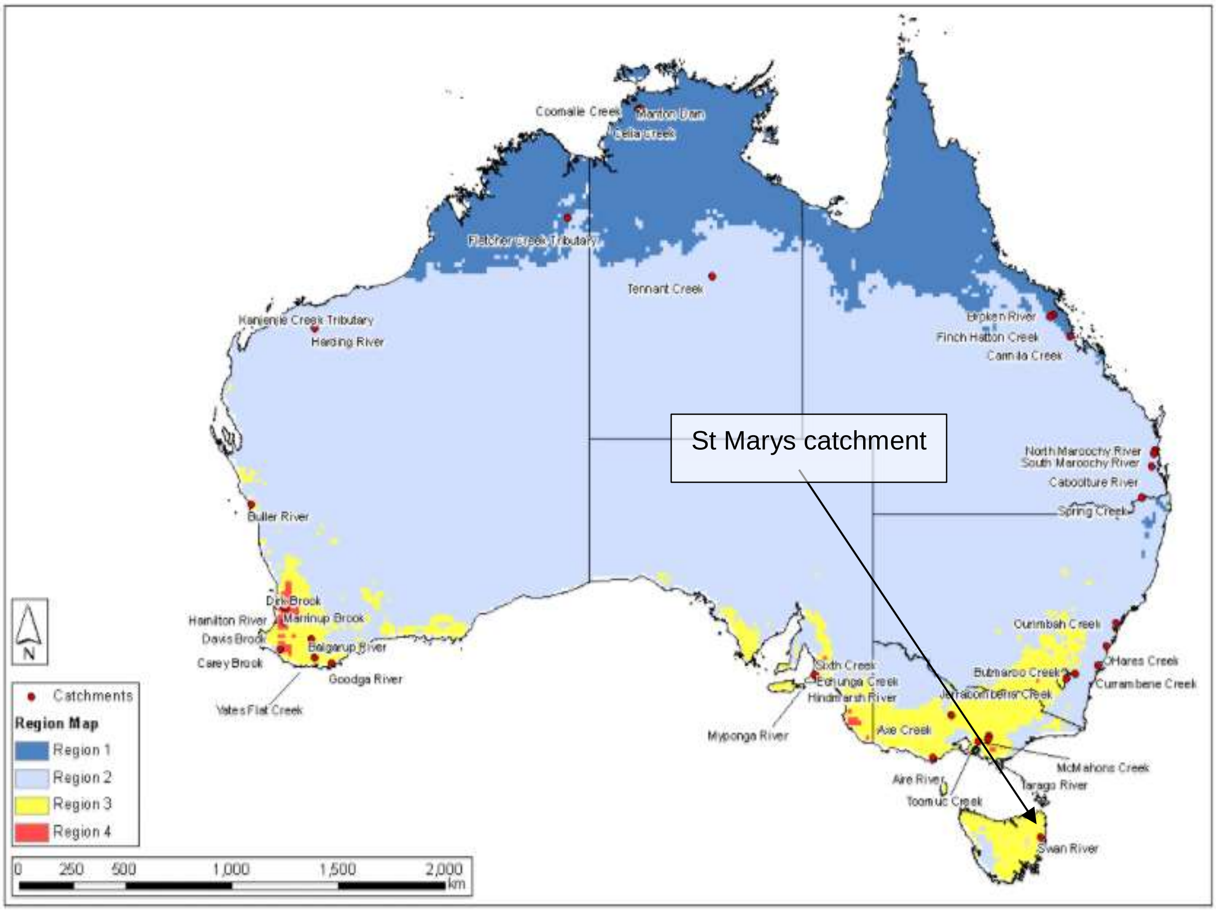

FIGURE 4-2 REGIONS ADOPTED FOR LOSS PREDICTION EQUATIONS

EQUATION 2-2 MEDIAN INPUT CALCULATIONS:

IL_s (Storm Initial Loss) and CL (Continuing Loss) equations are outlined below.

$$IL_s = -1.57 * s0_{wrt} + 0.14 * DES_{RAIN_{24HR}} + 18.8$$

$$CL = 0.03 * DES_{RAIN_{24HR}} + 0.06 * SOmax + 5.1$$

Where:

IL_s is the storm Initial Loss (mm)

CL is the Continuing Loss (mm/h)

s0_wtr is the soil moisture in the surface store in winter season (mm)

DES_RAIN_24HR is the design Rain Intensity (I24,50) (mm)

SO_{max} is the maximum storage of the surface soil layer (mm)

Based on median input values these equations determined an IL_s value of 27.5 mm and a CL of 3.1 mm/hr

ARR2016, Book 5, Chapter 3, Figure 5.3.18 and Figure 5.3.19 also outline median IL_s and CL values of 40-50 mm and 2-4 mm/hr respectively for the catchment, as shown in Figure 4-3 and Figure 4-4.

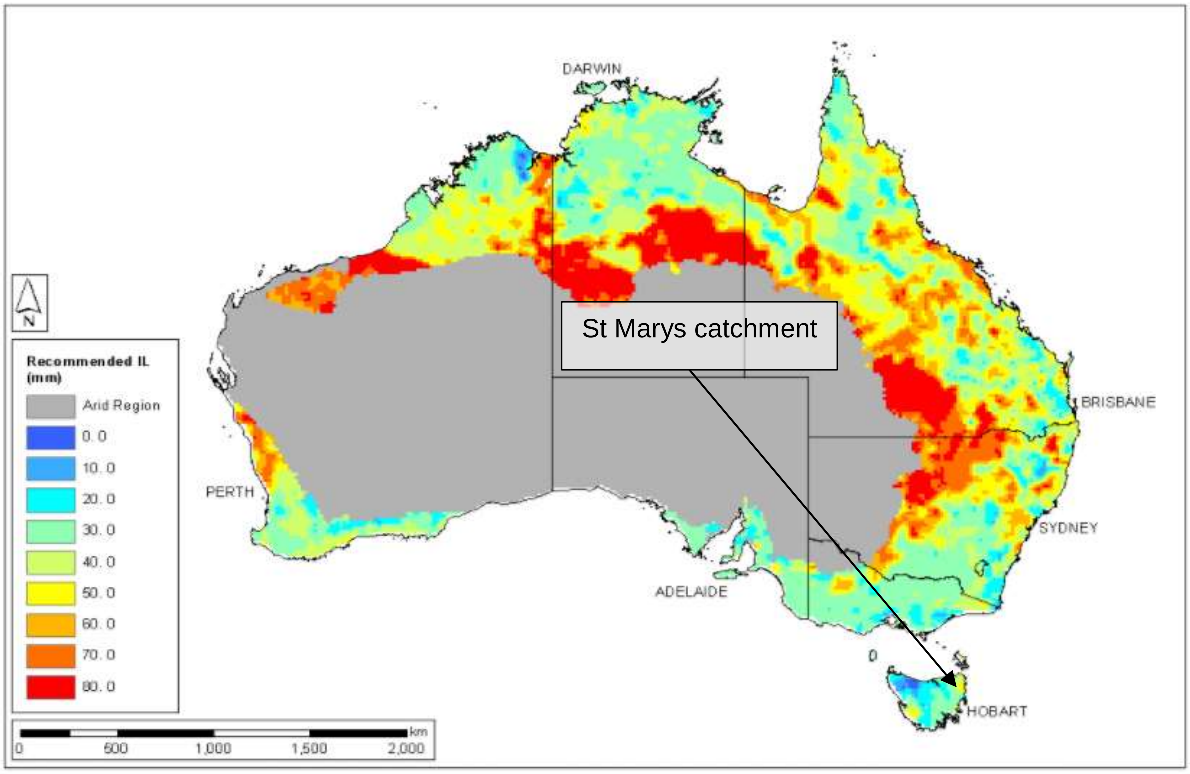

FIGURE 4-3 ARR RECOMMENDED MEDIAN IL$_S$ VALUES

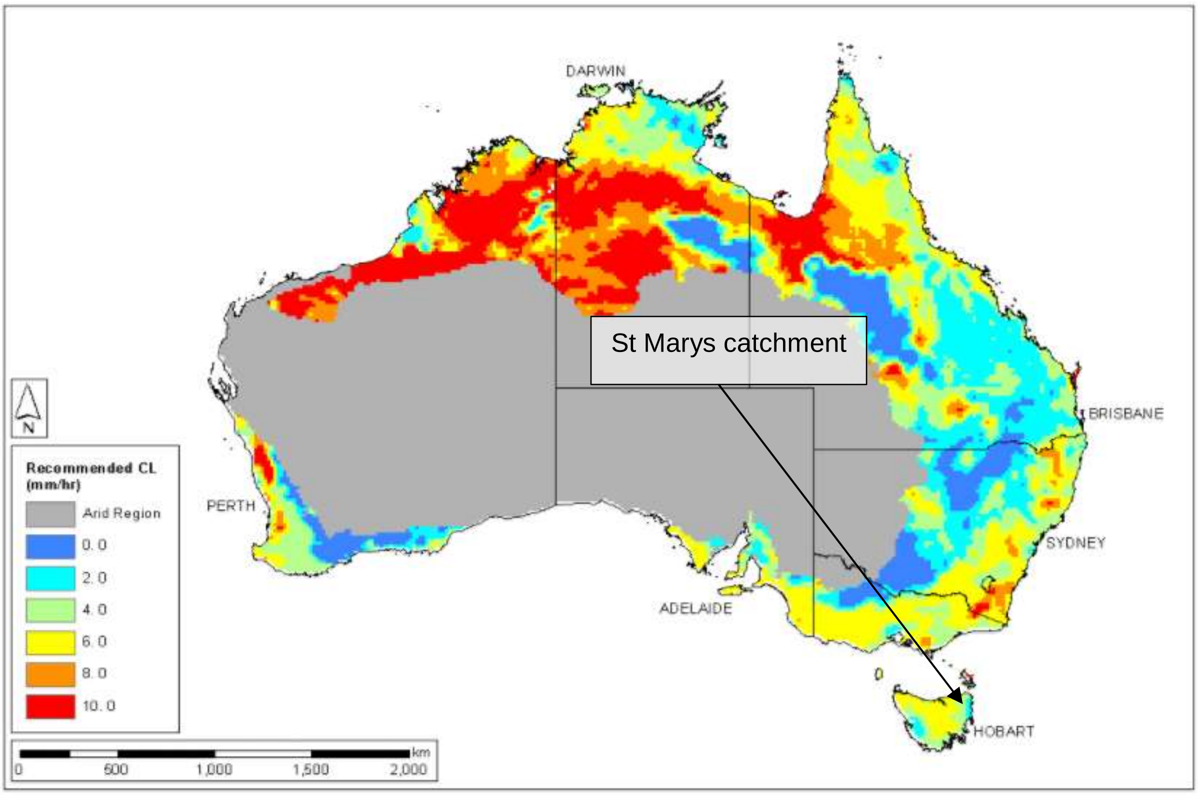

FIGURE 4-4 ARR RECOMMENDED MEDIAN CL VALUES

5343-01_R02v04a_StMarys_InterimFloodReport.docx

The loss values above are for a complete storm. If they are to be used with the IFD burst rainfall from the BoM, either pre-burst rainfall needs to be added to the rainfall burst, or the losses can be reduced to be suitable to use with burst rainfall not a complete storm. The ARR data hub gives median pre-burst rainfall depths of between 0.4 – 2.2 mm for events from 50% AEP to 1% AEP for 48 hour duration, giving some indication of how much ILs may be reduced by if using burst rainfall.

The CL values must also be factored up to account for models running at a timestep of less than an hour, the factor applied to this model is around 1.2 to 1.3.

TABLE 4-1 STORM LOSSES COMPARISON TABLE

Loss Type	ARR Data Hub	ARR Regional Equation	Median from ARR Map
Initial Loss	44 mm	27.5 mm	40 - 50 mm
Continuing Loss	0.7 mm/hr	3.1 mm/hr	2 - 4 mm/hr

The initial losses and continuing losses represented in Table 4-1 give a relatively close match between values. The differential between losses can be attributed to the regionalisation of the various approaches.

By adopting the losses from the ARR Region 3 equation and factoring the continuing loss up to account for the smaller timestep, and reducing the initial loss to convert the complete storm loss to a burst loss, the adopted losses were determined and are shown in Table 4-2.

TABLE 4-2 ADOPTED LOSSES

Loss Type	Loss
Initial Loss	44 mm
Continuing Loss	0.7 mm/hr

4.1.4 RORB Parameters - kc and m

As discussed in Section 3.2.2, a kc of 4.50 was adopted across the three calibration events for the catchment. These values were determined as appropriate and adopted for the design modelling.

The adopted kc values also match closely with the empirical estimation equation based estimates outlined in Table 3-2

4.1.5 Design Temporal Patterns

The varying time critical peaks can, in some catchments, represent vastly differing temporal patterns determined by ARR2016. There are 30 pre-determined temporal patterns for the St Marys catchment area of 75 km^2.These consist of three event characteristics; frequent (temporal patterns 1 – 10), intermediate (temporal patterns 11 – 20) and rare (temporal patterns 21-30). To demonstrate the variation across the temporal patterns eight of them are plotted in Figure 4-5.

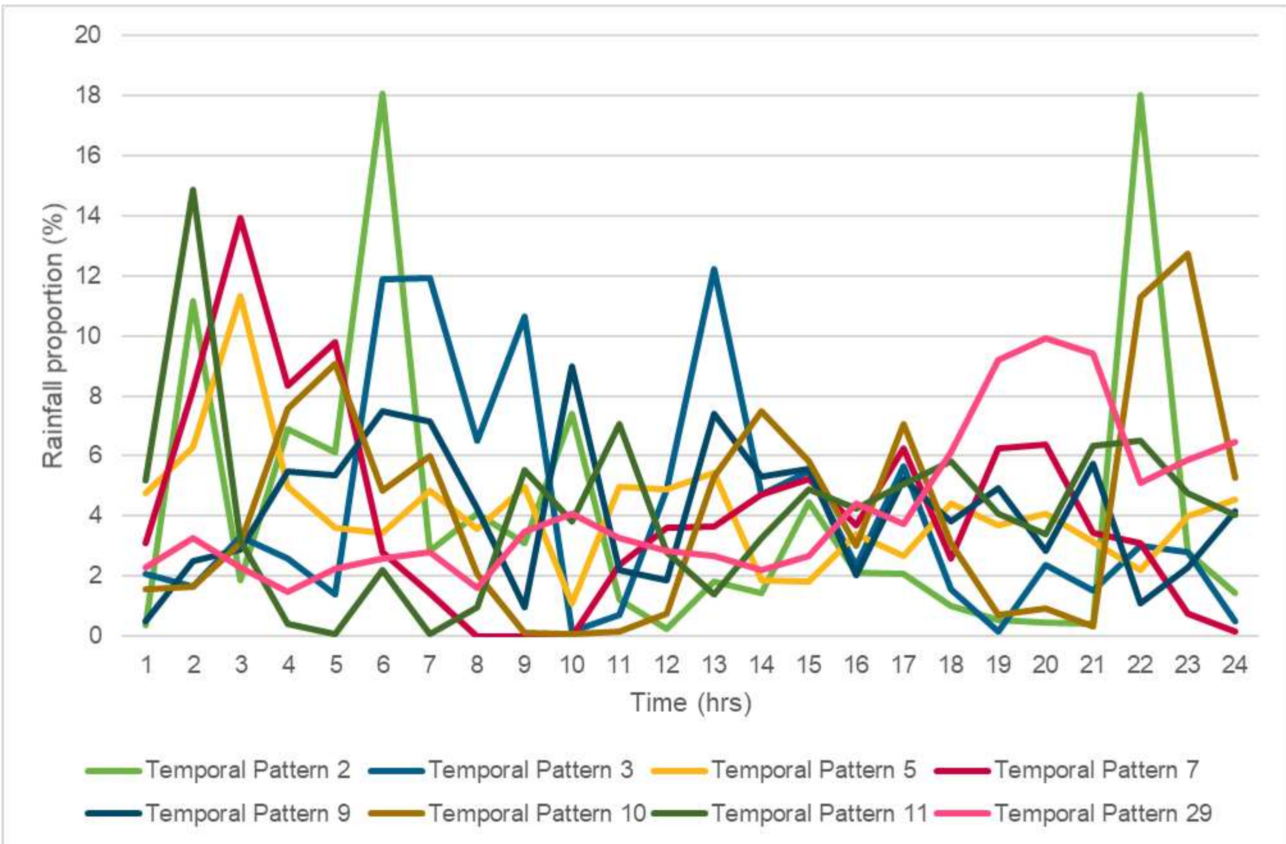

FIGURE 4-5 POINT TEMPORAL PATTERNS (FREQUENT TO RARE EVENT MODELLING)

4.2 Design Event Modelling

4.2.1 Monte Carlo Analysis

The RORB Monte Carlo analysis was undertaken adopting an initial loss of 44 mm with a probability distribution from ARR2016, a continuing loss of 0.70 mm/hr, and a kc value of 4.50 at the St Marys interstation area. During the Monte Carlo analysis, the RORB model was run 10,000 times, sampling for an extensive range of temporal patterns and rainfall initial losses. This is completed in a combination with the other set model parameters of rainfall intensities, spatial pattern, continuing loss, aerial reduction factors, kc and m. The software then fits a probability distribution to the result of the 10,000 runs and determines a statistical design peak flow at each RORB output location.

Similar to the calibration event modelling there are 6 output locations throughout the catchment RORB model. These locations were chosen for the tributaries and the model extent projections for the St Marys township. The analysis determined critical durations of 24 hours at St Marys for the 50%, 20%, 5%, 2%, and 1% AEP events and 48 hours for the 0.5% AEP flood event.

The determined peak flows at St Marys for each AEP are outline in Table 4-3.

TABLE 4-3 MONTE CARLO DETERMINED PEAK FLOWS AT ST MARYS (MAIN RD BRIDGE)

AEP (%)	Monte Carlo Determined Peak Flow (m^3/s)
20	49.9
10	65.8
5	81.1
2	101.8
1	112.2
0.5	125.5

4.2.2 Ensemble Analysis

The RORB model was run using an Ensemble Analysis, using the determined kc value of 4.50 and the initial loss of 44 mm and continuing loss of 0.70 mm/hr. The RORB Ensemble Analysis was run for all 30 ARR2016 recommended temporal patterns for each event duration. The peak flows determined in the Monte Carlo analysis were used to find a temporal pattern from the Ensemble Analysis producing a hydrograph with a similar peak flow.

The temporal patterns that determined peak flows that most closely matched the Monte Carlo results for each AEP are shown in Table 4-4.

TABLE 4-4 ADOPTED TEMPORAL PATTERN NUMBERS WHICH MOST CLOSELY MATCHED THE MONTE CARLO ANALYSIS PEAK FLOW (ARR 2016)

AEP (%)	Temporal Pattern (No.)
50	1
20	3
10	19

AEP (%)	Temporal Pattern (No.)
5	19
2	22
1	22
0.5	22

The Ensemble Analysis model results showed several temporal patterns in combination with design event and duration provided the best match to the Monte Carlo Analysis peak flows. To reduce the potential number of hydraulic runs, a single temporal pattern for each AEP was chosen. Temporal pattern 22 was shown to produce peak flows most like those produced in the Monte Carlo Analysis at the proposed hydrologic controlled interstation downstream of St Marys township along St Marys Rivulet for the 2%, 1% and 0.5% AEP events. It was therefore chosen as the temporal pattern to be used to produce inflow hydrographs to the hydraulic model across those events with another three separate temporal patterns (1,3 and 19) chosen for the remaining events as shown in Figure 4-6 demonstrates each temporal pattern over time against total rainfall proportion.

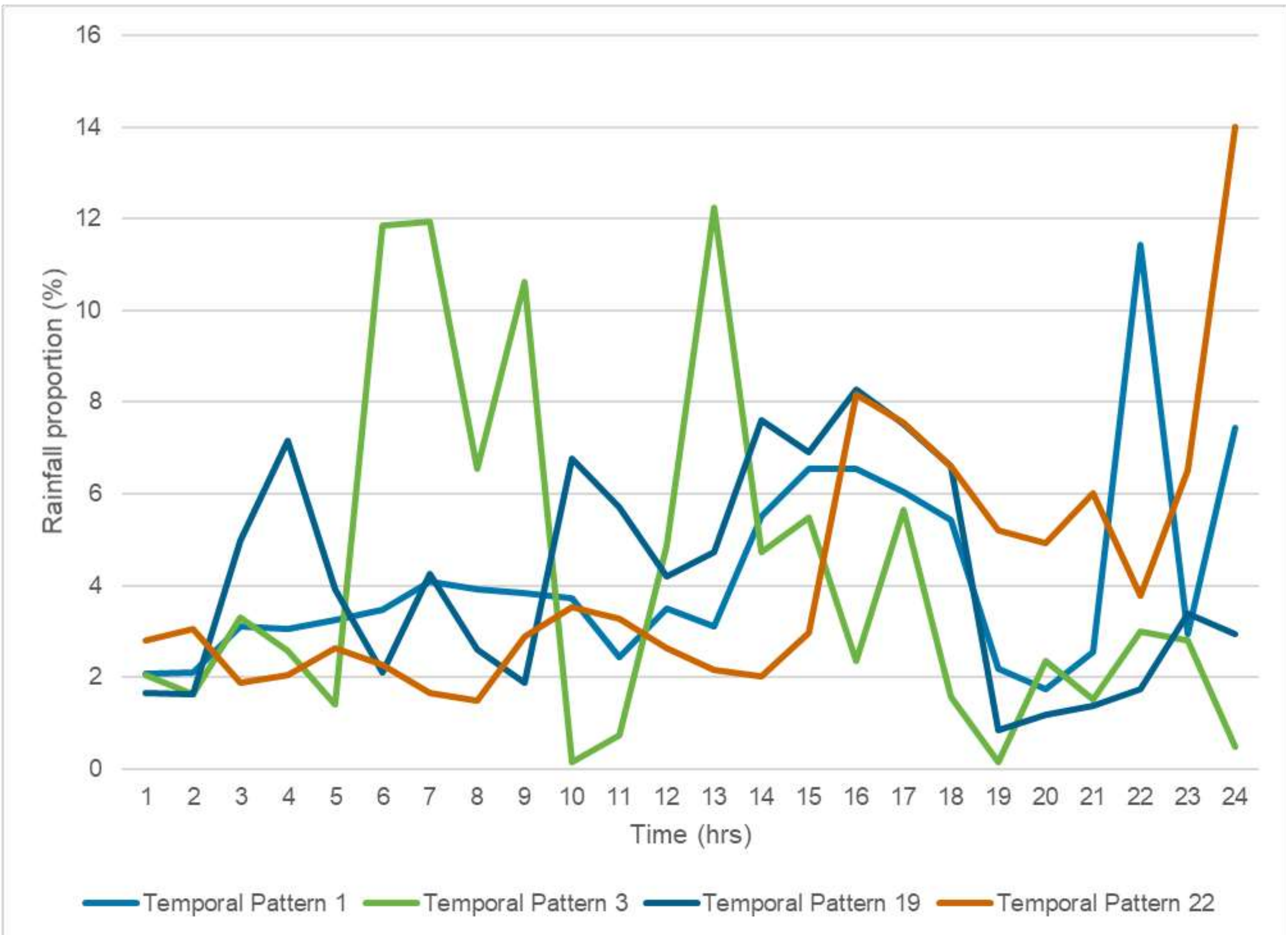

FIGURE 4-6 24HR AND 48HR DURATION - TEMPORAL PATTERNS USED FOR DESIGN MODELLING

4.2.3 RORB Modelling Outputs

The RORB model was used to generate inflows along St Marys Rivulet, Newmans Creek and St Patricks Creek for input to the hydraulic model. Further discussion around the inflow points is included in Section 4.3. The hydraulic model was run for two event durations (24 hour and 48 hour) across the seven AEPs and Climate change modelling, 31 total simulations. The RORB model outflows for the range of design events are shown in Figure 4-7.

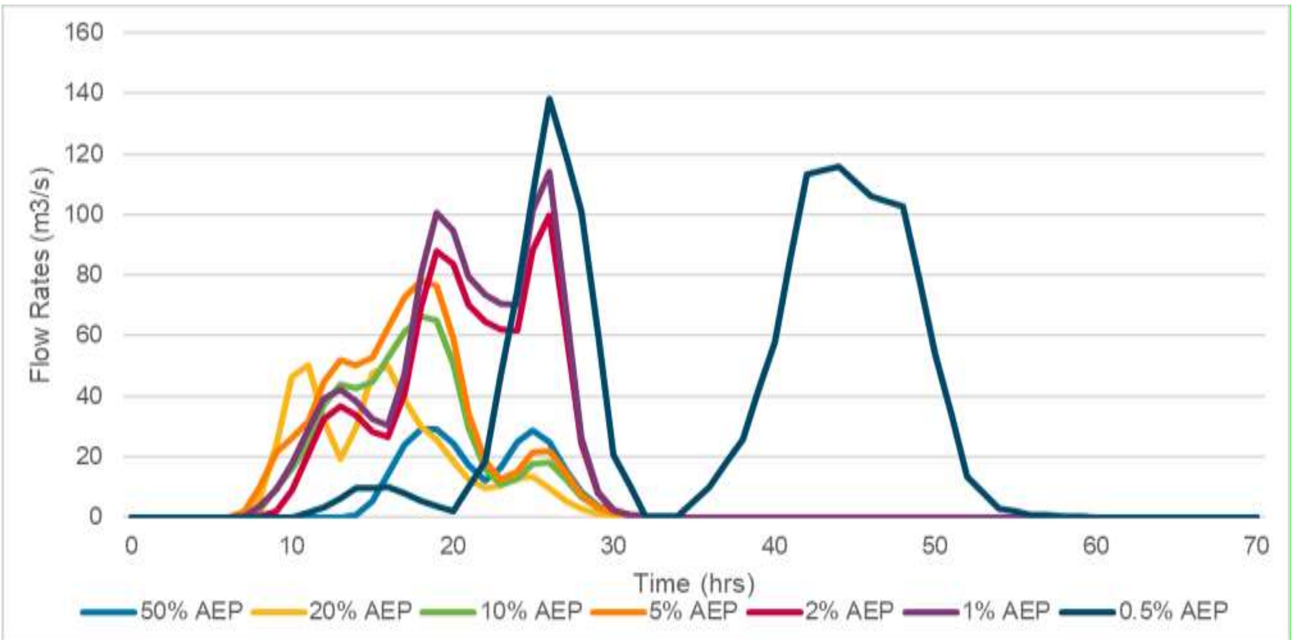

FIGURE 4-7 DESIGN HYDROGRAPHS FOR 24 AND 48 HOUR DURATION EVENTS AT ST MARYS

4.2.4 Probable Maximum Precipitation (PMP)

The Probable Maximum Precipitation is dependent on the location of the catchment and critical timing of the design event modelling undertaken in RORB. The Generalised Southeast Australia Method (GSAM) is designed to estimate the PMP for long durations (12 – 96 hours) which is representative of the 24 – 48 hour design event durations observed in the design event modelling. The resultant precipitation was estimated for Summer and Autumn periods and converted to flow through RORB modelling. The Maximum Seasonal Depth Rainfall Estimate was 1100 mm over a 24 hour period and 1290 mm over a 48 hour period.

The Probable Maximal Precipitation (PMP) was modelled in RORB to determine the Probable Maximal Flood (PMF) flow at St Marys. This was found to be 329.0 m^3/s and 266.9 m^3/s, for the 24 and 48 hour duration events respectively. The full PMP calculations are provided in 0.

4.2.5 Design Flow Summary

The design flow peaks that were applied to the hydraulic modelling are shown in Table 4-5 below.

TABLE 4-5 DESIGN FLOW SUMMARY

AEP Events	St Marys Rivulet (Main Rd Bridge)	St Marys Rivulet (Esk Highway)	Newmans Creek	St Patricks Creek
20%	50.5	36.6	12.8	20.3
10%	66.4	47.5	14.9	25.4
5%	78.4	55.9	17.5	29.9
2%	100	71.8	23.1	39.3
1%	114	81.1	26.4	44.7
0.5%	138	100	32.2	52.8
PMF	329	233	72.8	126

4.2.6 Design Flow Verification

As a method of verifying the adopted design flows, the flow estimates were compared against a range of other regional estimates including the ARR Regional Flood Frequency Estimation Model[7], the VicRoads Modified Rational Method and the Rational Method (Adams). The rational method is not recommended in ARR2016 as a flow estimate technique, however it is still useful for comparison purposes. It is of note that ARR1987 did not recommended a regional method for eastern Tasmania and so the Victorian-based rational and VicRoads rational methods were utilised instead for comparison purposes. The model produced the peak flow estimates shown in Table 4-6.

The C_{10} values for the Rational Method (Adams) and VicRoads Rational Method are more pertinent to catchments throughout Victoria. However, the closest representation of the climate in St Marys has been determined and averaged from the Aireys Inlet to Lorne region of Victoria which experiences high rainfall, with an average $C_{10} = 22.5$.

The peak flow comparison is shown in Table 4-6. The adopted design flows either fall within or are close to the range of regional estimates.

TABLE 4-6 DESIGN EVENT MODELLING PEAK FLOW COMPARISON

AEP (%)	Rational Method (Adams) Discharge (m^3/s)	Hydrological Recipes – Rural Catchment (m^3/s)	VicRoads Rational Method (m^3/s)	RFFE (m^3/s)	RORB Adopted Discharge (m^3/s)
20			56.87	48.4	**50.5**
10			70.83	66.7	**66.4**
5			89.52	86.7	**78.4**
2			115	117	**100**
1	100	99.2	139	143	**114**

[7] http://rffe.arr-software.org/ - Accessed 20/09/2017

4.3 Design Hydraulic Modelling

4.3.1 Hydraulic Model Application

The TUFLOW model was run with flows extracted from the RORB model for each of the required design events under existing conditions. The following design events were modelled – 20%, 10%, 5%, 2%, 1% and 0.5% AEP events and the Probable Maximum Flood.

As a stage-discharge relationship was used as the downstream boundary condition, it was not necessary to vary the boundary condition for each AEP event simulated.

Inflow boundaries were varied for each AEP event by varying the flow boundaries to match the outputs from the RORB modelling.

All TUFLOW model runs were controlled through a TUFLOW Event File (.tef) and a series of batch files constructed for use in this project. The use of the .tef file and batch files ensures that the base .tcf (TUFLOW Control File) does not change between runs, with all event specific parameters specified in the .tef file. This reduces the potential for error and assists in reducing model run and processing times.

4.3.2 TUFLOW model outputs and mapping

TUFLOW provides times-series of depths (m), water surface elevations (m AHD), flow velocities (m/s) and flood hazard (m^2/s) at each link location within any 1D element, and at all grid points within the 2D domain. These results were used to create flood maps and further analyse areas of concern regarding flooding within catchment areas.

The full range of design flood maps are provided in Appendix B while the range of design hazard maps are provided in Appendix C. Flood function maps are provided in Appendix D and are discussed further in Section 5.2.

5 FLOOD INTELLIGENCE

5.1 Flooding Consequences

Flood mapping was produced to identify the consequences of flooding for the various design flood events. Combined with the flash flood forecasting procedure described in Section 4.1, the flood consequence table allows emergency services and Council to quickly understand the likely impacts of flooding and plan and respond appropriately. Table 5-1 describes the key flooding consequences across the study area for each design event. This outlines property inundation and access/egress for properties within the floodplain.

The table was developed to be read from top to bottom, with each subsequent larger magnitude event reporting on the incremental changes in consequences. For example, if the reader wants to understand the consequences of a 2% AEP event, then the flood characteristics should be read for the 20%, 10%, 5% and 2% AEP events in succession. It is also recommended that the reader refer to the standard PDF maps provided with this study. There is a separate map for each modelled design event and they provide peak flood depths, extents and water surface elevations for each flood event.

The full range of design flood maps are provided in Appendix B, the range of design hazard maps are provided in Appendix C while the range of design flood function maps are provided in Appendix D. The flood function mapping is described further in Section 5.2.

The consequence in the tables below have been described in terms of depth of inundation, using the following key depth thresholds:

- Depths of 0.5 to 1 m, generally unsafe for vehicles, children and elderly
- Depths of 0.3 to 0.5 m, unsafe for small vehicles
- Depths below 0.3 m, generally safe for vehicles, people and buildings

The reasoning behind these specific depths relates to Australian Rainfall and Runoff Book 6 Chapter 7: Safety Design Criteria, as shown in Figure 5-1 below.

The criteria for the hazard mapping provided in Appendix C is also based on the flood hazard curves shown in Figure 5-1.

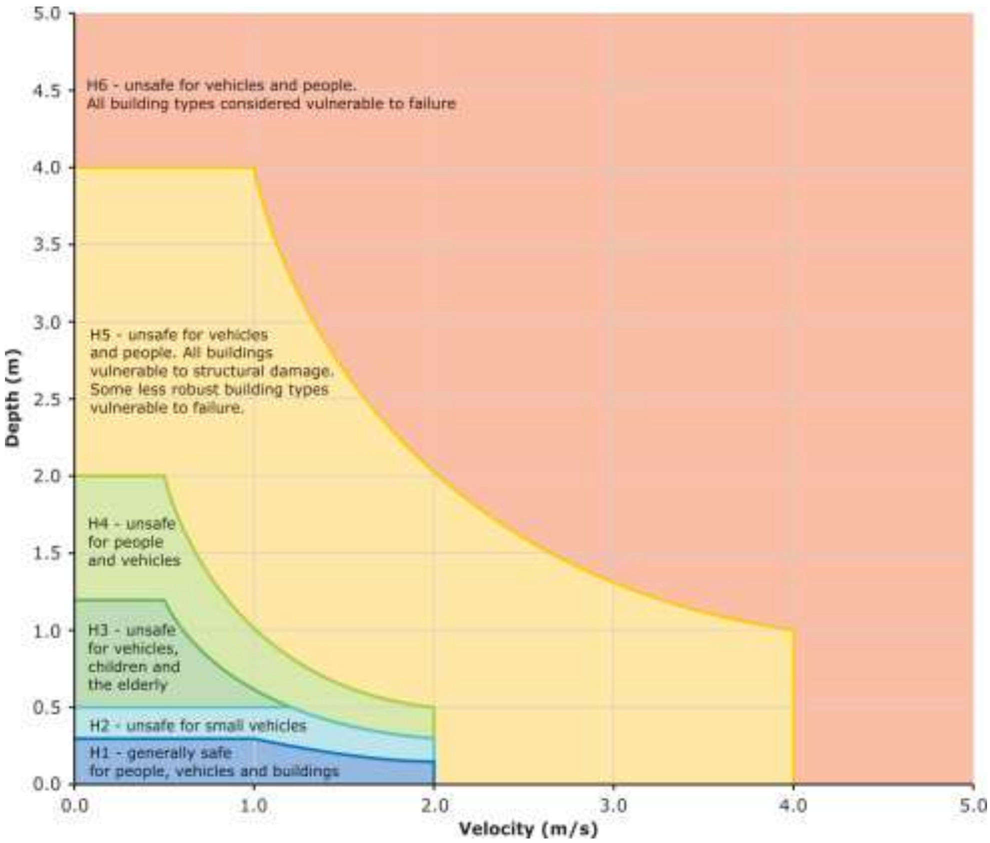

FIGURE 5-1 FLOOD HAZARD CURVES (SMITH ET AL, 2014)

TABLE 5-1 SUMMARY OF FLOODING CONSEQUENCES - ST MARYS

Flooding Event	Flood Consequences / Impacts	Key roadways inundated – Access and Egress	Possible/Suggested Response
20% AEP (5-year ARI) **Peak Flow: 51 m^3/s**	■ Flooding largely remaining within banks of inflow tributaries ■ Minor breakouts along St Marys Rivulet, located upstream of The Flat and downstream of Main Street and Story Street ■ Minor flooding for properties along Main Street, Aulichs Lane, and Groom Street ■ Minor ponding at the end of Groom Street ■ Minor flooding in paddocks and rural residential properties, particularly downstream of Story St.	■ No roadways inundated	■ Monitor rainfall and water levels ■ Preparation of implementation of evacuation plan ■ Issue minor flooding alert pertaining to driving through flood waters and property inundation ■ Prepare deployment of signage for remaining roads traversing St Marys Rivulet, Newmans Creek and Margisons Creek and consider closing roads depending on rainfall and water levels

Flooding Event	Flood Consequences / Impacts	Key roadways inundated – Access and Egress	Possible/Suggested Response

10% AEP (10-year ARI)
 	
Peak Flow: 66 m^3/s
	■ Impacts as described in 20% AEP event and:
	■ Floodwaters backup behind Esk Main Road
	■ Breakouts occurring onto the lower areas of several properties along Main Street but houses not impacted
	■ Floodwaters overtop The Flat Bridge on St Marys Rivulet. Some shallow inundation of Main Street near The Flat intersection.
	■ Large breakouts across paddocks downstream of St Marys township
	■ Further inundation of properties along Aulichs Lane
	■ Limited access to property at PO Box 20, St Marys
		■ 0.3 to 0.5 metres inundation depth
		  ■ The Flat (near St Marys Rivulet bridge)
		■ Below 0.3 metres inundation depth
		  ■ Main Street (near intersection with The Flat)
			■ Monitor rainfall and water levels
			■ Preparation of implementation of evacuation plan
			■ Issue minor flooding alert pertaining to driving through flood waters and property inundation
			■ Place “Road Closed” sign for The Flat
			■ Place “Water over road” signs for Main Street
			■ Prepare deployment of signage for remaining roads traversing St Marys Rivulet, Newmans Creek and Margisons Creek and consider closing roads depending on rainfall and water levels

Flooding Event	Flood Consequences / Impacts	Key roadways inundated – Access and Egress	Possible/Suggested Response

5% AEP
(20-year ARI)
 	
Peak Flow:
78 m^3/s
	▪ Impacts as described in 10% AEP event and:
	▪ Floodwater breakout along St Patricks Creek flowing parallel with St Marys Rivulet traversing Grey Road and Harefield Road
	▪ Large breakouts downstream of Story Road through paddocks
	▪ Properties inundated along Groom Street and Franks Street to shallow depths
	▪ Further property inundation along Main Street, Aulichs Lane, and Groom Street
	▪ Further inundation across Main Street near The Flat intersection
	▪ Minor flooding breakouts along Newmans Creek
	▪ Access to rural properties along Harefield Road becomes inundated
		▪ 0.5 to 1 metre inundation depth
		  ▪ No roads inundated to this depth
		▪ 0.3 to 0.5 metres inundation depth
		  ▪ Main Street (near intersection with The Flat)
		▪ Below 0.3 metres depth
		  ▪ Groom Street
		  ▪ Grey Road
		  ▪ Harefield Road
			▪ Continue to monitor rainfall and water levels
			▪ Preparation of implementation of evacuation plan
			▪ Prepare evacuation of properties along Aulichs Lane and intersection with Main Street.
			▪ Prepare evacuation of properties located within Newmans Creek and St Marys Rivulet boundaries
			▪ Issue medium flooding alert pertaining to driving through flood waters, property inundation and housing inundation
			▪ Place “Water over road” signs for Groom Street, Grey Road and Harefield Road
			▪ Place “Road Closed” sign for Main Street
			▪ Prepare deployment of signage for remaining roads traversing St Marys Rivulet, Newmans Creek and Margisons Creek and consider closing roads depending on rainfall and water levels

Flooding Event	Flood Consequences / Impacts	Key roadways inundated – Access and Egress	Possible/Suggested Response

2% AEP
(50-year ARI)
 	
Peak Flow:
100 m^3/s
	▪ Impacts as described in 5% AEP event and:
	▪ Flood backwater at Esk Main Road traversing St Marys Rivulet
	▪ Breakouts along Newmans Creek inundating properties located in the Newmans Creek/St Marys Rivulet wedge. Generally shallow depth. Above floor flooding unlikely.
	▪ Properties and houses along Main Street subject to inundation (below floor level)
	▪ Deepening floodwater around end of Groom Street
		▪ 0.5 to 1 metre inundation depth
		  ▪ The Flat
		  ▪ Main Street (near intersection with The Flat)
		▪ 0.3 to 0.5 metres inundation depth
		  ▪ Grey Road
		  ▪ Harefield Road
		▪ Below 0.3 metres depth
		  ▪ Esk Highway (near Irish Town Road
			▪ Continue to monitor rainfall and water levels
			▪ Mobilise sandbagging operation
			▪ Action evacuation plan, removal of furniture etc from properties in Newmans Creek/St Marys Rivulet wedge
			▪ Prepare evacuation of Groom Street
			▪ Place “Water over road” signs for Story Street

Flooding Event	Flood Consequences / Impacts	Key roadways inundated – Access and Egress	Possible/Suggested Response

1% AEP (100-year ARI)
 	
Peak Flow: 114 m^3/s
	▪ Impacts as described in 2% AEP event and:
	▪ Increased depths of flooding throughout the town
	▪ Additional breakout through properties on Groom Street, shallow depths
		▪ 0.5 to 1 metre inundation depth
		  ▪ Esk Highway (near Irish Town Road)
		▪ 0.3 to 0.5 metres inundation depth
		  ▪ No further roads inundated
		▪ Below 0.3 metres depth
		  ▪ No further roads inundated
			▪ Continue to monitor rainfall and water levels
			▪ Mobilise sandbagging operation
			▪ Action evacuation plan, removal of furniture etc from properties in Newmans Creek/St Marys Rivulet wedge
			▪ Issue flooding alert pertaining to sandbagging and removal of furniture
			▪ Issue larger area flood alert for remaining property inundation and driving risks through floodwaters

Flooding Event	Flood Consequences / Impacts	Key roadways inundated – Access and Egress	Possible/Suggested Response

0.5% AEP
 	
Peak Flow:
138 m^3/s
	▪ Impacts as described in 1% AEP event and:
	▪ Houses along Main street, Groom Street and Aulichs Lane inundated to depths above 0.5 metres
	▪ Numerous, large breakouts along St Marys Rivulet
	▪ No access to hospital facilities for properties east of Main Road Bridge
	▪ Restricted access to the township from properties east of Main Road bridge and south of Storey Street bridge
		▪ 0.5 to 1 metre inundation depth
		  ▪ Grey Road
		  ▪ Harefield Road
		▪ 0.3 to 0.5 metres inundation depth
		  ▪ No further roads inundated
		▪ Below 0.3 metres depth
		  ▪ No further roads inundated
			▪ Continue to monitor rainfall and water levels
			▪ Mobilise sandbagging operation
			▪ Action evacuation plan, removal of furniture etc from properties along Main street, Groom Street, Aulichs Lane and Storey Road
			▪ Issue flooding alert pertaining to sandbagging and removal of furniture
			▪ Issue extensive area flood alert for remaining property inundation and driving risks through floodwaters

Flooding Event	Flood Consequences / Impacts	Key roadways inundated – Access and Egress	Possible/Suggested Response
PMF **Peak Flow:** **330 m^3/s**	■ Increased depths throughout inundated areas. Main breakout through Groom Street area increases in depth and extent, ■ All downstream areas from Story Road inundated ■ No safe access along Main Street or Esk Highway to the east or Story Street to the south	■ No further roads inundated ■ No access to the township from the east or south due to inundation across Esk Highway, Main Street and Story Street.	■ Evacuate remaining properties within 0.5% AEP event extent

5.2 Flood Function

Flood-prone land can be categories by three hydraulic categories – floodways, flood storage and flood fringe (Floodplain Development Manual 2005). The FDM defines the three categories as:

"**Floodways** are those areas of the floodplain where a significant discharge of water occurs during floods and are areas often aligned with obvious natural channels. They are areas that, even if only partially blocked, would cause a significant increase in flood levels and/or a significant redistribution of flood flow, which may in turn adversely affect other areas. They are often, but not necessarily, areas with deeper flow or areas where higher velocities occur."

"**Flood storage** areas are those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flows."

"**Flood fringe** is the remaining area of land affected by flooding, after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels"

Defining these areas within an area of interest can be challenging and can be a subjective process. There is currently no recommended process in ARR2016 or the Floodplain Development Manual to categories these areas base on defined criteria that can be applied to numerical modelling results.

To ensure consistency in the definition of flood function across the range of events the delineation in this project was based on criteria derived from Howell et al. 2003 and shown below in Figure 5-1. This approach has been used in a number of New South Wales flood studies and is deemed an appropriate approach for systematically determining flood function across a range of events using numerical modelling outputs.

TABLE 5-2 CRITERIA FOR DEFINING HYDRAULIC CATEGORY (FLOOD FUNCTION)

Hydraulic Category	Criteria	Description
Floodway	Velocity x Depth > 0.25 m^2/s and Velocity > 0.25 m/s, OR Velocity > 1 m/s and Depth > 0.1 m	Flowpaths and channels where a significant proportion of flood flows are conveyed
Flood Storage	Depth > 0.2 m, Not Floodway	Areas that temporarily store floodwaters and attenuate flood flows
Flood Fringe	Not Floodway or Flood Storage	Generally shallow, low velocity areas within the floodplain that have little influence on flood behaviour

The flood function maps for the full range of design events are provided in Appendix D.

6 CLIMATE CHANGE SCENARIOS

6.1 Overview

A series of climate change scenarios were run using approaches recommended in Australian Rainfall and Runoff 2016. ARR2016 recommends using temperature and associated rainfall intensity projections provided on the Australian Climate Futures Tool[8] with an assumed 5% increase in rainfall intensity for each 1˚C rise in temperature. AR&R also recommends testing mid (RCP 4.5) and high-range (RCP 8.5) projection scenarios and this was undertaken for both the 10% and 1% AEP flood events for 2090 projected temperature rise.

In addition, temperature projections have been assessed specifically for Tasmania as part of the Climate Future's for Tasmania project. As consistent with the AR&R recommendations a 5% increase in rainfall intensity was assumed for each 1˚C rise in temperature. This data was extracted from the Tasmania Government's LIST mapping website[9] for the St Marys catchment and run for both the 10% and 1% AEP design events. Mid (A1) and high-range projection scenarios (B2) were used.

The modelled scenarios are described below, and each was modelled for both the 10% and 1% AEP events.

- **Scenario 1 – Australian Climate Futures Low Range (RCP 4.5) 2090 Projection** – 1.52˚C degree temperature increase = 7.6% increase in rainfall intensity
- **Scenario 2 – Australian Climate Futures High Range (RCP 8.5) 2090 Projection** – 3.21˚C degree temperature increase = 16.1% increase in rainfall intensity
- **Scenario 3 – Tasmania Climate Futures Low Range (B1) 2099 Projection** – 1.49˚C degree temperature increase = 7.5% increase in rainfall intensity
- **Scenario 4 – Tasmanian Climate Futures High Range (A2) 2099 Projection** – 2.48˚C degree temperature increase = 12.4% increase in rainfall intensity

6.2 Results and Discussion

The climate change scenarios described above were run through the RORB and TUFLOW models and the following key findings made:

- As would be expected the increase in rainfall intensity results in significant increases in peak flows and flood extents in each event with bigger increases associated with the higher rainfall intensity scenarios.
- The Australian Climate Futures - High Range scenario results in peak flows that are approximately a design event larger than current conditions i.e. the 10% AEP becomes a 5% AEP event under the high range scenarios.
- Peak flows at St Marys are increased across all scenarios and are shown in Table 6-1 for the 10% and 1% AEP scenarios respectively. It can be seen that the two low range scenarios have resulted in an increase in 1% AEP peak flow of approximately 9 m^3/s compared to current conditions (which equates to a 7.8% increase in flow). The Australian and Tasmanian Climate Futures High Range Scenarios have resulted in increases of flow in the 1% AEP event of 20 m^3/s and 15 m^3/s respectively (which equates to increases of 17.5% and 13.2%). Across all scenarios the percentage increase in peak flow is slightly larger than the percentage increase in rainfall intensity,

[8] https://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-futures-tool/introduction-climate-futures/
[9] https://maps.thelist.tas.gov.au/listmap/app/list/map

TABLE 6-1 CLIMATE CHANGE SCENARIONS – PEAK FLOW AT ST MARYS (MAIN RD BRIDGE)

Event	*Current Conditions*	Aus Climate Futures – Low Range	Aus Climate Futures – High Range	Tas Climate Futures – Low Range	Tas Climate Futures – High Range
10% AEP	*65.8*	71.9	77.9	71.8	75.3
1% AEP	*114*	123	134	123	129

The full range of mapping for the climate change scenarios is provide in Appendix E.

7 LAND USE SCENARIOS

7.1 Overview

A series of scenarios were run whereby St Marys was assumed to be at maximum developed based on the current planning zones. This involved modifying the roughness of all parcels zoned residential, urban or to the same roughness values as those already developed. The adopted roughness values are shown in Table 7-1 whilst a comparison of the developed areas under existing and maximum development scenarios is shown in Figure 7-1.

The result of the modelled scenarios are described below. The 10%, 5%, 2% and 1% AEP events were modelled and maps are provided in Appendix F.

TABLE 7-1 ADOPTED ROUGHNESS VALUES FOR MAXIMUM DEVELOPMENT SCENARIO

Planning Zone Type	***Adopted Mannings Rougness Values***
Rural Residential	0.06
Residential	0.15
Business/Commercial/Industrial	0.30

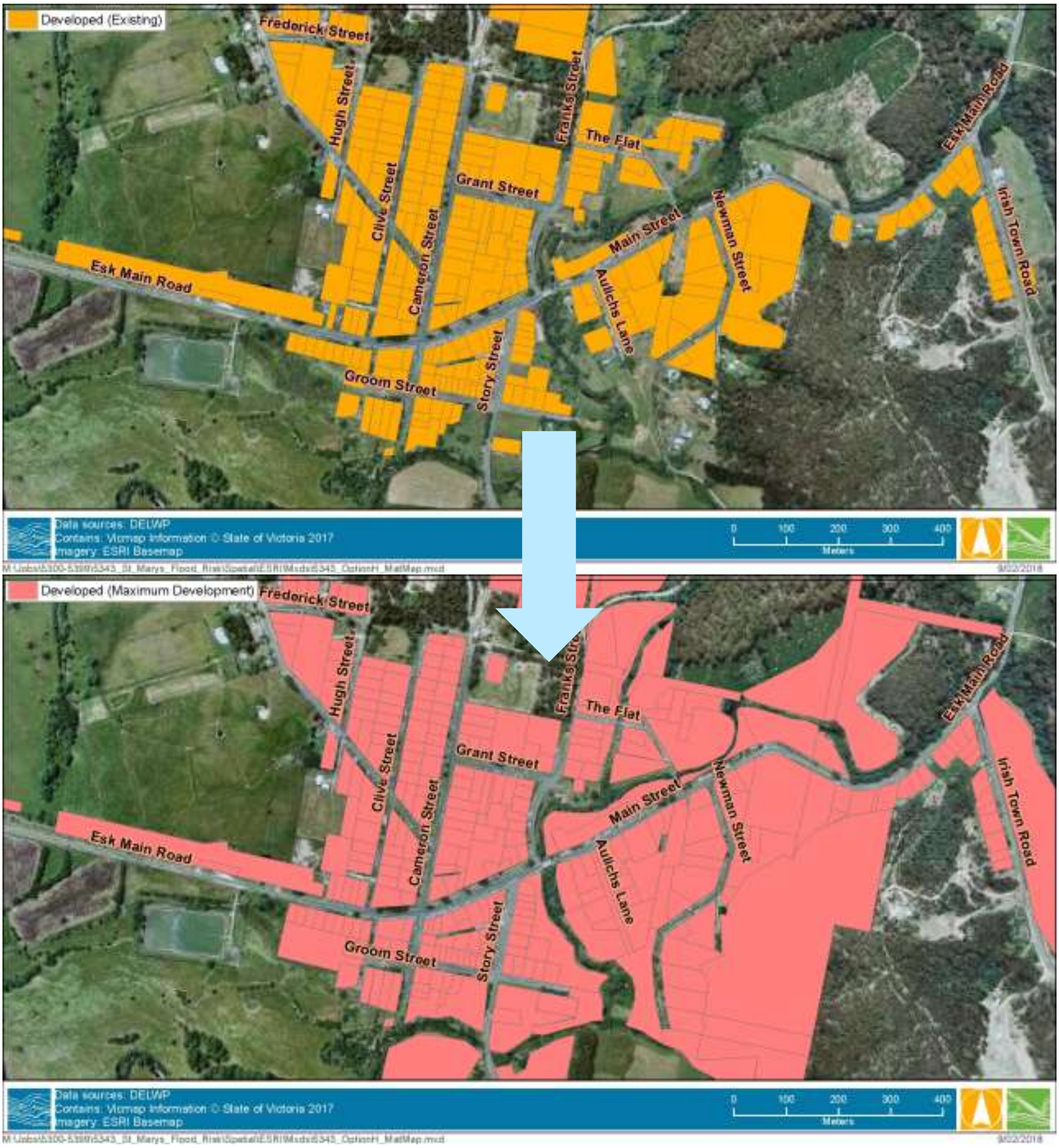

FIGURE 7-1 COMPARISON OF DEVELOPED AREAS UNDER CURRENT AND MAXIMUM DEVELOPMENT SCENARIOS

7.2 Results and Discussion

The land use scenarios described above were run through the TUFLOW model and the following key findings made:

- Changing the roughness map to maximum development as had a significant impact on flood levels with increases in levels occurring across the full range of modelled events.

- In the 1% AEP event there are significant increases in flood levels from just downstream of Irish Town Road extending to Story Street with average increases of 200-300 mm along this reach. The increase in levels has caused the breakout across Groom Street to be significantly larger with more properties impacted. The increase in flood levels has also increased the flood extent in the centre of town around the bakery and library.
- In the 2%, 5% an 10% AEP events the differences in flood levels are similar with increases of 200-300 mm along much of the reach between Irish Town Road and Story St. It is of note that the increase in flood levels in the 10% and 5% AEP events has caused breakouts to occur across Groom Street which do not occur under current condition in those events.
- The results show that flood behaviour in the township is very sensitive to increased levels of development, if it is assumed that all areas zoned residential/business/commercial are developed as per the planning scheme zones. The results highlight that future development of the township will need to have careful consideration for flood behaviour to ensure flood conditions aren't made worse or result in adverse impacts to existing properties.

The full range of mapping for the maximum development scenario is provide in Appendix F.

8 SUMMARY

This document has outlined the development of hydrological and hydraulic models for the St Marys Flood Investigation and the modelling a broad range of design events to understand flood risk at St Marys across a range of flood events. It has detailed how the models were built and calibrated using historic flood information.

The models were calibrated and validated to three historic events which occurred in January, June and November 2016 using streamflow and rainfall gauge data, anecdotal reports and flood photos. Overall a very good calibration was achieved across the three events, despite some significant data limitations.

The models have been demonstrated to operate accurately across a range of flood events and the model was deemed suitable for design event modelling.

This investigation has developed detailed design flood mapping for St Marys for a range of design flood events. The modelling was developed using best practice guidelines, with specific reference to Australian Rainfall and Runoff (2016).

Flood consequence tables have been provided to assist emergency services and Council in forecasting for floods, and then planning and responding in a timely manner. The tables show that roads begin overtopping in the 10% AEP event and above while external inundation of properties also occurs in the 10% AEP event and above.

The study has also produced a range of professional flood mapping outputs which can be used for ongoing floodplain management and flood response at St Marys. The mapping includes:

- Depth mapping which also includes water level contours and key points of interest;
- Hazard mapping based on Australian Rainfall and Runoff hazard categories;
- Flood function mapping which describes the floodplain in terms of floodway, flood storage and flood fringe areas and are based on Floodplain Development Manual definitions; and
- Climate change mapping based on a range of climate change projection scenarios for the 10% and 1% AEP design events.
- Land Use Mapping based on maximum levels of development with respect to planning scheme zones

The above mapping has been provided for the full range of modelled design events from the 5% AEP event up to the Probable Maximum Flood (PMF) event.

Following this study, it is recommended that the following actions be considered to build a more flood resilient community:

- Identify effective flood risk mitigation measures and update the Municipal Flood Emergency Plan with information from this document.
- Discuss the results of this investigation with Council's emergency management team and share with relevant stakeholders including SES and DPIPWE.
- Communicate appropriate information from this study to the community to ensure they are aware of the flood risks to themselves and to inform and support them to make their own flood plans, for the community and their own households and businesses.
- Adopt the 1% AEP flood levels for 'flood prone land' within the study area and make the study results available for flood risks to be considered in land use or development planning.

APPENDIX A
PMP CALCULATIONS

The Generalised Southeast Australia Storm Method (GSAM) determines the Probable Maximum Precipitation. The calculations are outlined in a series of worksheets with the calculations represented below.

TABLE 8-1 PMP SELECTION METHOD SUMMARY

WORKSHEET 1	
METHOD:	GSAM Coastal Zone
ZONE:	Coastal Zone
SEASON:	Annual
DURATION:	24 – 96 hours

The Annual Moisture Adjustment Factor

$$MAF = \frac{EPW_{Seasonal\ catchment\ average}}{EPW_{Seasonal\ standard}}$$

TABLE 8-2 CATCHMENT FACTORS

Topographical Adjustment Factor (TAF)		1.99853	
Season	**EPW** $_{\text{Seasonal Catchment Ave}}$	**EPW** $_{\text{Seasonal Standard}}$	**MAP**
Summer (Annual)	52.19	80.80	0.646
Autumn	42.15	71.00	0.594

TABLE 8-3 SEASONAL PMP ESTIMATES

Summer PMP values (mm)			Autumn PMP values (mm)		
Duration (hours)	Initial Depth (D_{summer})	PMP Estimate (D_sxTAFxMAF$_s$)	Duration (hours)	Initial Depth (D_{summer})	PMP Estimate (D_sxTAFxMAF$_s$)
24	850.25	1097.66	24	564.91	670.16
36	951.10	1227.85	36	695.76	825.39
48	1002.94	1294.77	48	817.74	970.09
72	1048.70	1353.84	72	1033.88	1226.49
96	1084.28	1399.79	96	1106.99	1313.24

TABLE 8-4 FINAL GSAM PMP ESTIMATES

Duration (hours)	Maximum of the Seasonal Depths	Preliminary PMP Estimate (nearest 10mm)	Final PMP Estimate (from envelope)
24	1097.6	1100.0	1100.0
36	1227.8	1230.0	1230.0
48	1294.7	1290.0	1290.0
72	1353.8	1350.0	1350.0
96	1399.7	1400.0	1400.0

APPENDIX B
DESIGN FLOOD MAPS

APPENDIX C DESIGN HAZARD MAPS

APPENDIX D FLOOD FUNCTION MAPS

APPENDIX E CLIMATE CHANGE MAPS

APPENDIX F LAND USE MAPPING (MAXIMUM DEVELOPMENT SCENARIO)

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