STATE EMERGENCY SERVICE

TASMANIAN STRATEGIC FLOOD MAP
RUBICON STUDY AREA MODEL CALIBRATION

REPORT

MARCH 2023

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Project Tasmanian Strategic Flood Map Rubicon Study Area Model Calibration	**Project Number** **120038**
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Revision History

Revision	Description	Distribution	Authors	Reviewed by	Verified by	Date
0	Draft report for review	Luke Roberts, SES	Sarah Blundy, Emven Wong, Fiona Ling	Daniel Wood	Mark Babister	MAR 22
1	Updated with response to review comments	Luke Roberts, SES	Sarah Blundy, Emven Wong, Fiona Ling	Daniel Wood	Mark Babister	APR 22
2	Report with minor revisions	Chris Irvine, SES	Sarah Blundy, Emven Wong, Fiona Ling	Daniel Wood	Mark Babister	MAR 23

Cover image: From Port Sorell, Tasmania: Travel guide and things to do - https://www.traveller.com.au/port-sorell-tasmania-travel-guide-and-things-to-do-1303bo

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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
ALS	Airborne Laser Scanning
AMS	Annual Maximum Series
ARF	Areal Reduction Factor
ARR	Australian Rainfall and Runoff
ATP	Areal Temporal Patterns
AWAP	Australian Water Availability Project
AWS	Automatic Weather Station
Bureau/BoM	Bureau of Meteorology
C	Lag parameter in WBNM
CFEV	Conservation of Freshwater Ecosystem Values (DPIPWE)
CL	Continuing Loss
DEM	Digital Elevation Model
DNRE	Department of Natural Resources and Environment
DPIPWE	Department of Primary Industries, Water and Environment
DRM	Direct Rainfall Method
DTM	Digital Terrain Model
FFA	Flood Frequency Analysis
FLIKE	Software for flood frequency analysis
FSL	Full Supply Level
GIS	Geographic Information System
GEV	Generalised Extreme Value distribution
GPS	Global Positioning System
HSA	Human Settlement Area
ICM	Infoworks ICM software (Innovyze)
IDW	Inverse Distance Weighting
IL	Initial Loss
IFD	Intensity, Frequency and Duration (Rainfall)
LiDAR	Light Detection and Ranging
mAHD	meters above Australian Height Datum
PERN	Catchment routing parameter in RAFTS
Pluvi	Pluviograph – Rain gauge with ability to record rain in real time
QAQC	Quality assurance and quality control
R	Channel routing parameter in WMAWater RAFTS WBNM hybrid model
RAF	RAFTS Adjustment Factor
RAFTS	hydrologic model
SCE	Shuffled Complex Evolution
SES	State Emergency Service
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software (hydrodynamic model)
WBNM	Watershed Bounded Network Model (hydrologic model)

1. INTRODUCTION

Flooding occurs regularly throughout Tasmania; the Bureau of Meteorology describes numerous major flood events that have occurred since the early 1800s. Following the 2016 Tasmanian floods, the need for state and local governments, communities and emergency response agencies to better understand flooding in Tasmania was identified. Improved flood intelligence would allow for targeted and appropriate investment in flood recovery and increased community resilience to future flood events. The Independent Review into the Tasmanian Floods of June and July 2016 found that there were gaps in flood studies and flood plans over Tasmania, both in comprehensiveness and currency.

The objectives of the Tasmanian Strategic Flood Mapping Project are to assist flood affected communities to recover from the 2016 floods through a better understanding of flood behaviour, and to increase the resilience of Tasmanian communities to future flood events. The targeted outcomes of the project are that post-flood recovery will be informed by up-to-date flood risk information, ownership of flood risk is appropriately allocated, flood risk can be included in investment decisions, and responsibility for flood mitigation costs can be appropriately allocated.

The Tasmanian Flood Mapping Project aims to address the objectives and outcomes by:

- providing communities with access to a high resolution digital terrain model that can be used for flood modelling, through collection of LiDAR data over Tasmania
- developing state-wide Strategic Flood Maps to support flood risk assessment and post event analysis and
- partnering with Local Government to deliver detailed flood studies and evacuation planning for communities with highest flood risk that do not have a current flood study.

This project addresses the second component of the Tasmanian Flood Mapping Project, the development of state-wide Strategic Flood Maps.

This report describes the calibration of hydrologic and hydrodynamic flood models for the Rubicon study area.

2. STUDY AREA

The Rubicon study area is situated in the northern Tasmania around Port Sorell. The two main rivers in the catchment are the Rubicon River and the Franklin Rivulet. There are many smaller watercourses which flow into Port Sorell including: Panatana Rivulet and Greens Creek to the west of Port Sorell and Sheepwash Creek and Branchs Creek east of Port Sorell.

The Rubicon River rises on the Christmas Hills and Punchs Terror near Elizabeth Town at the south of the study area. The Franklin Rivulet begins around Frankford in the south west of the catchment. The study area is largely agricultural with some forested areas especially in the west. The study area is covered partially covered by two different Tasmania Irrigation schemes (Tasmanian Irrigation, 2021); these transfer water for irrigation into the study area so should have limited impact for flooding. The upper reaches of the Rubicon River are part of Tasmanian Irrigation's Greater Meander scheme and receive irrigation water from Meander Dam and much of the area west of Port Sorell is part of the Sassafras Wesley Vale Irrigation Scheme, receiving water transferred from the Mersey River. The areas covered by these irrigation schemes have several hundred small dams. The main inland towns in the study area are Elizabeth Town in the south and Sassafras and Wesley Vale in the west. The western coast of Port Sorell has significant developed area including the towns of Port Sorell, Shearwater and Hawley Beach with a combined population close to 5000 people.

Large floods in the study area include the July 2000, August 2005 and June 2016 flood event.

The Rubicon study area has an area of 732 km^2. The area upstream of the Rubicon gauge at Tidal Limit is 264 km^2, and the Franklin Rivulet's catchment area is 135km^2. The Rubicon study area and the available gauge information are shown in Figure 1. Land use in the study area is shown in Figure 2.

3. AVAILABLE DATA

3.1. Historic Flow Data and Level Data

There are six flow gauges with data available in the Rubicon study area (Table 1), however many of them have very short records, and therefore may have no data for the calibration events of interest. These gauges are owned by DPIPWE, who supplied timeseries of flows for each site, and ratings and gaugings for some sites.

The main long term gauge in the study area is Rubicon River at Tidal Limit which is at the bottom of the Rubicon River. It has a largely complete record covering 55 years.

Table 1: Flow gauges

Gauge attribute	Rubicon River @ Elizabeth Town	Franklin Rivulet River U/S Tidal Limit	Rubicon River at Tidal Limit	Greens Creek D/S Torrington Rd	Greens Creek Upstream Frankford Rd	Panatana Rivulet Upstream Tidal Limit
Gauge number	17203-1	17201-1	17200-1	17210-1	17205-1	17204-4
Gauge abbreviated name	Rubicon at Elizabeth	Franklin Rivulet	Rubicon at Tidal	Greens Torrington	Greens Frankford	Panatana Rivulet
Start date	22/11/2006	01/01/1975	22/06/1967	29/07/2010	10/04/2014	28/06/2007
End date	current	10/02/1994	current	17/05/2018	current	current
Latitude	-41.45	-41.27	-41.24	-41.25	-41.23	-41.18
Longitude	146.56	146.61	146.56	146.55	146.56	146.53
High flow rating quality	Poor – rating extrapolated	Not known	Original DNRE rating considered poor to fair for high flows. Theoretical rating developed using local hydraulic model.	Not known	Not known	Poor – rating extrapolated and does not fit through gaugings
Used for calibration	Yes	No	Yes	No	Yes	Yes
Assumed local datum 0m in AHD	173.7	N/A	2.5	N/A	6.6	3.93
Highest Gauged Level (m local datum)	0.96	Not known	1.765	Not known	Not known	0.452

Gauge attribute	Rubicon River @ Elizabeth Town	Franklin Rivulet River U/S Tidal Limit	Rubicon River at Tidal Limit	Greens Creek D/S Torrington Rd	Greens Creek Upstream Frankford Rd	Panatana Rivulet Upstream Tidal Limit
Highest recorded stage height (m local datum)	2.44	N/A	3.26	1.49	1.37	2.69
Highest recorded flow (m^3/s)	28	N/A	265	10	N/A	31
Highest recorded stage height date	06/06/2016	N/A	06/06/2016	06/06/2016	06/06/2016	06/06/2016

3.1.1. Calibration Event Data Availability

Significant flows were recorded in the study area for one of the 13 flood events selected by the Bureau as calibration events for this project (Table 2). This was the June 2016 flood event which was the largest on record at all sites with data (however in some cases only from less than 10 years of record). The gauge covering the largest area of the study area, Rubicon River at Tidal limit, reached its highest recorded flow on record in the June 2016 event before the site was destroyed. At the other sites, flows were so far above gauged flows that rated flows are likely to be unreliable (Section 3.1.2). Therefore, two additional events, August 2005 and July 2000 were derived for this catchment as described in Tasmanian Strategic Flood Map, Addition Calibration Event Rainfalls (WMAwater, 2021d). At the Rubicon at Tidal gauge these were the 3rd and 4th largest events on record respectively with approximate AEPs between 5% and 10%. The second largest event on record was not used as there was insufficient sub-daily rainfall data available.

Table 2: Summary of calibration events in the Rubicon study area

Event name	Used for calibration	Event peak flow (m^3/s) (location)
2000 Jul	Yes	217 (Rubicon at Tidal)
2005 Aug	Yes	223 (Rubicon at Tidal)
2016 Jun	Yes	28 (Rubicon at Elizabeth) 31 (Panatana Rivulet) 28 (Greens Frankford) 10 (Greens Torrington) 300* (Rubicon at Tidal)

3.1.2. Rating Curve Quality

The Rubicon at Tidal site was the main site used in calibration. The DNRE rating at this site was considered to be fair, however the rating was extrapolated for flows above approximately 80 m^3/s and does not appear to account for the shape of the cross section. The rating at this site was extended using a local hydraulic model (WMAwater, 2021c). This rating has been used in calibration (Diagram 1).

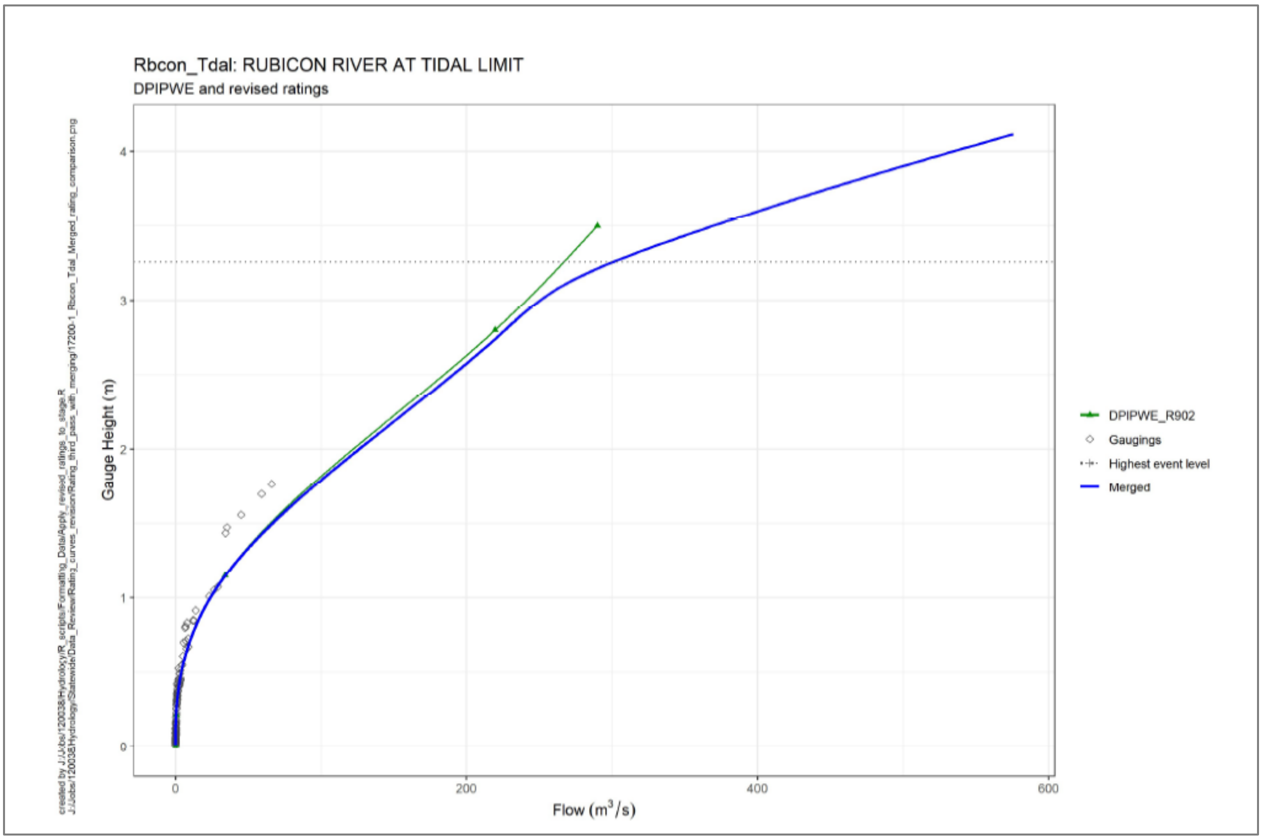

Diagram 1: Rubicon River at Tidal Limit – revised rating

The rating for Panatana Rivulet upstream of Tidal limit shows a very poor fit to the gaugings, based on information available on Water Data Online (Diagram 2, Bureau of Meteorology, 2021). The rating is extrapolated beyond the highest gauging, which is less than 2 m^3/s.

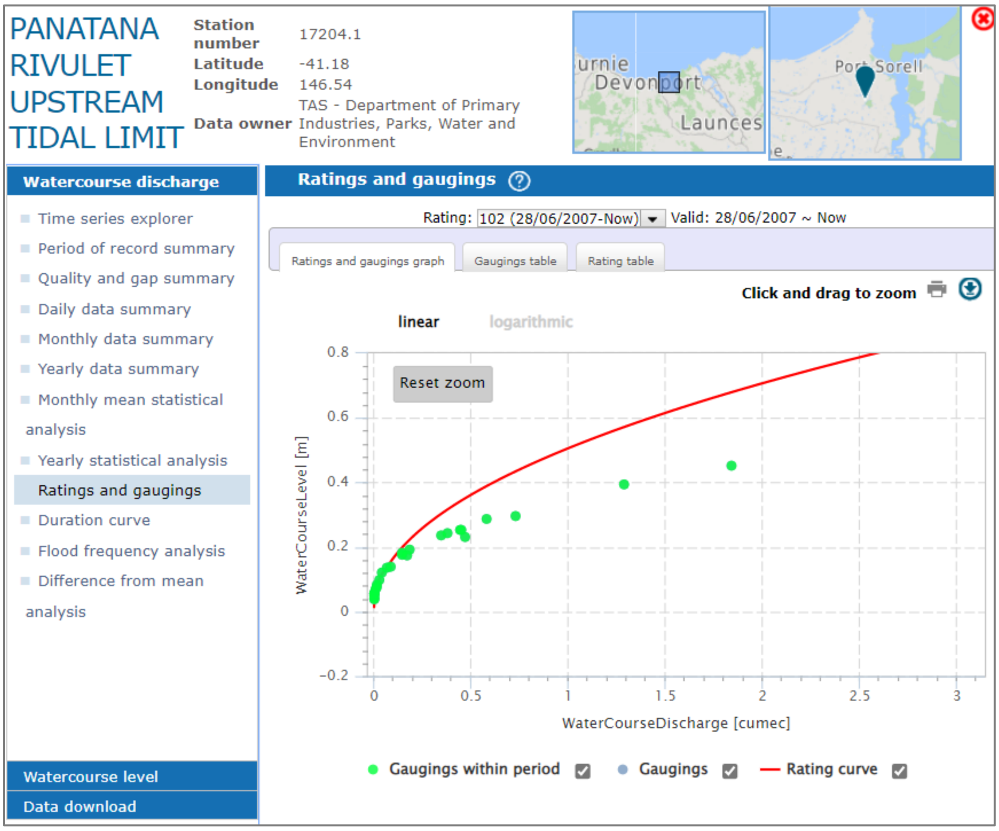

Diagram 2: Panatana Rivulet Upstream Tidal Limit rating and gaugings (screenshot from Bureau of Meteorology, 2021).

The Rubicon River at Elizabeth Town high flow rating is also considered to be poor, based on information available on Water Data Online (Diagram 3, Bureau of Meteorology, 2021). The rating is extrapolated for flows above 2.8 m^3/s and there is an inflection in the rating at around 15 m^3/s.

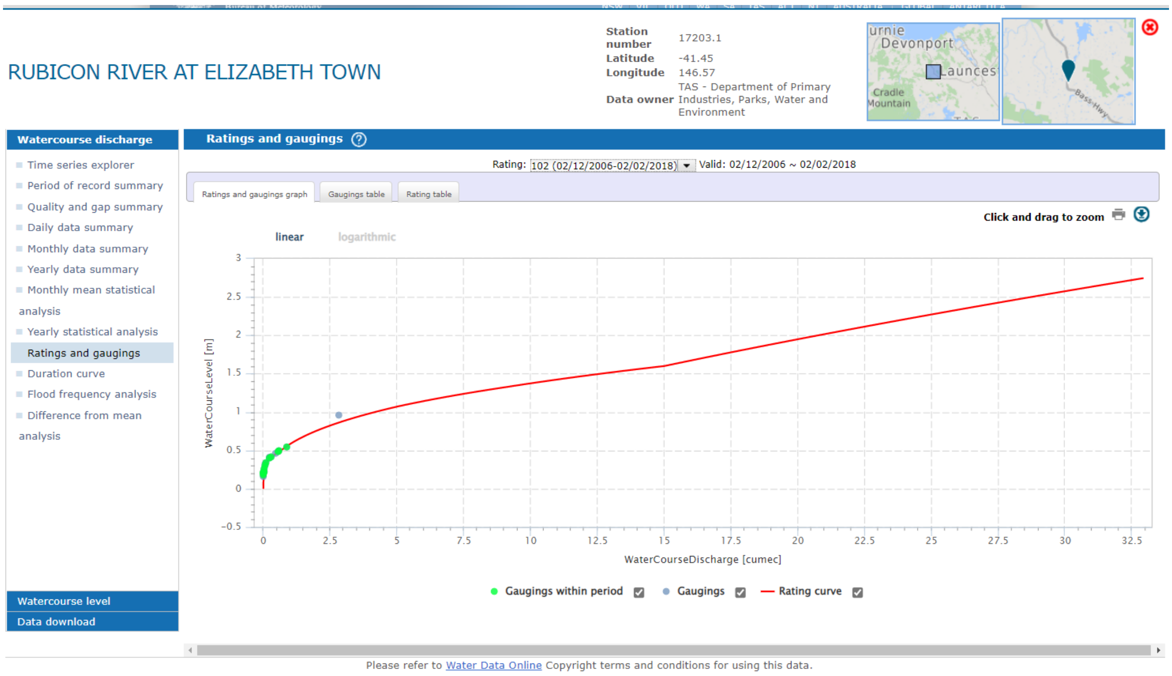

Diagram 3: Rubicon River at Elizabeth Town rating and gaugings (screenshot from Bureau of Meteorology, 2021)

No information was available on the ratings for the gauges on Green Creek or Franklin Rivulet.

3.2. Historic Rainfall Data

Rainfall data was provided by Bureau of Meteorology as part of the initial project data. The data provided included sub-daily rainfall timeseries data from four different sources: Automatic Weather Station (AWS) data, pluvio data, rolling accumulated rainfall from the Bureau's flood warning network, and 10 minutely accumulation from the Bureau's flood warning network. The datasets were in different formats and required processing to a common format before they could be used to produce rainfall inputs to the model. Rainfall data was provided for 13 events identified by the Bureau of Meteorology for use as calibration events for this project, although not all 13 events have data available or were significant events in the Rubicon catchment (see Data Review Report WMAwater (2020) for details on calibration events). The 2000 and 2005 calibration events at this site was added as an additional event as described in Tasmanian Strategic Flood Map, Addition Calibration Event Rainfalls (WMAwater, 2021d).

The AWS and pluvio data were found to be more consistently reliable. Where multiple data sources were available at the same site, AWS or pluvio data were prioritised for use over the event or accumulated data. Data that was recorded less frequently than at 3 hour intervals was excluded from the analysis.

A summary of the rain gauges and rainfall totals for this study area is shown in Table 3. There is one sub-daily rain gauge within the Rubicon study area at Devonport, with data available for all events. There was an additional rain gauge at Elizabethtown with data available for the June 2016 event. For all events there are gauges just south-east of the catchment near Deloraine. This gives good definition of rainfall totals across the catchment. The gauges in and around the Rubicon study area are shown in Figure 1.

Table 3: Available Rainfall Information

	July 2000	August 2005	June 2016
Number of Sub-daily Stations Available within the study area	1	1	2
Number of daily Stations Available within the study area	5	5	6
Number of sub-daily surrounding gauges ~15km	2	3	6
Number of daily surrounding gauges ~15km	19	18	16
Rainfall Totals	100-160 mm	60-120 mm	150-210 mm
Approx duration of rainfall event (hours)	72	36	36

*The number of daily gauges does not include daily gauges co-located with an active sub-daily gauge

The daily and sub-daily rain gauge data were used to create rainfall surfaces for each of the selected calibration events using an inverse distance weighting method. The method is described in detail in WMAwater 2021 and is summarised below.

1. Daily rainfall data from all gauges within Tasmania was extracted for each of the seven calibration events from 2000 – 2018

2. Rudimentary QAQC and infilling of daily record was undertaken
3. Daily rainfall surfaces for each event were fitted using all daily and available pluviograph data, using Inverse Distance Weighting (IDW)
4. Sub-catchment rainfall depths were calculated from all grid cells within the sub-catchment using areal weighted averages
5. Daily data in each sub-catchment was disaggregated using the temporal pattern from gauge assigned using Thiessen polygon method.

The rainfall surfaces for the selected calibration events are shown in Figure 3 to Figure 5.

3.3. Dam information

There are no significant dams in the Rubicon study area, and no dams were explicitly modelled. However there are many small farm dams, particularly in the catchments of the streams west of Port Sorell (e.g. Pantana Rivulet and Greens Creek).

3.4. Flood Levels and Extents

Flood survey levels and extents within the Rubicon study area were available from the 2016 surveyed flood extents program conducted after the June 2016 flood event. This information was used to verify the modelling results for the June 2016 event. This information however was limited to a small number of locations along Panatana Rivulet and Pardoe Creek and did not include Rubicon River, Greens Creek, or Franklin Rivulet (refer Section 6.4).

No other information was provided to enable verification of modelled flood levels and extents for the modelled calibration events for the study area.

4. METHODOLOGY OVERVIEW

The hydrological and hydrodynamic model calibration methodology has been outlined in the Hydrology Methods Report (WMAwater, 2021a) and the Hydrodynamic Methods Report (WMAwater, 2021b). Details on the methods are only included in this report where they deviate from the methods described in these reports or are specific for this catchment.

The modelling method includes the following steps:

- Data preparation
    - Extraction and collation of rainfall data for identified calibration events
    - Gridding rainfall data across each catchment
    - Extraction of flow data for identified calibration events at each flow site, and assessment of suitability of this data for calibration
- Hydrologic modelling
    - Identification of flow gauge locations
    - Identification of dam and diversion locations
    - Sub-catchment delineation in GIS
    - Inclusion of dam storage and spillway ratings where required and available
    - Event calibration for routing and losses using automated external RAFTS modelling tool. Output event sub-catchment rainfalls, routing parameters and event losses for input to ICM model
    - Running event calibration through ICM RAFTS model to provide sub-catchment pickups for direct input into ICM hydrodynamic model
    - As required, revise hydrologic parameters within ICM-RAFTS to obtain good match to historic flood information provided
    - Once a good match is achieved, provide ICM-RAFTS modified hydrologic parameters back to the external hydrologic model to ensure consistency
    - As required, confirm the response between the external hydrologic model and ICM hydrodynamic model is consistent to enable design event analysis
- Hydrodynamic modelling in ICM
    - Importing base DEM
    - Setting roughness values, referencing calibrated PERN value from hydrologic model
    - Meshing
    - Incorporation of structures
    - Setting up rainfall inputs (depth and temporal pattern), losses and dam/diversion outflows from the hydrologic model
    - Calibration model runs
    - Compare model results with hydrologic model runs and calibration points
- Model iteration (if necessary)
    - Adjust routing parameters values in both external and ICM RAFTS hydrologic model if necessary, based on results of hydrodynamic model calibration
    - Rerun hydrologic models for calibration events
    - Set roughness values in hydrodynamic model
    - Rerun hydrodynamic model for calibration events

5. HYDRODYNAMIC MODEL SETUP

5.1. Digital Elevation Model (DEM)

The base dataset that was used for the digital elevation model (DEM) of the hydrodynamic model was the SES state-wide 10 m DEM merged with 2 m DEM subsets at the gauges (where available). 2 m DEM subsets were used at all of the operational gauges in the study area, except for Rubicon River at Elizabeth Town. The SES state-wide 10 m DEM was used at this location as the 2 m DEM subset was found to have been artificially filled behind the road downstream.

The merged DEM was then clipped to the study area with a buffer zone to ensure 100% active mesh area in the model. Where no terrain information was available in the tidal zones, a ground level of -10 mAHD was applied in GIS to the clipped DEM. The resulting DEM is shown in Diagram 4.

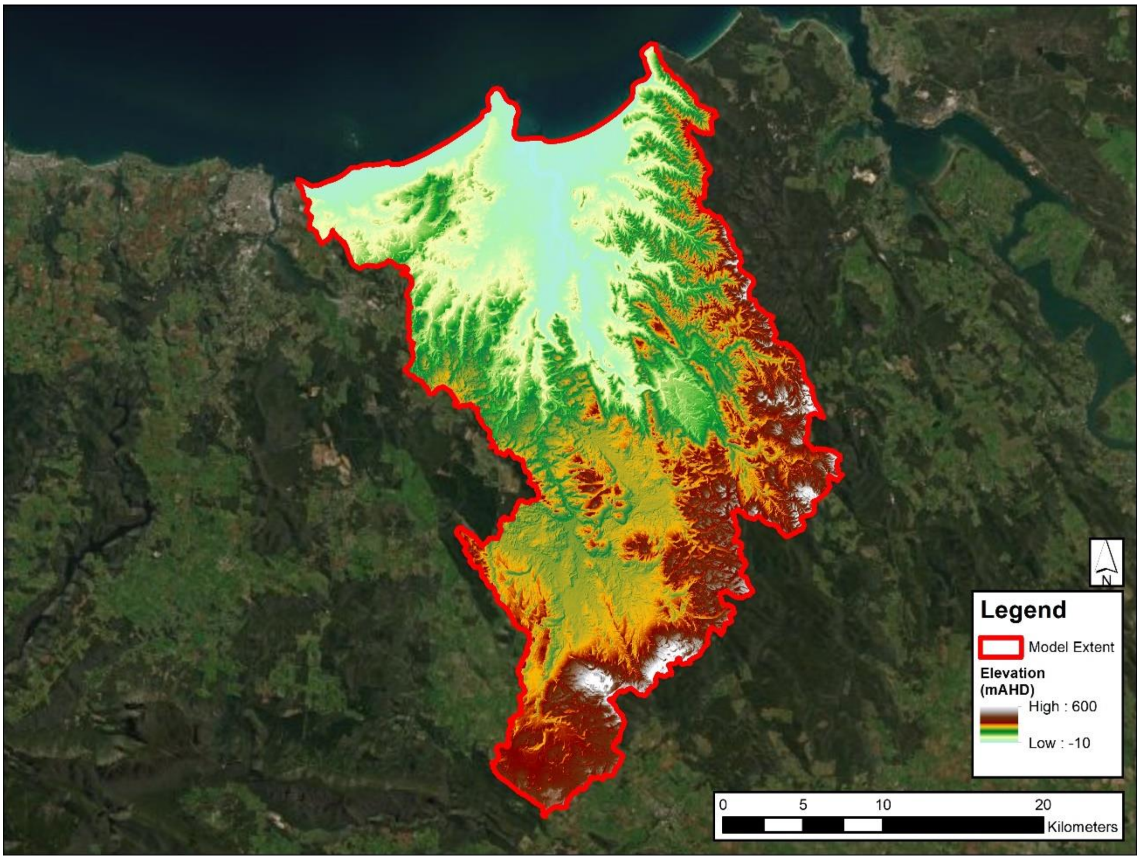

Diagram 4: DEM of the Rubicon study area

The SES state-wide 10 m DEM consists of a ‘Default DTM’ that is state-wide and a ‘LiDAR DTM’ that covers the areas where LiDAR data was available at the time, as shown in Diagram 5. The majority of the Rubicon study area is covered by the good quality ‘LiDAR DTM’.

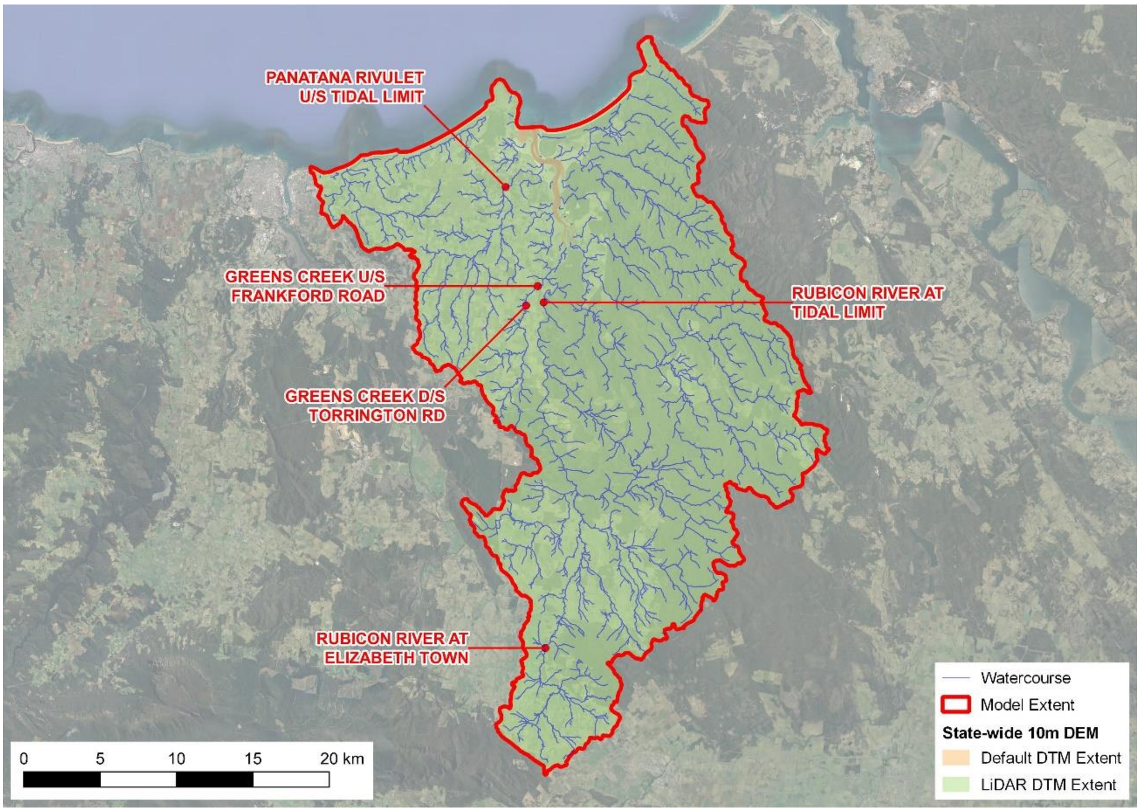

Diagram 5: ‘Default DTM’ extents for the Rubicon study area

A review of the DEM at Rubicon River at Elizabeth Town, Greens Creek u/s Frankford Road, and Panatana Rivulet u/s Tidal Limit found that the roads downstream were not adequately breached in the DEM. This resulted in elevated water levels at the gauge. As detailed drawings or survey of the structures at these locations were not available at the time, the structures were approximated with a channel carved in the 2D domain to allow for the free flow of water. A review of the modelling of these structures should be undertaken, should detailed drawings or survey be available.

5.2. Roughness

The base dataset that was used for the roughness of the hydrodynamic model was the SES state-wide roughness grid. This dataset was converted to a set of polygons for each land use and linked to a corresponding friction value (as detailed in the Hydrodynamic Modelling Methods Report). The polygons were then cleaned in GIS to ensure that the geometry was valid before being imported into the hydrodynamic model.

It is noted that, at this stage, the roughness values for streams vary greatly with sections of Manning’s n of 0.1 crossing streams in many locations. This issue is an artefact of the simplification of the roughness layer when it is converted into triangles. Where the issue was severe, a continuous zone of single roughness of 0.05 for all upper streams was utilised.

The resulting roughness layer is shown in Diagram 6.

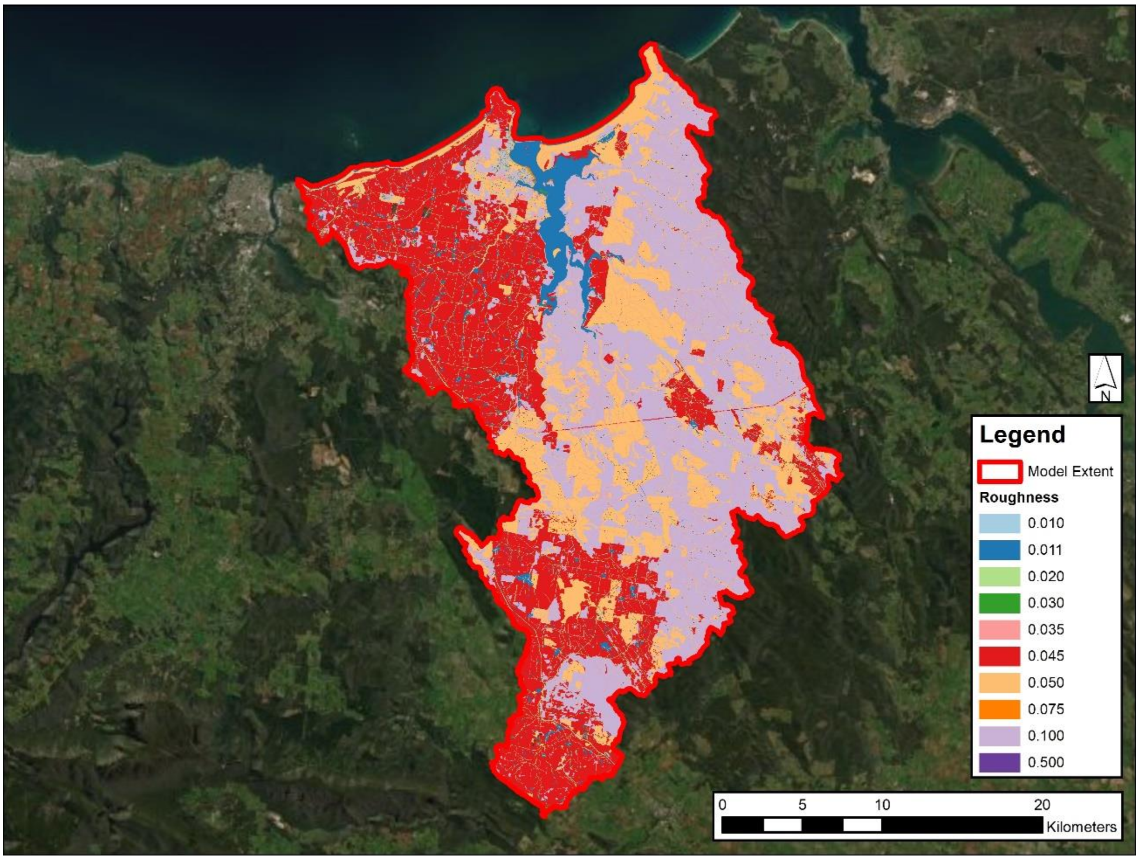

Diagram 6: Roughness layer for the Rubicon study area

5.3. Meshing

Meshing in the hydrodynamic model was undertaken using mesh zones, with the following rules:

- Base mesh zone – the default mesh size, set to a maximum of 2500 m² and a minimum of 400 m²
- Stream mesh zones – set as an independent mesh zone with a maximum mesh size of 400 m² and a minimum of 100 m²
- Upper stream mesh zones – streamlines of strahlar order 2-5 and strahlar order 6-8 were buffered by 10 m and 20 m either side of the centre line. These zones were then set to a maximum mesh size of 150 m² and a minimum of 100 m². This process was done to ensure that the meshing process did not result in artificial blocking of the flow paths along the upper streams.
- Human Settlement Areas and other areas of interest – set as an independent mesh zone with a maximum area of 100 m² and a minimum of 25 m²

The resulting mesh zones are shown in Diagram 7.

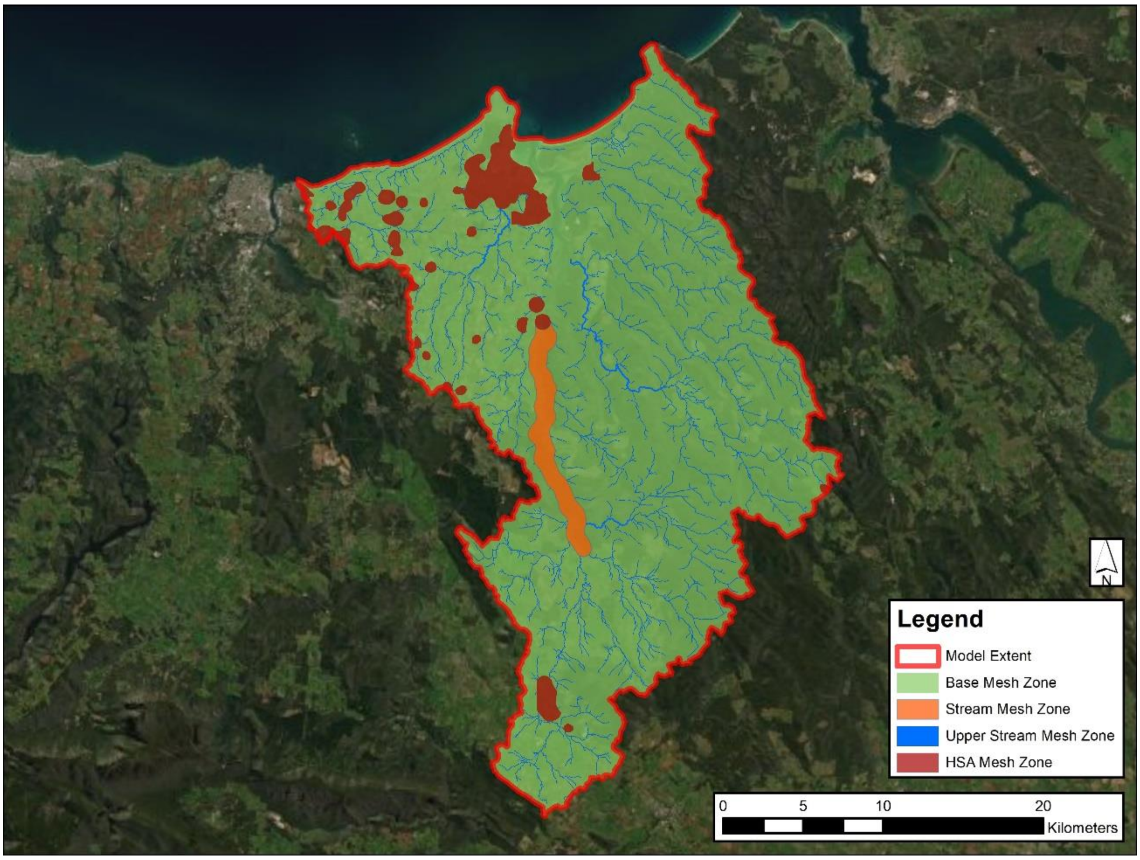

Diagram 7: Mesh zones for the Rubicon study area

5.4. Structures

Within the study area, five significant bridges were identified from the SES state-wide bridge database and these were modelled in the hydrodynamic model in the 2D domain using linear 2D bridge structures. Further discussion on this process is provided in the Hydrodynamic Modelling Methods Report (WMAwater, 2021b).

The bridges modelled included:

- Smiths and Others Road at Rubicon River
- Frankford Road at Rubicon River
- Footbridge at Panatana Rivulet
- Footbridge at Port Sorell
- Frankford Road at Franklin Rivulet

No other significant structures were identified in the study area (other than those discussed in Section 5.1).

The structure locations are shown in Diagram 8.

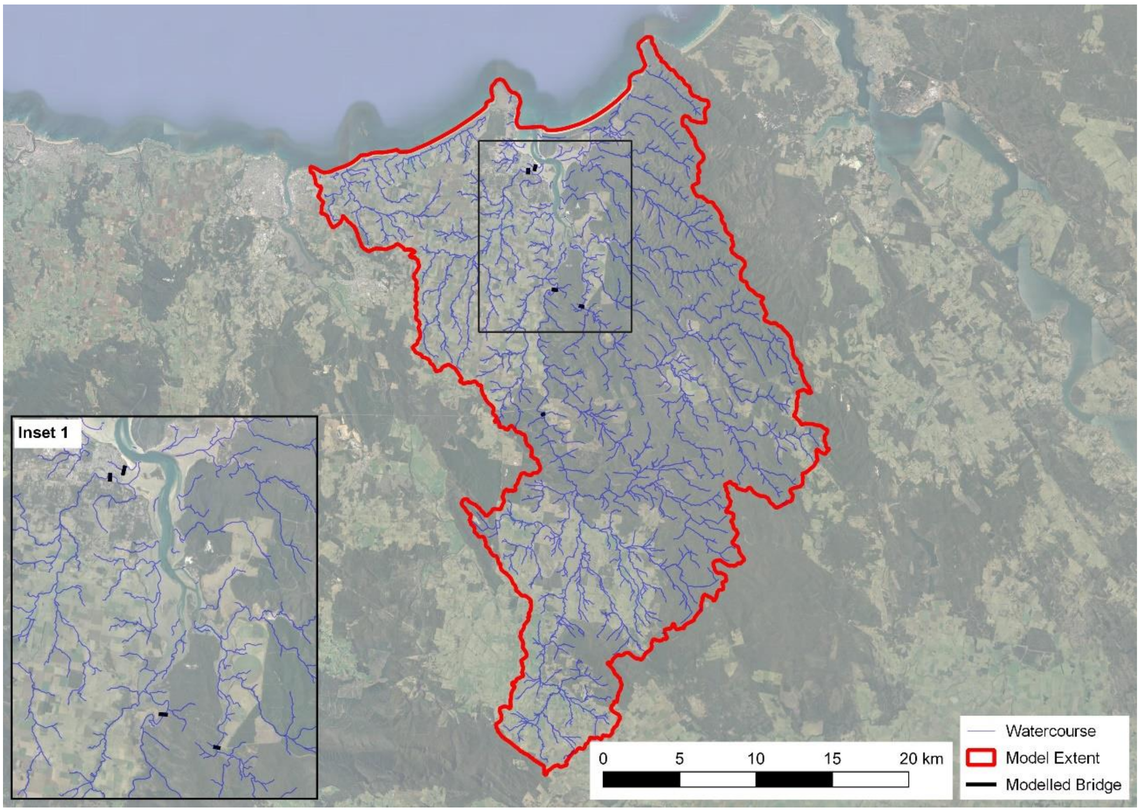

Diagram 8: Modelled structures in the Rubicon study area

5.5. Dams

No dams were modelled explicitly in the hydrodynamic model. The small dams in the upper reaches of Rubicon River and in the streams west of Port Sorell (Greens Creek and Panatana Rivulet) were modelled implicitly in the hydrodynamic model via the DEM.

5.6. Downstream Boundaries

Downstream boundaries were applied at the base of the model to provide interaction with the tidal zone. Synthetic tide data was provided by the Bureau of Meteorology (BoM) for the June 2016 calibration event and was used to set a varying tide level. This data was extracted off the coast of Port Sorell at 10 min time increments and was imported into ICM as a time varying boundary condition. Diagram 10 shows an example of the synthetic tide data that was extracted for the June 2016 event.

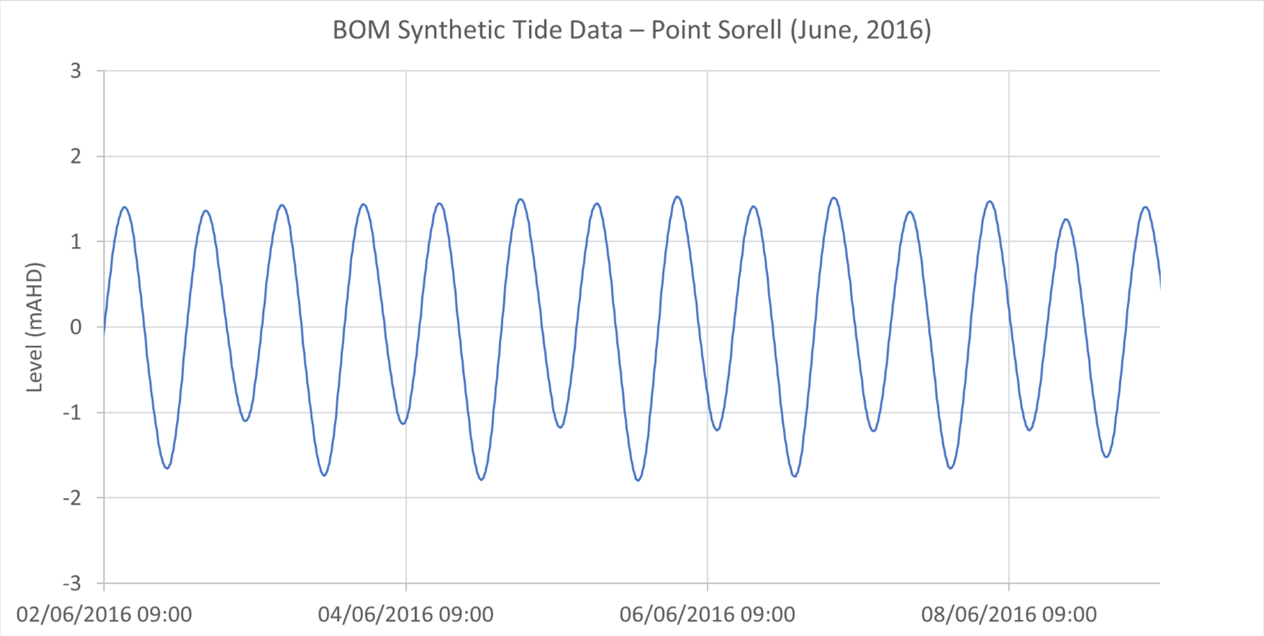

Diagram 9: Synthetic tide data off the coast of Port Sorell (June, 2016)

Given the proximity of the Rubicon study area to the Burnie Tide Gauge, real tide data was extracted for this study area for the July 2000 and August 2005 calibration events. This data was extracted at 60-minute time increments from the Bureau of Meteorology Australian Baseline Sea Level Monitoring Project Portal and was imported into the hydrodynamic model as a time varying boundary condition. The 60-minute time increment was used as this adequately captured the shape and peaks of the tide data.

Missing data was found between 21 July 2000 to 11 August 2000 (which includes the peak of the July 2000 calibration event) and was inferred from the last recorded high and low tide. Diagram 10 shows the tide data that was used for the July 2000 event.

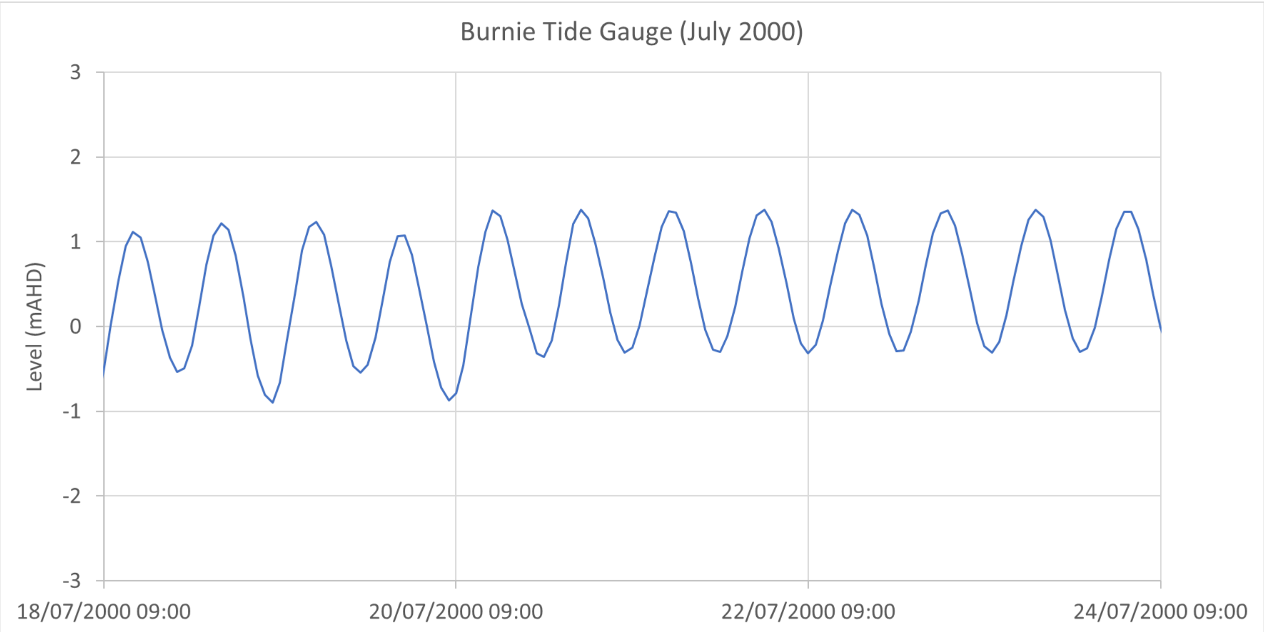

Diagram 10: Burnie Tide Gauge (July 2000)

5.7. Flow Application for Hydrodynamic Modelling

Two approaches were used for application of flow in ICM:

- ICM-RAFTS sub-catchment routing, applied to each sub-catchment in the model at the downstream end of the sub-catchment
- Direct rainfall to model overland flow (short duration events).

The reason for using two approaches is to enable the model to be run efficiently for longer durations by limiting the number of cells wet, focusing on the major tributary flooding while also ensuring the local areas in the upper tributaries are mapped for short duration flooding.

The two flow scenarios sit within the same ICM hydrodynamic model as alternative flow condition scenarios (base and direct rainfall). For the calibration events, only the ICM-RAFTS approach is used, where the rainfall information is derived from rainfall files created by the hydrologic model.

For the design events, an envelope of the ICM-RAFTS approach and the design rainfall approach will be used. Rainfall and temporal pattern information derived from the ARR datahub will be used to establish the design rainfall and temporal pattern information for the ICM-RAFTS approach and a synthetic, duration independent storm will be used to assess a range of storm durations and temporal patterns in a singular rainfall event for the design rainfall approach.

5.7.1. ICM-RAFTS Sub-catchment Routing

For the ICM-RAFTS sub-catchment routing, the RAFTS model within ICM was used to calculate the hydrologic routing at each sub-catchment. Rainfalls, model information and model parameters developed through the external hydrologic model were imported into ICM through the open data input tool.

The information imported into ICM included:

- Sub-catchment name
- Slope
- PERN
- RAF
- Initial and Continuing Loss
- Sub-catchment rainfalls (for calibration events)

Each sub-catchment is connected directly to the 2D mesh surface at the downstream end of the catchment. The resulting RAFTS sub-catchment model setup is shown in Diagram 11. Figure A 1 and Figure A 2 show the hydrological soil groups used to distribute the CL and the average PERN used for each sub-catchment.

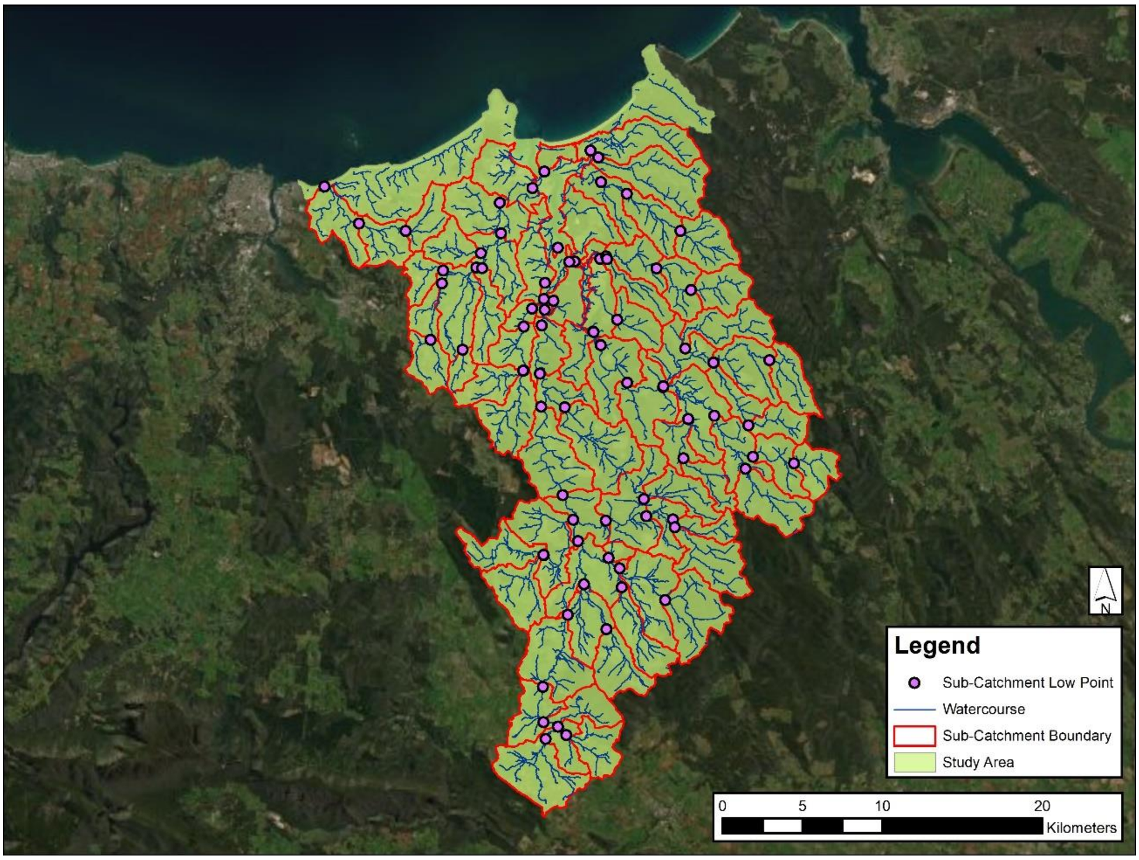

Diagram 11: RAFTS sub-catchment model setup for the Rubicon study area

6. CALIBRATION RESULTS

Mapping of the peak flood depths from the calibrated hydrodynamic model for each calibration event is shown in Figure 6 to Figure 8.

6.1. Sub-catchment Routing and Loss Parameters

The ICM model was run with the routing and loss parameters derived from the external hydrologic model and the calibration process was undertaken for each calibration event. A spatially varying sub-catchment routing parameter was not found to be necessary to achieve a reasonable calibration to the locations of interest and a single sub-catchment routing parameter was used (RAF of 1.6).

A RAF of 1.6 was assumed based on initial model runs with an RAF of 1.0, which indicated that the routing within the sub-catchment component of the model was faster than the recorded catchment responses.

A comparison of the selected RAF of 1.6 and an RAF of 1.0 at Rubicon River, Greens Creek, and Panatana Rivulet is shown in Diagram 12 to Diagram 14. Note that the comparison for Panatana Rivulet has been presented in terms of levels, as differences between the gauge and modelled rating curve were identified (refer Section 6.3.1).

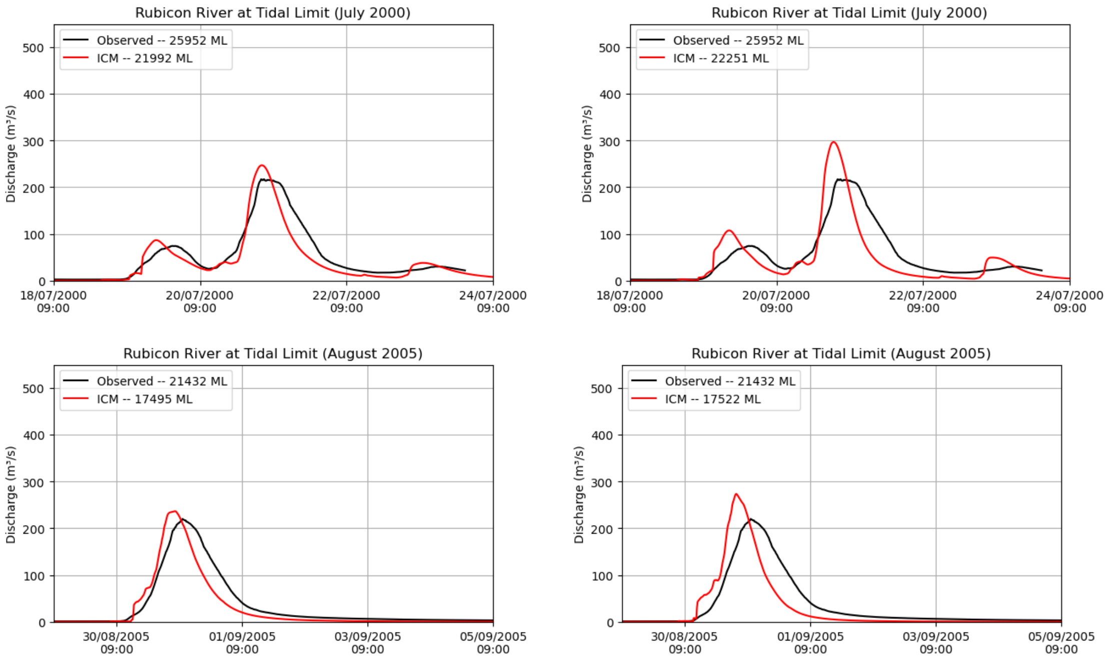

Diagram 12: Flow comparison at Rubicon River at Tidal Limit (left: RAF 1.6, right: RAF 1)

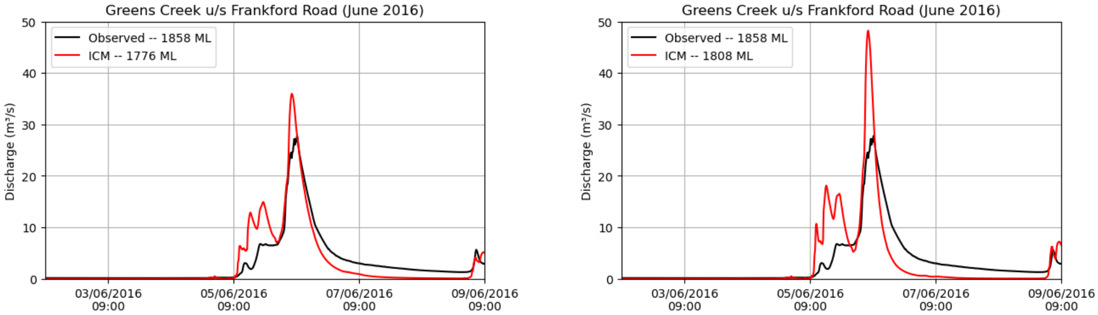

Diagram 13: Flow comparison at Greens Creek u/s Frankford Road (left: RAF 1.6, right: RAF 1)

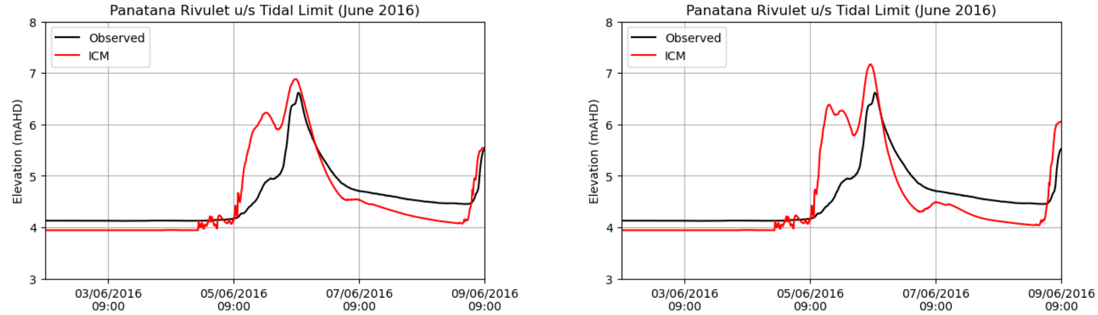

Diagram 14: Flow comparison at Panatana Rivulet u/s Tidal Limit (left: RAF 1.6, right: RAF 1)

Upon completion of the calibration process, the external hydrologic model and the ICM model were compared to ensure that the modelled flows are consistent. This is shown in Appendix C.

6.2. Initial Conditions

Prefilling of the ICM model was not found to be necessary to achieve a reasonable calibration to the locations of interest. On occasion it is necessary to prefill hydraulic models to manage the loss of flood volume due to local depression storage. This scenario however may result in filling of floodplain storage and as such should only be considered where necessary. To ensure there was no incidental filling of floodplain storage in this model it has been run without prefilling.

6.3. Gauge Results

Historic event information was available for the June 2016 event at four of the operational gauges in the study area. Historic event information was only available for the July 2000 and August 2005 events at Rubicon River u/s Tidal Limit as the other gauges were not yet installed.

Historic event information for the July 2000, August 2005, and June 2016 events were not available at Franklin River u/s Tidal Limit as this gauge was closed in 1994.

Comparisons of the gauge rating curves and the rating curves derived from the model are shown in Appendix D.

6.3.1. Rubicon River at Elizabeth Town

The modelled peak level shows a good match to the recorded value for the June 2016 event, noting a slight overestimation (Table 4). The modelled water level response also shows a good match to the timing of the recorded levels (Diagram 16).

Modelled flows compared very poorly to observed flows at this gauge (Diagram 15). The quality of the high flow rating at this gauge was considered to be poor (Section 3.1.2), and large differences were found between rating curve derived from the model and the DNRE rating (Figure D 1).

A gauge zero of 173.0 mAHD was provided for this gauge from the DNRE database. This was adjusted to 173.7 mAHD to better align with the DEM of the hydrodynamic model, noting that the SES state-wide 10 m DEM was used at this location as the 2m DEM subset was found to have been artificially filled behind the road downstream.

The good match to levels, and large differences in flows between the model and the gauge can only be explained by either rating curve issues, datum issues, or poor representation of the channel in ICM. Given that the modelled flow is high and ICM is unlikely to be overestimating the channel conveyance to the magnitude presented, the most likely cause of the discrepancy is errors in the rating.

Table 4: Calibrated parameters and results at Rubicon River at Elizabeth Town

Statistic	June 2016
IL (mm)	33
Average CL (mm/h)	0
RAF	1.6
Modelled Peak (m^3/s)	106
Observed Peak (m^3/s)	28
Peak % difference	+282%
Modelled Volume (ML)	5,751
Observed Volume (ML)	1,922
Volume % difference	+199%
Modelled peak (mAHD)	176.25
Observed peak (mAHD)	176.14
Peak difference (m)	+0.11

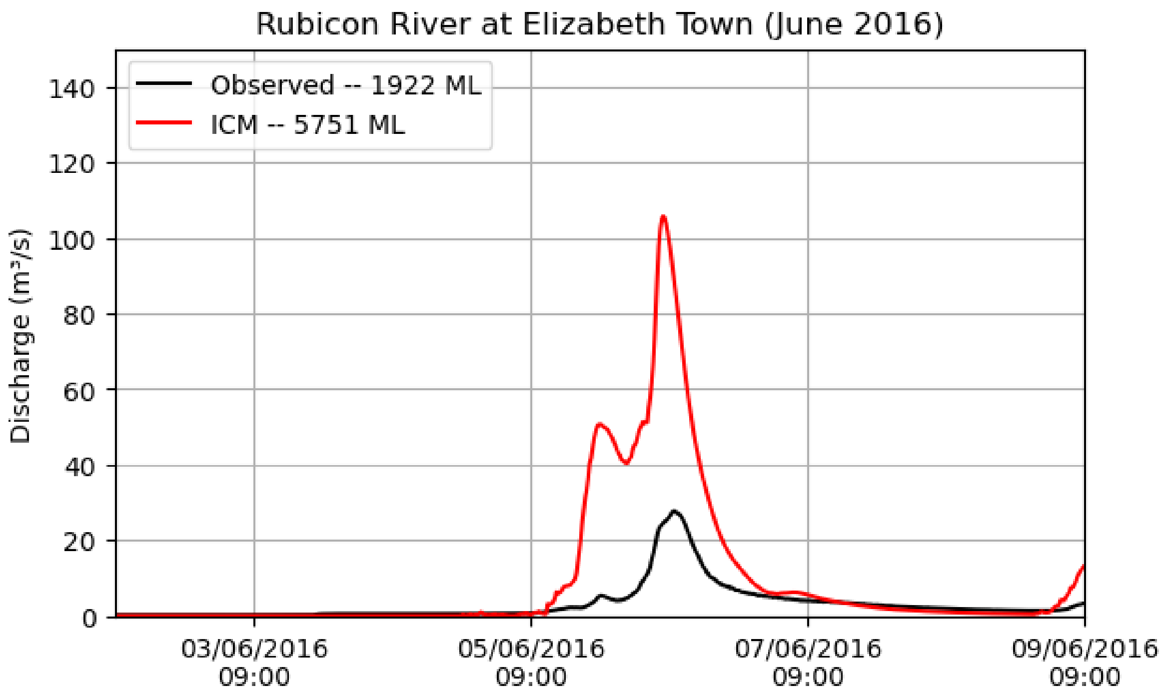

Diagram 15: June 2016 flow comparison at Rubicon River at Elizabeth Town

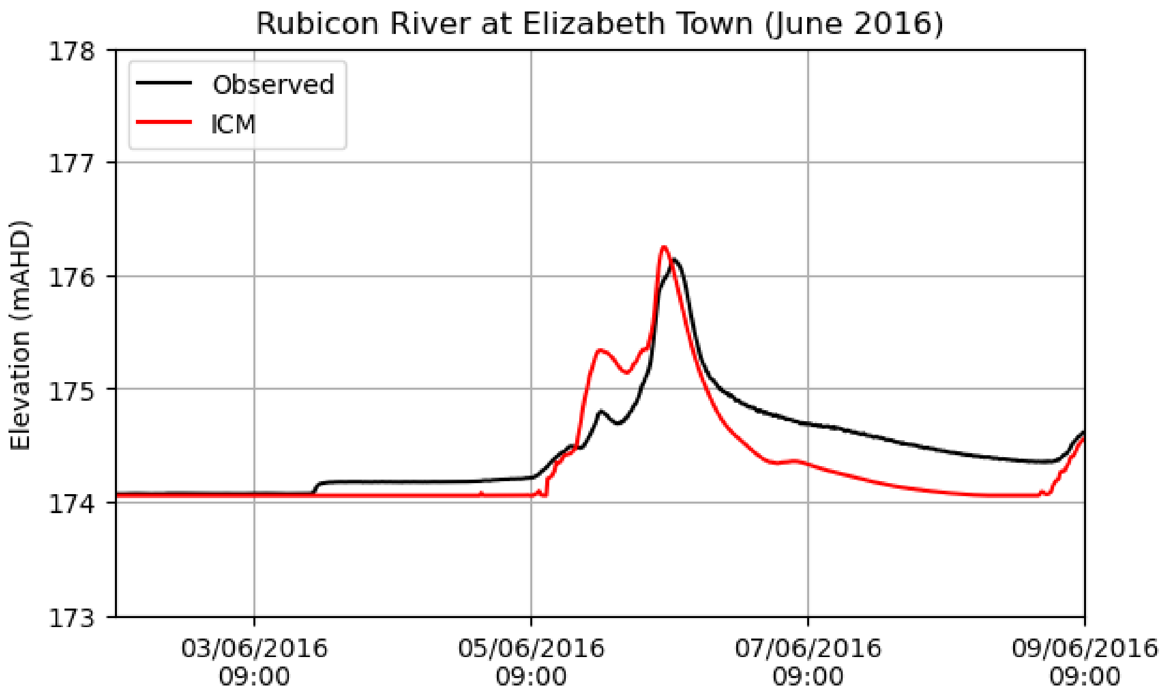

Diagram 16: June 2016 water level comparison at Rubicon River at Elizabeth Town

6.3.1. Rubicon River at Tidal Limit

During the June 2016 flood event the Rubicon River at Tidal limit gauge was damaged and failed to report the peak levels. To ensure reasonable calibration at this gauge, additional events (July 2000 and August 2005) have also been assessed.

The peak of the June 2016 event has been estimated for the purposes of this assessment. In all events modelled, a reasonable match to flow, level and shape is achieved (Diagram 17 to Diagram 22). The model slightly under-estimates water levels compared to the rating curve however the model is considered to provide a reasonable representation of conditions at the gauge (Appendix D).

A gauge zero of 2.74 mAHD was provided for this gauge from the DNRE database. This was adjusted to 2.50 mAHD to better align with the DEM of the hydrodynamic model.

Table 5: Calibrated parameters and results at Rubicon River at Tidal Limit

Statistic	June 2016*	July 2000	August 2005
IL (mm)	33	0	0
Average CL (mm/h)	0	1.59	1.59
RAF	1.6	1.6	1.6
Modelled Peak (m^3/s)	446	247	237
Observed Peak (m^3/s)	-*	217	220
Peak % difference	-*	+14%	+7%
Modelled Volume (ML)	33,951	21,992	17,495
Observed Volume (ML)	-*	25,952	21,432
Volume % difference	-*	-15%	-18%
Modelled peak (mAHD)	5.85	5.16	5.11
Observed peak (mAHD)	-*	5.22	5.27
Peak difference (m)	-*	-0.06	-0.15

* Gauge was damaged and failed to report the peaks.

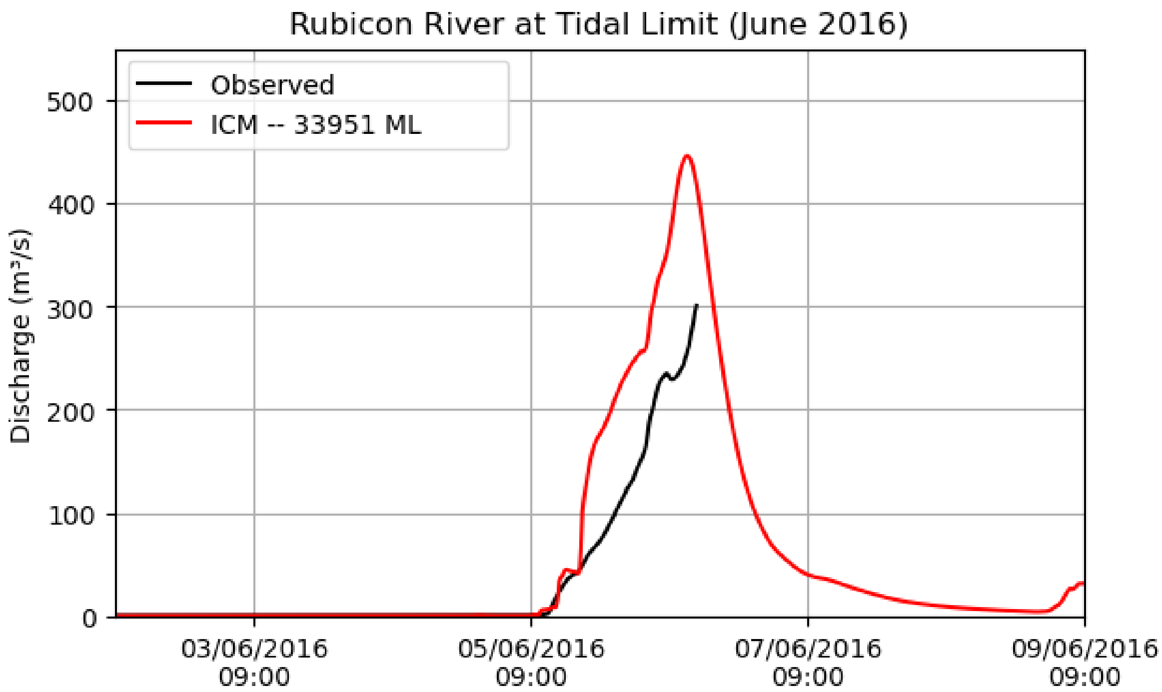

Diagram 17: June 2016 flow comparison at Rubicon River at Tidal Limit

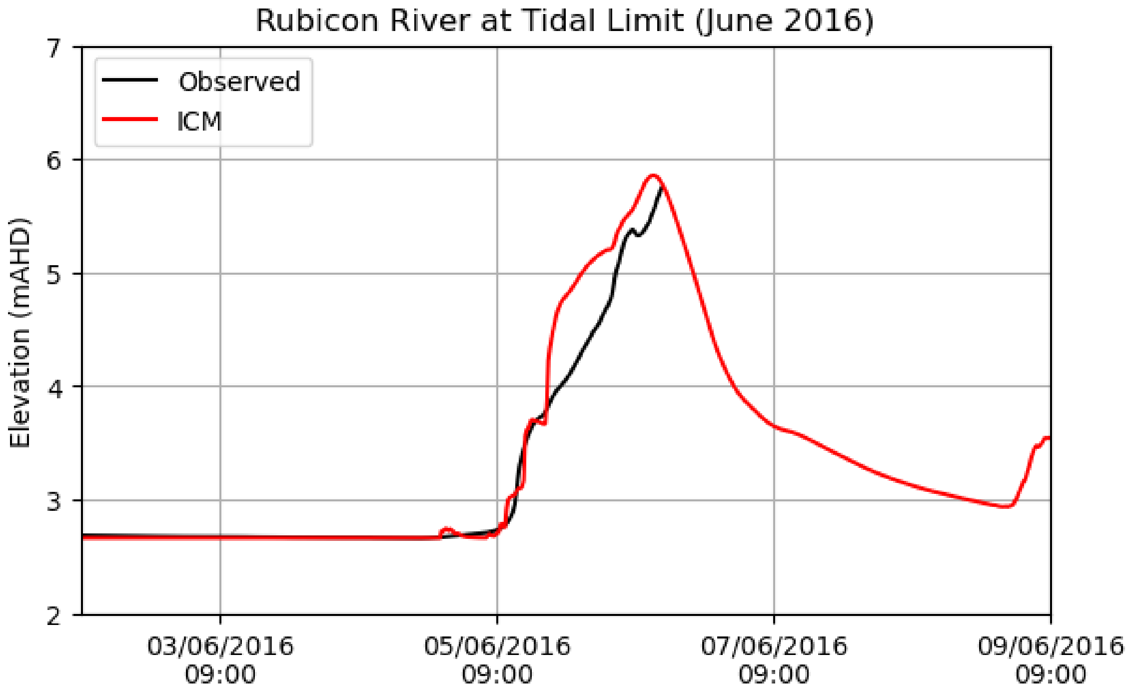

Diagram 18: June 2016 water level comparison at Rubicon River at Tidal Limit

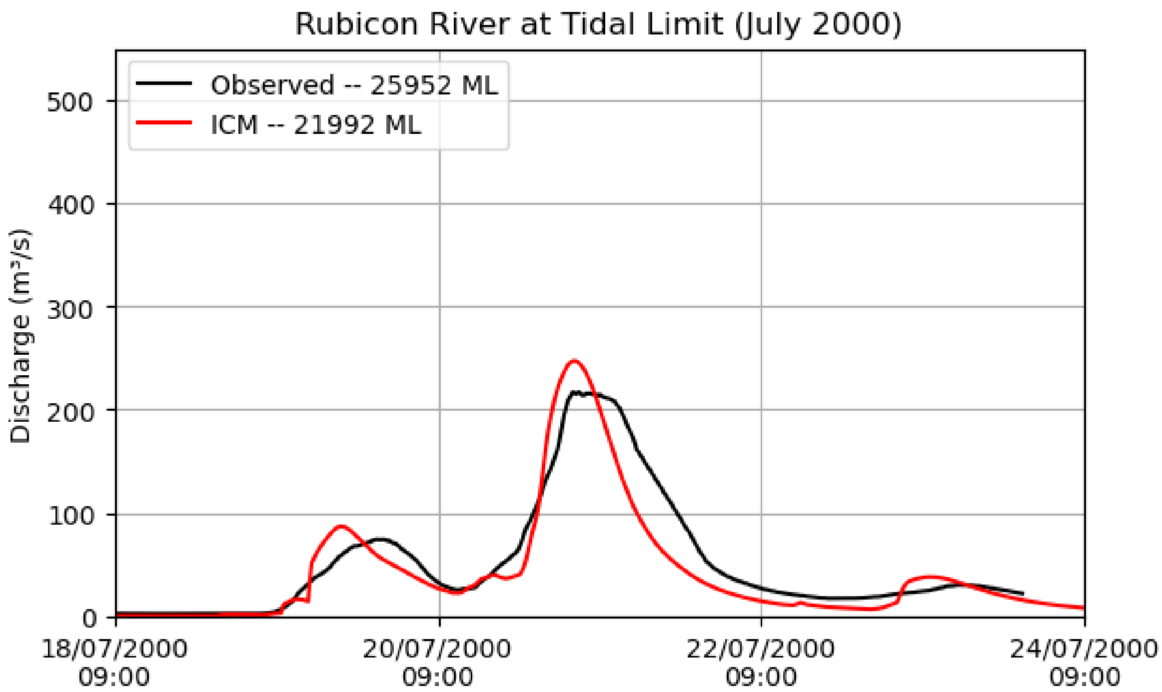

Diagram 19: July 2000 flow comparison at Rubicon River at Tidal Limit

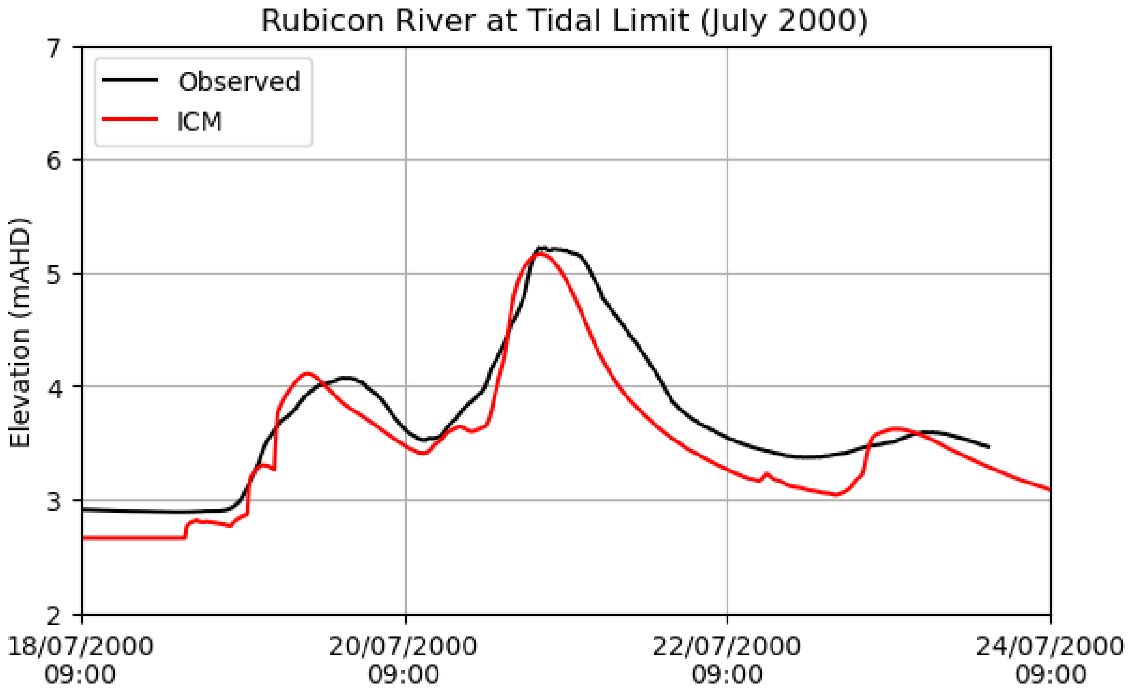

Diagram 20: July 2000 water level comparison at Rubicon River at Tidal Limit

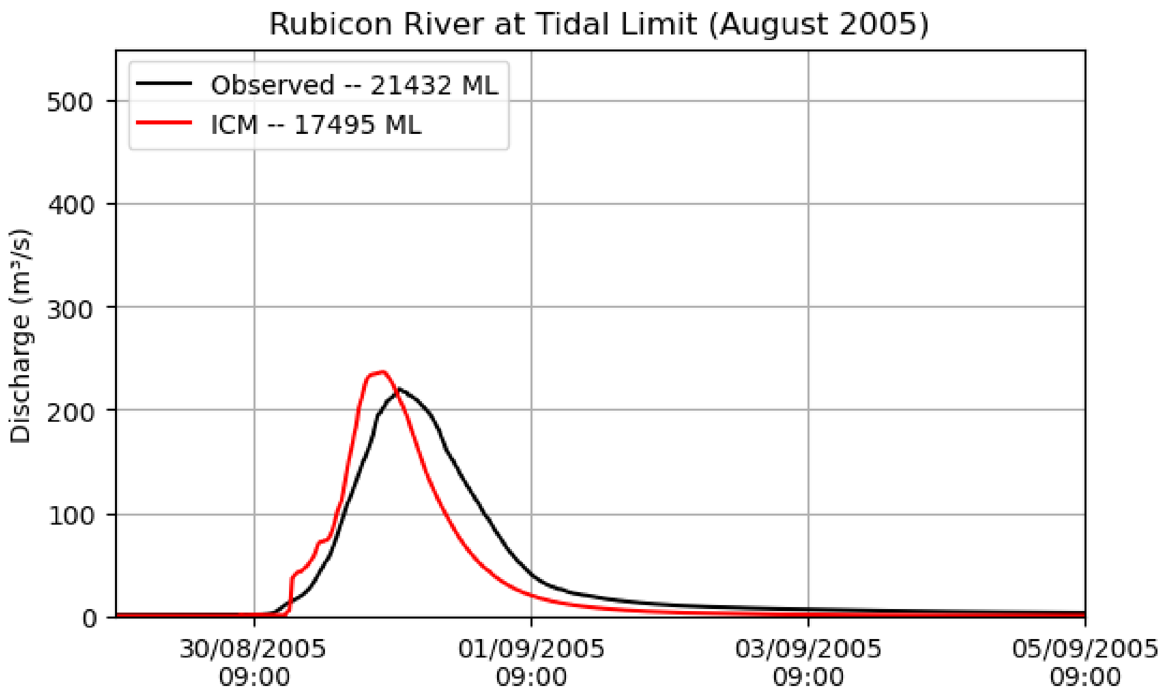

Diagram 21: August 2005 flow comparison at Rubicon River at Tidal Limit

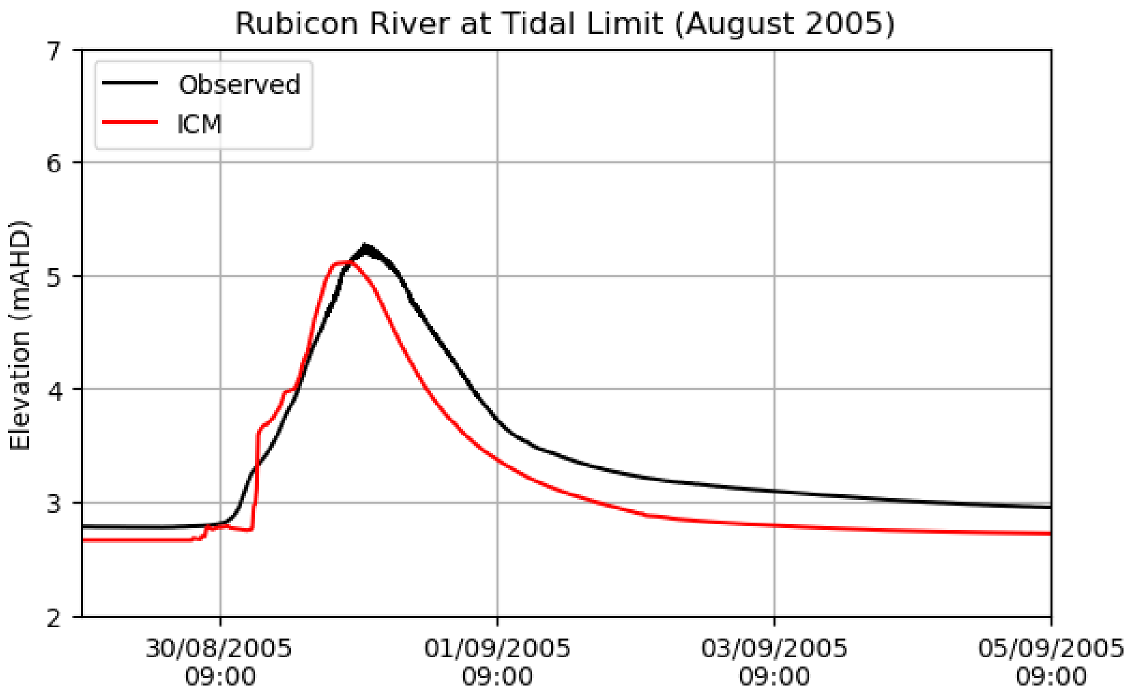

Diagram 22: August 2005 water level comparison at Rubicon River at Tidal Limit

6.3.1. Greens Creek u/s Frankford Road

The modelled peak flow and level show a good match to the recorded values for the June 2016 event, noting a slight overestimation (Table 6). The modelled hydrograph and water level response also shows a good match to the timing of the recorded flows and levels (Diagram 23 and Diagram 24). The discrepancy at the peak is likely due to temporal pattern deficiencies in the catchment rainfall data, overall however a good match to the shape of the event is achieved.

The continuing loss of 3 mm/h in this catchment is higher than the continuing loss for the same event in other gauge catchments in the study area. This is attributed to the large number of farm dams in the catchment, with some larger dams with storages of up to 390 ML. There are more than 50 farm dams within the catchment, with a total storage of more than 900 ML. This is a significant volume compared to the volume of the event. A continuing loss of 0 was trialled in this catchment and resulted in significant overestimation of both flows and levels for this event.

A gauge zero was not available for this gauge from the DNRE database, so an assumed gauge zero of 6.6 mAHD was assumed. This gauge zero was inferred from the DEM of the hydrodynamic model.

Only minor differences between the gauge and modelled rating curves were observed (Figure D 3).

It is noted that during the 2016 event there was also another gauge, Greens Creek u/s Torrington Road, located a short distance upstream of this gauge. Variances in the observed flow indicated a likely discrepancy in reporting at the other gauge. Noting these issues and the fact the gauge is no longer active, only Greens Creek u/s Frankford Road has been assessed.

Table 6: Calibrated parameters and results at Greens Creek u/s Frankford Road

Statistic	June 2016
IL (mm)	33
Average CL (mm/h)	3.00
RAF	1.6
Modelled Peak (m^3/s)	36
Observed Peak (m^3/s)	28
Peak % difference	+29%
Modelled Volume (ML)	1,776
Observed Volume (ML)	1,858
Volume % difference	-4%
Modelled peak (mAHD)	8.34
Observed peak (mAHD)	7.97
Peak difference (m)	+0.37

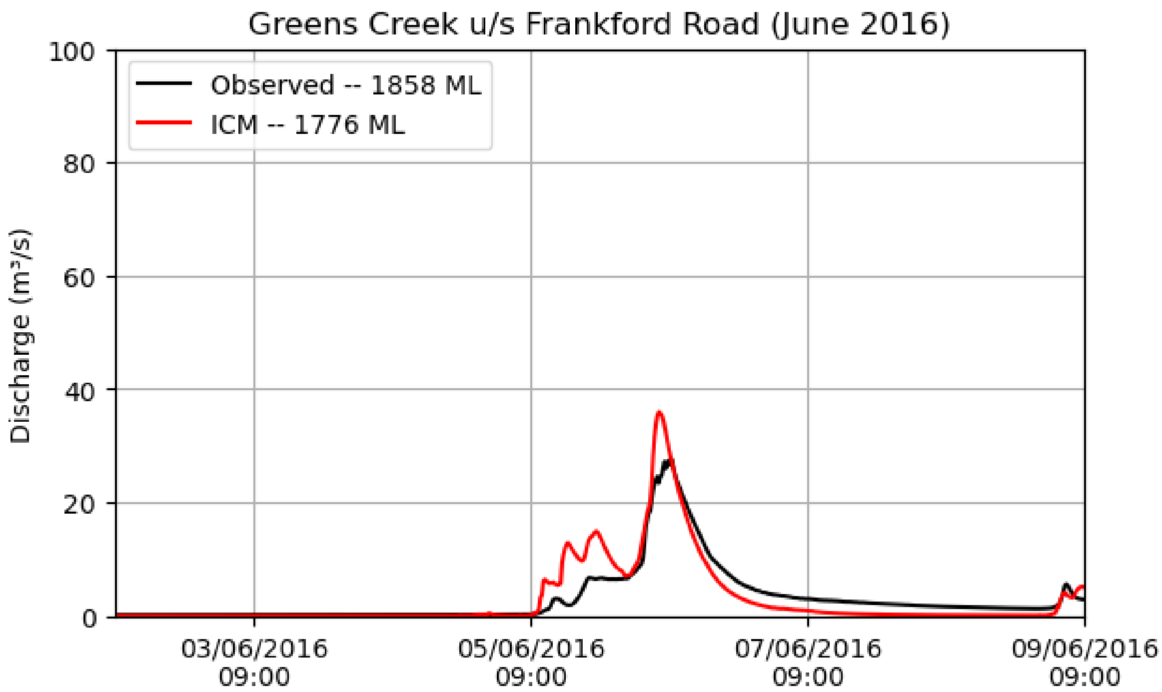

Diagram 23: June 2016 flow comparison at Greens Creek u/s Frankford Road

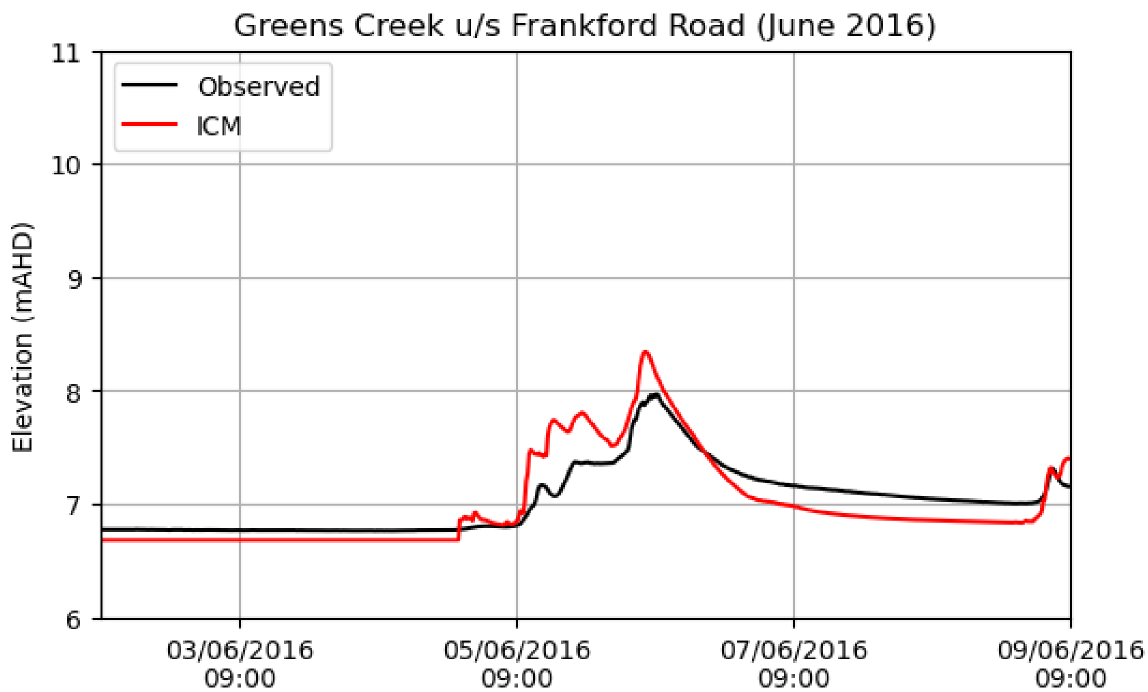

Diagram 24: June 2016 water level comparison at Greens Creek u/s Frankford Road

6.3.1. Panatana Rivulet u/s Tidal Limit

The modelled peak level shows a good match to the recorded value for the June 2016 event, noting a slight overestimation (Table 7). The modelled water level response also shows a good match to the timing of the recorded levels (Diagram 26).

Note a check of the modelled response utilising the losses established for Greens Creek u/s Frankford Road was undertaken however this resulted in a gross under estimation of the level at the gauge. It is considered the use of losses consistent with the regional estimates is appropriate given the outcome of the losses check.

The modelled flows show a very poor match to the observed flows (Diagram 25). The quality of the high flow rating at this gauge was considered to be poor (Section 3.1.2), and large differences were found between rating curve derived from the model and the DNRE rating (Figure D 4).

A gauge zero of 3.93 mAHD was provided for this gauge from the DNRE database.

Table 7: Calibrated parameters and results at Panatana Rivulet u/s Tidal Limit

Statistic	June 2016
IL (mm)	33
Average CL (mm/h)	0
RAF	1.6
Modelled Peak (m^3/s)	102
Observed Peak (m^3/s)	31
Peak % difference	+230%
Modelled Volume (ML)	8,011
Observed Volume (ML)	2,338
Volume % difference	+243%
Modelled peak (mAHD)	6.88
Observed peak (mAHD)	6.62
Peak difference (m)	+0.26

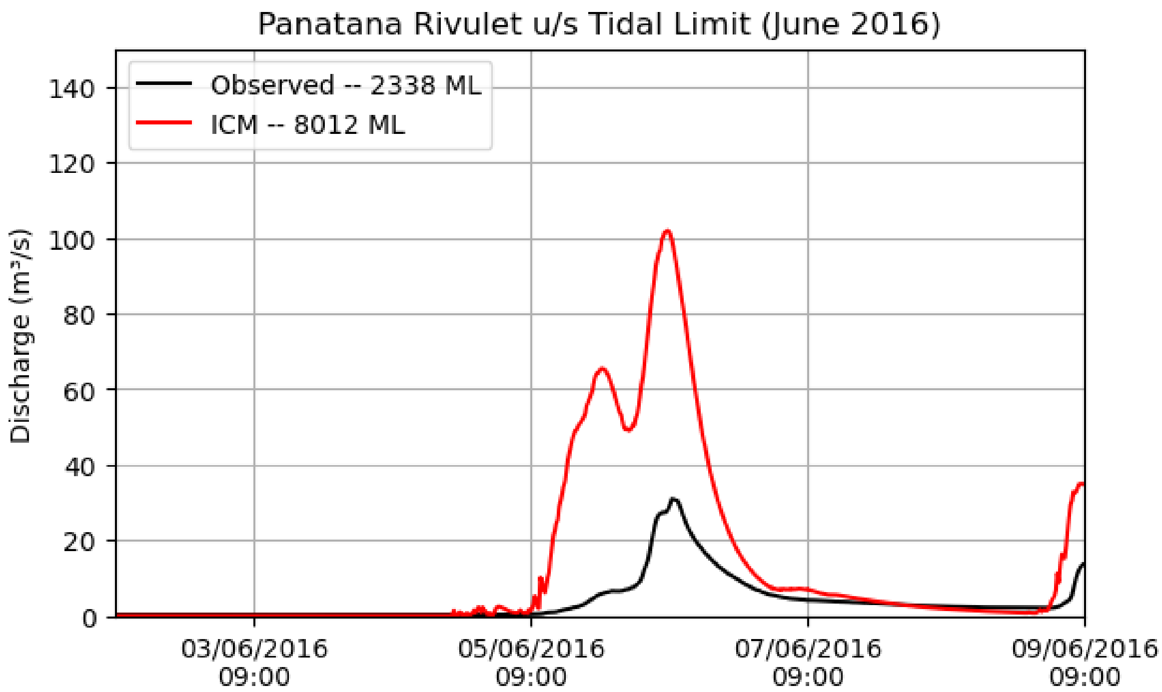

Diagram 25: June 2016 flow comparison at Panatana Rivulet u/s Tidal Limit

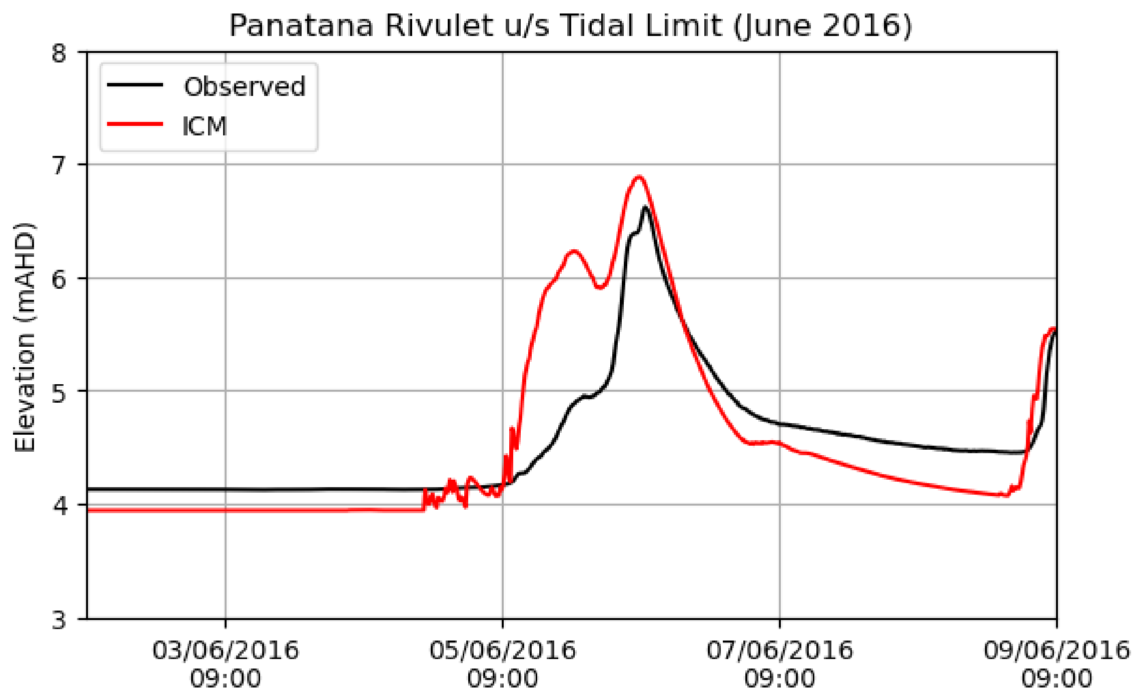

Diagram 26: June 2016 water level comparison at Panatana Rivulet u/s Tidal Limit

6.4. June 2016 Flood Survey

As part of the Tasmanian flood recovery program following the 2016 floods, the Tasmanian Government collected flood extents survey around impacted areas of Tasmania. The survey utilised damage locations, debris marks and witness accounts to survey the full extent of the June 2016 flood.

Within the Rubicon study area, the June 2016 flood survey was limited to a small number of locations along Panatana Rivulet and Pardoe Creek. Due to the limited number of points along Panatana Rivulet, the accuracy of the flood extent is likely to be poor beyond the immediate vicinity of the points. A flood extent is not available for Pardoe Creek as only one location was surveyed. The June 2016 flood survey does not include Rubicon River, Greens Creek, or Franklin River.

A comparison of the modelled and flood survey extents is shown in Figure 9. Diagram 27 and Diagram 28 show the modelled and surveyed flood extents for the June 2016 event. Diagram 29 shows the difference between the modelled and surveyed levels, with the upper and lower limits based on the confidence levels provided with the survey. There is generally a very good agreement between the surveyed and modelled levels for the June 2016 event through Panatana Rivulet and Pardoe Creek, with all points other than one falling within ±0.5 m of the surveyed levels.

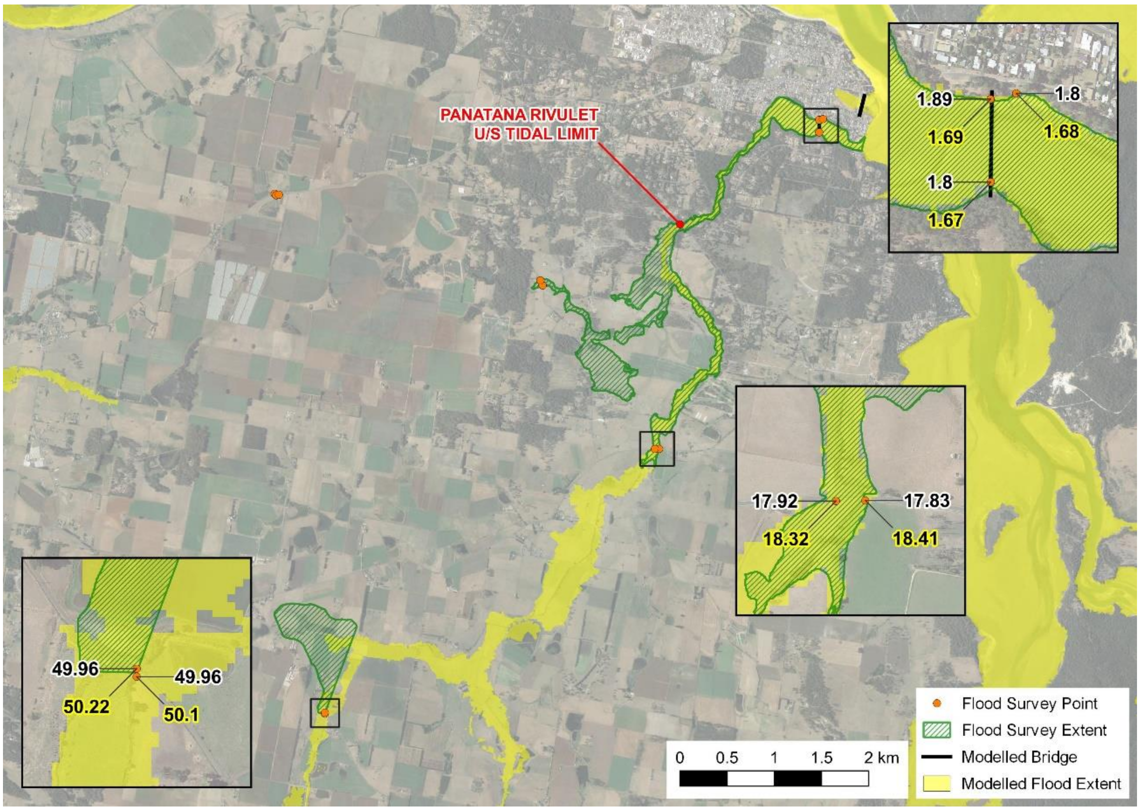

Diagram 27: Comparison to June 2016 flood survey along Panatana Rivulet. Modelled levels highlighted in yellow.

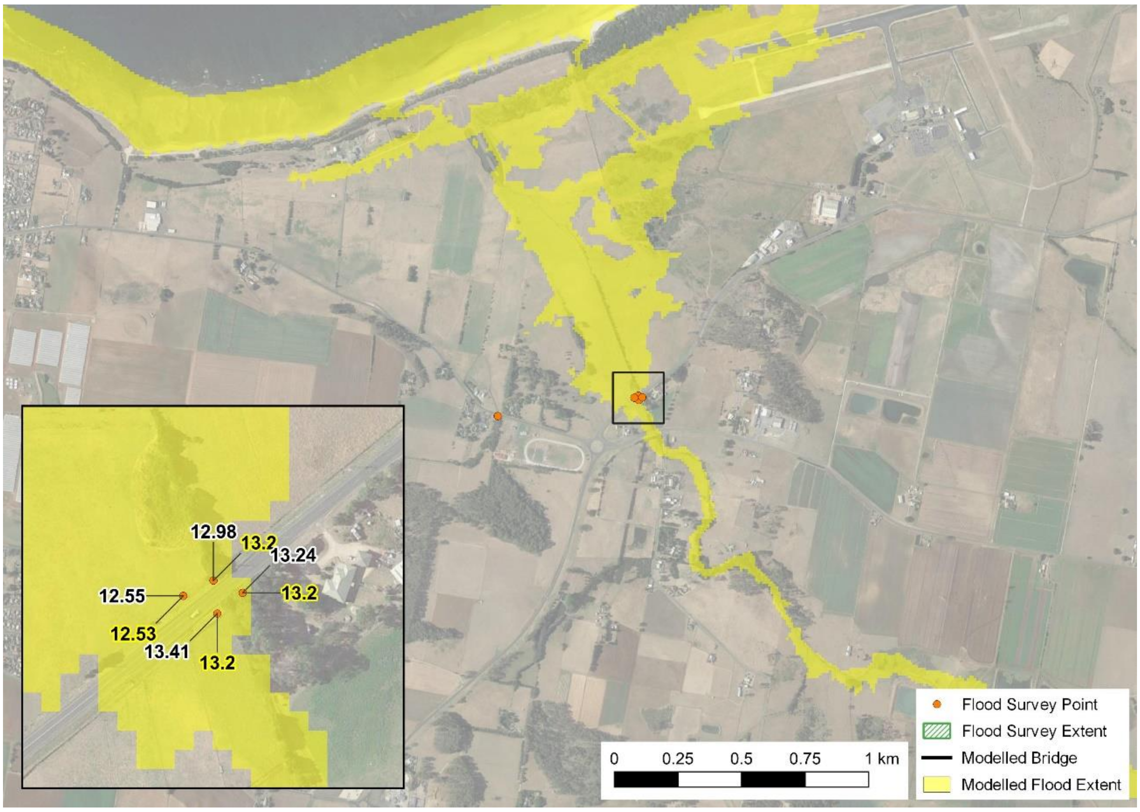

Diagram 28: Comparison to June 2016 flood survey along Pardoe Creek. Modelled levels highlighted in yellow.

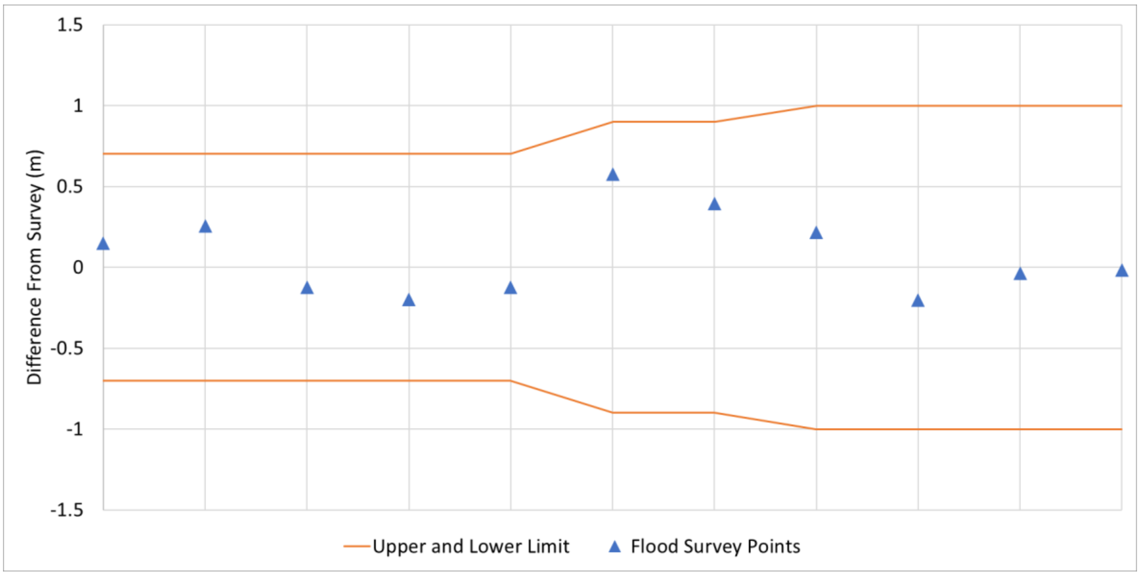

Diagram 29: Comparison to June 2016 flood survey – difference from the surveyed levels

6.5. Identified Issues

The following issues have been identified, which should be investigated further if future detailed analysis is undertaken:

- The model appears to respond appropriately to the additional calibration events at Rubicon Tidal gauge, where the events were identified as the 3rd and 4th largest events on record. Although the model appears to respond appropriately to the June 2016 calibration event at Rubicon River at Elizabeth Town, Greens Creek, and Panatana Rivulet, no other significant events were available at these locations due to their short period of operation. While the model is considered to be valid based on the available information, future detailed analysis should attempt the calibration of other events and locations to improve the confidence in the model calibration.
- If available, the representation of the structures downstream of Rubicon River at Elizabeth Town, Greens Creek u/s Frankford Road, and Panatana Rivulet u/s Tidal limit should be updated with as constructed or surveyed data
- If available, the representation of the rivers and channels that that are frequently submerged should be updated with improved bathymetry data.

7. UNCERTAINTY ASESSMENT

Significant flows were recorded in the study area for one of the 13 flood events selected by the Bureau as calibration events for this project, in June 2016. Two additional events, in July 2000 and August 2005, were used in calibration.

Flow data was available at one gauge for the July 2000 and August 2005 events. Flow data was available at five gauges for the June 2016 event, however the poor quality of the high flow ratings at four of the gauges results in very large uncertainties in the flows. Flood extents and depths were available for the June 2016 event in a small area of the catchment around the Panatana River and Pardoe Creek.

The uncertainty assessment for the modelling is shown in Table 8 and Appendix B.

Table 8: Uncertainty assessment for Rubicon study area model

Category	Quality statement
Hydrology – rainfall input quality	The quality of the rainfall data is generally fair. There is one sub-daily rain gauge within the Rubicon study area for all events with an additional gauge available for the June 2016 event, and additional sub-daily gauges just outside the study area in the south-east. There are at least five daily gauges within the study area with data available for calibration events.
Hydrology – observed flows	At all sites gaugings are within the river channel and are considerably lower than the highest recorded stage height. The high flow ratings at all sites other than Rubicon River at Tidal limit are considered to be very poor. The calibration events are at flows that are in the area of extrapolated rating curves at all sites. A theoretical rating was developed using a local hydraulic model at Rubicon River at Tidal Limit gauge and this rating has been used in calibration.
Hydrology – calibration events	Rubicon River at Tidal limit gauge reached its highest flow on record in the June 2016 event before the site was destroyed. The August 2005 and July 2000 events were the 3rd and 4th largest events at the Rubicon at Tidal gauge, with approximate AEPs between 5% and 10%.
Hydrology – calibration results	The hydrology calibration was considered to provide a very good match to peak flows for both calibration events at the Rubicon River at Tidal Limit gauge and a good match to observed volume. The match to observed flows for June 2016 at all other gauges was very poor due to the poor high flow ratings.
DTM definition	The base dataset that was used for the digital elevation model (DEM) of the hydrodynamic model was the SES state-wide 10 m DEM merged with 2 m DEM subsets at the gauges (where available). 2 m DEM subsets were used at all of the operational gauges in the study area, except for Rubicon River at Elizabeth Town. The SES state-wide 10 m DEM was used at this location as the 2 m DEM subset was found to have been artificially filled behind the road downstream.
DTM waterways	No bathymetric data was available and waterway definition was based on the LiDAR to water surface.
Hydrodynamic – observed flood depths	Flood depths were available for the June 2016 event for 11 survey points around the Panatana River and Pardoe Creek.

Category	Quality statement
Hydrodynamic – overall calibration results	The model results showed a very good to excellent match to peak levels for all events and gauges.
Hydrodynamic – calibration results, flood extents	The June 2016 flood survey in this study area was limited to a small number of locations along Panatana Rivulet and Pardoe Creek. Due to the limited number of points along Panatana Rivulet, the accuracy of the flood extent is likely to be poor beyond the immediate vicinity of the points. A fair to good match to the flood extent was obtained from the model results in the limited area for comparison.
Hydrodynamic – calibration results, flood depths	The results showed a good match to surveyed flood levels with modelled levels within ±0.52 m.

8. REFERENCES

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Figures

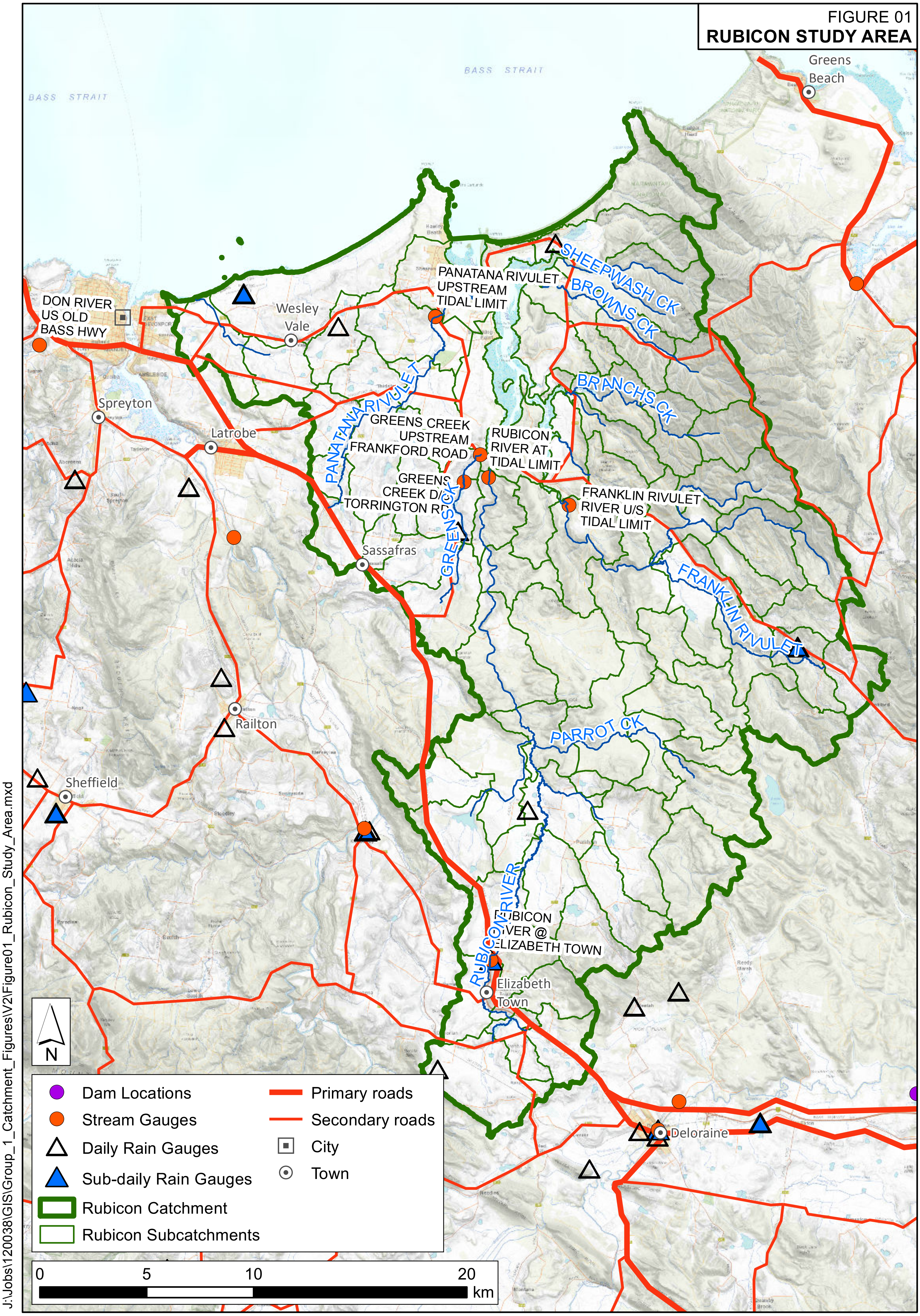

FIGURE 01
RUBICON STUDY AREA
BASS STRAIT
BASS STRAIT
Greens Beach
DON RIVER US OLD BASS HWY
Wesley Vale
PANATANA RIVULET UPSTREAM TIDAL LIMIT
SHEEPWASH CK
BROWNS CK
BRANCHS CK
PANATANA RIVULET
GREENS CREEK UPSTREAM FRANKFORD ROAD
RUBICON RIVER AT TIDAL LIMIT
GREENS CREEK D/S TORRINGTON RD
FRANKLIN RIVULET RIVER U/S TIDAL LIMIT
GREENS CK
FRANKLIN RIVULET
Spreyton
Latrobe
Sassafras
Railton
Sheffield
PARROT CK
RUBICON RIVER
RUBICON RIVER @ ELIZABETH TOWN
Elizabeth Town
Deloraine
N
Dam Locations
Stream Gauges
Daily Rain Gauges
Sub-daily Rain Gauges
Rubicon Catchment
Rubicon Subcatchments
Primary roads
Secondary roads
City
Town
0
5
10
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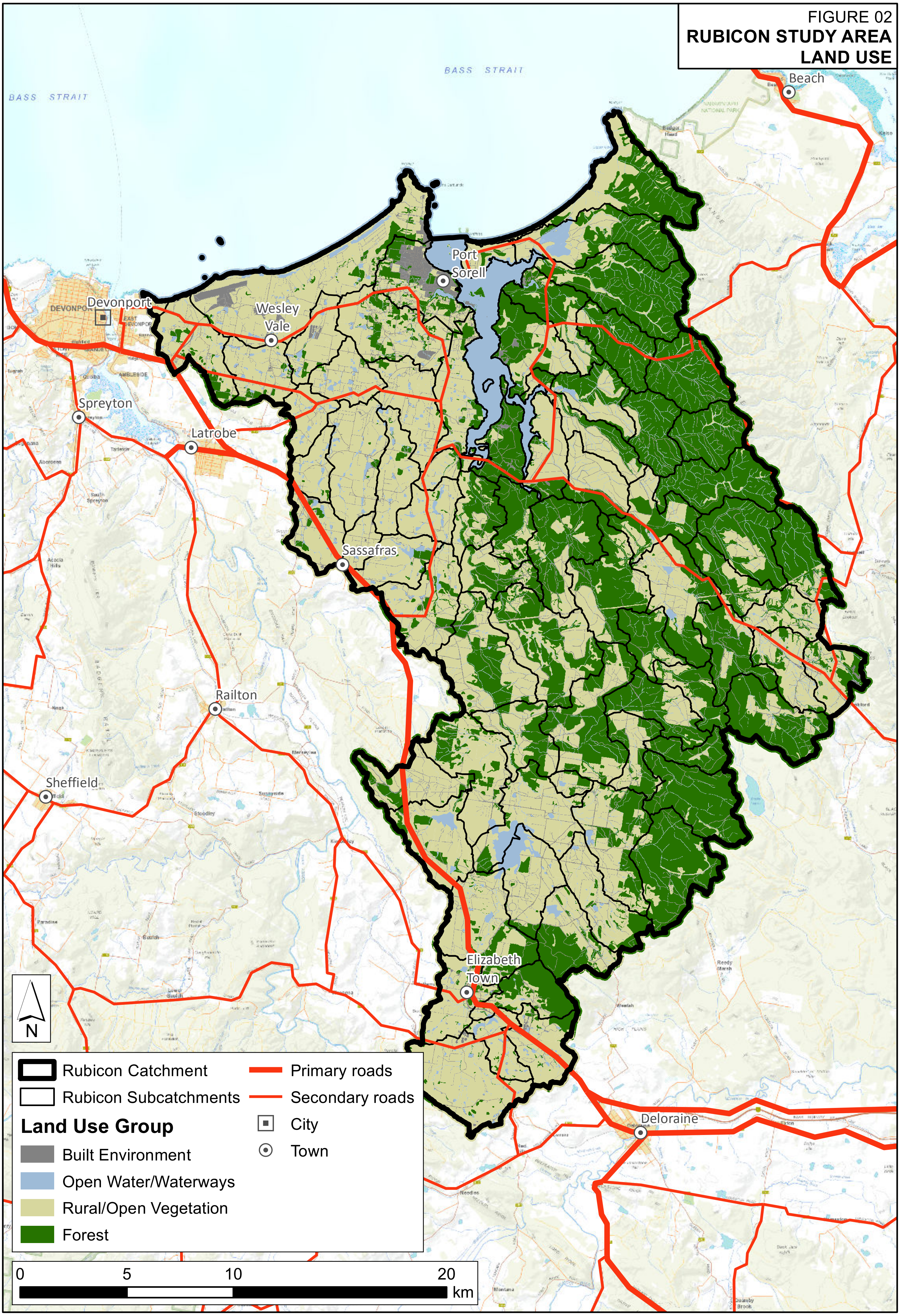

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FIGURE 03
RUBICON STUDY AREA
RAINFALL 2000_JUL

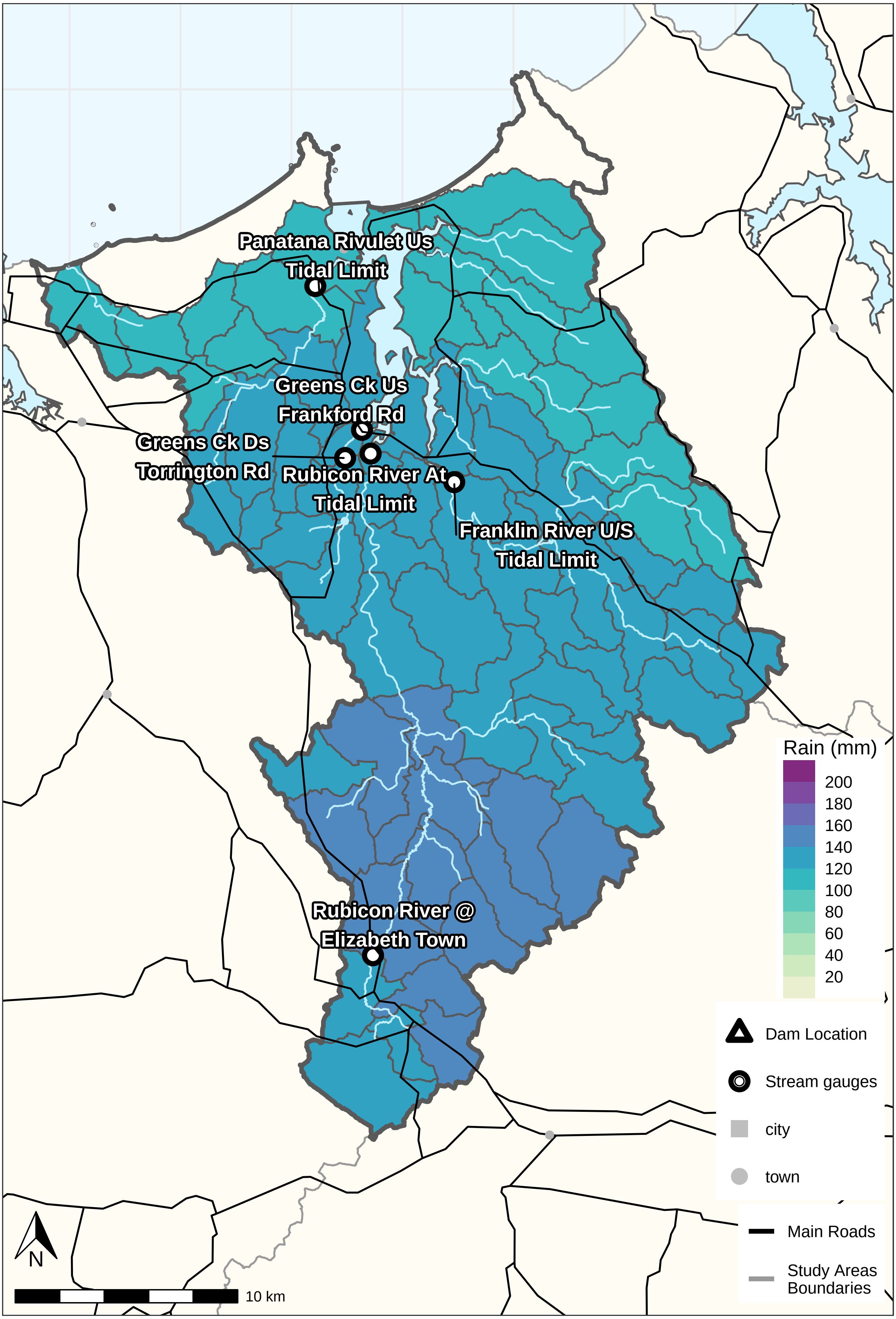

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FIGURE 04
RUBICON STUDY AREA
RAINFALL 2005_AUG

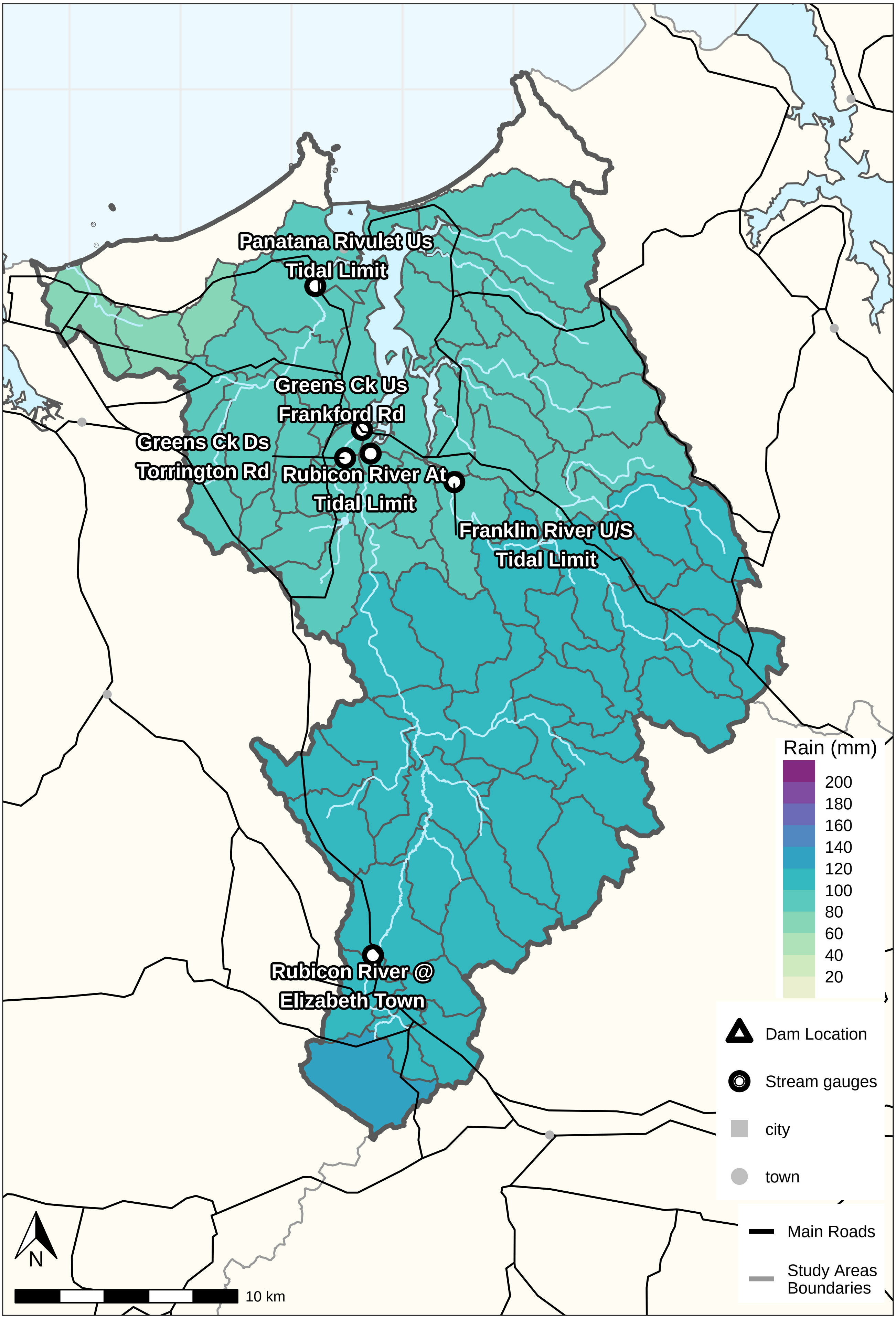

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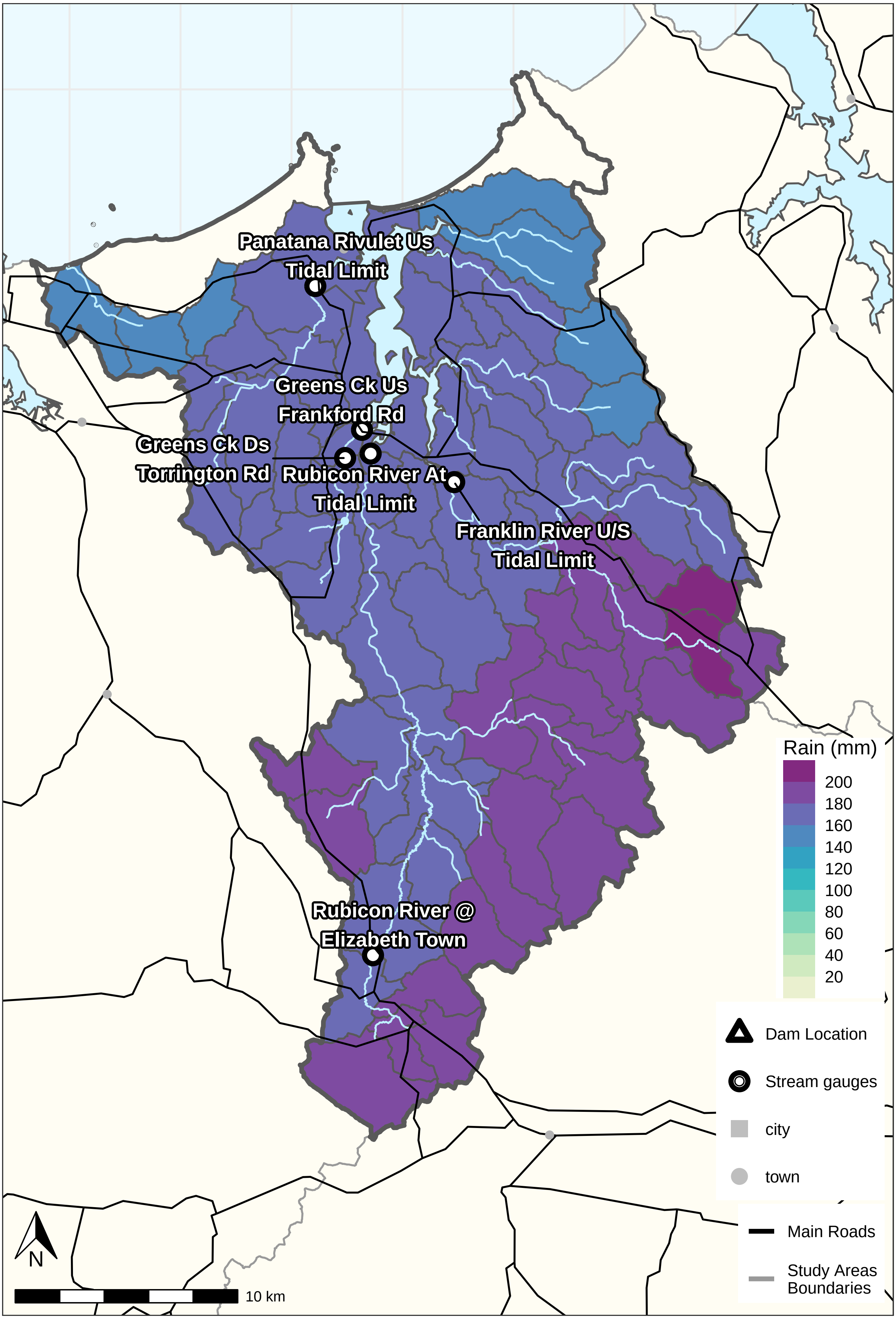
FIGURE 05
RUBICON STUDY AREA
RAINFALL 2016_JUN



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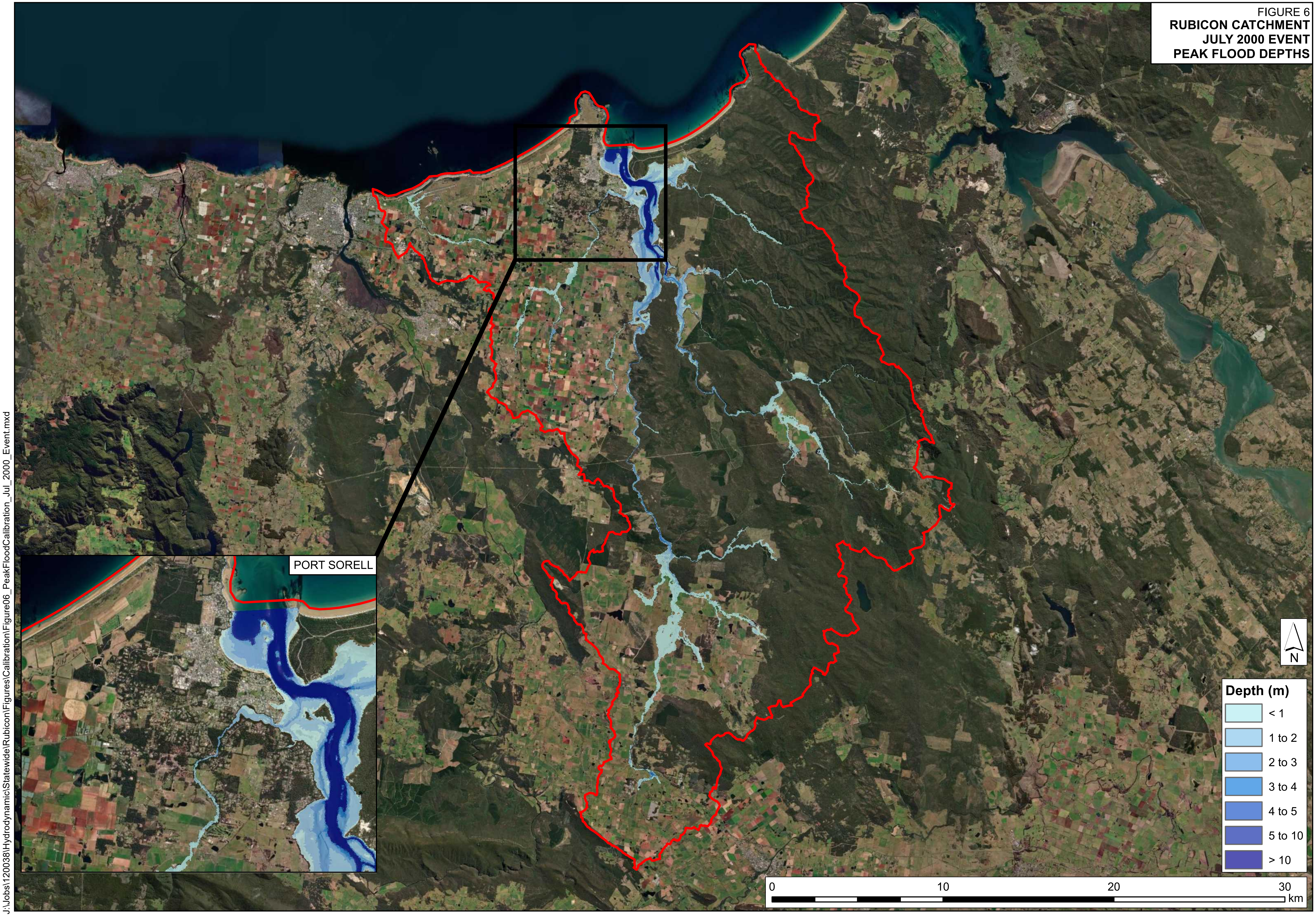
FIGURE 6
RUBICON CATCHMENT
JULY 2000 EVENT
PEAK FLOOD DEPTHS
PORT SORELL
N
Depth (m)
< 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 10
> 10
0
10
20
30
km
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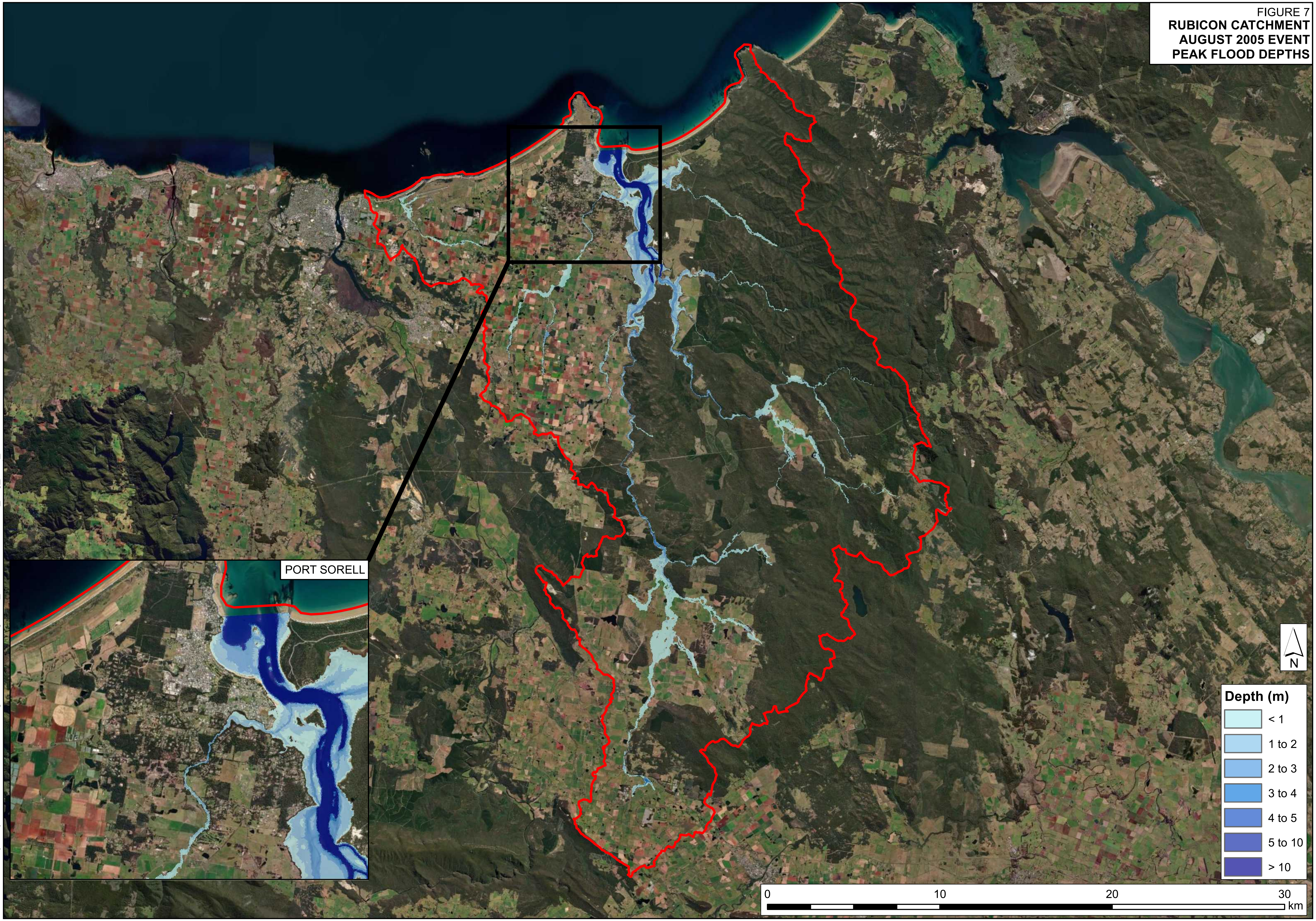
FIGURE 7
RUBICON CATCHMENT
AUGUST 2005 EVENT
PEAK FLOOD DEPTHS
PORT SORELL
N
Depth (m)
< 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 10
> 10
0
10
20
30
km
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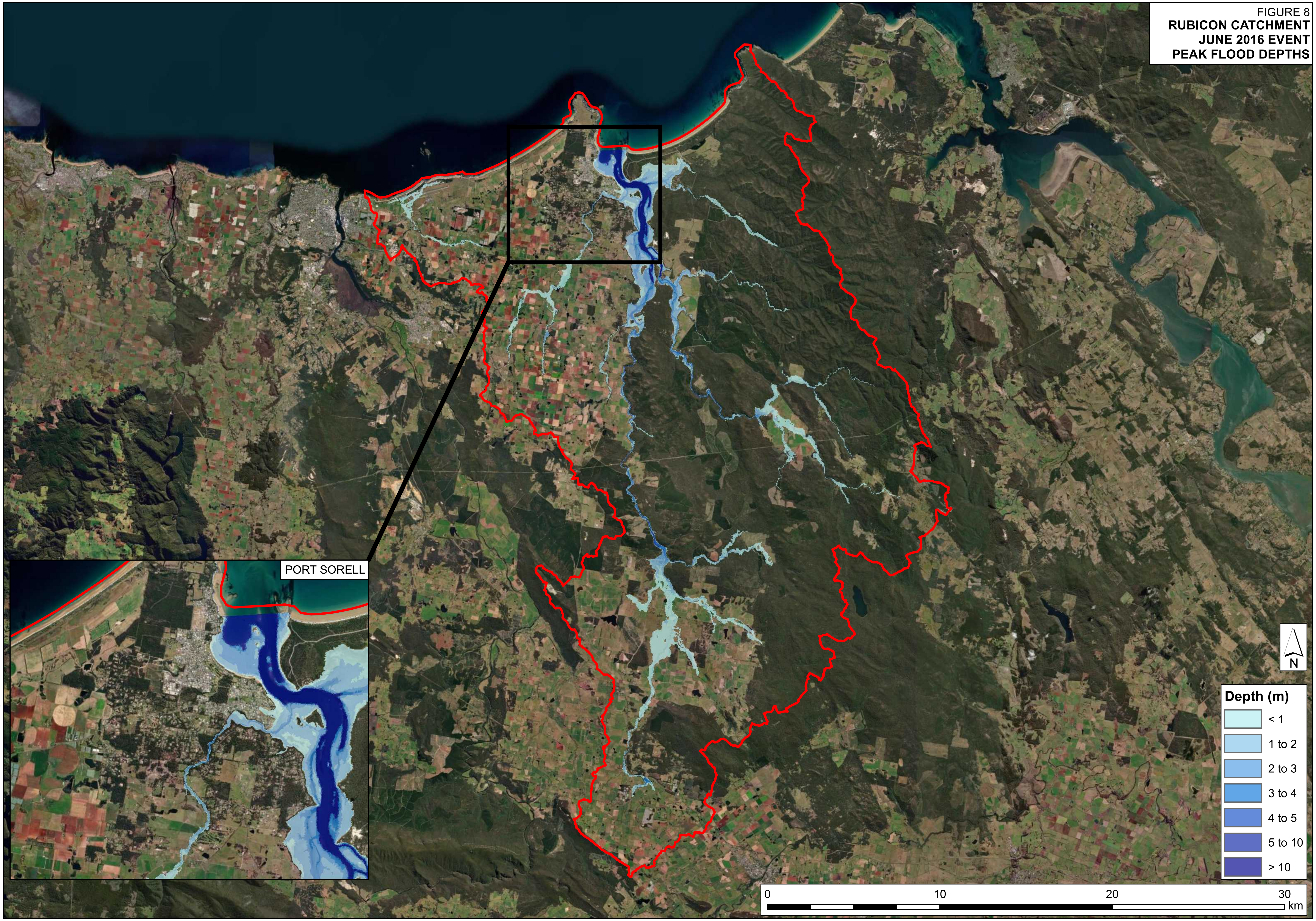


FIGURE 8
RUBICON CATCHMENT
JUNE 2016 EVENT
PEAK FLOOD DEPTHS

J:\Jobs\120038\Hydrodynamic\Statewide\Rubicon\Figures\Calibration\Figure08_PeakFloodCalibration_Jun_2016_Event.mxd

FIGURE 9
RUBICON CATCHMENT
JUNE 2016 EVENT
FLOOD EXTENT COMPARISSON
N
Flood Survey Point
Flood Survey Extent
Depth (m)
< 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 10
> 10
0
1
2
3
km
J:\Jobs\120038\Hydrodynamic\Statewide\Rubicon\Figures\Calibration\Figure09_PeakFloodComparison_Jun_2016_Event.mxd

Appendix A

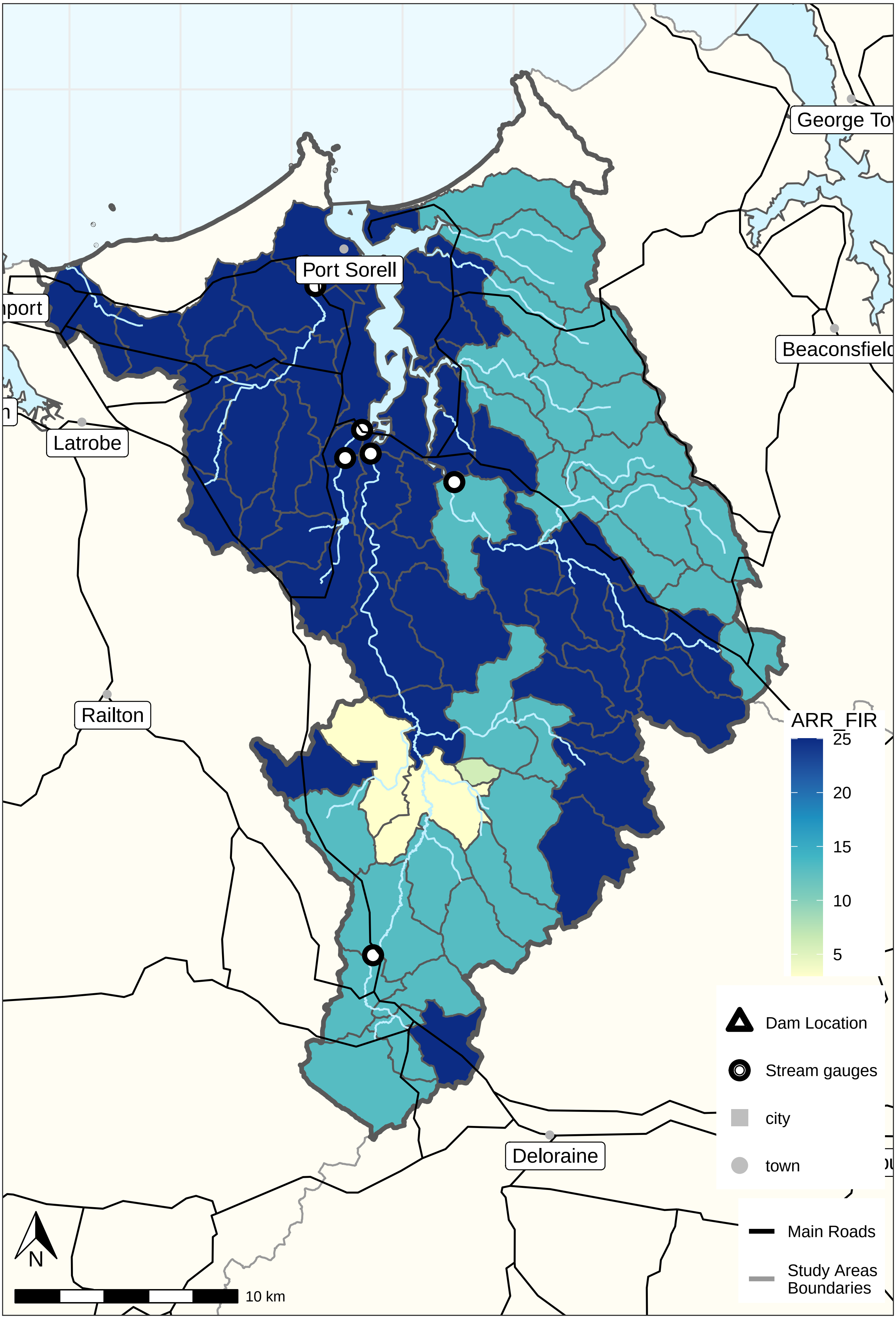
APPENDIX A. AVALIABLE DATA

A.1. Sub catchment data

FIGURE A1

HYDROLOGICAL SOIL GROUP MAPPING

DOMINANT SUBCATCHMENT SOIL INFILTRATION RATE



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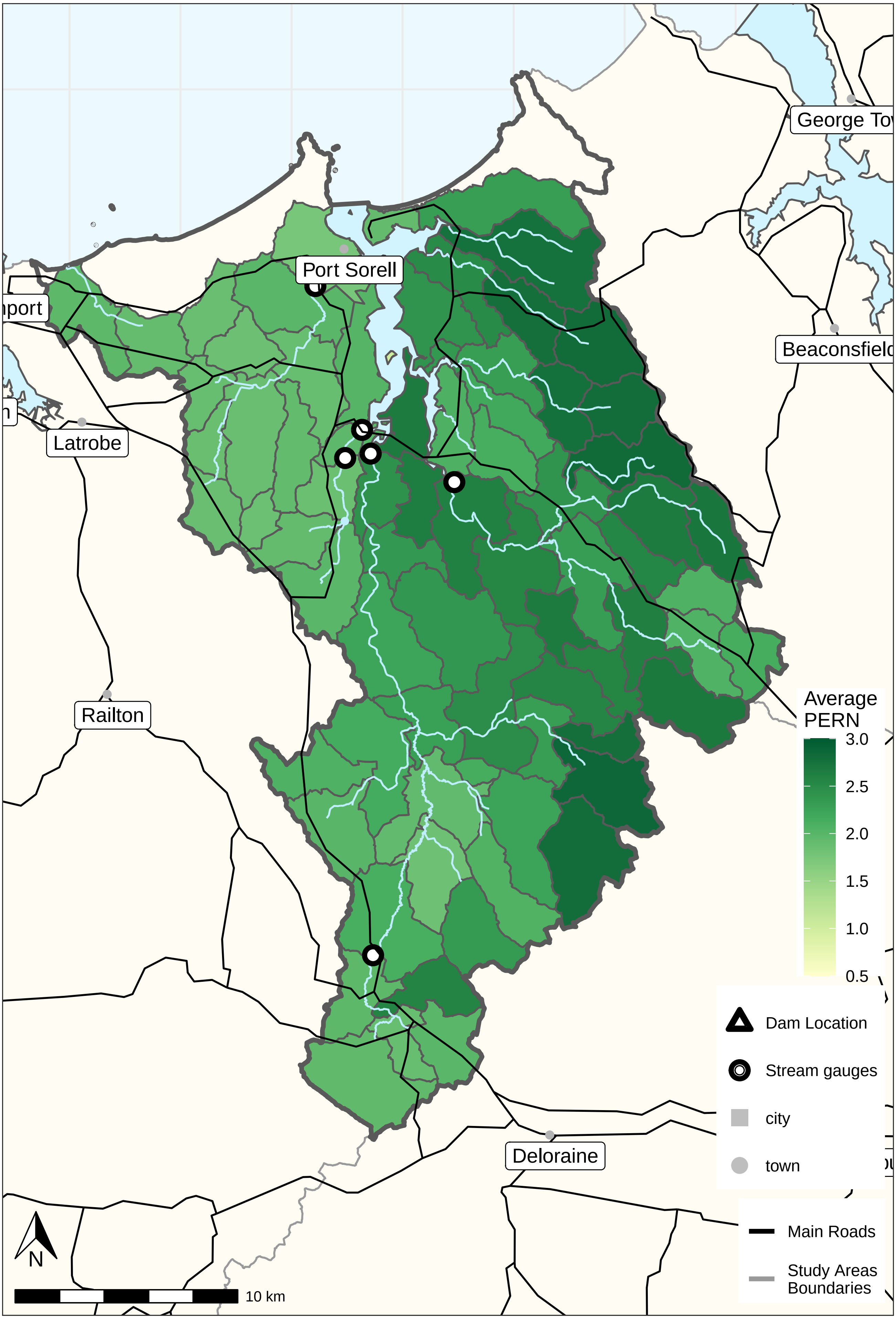
J:/Jobs/120038/Hydrology/Statewide/Calibration/Rubicon/Subcatchment_rainfalls/Figure_A1_Rubicon_SoilTypesReport.pdf

FIGURE A2

RUBICON STUDY AREA

SUBCATCHMENT AVERAGE PERN



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Appendix B

APPENDIX B. UNCERTAINTY ANALYSIS

B.1. Hydrologic Model Uncertainty

Table B 1 shows the calibration event rating. Green shading is used to highlight relevant statements.

Table B 1: Hydrology calibration event rating

Category	Rating				
	Poor	**Fair**	**Good**	**Very good**	**Excellent**
Rainfall input quality	Nearest pluvi > 15 km from catchment in unrepresentative location	Nearest pluvi > 15km from the catchment in similar climate area	Pluvi within the catchment or within 15km	1 pluvi within or very near catchment for each 300km2 of catchment area	1 pluvi within catchment for each 150km^2 of catchment area (spaced out)
	No daily rainfall sites within 15 km of catchment	No daily rainfall sites within 10 km of catchment	One daily rainfall site within 10 km of catchment in similar climate area	multiple gauges within 15km in different directions	multiple gauges within 10km in different directions
	Known high rainfall gradients (from BoM or investigation of surrounding gauges)	Known rainfall gradients for calibration events	No known large spatial variation in event rainfall relative to gauges	Event rainfall known to be generally spatially uniform if catchment is large, or well represented by raingauges	Event rainfall known to be spatially uniform if catchment is large, or well represented by raingauges
Observed flows	Highest gauging within channel and flow breaks out of channel at high flows.	Rating or gauging info unavailable, but flow contained in channel.	Calibration event is out of channel, good set of gaugings but no gaugings out of channel	Calibration event is out of channel, site has been gauged out of channel during different rating period (with changes at top end)	Calibration event is out of channel, site has been gauged during applicable rating period out of channel
	Rating extrapolated with no consideration for shape of cross section	Rating extrapolated with no consideration for shape of cross section	Rating shows consideration to shape of cross section	Rating shows consideration to shape of cross section	Rating shows consideration to shape of cross section
Calibration events	Smaller than 20% AEP	Between 20% and 10% AEP	Between 10% and 5% AEP	Between 5% and 2% AEP or within largest 4 events on record	Larger than 2% AEP or within largest 2 events on record

Table B 2 shows the hydrology calibration quality rating. The following shading is used to highlight relevant statements:

- Rubicon River at Tidal Limit shown in blue shading
- All other gauges shown in orange shading.

Table B 2: Hydrology calibration quality rating

Category	Rating				
	Poor	**Fair**	**Good**	**Very good**	**Excellent**
Hydrology calibration results – peak flow	Peak varies by more than 30%	Peak within 30% of observed	Peak within 20% of observed	Peak within 15% of observed	Peak within 10% of observed
Hydrology calibration results – hydrograph volume	Volume varies by more than 30%	Volume within 30% of observed	Volume within 20% of observed	Volume within 15% of observed	Volume within 10% of observed
Hydrology calibration results – hydrograph shape	Poor match to shape – modelled event routing does not match observed	Modelled and observed hydrographs have some similarities in shape	General characteristics of the modelled and observed hydrograph shape match in either rising limb or falling limb	Shape of the event generally matches well in rising and falling limbs	Shape of the event matches well including rising and falling limbs and recession

B.2. DTM Uncertainty

The overall study area DTM quality rating is shown in Table B 3 with green shading.

Table B 3: DTM rating

Category	Rating				
	Poor	**Fair**	**Good**	**Very good**	**Excellent**
DTM definition	Low resolution	Low resolution	High resolution at HSA/gauges	High resolution in HSA	High resolution in >60% of catchment
	Minimal Ground Control Points (GCP)	Minimal GCP	Reasonable GCP coverage	Good GCP coverage	Good GCP coverage
DTM waterways	Bathymetrical data unavailable	Bathymetrical data poor – e.g. LiDAR with estimated bathymetric information	Bathymetrical data reasonable	Bathymetrical data good	Detailed bathymetrical survey data available

B.3. Hydrodynamic Modelling Uncertainty

The hydrodynamic calibration event rating is shown in Table B 4, with relevant statements highlighted in green.

Table B 4: Hydrodynamic calibration event rating

Category	Rating				
	Poor	**Fair**	**Good**	**Very good**	**Excellent**
Calibration flood levels	Water level gauge data not available	Water level gauge data available	Water level gauge data available	Water level gauge data available	Water level gauge data available
		gauge zero level inferred	gauge zero level is known	gauge zero level is known	gauge zero level is known
		Sporadic water level gauge data available for event, low confidence in data	Reasonable confidence in gauged levels based on review of historic data	Good confidence in gauged levels based on review of historic data	Gauge is known to be regularly calibrated and of good quality (e.g. BOM flood warning sites)
Calibration flood depths	No survey extent available	Survey extent available with high uncertainty – few survey points and mostly interpolated	Survey extent available with medium uncertainty – survey points in critical areas, significant areas interpolated	Survey extent available with reasonable certainty – many survey points and limited interpolation	Survey extent available with survey points in all critical areas and limited interpolation

The hydrodynamic calibration event rating is shown in Table B 5. Green shading is used to highlight relevant statements.

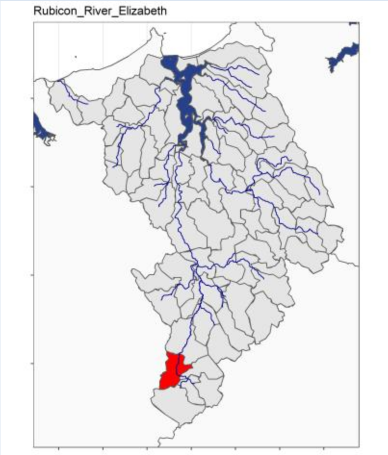
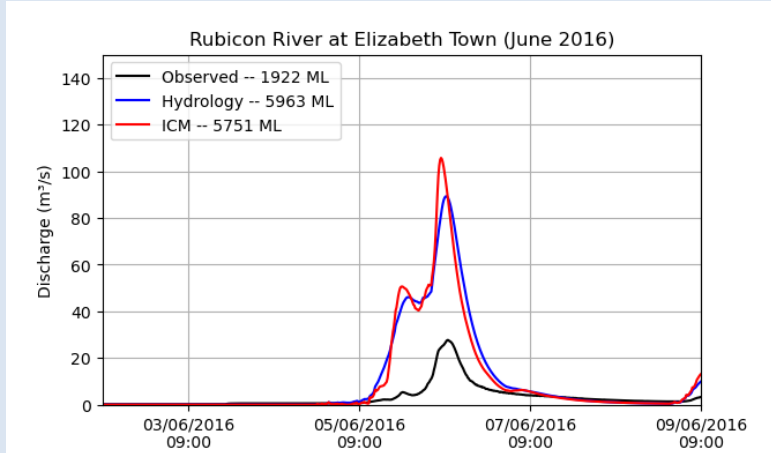
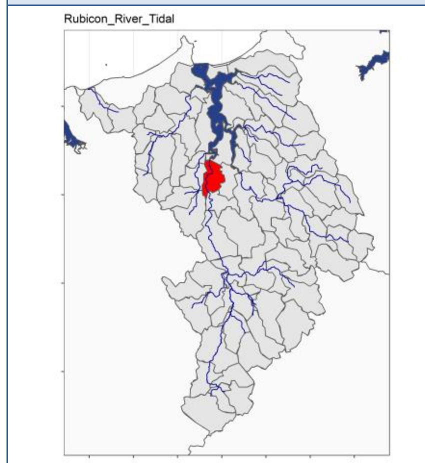
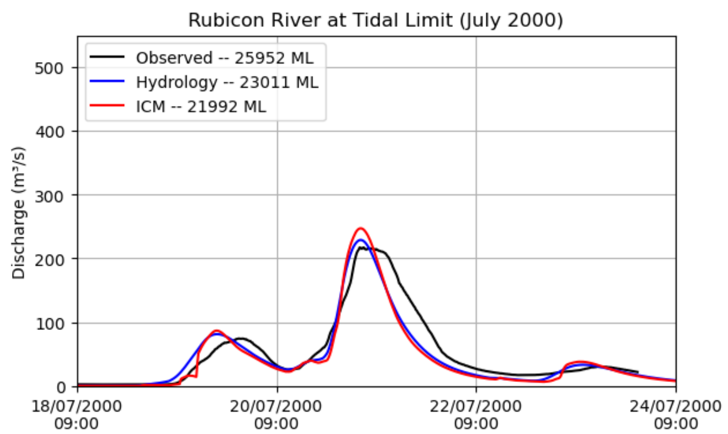
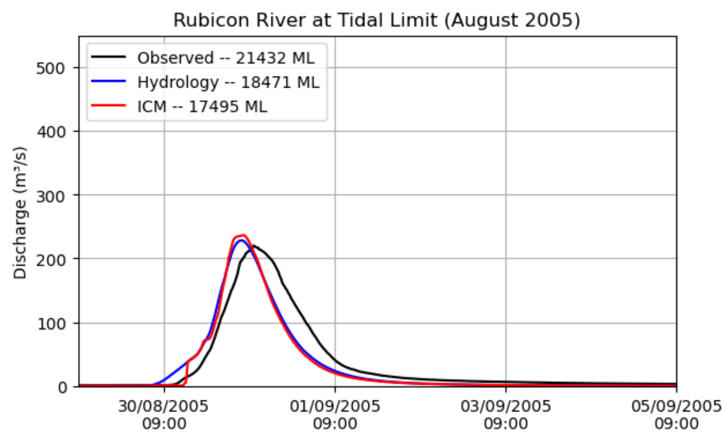
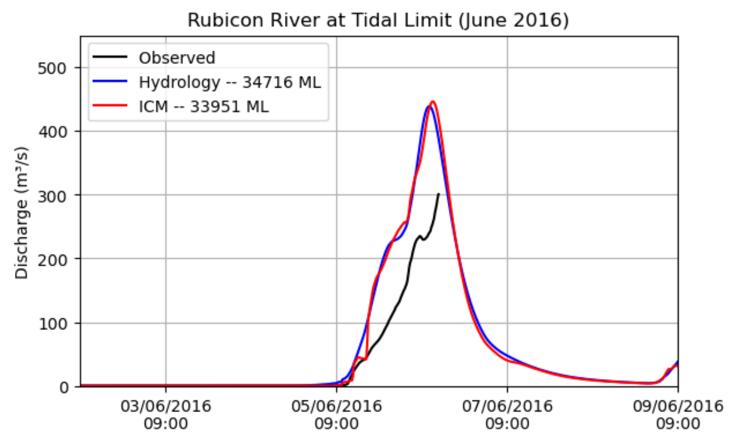
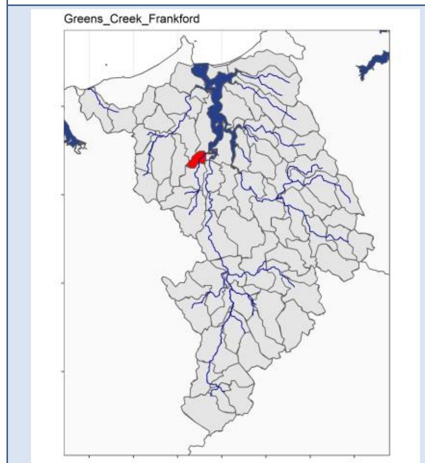
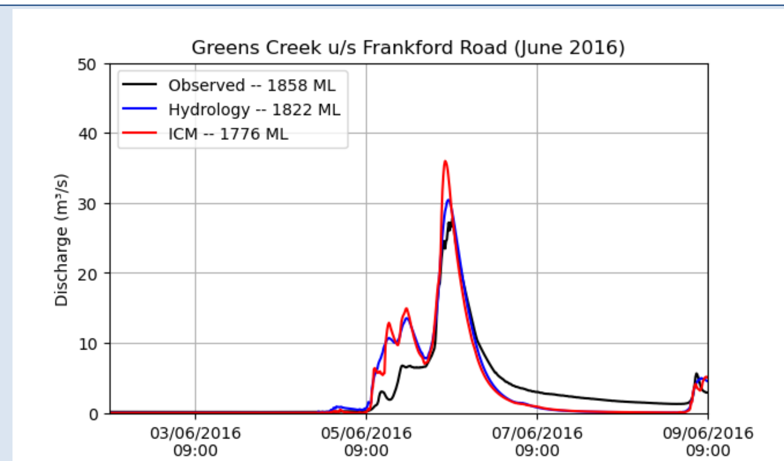
Table B 5: Hydrodynamic calibration quality rating

Category	Rating				
	Poor	**Fair**	**Good**	**Very good**	**Excellent**
Hydrodynamic calibration - peak levels	Peak level > +/- 1m of observed	Peak level within +/- 0.5m of observed	Peak within +/-0.5m of observed	Peak within +/-0.3m of observed	Peak within +/- 0.3m of observed
Hydrodynamic calibration – flood extents	Extent > 50m difference from observed	Extent lies within +/- 50m of recorded	Extent lies within +/- 20m of recorded	Extent lies within +/- 10m of recorded	Extent lies within +/- 5m of recorded
Hydrodynamic calibration - depths	Depth within > +/- 1m of Survey	Depth within +/- 1 m of Survey	Depth within +/- 0.5m of Survey	Depth within +/- 0.3m of Survey	Depth within +/- 0.3m of Survey

Appendix C

APPENDIX C. EXTERNAL HYDROLOGY MODEL AND ICM HYDRODYNAMIC MODEL COMPARISON

Figure C 1: Event hydrographs

Catchment	July 2000	August 2005	June 2016
	n/a	n/a	
			
	n/a	n/a	

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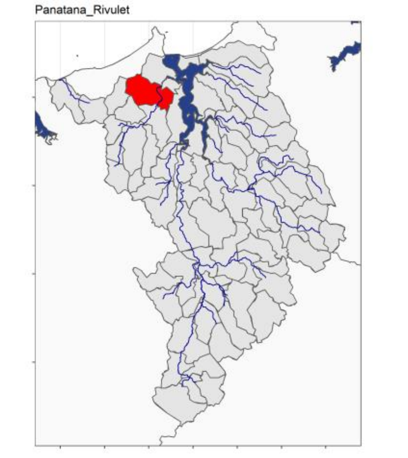
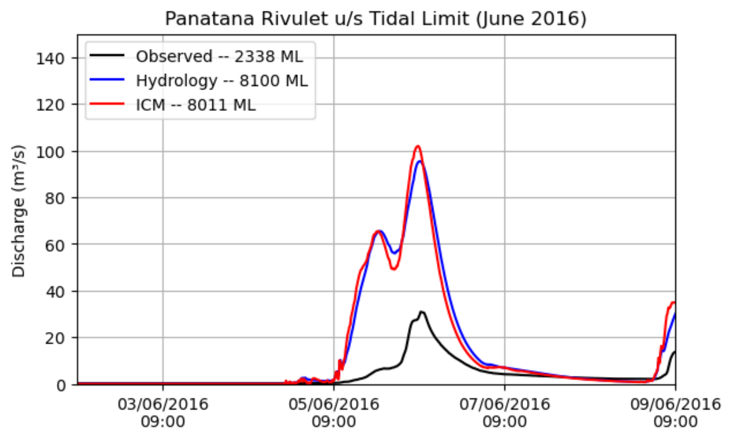
<tr><td>
</td><td>n/a</td><td>n/a</td><td>

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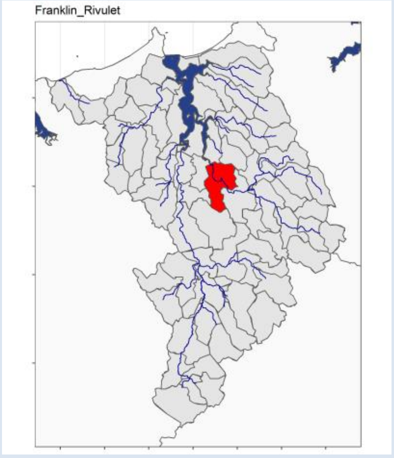
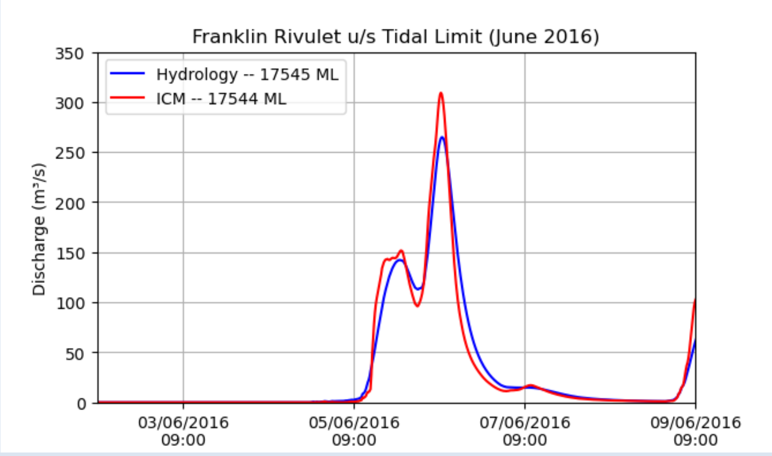
<tr><td>
</td><td>n/a</td><td>n/a</td><td>
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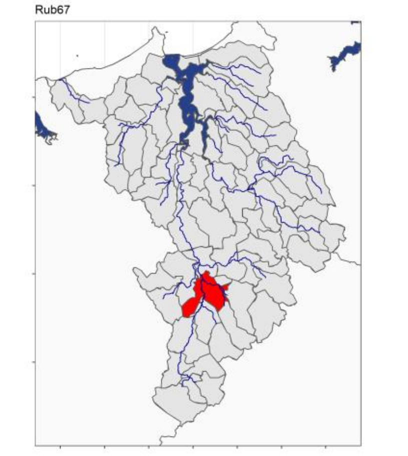
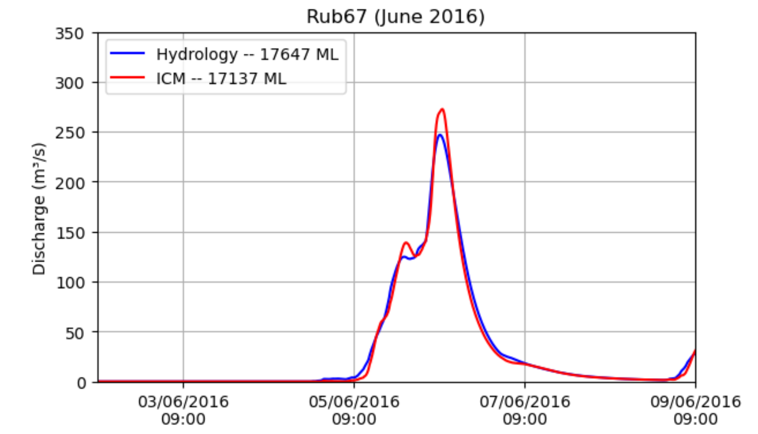
<tr><td>
</td><td>n/a</td><td>n/a</td><td>
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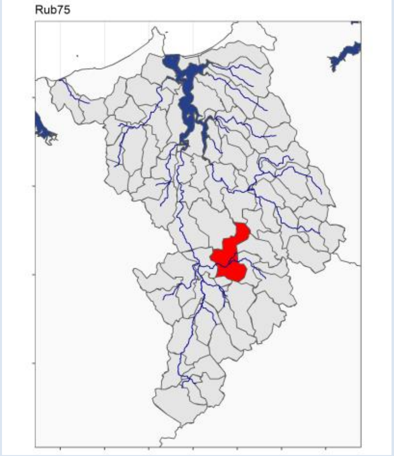
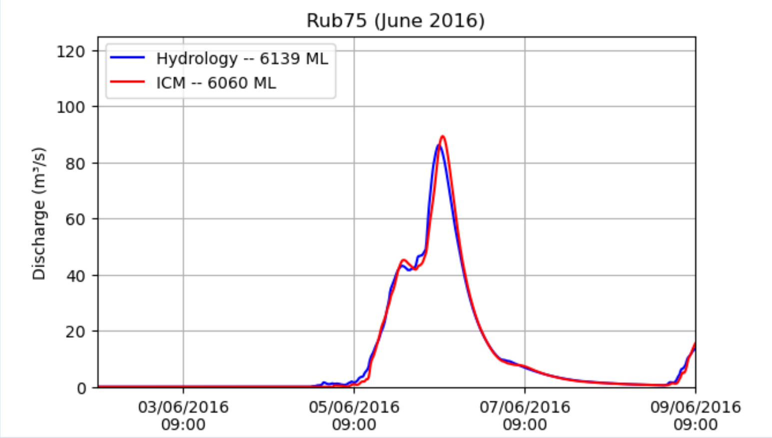
<tr><td>
</td><td>n/a</td><td>n/a</td><td>
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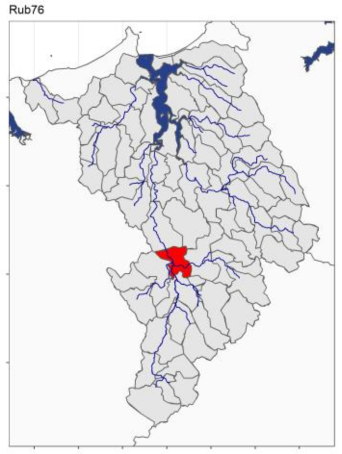
<td>
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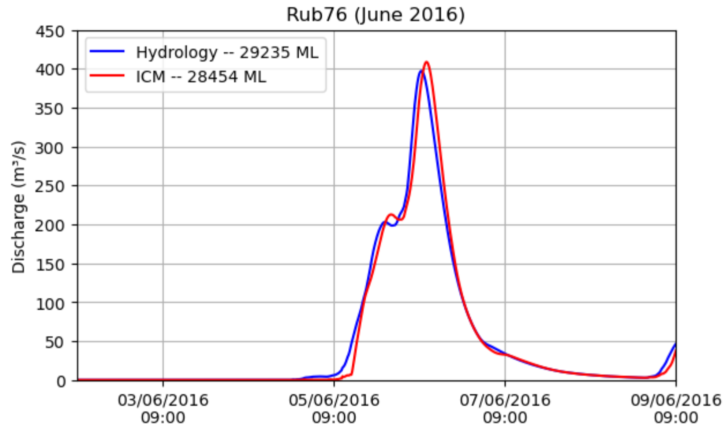
<td>
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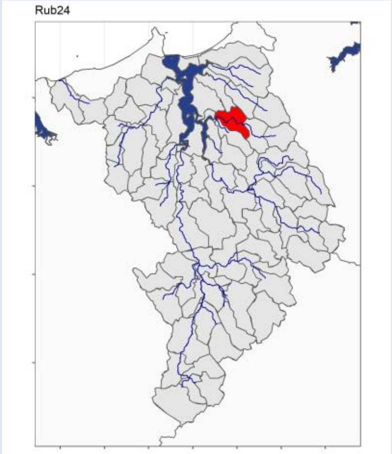
<td>
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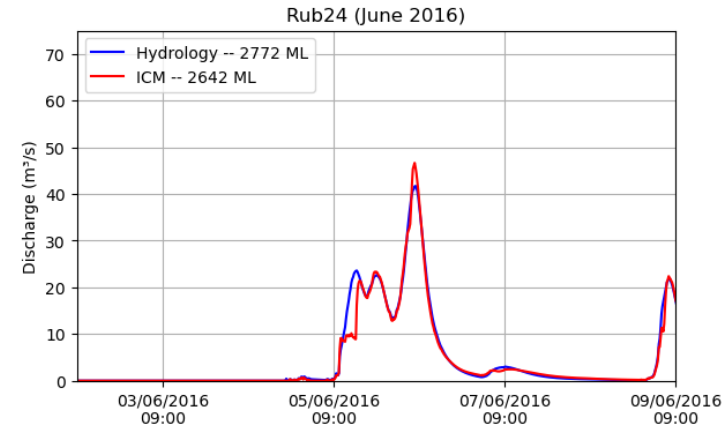
<td>
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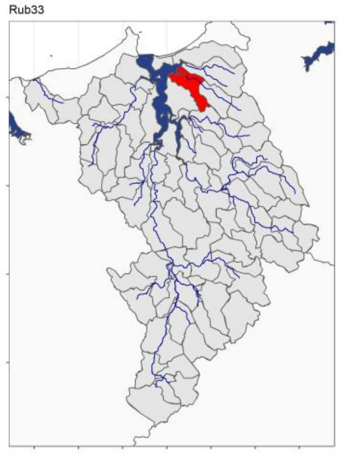
<td>
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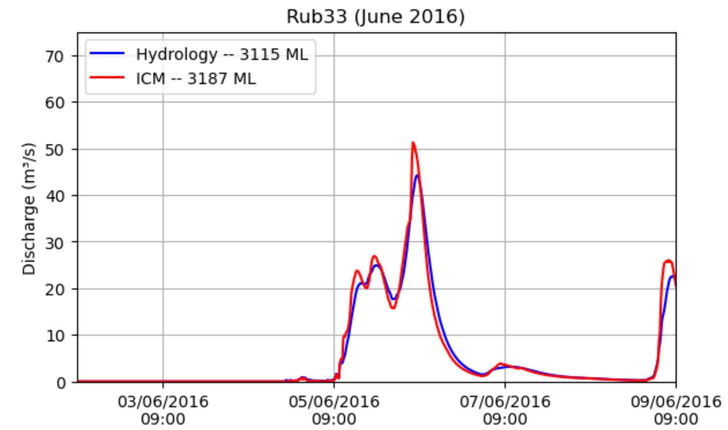
<td>
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Appendix D

APPENDIX D. RATING CURVE COMPARISON

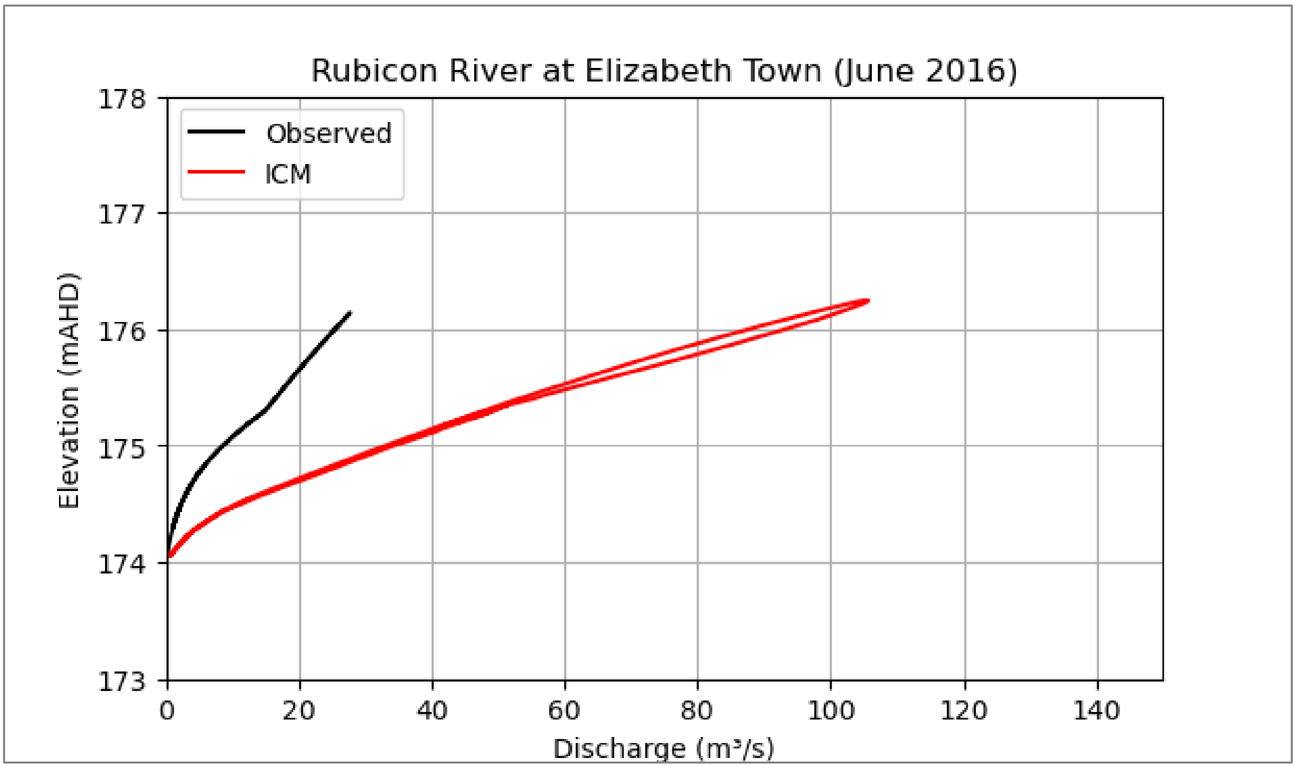

Figure D 1: Rating comparison – Rubicon River at Elizabeth Town, June 2016 event

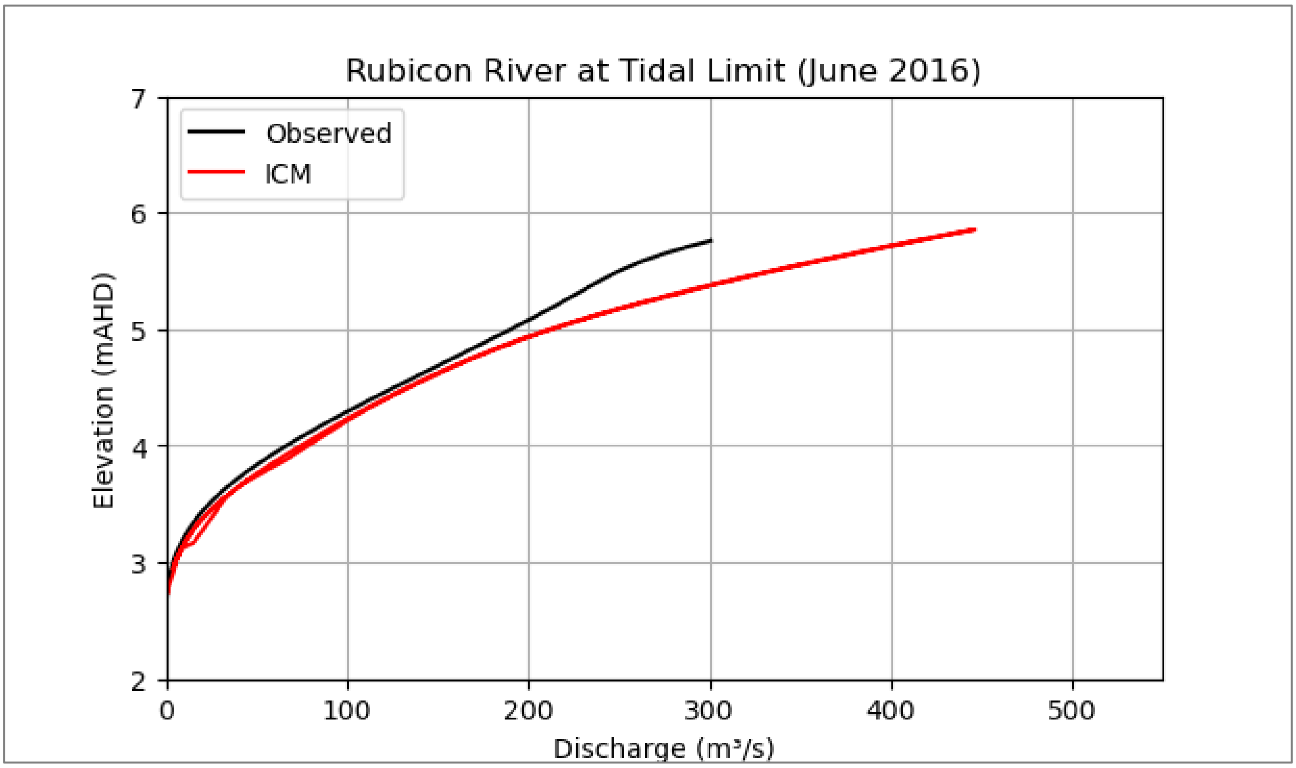

Figure D 2: Rating comparison – Rubicon River at Tidal Limit, June 2016 event

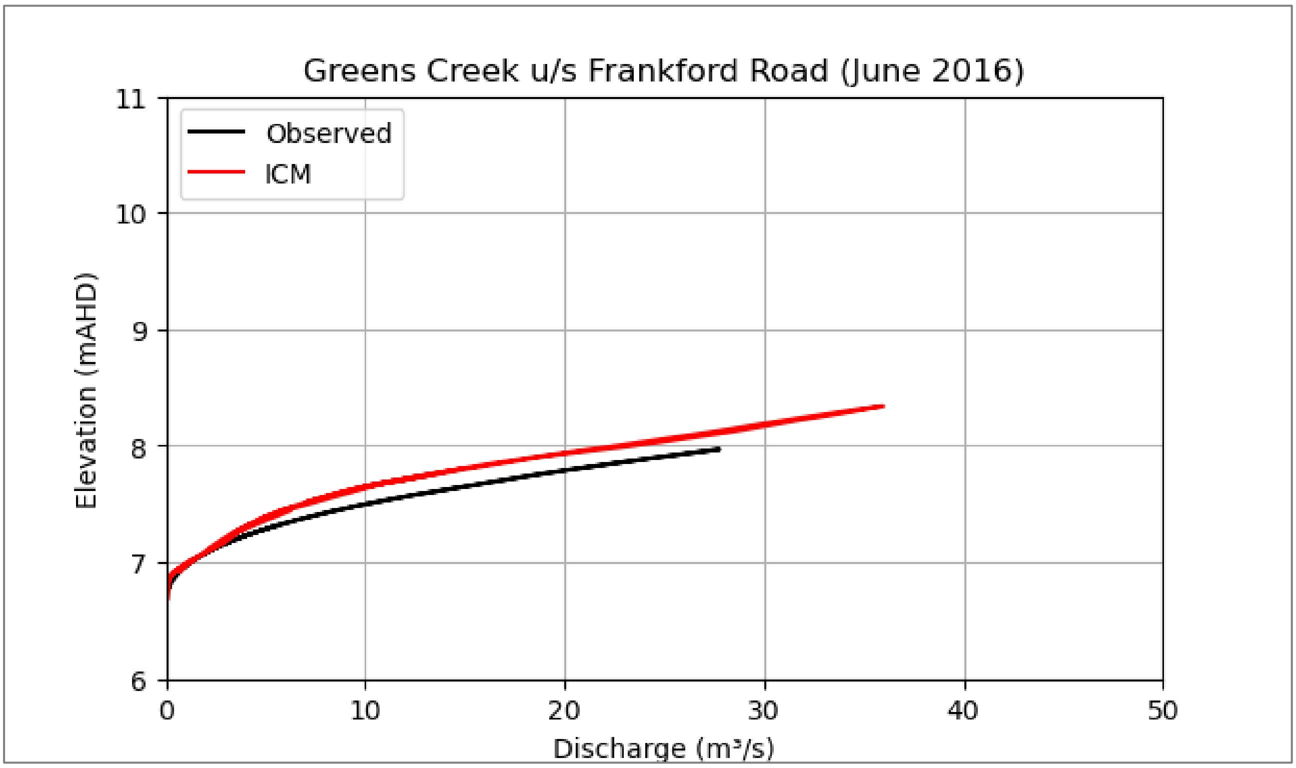

Figure D 3: Rating comparison – Greens Creek u/s Frankford Road, June 2016 event

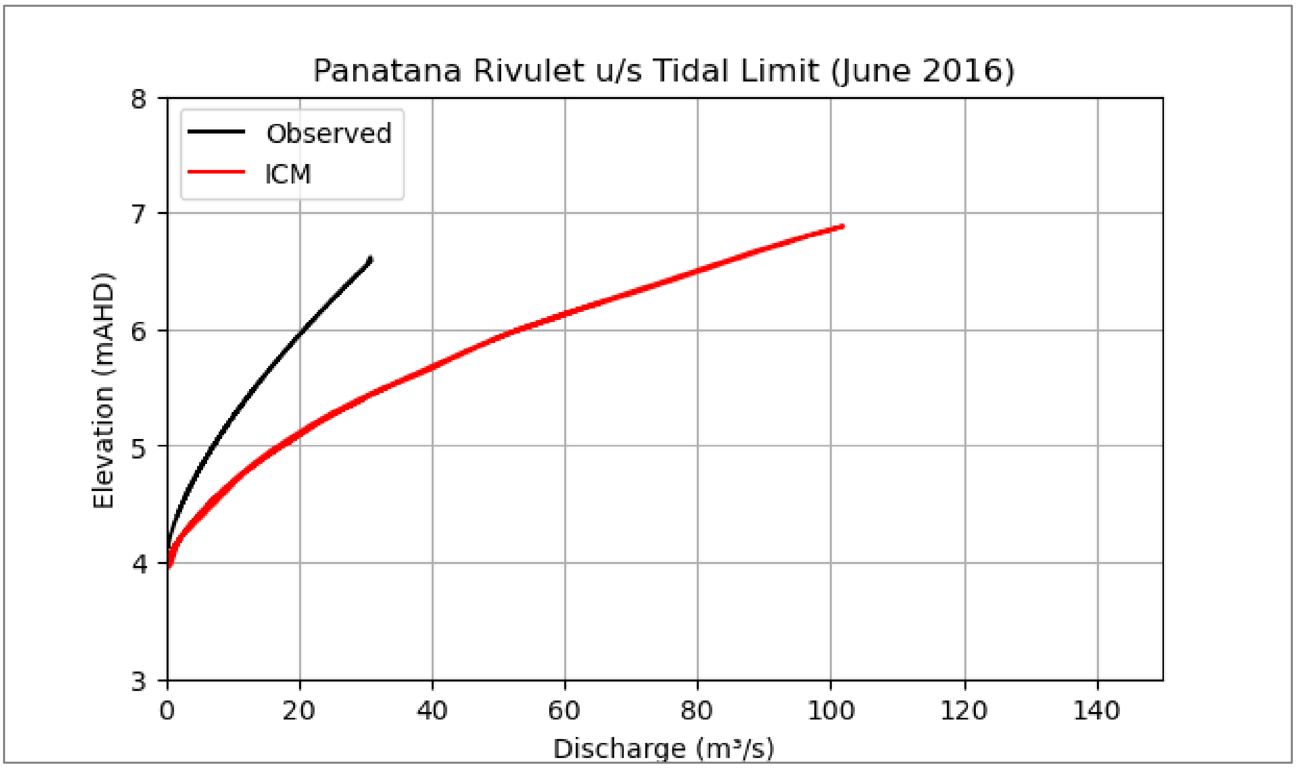

Figure D 4: Rating comparison – Panatana Rivulet u/s Tidal Limit, June 2016 event