STATE EMERGENCY SERVICE

TASMANIAN STRATEGIC FLOOD MAP
FORTH-LEVEN STUDY AREA MODEL CALIBRATION

REPORT

FEBRUARY 2023

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Project Tasmanian Strategic Flood Map Forth-Leven 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	Chris Irvine, SES	Sarah Blundy, Evmen Wong	Daniel Wood	Fiona Ling	OCT 22
1	Report updated to address review comments	Chris Irvine, SES	Sarah Blundy, Evmen Wong	Daniel Wood	Fiona Ling	FEB 23

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TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF FIGURES

LIST OF DIAGRAMS

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 (formerly DPIPWE)
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 Forth-Leven study area.

2. STUDY AREA

The Forth-Leven study area is situated in north-central Tasmania. There are three major catchments in this study area, the Forth River, Leven River and Gawler River catchments. The Forth River rises on the Central Plateau in the Cradle Mountain – Lake St Clair National Park and flows in a northerly direction to discharge into at Turners Beach. The Wilmot River is the major tributary of the Forth River. The Leven River rises on the Central Plateau and flows in a north-easterly direction. Both the Leven River and the smaller Gawler River discharges into the Leven Estuary, which flows into Bass Strait at Ulverstone. Smaller coastal rivers and creeks in the study area flow directly into Bass Strait. These include Buttons Creek, Claytons Rivulet, and Skeleton Creek.

Flow in the Forth River system is modified by hydro-electricity developments associated with the Mersey-Forth Power Scheme. This includes Cethana, Devils Gate and Paloona dams on the Forth River, and Gairdner Dam on the upper Wilmot River. Water is diverted from Lake Gairdner to Lake Cethana. Water is also diverted from the Mersey River into Lake Cethana. The Kindred North-Motton Irrigation Scheme operates in the study area, diverting approximately 2,500 ML of water from downstream of Paloona dam for irrigation.

The majority of the catchment above Lake Cethana is Wilderness World Heritage Area. Forestry is the major land-use in the middle catchment and land uses in the lower catchment include cropping, dairy and grazing farming (DPIPWE, 2016). Land use in the Leven River and Gawler River catchments includes forestry plantations and production in the upper catchment, and grazing and cropping in the lower catchment. Isandula Dam, on the West Gawler River, impounds water for water supply for Ulverstone (DPIPWE, 2016a).

The major town in the area is Ulverstone, and other towns include Gawler, Sprent, Turners Beach, Forth, Leith and Wilmot.

Large floods in the study area include the August 1970 and June 2016 events, which were widespread across the study area. The August 2007 flood event was significant in the Forth River, and January 2011 was a large event in the Leven River.

The Forth Leven study area has a total catchment area of 1,904 km^2. The Forth River catchment covers an area of 1,174 km^2, and the combined Leven River and Gawler River catchments cover an area of 730 km^2. The Forth Leven study area and the available gauge information are shown in Figure 1. Landuse in the Forth Leven study area is shown in Figure 2.

3. AVAILABLE DATA

3.1. Historic Flow Data and Level Data

There are twelve flow gauges with data available in the Forth-Leven study area; gauges on the Forth River and its tributaries are shown in Table 1 and gauges in the remainder of the study area are shown in Table 2. These gauges are owned by Hydro Tasmania, NRE (formerly DPIPWE) and TasWater. Data was supplied by the SES and Hydro Tasmania or accessed from BoM's Water Data Online (BoM 2021b) or the Tasmanian Water Data Portal (DPIPWE 2020). Data supplied or accessed included timeseries of flows, ratings and gaugings for these sites. There are several gauges where limited data was supplied where there was no sub-daily data available for any calibration event, including Wilmot at Moina (data until 1968) and Claytons Rivulet at Sprent (daily only for 1970). Gawler River at West Gawler and Claytons Rivulet D/S Bass Highway had data available for calibration events, however the calibration events were not significant on these rivers and there were questions about the exact location of these gauges, so they have not been included in the gauge descriptions.

Table 1: Flow gauges in the Wilmot and Forth catchments

Gauge attribute	Iris River At Middlesex Plains	Forth River a/b Lemonthyme	Wilmot River a/b Forth River	Forth River b/l Wilmot River
Gauge number	815-1	450-1	524-1	665-1
Gauge abbreviated name	Iris River	Forth a/b Lemonthyme	Wilmot a/b Forth	Forth b/l Wilmot
Start date	21/04/1994	12/12/1962	29/07/1966*	04/09/1972
End date	Current	Current	Current*	Current
Latitude	-41.53	-41.61	-41.27	-41.27
Longitude	145.99	146.13	146.23	146.25
High flow rating quality	Fair	Good	Fair (old datum) Poor (new datum)	Good
Used for calibration	Yes – flows only	Yes – flows only	Yes – flows only (old datum) Yes – levels only (new datum)	Yes – flows only
Assumed local datum 0m in AHD	733.6	224.71	26.0	16.7
Highest gauged level (m local datum)	1.5	6.5	3.0 (old datum) 1.8 (new datum)	7.6
Highest gauged flow (m^3/s)	35	360	118 (old datum) 6 (new datum)	1187
Highest recorded stage height (m local datum)	2.2	8.0	6.5*	7.8
Highest recorded flow (m^3/s)	139	477	594	1316
Highest recorded stage height date	05/06/2016	24/08/1970	06/06/2016	06/06/2016
Highest recorded flow date	05/06/2016	24/08/1970	06/06/2016	06/06/2016

* Wilmot above Forth has no data from 1982- 1997. During this time there appears to be a datum shift so recorded levels prior to this are not directly comparable with levels afterwards.

Table 2: Flow gauges in the remainder of the Forth-Leven study area

Gauge attribute	Gawler River at Cradle Coast Water Supply	Gawler River at West Gawler	Buttons Creek U/S Bass Highway	Claytons Rivulet U/S Bass Highway	Claytons Rivulet D/S Bass Highway*	Leven River at Bannons Bridge^
Gauge number	14253-1	14208-1	1088-1	14237-1	14209-1	14207-1
Gauge abbreviated name	Gawler River at Cradle	Gawler River at Gawler	Buttons Creek	Claytons U/S Bass	Claytons D/S Bass	Leven River
Start date	20/06/2008	24/03/1965	04/12/2007	04/12/2007	31/12/1969	18/06/1963
End date	Current	01/01/1983	Current	Current	26/07/1995	Current
Latitude	-41.21	-41.17	-41.16	-41.16	-41.16	-41.25
Longitude	146.14	146.15	146.19	146.21	146.21	146.09
High flow rating quality	Unknown	Unknown	Fair	Poor	Unknown	Good (re-rated)
Used for calibration	Yes – levels only	No	Yes – flows only	No	No	Yes
Assumed local datum 0m in AHD	27.18	N/A	19.8	5.6	N/A	36.75
Highest gauged Level (m local datum)	Not available	Not available	0.4	1.8	Not available	3.89
Highest gauged Flow (m^3/s)	Not available	Not available	2	18	Not available	230
Highest recorded stage height (m local datum)	2.4	2.9	0.8?	2.7	1.8	6.9
Highest recorded flow (m^3/s)	145	55	5	44	22	624
Highest recorded stage height date	14/01/2011	24/08/1970	14/01/2011	14/01/2011	24/08/1970	06/06/2016
Highest recorded flow date	14/01/2011	24/08/1970	14/01/2011	14/01/2011	24/08/1970	06/06/20016

* This gauge is named “downstream” Bass Highway, but the supplied coordinates show it upstream of Bass Highway

^ This gauge is named “at” Bannons Bridge, but the supplied coordinates show it approximately 500 m downstream of Bannons Bridge

3.1.1. Calibration Event Data Availability

Four of the 13 flood events selected by the Bureau as calibration events for this project had significant flows within the Forth-Leven study area and were used for calibration. Not all of these events were significant across the entire study area, so some events were only calibrated in the parts of the study area where they were particularly large. The events and the gauges that were used in calibration are shown in Table 3.

In addition to the information at the stream gauges, lake levels and spillway flows at the Hydro Tasmania dam locations were used for calibration (see Section 3.3). As so many calibration points were available, calibration was done looking across the entire study area, with the allowance that some sites would be over and some under and the rainfall and loss distribution is not perfect. Some Hydro gauges were not provided for this project; these gauges are available as daily average data on Water Data Online so have only been used for verification where necessary.

August 1970 was one of the largest events on record across the area with most gauges and dam spillways recording either their largest or second largest flow on record. There are several records with spikes in recorded flow data, particularly on the west side of the catchment. As this occurs at multiple locations (Lake Gairdner, Leven River and Gawler River) it is assumed this data is legitimate (not faulty data) and relates to an isolated intense rainfall burst. However, this burst was not seen in any of the sub-daily rainfall data available, so no attempt was made to try and match this peak with the rainfall data available.

August 2007 was a large event (second or third largest on record) on the Forth River, but smaller on the Wilmot River and Leven River. Conversely, January 2011 event was small of the Forth River and large on the other rivers in the study area. Therefore, for these events, results are only shown at gauges where flows were significant.

June 2016 was very large across the whole study area, mostly the 1st or 2nd largest event on record. Due to the size of this event, flows were generally far larger than the verified range of the rating curves (Section 3.1.2), especially for gauges with shorter record lengths. For some gauges, whilst results are presented comparing modelled and observed flows, calibration was undertaken to levels or flows only. These are noted in Table 3, with gauge specific reasons shown in Section 6.

Table 3: Summary of the largest events in the Forth-Leven study area

Event name	Used for calibration	Event peak flow (m^3/s) (location)
1970_Aug	Yes – flows only	477 (Forth a/b Lemonthyme)
	Yes – flows only	607 (Wilmot a/b Forth)
	Yes	716 (Leven River)
2007_Aug	No	45 (Iris River)
	Yes – flows only	410 (Forth a/b Lemonthyme)
	No	272 (Wilmot a/b Forth)
	Yes – flows only	927 (Forth b/l Wilmot)
	No	300 (Leven River)
2011_Jan	Yes – flows only	50 (Iris River)
	No	103 (Forth a/b Lemonthyme)
	Yes – levels only	710 (Wilmot a/b Forth)
	No	810 (Forth b/l Wilmot)
	Yes – flows only	5 (Buttons Creek
	No	44 (Claytons u/s Bass)
	Yes – levels only	145 (Gawler River at Cradle)
	Yes	586 (Leven River)
2016_Jun	Yes – flows only	140 (Iris River)
	Yes – flows only	430 (Forth a/b Lemonthyme)
	Yes – levels only	597 (Wilmot a/b Forth)
	Yes – flows only	1323 (Forth b/l Wilmot)
	Yes – flows only	3 (Buttons Creek
	No	28 (Claytons u/s Old Bass)
	Yes – levels only	65 (Gawler River at Cradle)
	Yes	725 (Leven River)

3.1.2. Rating Curve Quality

The rating curve quality for the gauges within the Forth catchment itself are typically considered to be good. However, as the calibration events are so large, the flows are in the extrapolated region of the rating curves. The Iris River and Wilmot above Forth gauges have event peaks many times higher than the largest gauged flow so there could be significant uncertainty in the rating curves at the peaks flows. Even the gauges with a single gauging within 30% of the largest event peak (Forth above Lemonthyme and Forth below Wilmot) could easily have uncertainty in the peaks, as their entire ratings are based on a single gaugings at these flows.

The rating curves throughout the rest of the catchment are much more uncertain at higher flows. These gauges are owned by NRE and may not typically be used for larger flow events. A re-rating for the Leven River was undertaken as part of the Rating Revision Report (WMAWater 2021c) as it has a long period of record. The rerating is shown in Diagram 1, this rating was applied to all historic events despite significant differences in the NRE rating curves covering the 1970 event to the later events. Other gauges have either no information on rating curves (sites on the Gawler River and Claytons DS Bass) or calibration event peaks between 2 and 12 times higher than the largest gauged flow (Buttons Creek, Clayton at Sprent and Claytons U/S Bass see Table 2). Notably, the only high flow gauging at Claytons River U/S Bass Highway occurred during the June 2016 event. This flow sits considerably off the applied rating for this event so may have been regarded as poor quality. The next largest gauging here has a flow of less than 1 m^3/s. Therefore, recorded flows for all these sites are likely to have very significant uncertainties. In some cases where the rating quality was considered too poor, only levels were used in calibration.

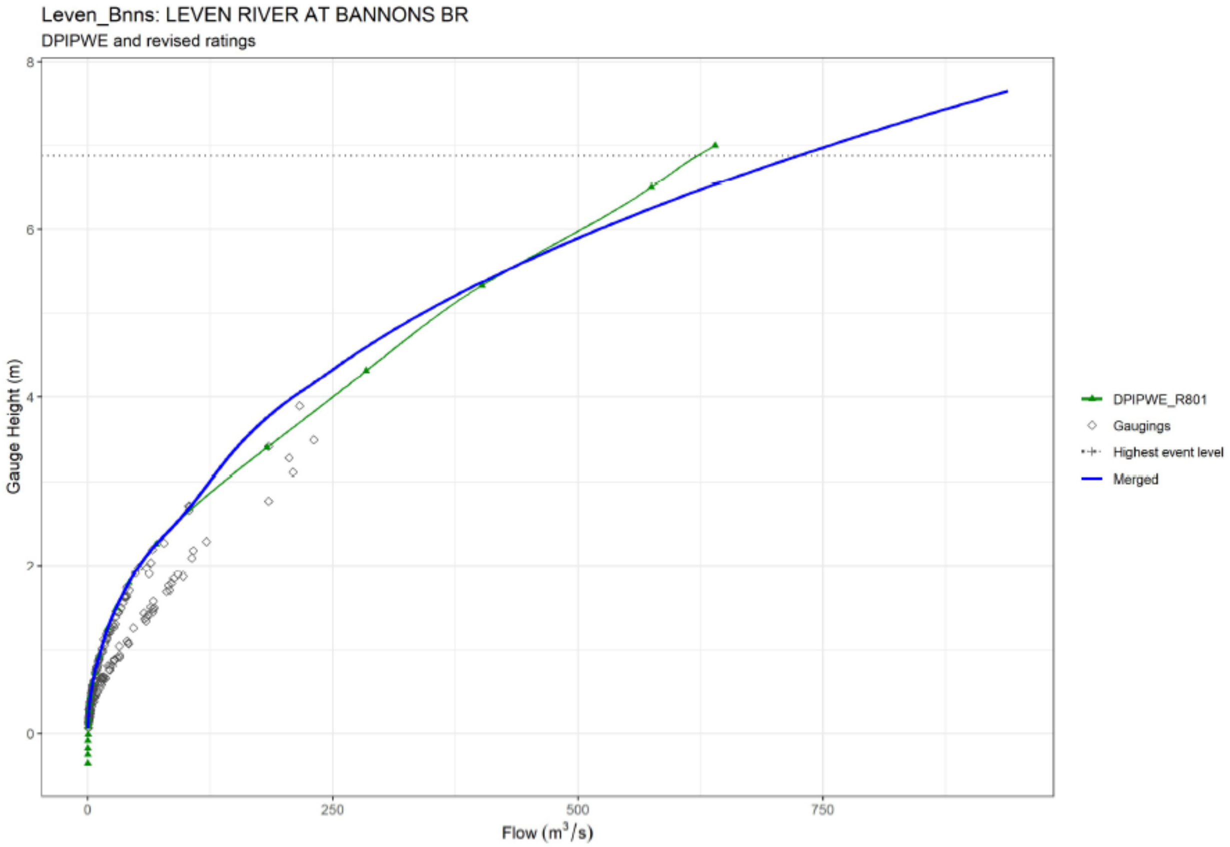

Diagram 1 Rating curve at Leven River at Bannons Bridge from the Rating Revision Report (WMAWater 2021c)

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 Forth-Leven study area (see Data Review Report WMAwater (2020) for details on calibration events).

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

Sub-daily rainfall data was also obtained from Hydro Tasmania at their gauges in and around this study area.

A summary of the rain gauges and rainfall totals for this study area is shown in Table 4. The gauges in and around the Forth-Leven study area, are shown in Figure 1.

Rainfalls for August 1970 were highly variable with depths up to 370 mm in the Iris River and Dove River in the south west of the catchment and less than 170 mm along the coast (Figure 3). In some parts of the study area there is significant variation between the rainfall depths in the AWAP gridded rainfalls (used for events prior to 1971) and the local gauges. For example, at Lake MaCrae near the southern tip of the study area, the Hydro Tasmania gauge recorded 139 mm while the nearest AWAP grid cell has a total of 336 mm. However, in other parts of the catchment such as at Lake Gairdner, the rainfall totals are almost identical. There are six sub-daily rain gauges in this study area for this event, which is more than would be expected for an event in 1970. However, all these gauges are owned by Hydro Tasmania and therefore in the upper reaches of the catchment. The only coastal sub-daily gauge in the nearby regions is at Burnie. As discussed in Section 3.1.1 there is a sudden increase in flow recorded in several flow gauges in the west of the study area. However, none of the sub-daily rain gauges show an intense rainfall burst at around 9am on the 24th of August which is presumed to have caused the spike, so therefore no attempt has been made to meet this intense peak in calibration.

August 2007 had rainfalls up to 300 mm in the southwest of the study area and much lower rainfalls (less than 100 mm) from approximately Lake Barrington to the coast (Figure 4). This is consistent with the findings in Section 3.1.1 that this event was large on the Forth River and its tributaries, but less significant on the Leven River and small coastal rivers. There was a very steep rainfall gradient in the upper catchment with almost double the rain (330 mm) falling at Cradle Valley than at Iris River (170 mm) 15km to the north of Cradle, and Borradaile Plains 20 km east of Cradle recording only 125 mm. Therefore, sub-catchment rainfall depths are sensitive to the rainfall distribution method used.

The January 2011 event had a completely inverse spatial pattern to the August 2007 event (Figure 5). January 2011 has the highest rainfalls in the coastal region, specifically to the west in the Leven River catchment and low rainfalls in the upper catchment especially along the upper Forth River upstream of Lake Cethana. Therefore, flows in the Forth River catchment are not significant with most of the Hydro lakes not even reaching full supply level. Once again, there was large rainfall gradient with 315 mm of rain recorded at the inland Penguin (Mount Gnomon) gauge but only 120 mm at Ulverstone 10 km away. Modelled flows are also likely highly dependent on the temporal pattern applied to each sub-catchment with an intense rainfall burst recorded on the morning of the 14th of January at some gauges (for example Lake Gairdner and Sheffield) but not others (Forthside Research Station and Burnie) despite the rest of the event being similar.

June 2016 saw widespread heavy rainfalls with the highest totals in the centre of the study area and lower totals in the far south and coastal areas (Figure 6). Rainfall was constant, with little variability in temporal pattern across most of the study area, with some more identifiable bursts in coastal areas. June 2016 was preceded by wet and cold conditions, so there was potentially snow on the ground at the beginning of the event in the elevated parts of the study area.

Table 4: Available Rainfall Information

	August 1970	**August 2007**	**January 2011**	**June 2016**
Number of Sub-daily Stations Available within the study area	6	7	6	7
Number of daily Stations Available within the study area*	10	10	8	8
Number of sub-daily surrounding gauges ~15km	0	9	4	5
Number of daily surrounding gauges ~15km	12	9	9	5
Rainfall Totals	150-370 mm	60-300 mm	70-290 mm	130-330 mm
Approx. duration of rainfall event (hours)	48	120	60	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 2021a 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 6

For events prior to 1971 the AWAP gridded rainfall depths were used as described in WMAwater 2021a due to lower coverage of rain gauges.

3.3. Dam Information

There are five dams that were identified in the Data Review Report (WMA 2020) for inclusion in the Forth-Leven study area model (Table 5). There are many small farm dams which have not been explicitly modelled in the lower catchment. These are particularly dense in the Claytons Rivulet, Buttons Creek, Gawler River and Skeleton River catchments.

Hydro Tasmania provided spillway flows, storage and spillway rating curves and lake levels for this project. As spillway rating curves are typically more accurate at high flows than stream gauges, spill flows were used during calibration and given higher weighting than gauges with large uncertainties. Sub-daily lake levels were only provided for this study area after calibration was completed, so were not included in the calibration process, but have been plotted in the results now that they are available.

Table 5 Information on major dams in the Forth-Leven study area

Name	Storage FSL (mAHD)	Active Storage Volume at FSL (ML)*	Year constructed
Lake Gairdner (Wilmot Dam)	472.44	7,400	1970
Lake Cethana	220.98	20,000	1971
Lake Barrington (Devils Gate Dam)	121.92	34,000	1969
Lake Paloona	53.34	6,750	1971
Lake Isandula	131.79	720	1966

*Storage volumes were supplied by Hydro Tasmania as "active" volume which is understood to be volume above the intake for power station or canal outflows so it is not the total volume of water in the storage.

Paloona Dam and Cethana Dam were not yet constructed during the August 1970 event. As there is no simple way to remove the dams from ICM, two external hydrologic models were created to assess the impact of the dams on modelled flows; one with the dams as constructed with a starting level of FSL (as at 2022) and one without these dams (as at 1970). This showed that these dams made a very significant difference to the flow attenuation (Diagram 2 - note that Paloona Dam is downstream of Cethana so the inflows to this reservoir will also be different.). Therefore, the model results are shown as an "as constructed" scenario (as at 2022) and do not reflect the true levels which occurred during the August 1970 event downstream of these dams. There were no recorded flows downstream of the dam locations, so this did not impact on calibration, but will show in the event mapping.

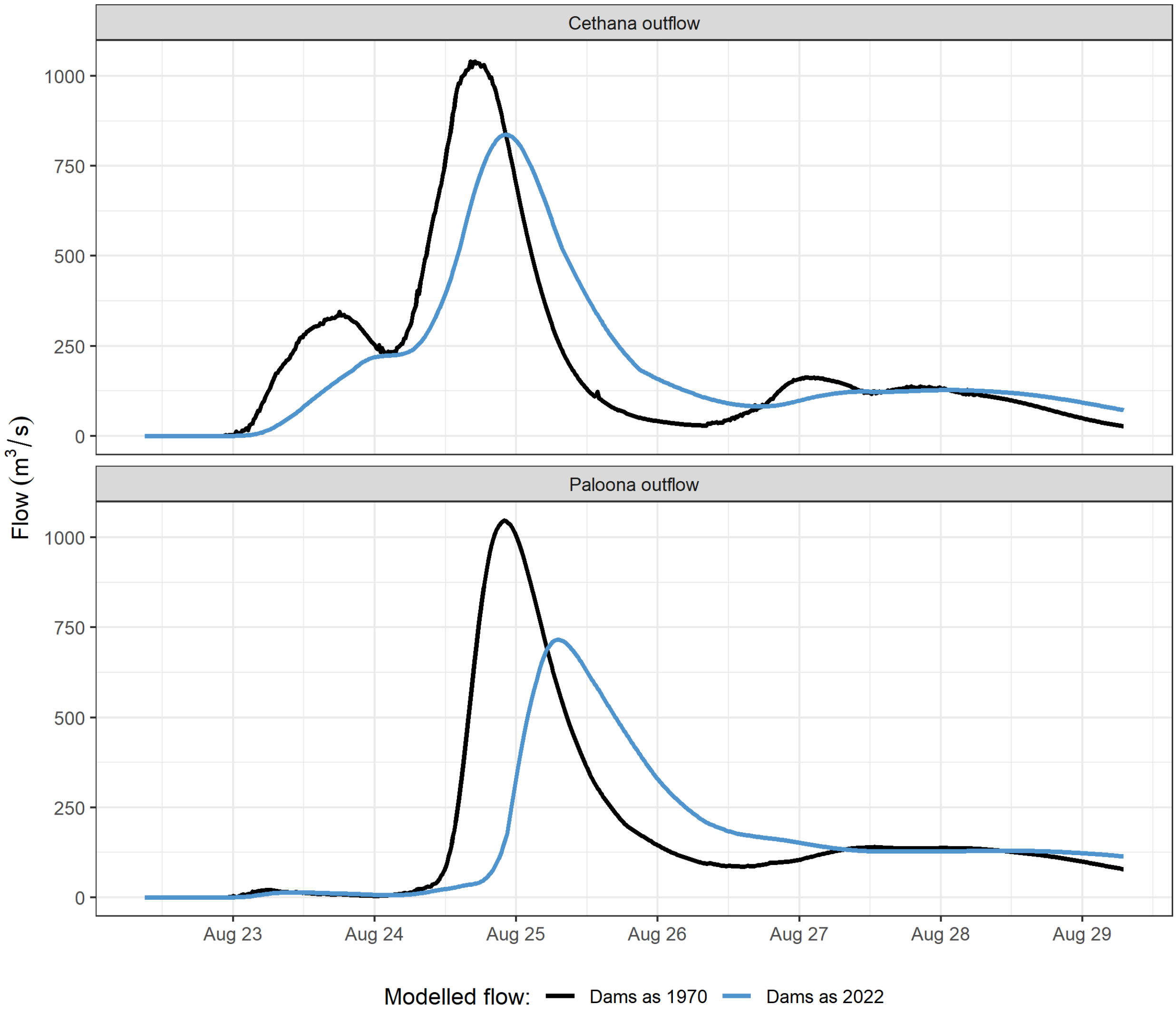

Diagram 2: External hydrological modelled outflow from Cethana Dam and Paloona Dam with (Dams as 2022) and without (Dams as 1970) these dams in the model.

As the aim of this project is not to model Hydro Tasmania's normal operations but flood flows, Hydro operations have not been included in the models. The power stations at Lake Cethana, Barrington and Paloona all release water directly downstream of the dams, so once dams are on spill, peak total outflows (spill plus power station discharge) are expected to be very similar, however some differences in timing may occur. Power station operations from Lake Gairdner divert water into the Forth River instead of spilling into the Wilmot River, so some differences are expected here. However, Wilmot Power Station capacity is about 18 m^3/s and flows on the Forth at Lake Cethana where water would be diverted to are up to around 800 m^3/s and flows at the gauge on the Wilmot River are up to 400 m^3/s so this should not result in a significant impact on calibration.

Similarly, Lemonthyme Power Station diverts flows from the Mersey River into the Forth River at Lake Cethana, and this has not been explicitly modelled. Lemonthyme Power Station capacity is approximately 43 m^3/s so is relatively small compared to peak flows observed on the Forth River.

3.4. Flood Levels and Extents

Flood survey levels and extents within the Forth-Leven 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.

No other information was available for the verification of modelled flood levels and extents.

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 known gauges and levees (where available). 2 m DEM subsets were available at all known gauges (refer Table 1 and Table 2) and levees (refer **Error! Reference source not found.**), except at Iris River at Middlesex Plains.

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 3.

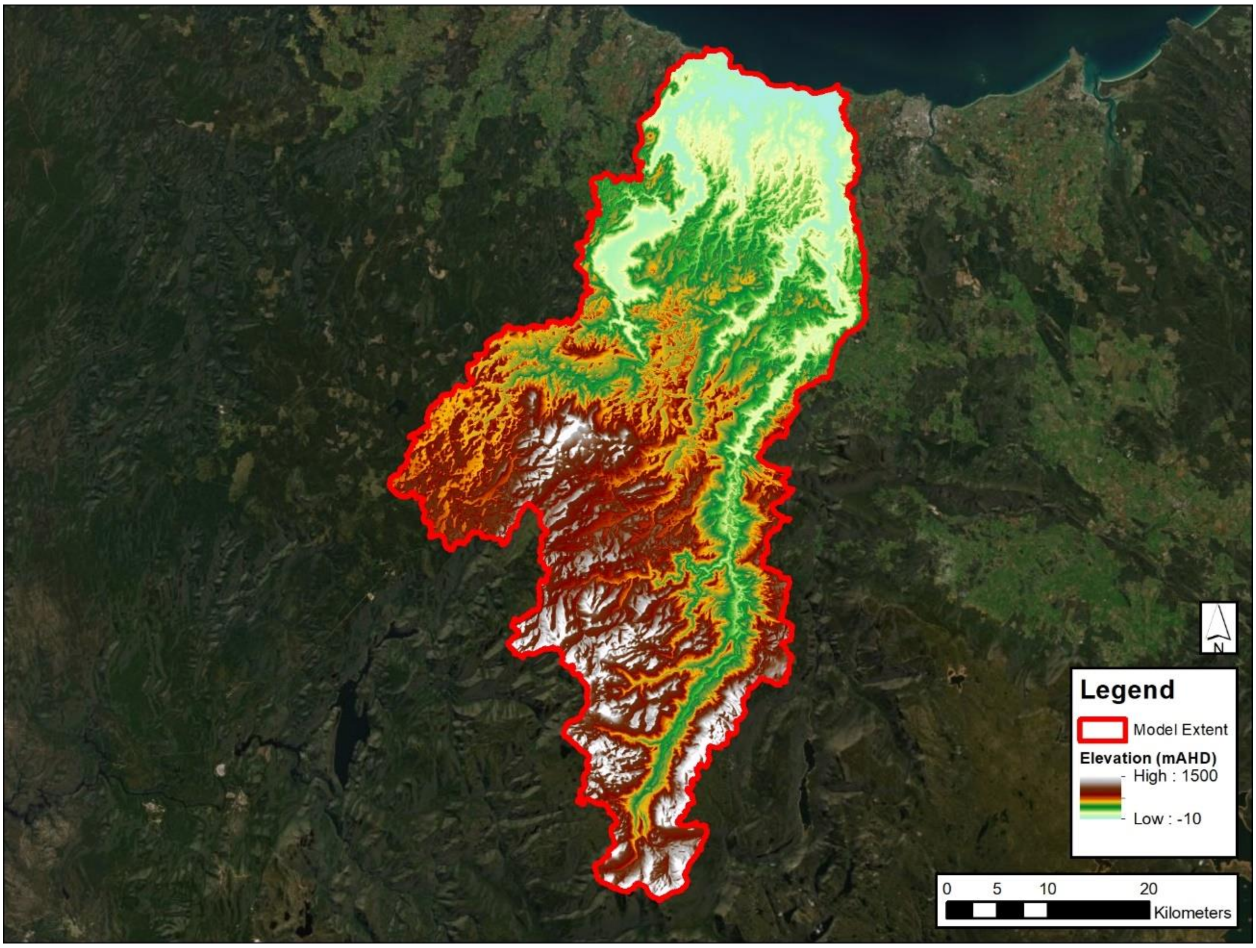

Diagram 3: DEM of the Forth-Leven study area

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 4. The majority of the Forth-Leven study area is covered by the good quality 'LiDAR DTM'.

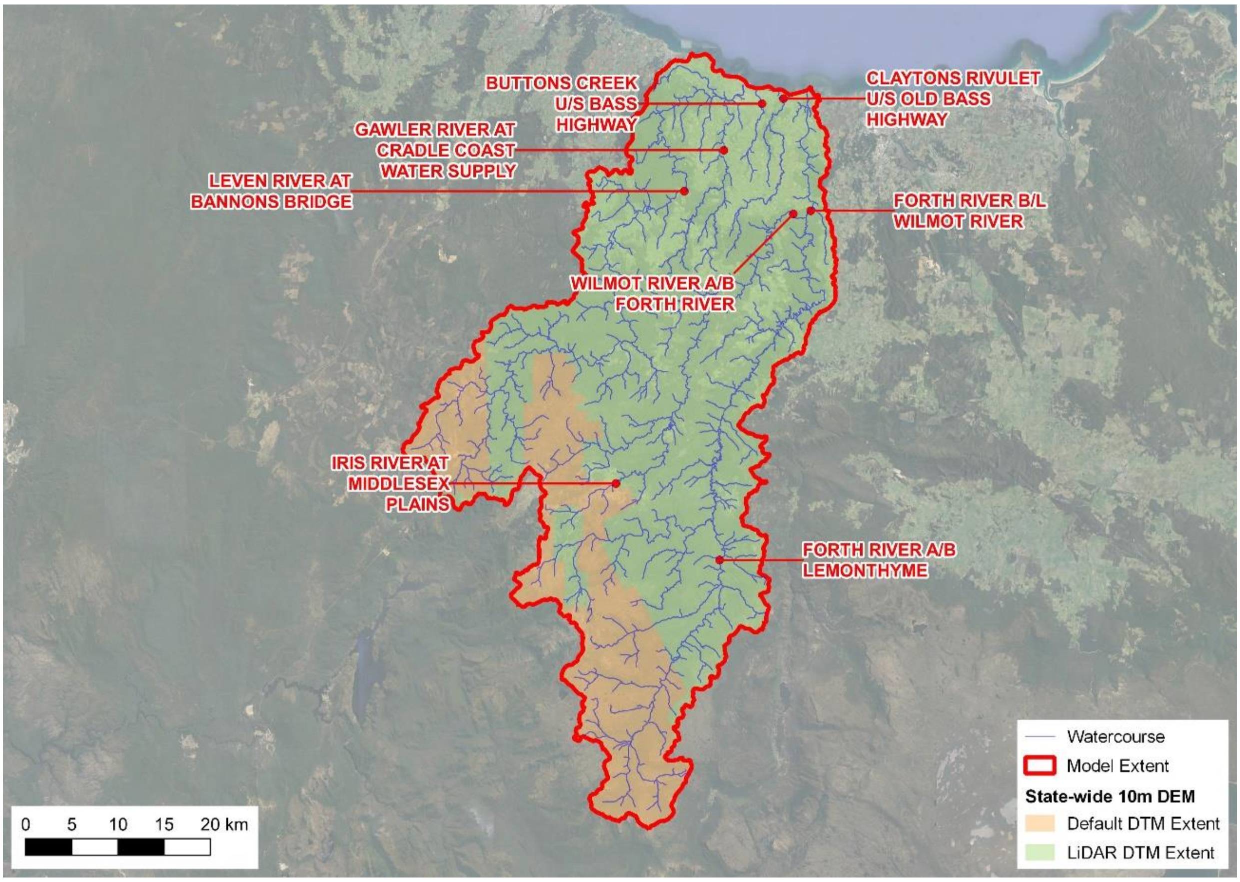

Diagram 4: 'Default DTM' extents for the Forth-Leven study area

A review of the DEM found the following:

- LiDAR data was not available in the upper reaches of Forth River, Wilmot River (including Iris River at Middlesex Plains), and Leven River. The lack of LiDAR in the upper reaches of Forth River had some impact on the routing of the hydrodynamic model (refer Section 6.2) and the lack of LiDAR at Iris River at Middlesex Plains meant that calibration was not attempted to levels at this gauge (refer to Section 6.4.1).
- At Claytons Rivulet u/s Bass Highway and Buttons Creek u/s Bass Highway, the 2 m DEM subsets were found to have been artificially filled behind the road downstream. The SES state-wide 10 m DEM was used instead.
- At Forth Road at Forth River, Bass Highway at Leven River, Hobbs Parade at Leven River, and West Gawler Road at Gawler River, the roadway was not adequately removed from the DEM. As improved topographic information was not available, the DEM was modified to allow for the free flow of water (and the bridges were not explicitly modelled).

The river entrance at Forth River was widened in response to the modelled levels being higher than expected, when compared to the 2016 flood level survey (Section 6.5). Prior to this modification the river entrance was found to increase the modelled levels at Bass Highway at Forth River by approximately 1.2 m in June 2016, which was believed to be erroneous.

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.

During the calibration process, the channel roughness at Wilmot River a/b Forth River, Forth River b/l Wilmot River, and Leven River at Bannons Bridge was decreased from the default of 0.05 to 0.03. Roughness was decreased in some areas to counteract the loss of conveyance in the area due to the lack of correct bathymetry. If improved bathymetric data is available in the future, this should be reviewed.

The resulting roughness layer is shown in Diagram 5.

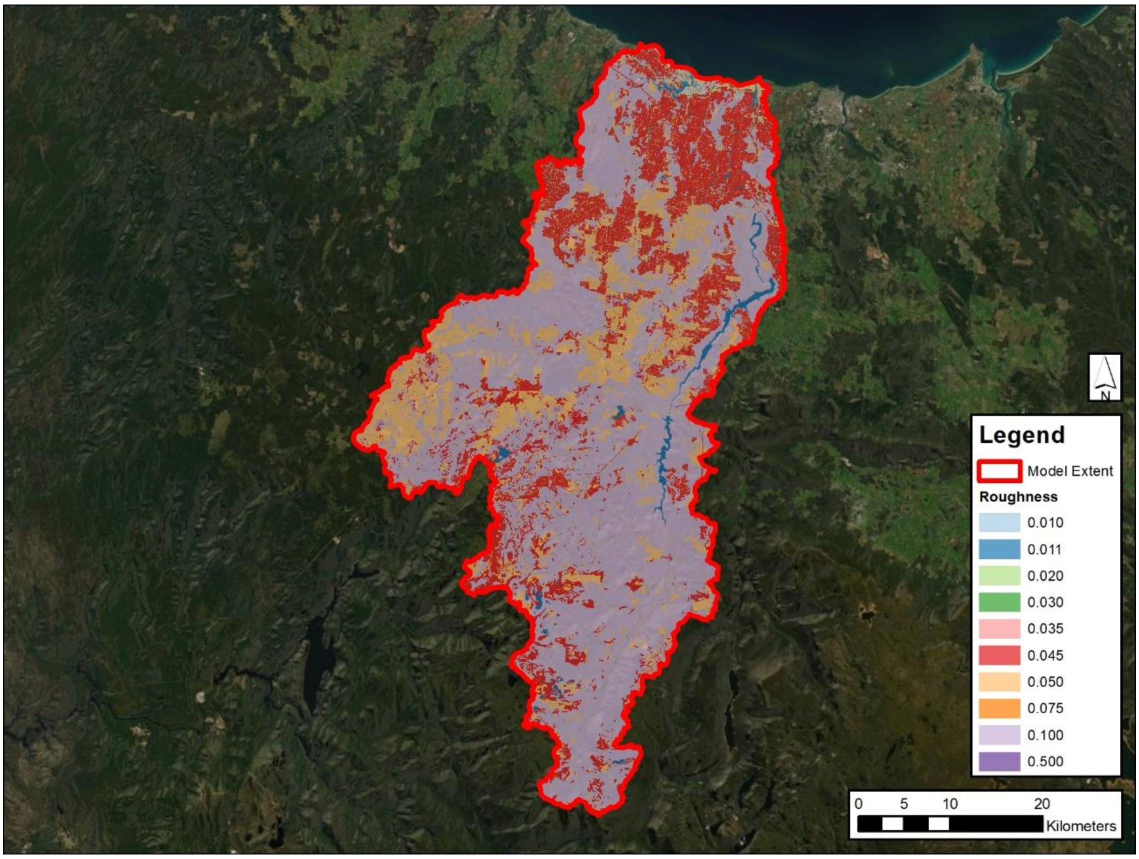

Diagram 5: Roughness layer for the Forth-Leven study area

5.3. Meshing

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

- Base mesh zone – the default mesh size, was set to a maximum of 2500 m^2 and a minimum of 400 m^2
- Stream mesh zones – set as an independent mesh zone with a maximum mesh size of 400 m^2 and a minimum of 100 m^2

- 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 m^2 and a minimum of 100 m^2. 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 m^2 and a minimum of 25 m^2
- Gauge/levee mesh zones – set as an independent mesh zone with a maximum area of 25 m^2 and a minimum of 10 m^2

The use of a 10 m^2 to 25 m^2 mesh zone at gauges and levees is a slight deviation from the standard methods (25 m^2 to 100 m^2), however, was found to improve the outcomes of the modelling.

The resulting mesh zones are shown in Diagram 6.

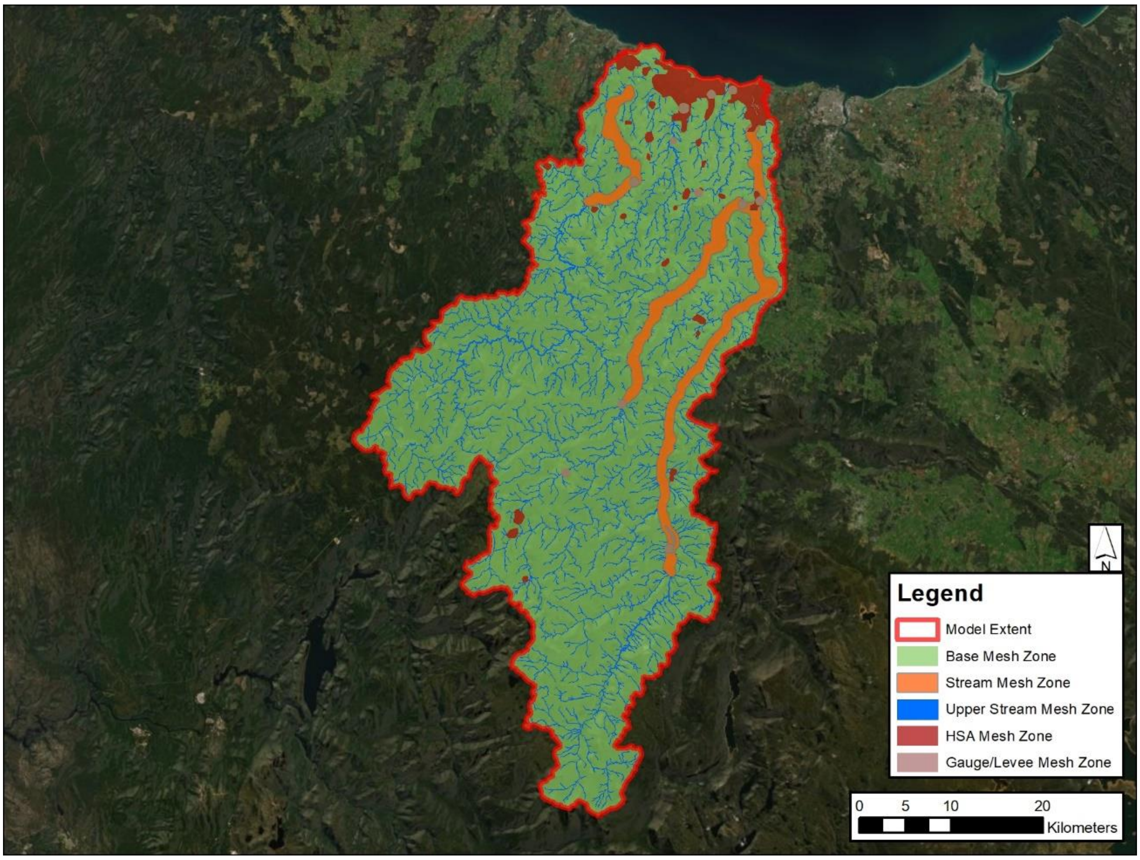

Diagram 6: Mesh zones for the Forth-Leven study area

5.4. Structures

Within the study area, eight 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:

- Spellmans Road at Wilmot River
- Leven Road at Leven River
- Penguin Cradle Trail at Leven River
- Loongana Road at Leven River
- Marshalls Bridge Road at Leven River
- South Riana Road at Leven River
- Bannons Bridge Road at Leven River
- Purtons Road at Leven River

The following bridges were removed from the model in response to the modelled levels being higher than expected, when compared to the gauge results (Section 6.4) and the 2016 flood level survey (Section 6.5):

- Wilmot Road at Wilmot River
- Paloona Road at Forth River
- Bass Highway at Forth River
- Railway at Forth River
- Golf Club Road at Leven River
- Railway at Leven River

Within the study area, several culverts were identified in the immediate vicinity of Claytons Rivulet u/s Bass Highway and Buttons Creek u/s Bass Highway. As detailed drawings or survey of the culverts were not available, the dimensions and inverts of the culverts were estimated from aerial and street imagery (where possible) and the DEM.

The details used for modelling the culverts are as follows:

- Wintara Road at Claytons Rivulet – assumed to be 1/9000x2100 RCBC
- Bass Highway at Claytons Rivulet – assumed to be 3/3000x2100 RCBC
- Bass Highway On/Off Ramp at Buttons Creek – assumed to be 2/3000x2100 RCBC
- Castra Road at Buttons Creek – assumed to be 3/3000x2100 RCBC
- Bass Highway at Buttons Creek – assumed to be 2/x3000x2100 RCBC
- Production Drive at Buttons Creek – assumed to be 2/3000x2100 RCBC

The locations of the modelled structures are shown in Figure 12. The locations of the known levees are also shown.

5.5. Dams

The storage and spillway elements of Lake Gairdner, Lake Cethana, Lake Barrington, Lake Paloona, and Lake Isandula were modelled in the hydrodynamic model as 1D elements using the storage and spillway rating curves supplied for the project (refer Section 3.3). These elements were then linked to the 2D domain.

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 calibration events and was used to set a varying tide level. This data was extracted off the coast of Ulverstone at 10 min time increments and was imported into ICM as a time varying boundary condition. Diagram 7 shows an example of the synthetic tide data that was extracted for the June 2016 event.

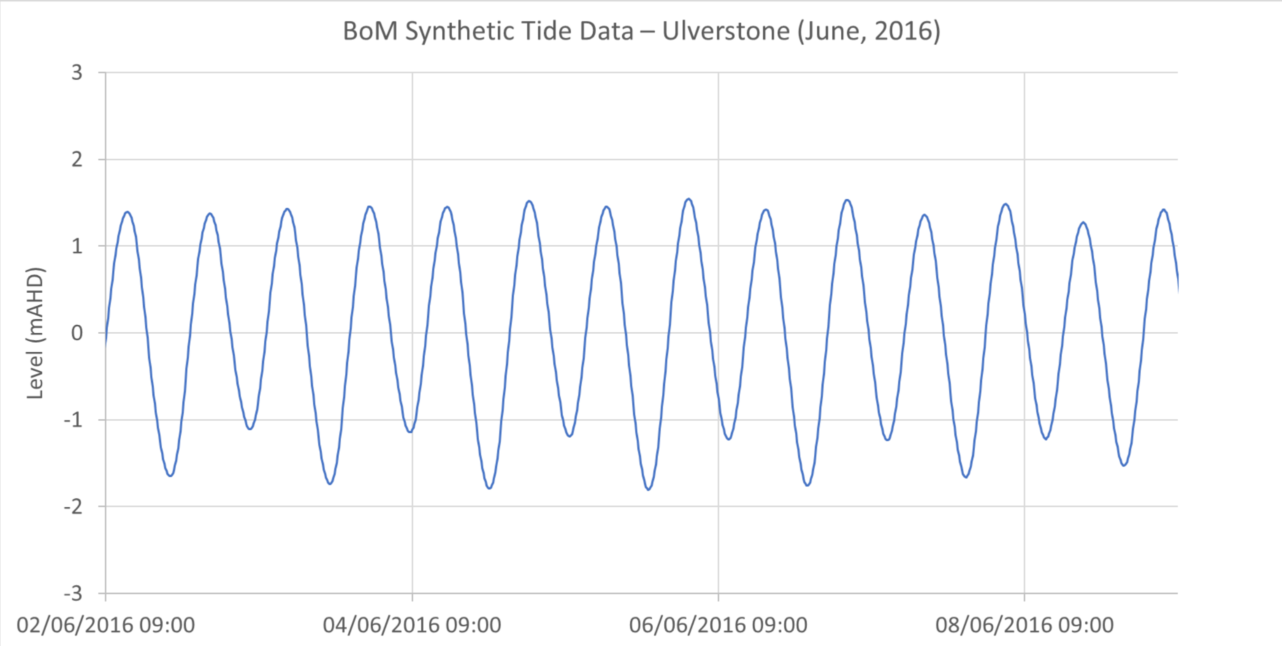

Diagram 7: Synthetic tide data off the coast of Ulverstone (June, 2016)

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 8.

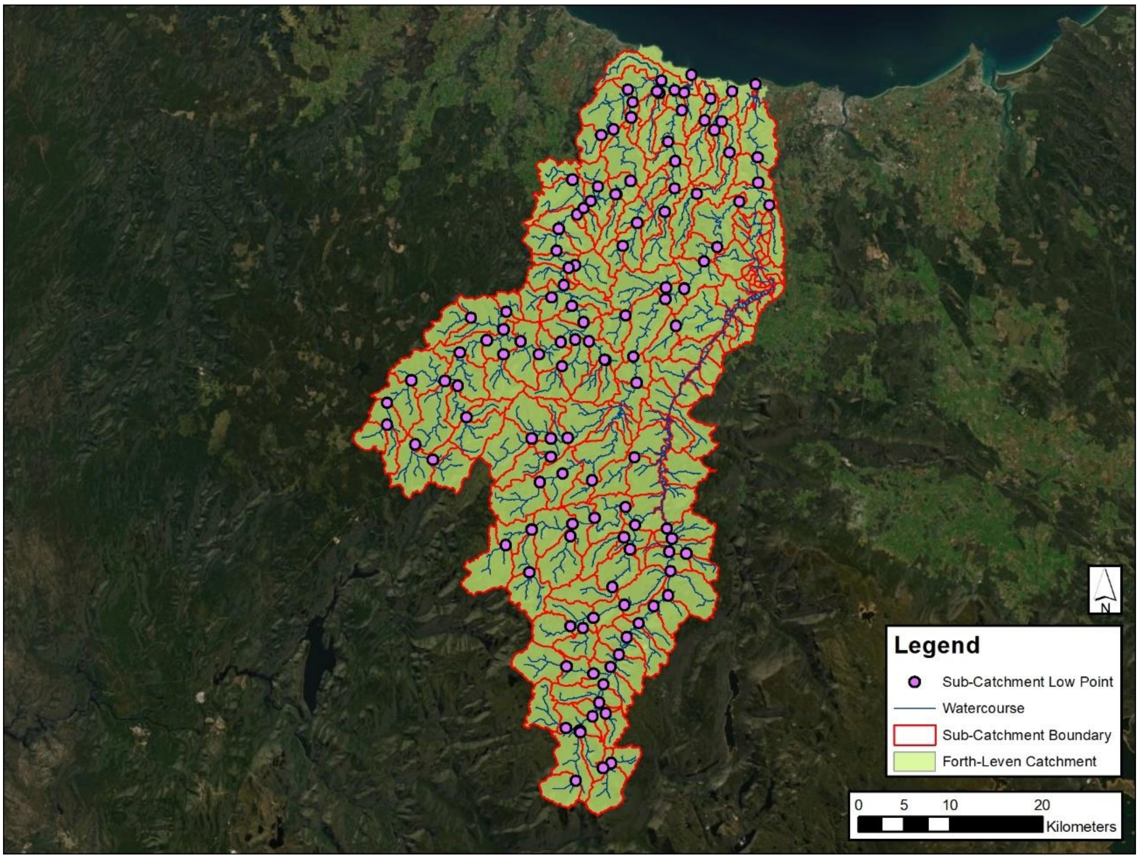

Diagram 8: RAFTS sub-catchment model setup for the Forth-Leven study area

6. CALIBRATION RESULTS

Mapping of the peak flood depths from the calibrated hydrodynamic model for each calibration event is shown in Figure 7 to Figure 10.

6.1. Discussion on Selected Approach

During the calibration of the hydrodynamic model it became clear that a calibration to both level and flow would not be possible, due to the lack of bathymetry and the large amount of flow that is present in the base conditions of the rivers. This is due to DEM utilising the water level in the channel as the assumed topography.

Noting the purpose of the calibration is to ensure the model is performing appropriately, a calibration focussed on achieving a good match to observed flood levels in the 2016 event (Section 6.5.1) was prioritised over a good match to flow at the key gauges. For reference however the average losses required to achieve a good flow match and a good level match are presented below (Table 6). If bathymetry data for the channels is obtained in the future the losses that match for flow would be a good starting point to confirm calibration.

For design event scenarios, a match to flow rather than level will be undertaken. This is to ensure the validity of the design events that are selected as well as to ensure that the levels are conservative. An alternative approach would be to utilise the same change in loss rate as established for the 2016 event to assess design flows, noting that this may result in non-conservative results in some locations.

Table 6: Catchment average calibrated parameters

Statistic	June 2016 (Flow Calibration)	June 2016 (Level Calibration)*
IL (mm)	20	20
Average CL (mm/h)	1.65	2.20

* As presented in Section 6.4 and Section 6.5. Catchment average CL was increased by 33% compared to the initial flow calibration.

6.2. 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.

To prevent the overfitting of parameters, a single IL and scaling to the default CLs (based on the soil types as described in the Hydrology Methods Report (2021a)) was used across the entire study area. It is acknowledged that there are some locations where flows are under or overestimated (for example, Leven River). Varying losses across the catchment could improve the fit at some of these locations, however, the poor fit is just as likely due to uncertainties in the recorded flows (Section 3.1.2) and distribution of rainfalls (Section 3.2) as to the actual loss behaviour of the catchment.

An RAF of 2 was adopted based on initial model runs with an RAF of 1, 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 2 and a RAF of 1 at key gauges for the June 2016 calibration even is shown in Diagram 9 to Diagram 11.

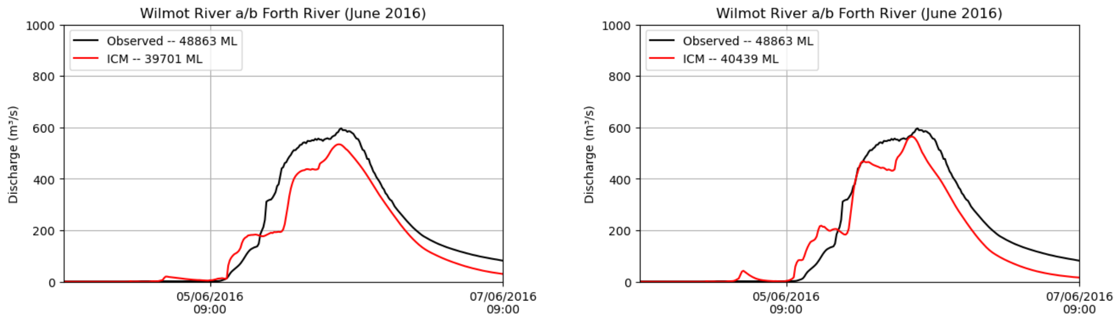

Diagram 9: Flow comparison at Wilmot River a/b Forth River (left: RAF 2, right: RAF 1)

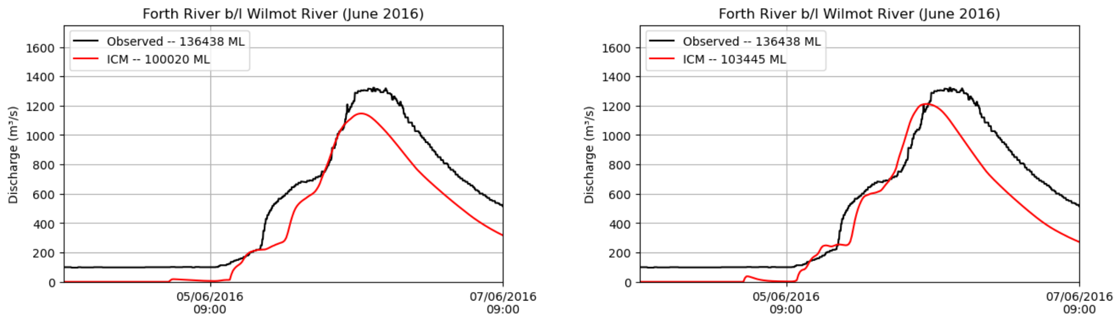

Diagram 10: Flow comparison at Forth River b/l Wilmot River (left: RAF 2, right: RAF 1)

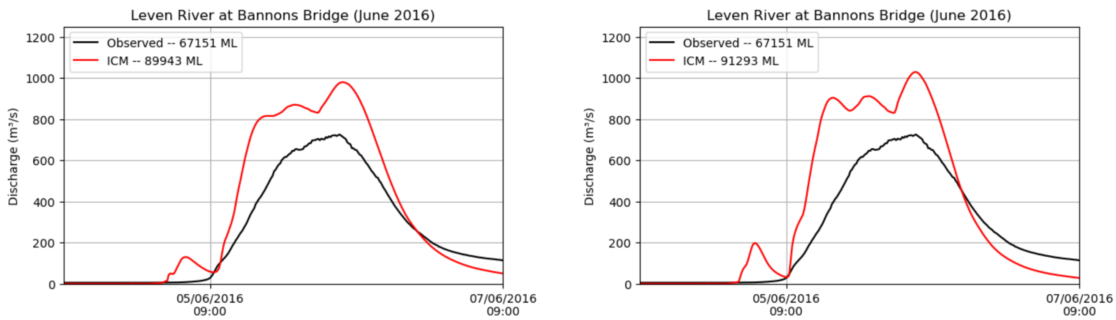

Diagram 11: Flow comparison at Leven River at Bannons Bridge (left: RAF 2, right: RAF 1)

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.

In the upper reaches of Forth River (where LiDAR data was not available), the poor quality 'Default DTM' resulted in some differences between the routing of the external hydrologic model and the ICM model. This appeared to be limited to the rising limb of the hydrographs however (as the artificial depressions were being filled) and did not impact on peak flows.

6.3. 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.

6.4. Gauge Results

As discussed in Section 3.1.1, the August 1970 and June 2016 calibration events were very large across the study area and were assessed at the gauges and lakes where historic event information was available. The August 2007 and January 2011 calibration events were only significant at selected locations in the study area and were only assessed at these locations.

The results for gauges and lakes on the Wilmot, Forth, and Leven Rivers are shown in the following sections. The gauges on the smaller creeks and rivers are then shown.

Comparisons of the gauge and modelled rating curves are shown in Appendix D.

6.4.1. Iris River at Middlesex Plains

Significant flows were recorded at Iris River at Middlesex Plains during the January 2011 and June 2016 events. Data was only available since 1994 and therefore was not used for the August 1970 event.

As noted in Section 3.1, the supplied rating curve was given a high flow rating quality of “fair”, with the highest gauging about 70% of January 2011 and 25% of June 2016 (1.5 m compared to 1.65 m and 2.2 m respectively).

Differences between the modelled and supplied rating curves were observed during model calibration (Figure D 1). As noted in Section 5.1, LiDAR data at this site was not available and therefore, there was a high degree of uncertainty in the DEM and modelled levels. As such, no changes were made to the default model and the modelled and observed levels have been presented below for illustration only.

The modelled and observed flows and levels at Iris River at Middlesex Plains are shown in Table 7 and Diagram 12 to Diagram 13. The modelled peak flow is overestimated in January 2011 and underestimated in June 2016 compared to the observed flows.

A gauge zero for this site was not provided by Hydro Tasmania, so a gauge zero of 733.6 mAHD was assumed. This gauge zero was inferred from the DEM of the hydrodynamic model.

Table 7: Calibrated parameters and results at Iris River at Middlesex Plains

Statistic	January 2011	June 2016
IL (mm)	20	20
Average CL (mm/h)	2.5	2.67
RAF	2	2
Modelled Peak (m^3/s)	73	76
Observed Peak (m^3/s)	50	140
Peak % difference	+62%	-45%
Modelled Volume (ML)	4,255	6,977
Observed Volume (ML)	3,761	10,382
Volume % difference	+13%	-33%
Modelled Peak (mAHD)	735.23	735.19
Observed Peak (mAHD)	735.25	735.80
Peak difference (m)	-0.02	-0.61

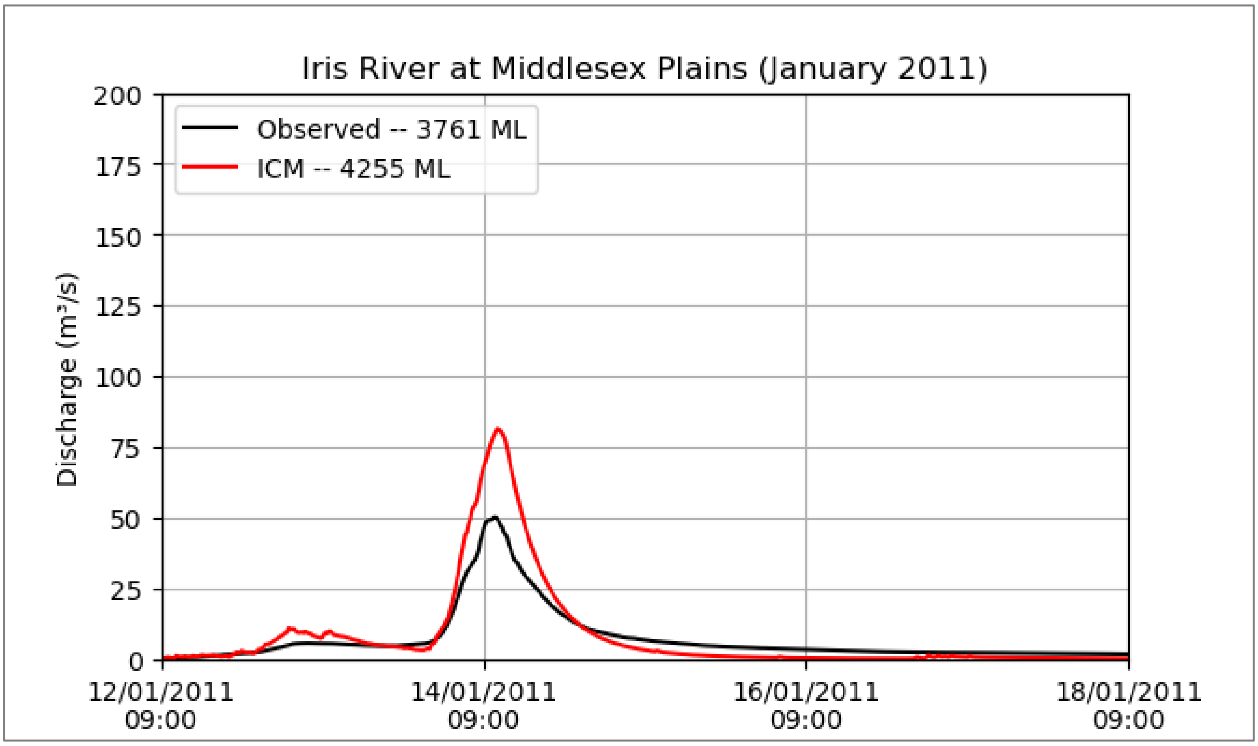

Diagram 12: January 2011 flow comparison at Iris River at Middlesex Plains

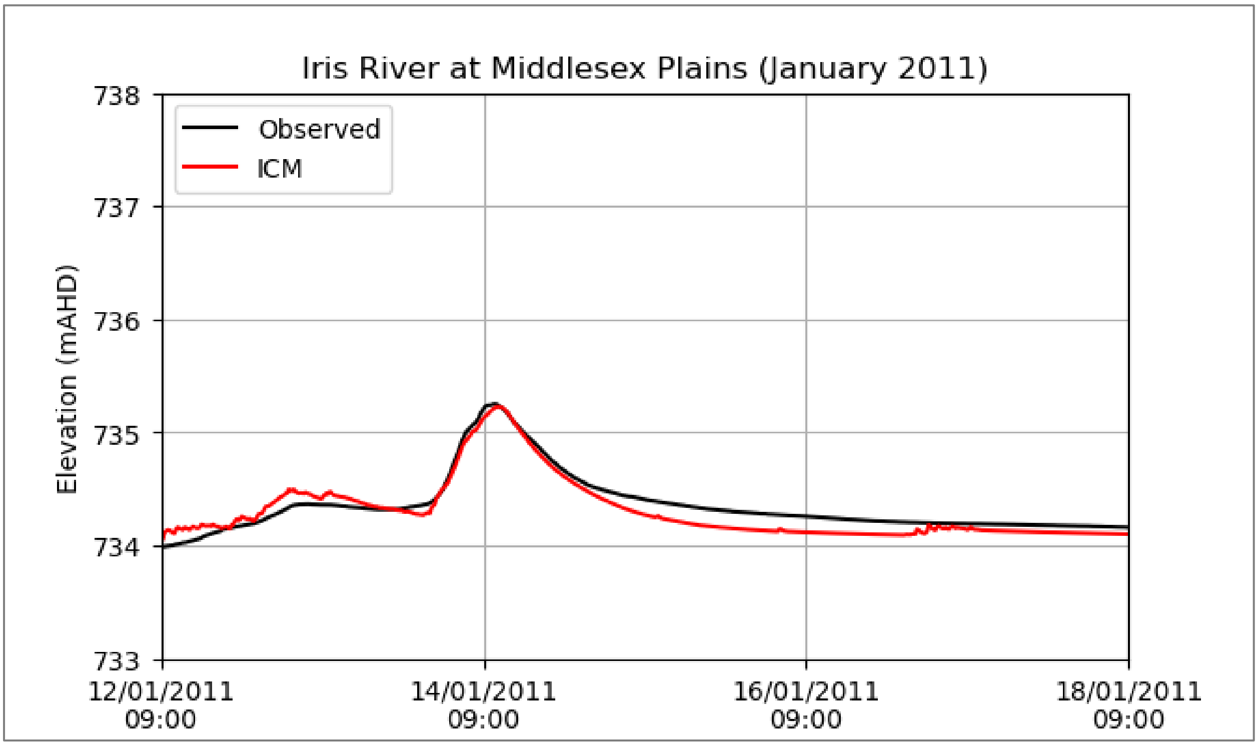

Diagram 13: January 2011 water level comparison at Iris River at Middlesex Plains

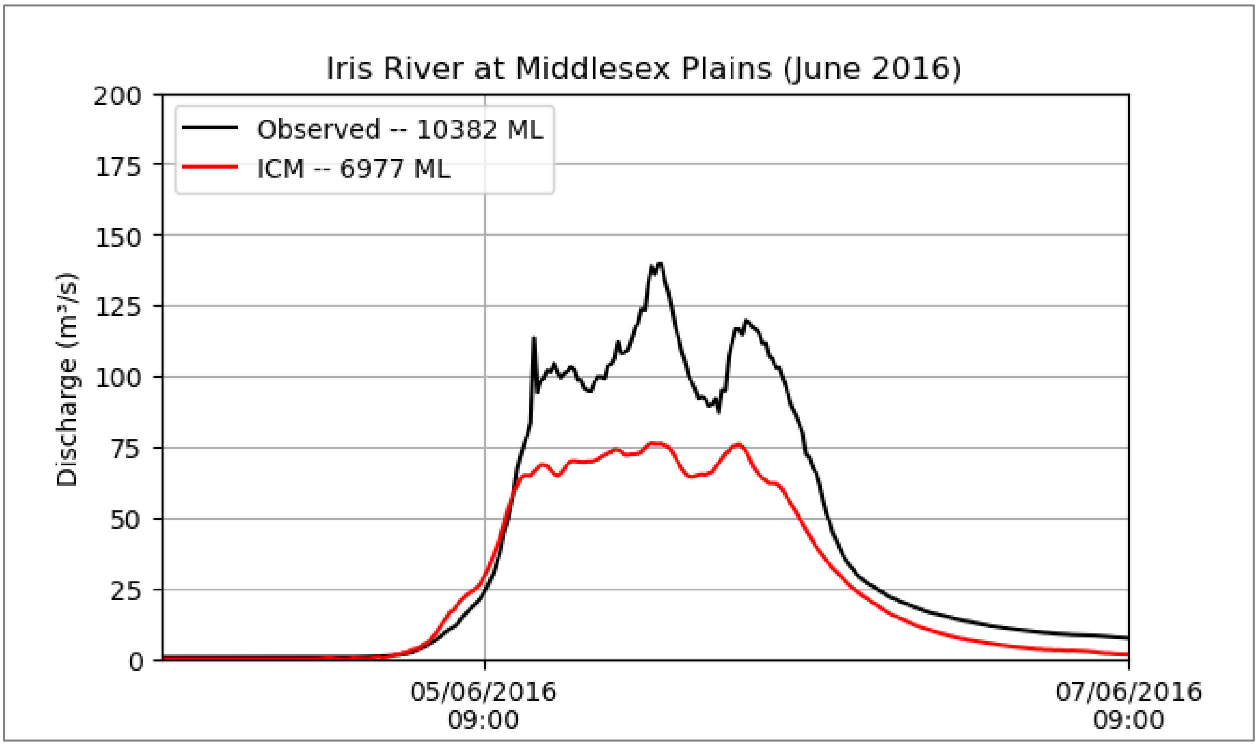

Diagram 14: June 2016 flow comparison at Iris River at Middlesex Plains

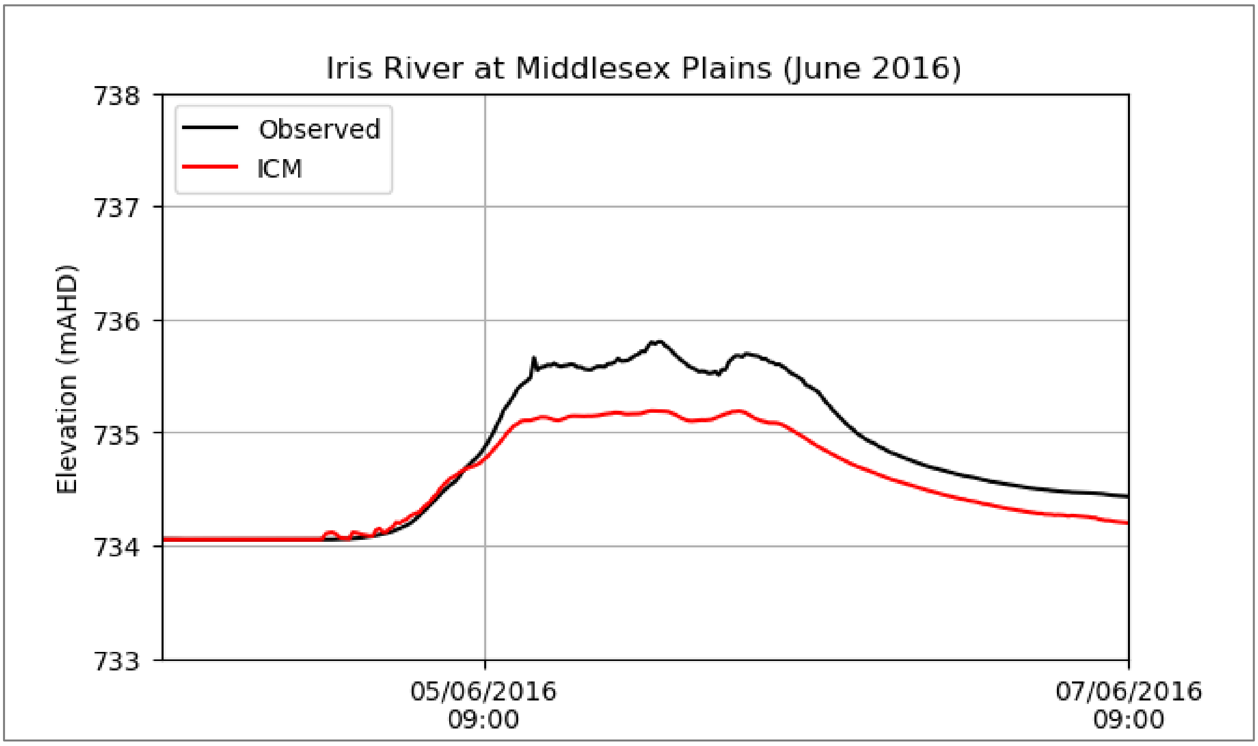

Diagram 15: June 2016 water level comparison at Iris River at Middlesex Plains

6.4.2. Lake Gairdner

Significant spills were recorded at Lake Gairdner during the August 1970, January 2011, and June 2016 events. Lake Gairdner discharges into Wilmot River via the spillway and can discharge into Lake Cethana (in Forth River) via a tunnel to Wilmot Power Station. As discussed in Section 3.3, the power station flows were not modelled as they were deemed to be a small proportion of flood flows even at peak capacity (approximately 20 m^3/s).

The modelled and observed spills at Lake Gairdner are shown in Table 8 and Diagram 16 to Diagram 18. The modelled spills show a poor to fair match to the observed, with peak flows and volumes underestimated in for all modelled events. Lake Gairdner's catchment area is largely made up of alpine plains, as discussed in Section 3.2 there may potentially have been snow fall in the week or so leading up to the June 2016 flood event, which would then have melted during the event. This could explain the underestimation of event volumes upstream of Lake Gairdner as snow melt would not be included in the recorded precipitation.

As discussed in Section 3.1.1, no attempt was made to match to the observed peak of the August 1970 event (which was believed to be due to an isolated intense rainfall burst that was not captured in the available rainfall data), but the overall shape of the event was considered.

Table 8: Calibrated parameters and results at Lake Gairdner

Statistic	August 1970	January 2011	June 2016
IL (mm)	0	20	20
Average CL (mm/h)	2.5	2.5	2.67
RAF	2	2	2
Modelled Peak (m^3/s)	304	295	294
Observed Peak (m^3/s)	448	317	430
Peak % difference	-32%	-7%	-32%
Modelled Volume (ML)	24,214	10,551	22,215
Observed Volume (ML)	34,818	13,008	33,958
Volume % difference	-31%	-19%	-35%

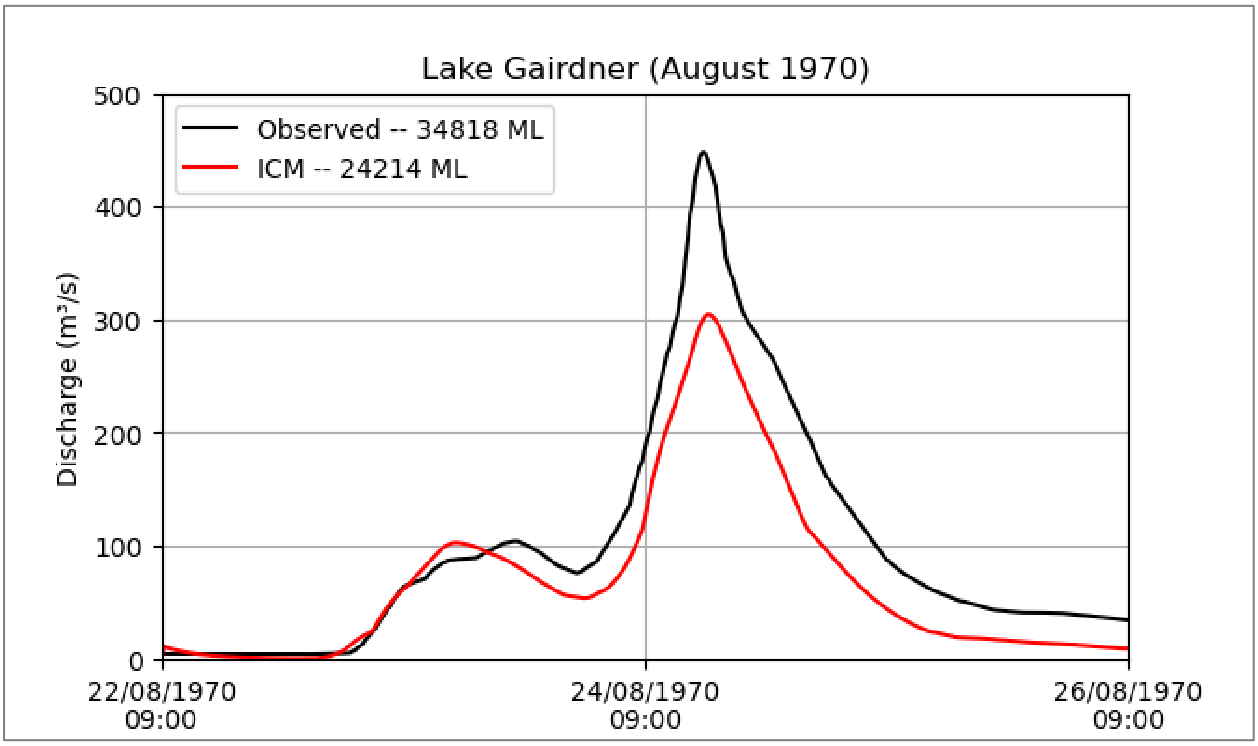

Diagram 16: August 1970 flow comparison at Lake Gairdner

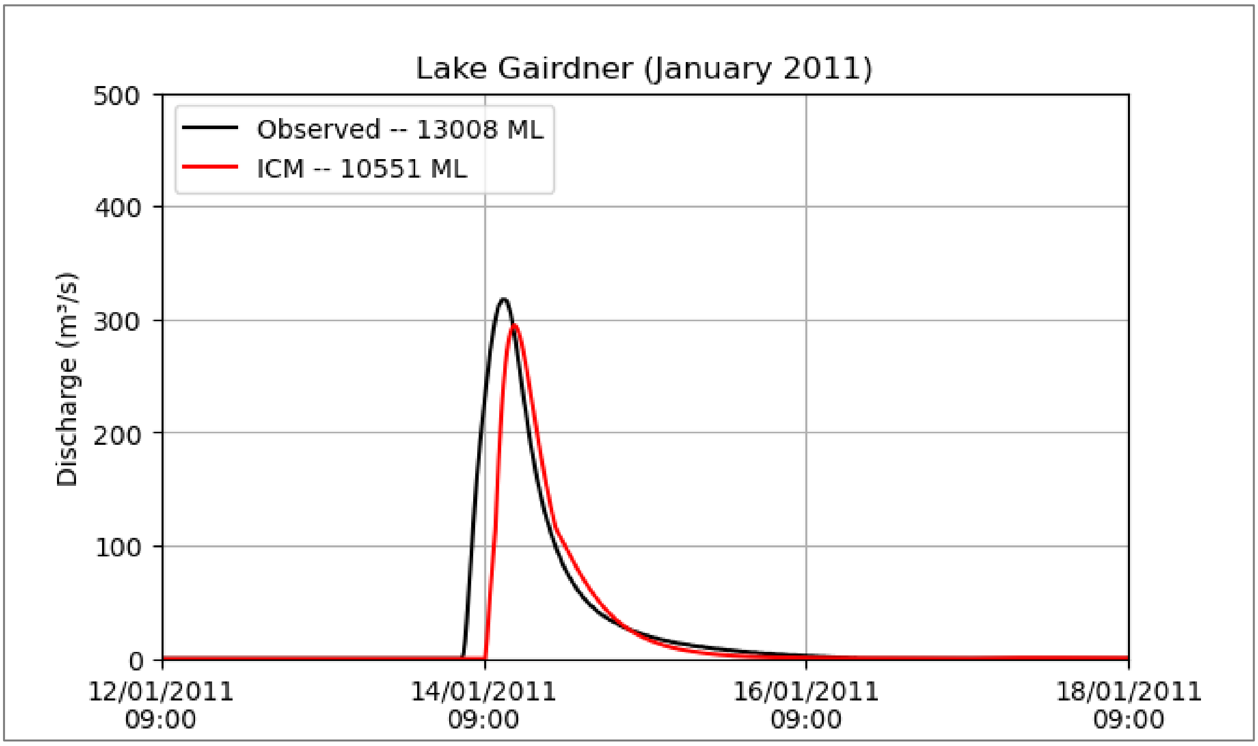

Diagram 17: January 2011 flow comparison at Lake Gairdner

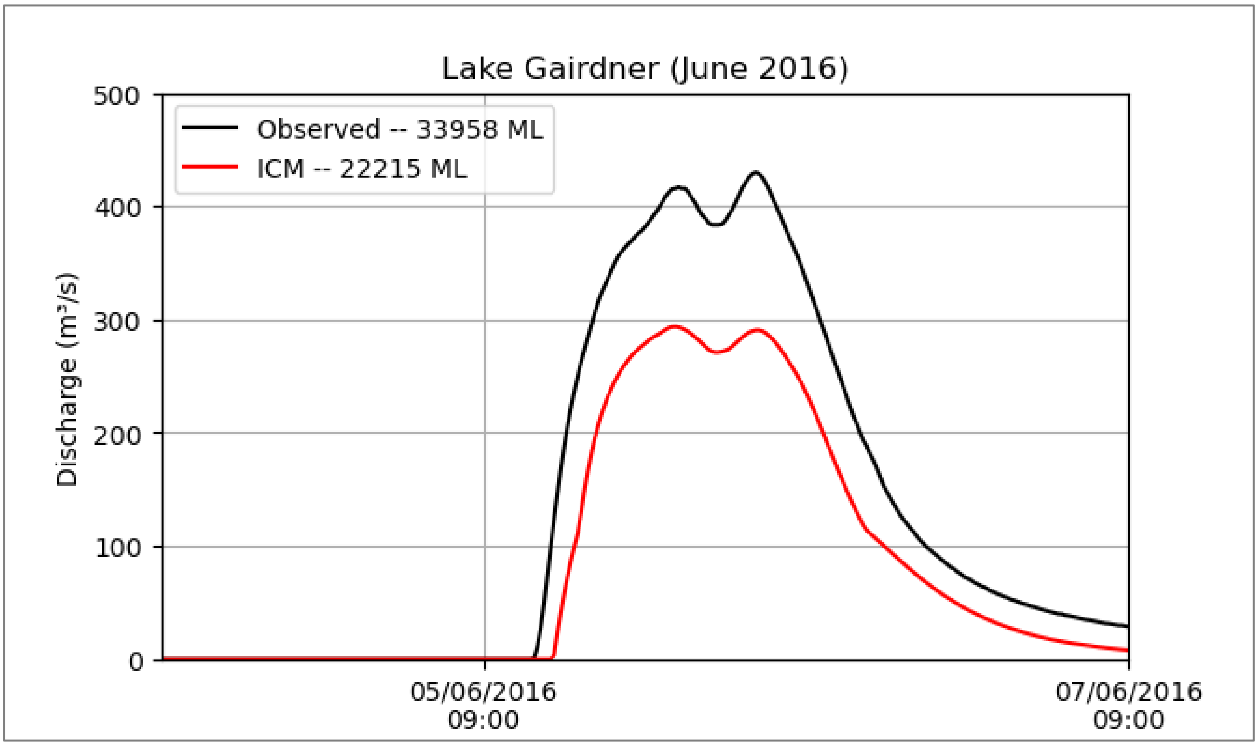

Diagram 18: June 2016 flow comparison at Lake Gairdner

6.4.3. Wilmot River a/b Forth River

Significant flows were recorded at Wilmot River a/b Forth River during the August 1970, January 2011, and June 2016 events. As noted in Section 3.1, there was a datum shift at this site when it was reopened after the 15-year closure from 1982-1997.

The supplied rating curve was given a high flow rating quality of “fair” pre datum shift, with the highest gauging at about 20% of the observed peak flow for August 1970. As the reason for the datum shift, and any potential changes in the location or cross-section profile when the site was re-established is not known, model calibration was attempted to flows only for August 1970.

The supplied rating curve was given a high flow rating quality of “poor” post datum shift, with the highest gauging at less than 1% of the observed peak flow for January 2011 and June 2016. Due to the uncertainty in the site’s rating at high flows, model calibration was attempted to levels only for January 2011 and June 2016.

In keeping with some of the other sites, the channel roughness at this location was decreased (Section 5.2). It is noted that the supplied DEM does not appear to contain the full river bathymetry at this location, and the change to the channel roughness may be partially or fully compensating for this (rather than an actual change to the channel roughness).

It is also noted that this site is approximately 200 m upstream of Wilmot Road at Wilmot River, which was found to increase the levels at the gauge by approximately 1 m in June 2016 with the default bridge parameters. This was believed to be erroneous for the likely structure and the bridge was removed from the model, enabling appropriate conveyance through the section. Future iterations of the model should review the bridge structure and utilise survey or design drawings of the bridge should they become available.

The modelled and observed flows and levels at Wilmot River a/b Forth River are shown in Table 9 and Diagram 19 to Diagram 23. The modelled flows show a fair match to the observed for August 1970, looking at the event as a whole and not the isolated burst at the peak. The modelled levels show a poor to fair match to the observed for January 2011 and June 2016, with peak level underestimated in January 2011 and overestimated in June 2016.

As discussed in Section 3.1.1, no attempt was made to match to the observed peak of the August 1970 event (which was believed to be due to an isolated intense rainfall burst that was not captured in the available rainfall data).

A gauge zero for this site was not provided by Hydro Tasmania, so a gauge zero of 26.0 mAHD was assumed. This gauge zero was inferred from the DEM of the hydrodynamic model.

Table 9: Calibrated parameters and results at Wilmot River a/b Forth River

Statistic	August 1970	January 2011	June 2016
IL (mm)	0	20	20
Average CL (mm/h)	2.37	2.37	2.53
RAF	2	2	2
Modelled Peak (m^3/s)	441	401	534
Observed Peak (m^3/s)	607	710	597
Peak % difference	-27%	-44%	-11%
Modelled Volume (ML)	34,939	25,151	39,701
Observed Volume (ML)	49,269	29,949	48,863
Volume % difference	-29%	-16%	-19%
Modelled Peak (mAHD)	-	32.19	32.93
Observed Peak (mAHD)	-	32.90	32.55
Peak difference (m)	-	-0.71	+0.38

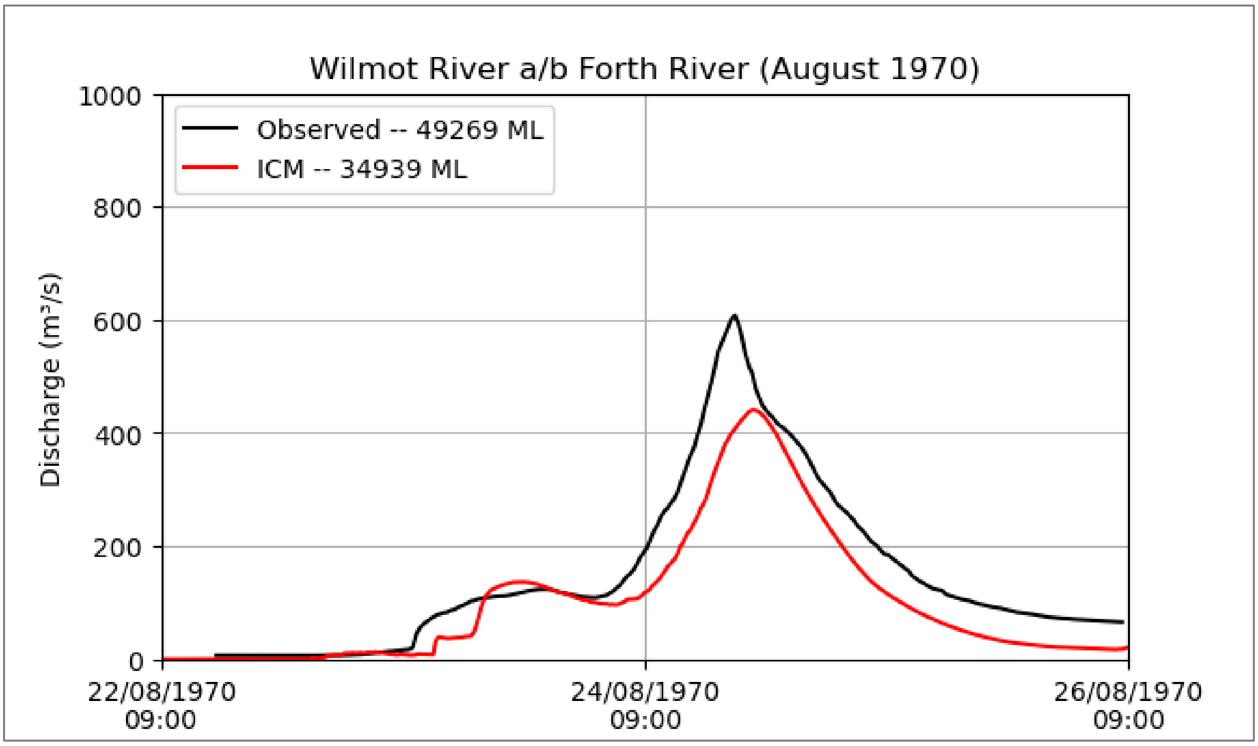

Diagram 19: August 1970 flow comparison at Wilmot River a/b Forth River

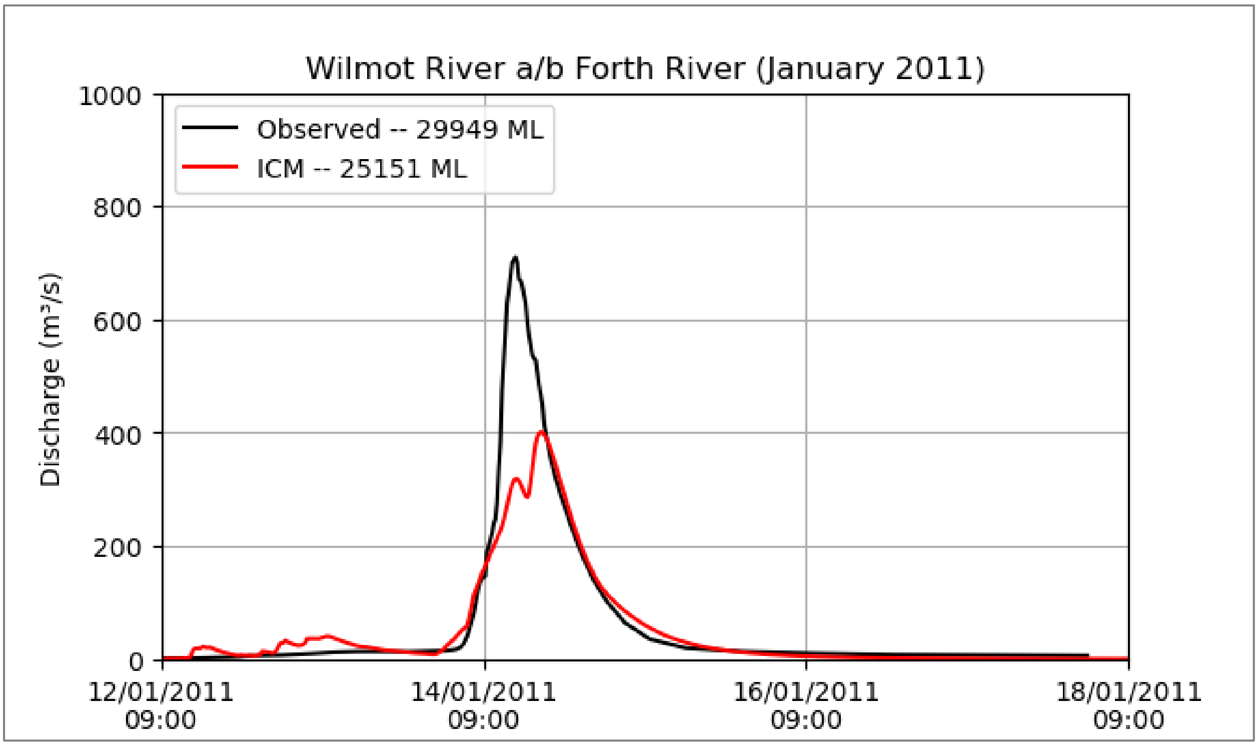

Diagram 20: January 2011 flow comparison at Wilmot River a/b Forth River

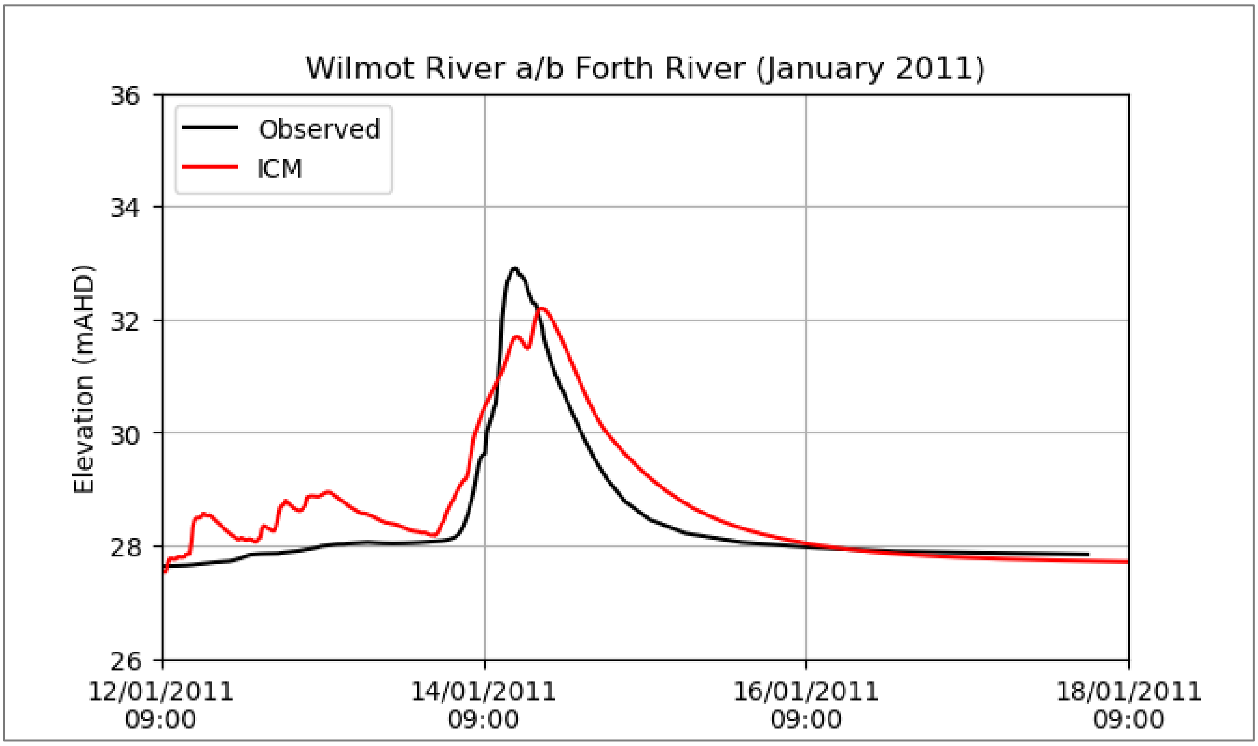

Diagram 21: January 2011 water level comparison at Wilmot River a/b Forth River

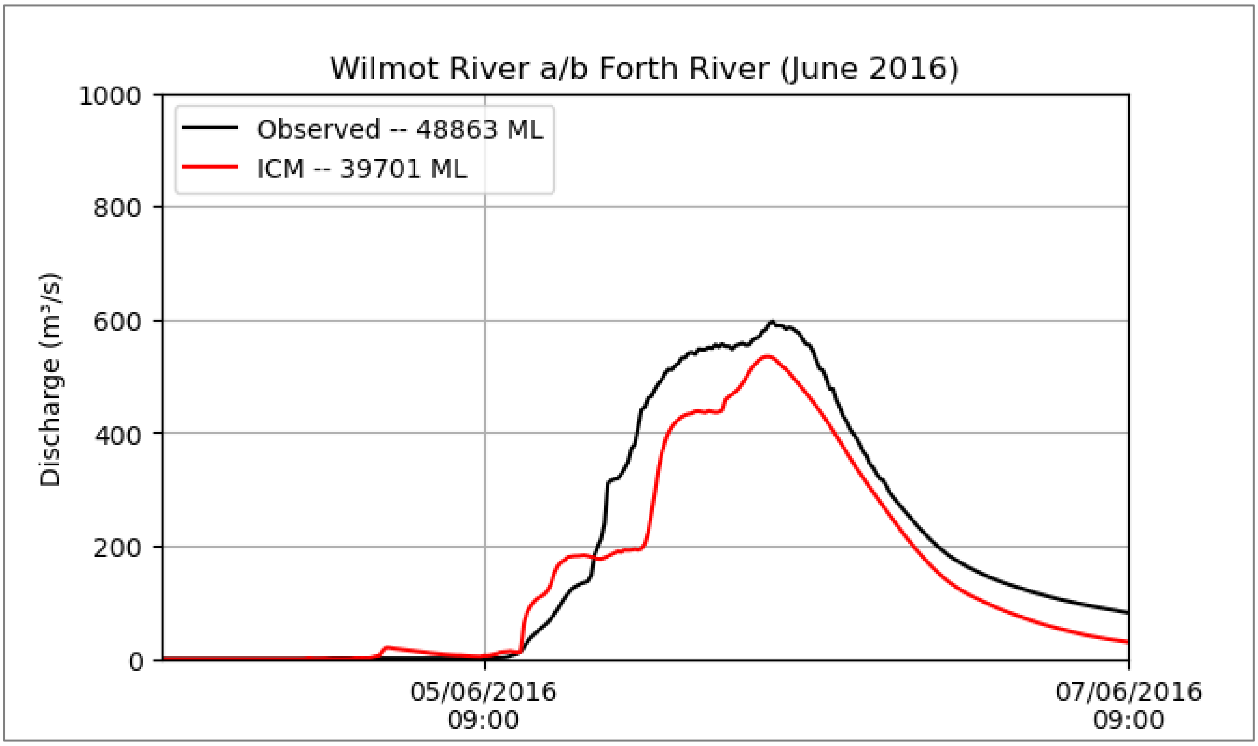

Diagram 22: June 2016 flow comparison at Wilmot River a/b Forth River

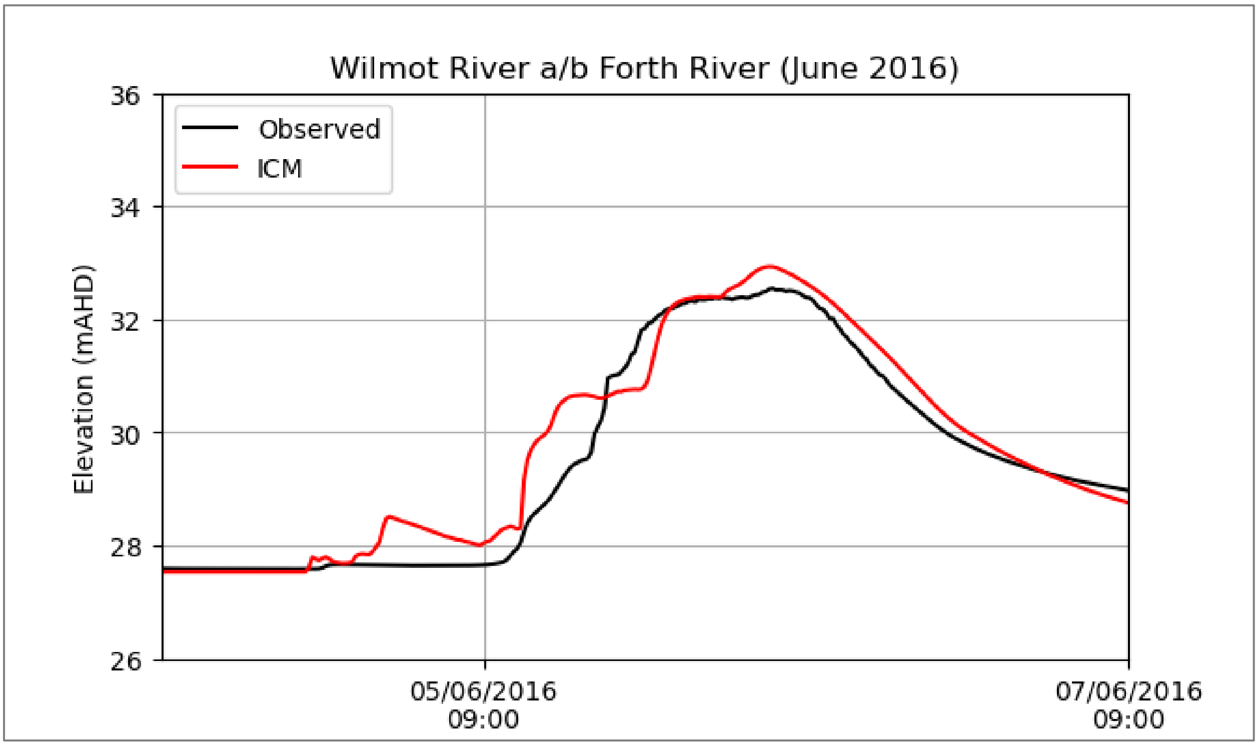

Diagram 23: June 2016 water level comparison at Wilmot River a/b Forth River

6.4.4. Forth River a/b Lemonthyme

Significant flows were recorded at Forth River a/b Lemonthyme during the August 1970, August 2007, and June 2016 events.

As noted in Section 3.1, the supplied rating curve was given a high flow rating quality of “good”, with the highest gauging between 75% to 90% of August 1970, August 2007, and June 2016 (6.50 m compared to 8.10 m, 7.16 m, and 7.44 m respectively).

Differences between the modelled and supplied rating curves were observed during model calibration (Figure D 3), and it was noted that the modelled levels at the site were controlled by artificial blockages in the model downstream. Although the 2 m DEM version of the LiDAR data was used at the site, the 10 m DEM version was used downstream, which is too coarse to adequately capture the narrow channel of Forth River in this area.

Due to the uncertainty in the modelled levels at the site, model calibration was attempted to flows only. It is recommended that the DEM downstream of the site be reviewed, should improved topographic information be available and if future detailed analysis is undertaken.

The modelled and observed flows and levels at Forth River a/b Lemonthyme are shown in Table 10 and Diagram 24 to Diagram 29. The modelled flows show a poor to fair match to the observed, with peak flow overestimated in August 1970 and underestimated in August 2007 and June 2016.

A gauge zero of 224.71 mAHD was provided for this gauge from Hydro Tasmania.

Table 10: Calibrated parameters and results at Forth River a/b Lemonthyme

Statistic	August 1970	August 2007	June 2016
IL (mm)	0	20	20
Average CL (mm/h)	1.70	0.82	1.82
RAF	2	2	2
Modelled Peak (m^3/s)	616	376	364
Observed Peak (m^3/s)	477	410	430
Peak % difference	+29%	-8%	-15%
Modelled Volume (ML)	47,338	48,328	35,353
Observed Volume (ML)	50,822	65,424	47,893
Volume % difference	-7%	-26%	-26%
Modelled Peak (mAHD)	235.83	233.94	233.84
Observed Peak (mAHD)	232.81	231.87	232.15
Peak difference (m)	+3.02	+2.07	+1.70

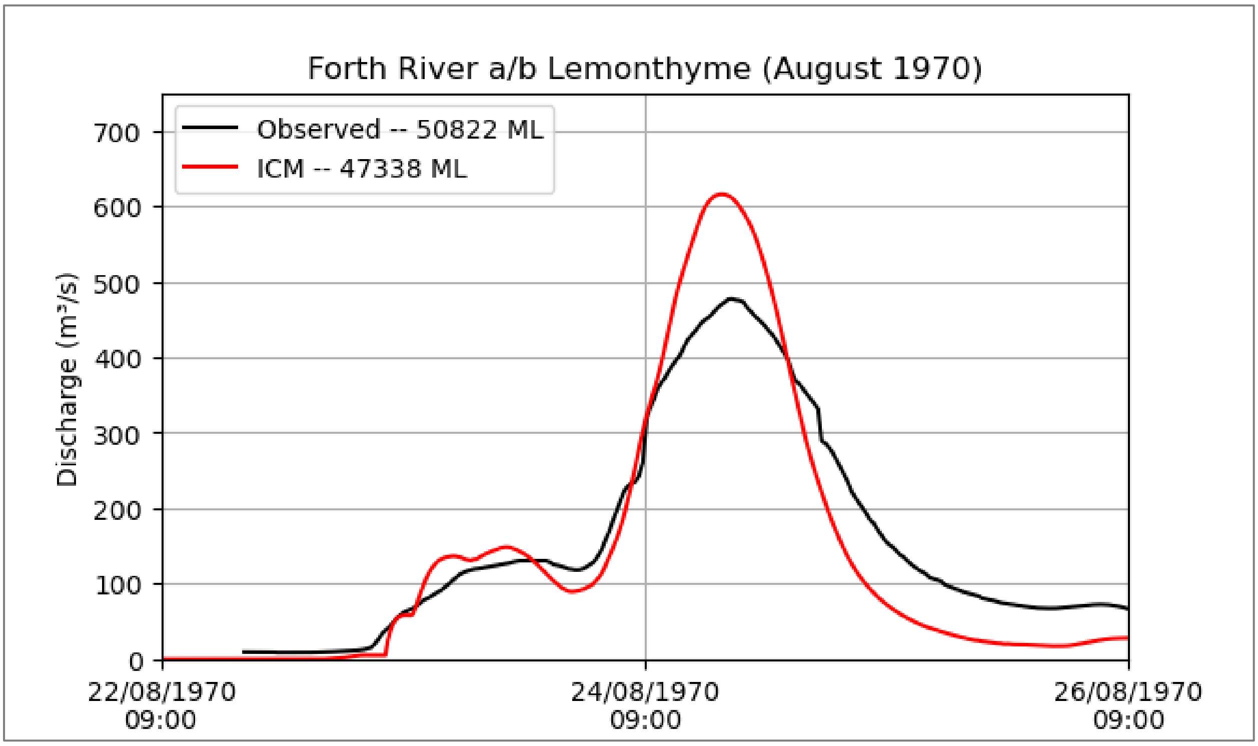

Diagram 24: August 1970 flow comparison at Forth River a/b Lemonthyme

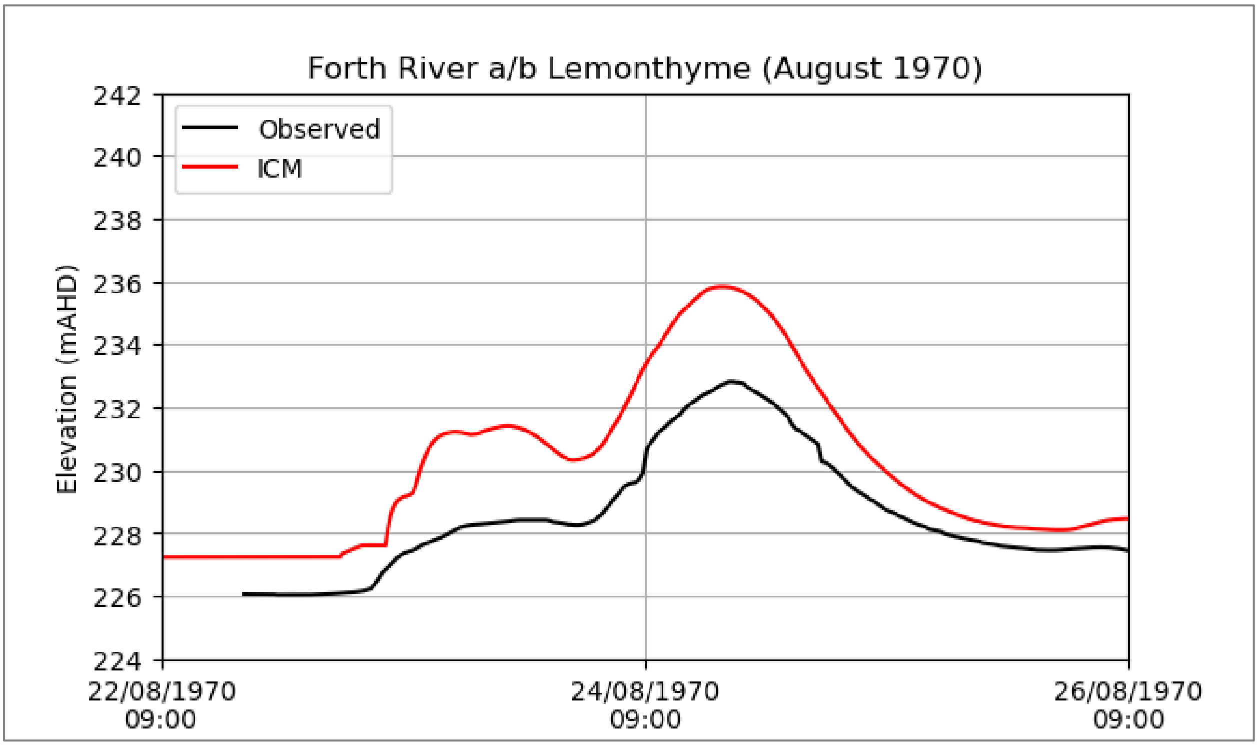

Diagram 25: August 1970 water level comparison at Forth River a/b Lemonthyme

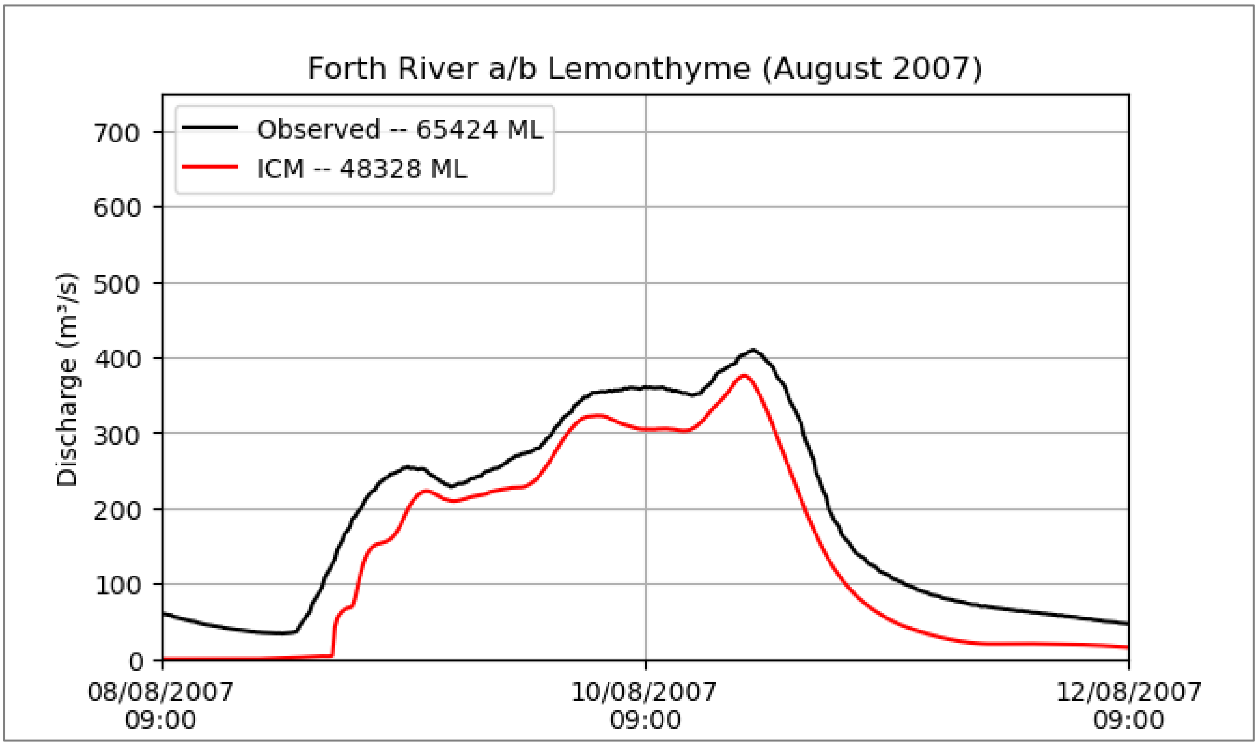

Diagram 26: August 2007 flow comparison at Forth River a/b Lemonthyme

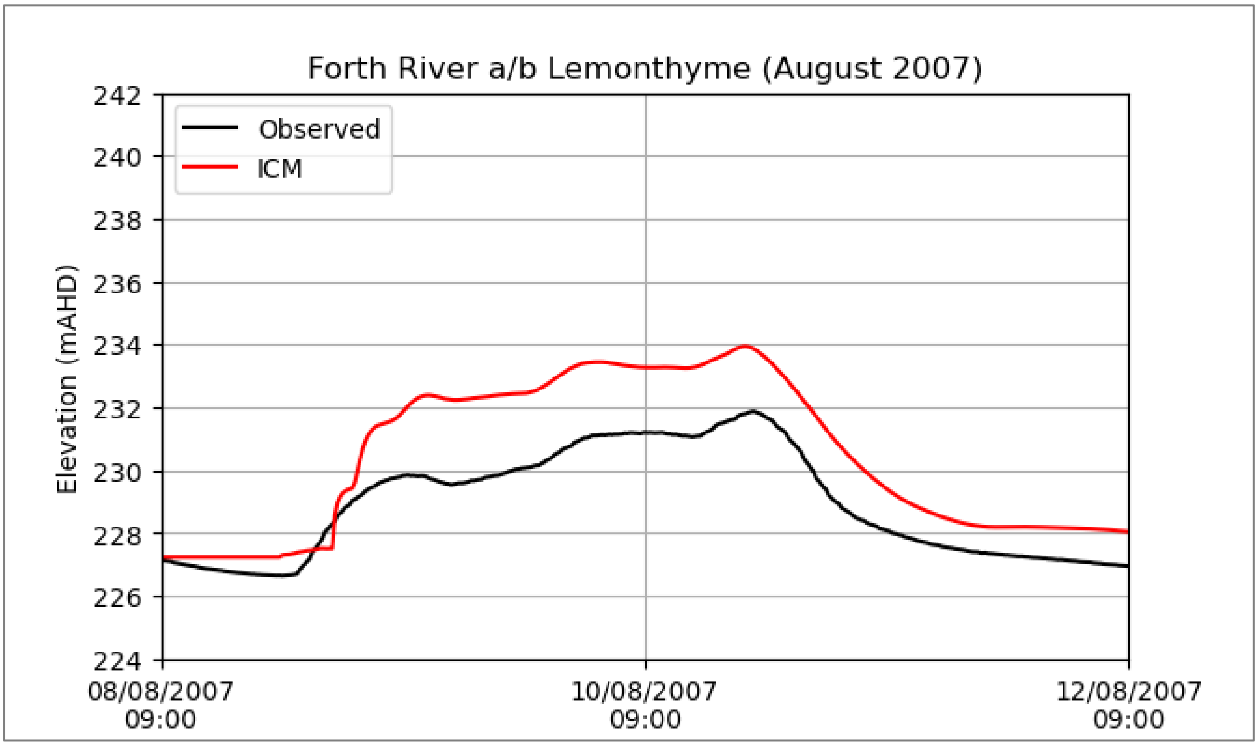

Diagram 27: August 2007 water level comparison at Forth River a/b Lemonthyme

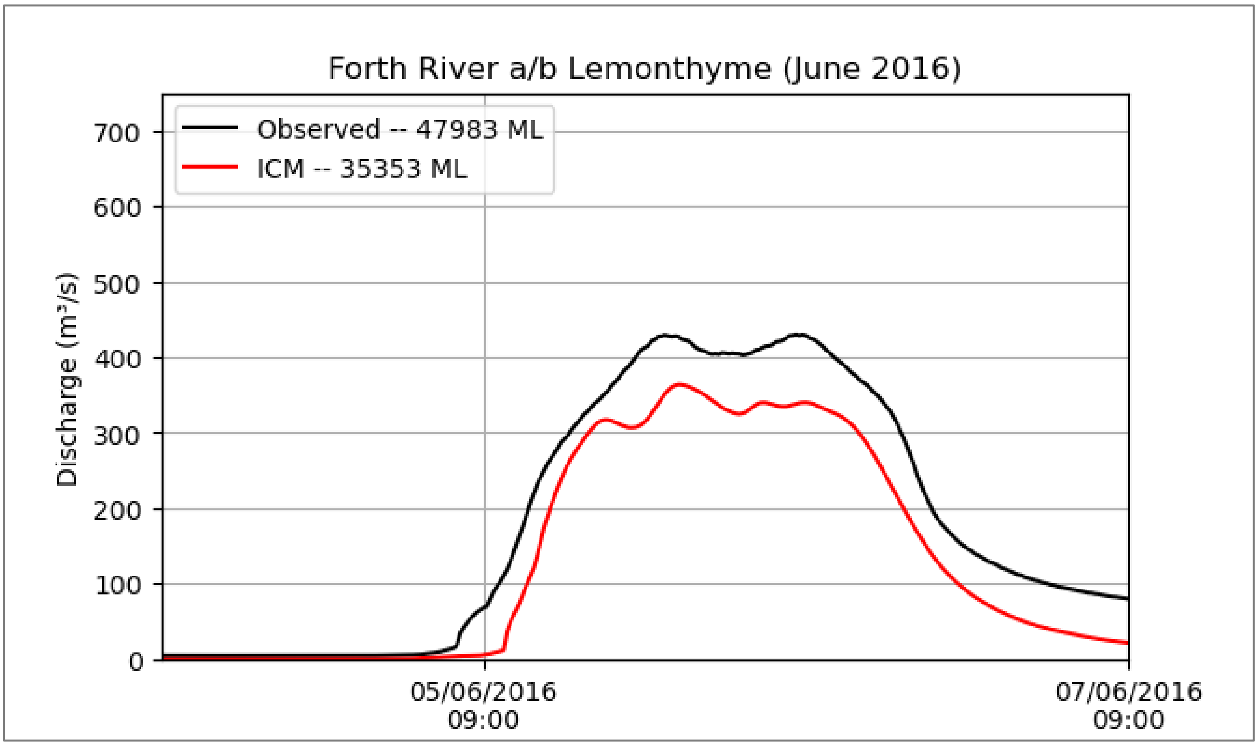

Diagram 28: June 2016 flow comparison at Forth River a/b Lemonthyme

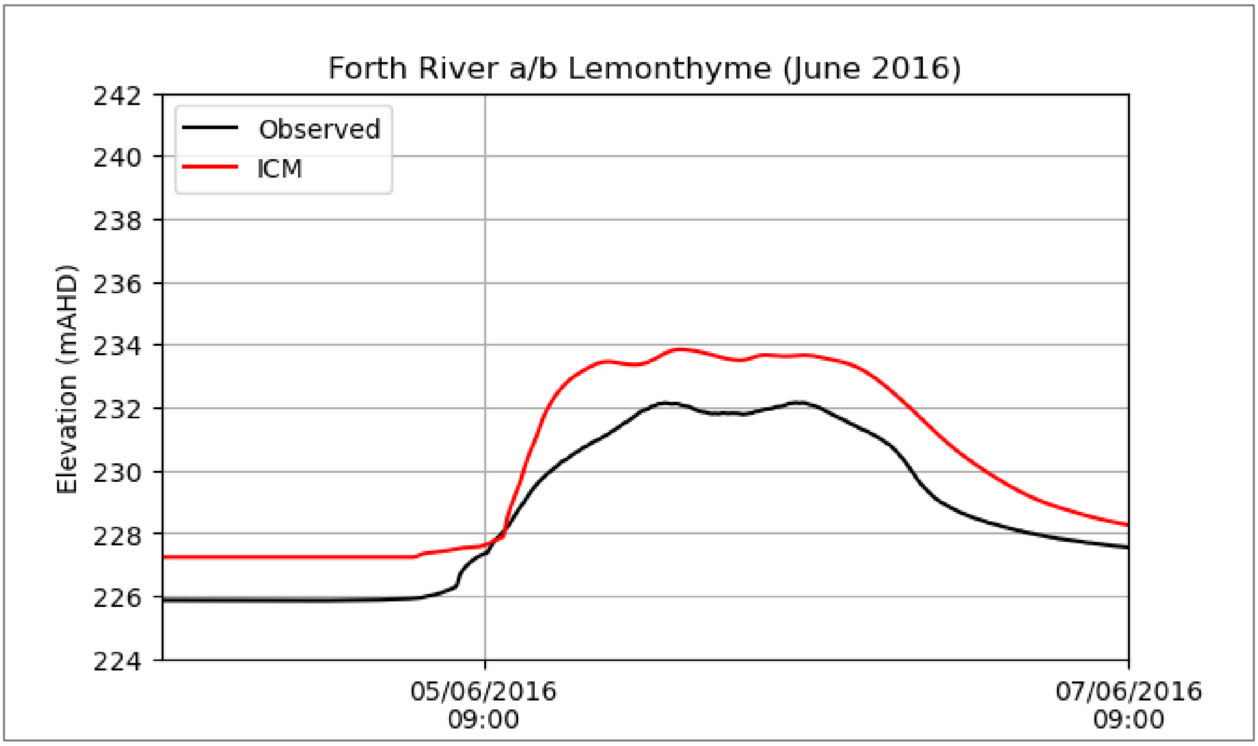

Diagram 29: June 2016 water level comparison at Forth River a/b Lemonthyme

6.4.5. Lake Cethana

Significant spills were recorded at Lake Cethana during the August 2007 and June 2016 events. Lake Cethana was not dammed at the time of the August 1970 event.

Although Lake Cethana is located on Forth River, it can also receive flows from Wilmot River (via the Wilmot Power Station) and Mersey River (via the Lemonthyme Power Station). Lake Cethana discharges into Lake Barrington via the Cethana Power Station and spillway.

As discussed in Section 3.3, the inflows from the Wilmot Power Station and Lemonthyme Power Station were not modelled as they were deemed to be a small proportion of flood flows even at peak capacity (approximately 20 m^3/s and 45 m^3/s respectively). In addition, the outflows from the Cethana Power Station were not modelled as they discharge immediately downstream of the dam along with the spills.

The modelled spills and observed outflows at Lake Cethana are shown in Table 11 and Diagram 30 to Diagram 31. Observed outflows are power station discharge plus spill. The modelled spills show a good match to the observed for August 2007, but a poor match for June 2016, with peak flow underestimated. To enable a fair comparison of peak flows, the observed spills at Lake Cethana include the outflows from the Cethana Power Station.

Table 11: Calibrated parameters and results at Lake Cethana

Statistic	August 2007	June 2016
IL (mm)	0	20
Average CL (mm/h)	0.95	2.10
RAF	2	2
Modelled Peak (m^3/s)	599	659
Observed Peak (m^3/s)	627	871
Peak % difference	-5%	-24%
Modelled Volume (ML)	82,067	56,277
Observed Volume (ML)	110,392	90,928
Volume % difference	-26%	-38%

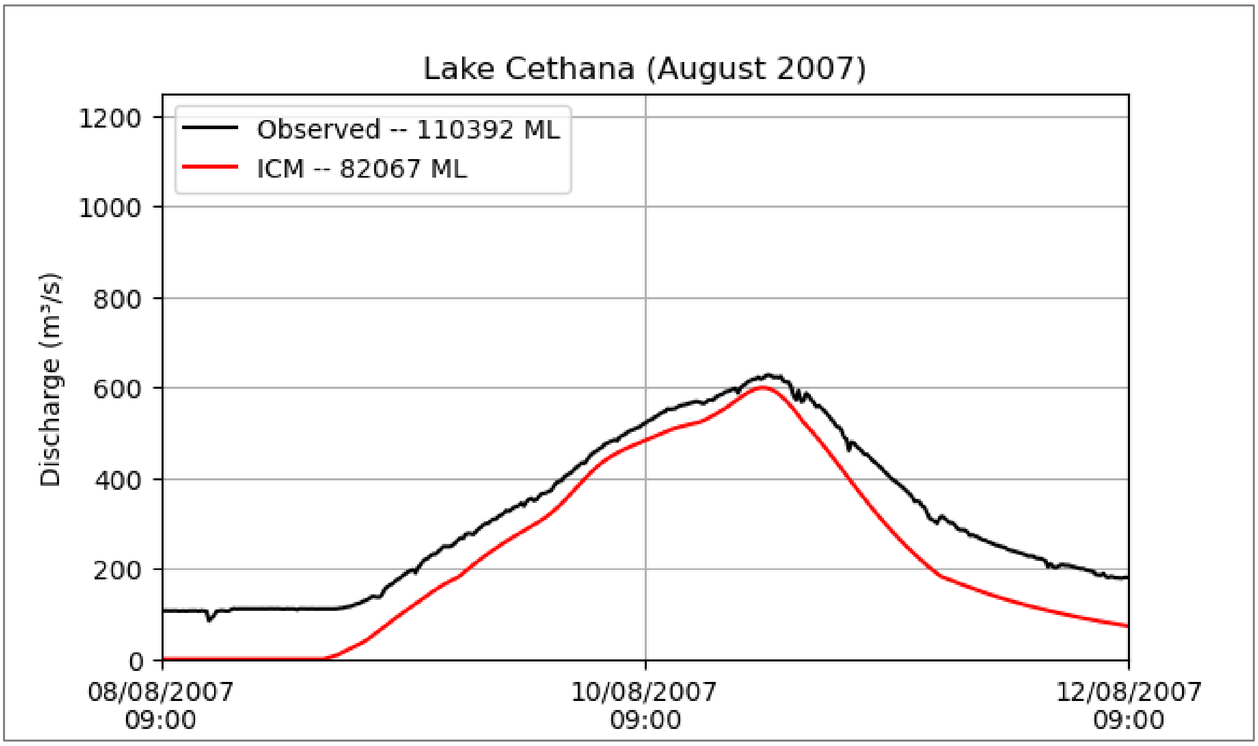

Diagram 30: August 2007 flow comparison at Lake Cethana

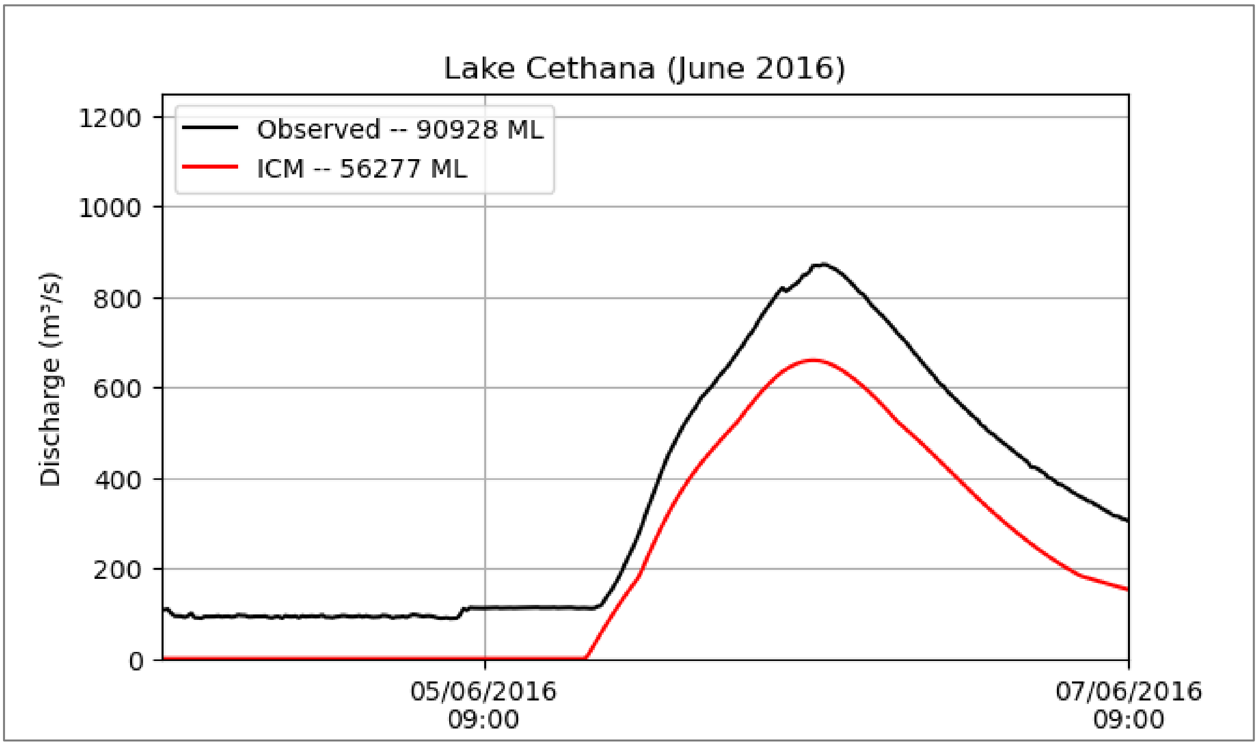

Diagram 31: June 2016 flow comparison at Lake Cethana

6.4.6. Lake Barrington

Significant spills were recorded at Lake Barrington during the August 2007 and June 2016 events. As Lake Cethana upstream was not dammed at the time of the August 1970 event, the results at Lake Barrington for the August 1970 event have been omitted.

Lake Barrington discharges into Lake Paloona via the Devils Gate Power Station and spillway. As discussed in Section 3.3, the outflows from the Devils Gate Power Station were not modelled as they discharge immediately downstream of the dam along with the spills.

The modelled spills and observed discharge at Lake Barrington are shown in Table 12 and Diagram 32 to Diagram 33. Observed discharges include power station flows and spillway outflows (note at Lake Barrington the observed power station inflows and outflows also exactly cancel each other out). The modelled spills show a good match to the observed for August 2007, but a poor match for June 2016, with peak flow underestimated. To enable a fair comparison of peak flows, the observed spills at Lake Barrington include the outflows from the Devils Gate Power Station.

Table 12: Calibrated parameters and results at Lake Barrington

Statistic	August 2007	June 2016
IL (mm)	0	20
Average CL (mm/h)	1.07	2.38
RAF	2	2
Modelled Peak (m^3/s)	628	728
Observed Peak (m^3/s)	654	910
Peak % difference	-4%	-20%
Modelled Volume (ML)	77,455	60,743
Observed Volume (ML)	103,574	90,261
Volume % difference	-25%	-33%

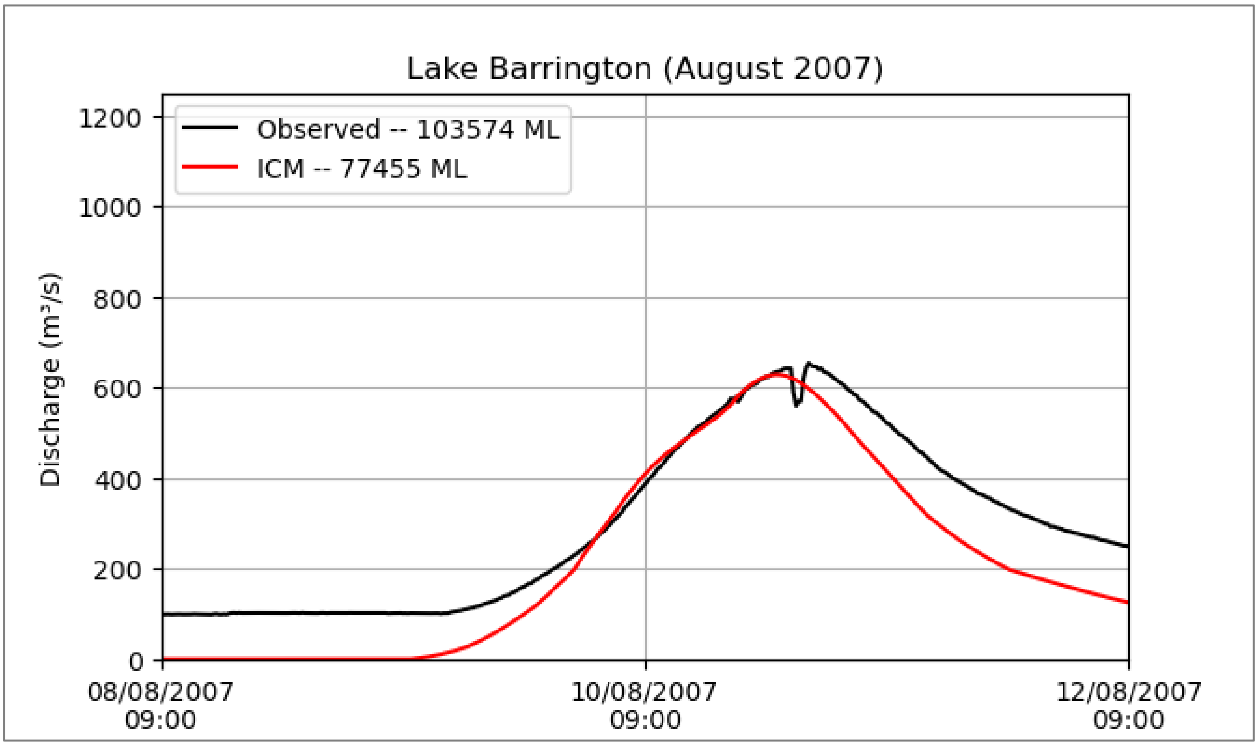

Diagram 32: August 2007 flow comparison at Lake Barrington

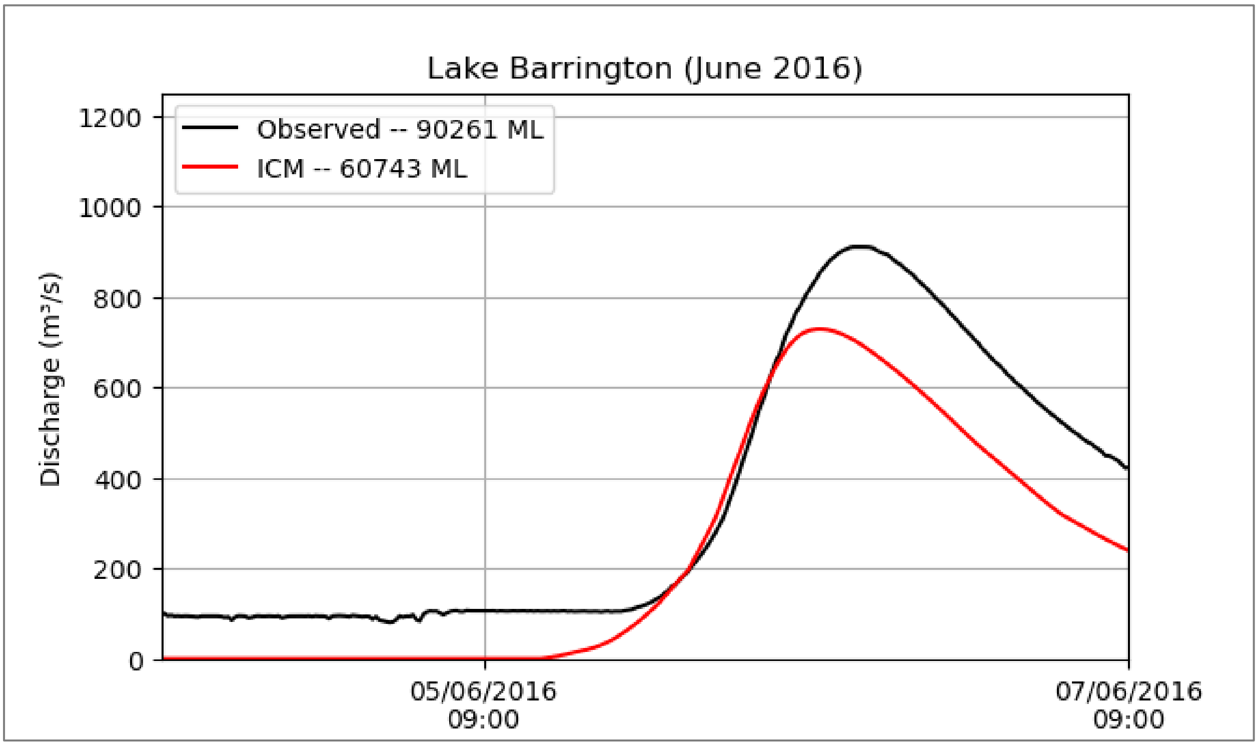

Diagram 33: June 2016 flow comparison at Lake Barrington

6.4.7. Lake Paloona

Significant spills were recorded at Lake Paloona during the August 2007 and June 2016 events. Lake Paloona was not dammed at the time of the August 1970 event.

Lake Paloona discharges into Forth River via the Paloona Power Station and spillway. As discussed in Section 3.3, the outflows from the Paloona Power Station were not modelled as they discharge immediately downstream of the dam along with the spills.

The modelled spills and observed discharge at Lake Paloona are shown in Table 13 and Diagram 34 to Diagram 35. Observed discharge includes both power station flows and spillway discharge. The modelled spills show a good match to the observed for August 2007, but a poor match for June 2016, with peak flow underestimated. To enable a fair comparison of peak flows, the observed spills at Lake Paloona include the outflows from the Paloona Power Station.

Table 13: Calibrated parameters and results at Lake Paloona

Statistic	August 2007	June 2016
IL (mm)	0	20
Average CL (mm/h)	1.05	2.32
RAF	2	2
Modelled Peak (m^3/s)	627	722
Observed Peak (m^3/s)	608	888
Peak % difference	+3%	-19%
Modelled Volume (ML)	74,481	60,701
Observed Volume (ML)	95,104	84,860
Volume % difference	-22%	-29%

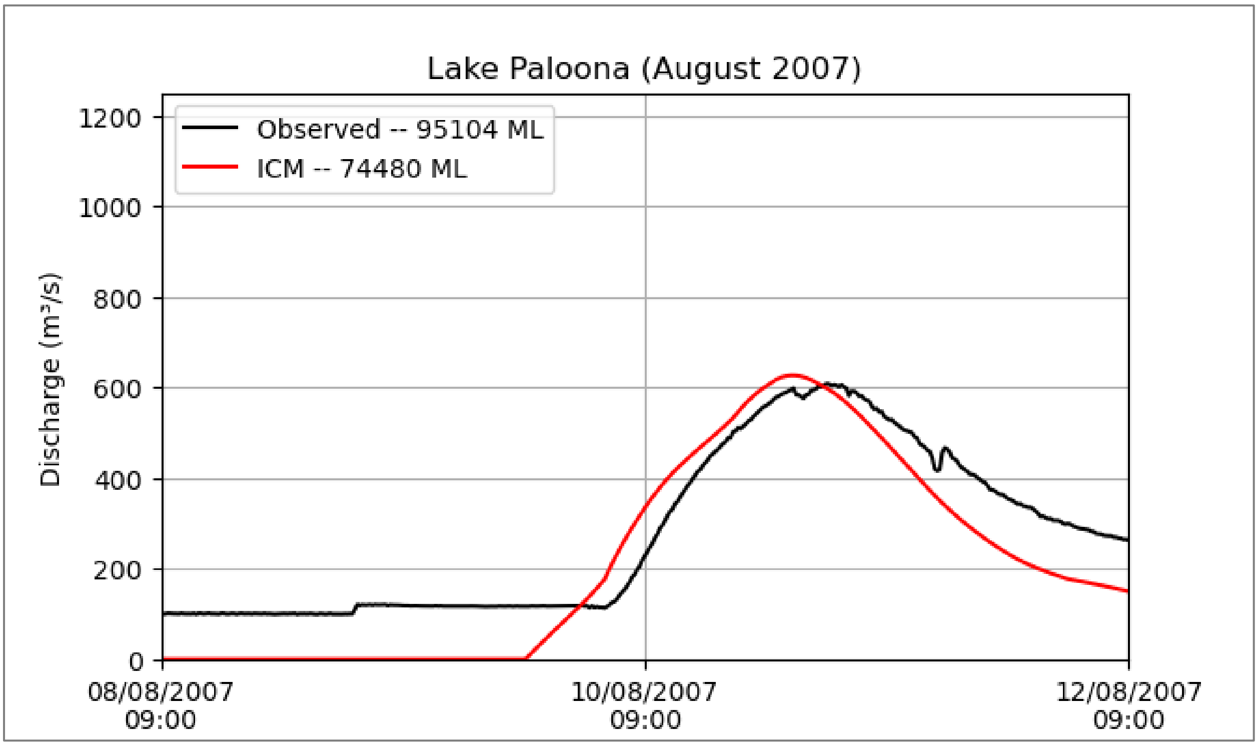

Diagram 34: August 2007 flow comparison at Lake Paloona

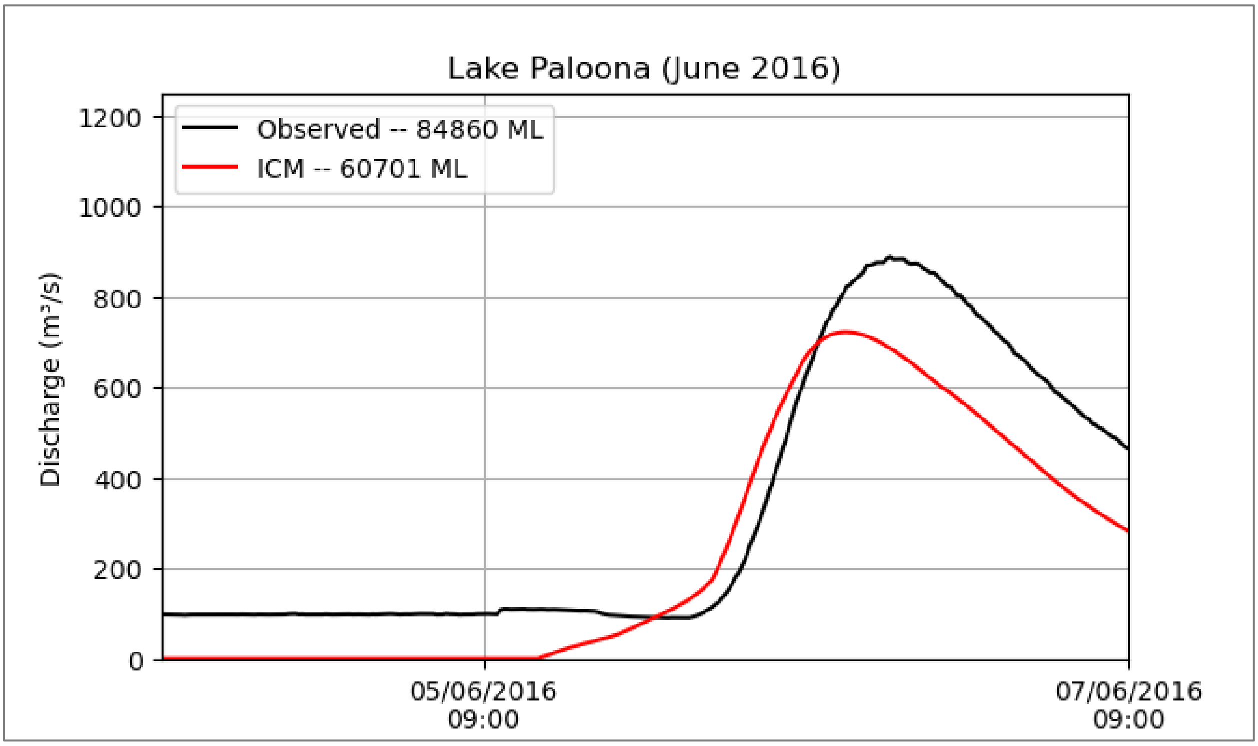

Diagram 35: June 2016 flow comparison at Lake Paloona

6.4.8. Forth River b/l Wilmot River

Significant flows were recorded at Forth River b/l Wilmot River during the August 2007 and June 2016 events. Data was only available since 1972 and therefore was not used for the August 1970 event.

As noted in Section 3.1, the supplied rating curve was given a high flow quality rating of “good” with the highest gauging above that of August 2007 and about 90% of June 2016 (7.60 m compared to 6.49 m and 7.93 m respectively).

Differences between the modelled and supplied rating curves were observed during model calibration and the channel roughness at this location was decreased (Section 5.2). It is noted that the supplied DEM does not appear to contain the full river bathymetry at this location, and the change to the channel roughness may be partially or fully compensating for this (rather than an actual change to the channel roughness).

It is also noted that this site is approximately 400 m upstream of Paloona Road at Forth River, which was found to increase the levels at the gauge by approximately 1 m in June 2016 with the default bridge parameters. This was believed to be erroneous for the likely structure and the bridge was removed from the model, enabling appropriate conveyance through the section. Future iterations of the model should review the bridge structure and utilise survey or design drawings of the bridge should they become available.

These changes were not able to reconcile the differences between the modelled and supplied rating curves (Figure D 4), and model calibration was attempted to flows only. It is recommended that the DEM at the site be reviewed, should improved topographic information become available and future analysis is undertaken.

The modelled and observed flows and levels at Forth River b/l Wilmot River are shown in Table 14 and Diagram 36 to Diagram 39. The modelled flows show a poor to fair match to the observed for August 2007 and June 2016, with peak flow underestimated in both events. Note that observed flows include the outflows from Paloona Power Station, giving a steady flow of approximately 100 m^3/s.

A gauge zero for this site was not provided by Hydro Tasmania, so a gauge zero of 16.7 mAHD was assumed. This gauge zero was inferred from the DEM of the hydrodynamic model.

Table 14: Calibrated parameters and results at Forth River b/l Wilmot River

Statistic	August 2007	June 2016
IL (mm)	0	20
Average CL (mm/h)	1.00	2.23
RAF	2	2
Modelled Peak (m^3/s)	804	1147
Observed Peak (m^3/s)	927	1323
Peak % difference	-13%	-13%

Statistic	August 2007	June 2016
Modelled Volume (ML)	95,012	100,020
Observed Volume (ML)	135,710	136,438
Volume % difference	-30%	-27%
Modelled Peak (mAHD)	24.49	26.23
Observed Peak (mAHD)	23.19	24.63
Peak difference (m)	+1.29	+0.83

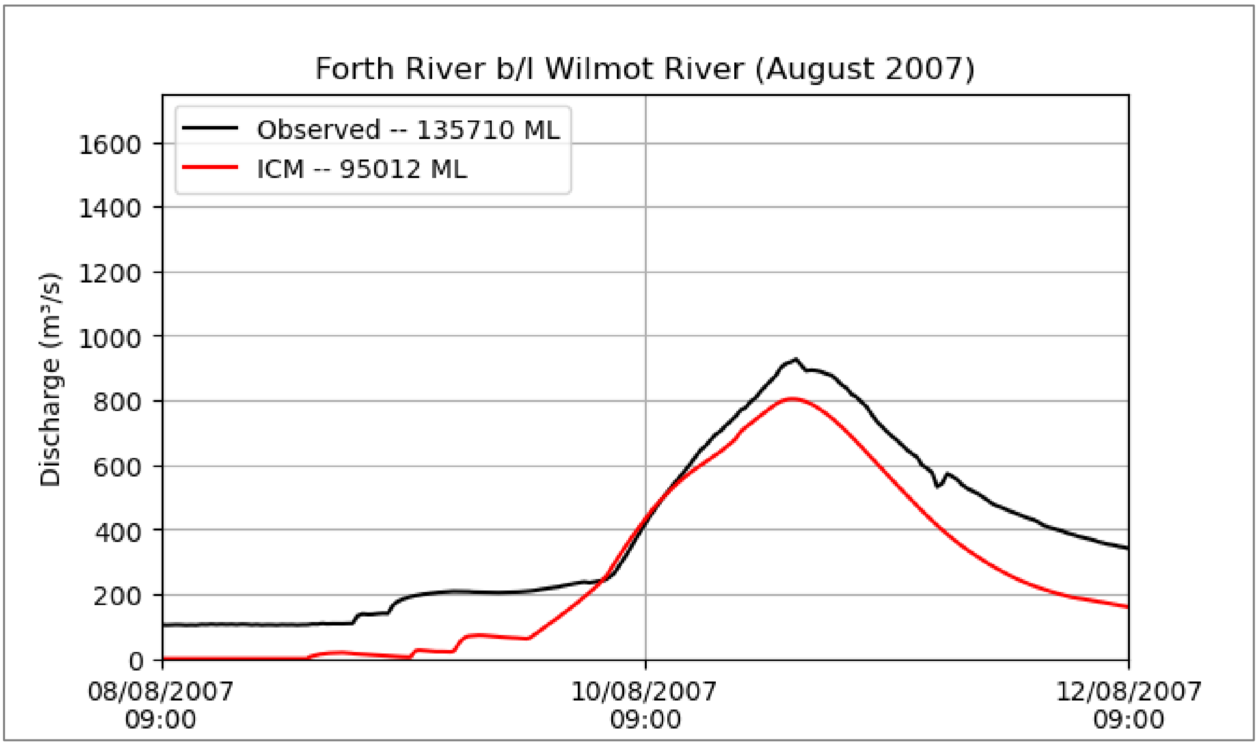

Diagram 36: August 2007 flow comparison at Forth River b/l Wilmot River

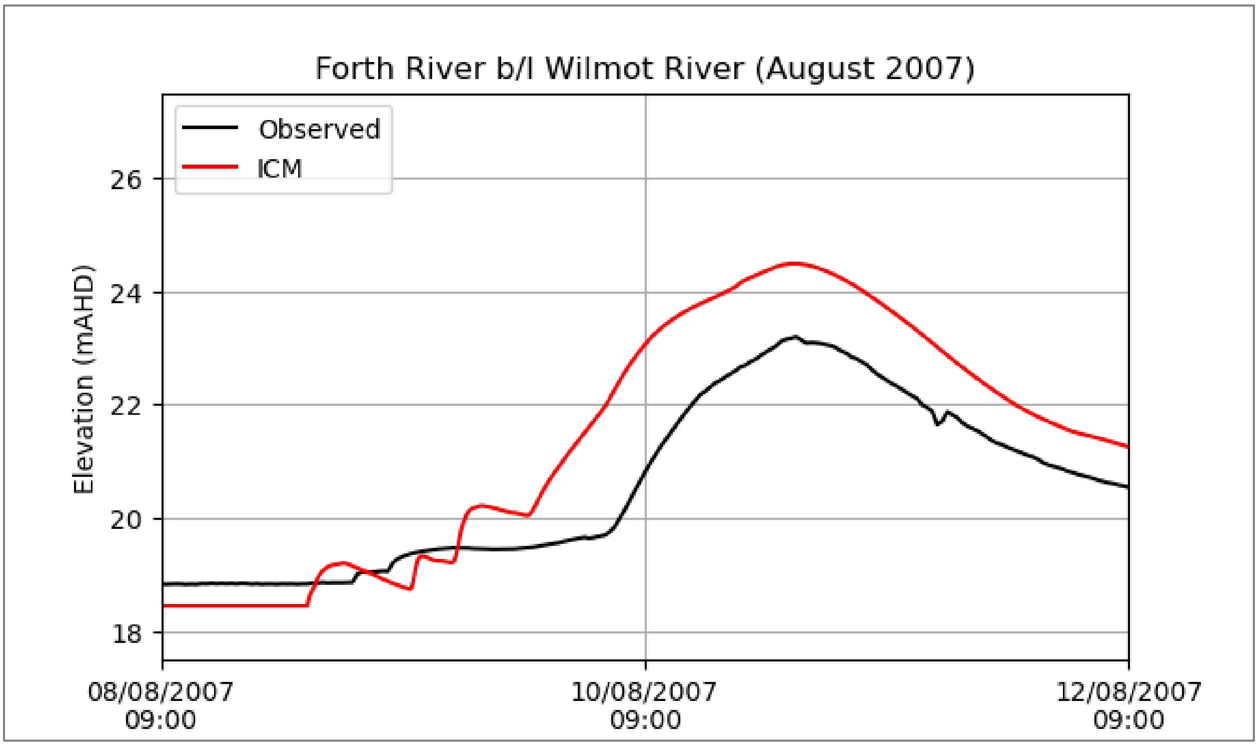

Diagram 37: August 2007 water level comparison at Forth River b/l Wilmot River

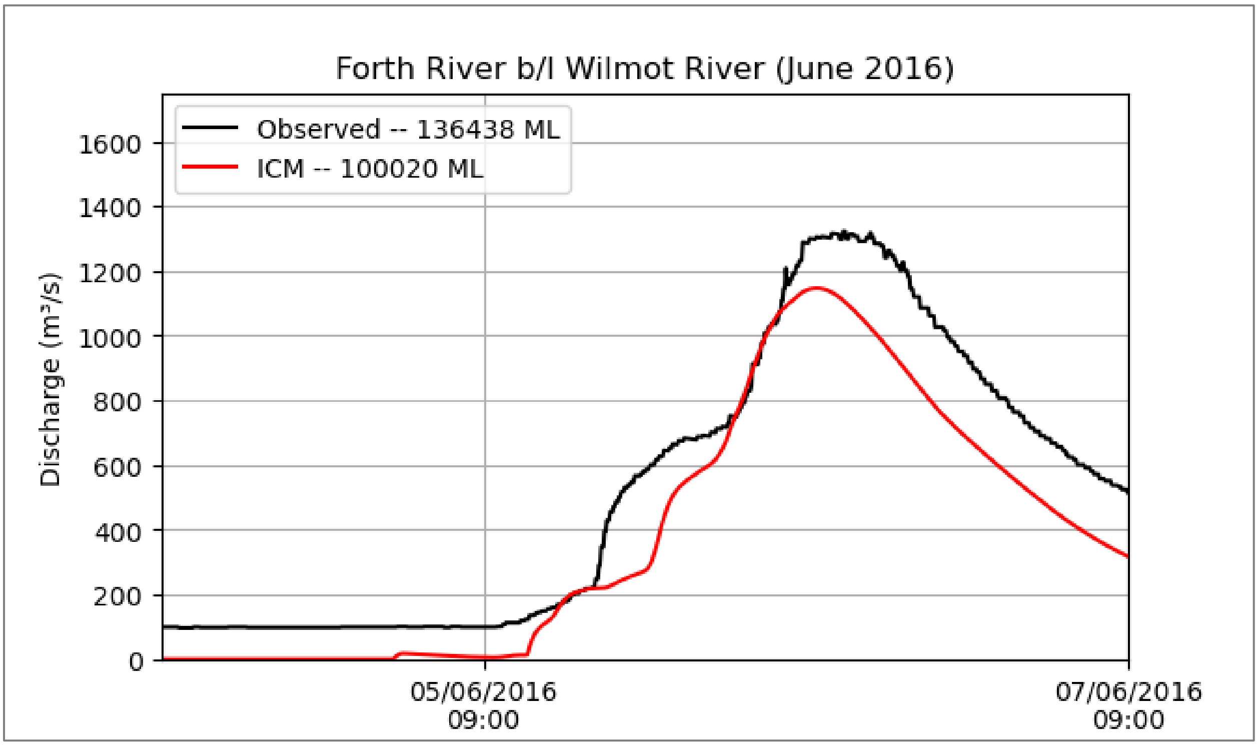

Diagram 38: June 2016 flow comparison at Forth River b/l Wilmot River

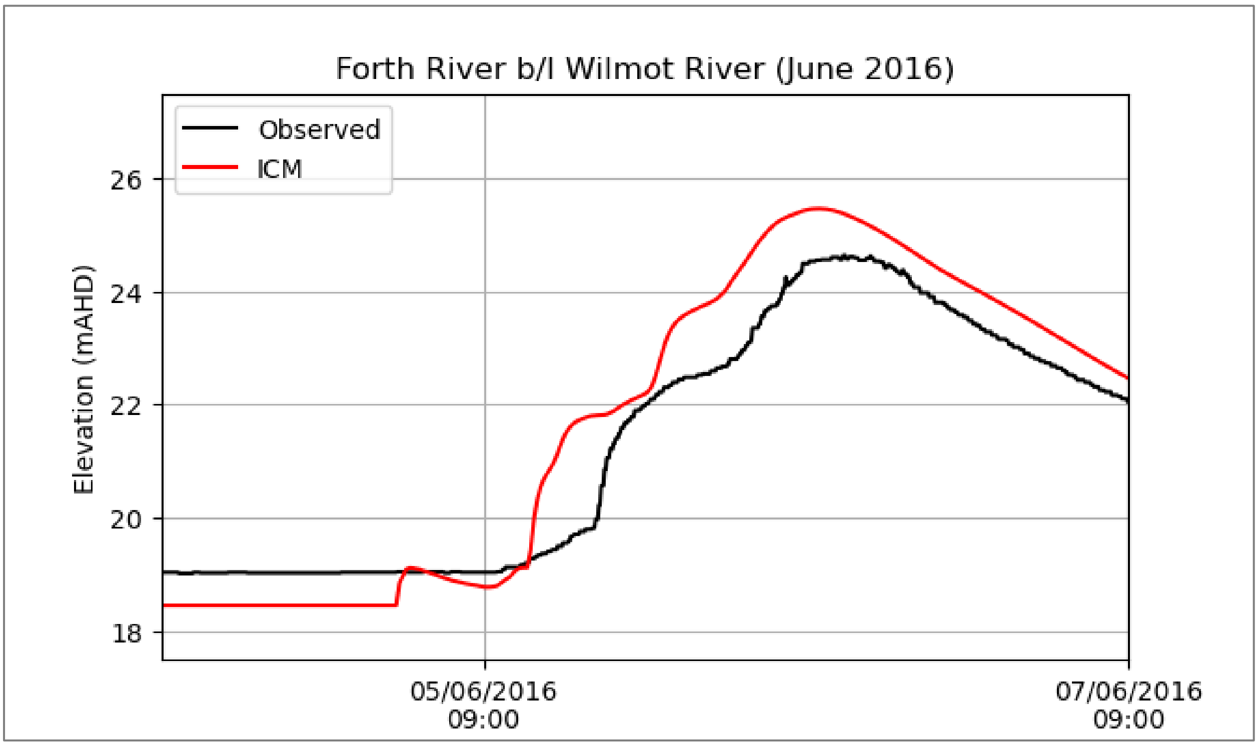

Diagram 39: June 2016 water level comparison at Forth River b/l Wilmot River

6.4.9. Leven River at Bannons Bridge

Significant flows were recorded at Leven River at Bannons Bridge during the August 2007 and June 2016 events.

As noted in Section 3.1, this site was rerated using a local hydrodynamic model which was given a high flow quality rating of "good" (herein referred to as the supplied rating curve). Differences between the modelled and supplied rating curve were observed during model calibration and the channel roughness at this location was decreased (Section 5.2). This resulted in a good agreement between the slope of the modelled and supplied rating curves at high flows (Figure D 5).

The supplied DEM does not contain the full river bathymetry at this location, and it is acknowledged that the change to the channel roughness may be partially or fully compensating for this (rather than an actual change to the channel roughness).

The modelled and observed flows and levels at Leven River at Bannons Bridge are shown in Table 15 and Diagram 40 to Diagram 45. The modelled flows and levels show a fair match to the observed for August 1970, looking at the event as a whole and not the isolated burst at the peak. The modelled flows and levels show a poor match to the observed for January 2011 and June 2016, with peak flow and level overestimated in both events.

As discussed in Section 3.1.1, no attempt was made to match to the observed peak of the August 1970 event (which was believed to be due to an isolated intense rainfall burst that was not captured in the available rainfall data).

A gauge zero of 42.35 mAHD was provided for this site from the DNRE database, however, this value was believed to be erroneous when compared to the DEM and results of the hydrodynamic model. A gauge zero of 36.75 mAHD was used instead.

Table 15: Calibrated parameters and results at Leven River at Bannons Bridge

Statistic	August 1970	January 2011	June 2016
IL (mm)	0	20	20
Average CL (mm/h)	1.90	1.90	2.02
RAF	2	2	2
Modelled Peak (m^3/s)	614	970	980
Observed Peak (m^3/s)	716	586	725
Peak % difference	-14%	+66%	+35%
Modelled Volume (ML)	59,853	64,329	89,943
Observed Volume (ML)	47,783	44,713	67,151
Volume % difference	+25%	+44%	+34%
Modelled Peak (mAHD)	43.05	44.52	44.56
Observed Peak (mAHD)	43.60	43.05	43.63
Peak difference (m)	-0.55	+0.48	+0.93

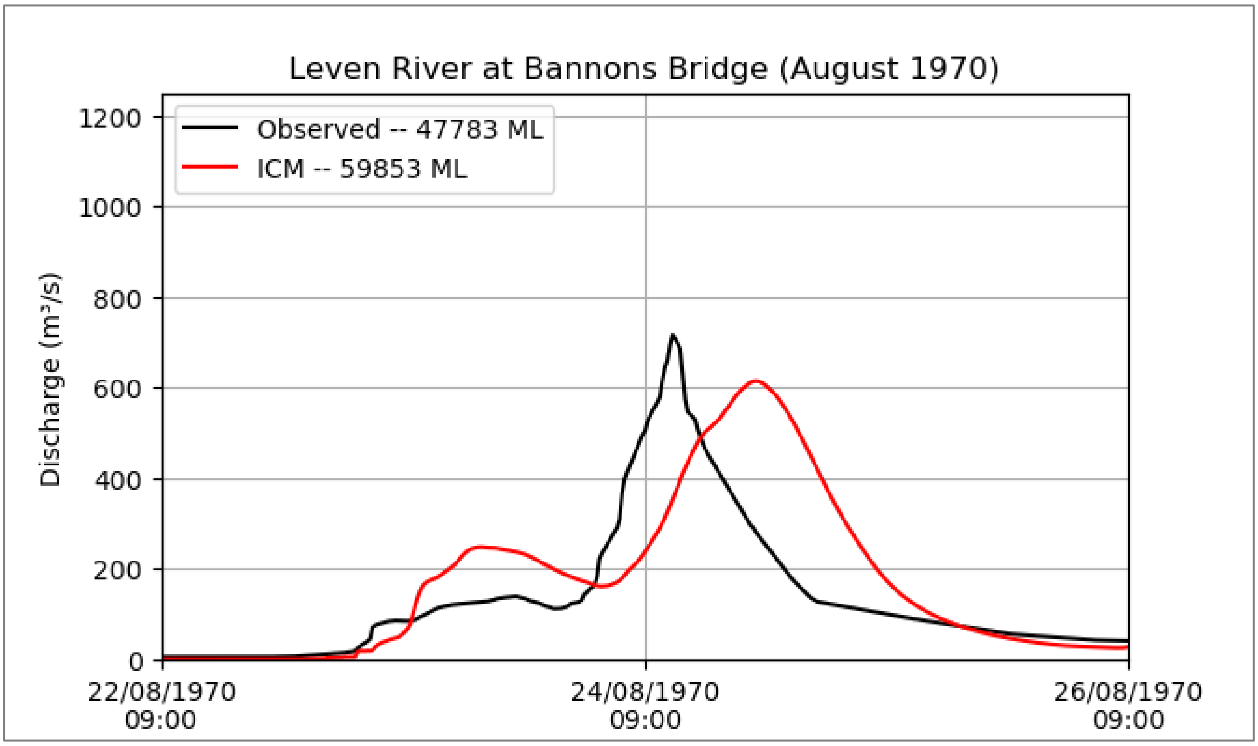

Diagram 40: August 1970 flow comparison at Leven River at Bannons Bridge

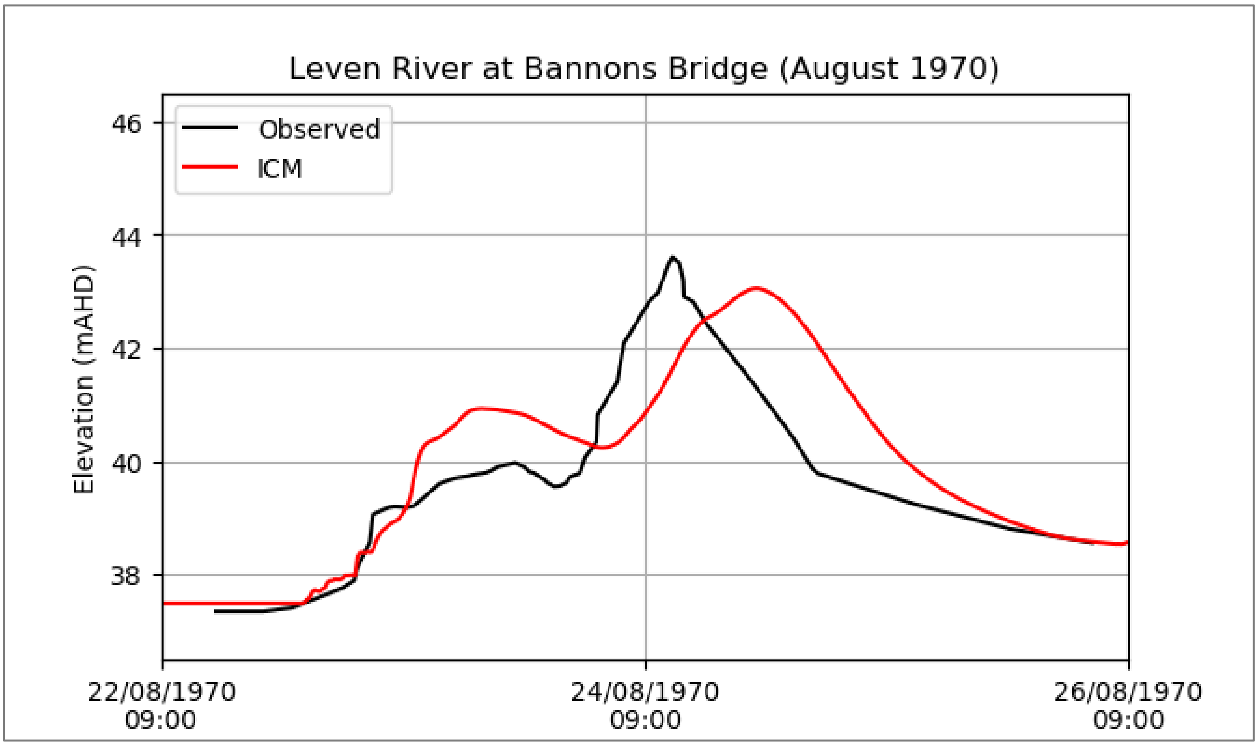

Diagram 41: August 1970 water level comparison at Leven River at Bannons Bridge

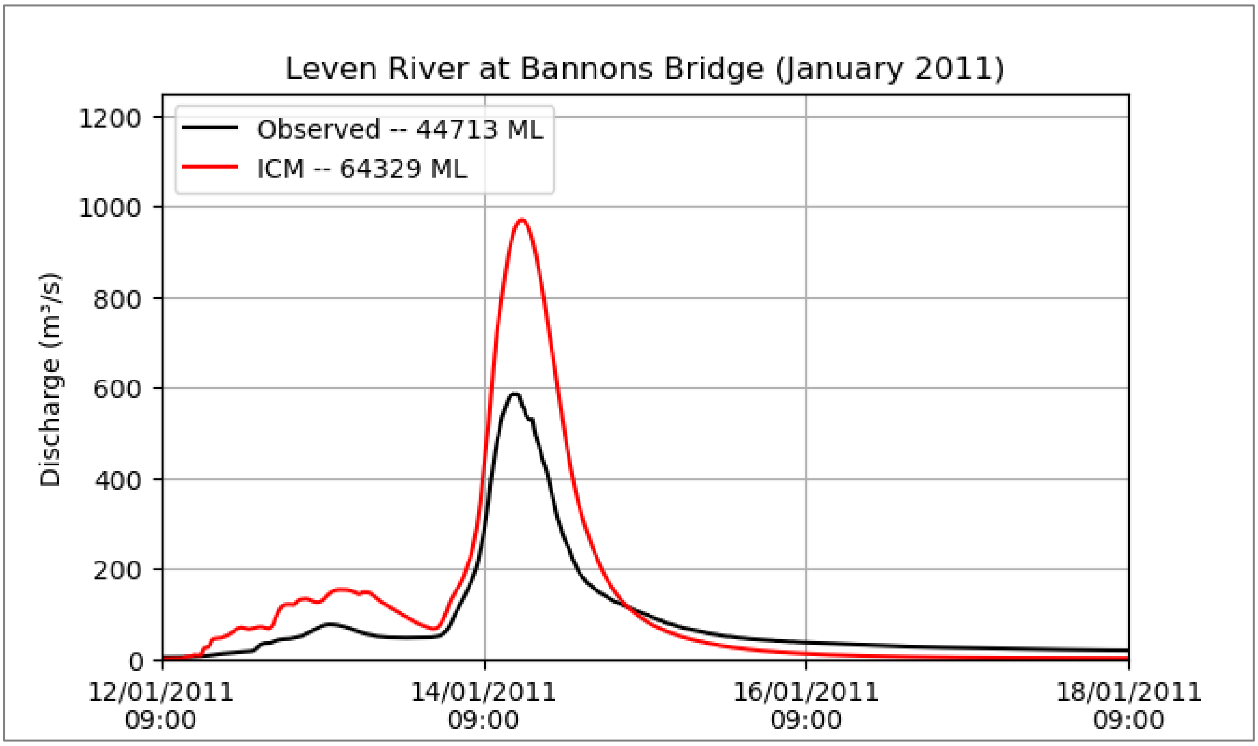

Diagram 42: January 2011 flow comparison at Leven River at Bannons Bridge

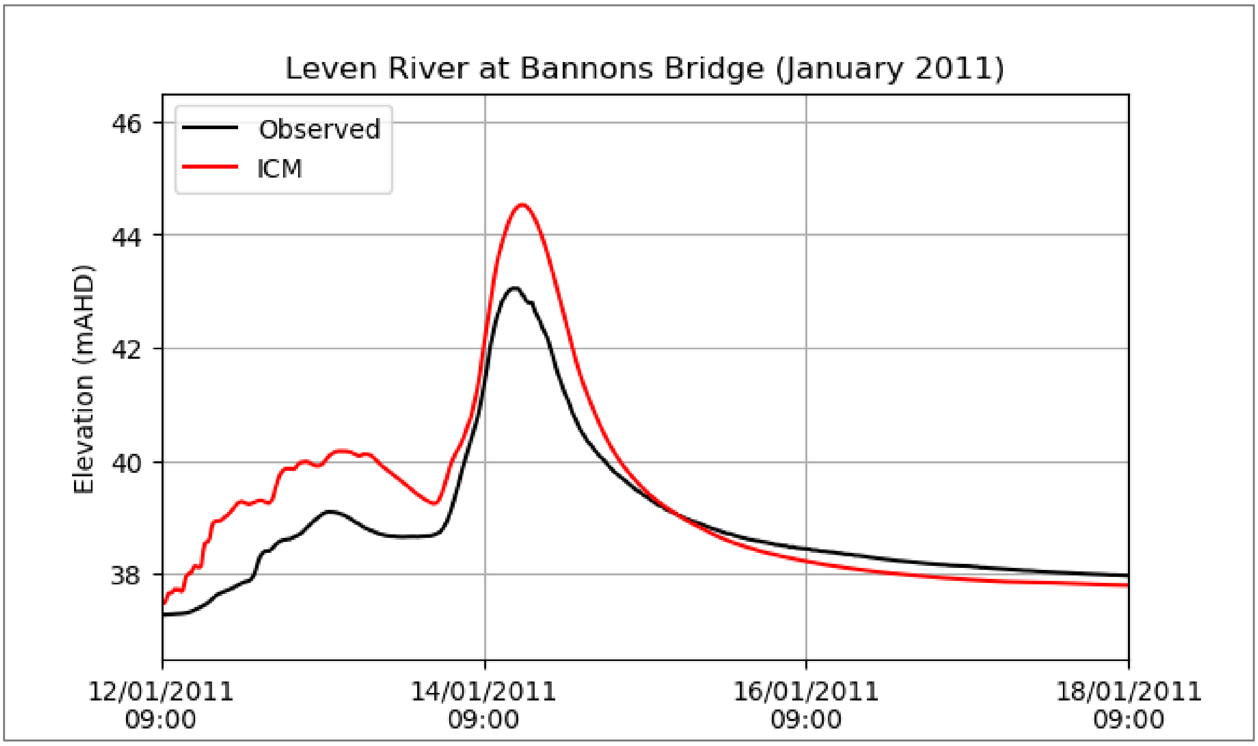

Diagram 43: January 2011 water level comparison at Leven River at Bannons Bridge

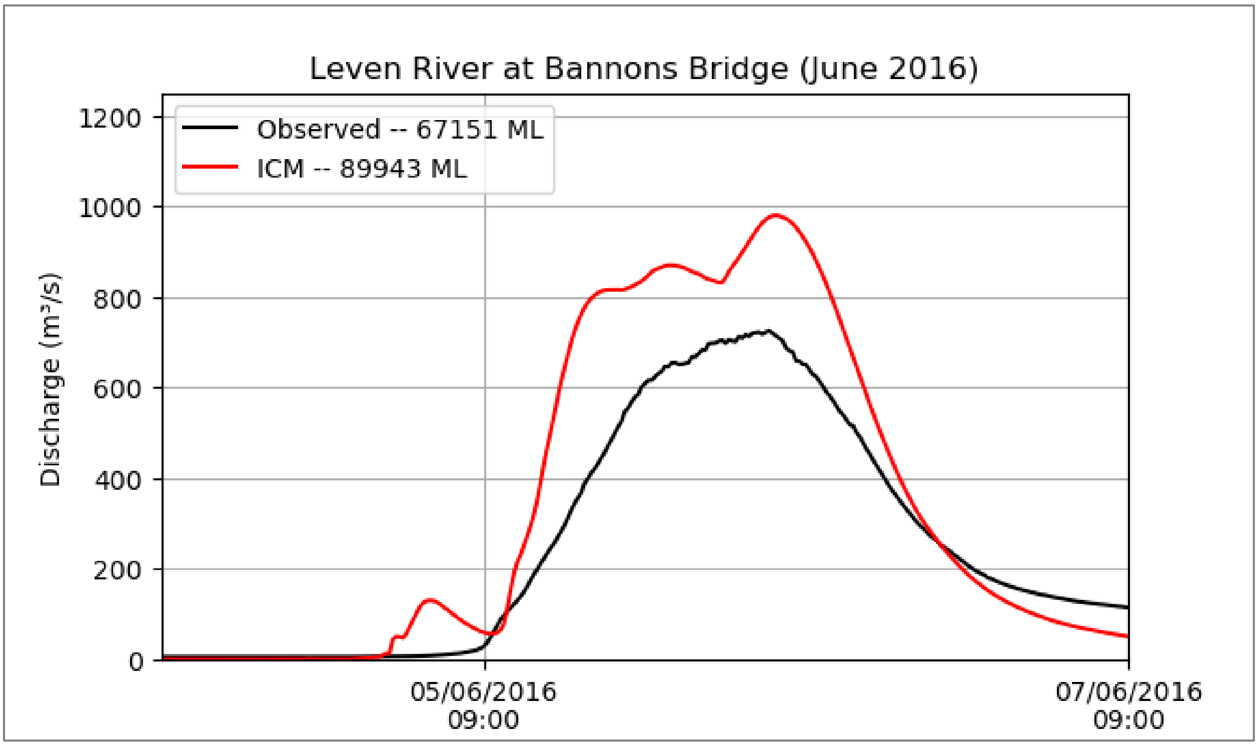

Diagram 44: June 2016 flow comparison at Leven River at Bannons Bridge

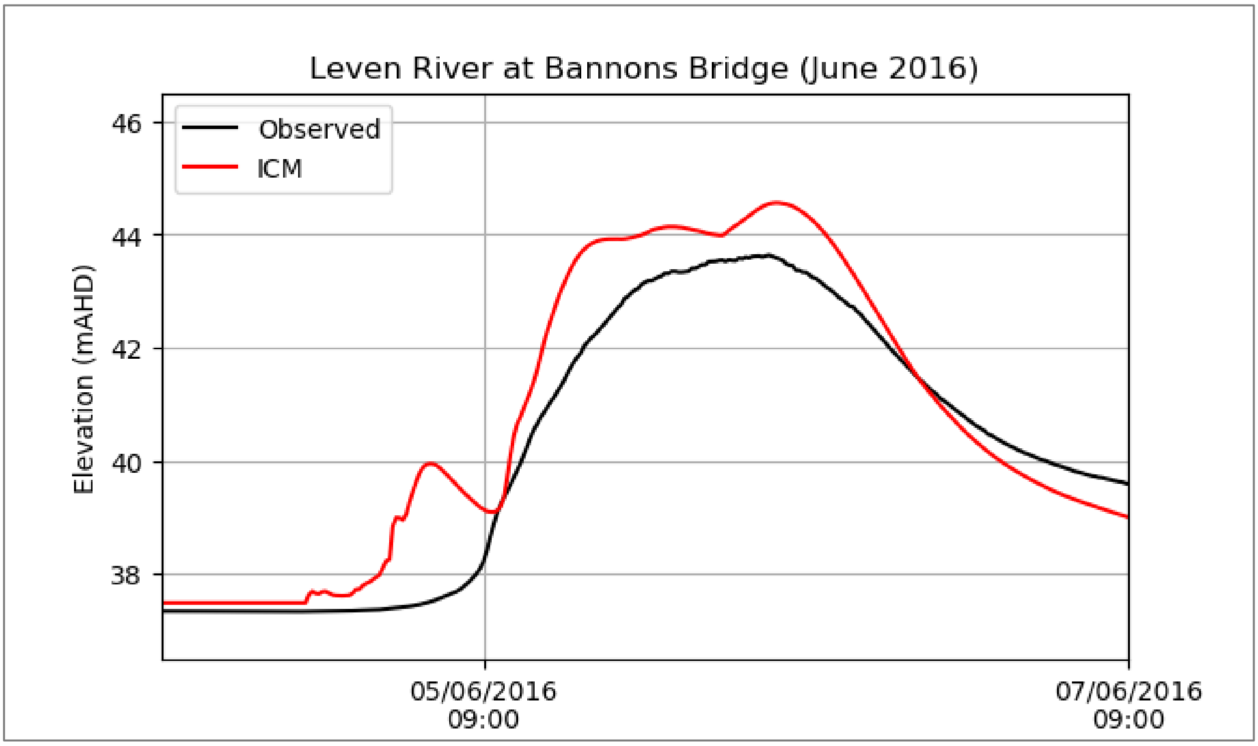

Diagram 45: June 2016 water level comparison at Leven River at Bannons Bridge

6.4.10. Gawler River at Cradle Coast Water Supply

Significant flows were recorded at Gawler River at Cradle Coast Water Supply for the January 2011 and June 2016 events. Data was only available since 2008 and therefore was not used for the August 1970 event.

Differences between the modelled and supplied rating curves were observed during model calibration (Figure D 7). As the quality of the supplied rating curve was not able to be determined (Section 3.1.2), no changes were made to the default model and model calibration was attempted to levels only. The flows for January 2011 and June 2016 have been presented below for illustration only.

The modelled and observed flows and levels at Gawler River at Cradle Coast Water Supply are shown in Table 16 and Diagram 46 to Diagram 49. The modelled levels show a fair match to the observed for January 2011 and June 2016, with peak level matched in January 2011 and overestimated in June 2016.

As noted in Section 3.3, there are a significant number of small dams along Gawler River that are not explicitly modelled in the hydrodynamic model.

A gauge zero of 27.18 mAHD was provided for this gauge from the DNRE database.

Table 16: Calibrated parameters and results at Gawler River at Cradle Coast Water Supply

Statistic	January 2011	June 2016
IL (mm)	20	20
Average CL (mm/h)	2.34	2.49
RAF	2	2
Modelled Peak (m^3/s)	212	130
Observed Peak (m^3/s)	145	65
Peak % difference	+46%	+98%
Modelled Volume (ML)	9,362	9,778
Observed Volume (ML)	7,274	5,053
Volume % difference	+29%	+93%
Modelled Peak (mAHD)	29.55	29.18
Observed Peak (mAHD)	29.61	28.89
Peak difference (m)	-0.06	+0.29

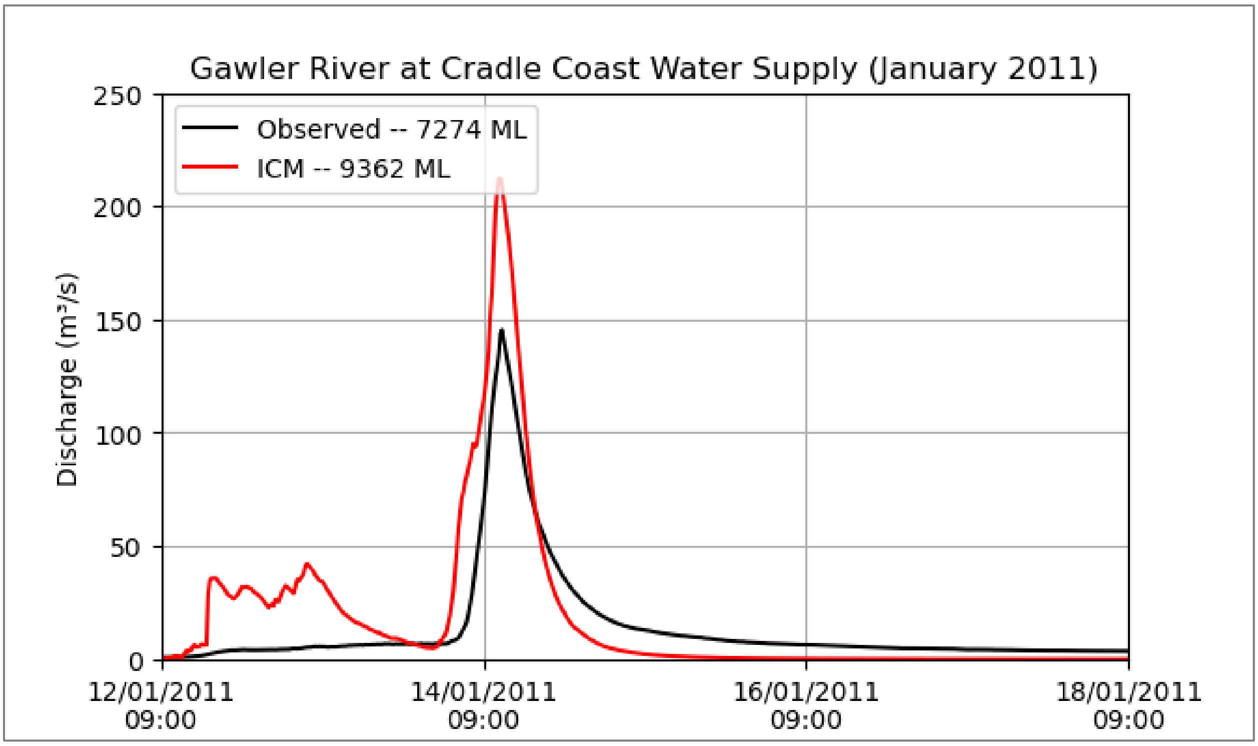

Diagram 46: January 2011 flow comparison at Gawler River at Cradle Coast Water Supply

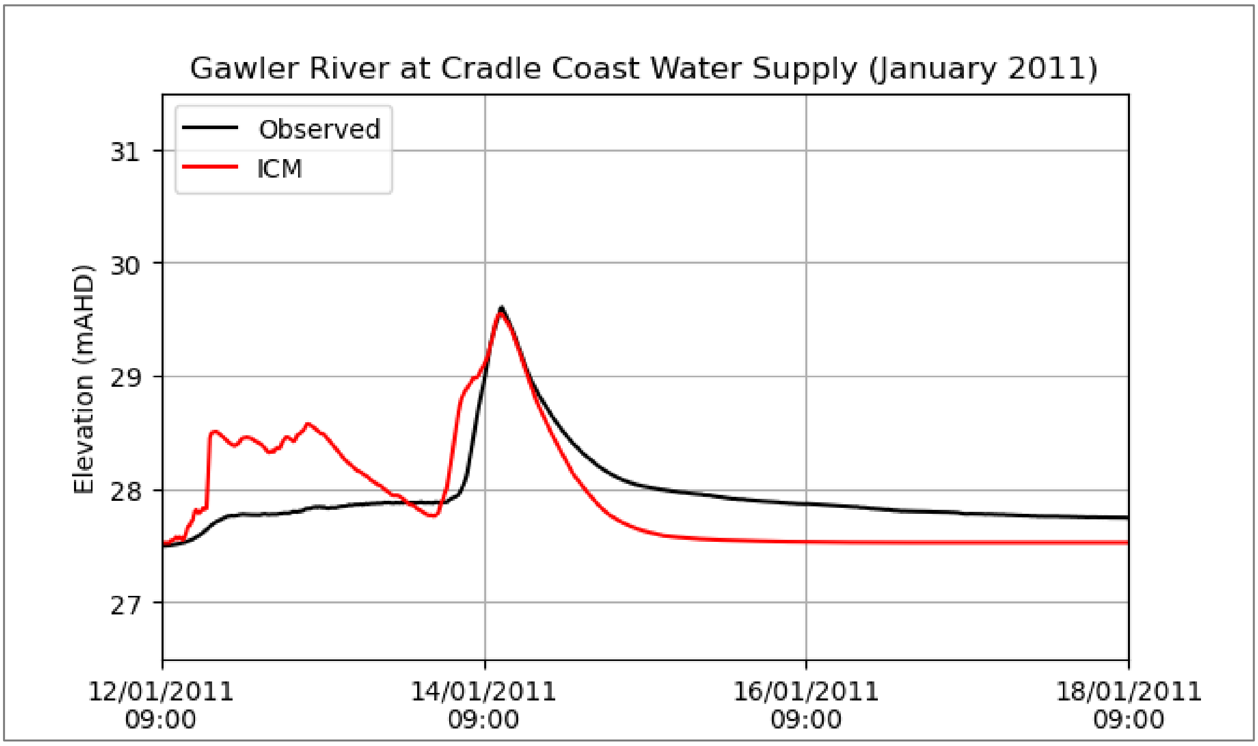

Diagram 47: January 2011 water level comparison at Gawler River at Cradle Coast Water Supply

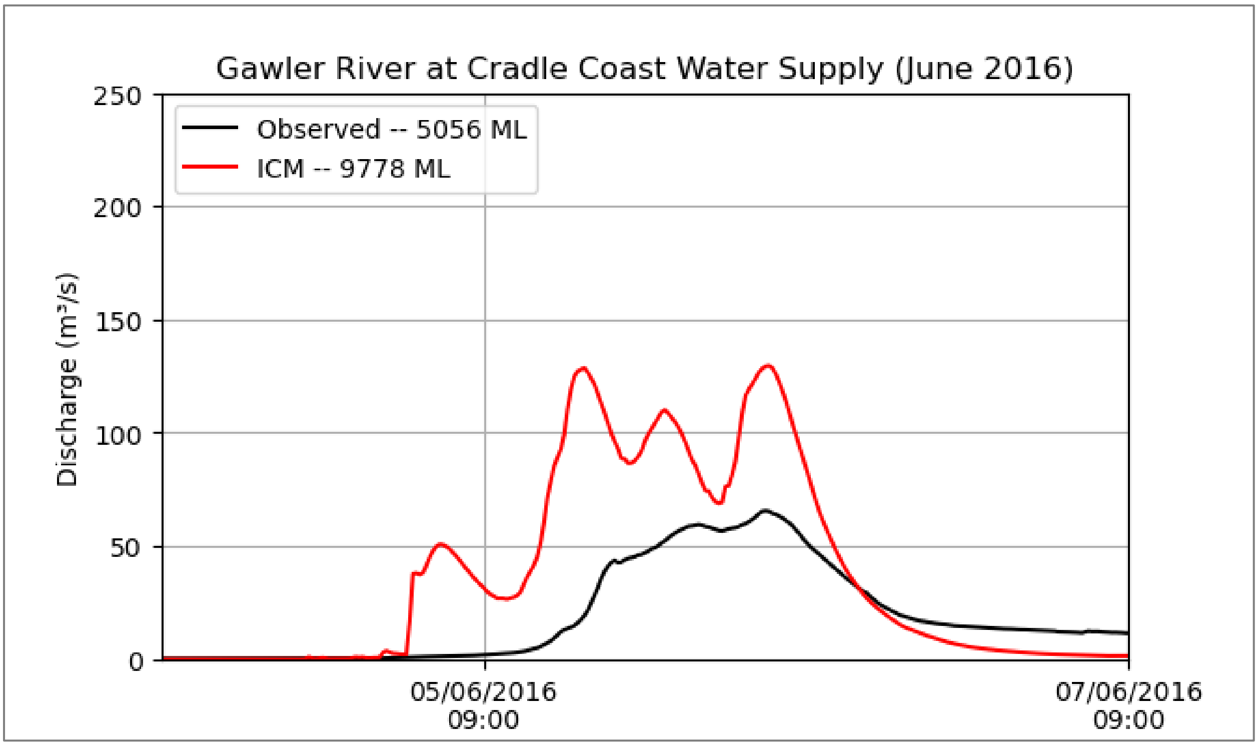

Diagram 48: June 2016 flow comparison at Gawler River at Cradle Coast Water Supply

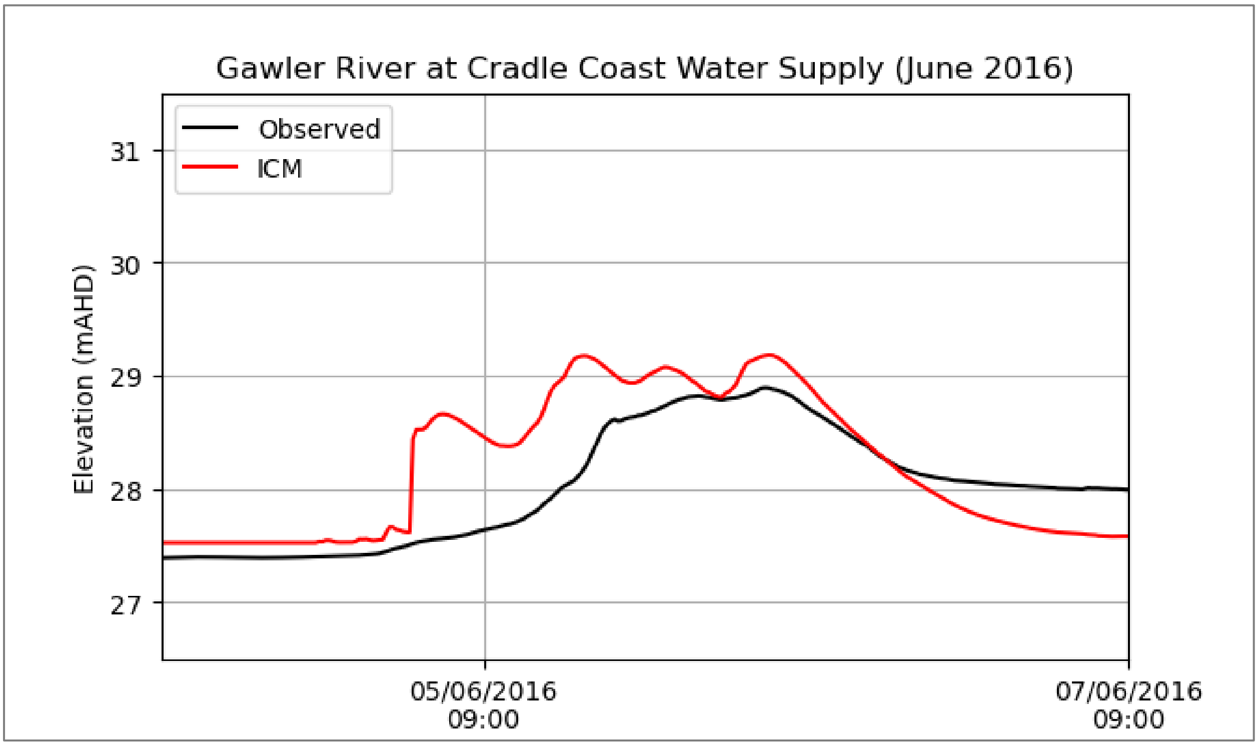

Diagram 49: June 2016 water level comparison at Gawler River at Cradle Coast Water Supply

6.4.11. Buttons Creek u/s Bass Highway

Significant flows were recorded at Buttons Creek u/s Bass Highway for the January 2011 and June 2016 events. Data was only available since December 2007 and therefore was not used for the August 1970 and August 2007 events.

As noted in Section 3.1, the supplied rating curve was given a high flow quality rating of “fair” with the highest gauging about 40% of January 2011 and 70% of June 2016 (0.4 m compared to 0.83 m and 0.66 m respectively). As noted in Section 5.1 and 5.4, the 10 m DEM version of the LiDAR data at the site had to be used instead of the preferred 2 m DEM version and the culverts at Castra Road, Bass Highway, and Production Drive were based on assumed data.

Due to the uncertainty in the accuracy of the DEM and structures, model calibration was attempted to flows only. It is recommended that the DEM and structures be reviewed, should improved topographic and structure data be available and if future detailed analysis is undertaken.

The modelled and observed flows and levels at Buttons Creek u/s Bass Highway are shown in Table 17 and Diagram 46 to Diagram 49. The modelled flows show a poor match to the observed for January 2011 and June 2016, with peak flow greatly overestimated in both events.

As noted in Section 3.3, there are a significant number of small dams along Buttons Creek that are not explicitly modelled in the hydrodynamic model.

A gauge zero of 18.87 mAHD was provided for this gauge from the DNRE database. This was adjusted to 19.8 mAHD to better align with the DEM of the hydrodynamic model.

Table 17: Calibrated parameters and results at Buttons Creek u/s Bass Highway

Statistic	January 2011	June 2016
IL (mm)	20	20
Average CL (mm/h)	2.50	2.67
RAF	2	2
Modelled Peak (m^3/s)	46	30
Observed Peak (m^3/s)	5	3
Peak % difference	+837%	+838%
Modelled Volume (ML)	2,016	1,873
Observed Volume (ML)	595	286
Volume % difference	+239%	+555%
Modelled Peak (mAHD)	21.41	21.05
Observed Peak (mAHD)	20.63	20.46
Peak difference (m)	+0.78	+0.60

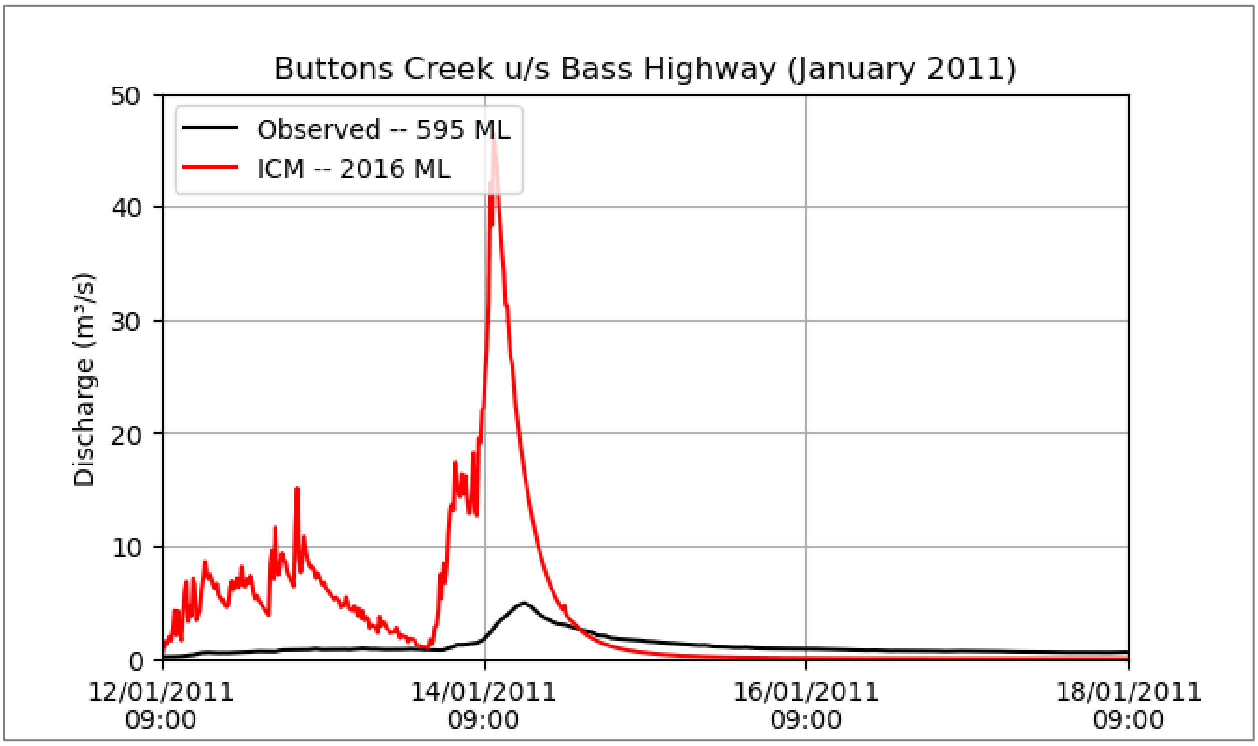

Diagram 50: January 2011 flow comparison at Buttons Creek u/s Bass Highway

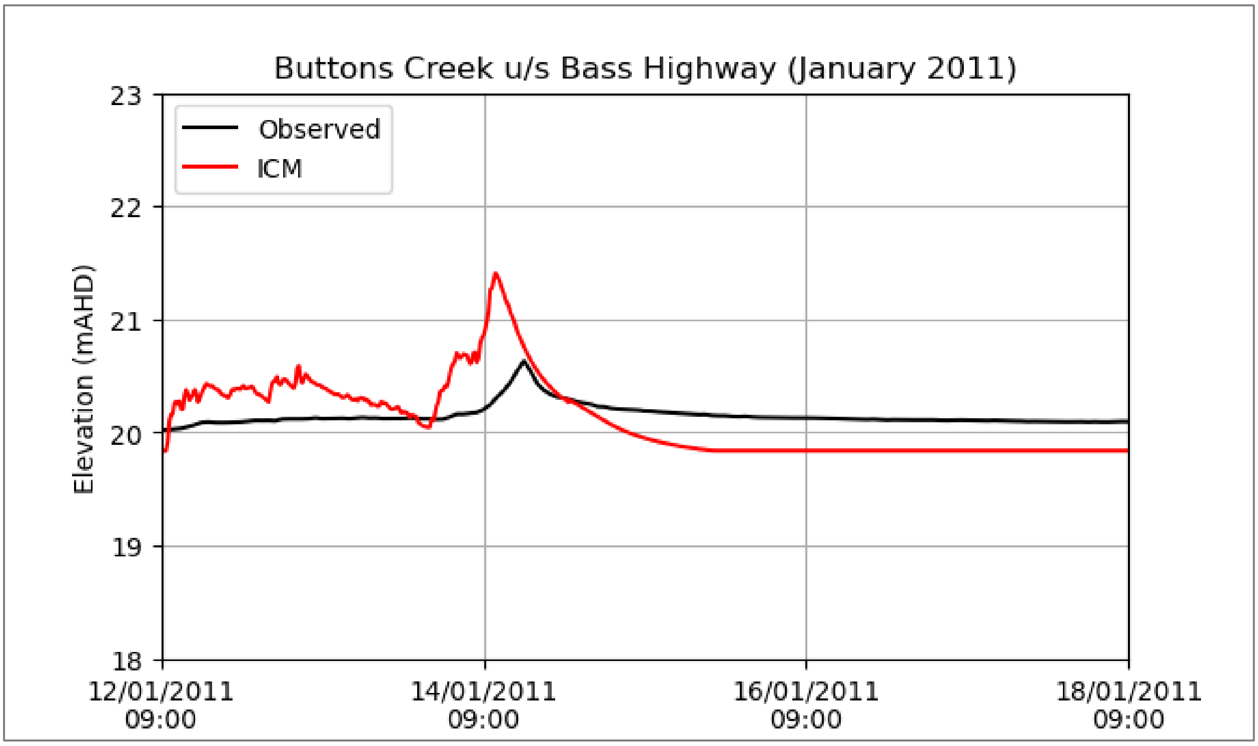

Diagram 51: January 2011 water level comparison at Buttons Creek u/s Bass Highway

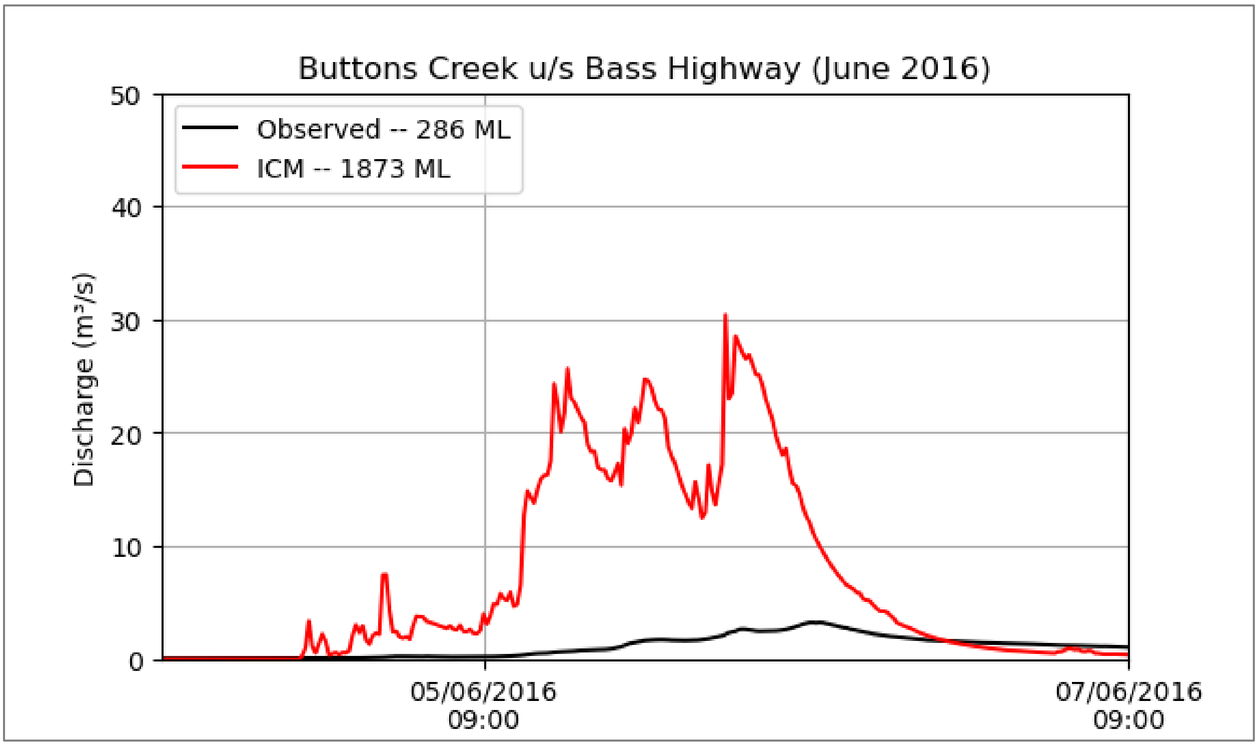

Diagram 52: June 2016 flow comparison at Buttons Creek u/s Bass Highway

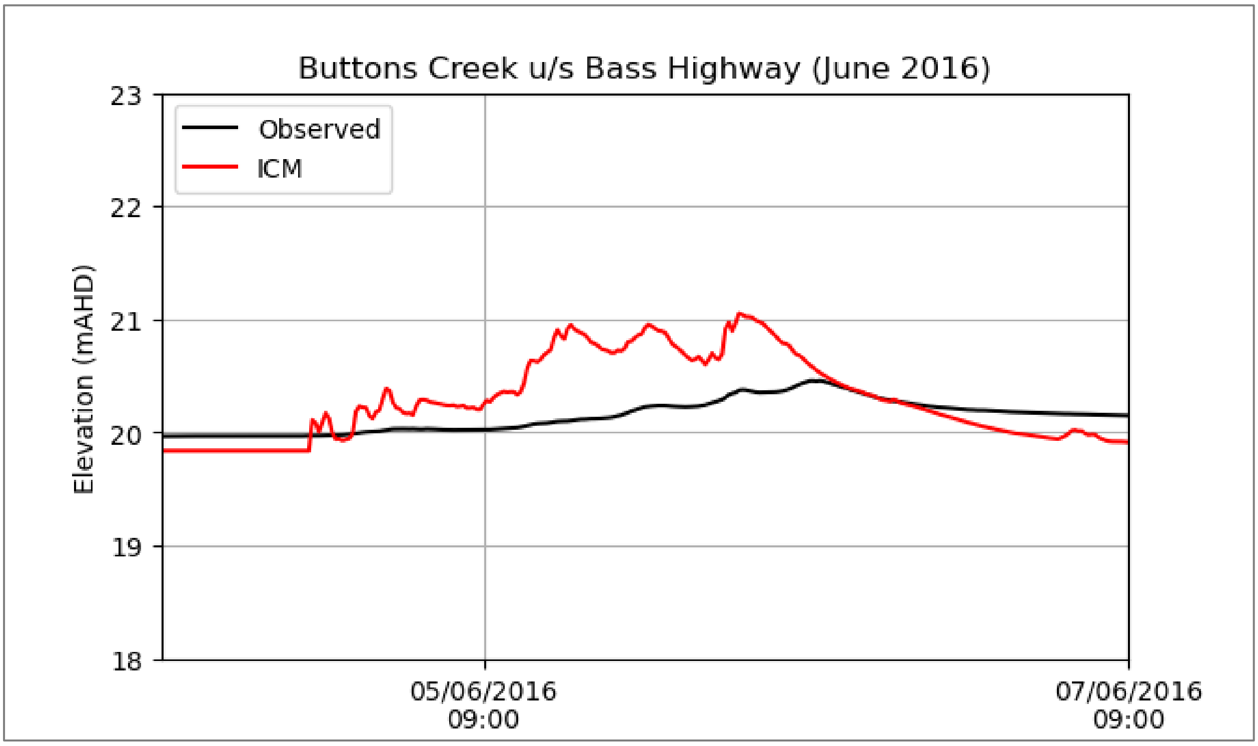

Diagram 53: June 2016 water level comparison at Buttons Creek u/s Bass Highway

6.5. 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 Forth-Leven study area, 43 points were surveyed as part of the June 2016 flood survey, with all points (but one) available for comparison against the hydrodynamic model (downstream of the model inflows). Figure 11 shows the surveyed and modelled flood extents for the June 2016 event. It is noted that where there are a limited number of points along a reach, then the accuracy of the surveyed flood extent is likely to be poor beyond the immediate vicinity of the points.

Survey information was available along the downstream reaches of Wilmot River, Forth River, and Leven River, covering key areas such as Wilmot and Forth River near Lake Paloona, Forth River near Forth, Forth River at Bass Highway, Leven River at Bannons Bridge, and Leven River at Hobbs Parade. Limited survey information was available along Gawler River and Buttons Creek. Survey information was not available along Claytons Rivulet.

Diagram 54 to Diagram 59 show the modelled and surveyed flood extents and levels. The following points are of note:

- Downstream of Wilmot River a/b Forth River and Forth River b/l Wilmot River (Diagram 54) the modelled levels show a fair match to the survey, with the levels overestimated by 0.4 m at Wilmot River and 0.8 m at Forth River. This is expected given the results at the gauge.
- In the lower reaches of Forth River (Diagram 55 and Diagram 56), the modelled levels show a fair match to the survey, with the levels overestimated by as much as 0.6 m at Forth Road and Bass Highway. This was not able to be fully resolved with the modification to the DEM at Forth Road and the river entrance (Section 5.1). It is noted that the channel bed in the supplied DEM is higher than expected, when compared to river cross-section survey from an existing study (Section 6.6).
- Upstream of Leven River at Bannons Bridge (Diagram 58), the modelled levels show a fair match to the survey, with the levels overestimated by 0.65 m. This is expected given the results at the gauge.
- In the lower reaches of Leven River (Diagram 58), the modelled levels show a fair match to the survey, with the levels overestimated by as much as 0.65 m at Hobbs Parade. This is expected given the results at the Leven River gauge, but it is also likely that the channel bed in the supplied DEM is higher than expected.
- In the lower reaches of Gawler River, the modelled levels show a poor match to the survey, with the levels overestimated by as much as 1.4 m at West Gawler Road. This was not able to be resolved with the modification to the DEM at West Gawler Road (Section 5.1).

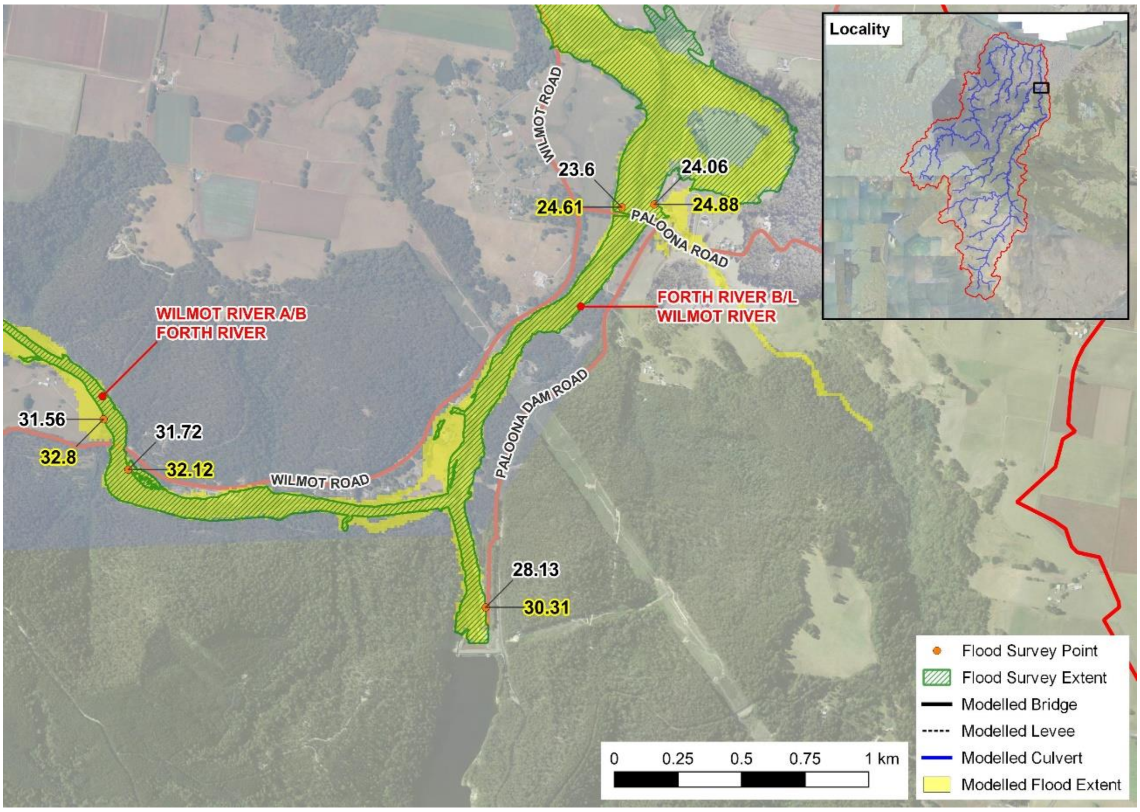

Diagram 54: Comparison to June 2016 flood survey along Wilmot and Forth River near Lake Paloona. Modelled levels highlighted in yellow.

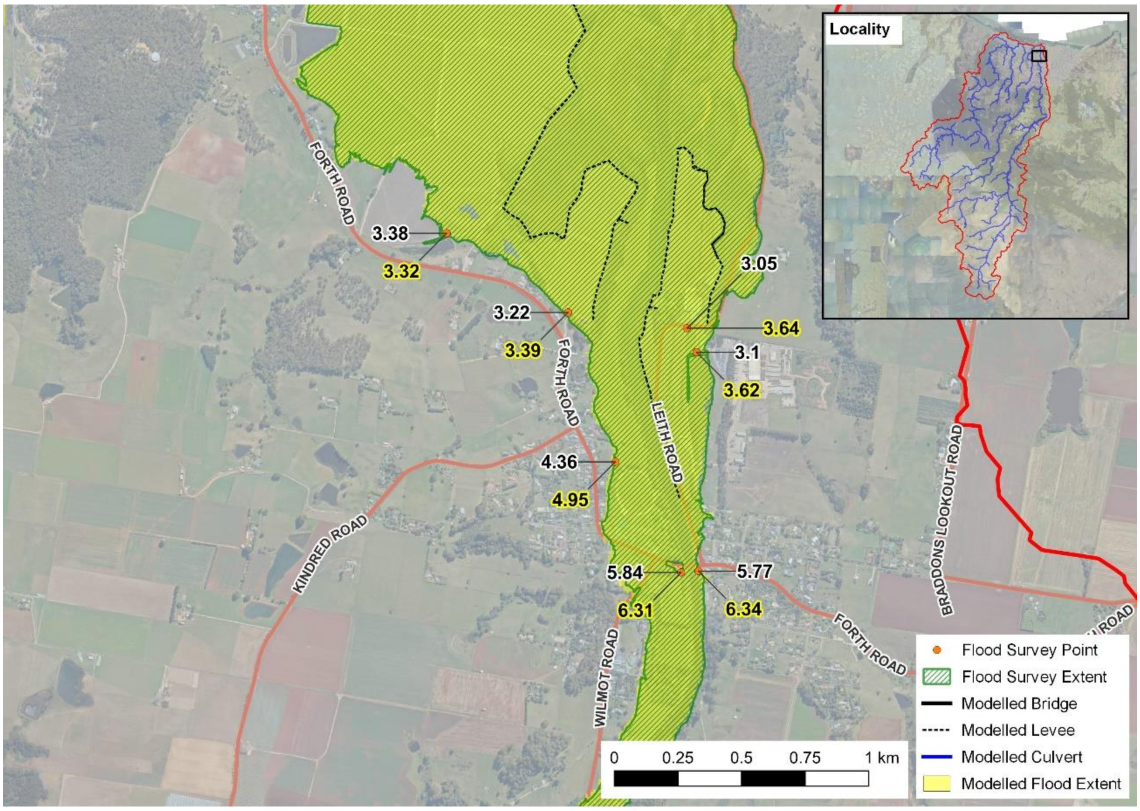

Diagram 55: Comparison to June 2016 flood survey along Forth River near Forth. Modelled levels highlighted in yellow.

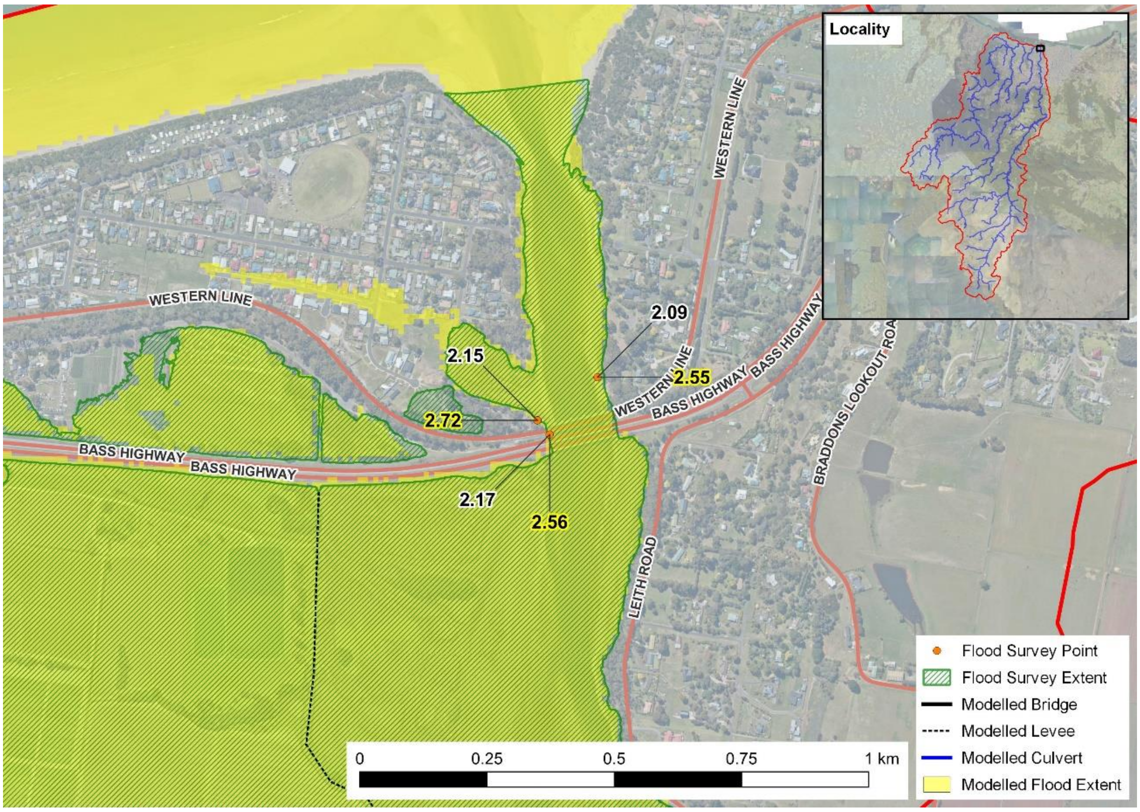

Diagram 56: Comparison to June 2016 flood survey along Forth River at Bass Highway. Modelled levels highlighted in yellow.

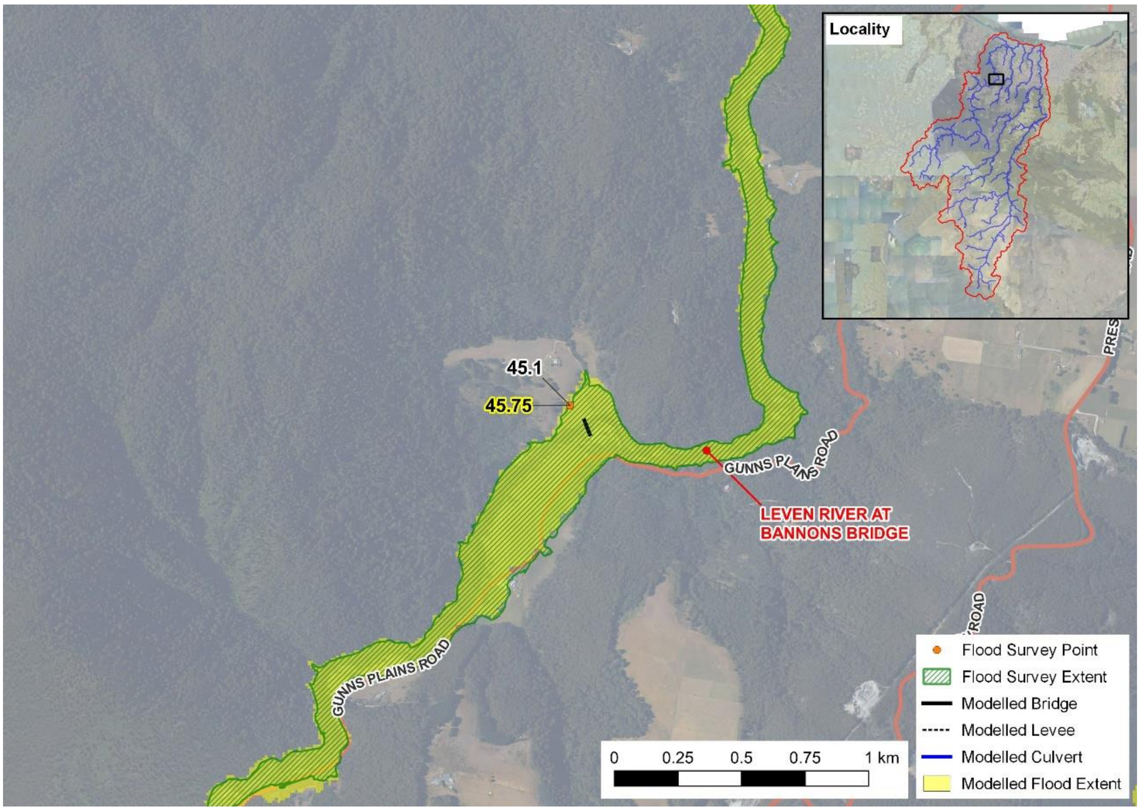

Diagram 57: Comparison to June 2016 flood survey Leven River at Bannons Bridge. Modelled levels highlighted in yellow.

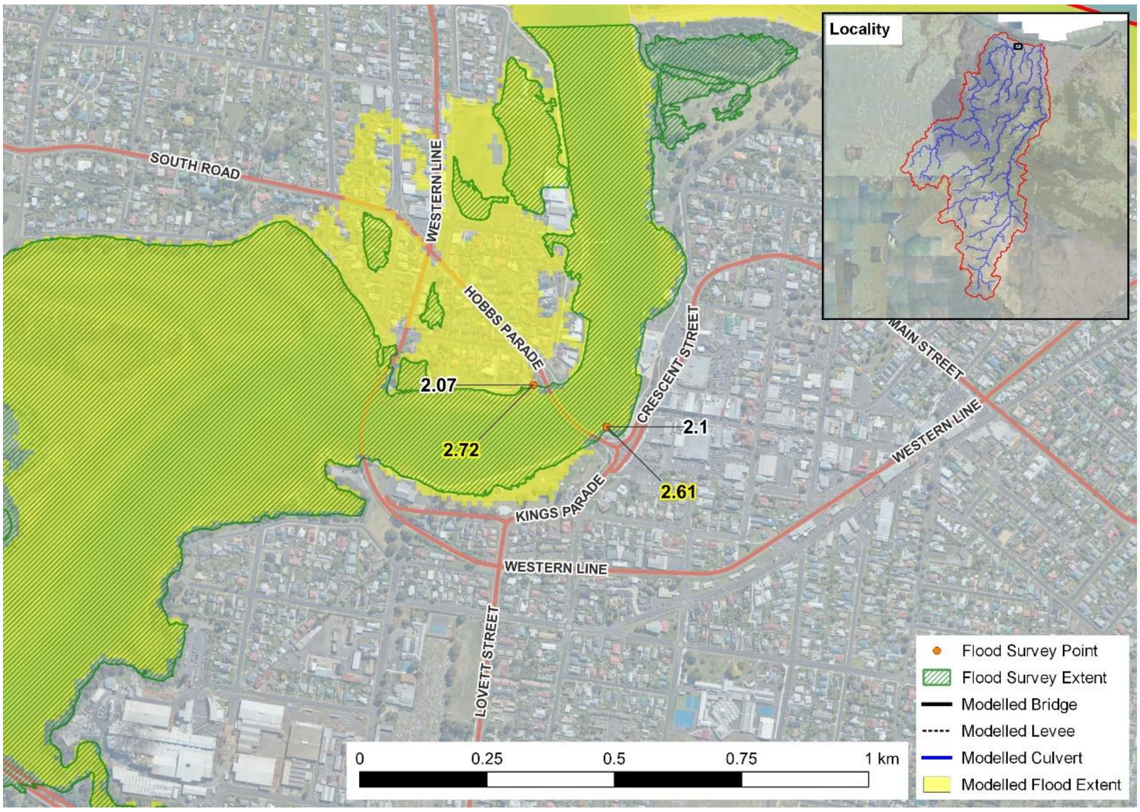

Diagram 58: Comparison to June 2016 flood survey along Leven River at Hobbs Parade. Modelled levels highlighted in yellow.

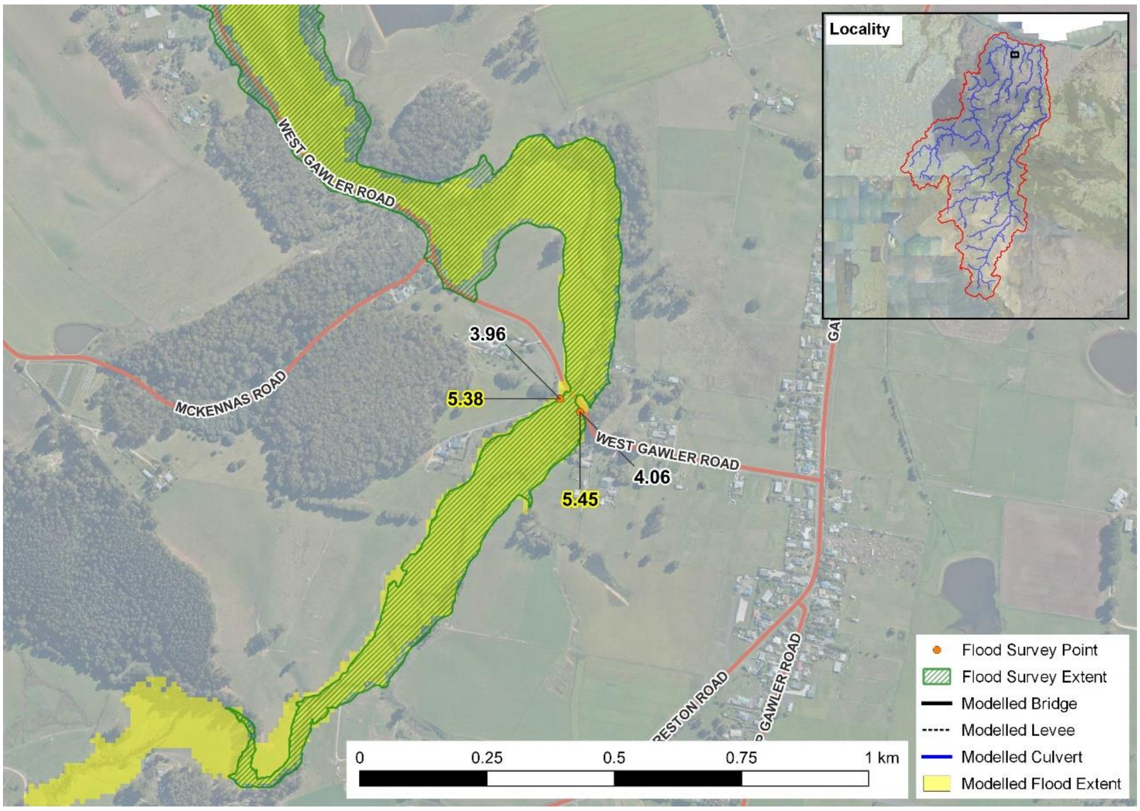

Diagram 59: Comparison to June 2016 flood survey along Gawler River. Modelled levels highlighted in yellow.

6.5.1. Summary of Levels

Diagram 60 shows the difference between the modelled and surveyed levels, with the upper and lower limits based on the uncertainty of the survey and DEM. There is generally a good agreement between the surveyed and modelled levels for the June 2016 event, with most points falling within the upper and lower limits. The flood survey points in the lower reaches of Forth River and Leven River have been highlighted in red.

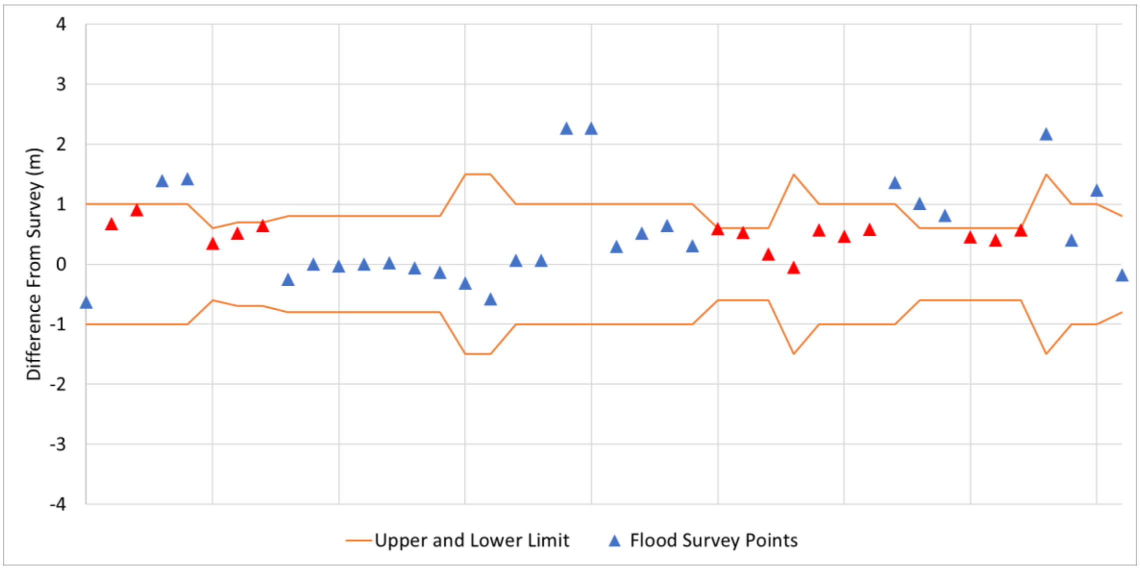

Diagram 60: Comparison to June 2016 flood survey across the Forth-Leven study area. Flood survey points in the lower reaches of Forth River and Leven River highlighted in red.

6.6. Comparison to Previous Studies

Central Coast Council commissioned Entura to undertake a flood study of the lower reaches of Forth River (Entura, 2014). This project involved the hydraulic modelling of the August 2007 event for the 3 km section of Forth River between Forth Road and Bass Highway (and some distance upstream and downstream).

The following items are of note:

- River cross-section survey of the lower reaches of Forth River was undertaken and used in modelling of the 2014 study. Other than a long profile of the river cross-section survey, this data was not available in a suitable format in the flood study report to be able to be used in the present study.
- The long profile of the river cross-section survey suggests that the channel bed ranges from -2 mAHD at Forth Road to -5 mAHD at Bass Highway to -2 mAHD at the river entrance. The channel bed in the supplied DEM of the present study is higher than this at approximately -1 mAHD.
- In the 2014 study, the inflows to the hydraulic model of August 2007 were the recorded flows at Forth River b/l Wilmot River and the recorded flows at Forth River a/b Lemonthyme (scaled by catchment area and rainfall to account for the natural catchment downstream of the Forth River gauge). The recorded flow at Forth River b/l Wilmot River for August 2007 was 930 m^3/s. In the present study, the modelled flow at Forth River b/l Wilmot River

for August 2007 was 800 m^3/s.

- Flood level survey of August 2007 in the lower reaches of Forth River was used in the calibration of the 2014 study. Table 18 compares the modelled levels of August 2007 in the present study to the surveyed and modelled levels in the 2014 study.

Table 18: Comparison to August 2007 surveyed and modelled levels (mAHD)

Location	August 2007 Surveyed Level*	August 2007 Modelled Level (2014 Study)*	August 2007 Modelled Level (Present Study)	Difference (m)
Downstream of Bass Highway at Forth River	1.5	1.98	2.10	+0.12
Near Forth Cemetery at Forth River	3.0	3.14	3.75	+0.61
Near Forth Sports Grounds at Forth River	3.9	4.13	4.85	+0.72
Near William Street at Forth River	4.0	4.33	5.25	+0.92

* Taken from Entura, 2014

The modelled levels in this study are greater than those of the surveyed and modelled levels in the 2014 study, despite the modelled flows at Forth River b/l Wilmot River being lower in the current study. This is assumed to be due to the differences in the channel bed and it is recommended that the supplied DEM in the present study be reviewed, should improved topographic information be available and if future detailed analysis is undertaken.

It is understood that Central Coast Council commissioned Entura to undertake an update to the flood study following the June 2016 event, however, this was not able to be found at the time of writing.

6.7. Identified Issues

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

- Eight flow gauges were used in model calibration and verification. While the rating quality at some of these gauges is likely good, the largest calibration events are significantly above the highest gaugings and therefore well into the extrapolated range. At many sites, the observed peak for at least one calibration event is over twice the highest gauged flow and, in some cases, it is up to 12 times the highest gauged flow. This introduces considerable uncertainty into the observed flow data.
- There are steep rainfall gradients across the study area during flood events, and these may not necessarily be well represented by the rainfall gauges. The AWAP gridded data and gauge data showed significant differences at some gauges for the 1970 event.
- The following issues were observed in the DEM. If further modelling is undertaken in this catchment, the DEM should be refined if possible.
  - The supplied DEM does not contain full river bathymetry throughout much of the study area. Channel roughness was adjusted to obtain improved calibration results at gauges, and this may be partially or fully compensating for this issue. This has impacted the ability of the model to represent observed flood levels and extents, when matching flows.
  - Due to the lack of bathymetry in the DEM, it became evident during the calibration of the hydrodynamic model, that a calibration to both level and flow would not be possible. Noting the purpose of the calibration is to ensure the model is performing appropriately, a calibration focussed on achieving a good match to observed flood levels in the 2016 event (Section 6.5.1) was prioritised over a good match to flow at the key gauges. If bathymetry data for the channels is obtained in the future the losses that provide the best calibration to flows would be a good starting point to confirm calibration.
  - Comparisons of rating curves derived from the model with supplied ratings suggests that the DEM has insufficient detail to align precisely with the provided gauge zero at some gauge sites.
  - LiDAR data was not available in the upper reaches of Forth River, Wilmot River (including Iris River at Middlesex Plains), and Leven River. The lack of LiDAR in the upper reaches of Forth River had some impact on the routing of the hydrodynamic model (refer Section 6.1) and the lack of LiDAR at Iris River at Middlesex Plains meant that calibration was not attempted to levels at this gauge (refer to Section 6.3.1).
  - At Claytons Rivulet u/s Bass Highway and Buttons Creek u/s Bass Highway, the 2 m DEM subsets were found to have been artificially filled behind the road downstream. The SES state-wide 10 m DEM was used instead.
  - At Forth Road at Forth River, Bass Highway at Leven River, Hobbs Parade at Leven River, and West Gawler Road at Gawler River, the roadway was not adequately removed from the DEM. As improved topographic information was not available, the DEM was modified to allow for the free flow of water (and the bridges were not explicitly modelled).
  - The river entrance at Forth River was widened in response to the modelled levels being higher than expected, when compared to the 2016 flood level survey.

- For design event scenarios, a match to flow rather than level will be undertaken. This is to ensure the validity of the design events that are selected as well as to ensure that the levels are conservative.

7. UNCERTAINTY ASESSMENT

Significant flows were recorded in areas of the catchment area for four of the 13 flood events selected by the Bureau as calibration events for this project: August 1970, August 2007, January 2011 and June 2016. The August 1970 and June 2016 events were very large across the whole study area. August 2007 was only significant in the Forth River catchment, whilst January 2011 was only significant in the study area excluding the Forth River.

Eight flow gauges and four reservoir spill flows were used for calibration within the study area. The underlying DEM used for the modelling lacks channel bathymetry. This meant that a calibration to both level and flow was not possible as a significant proportion of the flow should be within the channel. Noting the purpose of the calibration is to ensure the model is performing appropriately, a calibration focussed on achieving a good match to observed flood levels in the 2016 event was prioritised over a good match to flow at the key gauges.

Within the Forth-Leven study area, 43 points surveyed as part of the June 2016 flood survey were available for comparison against the hydrodynamic model results.

The uncertainty assessment for the modelling is shown in Table 19 and Appendix B.

Table 19: Uncertainty assessment for Forth-Leven study area model

Category	Quality statement
Hydrology – rainfall input quality	The quality of the rainfall data is generally fair to good. Between six and seven pluviographs were operating in the study area during the calibration events, however these are mostly located in the upper catchment for earlier events. There were large differences between AWAP gridded rainfalls and gauge rainfalls in some areas for the 1970 event. There were between eight and ten daily rainfall stations operating for the calibration events. Given the large area, and the known high variations in rainfalls over the area, this introduces a high degree of uncertainty in the spatial and temporal distribution of rainfall for some events.
Hydrology – observed flows	Eight flow gauges were used for model calibration and validation. The qualities of the ratings are generally considered to be good within the Forth River catchment. At the other gauges, the ratings are considered to be very poor to fair for high flows. The rating for the Leven River gauge was revised in the high flow range using results of local hydraulic modelling. The largest calibration events at all gauges are significantly above the highest gaugings and therefore well into the extrapolated range. At many sites, the observed peak for at least one calibration event is over twice the highest gauged flow and at some gauges it is up to 12 times the largest gauged flow.
Hydrology – calibration events	The August 1970 and June 2016 events were large over the whole study area and were the largest or second largest events on record at many gauges. August 2007 event was only a significant event in the upper catchment, being the 2nd and 3rd largest event on record in the Forth River catchment. January 2011 event was significant in the study area other than on the Forth River.

Hydrology – calibration results	The hydrology calibration was considered to provide a very good to excellent match to observed flow hydrographs at gauges on the Forth a/b Lemonthyme, and Forth b/l Wilmot gauges. The hydrology calibration gave a poor to fair fit to observed flow hydrographs for all the remaining sites.
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. Overall, the DTM definition was considered to be poor to fair, noting that there was insufficient detail to be able to represent the gauge sites.
DTM waterways	No bathymetric data was available and waterway definition was based on the LiDAR to water surface. This resulted in a poor representation of waterways in the model.
Hydrodynamic – calibration results, peak levels	The hydrodynamic model results provided very good to excellent fits to peak levels at Claytons u/s Bass Hwy and Gawler at Cradle Coast gauge sites. The model gave a poor fit to observed levels at Forth b/l Wilmot and Forth a/b Lemonthyme gauges. The model gave a fair to good fit to observed levels at Wilmot a/b Forth, Leven at Bannons Bridge and Iris gauges.
Hydrodynamic – calibration results, flood extents	Flood extents were available for the June 2016 flood. These were derived from 43 surveyed flood points within the study area. The comparison between modelled flood extent and that derived from the survey was generally good in the upper reaches of the surveyed area and poorer in the lower reaches. This may be due to a combination of the representation of the river channels in the DEM and issues with the survey points.
Hydrodynamic – calibration results, flood depths	43 flood depth points from the June 2016 flood survey were available for comparison against the hydrodynamic model results. Comparison of the model results with the surveyed depths showed a generally good to excellent match with 80% of the model depths inside the stated bounds of uncertainty of the survey and DEM.

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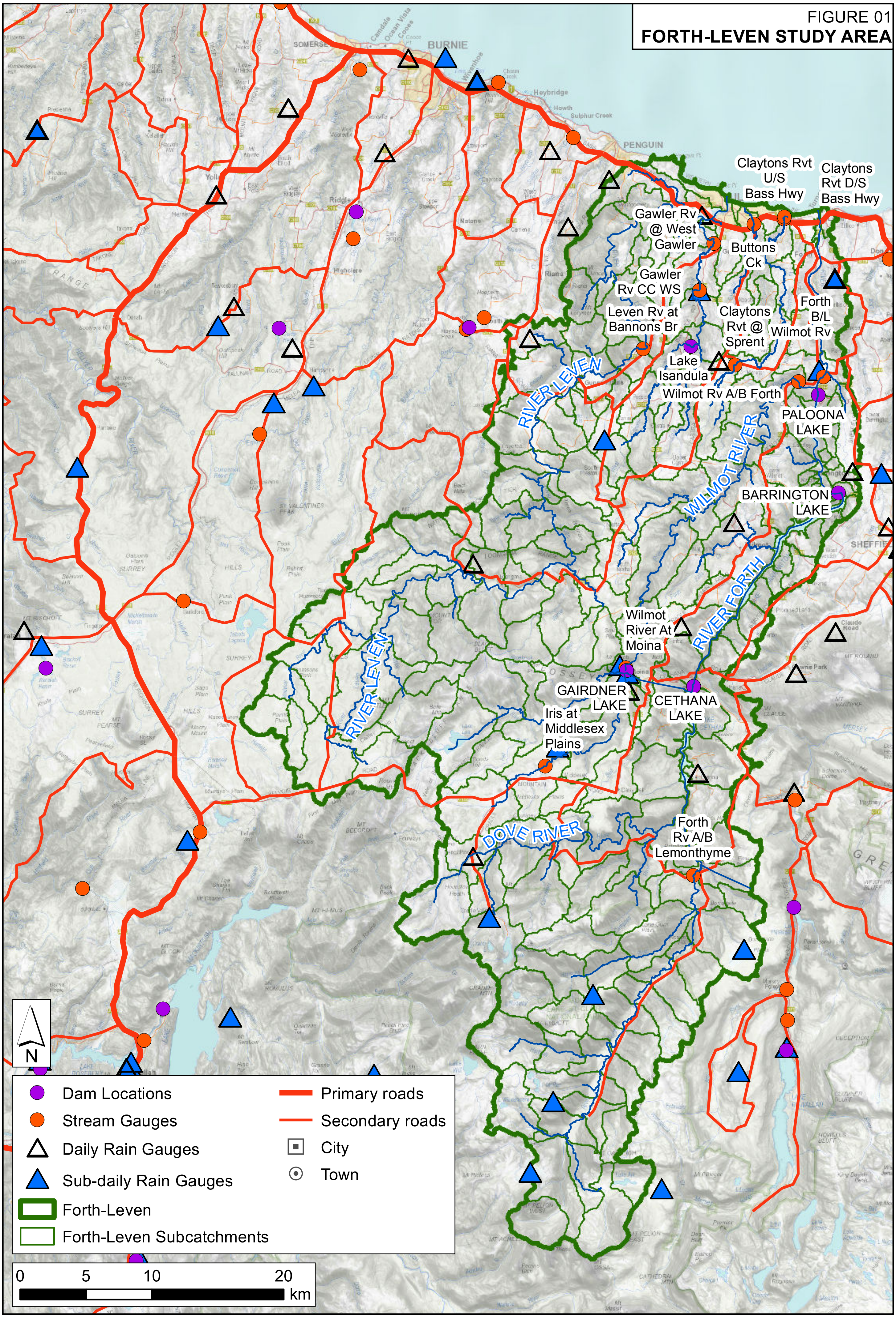
Figures



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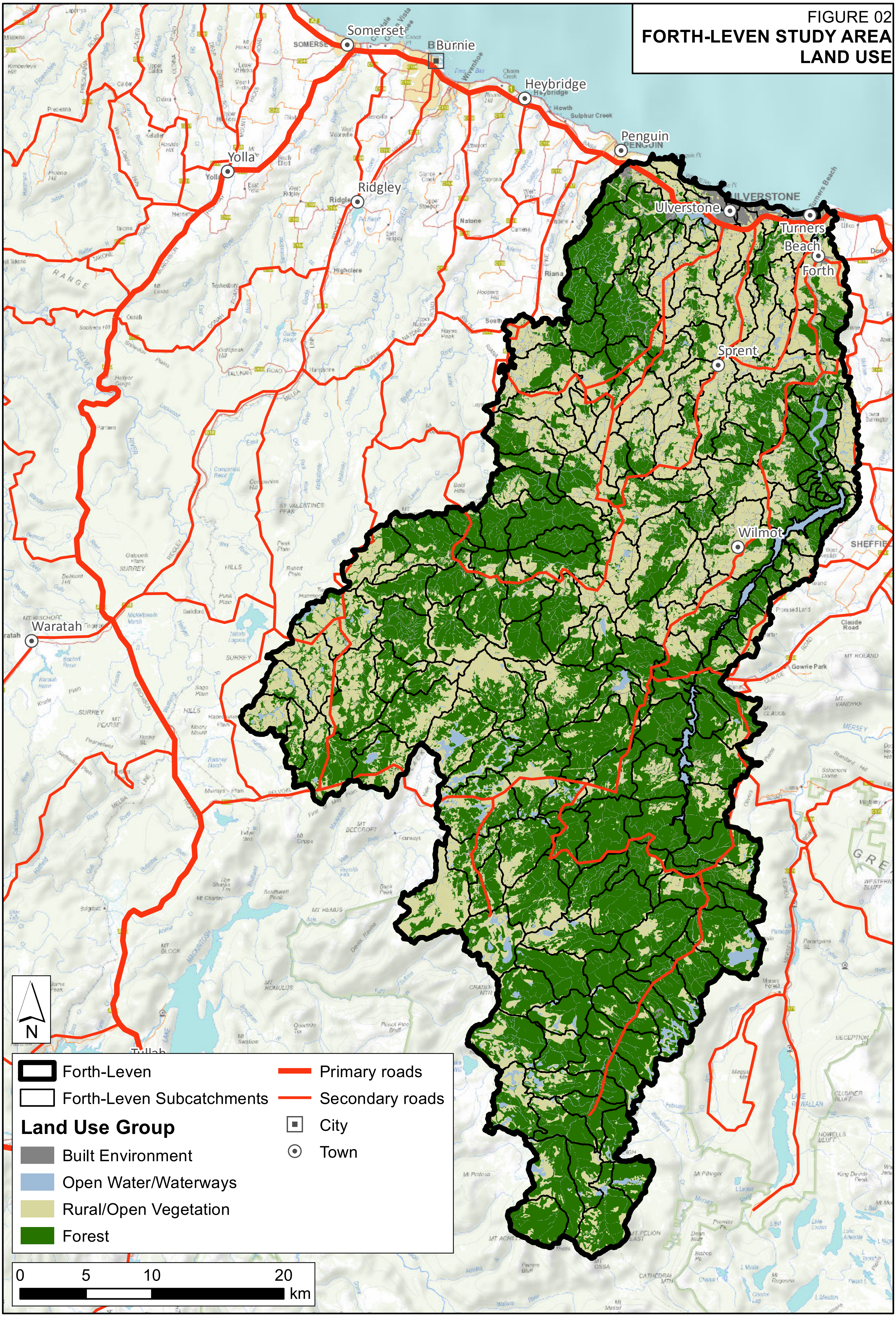

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FIGURE 03
FORTH−LEVEN STUDY AREA
RAINFALL 1970_AUG

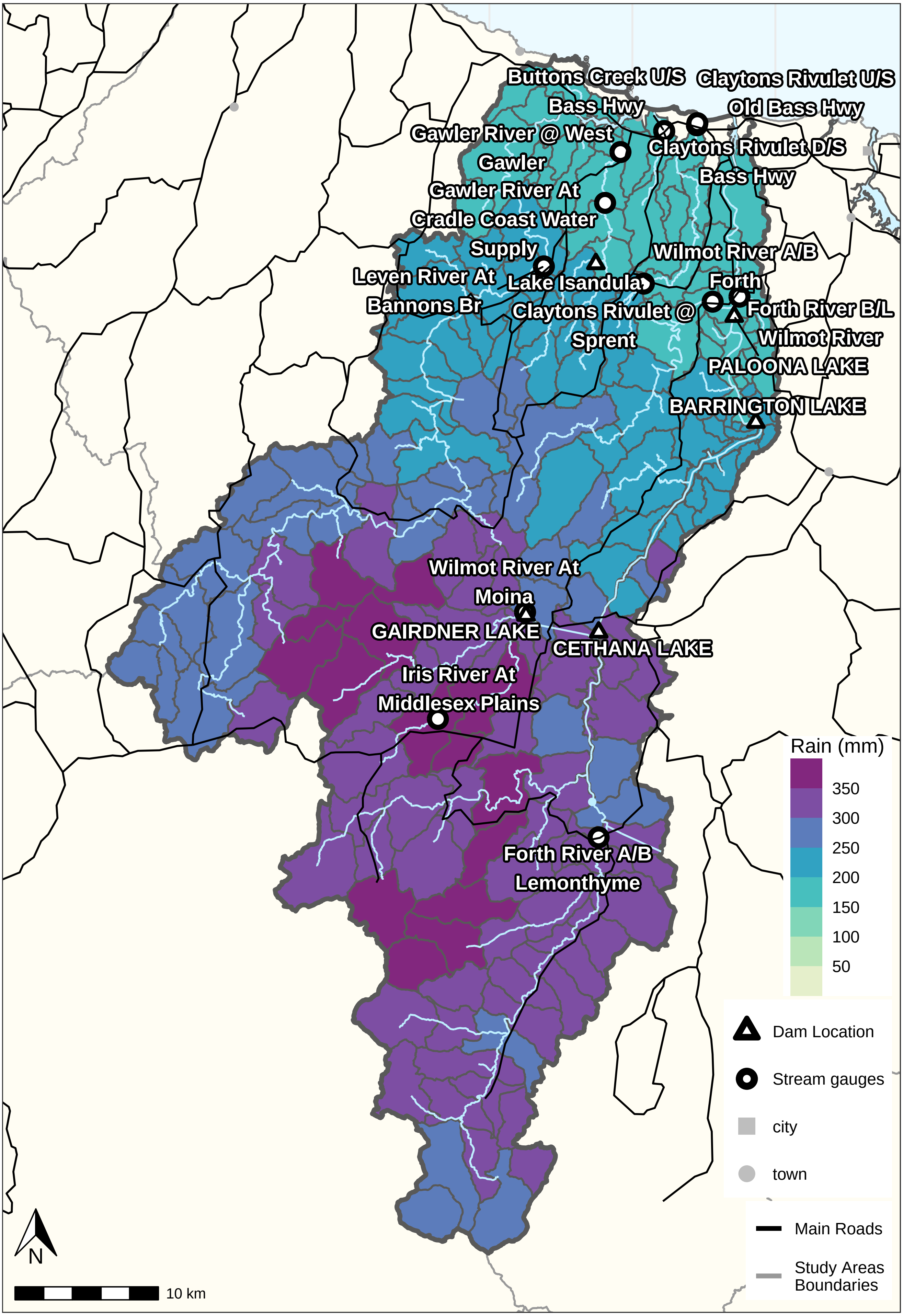

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FIGURE 04
FORTH−LEVEN STUDY AREA
RAINFALL 2007_AUG

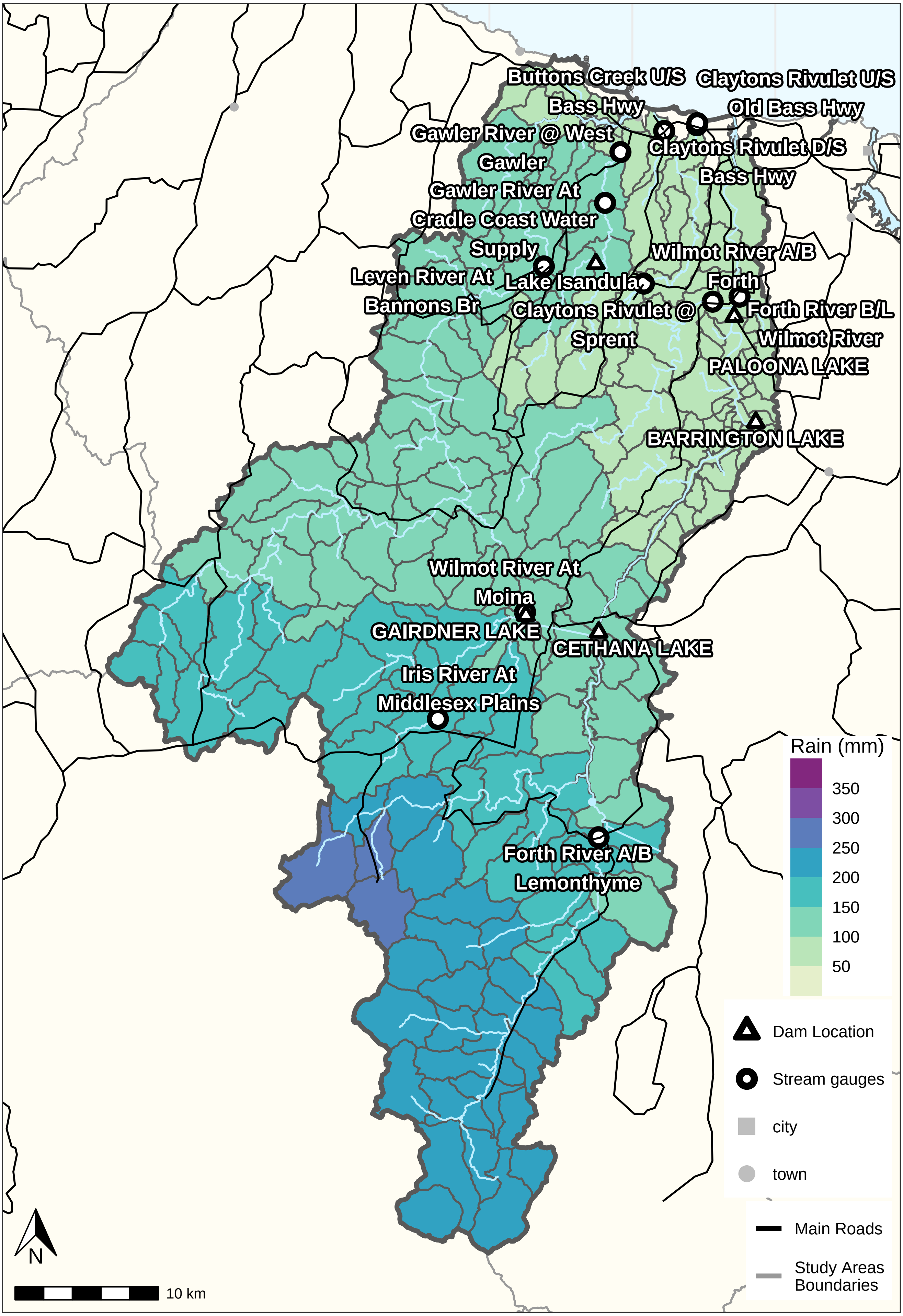

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FIGURE 05

FORTH−LEVEN STUDY AREA

RAINFALL 2011_JAN

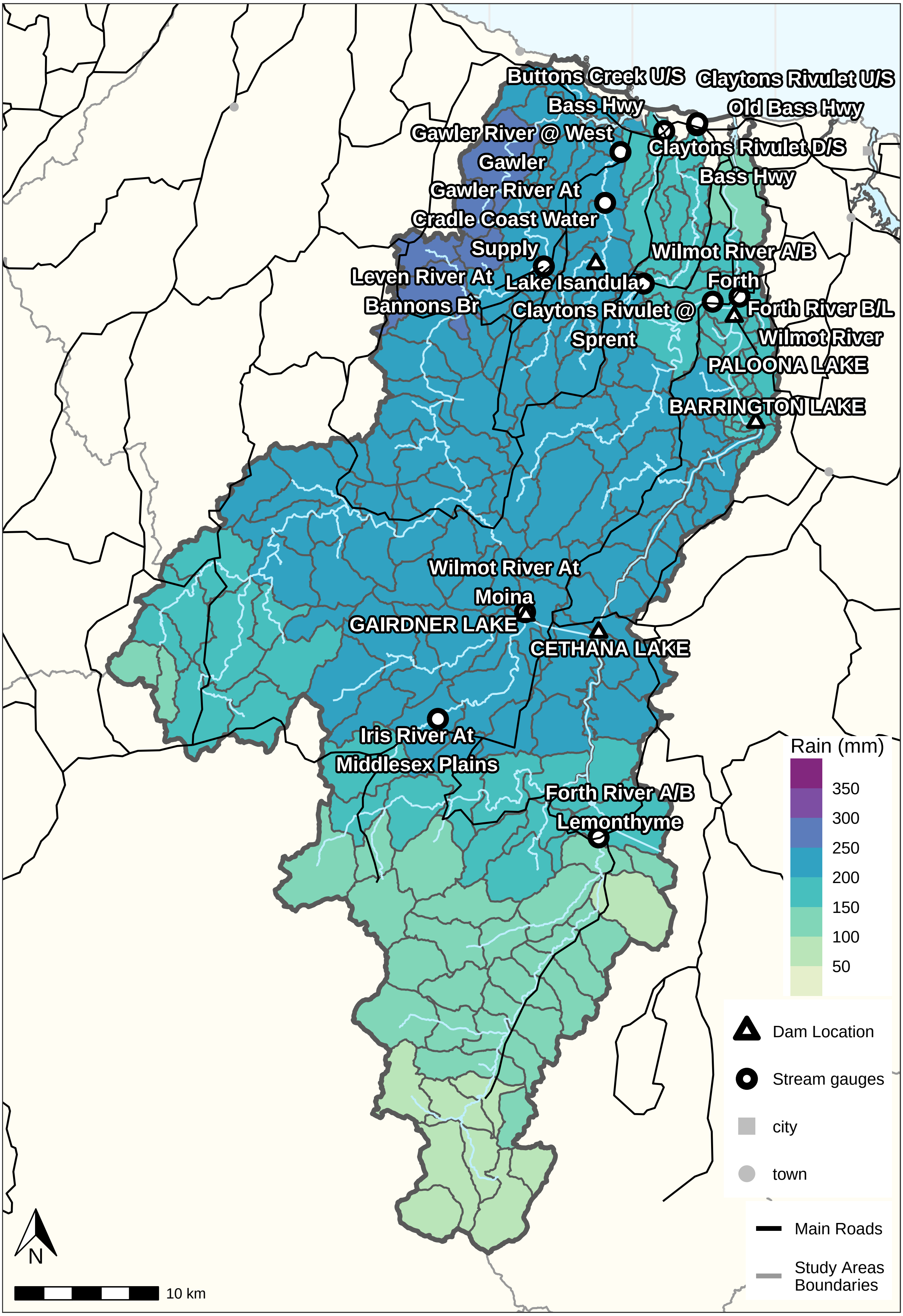

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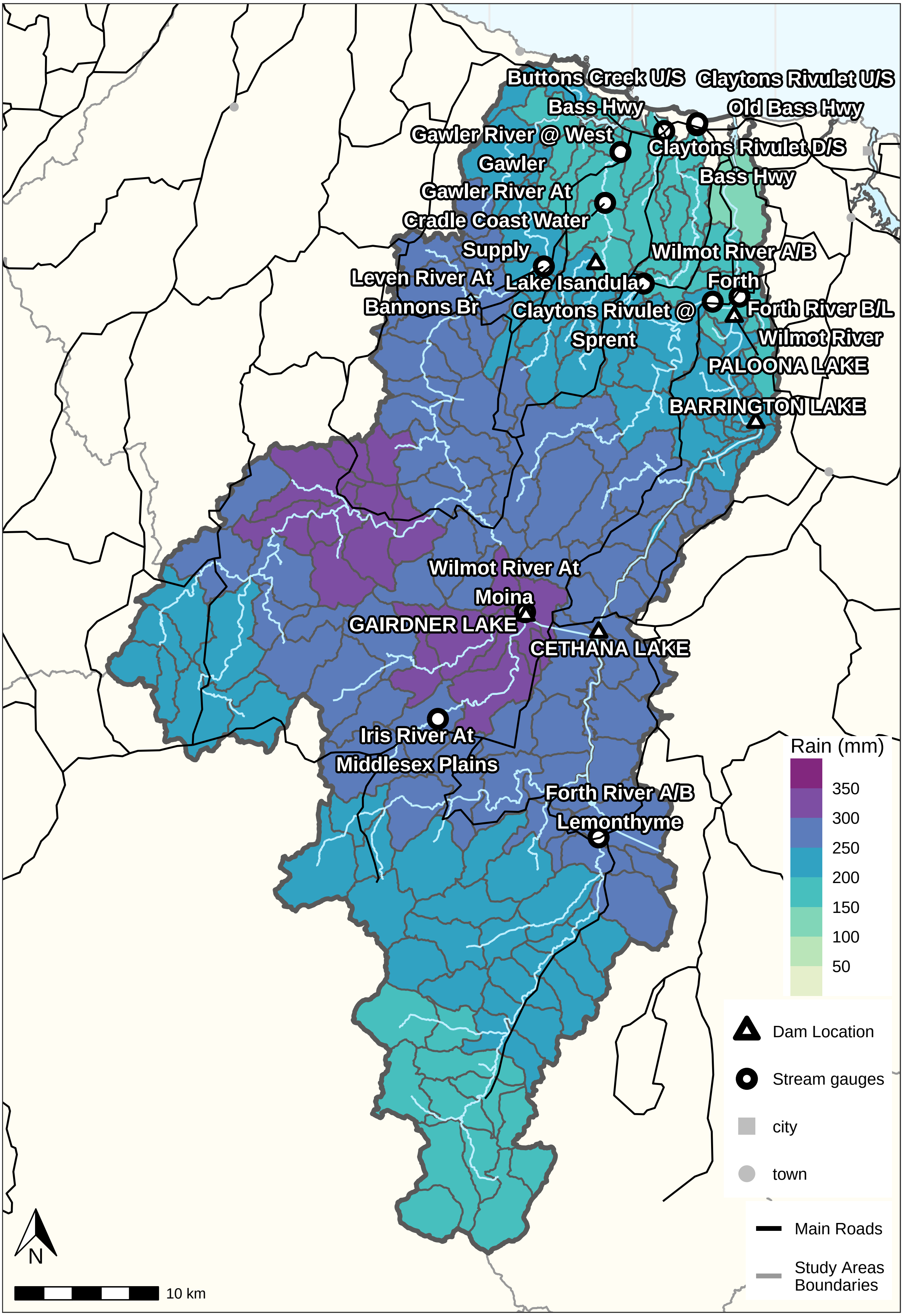
FIGURE 06
FORTH−LEVEN STUDY AREA
RAINFALL 2016_JUN



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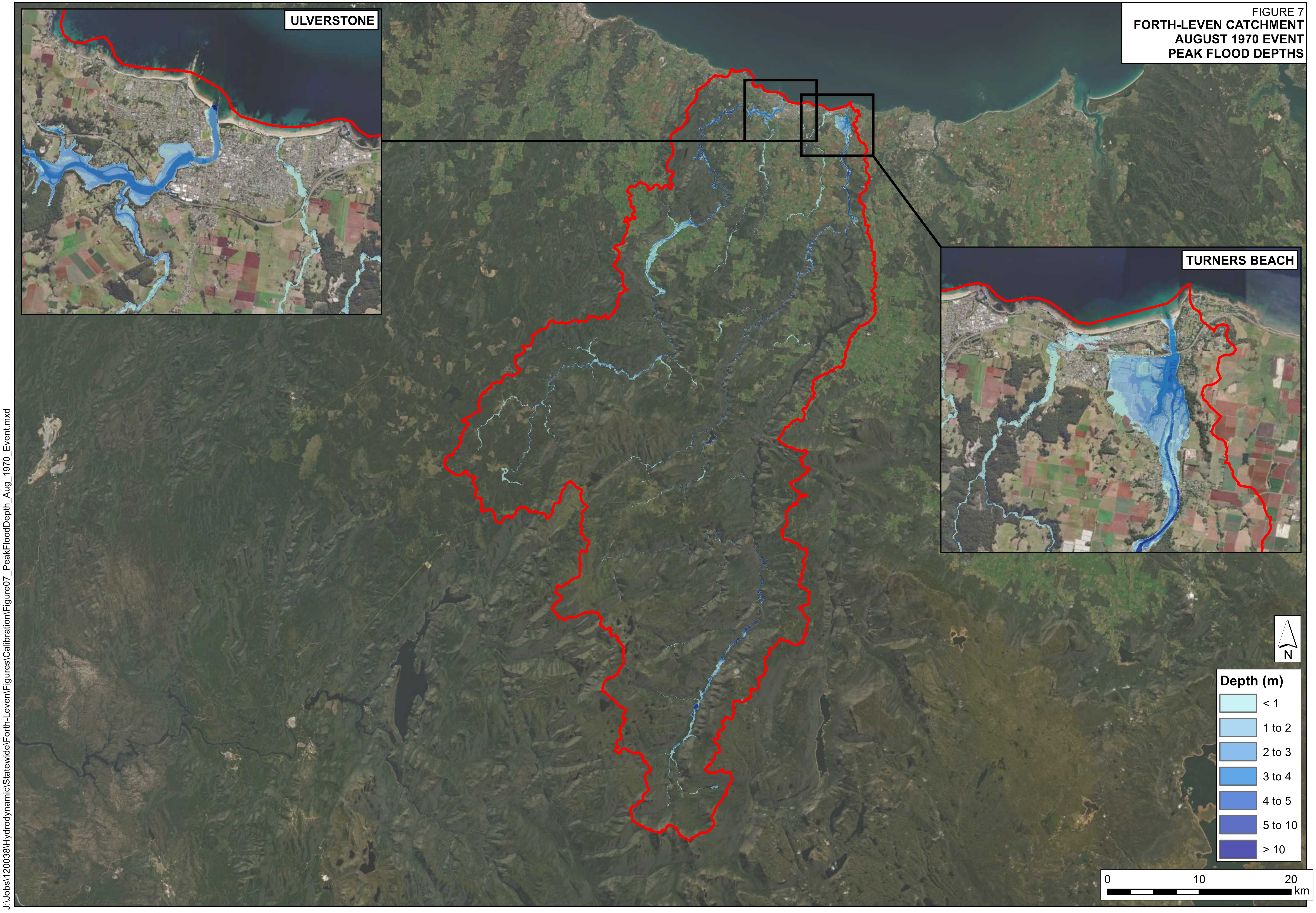
FIGURE 7
FORTH-LEVEN CATCHMENT
AUGUST 1970 EVENT
PEAK FLOOD DEPTHS
ULVERSTONE
TURNERS BEACH
N
Depth (m)
< 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 10
> 10
0
10
20
km
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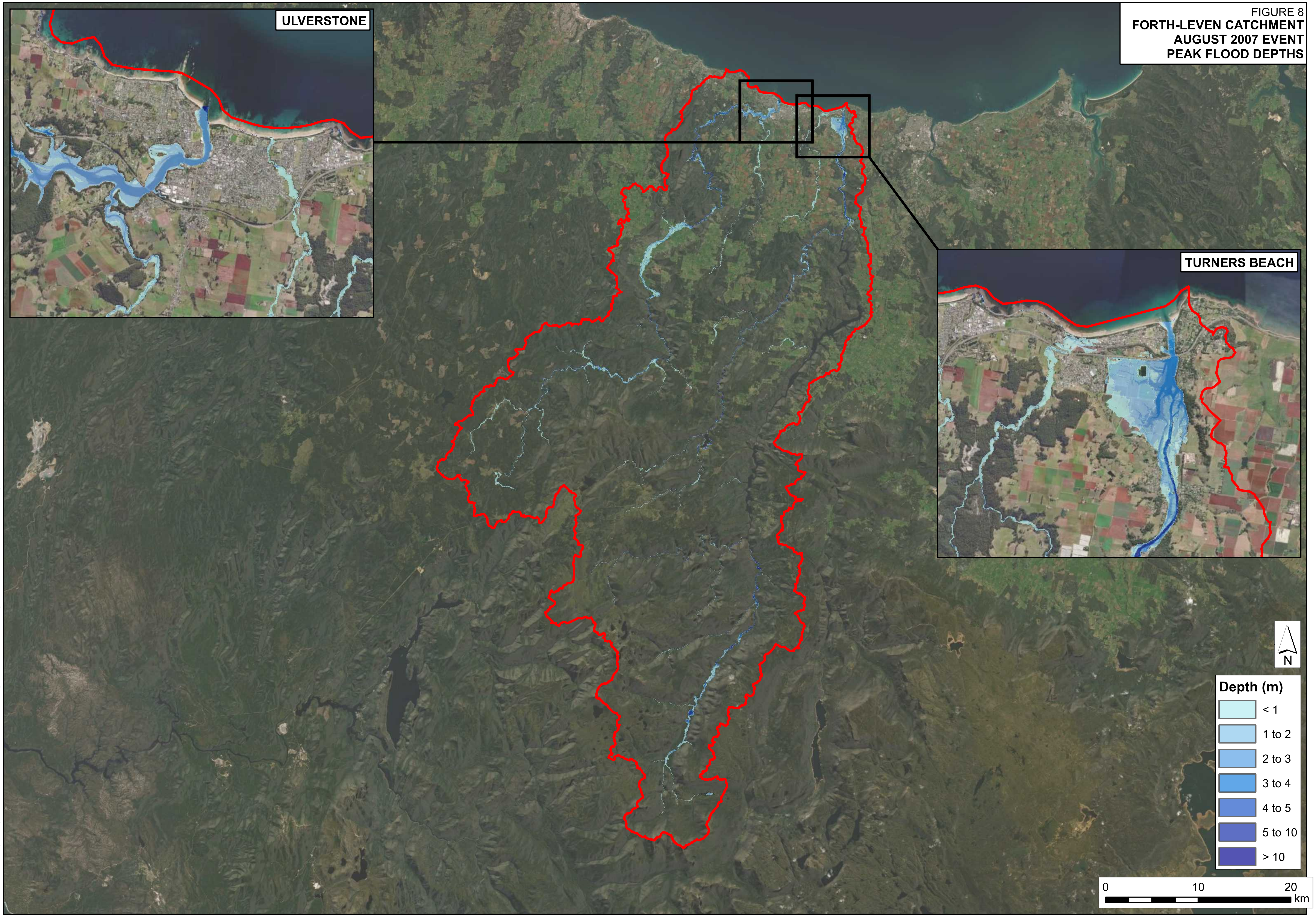
FIGURE 8
FORTH-LEVEN CATCHMENT
AUGUST 2007 EVENT
PEAK FLOOD DEPTHS
ULVERSTONE
TURNERS BEACH
N
Depth (m)
< 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 10
> 10
0
10
20
km
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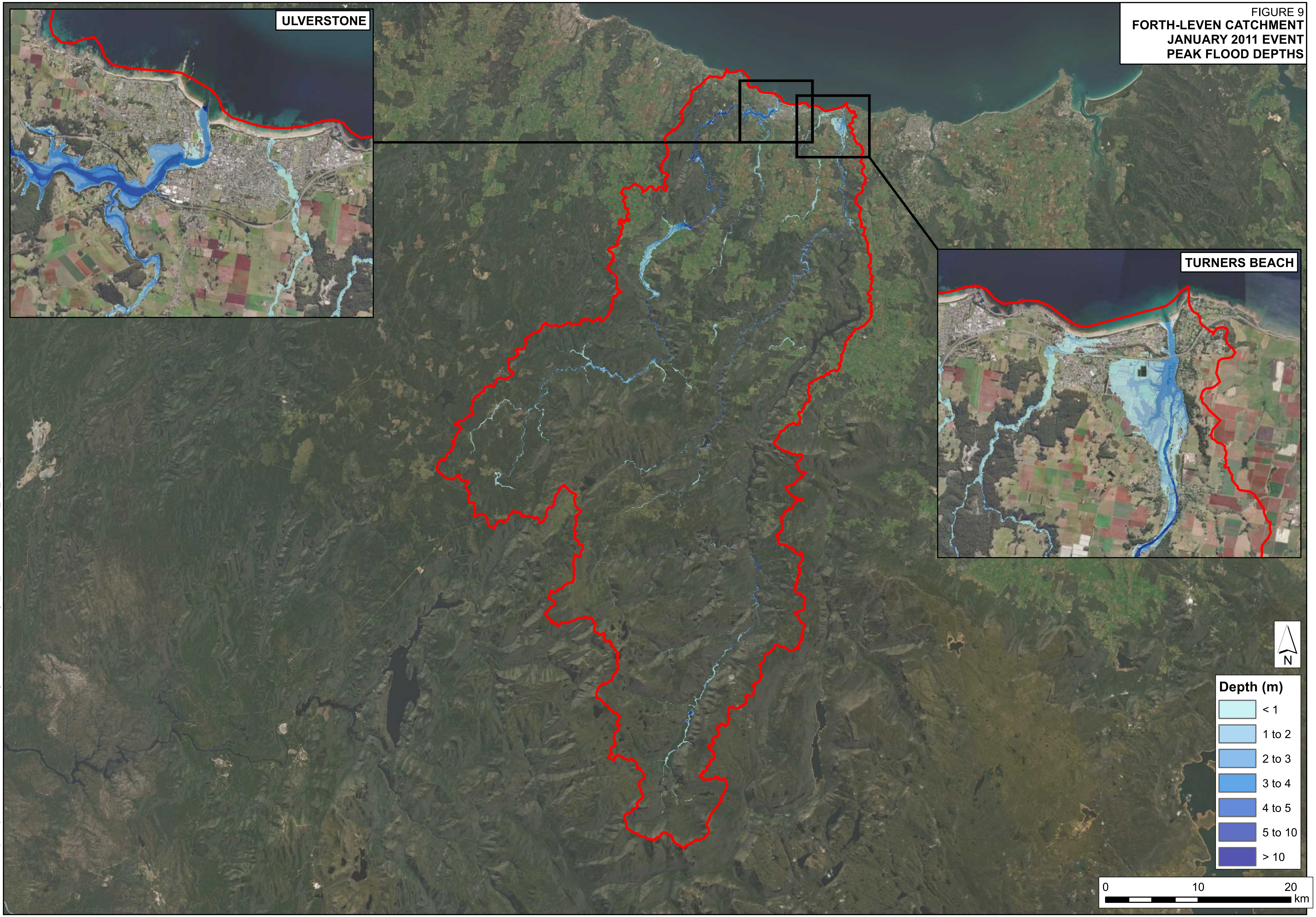

FIGURE 9
FORTH-LEVEN CATCHMENT
JANUARY 2011 EVENT
PEAK FLOOD DEPTHS

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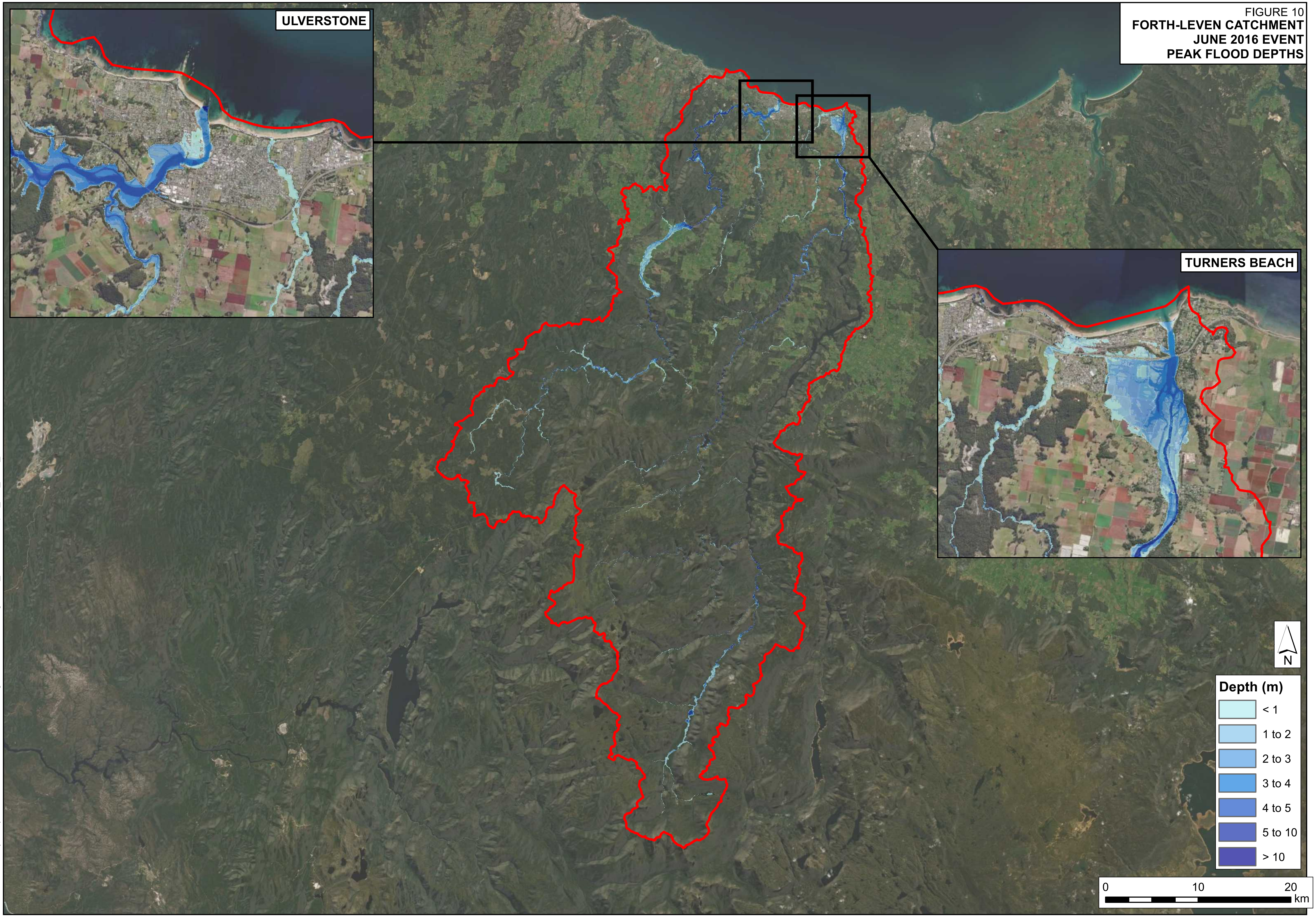

FIGURE 10
FORTH-LEVEN CATCHMENT
JUNE 2016 EVENT
PEAK FLOOD DEPTHS

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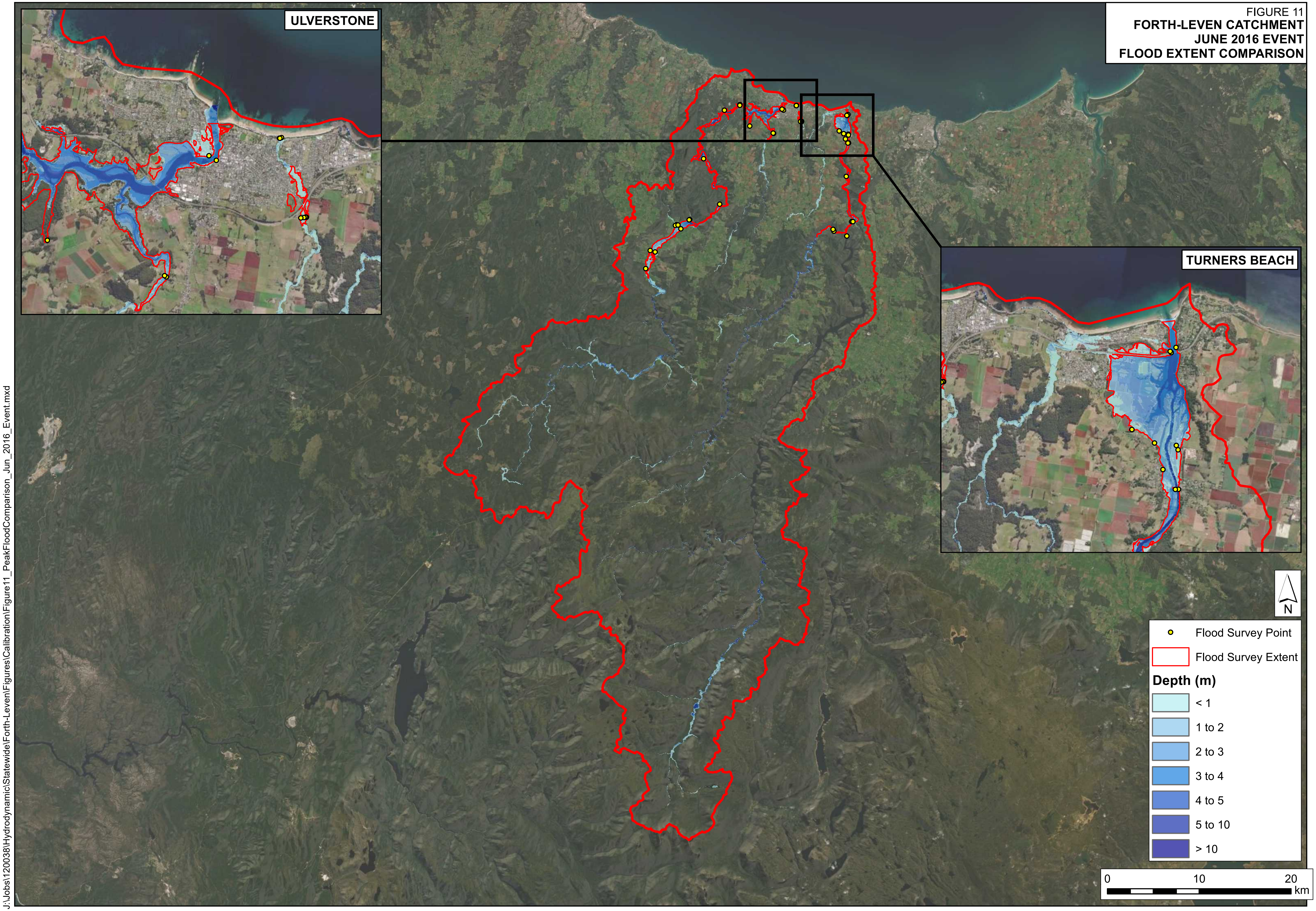
FIGURE 11
FORTH-LEVEN CATCHMENT
JUNE 2016 EVENT
FLOOD EXTENT COMPARISON
ULVERSTONE
TURNERS BEACH
N
Flood Survey Point
Flood Survey Extent
Depth (m)
< 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 10
> 10
0
10
20
km
J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Calibration\Figure11_PeakFloodComparison_Jun_2016_Event.mxd

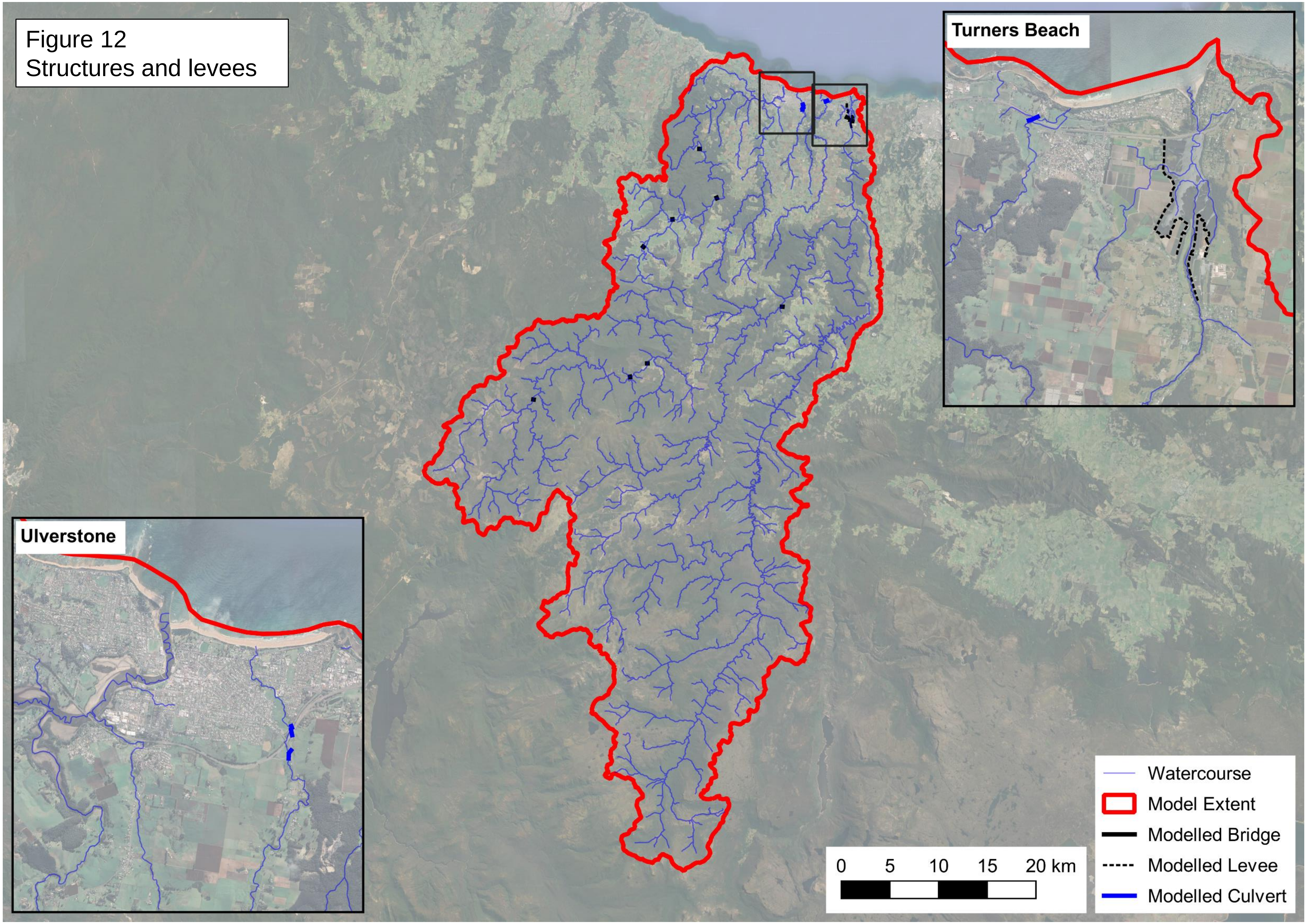
Figure 12
Structures and levees
Turners Beach
Ulverstone
Watercourse
Model Extent
Modelled Bridge
Modelled Levee
Modelled Culvert
0 5 10 15 20 km

Appendix A

APPENDIX A. AVAILABLE DATA

A.1. Sub catchment data

FIGURE A1

HYDROLOGICAL SOIL GROUP MAPPING

DOMINANT SUBCATCHMENT SOIL INFILTRATION RATE

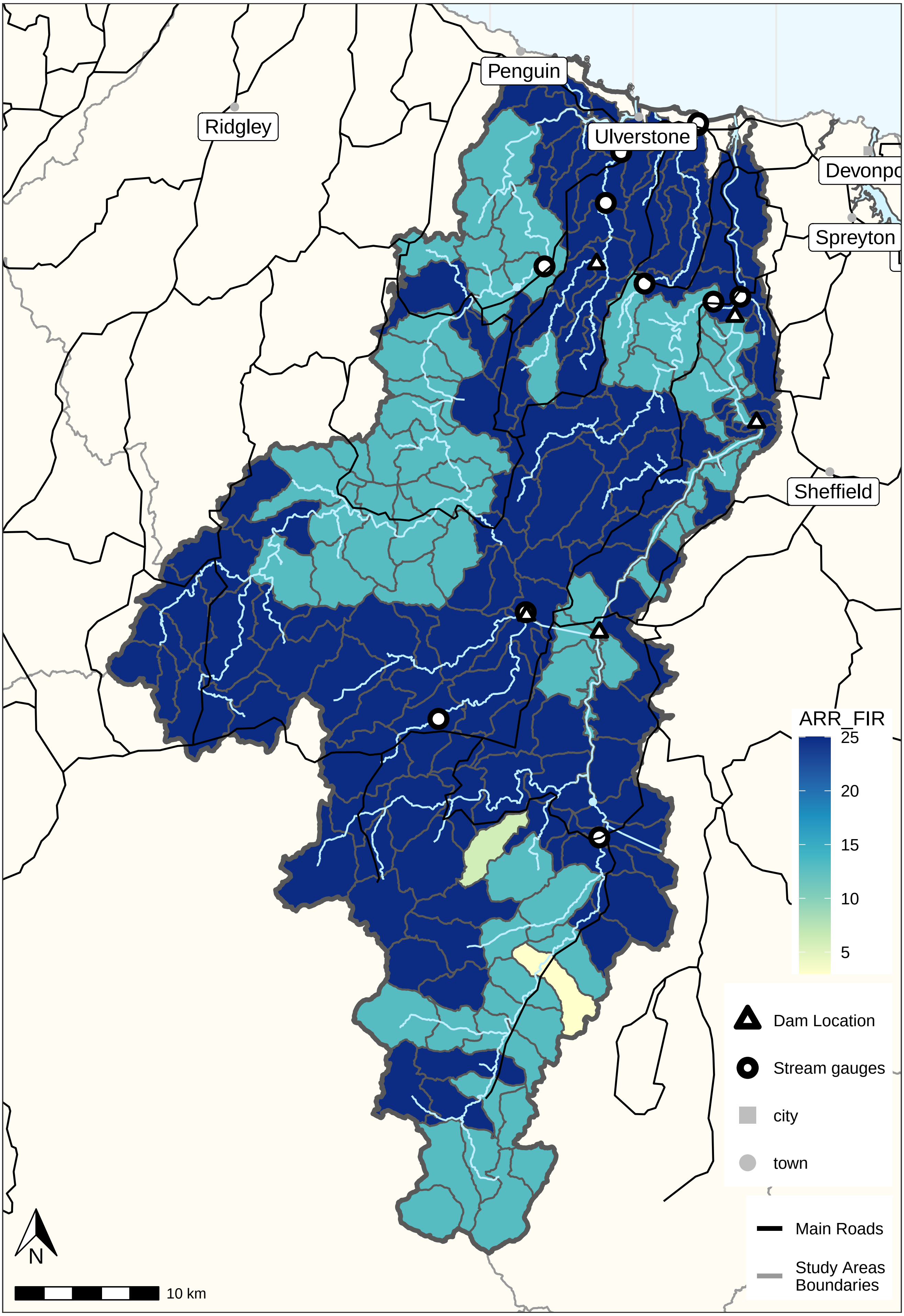

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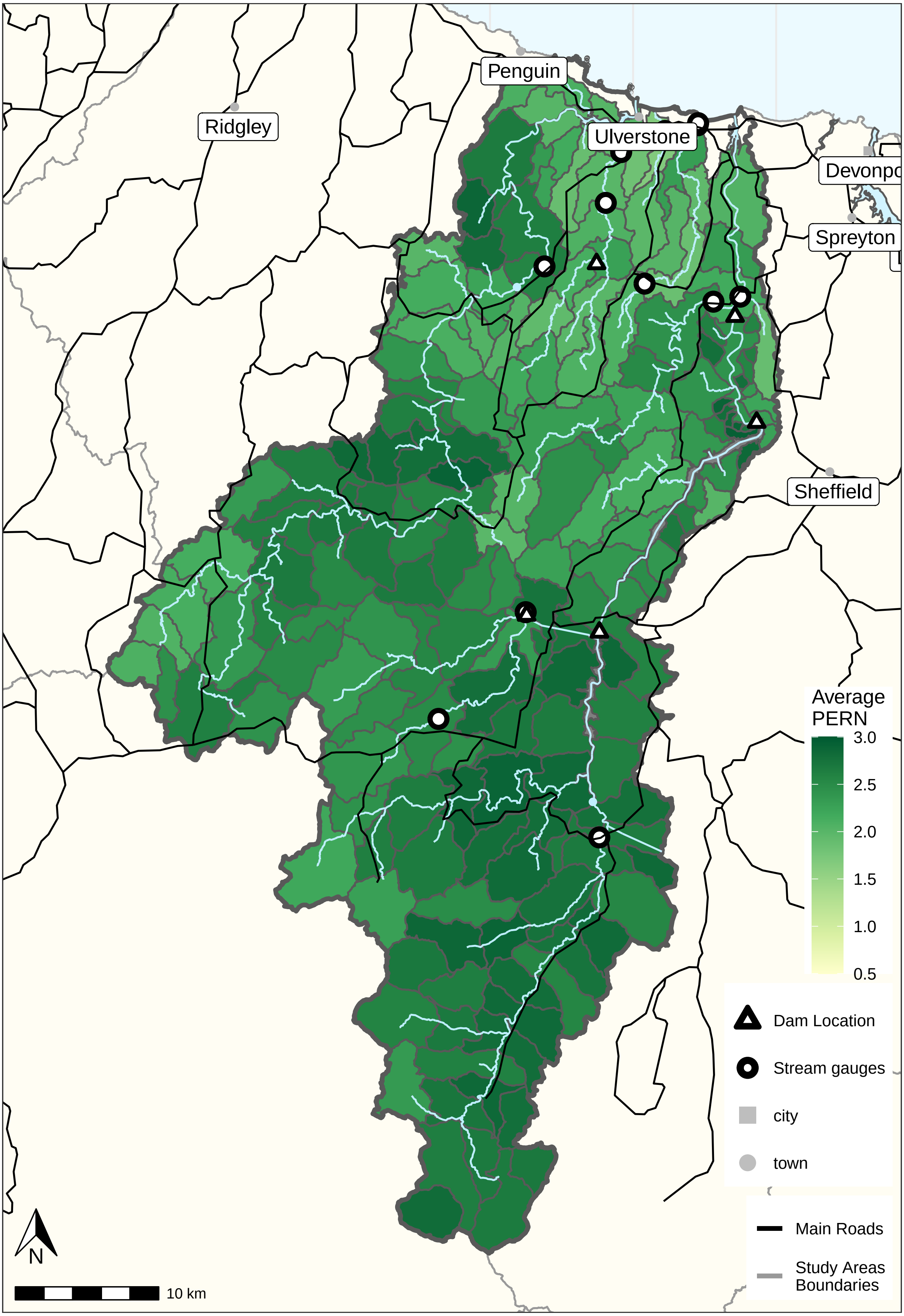
FIGURE A2

FORTH−LEVEN 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:

- Blue – Iris River, Wilmot 1970 and 2011, Leven at Bannons Bridge, Gawler at Cradle Coast, Buttons Creek
- Green – Forth a/b Lemonthyme 2016, Forth b/l Wilmot, Wilmot 2016
- Orange – Forth a/b Lemonthyme 2007

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 Model 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. The following shading is used to highlight relevant statements:

- Blue – Wilmot a/b Forth, Leven at Bannons Bridge, Iris 2016
- Orange – Iris 2011, Gawler at Cradle Coast
- Purple – Forth b/l Wilmot, Forth a/b Lemonthyme
- Green – comparison to flood survey

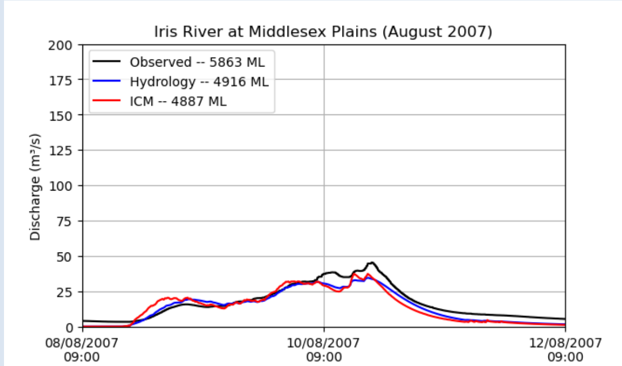
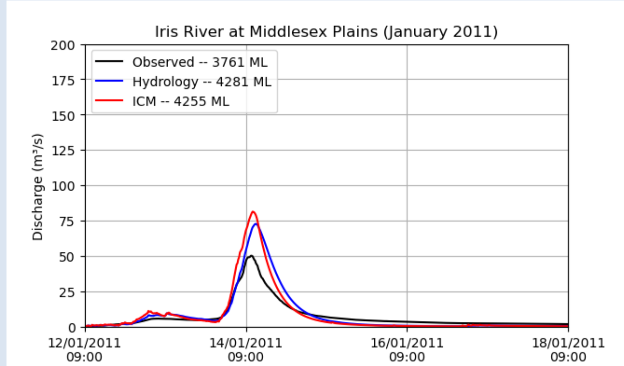
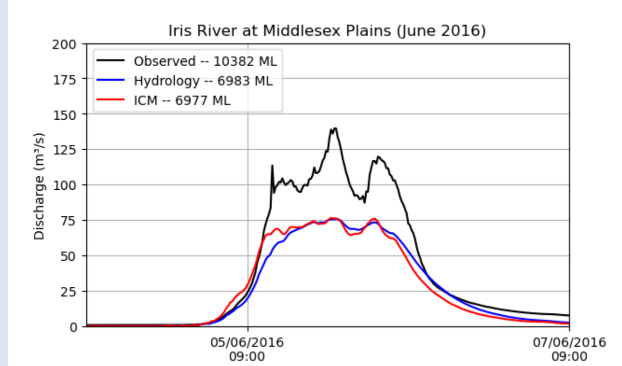
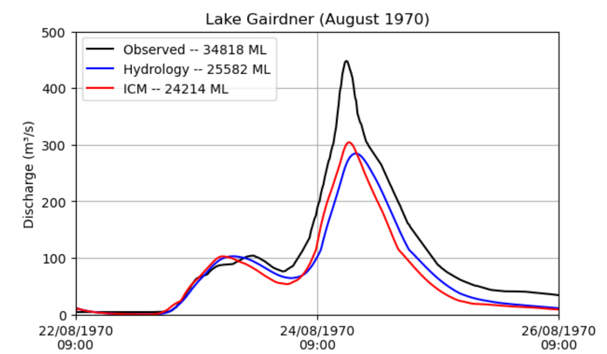
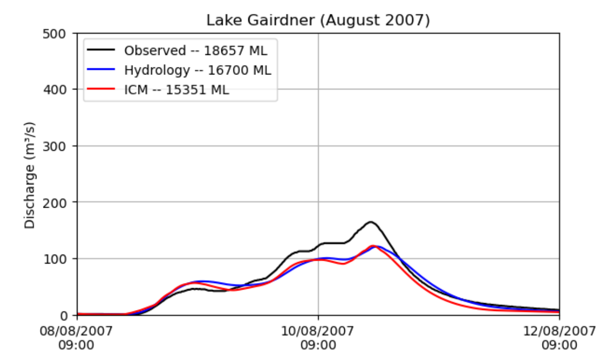
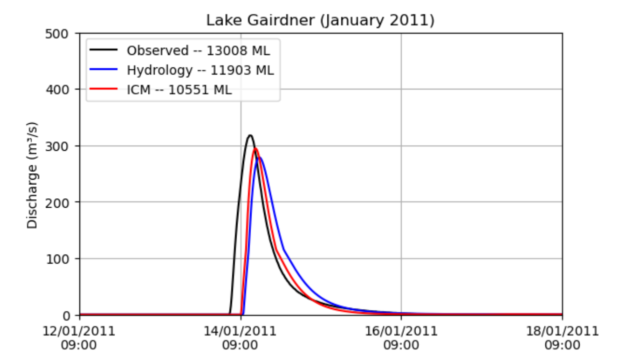
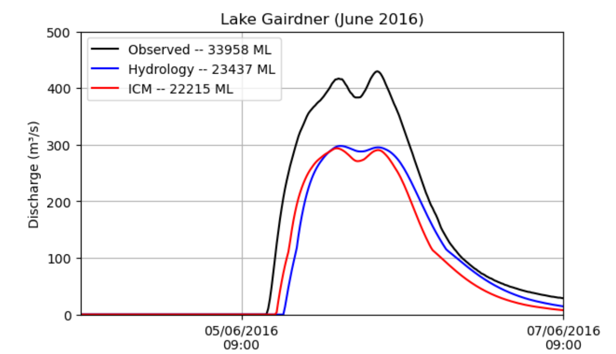
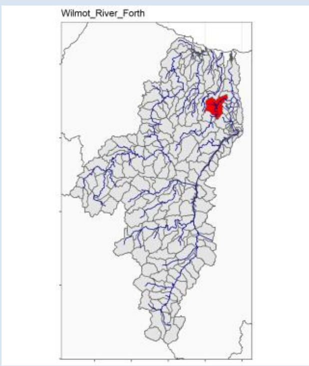
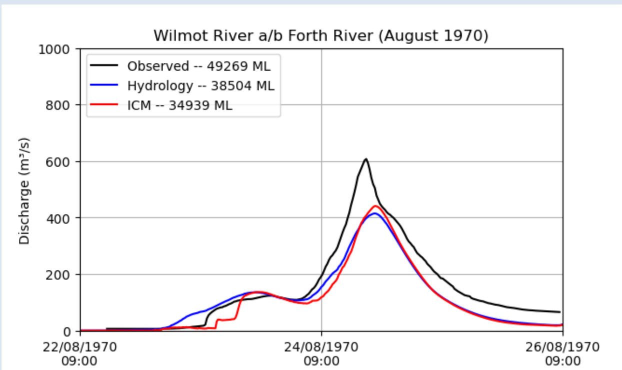
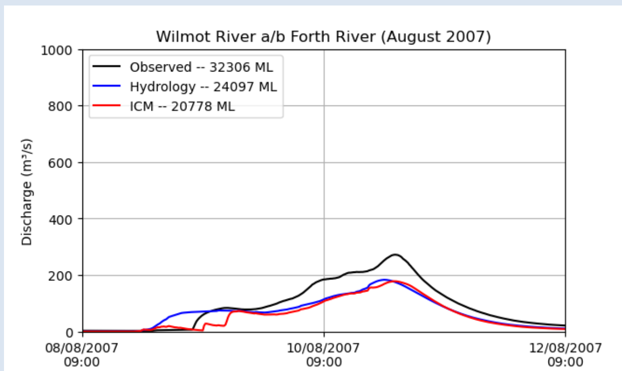
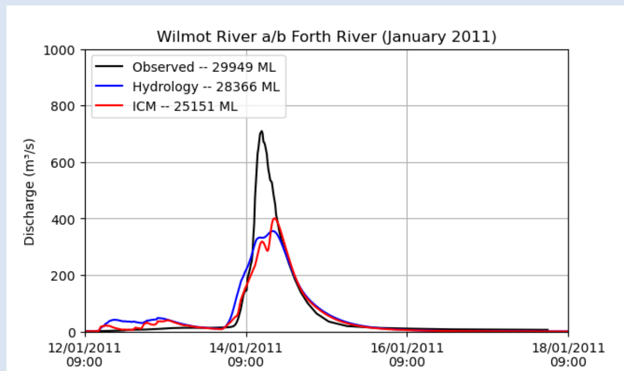
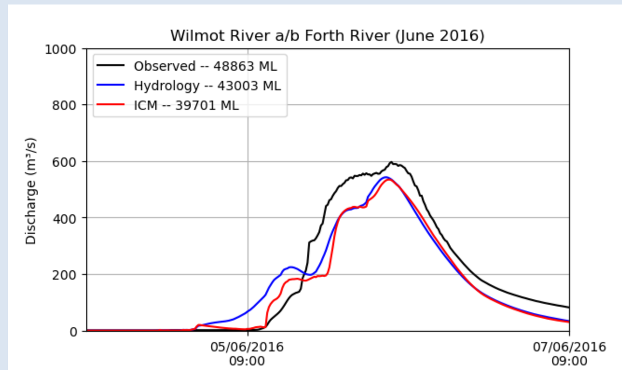
Table B 5: Hydrodynamic calibration quality rating

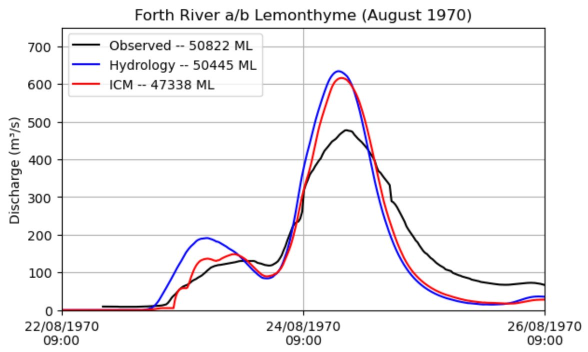
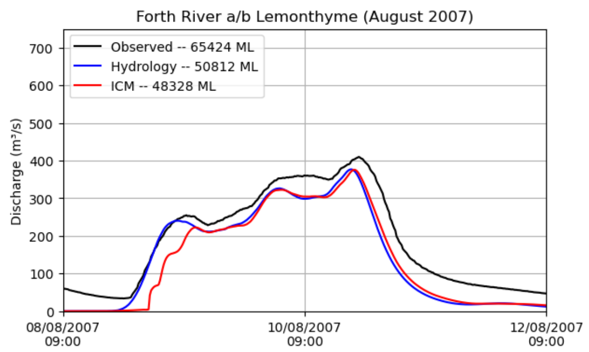
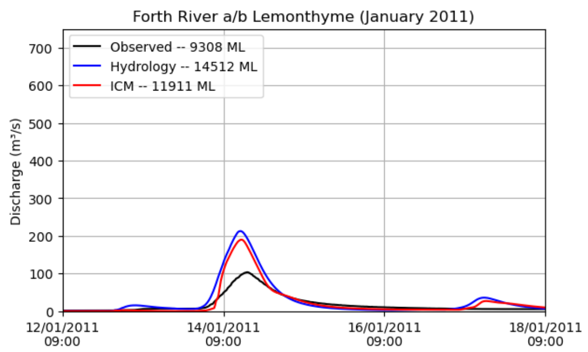
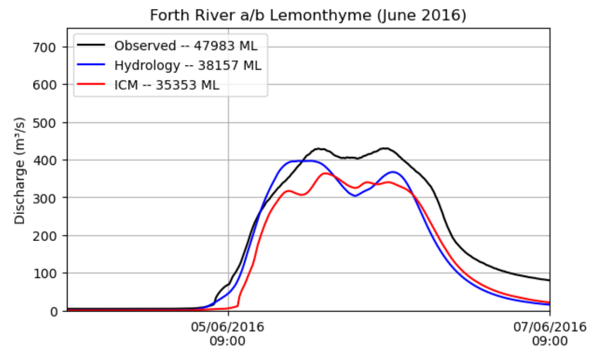
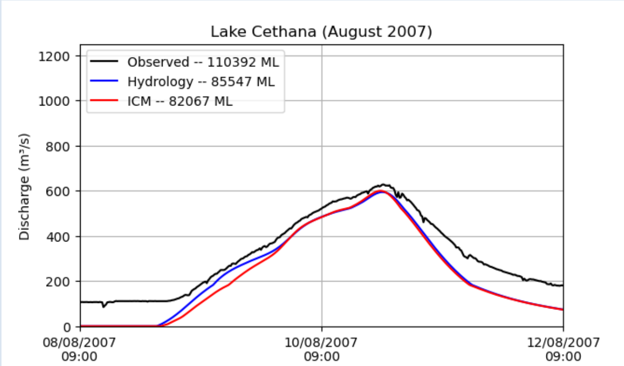
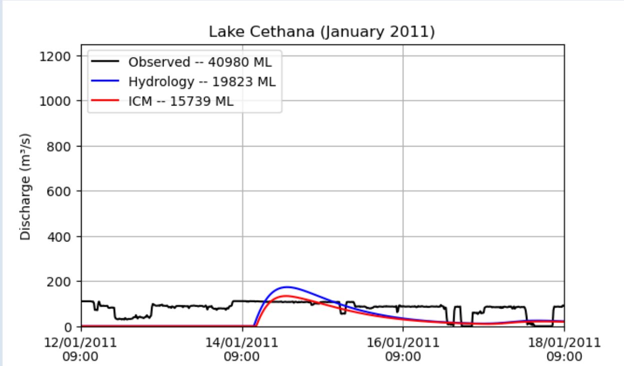
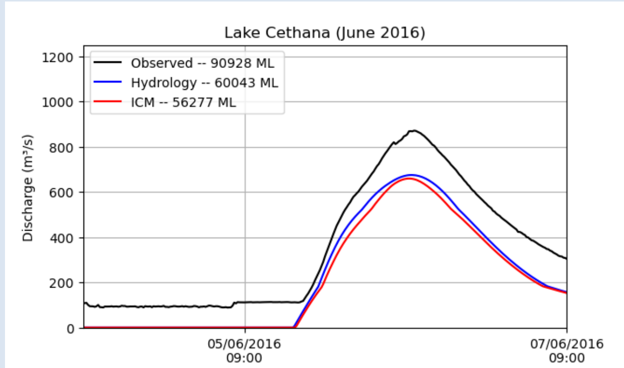
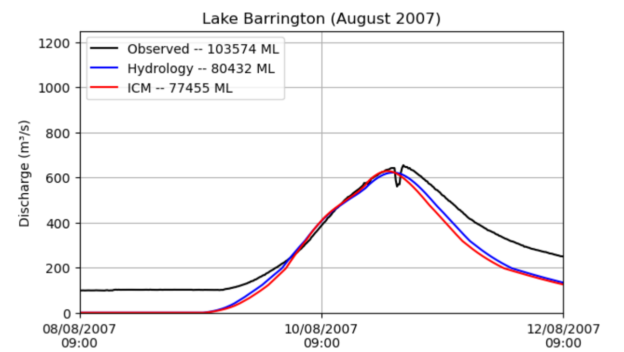
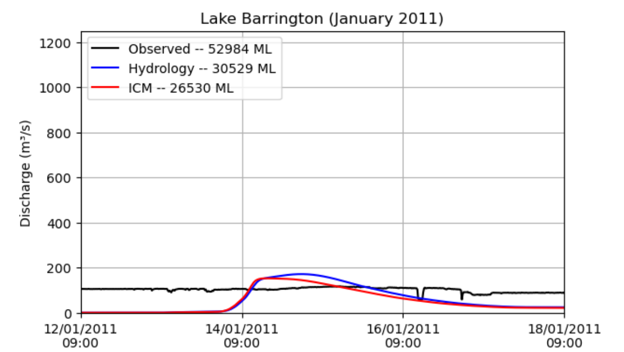
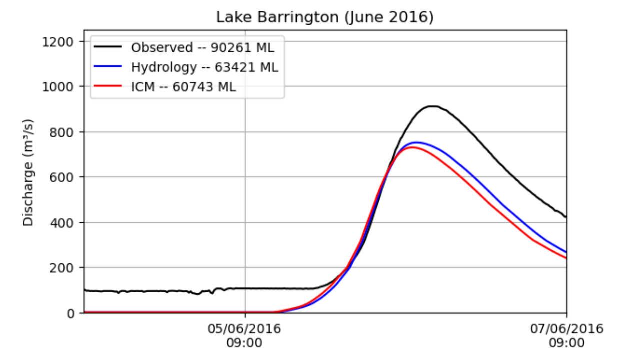
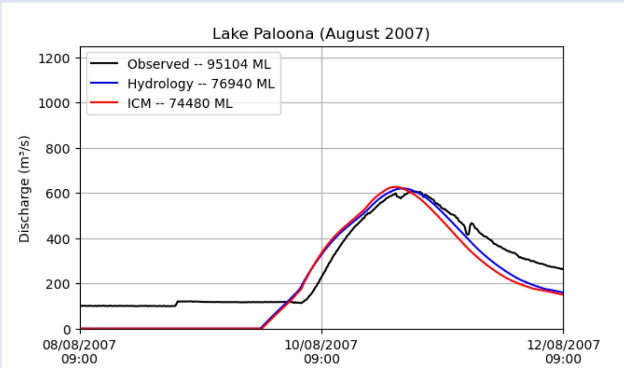
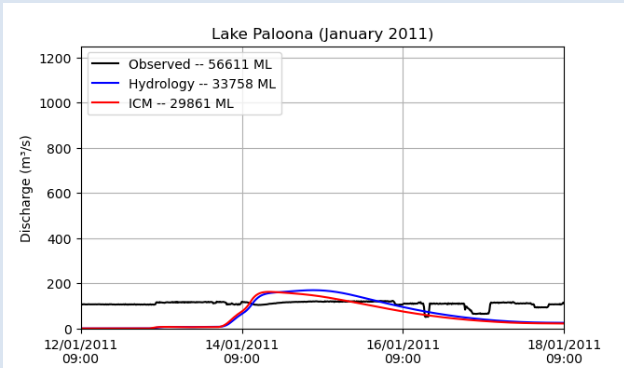
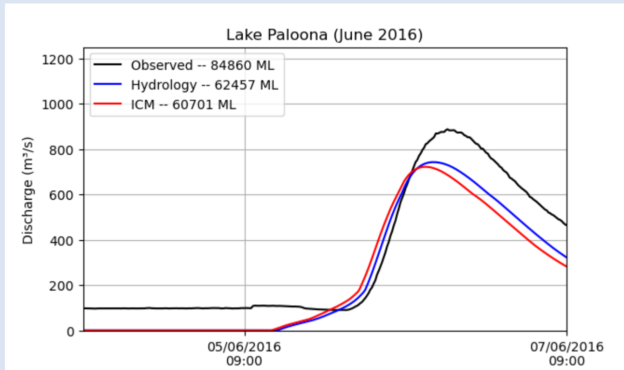
Category	Rating				
	Poor	**Fair**	**Good**	**Very good**	**Excellent**
Hydrodynamic calibration - peak levels	Peak level > +/- 1m of observed	Peak level within +/-1 m of observed	Peak within +/-0.5m of observed	Peak within +/-0.3m of observed	Peak within +/- 0.3m of observed
Hydrodynamic calibration – 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 more than +/- 1m difference from 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	August 1970	August 2007	January 2011	June 2016
	N/A			
Lake Gairdner				
				

				
Lake Cethana	N/A			
Lake Barrington	N/A			
Lake Paloona	N/A			

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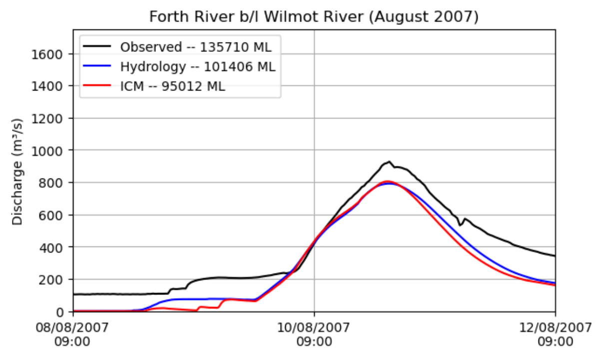
<td>
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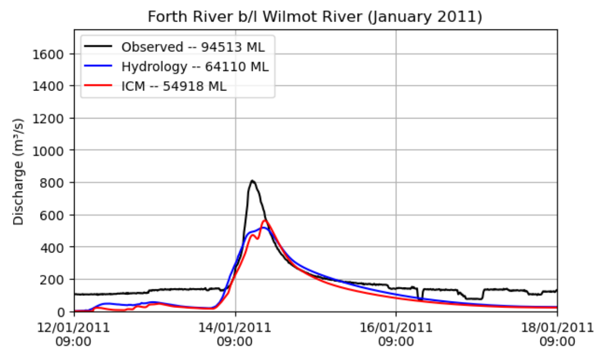
<td>
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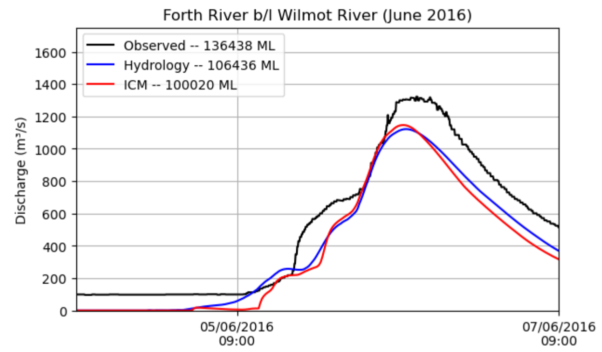
<td>
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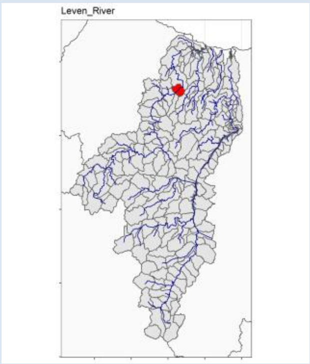
<td>
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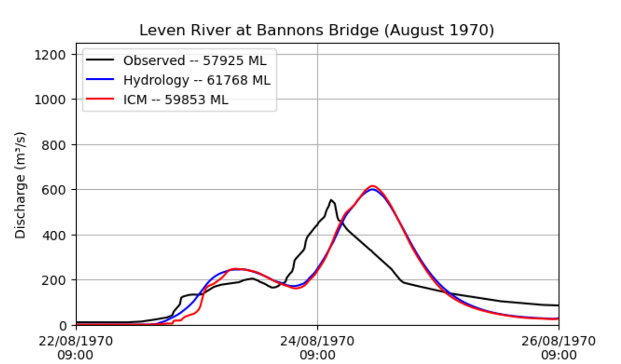
<td>
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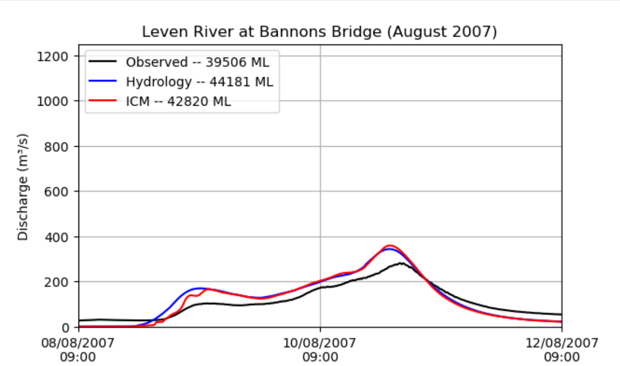
<td>
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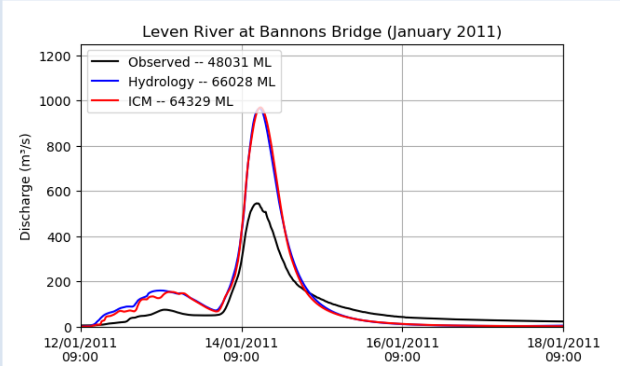
<td>
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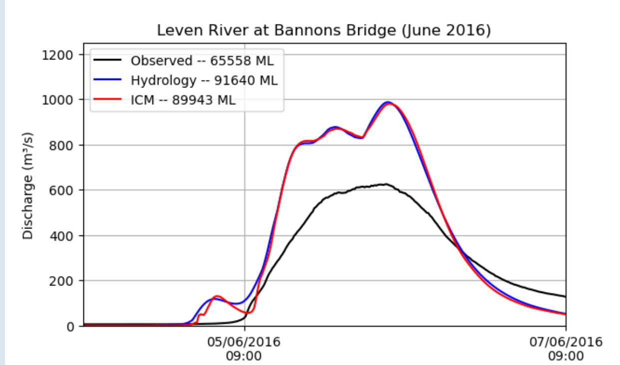
<td>
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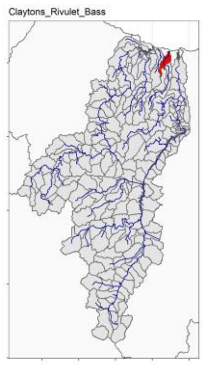
<td>
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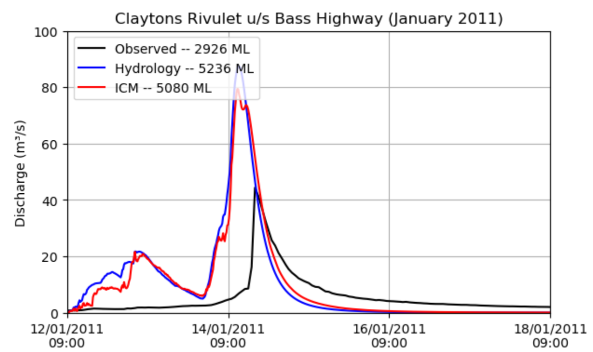
<td>
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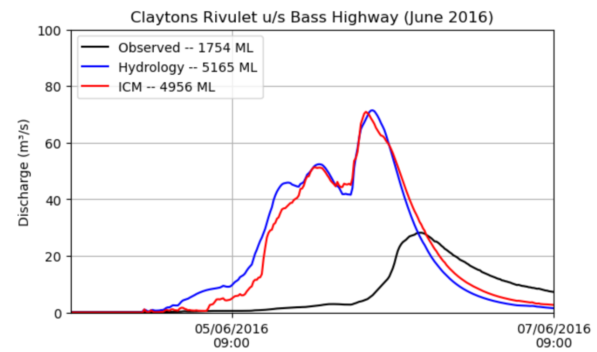
<td>
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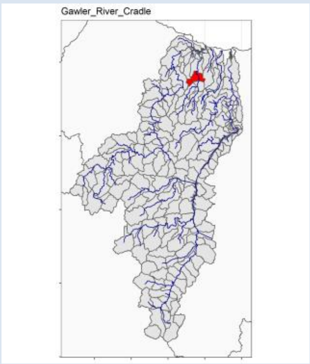
<td>
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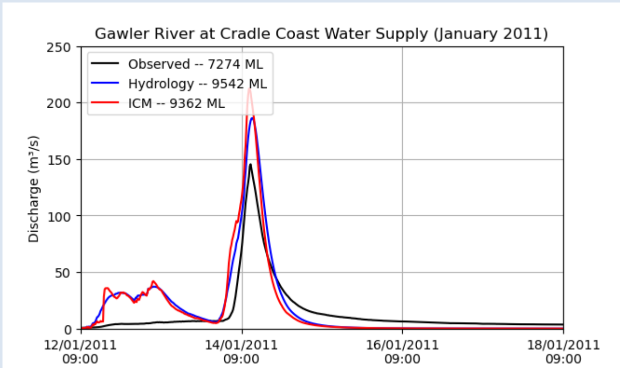
<td>
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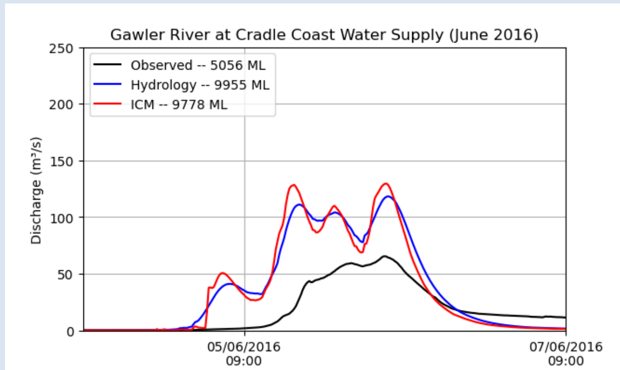
<td>
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Buttons_Creek

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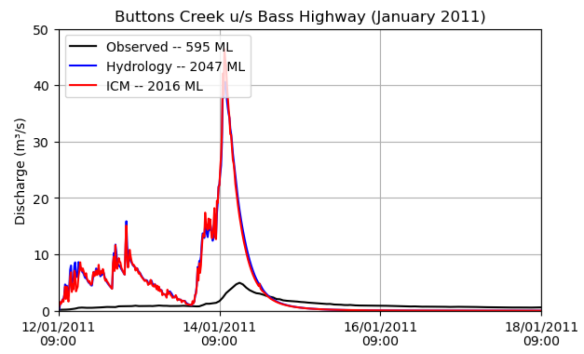
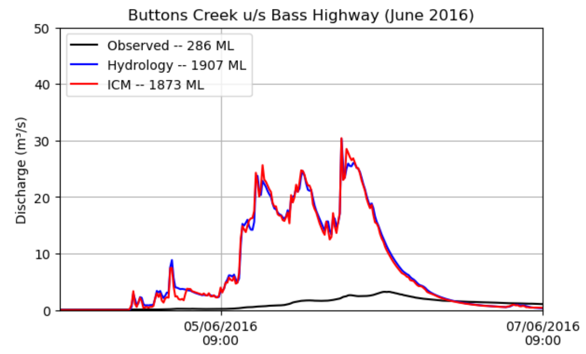
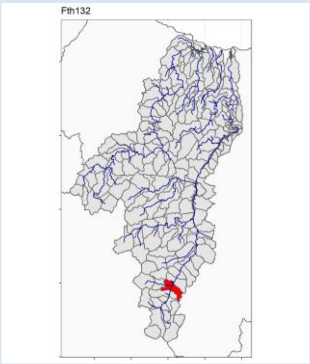
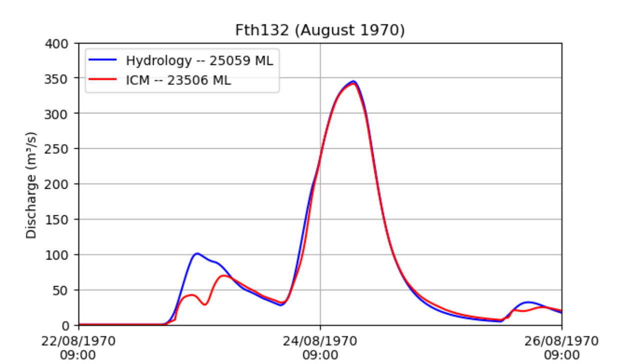
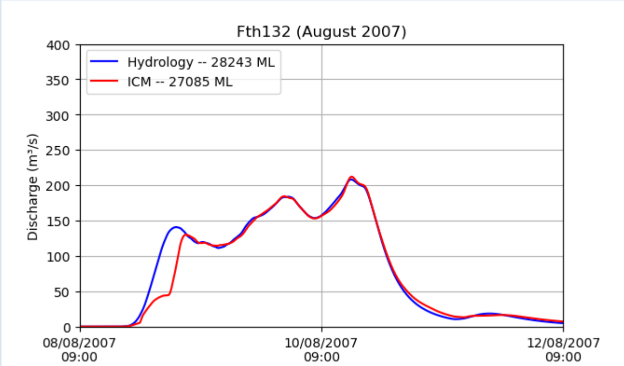
N/A

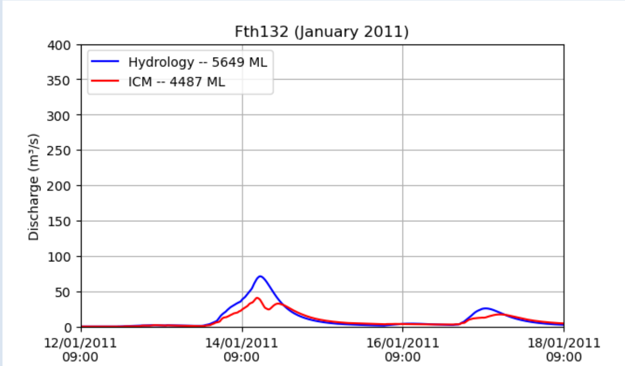

Buttons Creek u/s Bass Highway (January 2011)
Observed -- 595 ML
Hydrology -- 2047 ML
ICM -- 2016 ML
Discharge (m³/s)

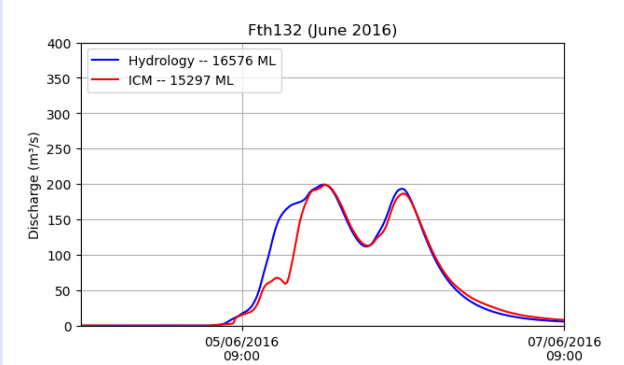

Buttons Creek u/s Bass Highway (June 2016)
Observed -- 286 ML
Hydrology -- 1907 ML
ICM -- 1873 ML
Discharge (m³/s)


Fth132

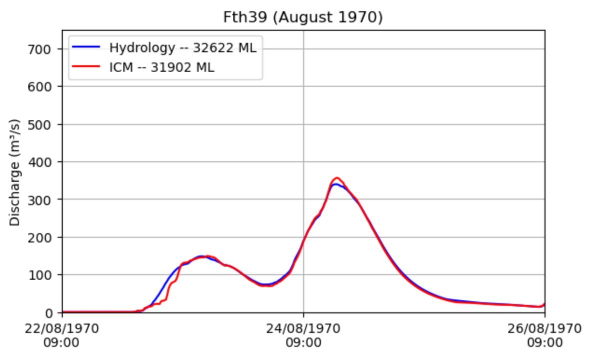

Fth132 (August 1970)
Hydrology -- 25059 ML
ICM -- 23506 ML
Discharge (m³/s)

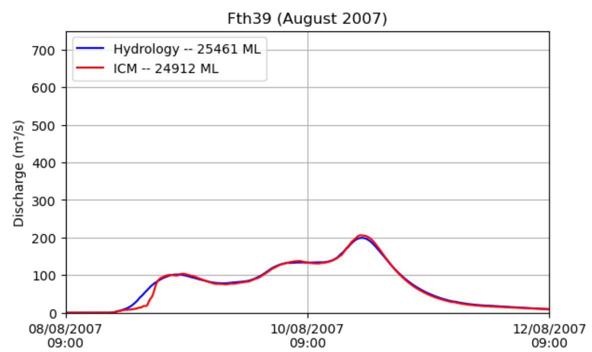

Fth132 (August 2007)
Hydrology -- 28243 ML
ICM -- 27085 ML
Discharge (m³/s)

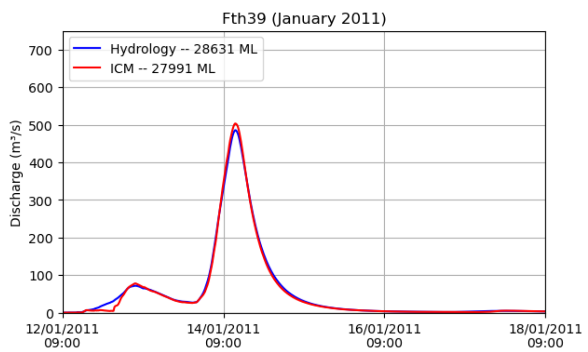

Fth132 (January 2011)
Hydrology -- 5649 ML
ICM -- 4487 ML
Discharge (m³/s)

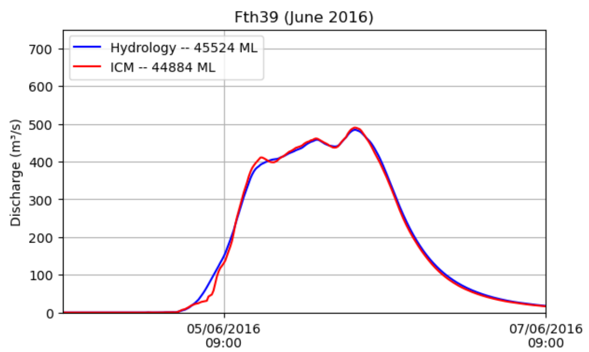

Fth132 (June 2016)
Hydrology -- 16576 ML
ICM -- 15297 ML
Discharge (m³/s)


Fth39


Fth39 (August 1970)
Hydrology -- 32622 ML
ICM -- 31902 ML
Discharge (m³/s)


Fth39 (August 2007)
Hydrology -- 25461 ML
ICM -- 24912 ML
Discharge (m³/s)


Fth39 (January 2011)
Hydrology -- 28631 ML
ICM -- 27991 ML
Discharge (m³/s)


Fth39 (June 2016)
Hydrology -- 45524 ML
ICM -- 44884 ML
Discharge (m³/s)

Appendix D

APPENDIX D. RATING CURVE COMPARISON

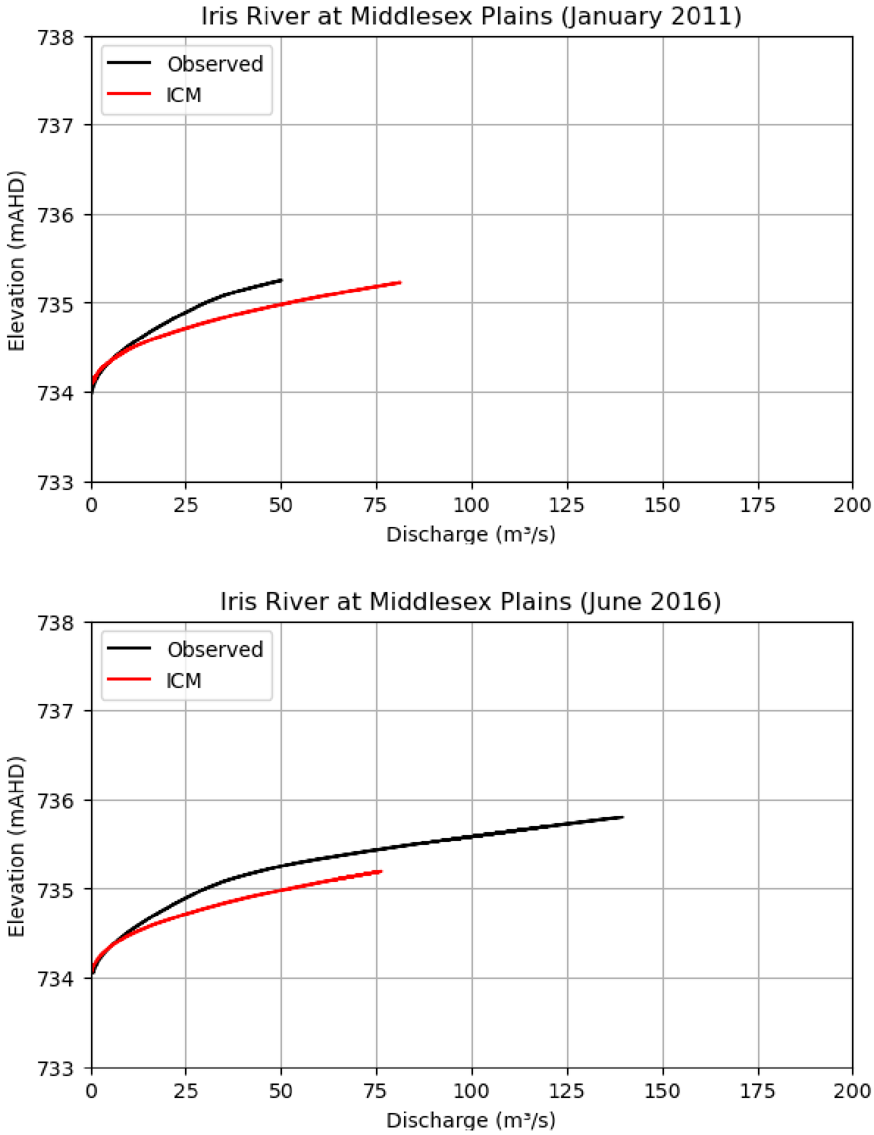


Figure D 1: Rating curve comparison at Iris River at Middlesex Plains

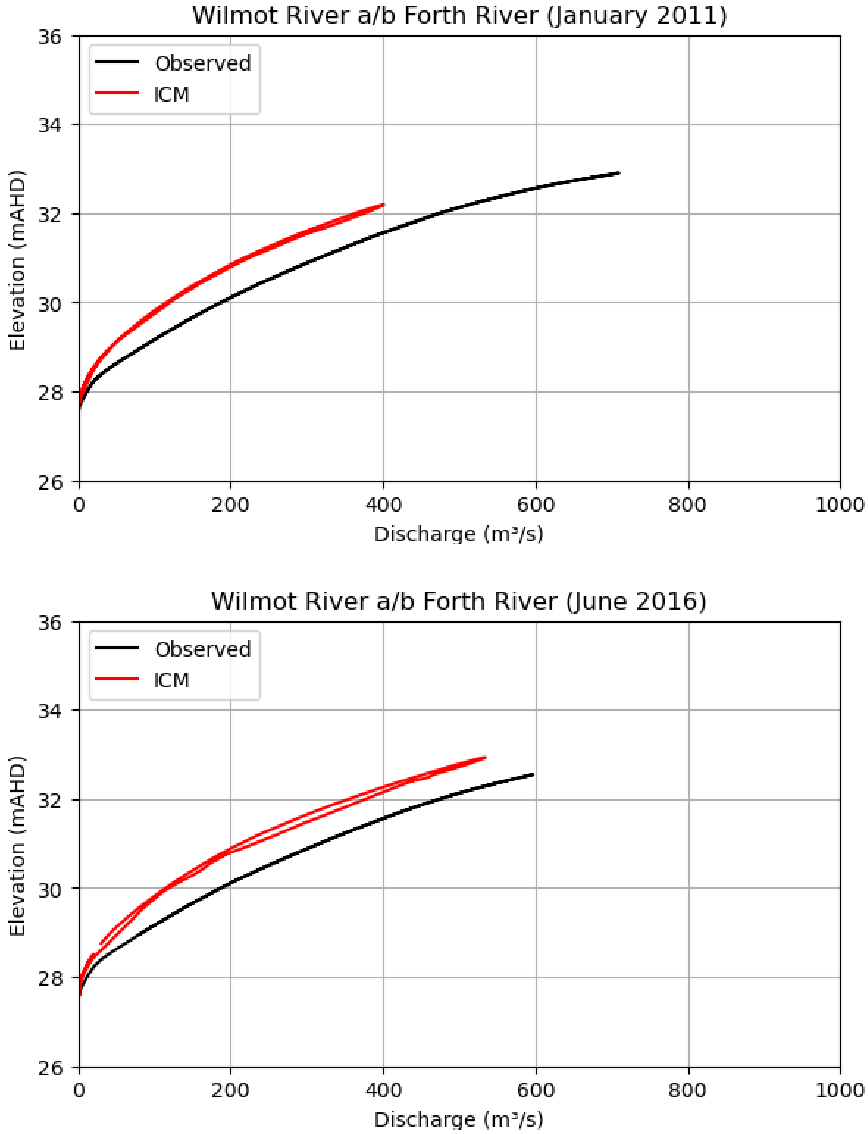


Figure D 2: Rating curve comparison at Wilmot River a/b Forth River

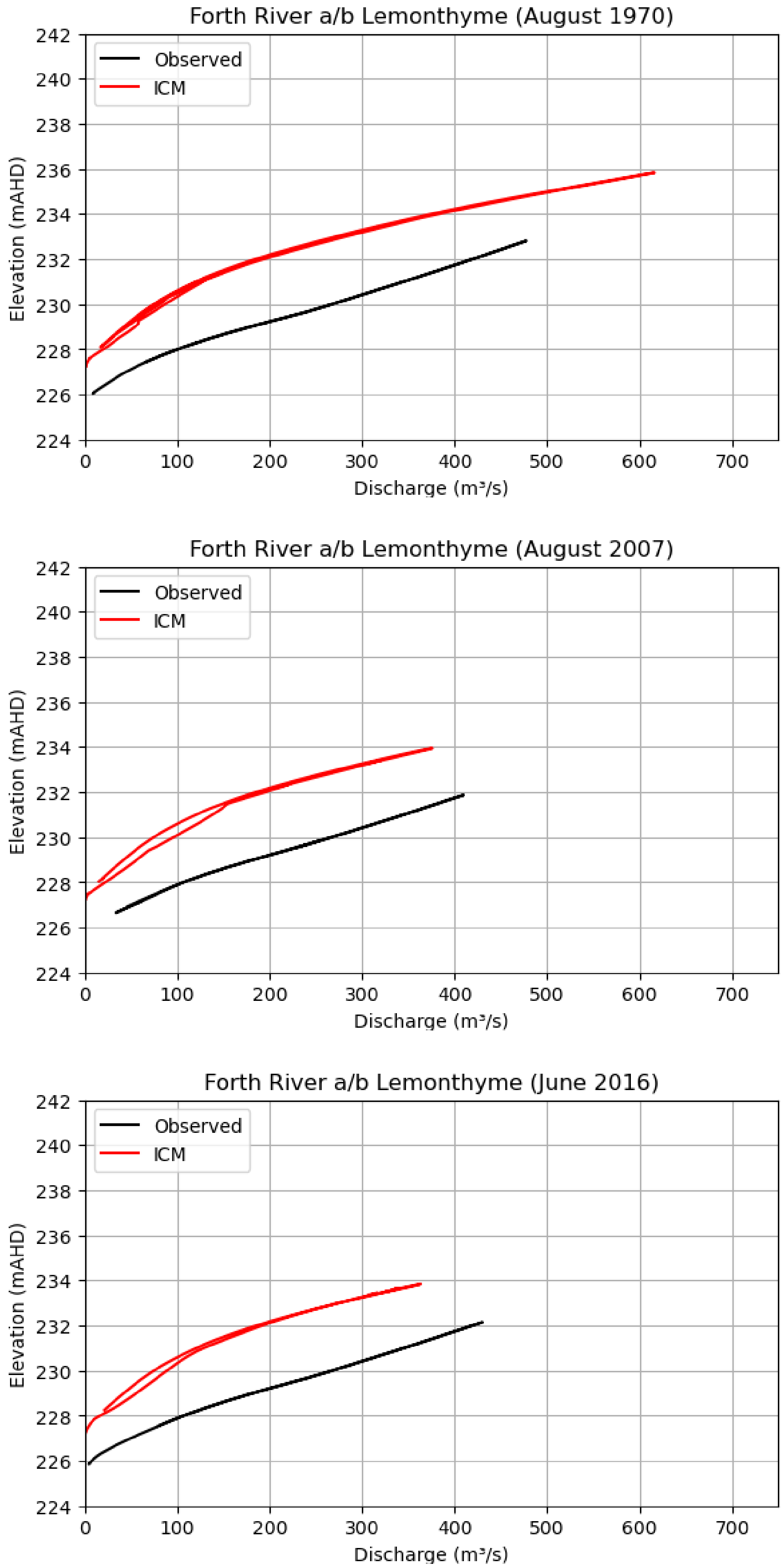
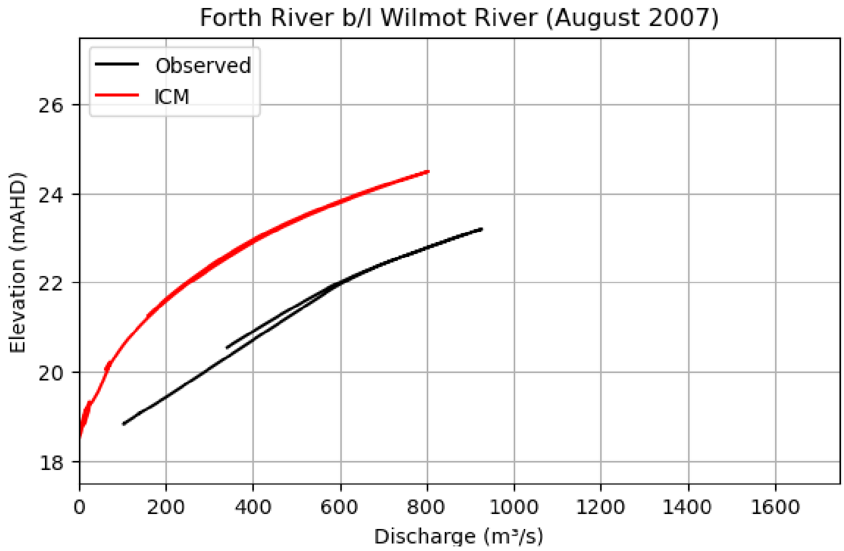


Figure D 3: Rating curve comparison at Forth River a/b Lemonthyme



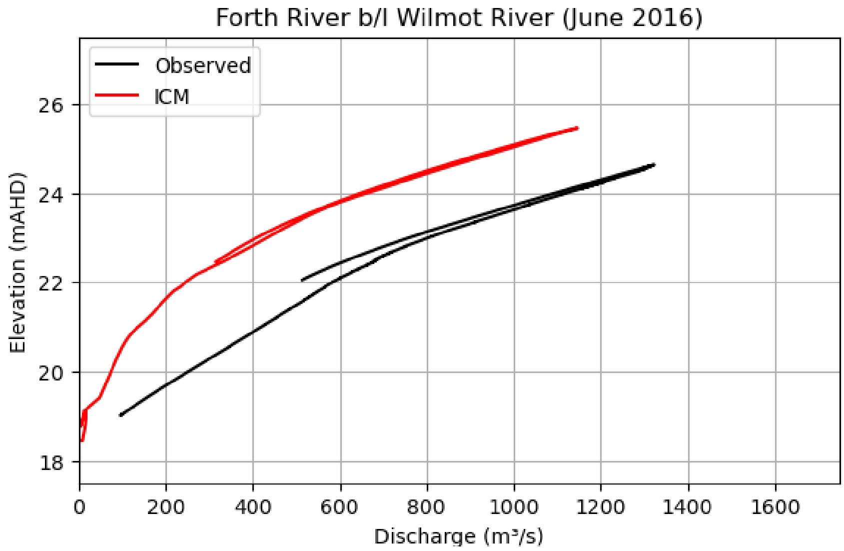


Figure D 4: Rating curve comparison at Forth River b/l Wilmot River

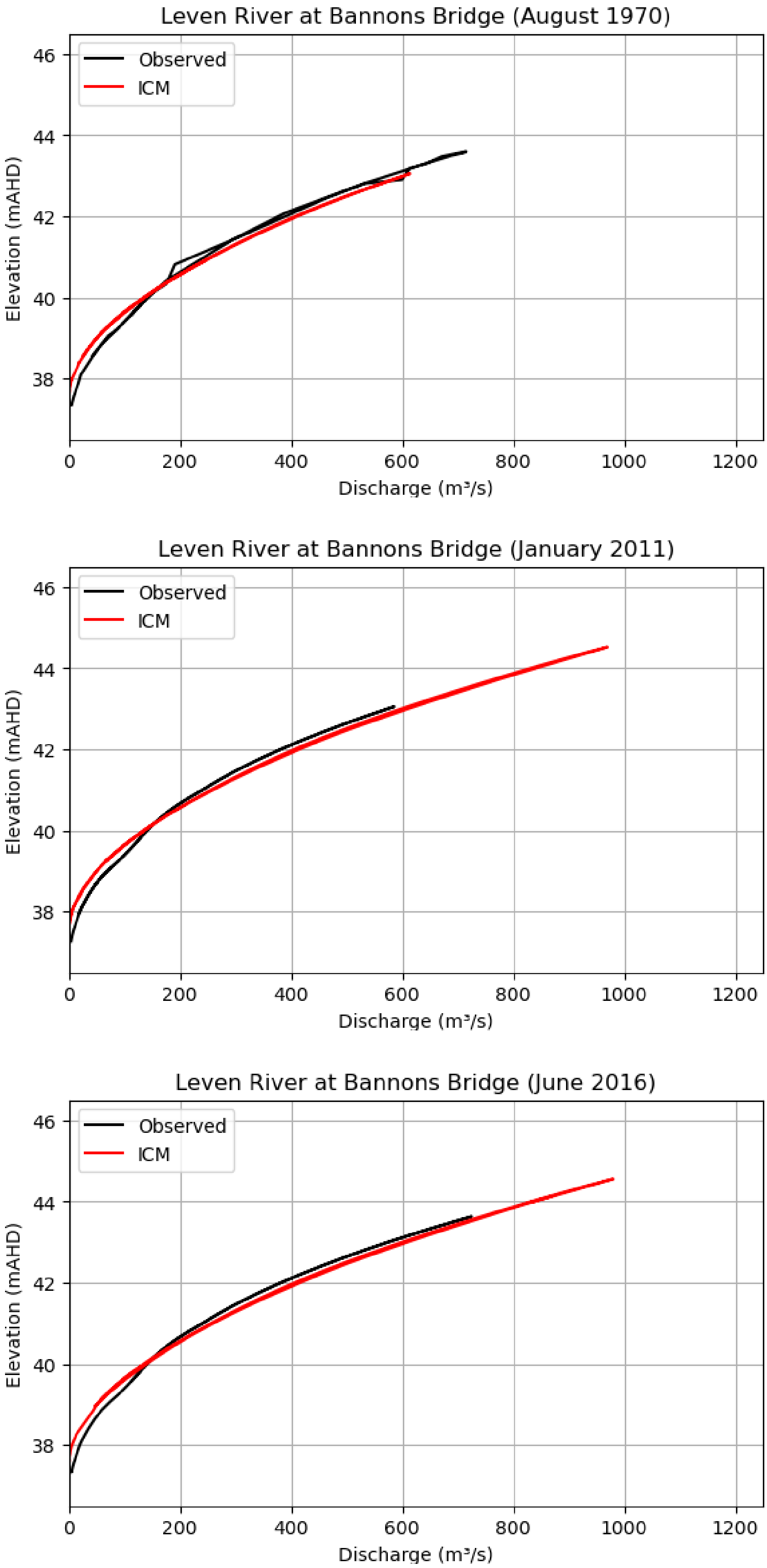


Figure D 5: Rating curve comparison at Levens River at Bannons Bridge

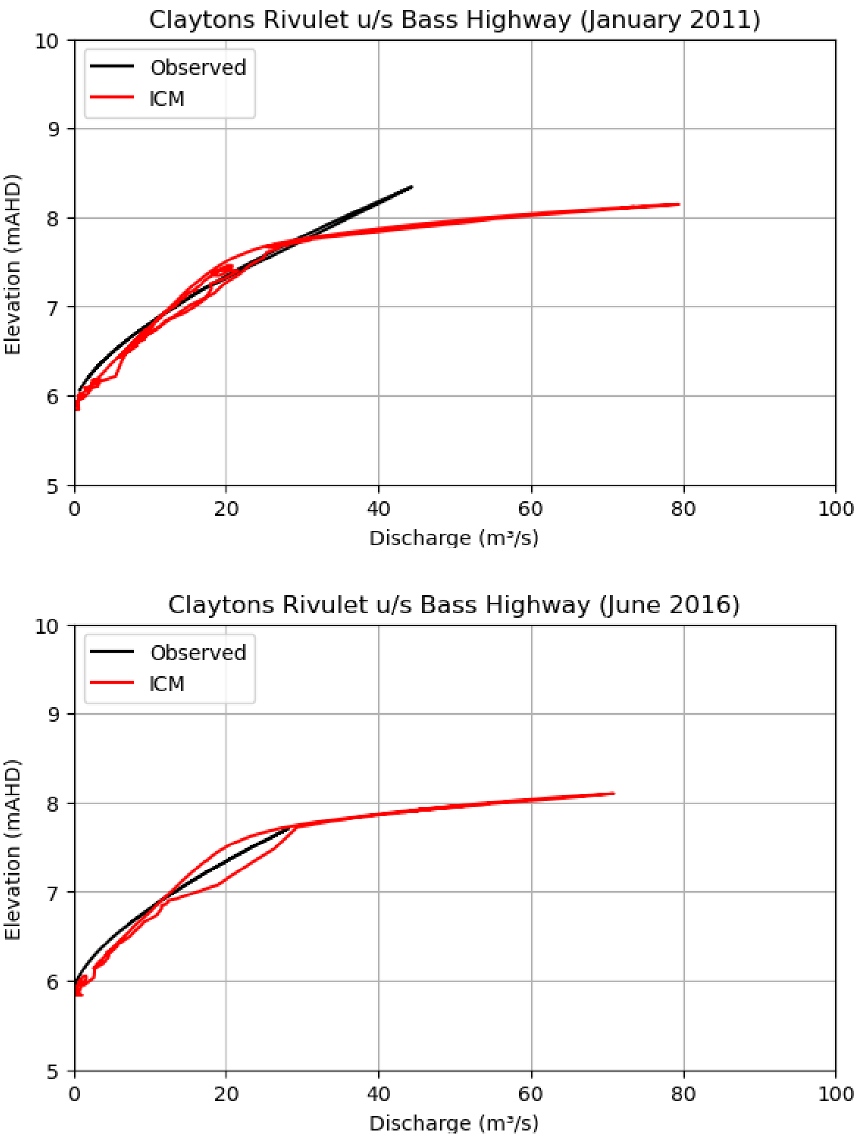


Figure D 6: Rating curve comparison at Claytons Rivulet Bass Highway

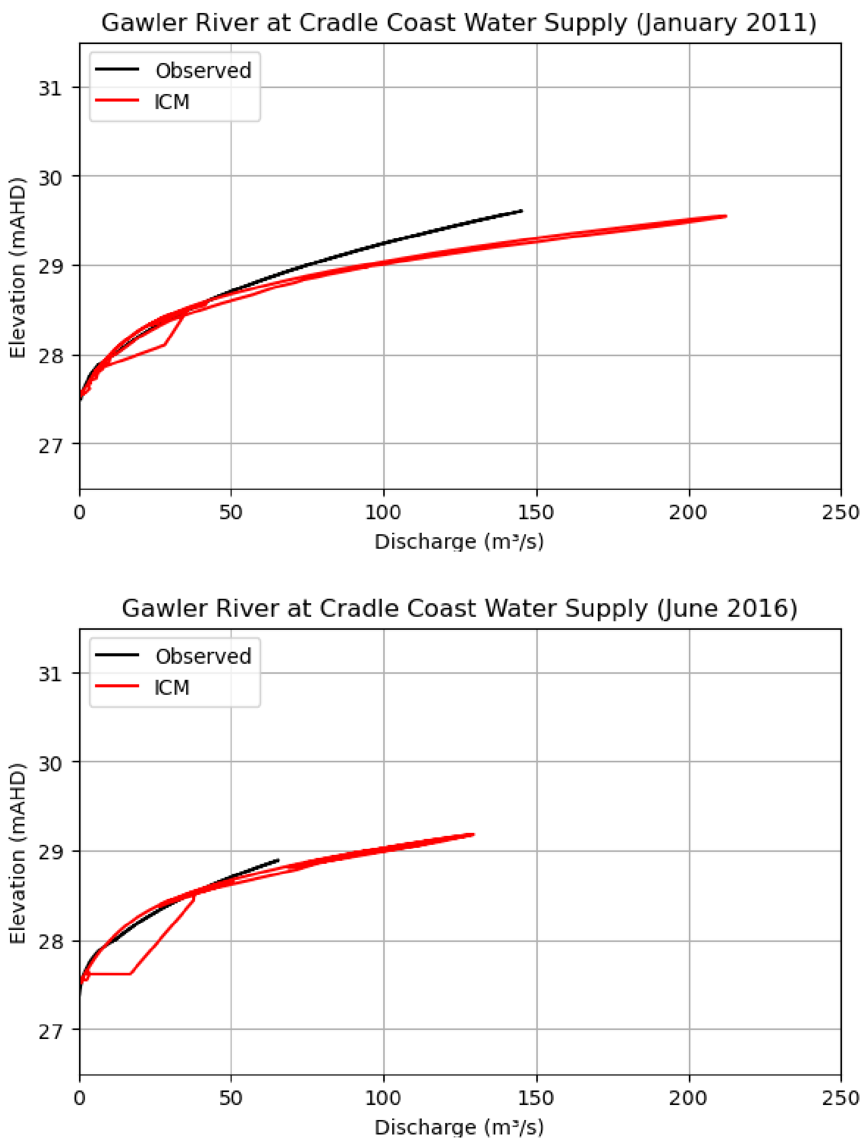


Figure D 7: Rating curve comparison at Gawler River at Cradle Coast Water Supply

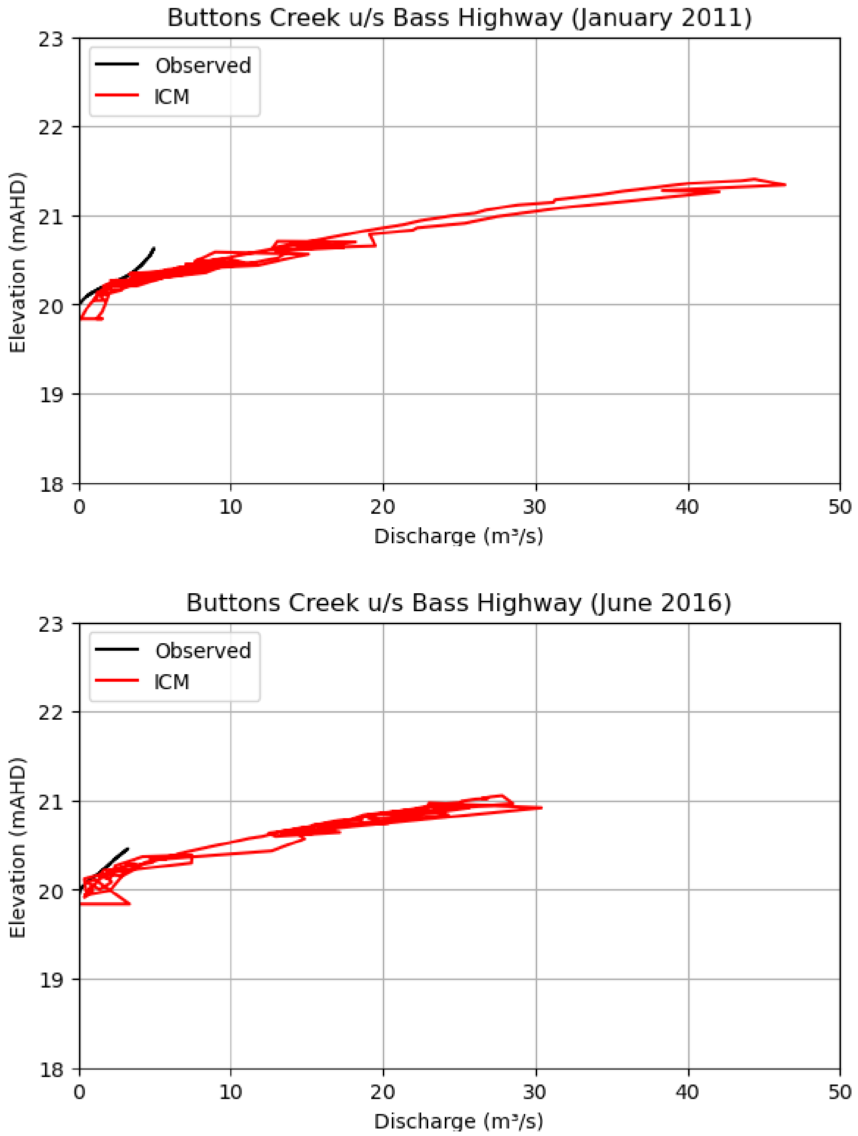


Figure D 8: Rating curve comparison at Buttons Creek u/s Bass Highway