STATE EMERGENCY SERVICE

TASMANIAN STRATEGIC FLOOD MAP
INGLIS RIVER CATCHMENT MODEL CALIBRATION

DRAFT

JUNE 2021

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Project Tasmanian Strategic Flood Map Inglis River Catchment Model Calibration	**Project Number** **120038**
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1	Updated report for review	Luke Roberts, SES	Sarah Blundy, Fiona Ling, Mark Smith	Daniel Wood	Mark Babister	MAY 21
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Cover image: Inglis River mouth at Wynyard - June 2016 flood.

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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
ALS	Airborne Laser Scanning
AMS	Annual Maximum Series
ARF	Areal Reduction Factor
ARR	Australian Rainfall and Runoff
AWAP	Australian Water Availability Project
AWS	Automatic Weather Station
Bureau	Bureau of Meteorology
C	Lag parameter in WBNM
CFEV	Conservation of Freshwater Ecosystem Values (DPIPWE)
CL	Continuing Loss
DEM	Digital Elevation Model
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
GIS	Geographic Information System
GEV	Generalised Extreme Value distribution
GPS	Global Positioning System
HAS	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
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 of the Inglis River study area. This study area is one of two validation catchments used to validate methods and data for the project.

2. STUDY AREA

The Inglis River is situated in the Northwest of Tasmania. The river originates in the Campbell Ranges and flows northwards before discharging into Bass Straight at Wynyard. The major tributary of the Inglis River is the Flowerdale River. The study area includes several smaller watercourses that discharge directly into Bass Straight. The Inglis-Flowerdale catchment has an area of 471 km^2. The main towns within the catchment are Wynyard and Boat Harbour. This catchment experienced severe flooding during the June 2016 flood event. The Inglis River catchment and the available gauge information are shown in Figure 1.

3. AVAILABLE DATA

3.1. Historic Flow Data and Level Data

There are three main flow gauges available in the Inglis study area (including neighbouring streams that are not direct tributaries of the Inglis), as shown in Table 1. These gauges are owned by DPIPWE, who supplied timeseries of flows, ratings and gaugings for each site. The gauge on the Inglis River itself (Inglis River above Flowerdale) was closed over 30 years ago and had no data available for any of the calibration events. Flowerdale River at Moorleah is a gauge on the major tributary of the Inglis River, approximately 12 km upstream of the confluence. It has a long record length and data available for all but the first three calibration events identified by BoM (i.e., all events after 1960). There is also a gauge on the Seabrook Creek at Bass Hwy, a small neighbouring catchment that has been included in the wider Inglis catchment for this project. This gauge also has a long period of record, starting in 1970, however there is a gap of about 11 years from mid-1996 to mid-2007.

Table 1: Flow gauges

Gauge attribute	Inglis River A/B Flowerdale	Flowerdale River at Moorleah	Seabrook Creek U/S Bass Hwy
Gauge number	14210-1	14215-1	14220-1
Gauge abbreviated name	NA	Moorleah	Seabrook
Start date	06/06/1967	21/03/1966	04/05/1977
End date	07/02/1989	19/03/2018	19/03/2018
Latitude	-41.003	-40.967	-41.011
Longitude	145.626	145.609	145.766
Rating quality	Poor	Good	Poor
Used for calibration	No	Yes	Partly
Used for FFA	No	Yes	No
Assumed local datum 0m in AHD		24.769	7.098
Highest Rated Level (m local datum)		1.0	~0.95m
Highest recorded date	10/10/1979	6/6/2016 (stage)	5/6/2016 (stage) 10/10/1979 (flow)
Highest recorded stage height (m local datum)	4.36	4.76	2.22
Highest recorded flow (m^3/s)	95.2	262.5	82.9

3.1.1. Calibration Event Data Availability

Significant flows were recorded in the Inglis study area for 3 of the 13 flood events selected by the Bureau as calibration events for this project (Table 2). The June 2016 and January 2011 events are the two largest events on record at the Moorleah gauge, both with an AEP rarer than 10%. The August 2007 event has an AEP of approximately 20%. There were other events larger than the 2007 event recorded at the gauge, however these were not included in the list of calibration events provided for this project.

Table 2: Summary of the largest events in the Inglis catchment, selected from the 13 calibration events supplied for the project

Event name	Used in calibration	Event peak flow (m^3/s) (location)
2007_Aug	Yes, but no useable data at Seabrook	94 (Flowerdale)
2011_Jan	Yes	201 (Flowerdale) 34 (Seabrook)
2016_Jun	Yes, at Flowerdale. Re-rated flow used for verification at Seabrook	256 (Flowerdale) 96 (Re-rated Seabrook)

3.1.2. Rating Curve Analysis

The highest gauged flows at both the Moorleah and Seabrook gauges were significantly below the level of the floods of interest; the highest stage levels each site has been gauged at are approximately 1 m above the local gauge datums. Peak levels in June 2016 were 4.75 m and 2.22 m for Moorleah and Seabrook respectively. While the extrapolation of the rating curve beyond gauged data to the levels of the calibration events is larger at Moorleah than Seabrook, initial review of other available data gave more confidence in the Moorleah rating than the Seabrook rating curve.

To provide an initial verification of the rating curves, the June 2016 event was run through a draft version of the hydrodynamic model with no losses. No refinement had been undertaken to the channel at this point so it was anticipated there would be a poor match in the lowest part of the rating curves, but that the results could assist in understanding the uncertainties in the higher portion of the rating curves. Details for each of the gauges are given in the sections below.

3.1.2.1. Flowerdale at Moorleah Gauge Review

There were inconsistencies in the gauge zero values provided at the Moorleah gauge for this project. Therefore, uncertainties around the gauge zero at Moorleah required a review of the levels in the DEM at the gauge against the Cease to Flow (CTF) level in the dataset provided. The review indicated that a CTF level of 0.55 m local datum matched well with a surface level of 25.3 mAHD on the weir in the DTM. This level is reasonably consistent with one of the gauge zero values provided (i.e., 0.55 m above a gauge zero of 24.769 mAHD would be 25.319 m AHD) and thus this gauge zero of 24.769 m AHD has been adopted as the gauge datum.

The ICM discharge-level relationship and the DPIPWE rating curve showed very similar behaviour in the high flow portion of the rating curve (Diagram 1). The DPIPWE rating curve shows an increase of 107 m^3/s between stage heights of 3 m and 4 m while the ICM relationship shows a change of 93 m^3/s between these stage heights. This shows reasonable consistency in the relationships in the range of levels and flows of interest. Therefore, the DPIPWE's Moorleah rating curve was used unaltered.

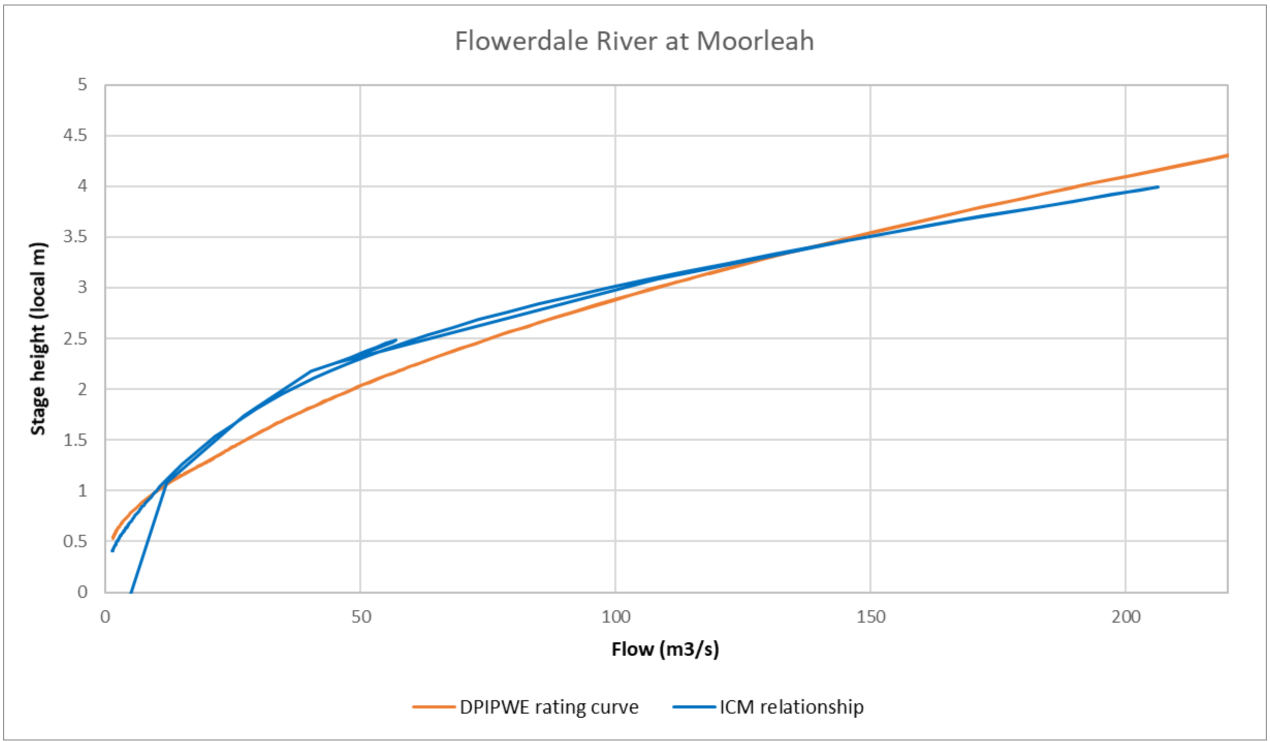

Diagram 1 DPIPWE rating curve and the draft ICM relationship at Flowerdale River at Moorleah gauge site

3.1.2.2. Seabrook Gauge Review

At the Seabrook gauge, a review of the surrounding terrain identified that there are likely to be alternate flow paths at higher flows (Diagram 2). This includes a breakout from the channel upstream of the gauge that results in water bypassing the gauge at high flows. There was also a large shift in the rating curve after the 10-year data gap. The gaugings over the two periods were very similar for stage heights below 0.6 m suggesting that the gauge was not moved and that there was no change in the local control, but stage heights of 2 m which had previously been rated to flows greater than 80 m^3/s have since been rated to flows of about 40 m^3/s. This led to further investigation being carried out on the rating at the Seabrook gauge.

A review of the location of the Seabrook gauge identified that there is a breakout to the west of the gauge location which is not considered within the DPIPWE rating curve. Diagram 2 shows the location of this breakout. To consider this in the hydrologic calibration, an initial run of the ICM model was undertaken to investigate differences in the rating curves. This showed very large deviations between the ICM and DPIPWE relationships (Diagram 3). The site has been gauged at approximately 0.95 m (~8 mAHD) and only once above 0.3 m (~7.4 m), so large uncertainties in the DPIPWE rating curve at higher levels are expected. Therefore, the ICM relationship was used to refine the rating curve above 9.0 mAHD to better approximate the contribution of flow through the bypass.

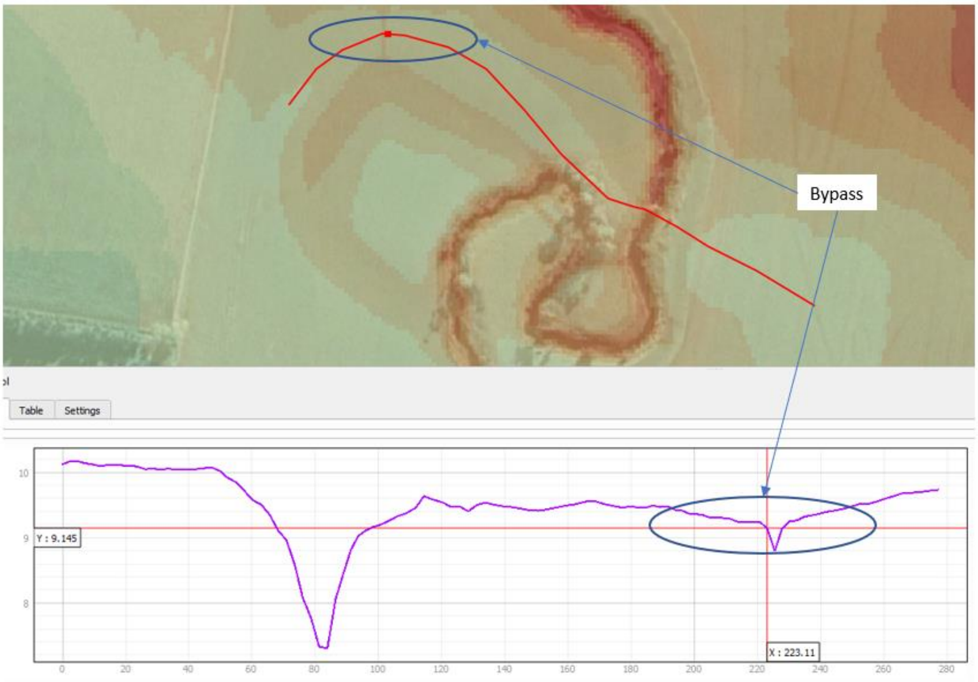

Diagram 2 – Seabrook Creek Gauge Bypass

The rating curve that has been used in the calibration of the hydrologic model for Seabrook Creek at Bass Highway is presented in Diagram 3. Note that in the August 2007 event the Seabrook gauge recordings cut out near the beginning of the event, so it could not be used for model calibration or verification. The combined rating curve results in a change in peak flow from ~40m^3/s to ~95 m^3/s (Diagram 4) in the June 2016 calibration event.

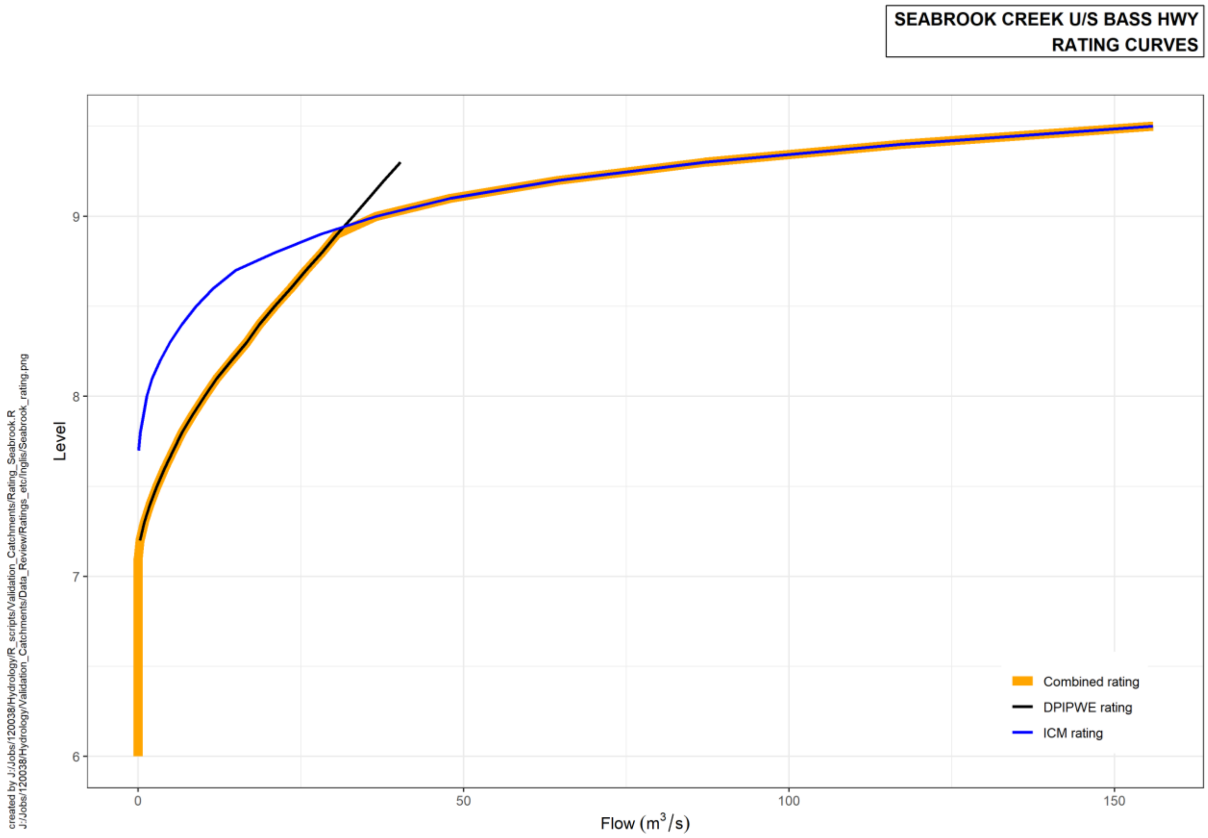

Diagram 3 – Seabrook Rating Curve – Combined rating used in calibration.

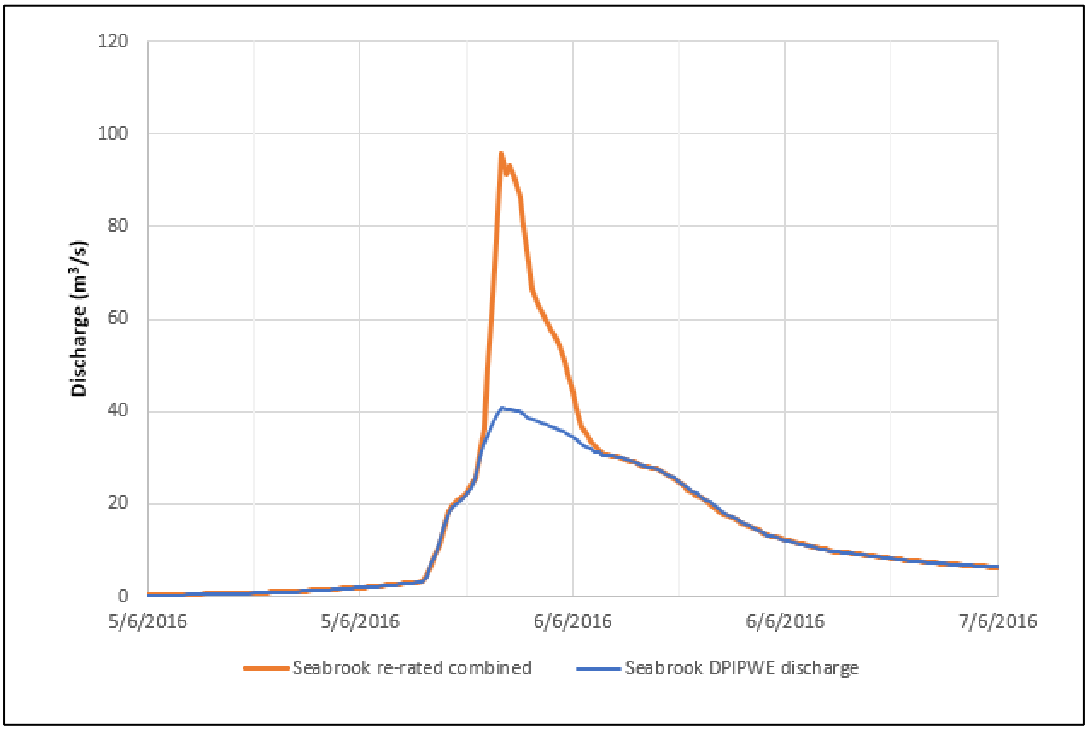

Diagram 4 June 2016 flow at Seabrook Creek gauge with the original DPIPWE rating (blue) and re-rated using revised combined rating (orange).

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 Inglis catchment (see Data Review Report WMAwater (2020a) for details on calibration events).

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

There are two sub-daily rain gauges within the Inglis study area, however only one gauge was available for each event as Wynyard Airport had no data for August 2007 and Preolenna (in the southwest of the catchment) only had data for August 2007. Some gauges outside the study area (Burnie, Luncheon Hill and Waratah) influenced rainfall in sub-catchments along the boundaries of the catchment. The gauges in and around the Inglis study area, are shown in Figure 1.

Table 3 – Available Rainfall Information

	August 2007	January 2011	June 2016
Sub-daily stations available within the catchment	Preolenna	Wynyard Airport	Wynyard Airport
Number of sub-daily surrounding gauges with some influence	3	1	1
Rainfall Totals	100-150mm	155-270mm	116-300mm
Duration of Event	60 hours	70 hours	40 hours
Daily gauges within catchment *	4	3	3

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

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

1. Daily rainfall data from all gauges within Tasmania was extracted for each of the seven calibration events from 2007 – 2018
2. Rudimentary QAQC and infilling of daily record was undertaken

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

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

3.2.1. Rainfall Data Quality – 2011 Rainfall Event.

A review of the rainfall that was recorded for the January 2011 event identified that there was a large variance in the rainfall totals across the region. This is highlighted inland of the Inglis River catchment, where two rainfall gauges located less than 30 km apart (parts of this catchment are 30 km from the nearest gauges) recorded rainfall totals of 281 mm (at Iris River) and 41 mm (at Que River). While these stations are some distance from the study area, it gives a good indication that rainfall gradients were steep in this event and that the gauge network may not have adequately measured the rainfall for the event. Given the high variability present in the rainfall station rainfall totals and rainfall distribution, it is likely that the rainfall representation on a catchment basis will be limited.

There is a clear mismatch in timing between the observed flows and the nearby available pluviograph data for this event. Almost 70% of the rainfall had fallen on the catchment by early morning on the 14/01/2011 when the low point between the two flow peaks at Flowerdale occurred, during the lull in the rainfall. However, the first peak of the hydrograph is less than a quarter of the volume of event overall. While some additional runoff is expected off a wet catchment for the second peak, this would require less than a third of the rainfall to produce three times the flow volume for the second peak. Therefore, with the available sub-daily rainfall data it is difficult to get a good fit for this event. A calibration was still undertaken for this event, but discrepancies between modelled and observed flows are likely due to the unrepresentative rainfall data and should not reflect overall model uncertainty in this catchment.

3.3. Flood Levels and Extents

Flood survey levels and extents within Inglis 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 provided to enable verification of modelled flood levels and extents for other rainfall events for the study area.

3.4. Design Event Data

The design inputs (Intensity Frequency Duration (IFD) depths, losses, pre-burst rainfalls, Areal Reduction Factors and temporal patterns) were available through the ARR Data Hub (Babister et al, 2016) or the Bureau of Meteorology website (Bureau of Meteorology, 2019).

3.4.1. Design Rainfall Depths and Spatial Pattern

Intensity Frequency Duration (IFD) information was sourced from the Bureau of Meteorology website (Bureau of Meteorology, 2019). IFD information was sourced for each individual sub-catchment to give a spatial pattern across the study area. Examples of sub-catchment rainfalls are shown in Figure A1 to Figure A 3.

3.4.2. Temporal Patterns

ARR 2016 Book 2 Chapter 5 (Ball et. al. 2019) recommends the use of areal temporal patterns for catchments greater than 75 km^2. Therefore, for flood frequency analysis at the Moorleah gauge the areal temporal patterns relevant to this location were downloaded from the ARR Data Hub. An example of the temporal patterns downloaded from the Data Hub is shown in Figure A 4.

For selection of the final design runs applicable to the entire study area, areal and point temporal patterns were downloaded from the ARR Data Hub. When assessing the reference critical flow for each sub-catchment (as described in the Hydrology Methods Report), point temporal patterns were used for sub-catchments with an upstream area of less than 75 km^2 or used to assess shorter storms if the critical duration on a larger catchment was identified as 12 hours (the shortest duration available with areal temporal patterns).

3.4.3. Pre-burst

Pre-burst depths were taken from the ARR Data Hub as a ratio of the IFD depths. The median pre-burst depth ratios were used for sensitivity testing of the catchment to pre-burst. This showed that adding pre-burst rainfalls had an insignificant effect, as the calibrated storm initial losses were of similar or larger magnitude, so pre-burst rainfalls were not used for design modelling. Including pre-burst depths with a pre-burst temporal pattern had less than a 0.5% impact on peak flows to the Moorleah gauge for the 2%, 1% and 1 in 200 AEP flows.

3.4.4. Losses

Initial values for sub-catchment initial loss (IL) and continuing loss (CL) were derived from the unpublished Hydrologic Soil Groups of Tasmania data that was provided for use in this project (DPIPWE 2019).

3.4.5. Baseflow

Baseflow was calculated for each calibration event and was found to be less than 5% of the event peaks. In line with ARR 2016 Book 5 Chapter 4 (Ball et. al. 2019) baseflows less than 5% are considered a small component compared to runoff, and a simplified approach to baseflow calculations was therefore undertaken. Hydrodynamic modelling of the calibration events showed that large flood events in this study area were peak rather than volume driven. Baseflows will be of a component of the hydrograph for the AEPs of interest (2%, 1% and 0.5%) and therefore baseflow was not included in the design events.

3.4.6. Climate Change

3.4.6.1. Rainfall Factors

Climate change factors for the study area were downloaded from the ARR Data Hub. ARR recommends the use of the RCP4.5 and RCP8.5 values, however the Tasmanian Interim Planning Scheme recommends the use of RCP8.5 and this has been adopted for this project. Using RCP8.5 results for the year 2090 gives a rainfall scaling factor of 16.3% increase to IFDs.

3.4.6.2. Boundary Conditions

Sea level rise was included in the climate change scenario and was applied at the downstream boundary of the hydrodynamic model. The rise in water level was taken from the Tasmanian Local Council Sea Level Rise Planning Allowances, which uses sea level rise projections based on RCP 8.5 for 2100. This gave a rise in sea level of 0.83 m for the Wynyard-Waratah Council area.

The levels from this document were deemed most appropriate to be consistent with best practise planning around Tasmanian Councils.

4. HYDROLOGIC MODEL METHODOLOGY

The hydrological model methodology has been outlined in the Draft Hydrology Methods Report (WMAwater, 2020b) and the Addendum to the Hydrology Methods Report (WMAwater 2021). 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 study area. For the Inglis study area, there were no departures from the standard methods for hydrologic modelling.

The following is an overview of the hydrologic modelling method.

- Data preparation
    - Derivation of rainfall surfaces for each calibration event, using Inverse Distance Weighting (IDW) (WMAwater, 2021)
    - Extraction of flow data for identified calibration events at each flow site
    - Fitting FFA to suitable flow records
    - Extraction of design data – IFDs, temporal patterns, pre-burst rainfalls from ARR DataHub (automated in the modelling process)
- Hydrologic modelling
    - Identification of flow gauge locations
    - Identification of dam and diversion locations
    - Sub-catchment delineation
    - Include dam storage and spillway ratings where required
    - Event calibration for PERN parameter and event losses, using automated WMAwater RAFTS modelling tool, IDW rainfall surfaces and available flow data. Output event sub-catchment rainfalls, routing parameters and event losses for input to hydraulic model
    - Calibration of design losses to FFA using automated WMAwater RAFTS model
    - Run design events in WMAwater RAFTS modelling tool, with design data, calibrated routing parameters and design losses. Outputs design sub-catchment rainfalls for input to hydraulic model.

5. HYDRODYNAMIC MODEL TERRAIN SETUP AND MESHING

5.1. Base DEM Management

The base dataset used for raw data was the SES state-wide 10 m DEM (including bathymetry) merged with available 2 m DEM subsets. Given that there was greater than 90% coverage of higher resolution (2 m) DEMs over the Inglis study area, the final DEM was merged to a 2 m grid size. This was 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 and merged into the clipped DEM. The DEM was successfully imported to ICM via the grid import interface (Diagram 5).

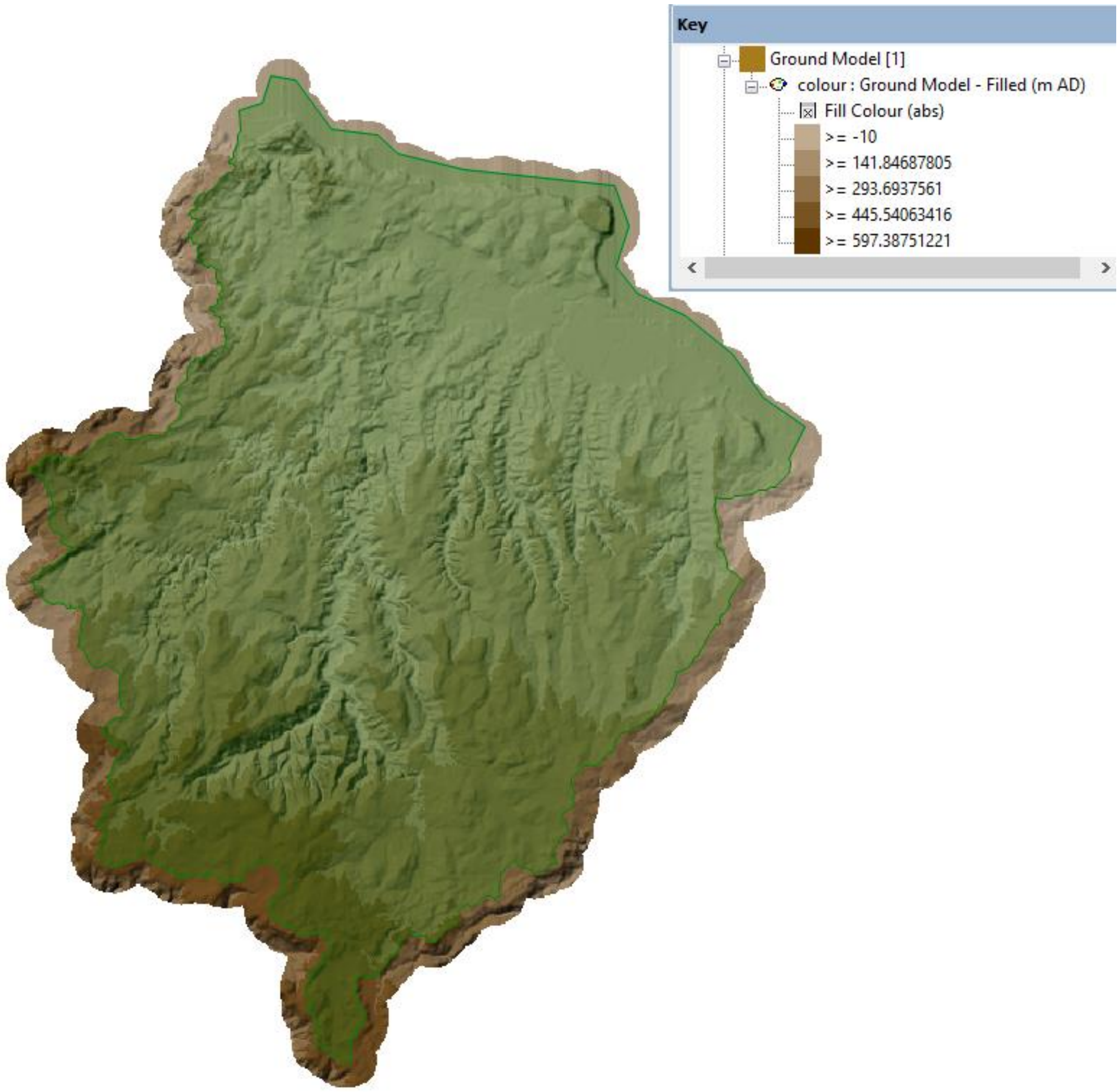

Diagram 5: Inglis River study area imported to ICM

5.2. Roughness Grid

The base information for the roughness grid was the roughness raster provided by SES for this project. The whole of state dataset was converted to a set of polygons for each land use zone in GIS, and the dataset was cleaned to ensure that the geometry was valid. This data was then exported as a csv file to link land use to friction values.

It is noted that at this stage the roughness values for streams vary greatly with sections of Manning's n of 0.1 crossing streams in many locations. This issue is an artefact of the simplification of the roughness layer when it is converted into triangles. Where the issue was severe, a 10 m buffered zone of single roughness of 0.035 for all upper streams was utilised. 0.035 was selected as in the upper reaches the computation of levels in triangles also results in artificial attenuation of flow and thus a slightly lower value than the norm was utilised.

This change will be revised on a case-by-case basis in future assessments as it is managing a very specific issue. The values derived are shown in the 'Hydrodynamic Modelling Report'. The roughness layer in ICM is shown in Diagram 6.

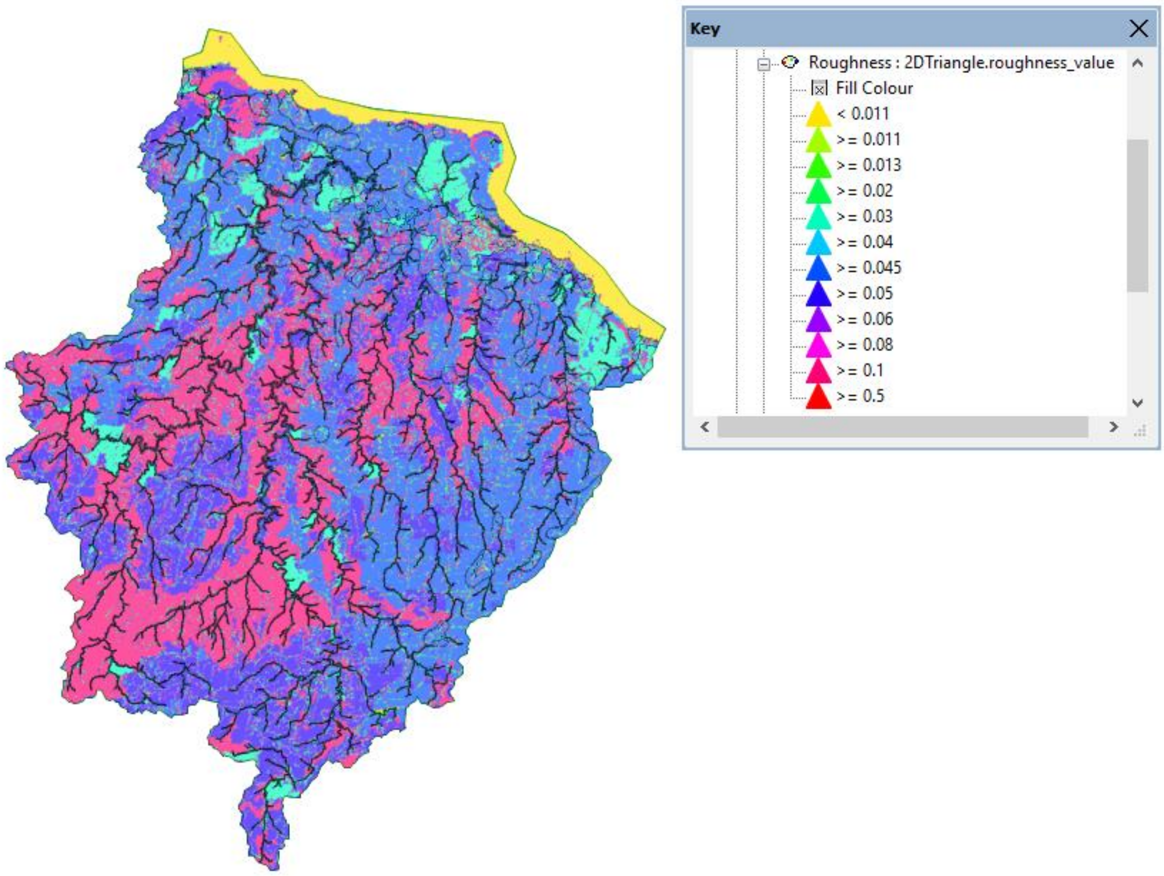

Diagram 6: ICM roughness layer for Inglis River study area

5.3. Meshing

Meshing in ICM was undertaken using zones, with the following rules:

- Base 2d Zone – regional extent mesh size set to a maximum of 2500 m^2 with a minimum of 400 m^2
- Stream zone – set as an independent area with a maximum mesh size of 400 m^2 and a minimum of 100 m^2
- Human Settlement Area – set as an independent mesh zone with a maximum area of 100 m^2 and a minimum of 25 m^2
- Upper stream reaches – streamlines of strahlar order 2-5 were buffered by 10 m either side of the centre line with strahlar order 6-8 buffered by 20 m either side of the centre line and incorporated into the hydrodynamic model as a mesh zone. The mesh zones had a maximum area of 150 m^2. This process was to ensure that the meshing process did not result in artificial blocking of the flow paths along main stream lines.

The resulting mesh zones for the Inglis study area are shown in Diagram 7.

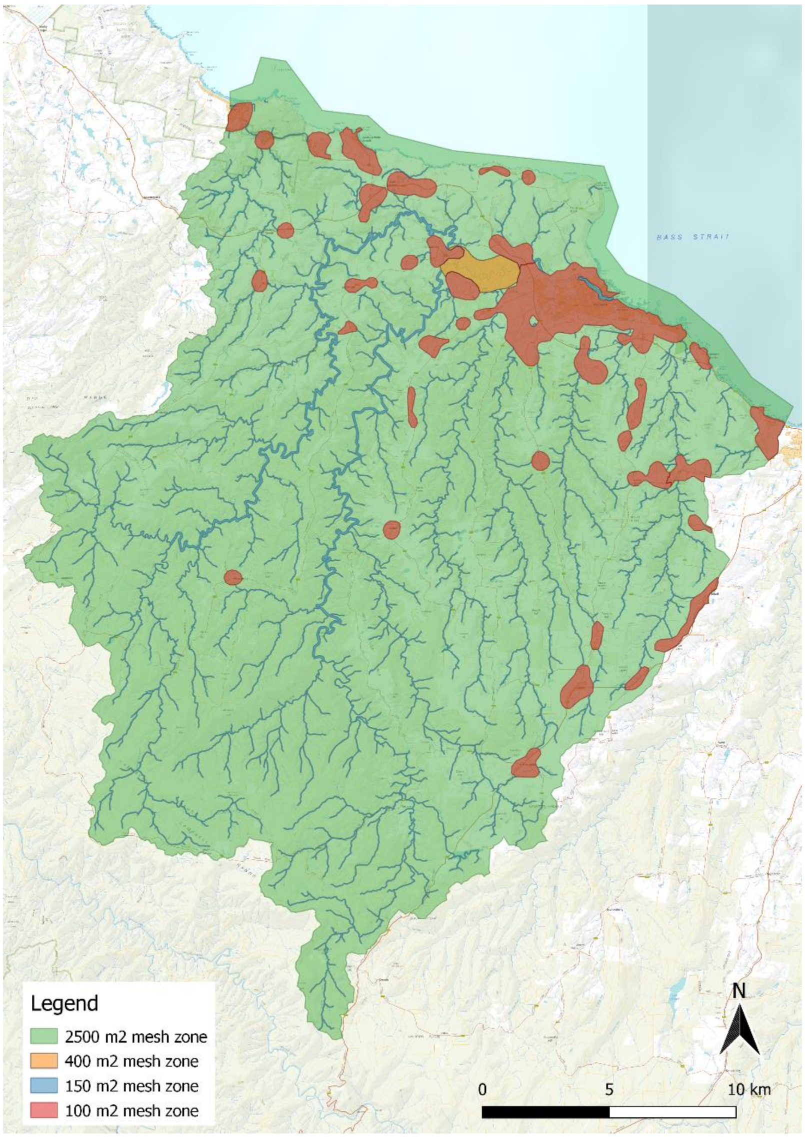

Diagram 7: Mesh Zones. Human Settlement Areas shown in brown.

5.4. Structures

Bridges are represented within the ICM model as linear 2D bridge structures, using the SES state-wide bridge database for location and reach of associated structures.

For the Inglis River study area a total of 16 bridges longer than 15 m were identified and imported into the validation model; further discussion on this process is provided in the Hydrodynamic Modelling Methods Report.

A major culvert was identified under the Burnie Airport as a significant 1D structure to be included in the model. It was identified and included as it posed as a major obstruction to creek flow that resulted in a diversion of flows through human settlement areas. Unfortunately, no data exists as to the dimensions of the existing culvert, so assumptions were made on the size, length and grade of the culvert based on available aerial and DEM data. The culvert was assumed to be of rectangular shape approximately 8 metres wide by 2 metres high. Further site visits to obtain the exact size should be undertaken in any future detailed studies.

5.5. Downstream Boundaries

Downstream boundaries were applied at the base of the model to provide interaction with the tidal zone. The Bureau provided synthetic tide data was used to set a varying tide for historic events. While the Nation Tidal Centre (NTC) provided Highest Astronomical Tide (HAT) values at 5 km^2 cells gave a static design tide level.

Diagram 8 shows the synthetic tidal data extracted from the Bureau mesh layer at Freestone Cove, Wynyard for July 2016 storm event. In the modelled calibration events, varying tidal data was included as the tidal boundary condition in ICM at 10 min time intervals. It is noted that the Burnie tide gauge is in close proximity to the subject site. As no calibration data was available within the tidal influence zone for this study to further inform tidal levels, and in general synthetic tide information is to be utilised in the state-wide study, this information has not been incorporated into the model.

Climate Change scenario uses the NTC HAT tide level, representing the 8.5RCP climate change increase for each storm frequency on the same 5 km^2 grid.

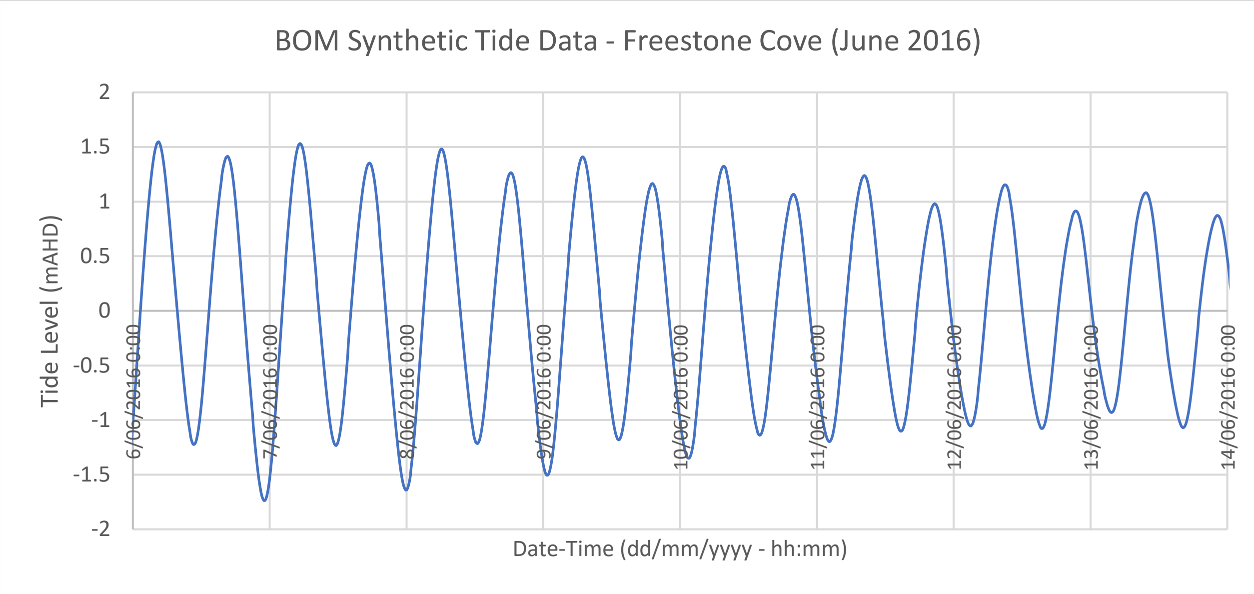

Diagram 8: Example of synthetic tide data

5.6. Flow Application for Hydrodynamic Modelling

Two approaches were used for application of flow in ICM:

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

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, focussing on the major tributary flooding while also ensuring the local areas in 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 direct rainfall modelling, a synthetic, duration independent storm event is used to assess the areas for a range of storm durations and temporal shapes in a singular rainfall event.

For traditional RAFTS modelling, the rainfall information is derived from rainfall files created by the hydrologic model (in the scenario of a calibration event). For design event modelling rainfall and temporal pattern information derived from ARR datahub has been utilised to establish design rainfall and temporal patterns within the ICM interface.

5.7. Direct Rainfall

A requirement of the brief is to assess flow paths over the entirety of the study area. A lumped inflow approach applying flow at the downstream end of each sub-catchment captures the majority of flow paths, however it is not capable of assessing flow paths in headwater catchments. For these upper areas of catchments, an alternative approach was used where direct rainfall was applied. This model enabled rainfall excess to be applied directly to all active mesh elements within the hydrodynamic model, thus enabling flow path representation of the overland flow paths present in the zone.

To use direct rainfall, the model was setup to enable rainfall to be applied to all mesh elements. The sub-catchment layer was used to spatially vary the rainfall in the model, with a different rainfall temporal pattern and depth able to be applied for each sub-catchment. The files were input automatically with a flag linking the rainfall to the spatial zone in the model. The intent of the direct rainfall component is to model only the uppermost regions of catchments with a higher resolution.

To assess these upper areas of catchments, an alternating block storm approach, rather than an ensemble storm approach was used, for the direct rainfall zones. The use of the alternating block enables the assessment of a range of durations to be undertaken within a single temporal pattern. This approach provides a reasonable estimation of peak flow (and thus level and hazard) for a range of storms within the area of interest, but is not capable of producing realistic hydrographs. Whilst this method has the potential to overestimate flows, this was not considered to be an issue for the modelling, as the direct rainfall is only used for mapping purposes and not as input to downstream sub-catchments. A detailed description of the alternating block temporal pattern is included in the Hydrodynamic methods report (WMAwater 2020a).

5.7.1. Traditional RAFTS Sub-catchment Routing

For traditional RAFTS sub-catchment routing, the RAFTS model within ICM is used to calculate the hydrologic routing in each sub-catchment. Rainfalls, model information and model parameters developed through in the RAFTS model in the WMAwater framework, were input into ICM through the open data input tool.
The information input to ICM includes:

- Sub-catchment name
- Slope
- PERN
- C
- 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 RAFTS sub-catchment model setup in ICM for the Inglis River study area is shown in Diagram 9.

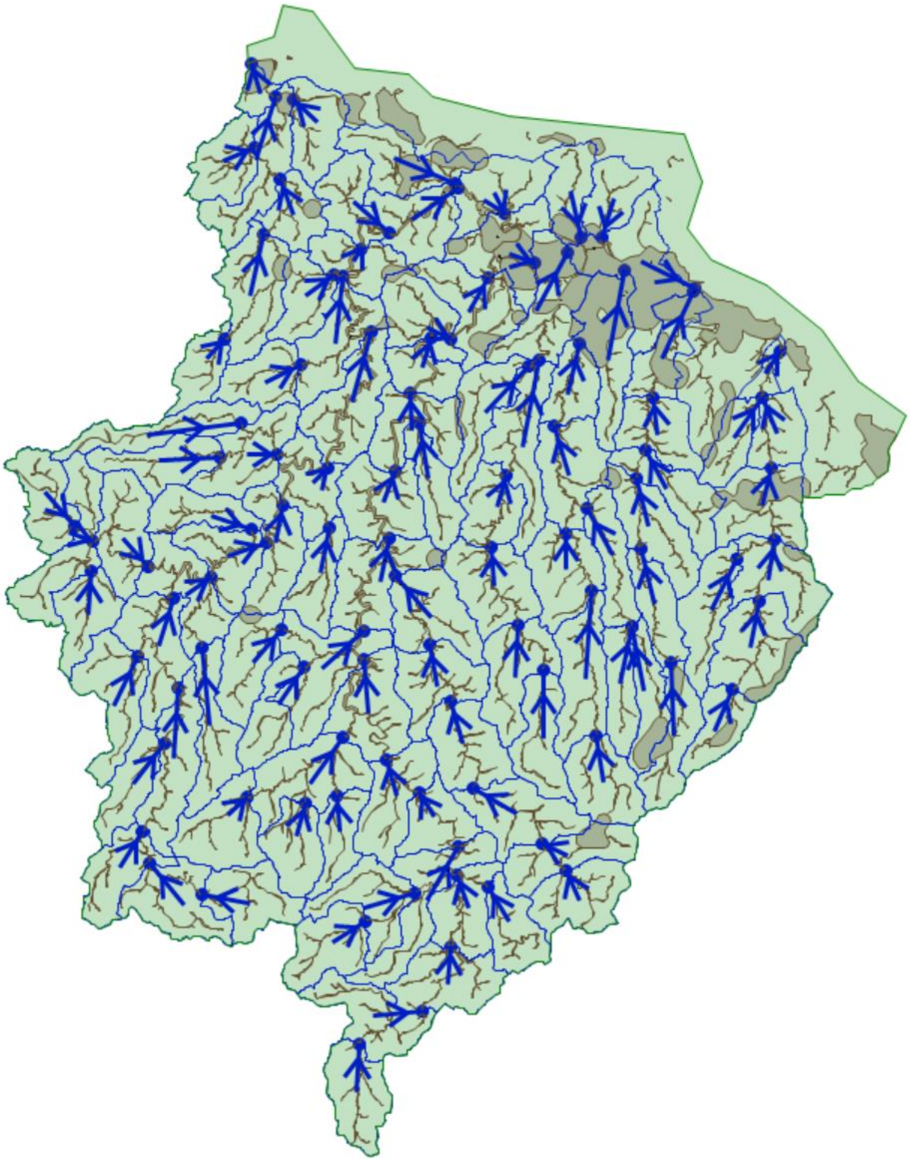

Diagram 9: ICM RAFTS traditional sub-catchment model setup for the Inglis River study area.

6. LIMITATIONS

One of the aims of the Tasmanian Strategic Flood Mapping project is to develop state-wide Strategic Flood Maps to support flood risk assessment and post event analysis. This is a regional flood mapping study and the methodology has been developed to provide mapping at a state-wide scale, as distinct from undertaking detailed flood studies over particular areas. The SES and local government can use the regional mapping to identify areas where further detailed flood studies would be beneficial. Limitations and assumptions were required in order to produce state-wide strategic flood maps within a reasonable timeframe and budget. The following are some of the limitations and assumptions in the data and the methodology.

- The scope of the project, as defined by SES, included thirteen calibration events. These events were selected by Bureau of Meteorology as significant events over Tasmania. Investigation of flow data at gauge sites has shown that, in many catchments, there are more significant flood events than those selected, that would be more suitable for model calibration. In the Inglis study area, three of the thirteen calibration events were significant.
- There are two sub-daily rain gauges within the Inglis study area, however only one gauge was available for each event, limiting the information on temporal distribution of rainfall during the events. Some gauges outside the study area (Burnie, Luncheon Hill and Waratah) influenced rainfall in sub-catchments along the boundaries of the study area.
- The highest gauged flows at both the Moorleah and Seabrook gauges were significantly below the level of the floods of interest. The ICM discharge-level relationship and the DPIPWE rating curve showed very similar behaviour in the high flow portion of the rating curve, at Moorleah, therefore the rating curve was adopted, noting that there is some uncertainty in the high flow rating. At Seabrook, the ICM discharge-level relationship was used for the higher flow portion of the rating curve.
- Design events are selected by running design rainfalls through the hydrological model across the entire study area with a range of ARFs to select representative ARFs, storm durations and temporal patterns to be run through the hydrodynamic model. The selection of these three ARF-duration-TP sets per AEP does introduce error compared to running each sub-catchment’s ideal ARF-duration-TP set through the hydrodynamic model, however running thousands of runs of the hydrodynamic model is clearly not feasible for a state-wide study. Enough ARF-duration-TP sets are used in order to keep the error within agreed bounds.
- In the headwater catchments, direct rainfall was defined as the dominating event. Direct rainfall was also applied to all sub-catchments, however the critical duration of the primary flow path was not defined by this scenario. In the direct rainfall zones, an alternating block storm approach, rather than an ensemble storm approach was used. The use of the alternating block enables the assessment of a range of durations to be undertaken within a single temporal pattern. This approach provides a reasonable estimation of peak flow (and thus level and hazard) for a range of storms within the area of interest, but is not capable of producing realistic hydrographs. Whilst this method has the potential to overestimate flows, this was not considered to be an issue for the modelling, as the direct rainfall is only used for mapping purposes and not as input to downstream sub-catchments.
- The base dataset used for raw data was the SES state-wide 10 m DEM (including bathymetry) merged with available 2 m DEM subsets. The 2 m DEM was unable to be

used for bathymetry due to issues with breaching.

- The coarse definition of the hydraulic model does not allow for the detailed assessment of low flow hydraulic features. This means that modelled water levels at gauges for lower flows will not necessarily compare well with observed water levels.
- Bridges are represented within the ICM model as linear 2D bridge structures, using the SES state-wide bridge database for location and reach of associated structures.
- The major culvert under the Burnie Airport was assumed to be of rectangular shape approximately 8 metres wide by 2 metres high, as data was not available on the dimensions of this culvert. Further site visits to obtain the exact size should be undertaken in any future detailed studies.
- Synthetic tide data was used to set a varying tide for historic events. Whilst observed data may be available at specific locations, it is not available state-wide, therefore synthetic tide data has been used as a consistent methodology.
- There are some uncertainties associated with levels surveyed in the June 2016 flood event. In particular, levels upstream of Saunders Street Bridge, upstream of Wynyard and in the area where Big Creek crosses the Bass Highway. In these locations, surveyed flood levels are not necessarily consistent with anecdotal reports of flooding or with other surveyed levels in the area.

7. CALIBRATION RESULTS

7.1. Hydrologic Model Calibration

7.1.1. Flowerdale River at Moorleah

The model calibrated reasonably well at the Flowerdale River gauge for the August 2007 and June 2016 events. As results appeared reasonable by changing only the losses, BX was left at 1 allowing the PERNs to be defined based on the sub-catchment land use with no scaling. The model matched the event shape and peak of the August 2007 event very well considering the observed hydrograph was complex. The model underestimates flow during the recession which causes an overall underestimation of model volumes, however this is not during the main part of the event. For June 2016 the modelled flow is quicker to respond, but is still able to represent the hydrograph fairly well.

The model does not reproduce the January 2011 event well. This is very likely due to the poor temporal and spatial representation of rainfall for this event, as discussed in Section 3.2.1. The study area average rainfall shows almost 70% of the rainfall had fallen on the study area by early morning on the 14/01/2011 when the low point between the two flow peaks occurred, during the lull in the rainfall. However, the first peak of the hydrograph is less than a quarter of the volume of event overall. Losses are expected to be higher for an initial peak, and some water from the first rainfall burst may still have been routing to the gauge by the second rainfall burst, but for a relatively small, flashy catchment it is expected that almost 24 hours of minimal rainfall would allow most of the runoff to reach the gauge. The model was unable to reach the peak observed in the second part of the hydrograph. However, it is readily believable that the model would replicate observed behaviour with some changes to the rainfall temporal pattern. Therefore, the results for this event are shown for completeness, but are not an indication of overall model performance in this study area as it is not possible to replicate the observed flow in a hydrologic model with the rainfall data available.

Details of the calibration results are shown in Table 4 and plots are provided in Appendix B.

Table 4: Flowerdale River at Moorleah calibration event losses, routing parameters and fit statistics with individual routing parameters for each event.

Statistic	2007 Aug	2011 Jan	2016 Jun
IL	22	89	80
Average CL	0.8	0	0
BX	1	1	1
Modelled Peak (m^3/s)	100.4	166.7	266.8
Observed Peak (m^3/s)	97.6	202.7	262.5
Modelled Volume (ML)	11,500	12,500	12,300
Observed Volume (ML)	12,900	16,500	17,400
Volume % difference	-10.9%	-24.4%	-29.3%

7.1.1. Seabrook Creek at Bass Highway

There were significant concerns about the quality of the DPIPWE rating curve at Seabrook Creek so a combined rating curve was used as described in Section 3.1.2.2.

The January 2011 event was small enough to be in the part of the original rating curve in which there is some confidence, however similar issues with the rainfall as were observed at Moorleah occurred (see Section 3.2.1). Therefore, extremely high losses were required to facilitate a reasonable calibration for this event, balancing the difference in peaks and hydrograph volumes.

For the June 2016 event, the modelled hydrograph is slower to respond than the observed hydrograph, resulting in over estimation of volume for the main part of the event, but underestimation of volume on the recession. However the modelled and observed hydrograph peaks match closely and the hydrograph shape is generally similar, if a little broader at the peak than observed. Taking account of the uncertainty in the rating curve this is considered to be an acceptable fit.

Table 5: Seabrook Creek at Bass Highway calibration event losses, routing parameters and fit statistics with individual routing parameters for each event.

Statistic	2011 Jan	2016 Jun
IL	150	85
CL	6	4.5
BX	1	1
Modelled Peak (m^3/s)	34.5	99.5
Observed Peak (m^3/s)	33.7	95.8
Modelled Volume (ML)	1120	2690
Observed Volume (ML)	2150	3360
Volume % difference	-47.7%	-20%

7.1.2. Calibration of Design Losses

FFA was undertaken at Flowerdale River at Moorleah gauge site, where there was a long record length. The best fit to the data was achieved with a LP3 distribution using the Bayesian fitted technique in FLIKE (Figure 6).

Table 6 Fitted flood frequency for Flowerdale River at Moorleah

AEP	Peak flow (m^3/s)	90% confidence interval (m^3/s)	
		Lower	Upper
50%	71	62	82
20%	113	98	131
10%	142	122	170
5%	170	143	212
2%	208	169	278
1%	237	187	336
1 in 200	266	204	401

The calibrated hydrologic model was run through the solver and the initial and continuing losses that best matched the curve were estimated. As the events of relevance to this study are of 2% AEP or larger, the results were weighted to this end of FFA curve. The catchment-average loss was distributed across the study area using the hydrological soil group final infiltration rates. The adopted values of losses were an initial loss of 0 and continuing losses shown in Table 8; only soil type A and B were present as the dominant soil type in any sub-catchment. The resulting FFA is shown in Figure 6. This gives a good fit of modelled flows to fitted FFA flows up to the 1% at all AEPs. There is a significant change in shape to the modelled curve at the 1% AEP which is clearly evident in the IFDs in this region and therefore inevitable.

Table 7 Fitted flood frequency for Flowerdale River at Moorleah (observed) and modelled peaks

AEP	Observed peak flow (m^3/s)	Modelled peak flow (m^3/s)	Percent difference
50%	71	68	-5%
20%	113	110	-2%
10%	142	140	-1%
5%	170	173	1%
2%	208	218	5%
1%	237	253	7%
1 in 200	266	322	21%

Table 8: Adopted continuing loss for each soil type

Continuing Loss (mm/h)	
Soil Type A	**Soil Type B**
3	1.56

It is noted that initial losses in the calibration models are much higher than the design losses. This is not uncommon, with calibration events often having preceding rainfall that the initial loss in the model manages. We have adopted a design burst methodology for this study area, and the initial loss therefore applies to the burst within a storm. Model runs were undertaken using a complete storm approach, and the results were found to have less than 0.5% impact on design flows at Moorleah gauge. This is due to the calibrated storm losses being of similar magnitude to the design pre-burst rainfalls. As an example, from ARR DataHub (Babister et.al., 2016), the 90% pre-burst depth for a 1% AEP design event of 24 hours duration in this study area is 94 mm. The June 2016 event was approximately a 24 hour duration burst and less than 1% AEP. The calibrated initial loss for this event was 80 mm, which is of similar magnitude to the 90% ARR pre-burst, and thus supports the use of zero initial loss for design bursts. The loss may also, to some extent, be managing the spatial variability that was present in the actual event but is not captured by the rainfall stations used to inform the model. Design event models by definition have a fixed event and rainfall and, as such, the utilisation of an initial loss to manage preceding rainfall or spatial variance is not necessary.

7.2. Calibration Event Hydrodynamic Modelling

The ICM model was run with rainfall and parameter inputs derived from the hydrologic model at each sub-catchment for each calibration event. Prefilling of the model was undertaken to eliminate artificial blockages/sinks caused by model and DEM parameters. The results of the hydrodynamic modelling at Moorleah are summarised in Table 9.

Table 9: Hydrodynamic model calibration event results at Flowerdale River - Moorleah

Statistic	2007 Aug		2011 Jan		2016 Jun	
	Flow	Level	Flow	Level	Flow	Level
Hydrodynamic model peak	94 m^3/s	28.15 mAHD	145 m^3/s	28.63 mAHD	242 m^3/s	29.60 mAHD
Hydrology model peak	100 m^3/s		167 m^3/s		267 m^3/s	
Observed peak	98 m^3/s	27.62 mAHD	202 m^3/s	28.59 mAHD	262 m^3/s	29.52 mAHD
Peak flow difference to hydrology	-6%		-13%		-9%	
Peak difference to observed	-4%	0.53 m	-28%	0.04 m	-8%	0.08 m

Flow comparisons for all three calibration events against hydrology show good correlation. In the 2007 event there is an over estimation of level which is likely due to the poor resolution of the lower section of the channel, which is not unexpected in a model of this resolution.

The results of the model calibration at Seabrook gauge are shown in Table 10. The calibration results show a good match to observed, with modelled peak levels within approximately 150 mm of observed levels.

Table 10: Hydrodynamic model calibration event results at Seabrook – US Bass Highway

Statistic	2011 Jan		2016 Jun	
	Flow	Level	Flow	Level
Hydrodynamic model peak	43 m^3/s	9.03 mAHD	101 m^3/s	9.33 mAHD
Hydrology model peak	35 m^3/s		99 m^3/s	
Observed peak	34 m^3/s	8.89 mAHD	96 m^3/s	9.32 mAHD
Peak flow difference to hydrology	23%		2%	
Peak difference to observed	26%	0.14 m	6%	0.01 m

The modelled depths for all calibration events for the study area are shown in Figure 9 to Figure 11.

7.2.1. Level Results for Flowerdale at Moorleah and Seabrook u/s Bass Highway

There is a good match between the modelled and observed flood levels for the June 2016 and January 2011 at both gauges, with a general trend of slight over estimation at Moorleah. In the August 2007 event there is a poor fit of level at Moorleah.

The 2007 event is much smaller than other modelled events and correlates to between a 50% and 20% AEP. The issues present at this gauge are likely due to poor representation of the channel at low flows, which affect both flow response and level representation. This indicates that if this model was to be used to assess more frequent flow events, further work would be required to ensure appropriate representation.

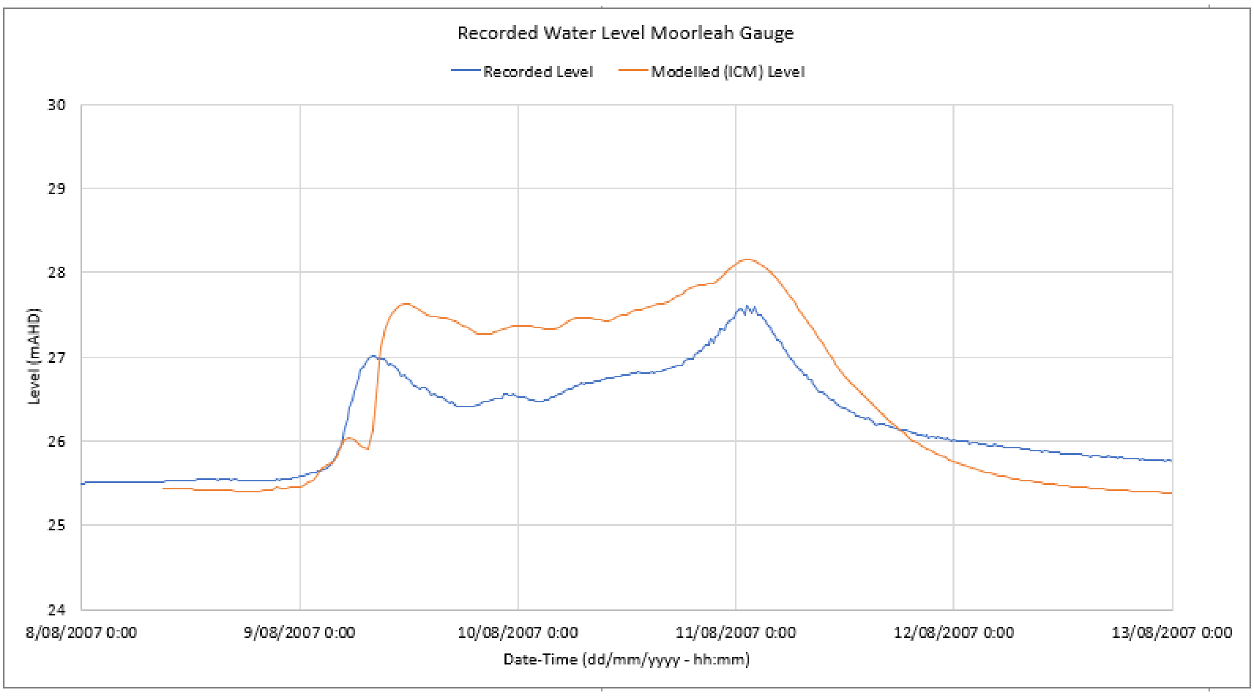

Diagram 10: August 2007 water level comparison at Moorleah

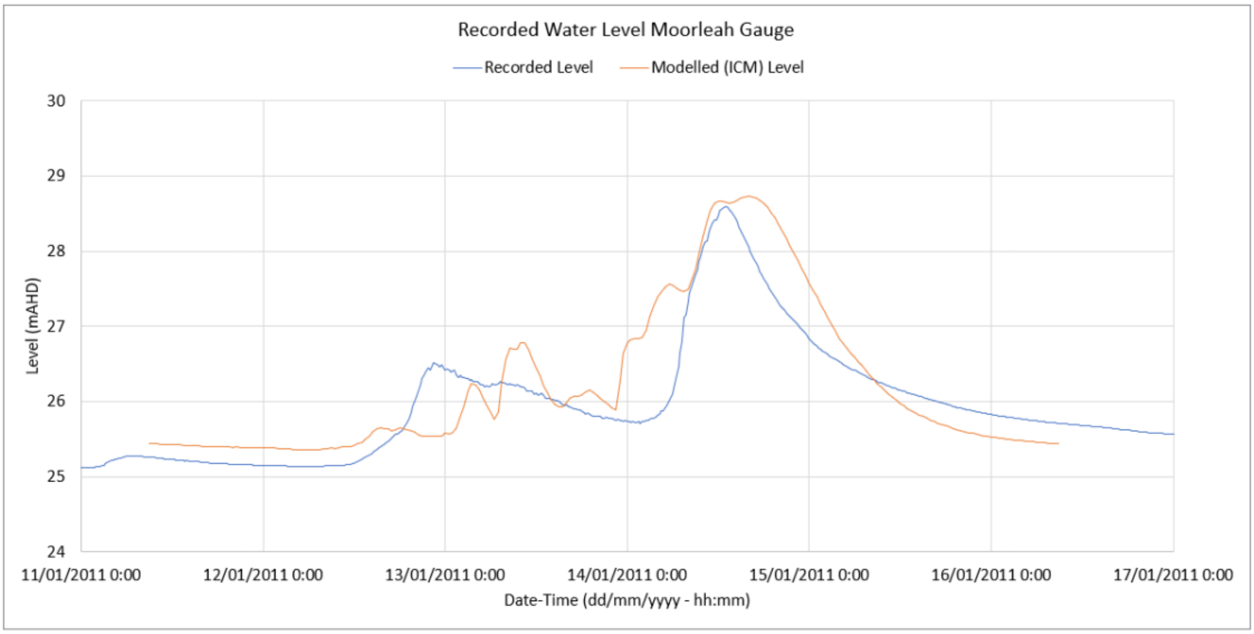

Diagram 11: January 2011 water level comparison at Moorleah

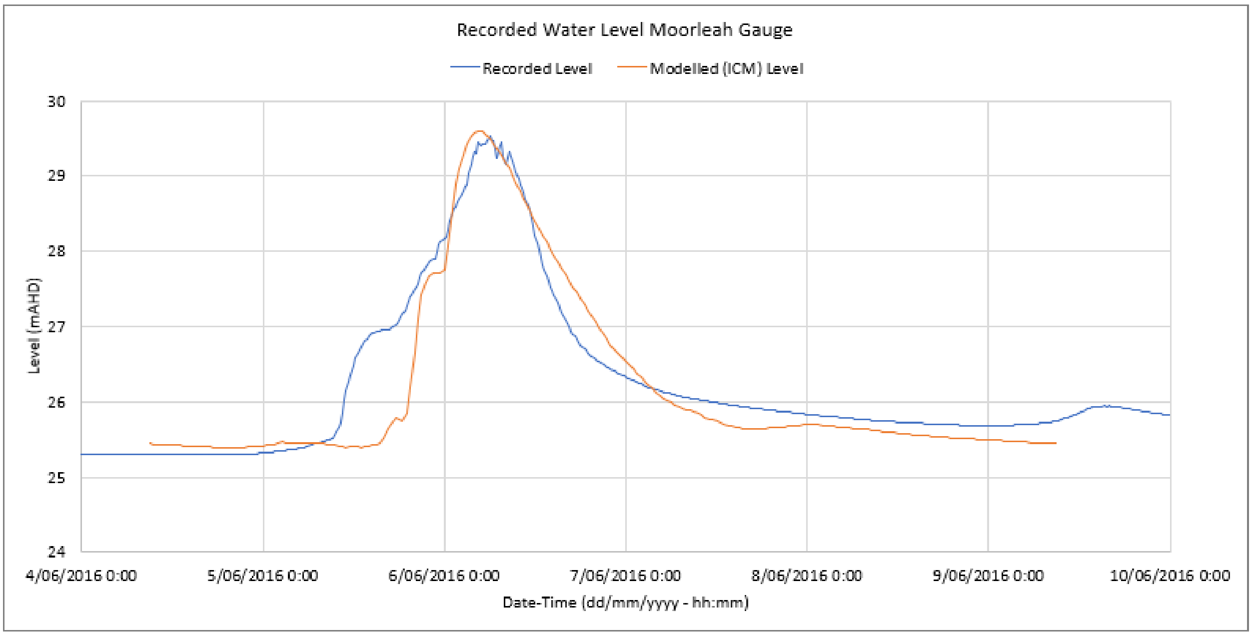

Diagram 12: June 2016 water level comparison at Moorleah

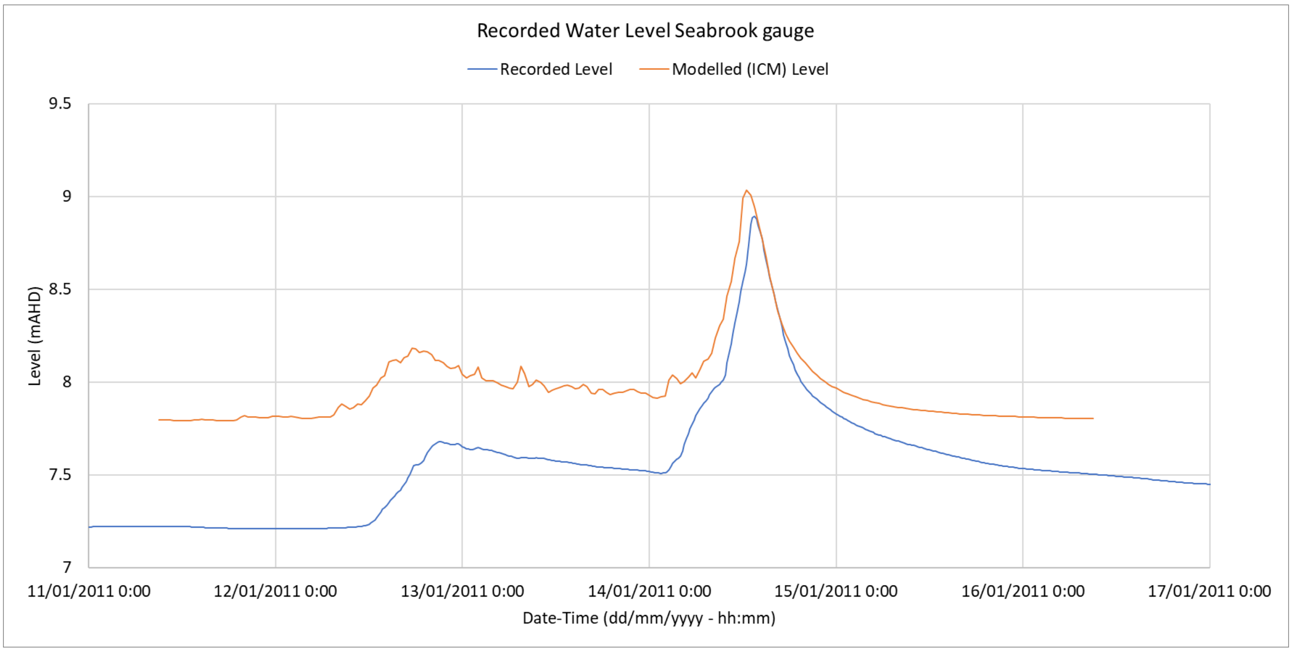

Diagram 13: January 2011 water level comparison at Seabrook

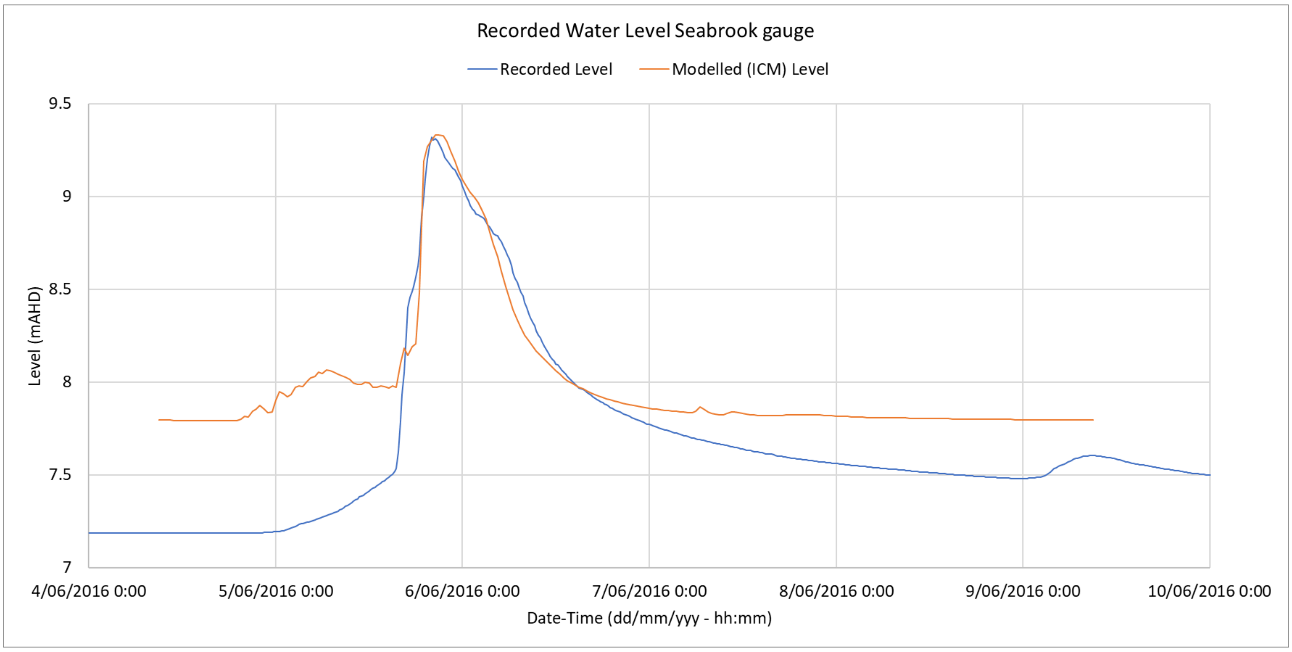

Diagram 14: June 2016 water level comparison at Seabrook

7.2.2. Verification Against 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. This information is compared to the flood extents developed by this validation model using the June 2016 event as a validation event.

Figure 8 shows the flood extent derived from model results overlain by the outline of the 2016 flood extent surveyed after the fact and digitised to GIS. The lower reaches show a relatively good fit to the surveyed extent. Diagram 15 shows the extent through the key area of Wynyard. A very good match to extent is present through this zone.

Diagram 15: Flood Extent Fit at Wynyard.

Diagram 16 shows a comparison of levels surveyed in the event. At Saunders Street Bridge a good match is present (within 400 mm) however further upstream surveyed levels are lower than those surveyed at the bridge. It is considered that the upstream points are erroneous, with these values extracted off debris marks in bank rather than off the bridge.

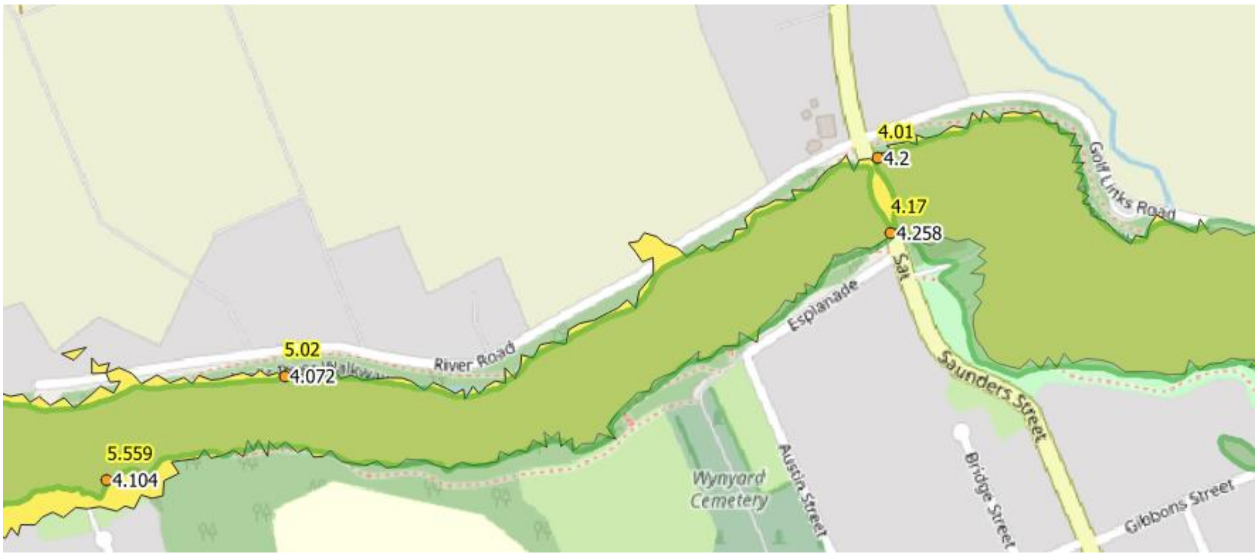

Diagram 16: Flood Levels surveyed (white) v modelled (yellow), mAHD

Survey data was also available near the confluence of Flowerdale and Inglis River. Diagram 17 shows the comparison of surveyed against modelled results in this location. In general, a good match is evident, however one surveyed level varies significantly from adjacent points making a good match difficult. A good match to extent is also shown in the vicinity of the points.

Diagram 17: Confluence of Flowerdale and Inglis River Flood Levels surveyed (white) v modelled (yellow)

Upstream of Wynyard is a zone that appears to have a large, surveyed extent but minimal extent in the flood model. A review of the provided information identified that there are no datapoints within the tributary upstream of Fists Lane, through this zone. The extent provided upstream of this location should be removed from the layer in future versions to prevent misunderstanding. At Fists Lane the surveyed level is within 100 mm of the modelled level.

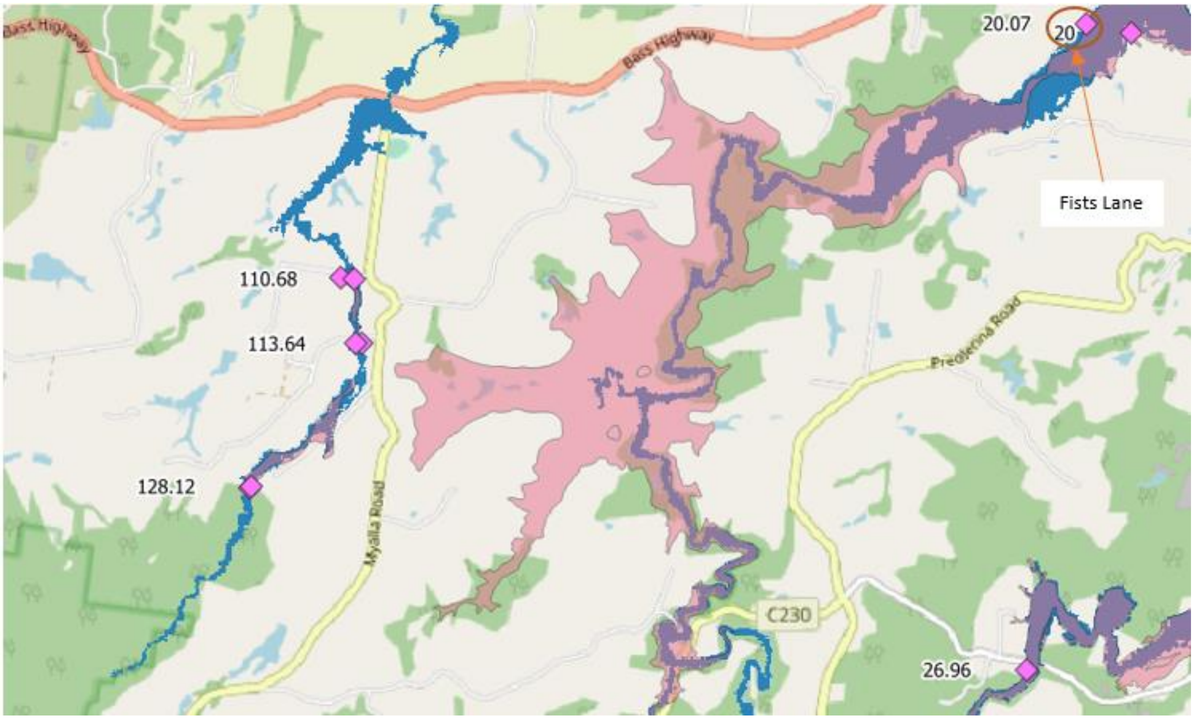

Diagram 18: Flood Extent – Incorrect Extrapolation Upstream of Fists Lane.

Other locations where a significant amount of surveyed data was present were along tributaries to Inglis river that pass through human populated areas e.g. Big Creek and Camp Creek. Diagram 19 shows the comparison of surveyed against modelled results where Big Creek crosses the Bass Highway. In general, a poor match is consistent throughout these tributaries that confluence Inglis river downstream of the Flowerdale gauge. The DEM and the structure in this were checked (noting that the structure is an estimated size) however no immediate resolution to this discrepancy is apparent.

The surveyed levels present in the dataset indicate only minor levels of flooding (< 0.5 m upstream of Bass Highway) however several news reports and Council minutes indicate flooding in the area that was high enough to severely impact eight properties within Stanwyn Court (located downstream of Bass Highway, https://www.theadvocate.com.au/story/3961706/rylah-tours-stanwyn-court/), which utilising the surveyed extent only has minor inundation of 2-3 properties, as shown on Diagram 20. Ultimately it is considered that the actual flood level is somewhere between the modelled and the surveyed however without further information there is no clear way to appropriately assess this zone.

Diagram 19: Flood extent at the intersection of Big Creek and Bass Highway

Diagram 20: Stanwyn Court Extent Variance

Review of levels through Camp Creek identify that LiDAR elevations in the area are higher than surveyed flood levels. The reason for this discrepancy is not fully understood however ultimately this makes a level comparison in the area difficult to achieve.

7.2.2.1. Summary of Survey Levels

Diagram 21 presents the outcomes of the comparison of the surveyed levels at all locations within the model extent. The upper and lower limits are based on the confidence levels provided with the survey points. Note that some levels were present at Lake Llewellyn however a review of the area indicates that the DEM does not represent the Lake and thus the area has been omitted.

Apart from the previously discussed Big Creek catchment (circled in red) the calibration results are considered reasonable for the scope of the project. Gauged catchments, as to be expected, performed better than ungauged catchments.

Diagram 21: June 2016 Level Results – Difference from Recorded Level

7.2.2.2. Identified Issues

Through the level and extent review the following issues were identified within the model, which if future detailed analysis is undertaken, should be investigated further:

- Big Creek at and downstream of the Bass Highway has survey level significantly lower than the modelled level, further data would be needed to ascertain the exact cause of the poor match and provide a better calibration.
- Lake Llewellyn is poorly defined within the DEM. Levels in the vicinity of the lake should not be utilised until improved information is available.
- Camp Creek downstream of the airport has surveyed levels significantly lower than the DEM ground surface. Further review of this section should occur in the future to determine where the issue lies (survey or LiDAR).

8. DESIGN EVENT MODELLING

8.1. Design Event Selection

Design inputs were run through the hydrological model across the entire study area with a range of ARFs to select representative ARFs, storm durations and temporal patterns to be run through the hydrodynamic model. The selected storms, and how many sub-catchments are best represented by each, are shown in Table 11. The temporal patterns for each selected run are shown in Figure 7. Diagram 22 shows which ARF-duration-TP set gives representative flows for each sub-catchment, and also shows headwater sub-catchments where only direct rainfall is applied. In the headwater catchments, direct rainfall was defined as the dominating event. As discussed in Section 5.7, direct rainfall is applied to all sub-catchments, however the critical duration of the primary flow path is not defined by this scenario.

Table 11: Selected storms for each AEP with the number of sub-catchments best represented by each set

AEP	Storm duration (min)	ARF bin	# sub-catchments
2%	180	45	18
2%	270	45	30
2%	720	250	17
1%	180	45	16
1%	270	45	29
1%	720	250	20
0.5%	180	45	15
0.5%	270	45	29
0.5%	720	250	21

The selection of these three ARF-duration-TP sets per AEP does introduce error compare to running each sub-catchment's ideal ARF-duration-TP set through the hydrodynamic model, however running thousands of runs of the hydrodynamic model is clearly not feasible. A summary of the magnitude of the errors introduced is shown in Table 12. Each sub-catchment's absolute percentage error is calculated using the following equation:

$SC\_Q\_Peak_{ref}$ = Sub-catchment peak flow run with ARF from that sub-catchment's ARF bin, with critical duration calculated at this gauge, and TP above the mean selected.

$SC\_Q\_Peak_{sel}$ = Sub-catchment peak flow run with ARF, storm duration and TP from the selected pattern which give peak closest to $SC\_Q\_Peak_{ref}$

$$\text{Absolute subcatchment percentage error} = \left| \frac{(\text{SC\_Q\_Peak}_{sel} - \text{SC\_Q\_Peak}_{ref})}{\text{SC\_Q\_Peak}_{ref}} \right| \times 100$$

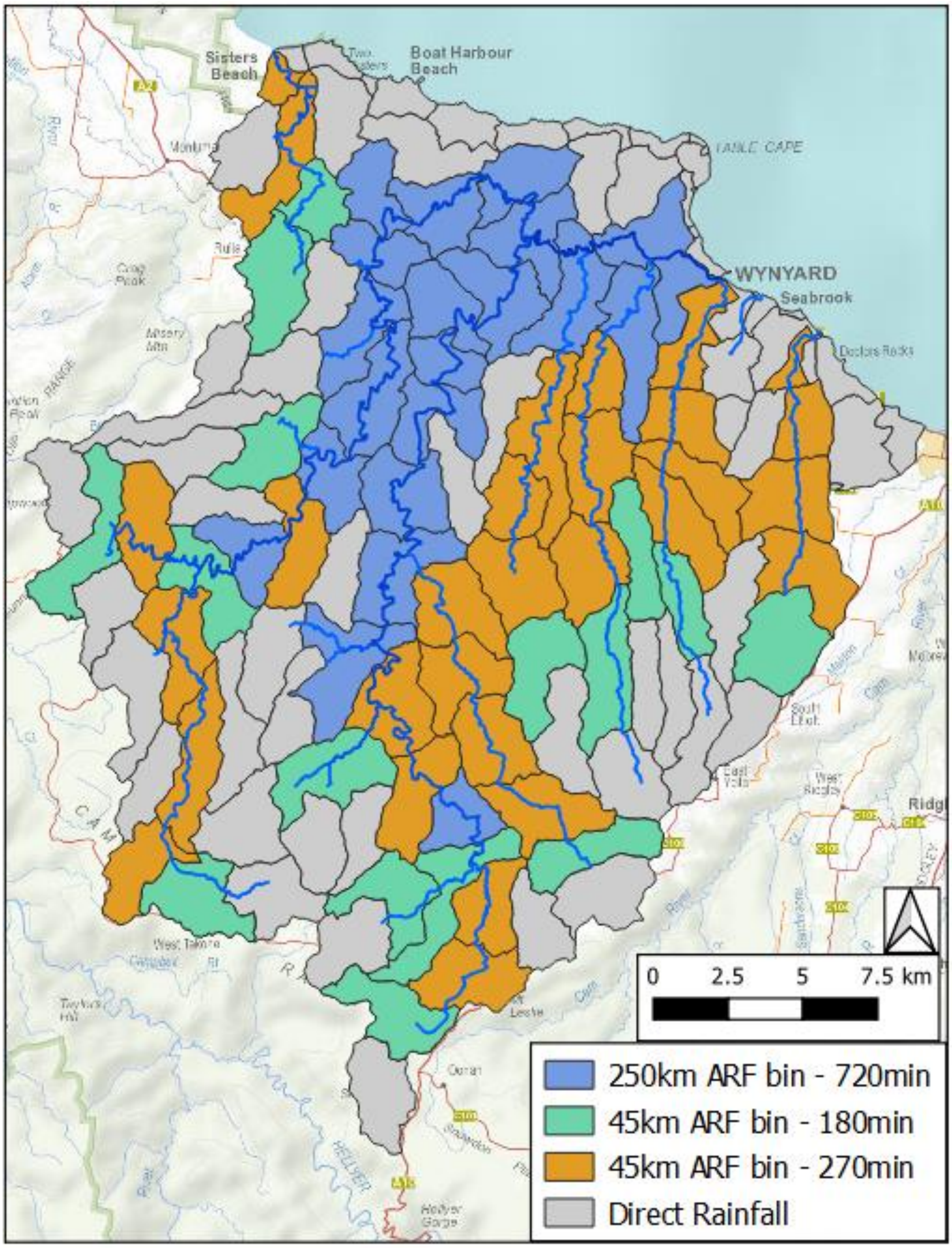

Diagram 22: ARF set relevant for each sub-catchment for the 1% AEP event

Table 12: Sub-catchment errors using the ARF-TP-duration sets shown in Table 11 for each AEP

AEP	Absolute sub-catchment error		
	Mean across sub-catchments	90th %ile across sub-catchments	Max of all sub-catchments
2%	2.0%	5.3%	9.7%
1%	2.1%	5.4%	11.3%
0.5%	2.0%	5.5%	11.2%

8.2. Design Event Hydrodynamic Modelling

There were no flood studies available within the Inglis study area for comparison of flood extents or flows for design events. Therefore, flows and levels have been compared solely to gauge FFA results at Flowerdale. Results of design event modelling are shown in Figure 12 to Figure 27.

8.2.1. Description of Flooding

Within the primary human settlement area of Wynyard, the primary flooding experienced is peak flow driven. While there is some floodplain storage present on Inglis River upstream of Wynyard (west of Bass Highway), through the town the peak flow rate generally determines the extent of flooding experienced. This mechanism is similar in the majority of the upstream catchment areas, with flow paths and creeks well defined and minimal breakouts in the 1% AEP event.

8.2.2. Review of Design Event Results at Flowerdale Gauge, Moorleah

A review of the design levels produced from the hydrodynamic model at Moorleah was undertaken, compared to levels derived from the Moorleah Gauge FFA. The FFA flows were converted to levels by translating the flows using the gauge rating curve, acknowledging there is a large amount of uncertainty in the rating at higher flows.

When compared against modelled levels from the hydrodynamic model at the Moorleah gauge, the modelled design events produce a reasonable fit to the FFA for both flow and level. The flows are within derived confidence intervals as presented in Table 6.

Table 13: FFA level comparison at Moorleah

Event	Hydrodynamic model peak flow (m^3/s)	Hydrodynamic model peak level (mAHD)	FFA/Obs peak Flow (m^3/s)	FFA/Obs peak level (mAHD)	Peak flow difference (%)	Peak level difference (m)
2007	94	28.15	98	27.62	-4	0.53
2011	145	28.63	202	28.59	-28	0.04
2% AEP	202	29.32	208	28.97	-3	0.35
1% AEP	227	29.55	237	29.27	-4	0.28
2016	242	29.60	262	29.52	-8	0.08
0.5%AEP	277	29.96	266	29.55	4	0.41

9. UNCERTAINTY ASESSMENT

Three of the study calibration events were significant in the Inglis study area: August 2007, January 2011, and June 2016. Reliable flow data was available at Flowerdale at Moorleah gauge for these events. This gauge is in the lower reaches of the Flowerdale River, which is the major tributary of the Inglis River. The rainfall quality for the 2007 and 2016 events was considered to be good for this regional study level, whilst the spatial variability of the rainfall in the 2011 event does not appear to have been well captured in the rain gauges.

Flood extents were available for the June 2016 floods in the lower reaches of the rivers. The model results show a relatively good fit with the surveyed extents and levels where the surveyed levels were considered to be reliable. In some locations the surveyed levels appear to be erroneous. Calibration results within the hydrodynamic model generally indicate a good correlation between recorded and modelled information for infrequent events, considering that this is a regional flood modelling study. In frequent events the resolution of the model limits the ability of the model to replicate recorded events.

The uncertainty assessment for the modelling is shown in Table 14. The method for uncertainty assessment is described in Addendum to WMAwater (2020c), and further details on the uncertainty assessment are included in Appendix C. The uncertainty assessment descriptors and quality assessments are based on consideration of the regional nature of this state-wide modelling study. The uncertainty assessment is not reflective of an equivalent detailed flood study for a specific area.

Table 14: Uncertainty assessment for Inglis River study area model

Category	Quality statement
Hydrology – rainfall input quality	The rainfall quality for the calibration events is generally good, with at least 2 sub-daily rainfall gauges providing information for each calibration event, and 3 or 4 daily rainfall gauges within the study area. However, the rain gauge network did not fully capture the spatial rainfall variability during the 2011 calibration event.
Hydrology – observed flows	There are two flow gauges that were operating during calibration events within the study area. The rating at the Flowerdale at Moorleah gauge is considered to be good based on comparison of results from ICM with the rating. The rating at the Seabrook gauge is poor, with a significant proportion of flow bypassing the gauge site at high flows.
Hydrology – calibration events	The June 2016 and January 2011 events are the two largest events on record at the Moorleah gauge, both with an AEP rarer than 5%. The August 2007 has an AEP of approximately 20%.
Hydrology – calibration results, peak flows	The hydrology calibration was considered to provide an excellent match to peak flows, with differences of less than 3% between modelled and observed peaks, other than for the 2011 event.,
Hydrology – calibration results, hydrograph volume	The modelled hydrograph match to observed hydrograph volumes was considered to be fair to good
Hydrology – calibration results, hydrograph shape	The modelled hydrograph shapes were generally good, other than for the 2011 event where the shape was considered fair in comparison to the

	observed hydrograph.
DTM definition	The 2 m DEM provided by SES was utilised to inform levels within the study area. In areas where discrepancies in the 2 m DEM were identified the 10 m DEM was used to inform a better approximation of ground level. The DTM definition was considered to be good.
DTM waterways	Representation of waterways in the DTM was considered to be poor to fair as no bathymetric data was available and waterway definition was based on the LiDAR to water surface.
Hydrodynamic – observed flood levels	Water level data is considered fair for Moorleah gauge, where gauge zero was inferred based on the results of hydrodynamic modelling. There is good confidence in the gauged levels based on hydrodynamic model results.
Hydrodynamic – observed flood depths	Surveyed flood levels were available for the June 2016 flood event. Overall, the quality of the flood extents provided was considered to be fair to good, with survey points available and significant areas interpolated. However, some of the surveyed levels and extents are considered to be in error, where they are not consistent with other levels in the area, or were taken from debris marks on the bank. The extent provided upstream of Wynyard is not based on any datapoints upstream of Fists Lane and is not reliable.
Hydrodynamic – overall calibration results	Calibration results within the hydrodynamic model generally indicate a good correlation between recorded and modelled information for infrequent events. In frequent events the resolution of the model limits the ability of the model to replicate recorded events.
Hydrodynamic – calibration results, peak flows	The model calibration to peak flows at Moorleah was very good to excellent, with hydrodynamic model flows within 10% of the hydrologic model peak flows and observed peak flows for 2007 and 2016 calibration events.
Hydrodynamic – calibration results, peak levels	• Model calibration to peak levels at Moorleah was considered to be poor for 2007 event, with levels within 0.9 m of observed – this smaller event is impacted by model resolution. • Calibration to peak levels is good for 2011 and 2016 events, with levels within 0.4 m of observed.
Hydrodynamic – calibration results, flood extents	• Modelling of flood extents for the 2016 event was considered to be good in areas where there is confidence in the quality of the flood extent data provided, including around Wynyard, Saunders St bridge, and near the confluence of the Flowerdale and Inglis rivers. • There is a poor match to flood extents in the area upstream of Fists Lane, where the flood extent provided is considered to be unreliable. • There is a poor match to flood extents in the area where Big Creek crosses the Bass Highway. Surveyed flood levels in this area are not necessarily consistent with anecdotal reports of flooding. It is considered that the actual flood level is somewhere between the modelled and the surveyed, however without further information there is no way to appropriately assess this zone.
Hydrodynamic – calibration results, flood depths	• Modelled flood depths were compared to the surveyed depths for the 2016 flood event. The modelled flood depths were considered to be a very good to excellent match to surveyed flood levels at Saunders St bridge, Fists Lane and around the confluence of the Inglis and

	Flowerdale rivers with almost all depths within 0.3 m of observed. • The match to surveyed flood depths upstream of Saunders St bridge was poor, however the surveyed flood levels are inconsistent with those downstream. • There was a poor fit to surveyed flood depths with very large differences between surveyed and modelled flood levels in the Big Creek catchment

10. CONCLUSIONS AND LEARNINGS

One of the aims of the Tasmanian Strategic Flood Mapping project is to develop state-wide Strategic Flood Maps to support flood risk assessment and post event analysis. This is a regional flood mapping study and the methodology has been developed to provide mapping at a state-wide scale, as distinct from undertaking detailed flood studies over particular areas. The SES and local government can use the regional mapping to identify areas where detailed flood studies would be beneficial.

The Inglis River study area was modelled as one of two validation catchments to validate methods and data for the overall project. The methods and data used are generally suitable for state-wide modelling, noting the limitations discussed in Section 6. The following points are noted for the state-wide modelling, based on modelling in this validation catchment.

- The thirteen calibration events provided for this project will not necessarily provide significant events for calibration in all study areas state-wide.
- Sub-daily rainfall data availability can be limited for some study areas, and this can impact on the model calibration.
- There are limitations with rating curves at stream gauges, where the high flow ratings are based on extrapolation beyond gauged values. Ratings are being revised for 35 gauges state-wide with long record lengths, based on modelling. These will be used in the state-wide modelling when available.
- Information on significant structures may not be available for some study areas. In this study area, no information on the culvert underneath Burnie Airport was available. In these cases, structure dimensions will be assumed, and this has potential to impact on the model results in these areas. These structures will be identified as requiring additional information where this is likely to result in improved model results.
- During the process, issues with the 2 m DEM, specifically associated with the breaching process, were identified. This is a state-wide issue. State-wide runs will use the 10 m DEM as the base information with the 2 m DEM used to inform higher detail around key structures. Prior to incorporation, the 2 m DEM in the area will be reviewed to ensure errors are not present.
- The coarse definition of the hydraulic model does not allow for the detailed assessment of low flow hydraulic features. This means that modelled water levels at gauges for lower flows will not necessarily compare well with observed water levels.
- Based on the outcomes, a roughness buffer will be applied to minor streams to reduce instances of high friction causing unreasonable blockage in the state-wide model.

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WMAwater (2021): Tasmanian Strategic Flood Map Hydrology Methods Report - Addendum, May 2021. Report for State Emergency Service, Tasmania.

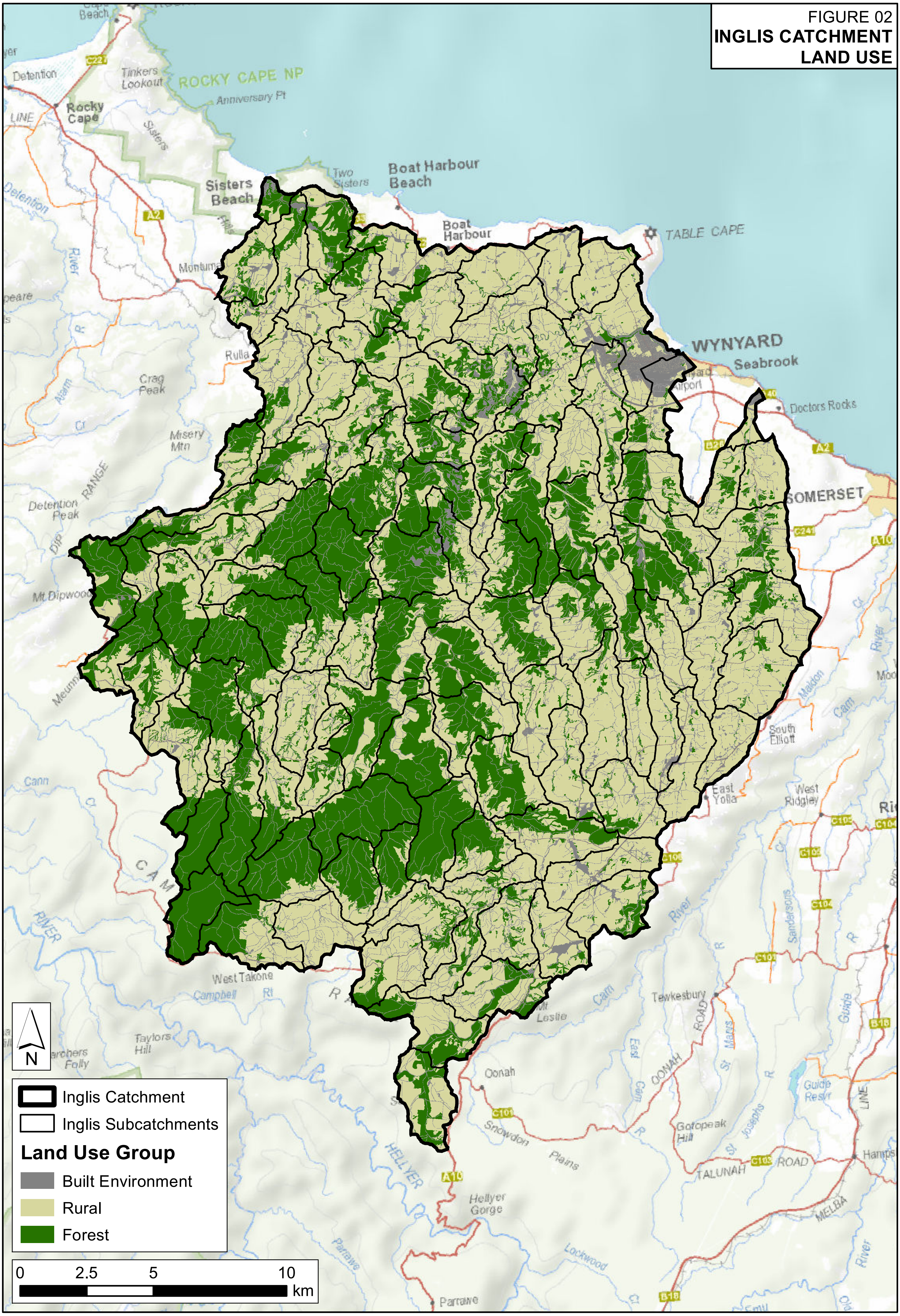
Figures

Appendix A

FIGURE 01
INGLIS STUDY AREA

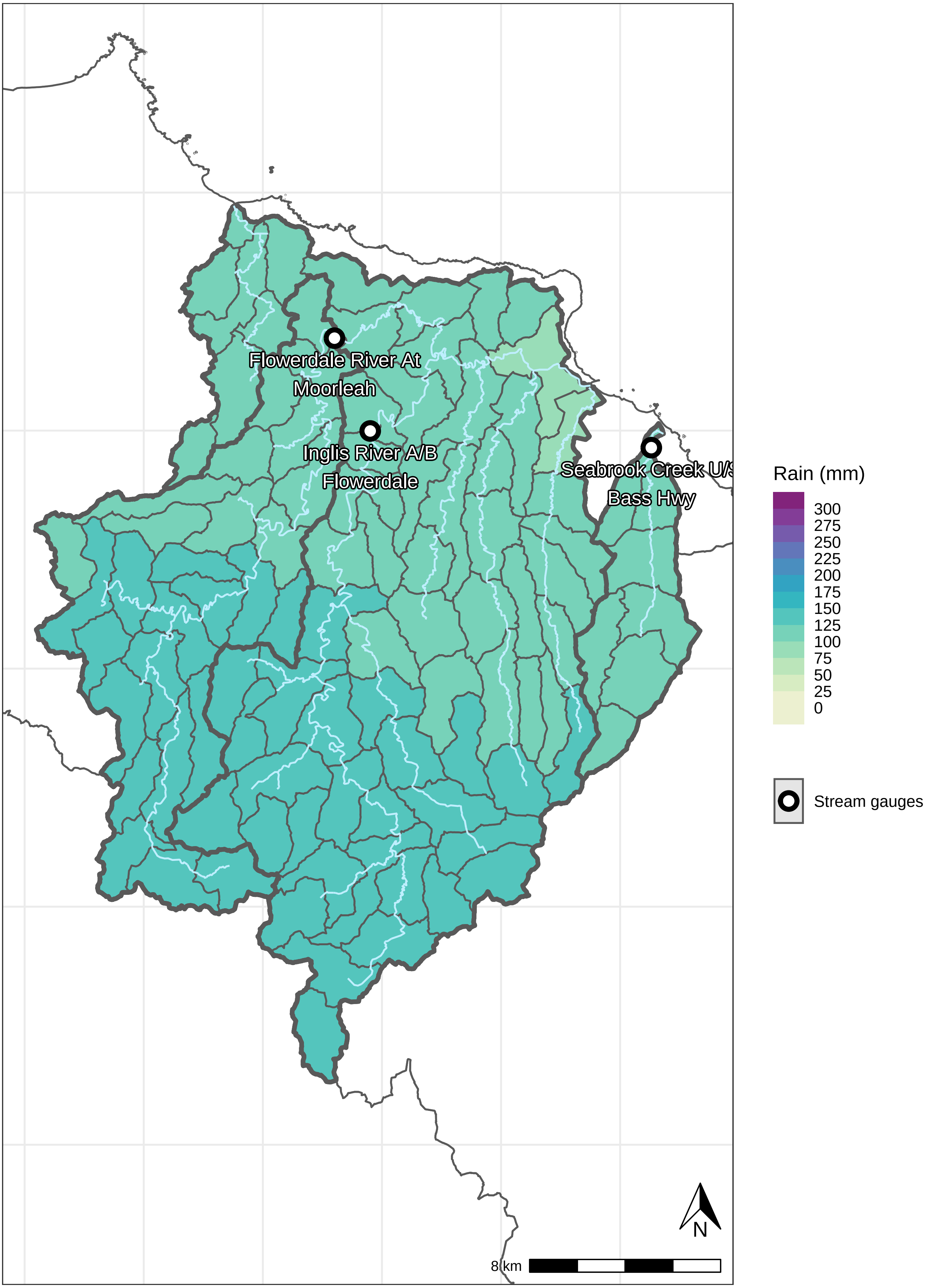
J:\Jobs\120038\GIS\hydrology\Map\Validation_Catchments\Inglis\Figure01_Inglis_Study_Area.mxd

FIGURE 02
INGLIS CATCHMENT LAND USE



J:\Jobs\120038\GIS\hydrology\Map\Validation_Catchments\Inglis\Figure02_Inglis_Catchment_Land_Use_SubOutline.mxd

FIGURE 3
INGLIS
WHOLE_CATCHMENT 2007_AUG



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J:/Jobs/120038/Hydrology/Validation_Catchments/Calibration/Inglis_postRainfallVariation/Subcatchment_rainfalls/Figure3Rain_Whole_catchment 2007_Aug.pdf

FIGURE 4
INGLIS
WHOLE_CATCHMENT 2011_JAN

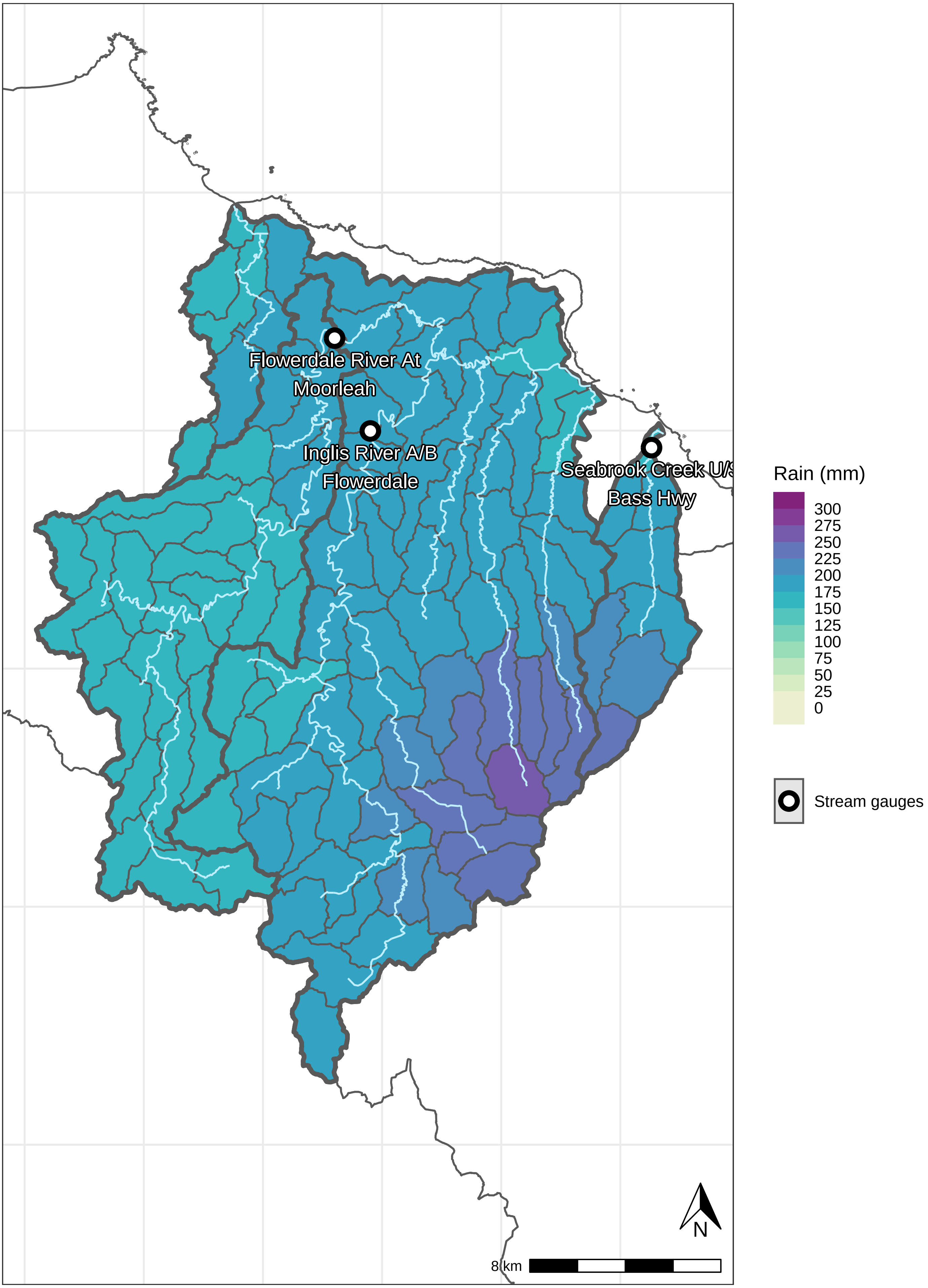

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FIGURE 5
INGLIS
WHOLE_CATCHMENT 2016_JUN

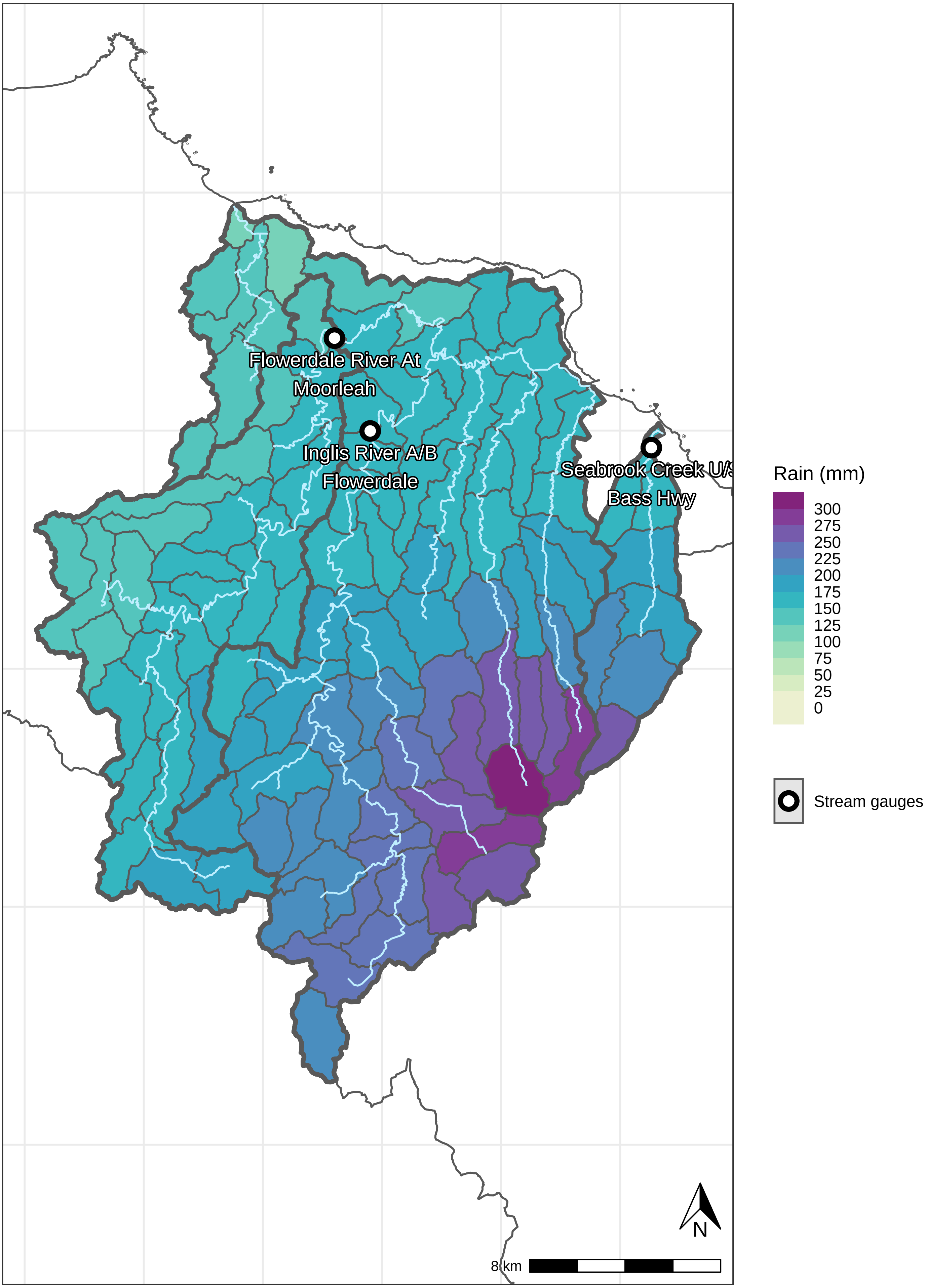

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FIGURE 06
FLOWERDALE RIVER AT MOORLEAH
FLOOD FREQUENCY

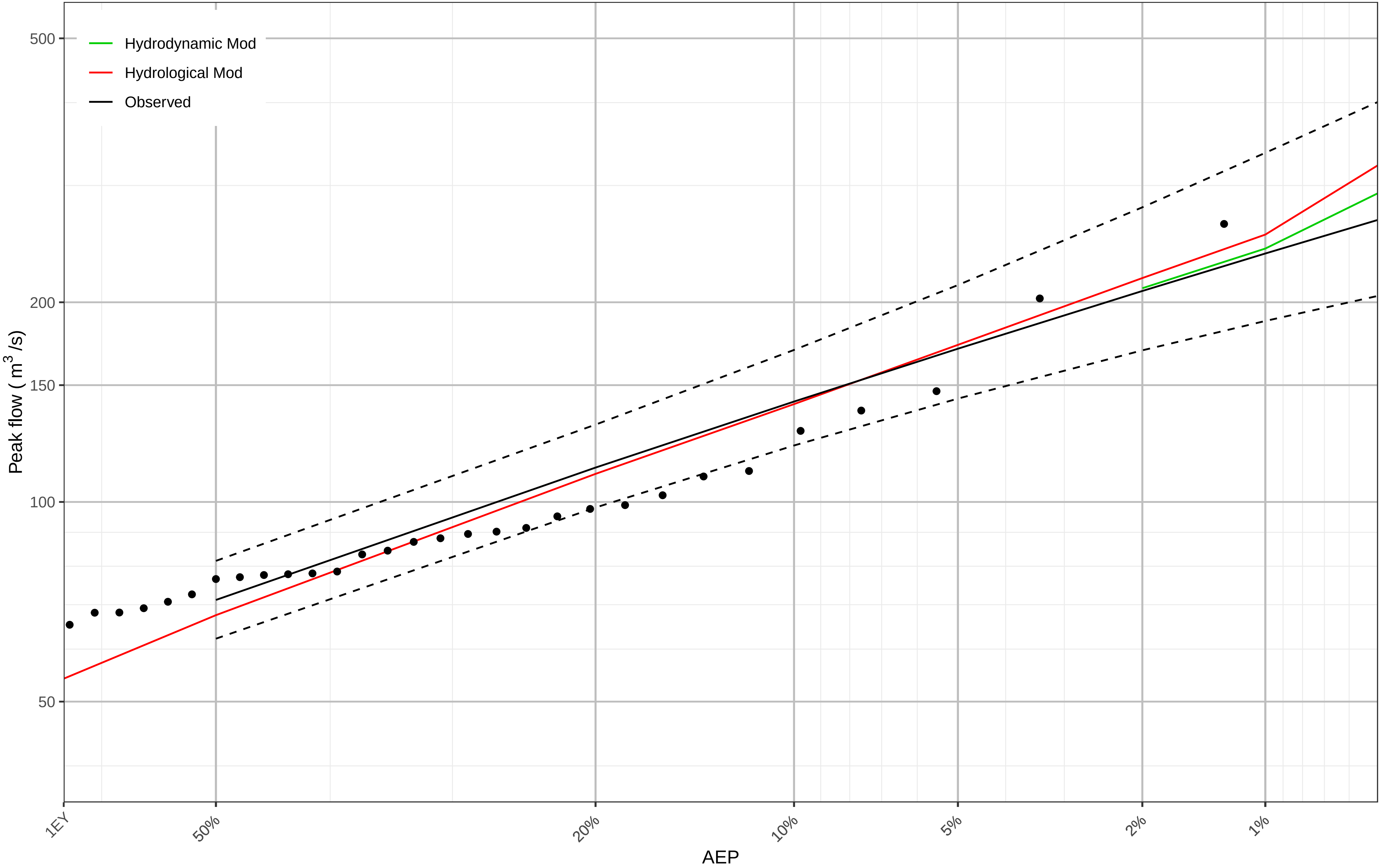
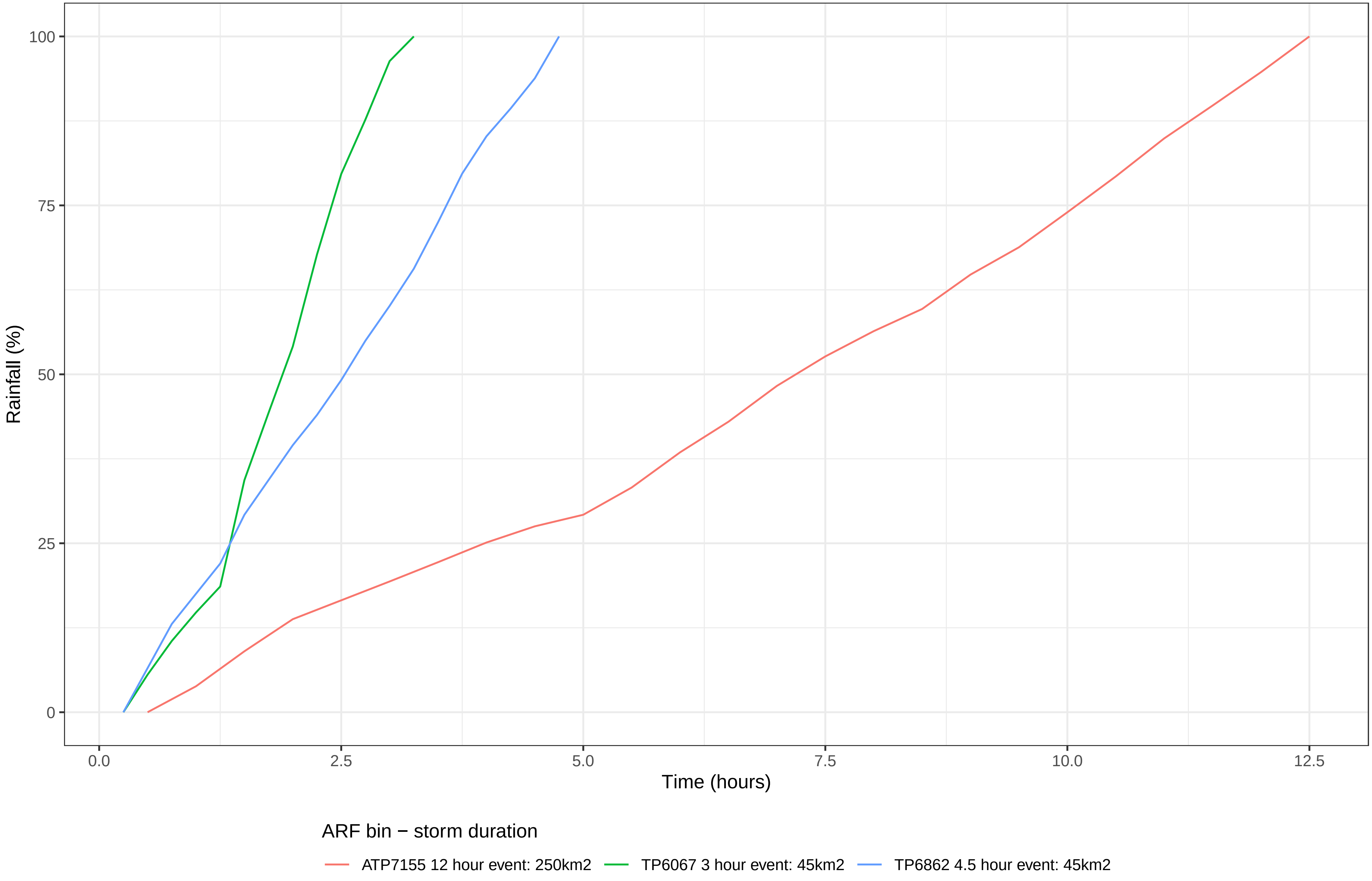


FIGURE 7
SELECTED DESIGN TEMPORAL PATTERNS
BY STORM DURATION AND ARF AREA



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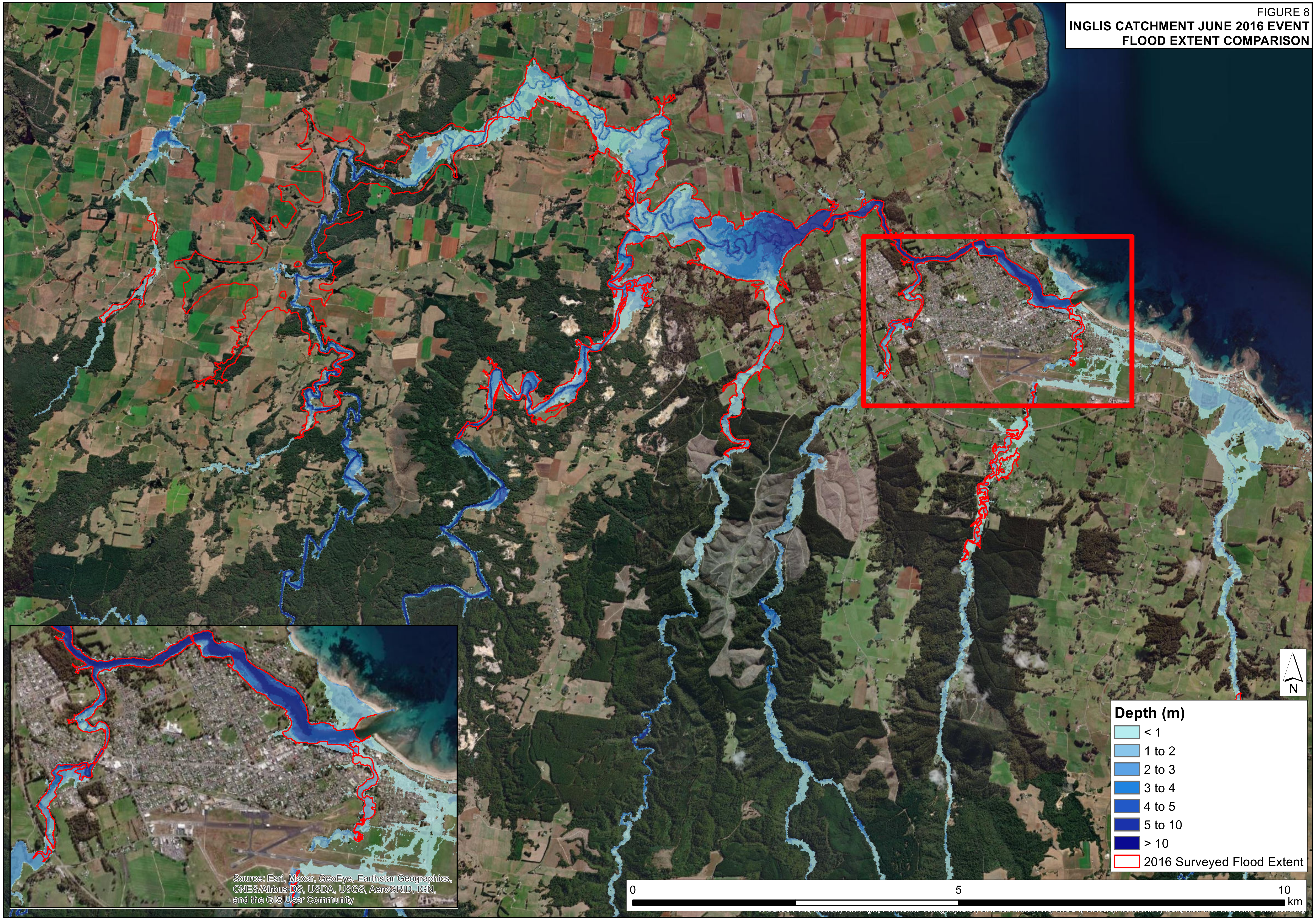

FIGURE 8
INGLIS CATCHMENT JUNE 2016 EVENT FLOOD EXTENT COMPARISON

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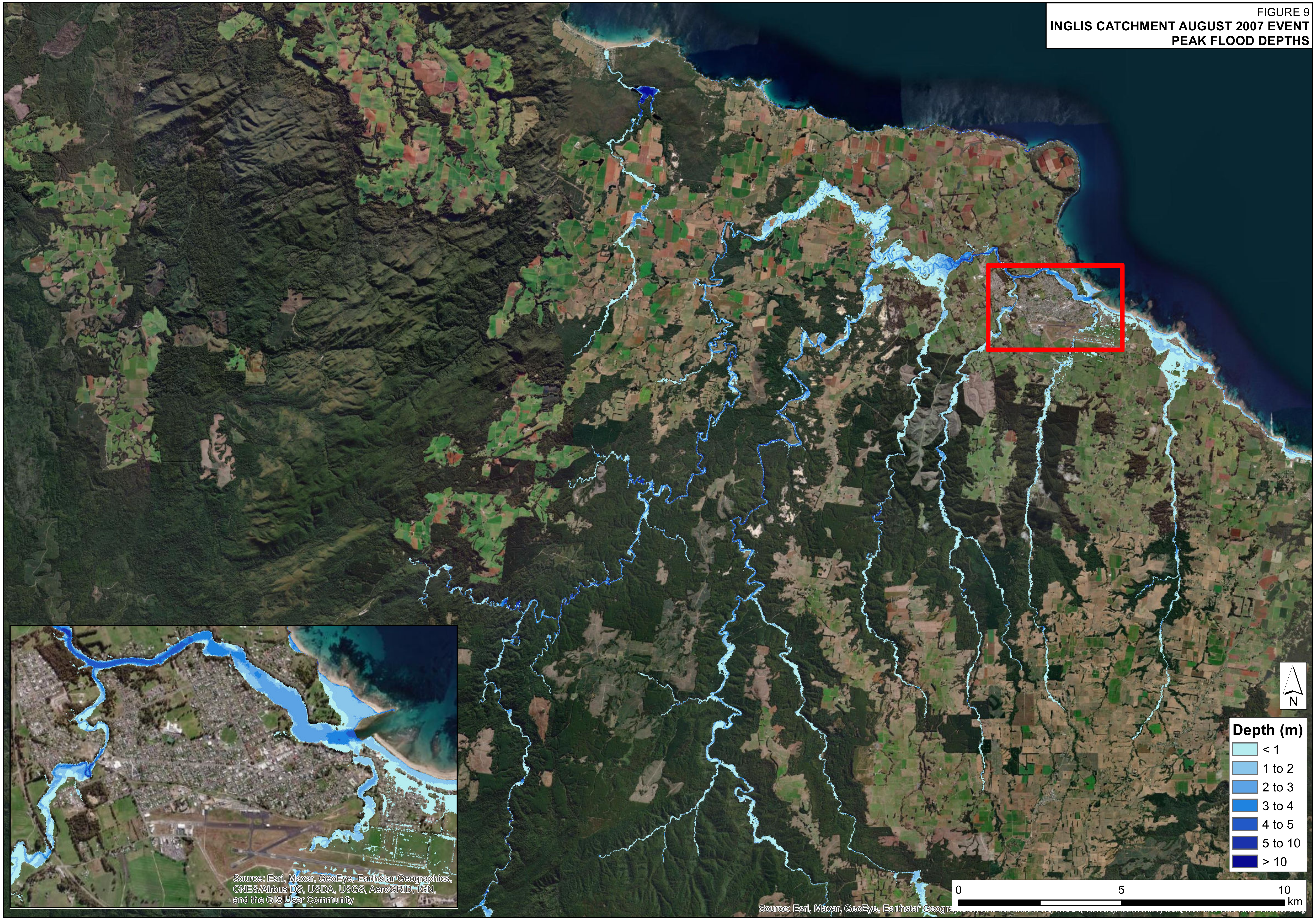
FIGURE 9
INGLIS CATCHMENT AUGUST 2007 EVENT PEAK FLOOD DEPTHS



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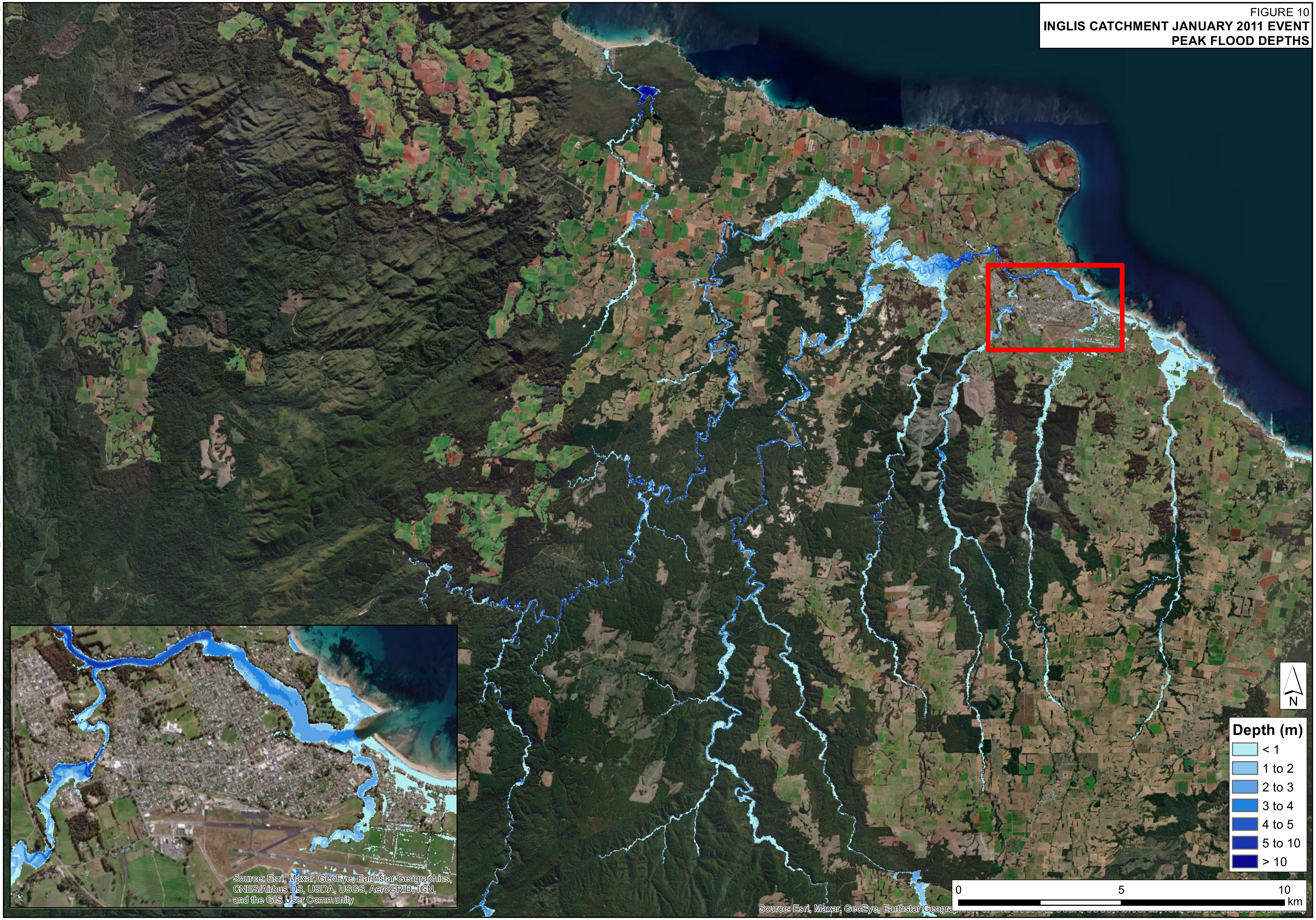

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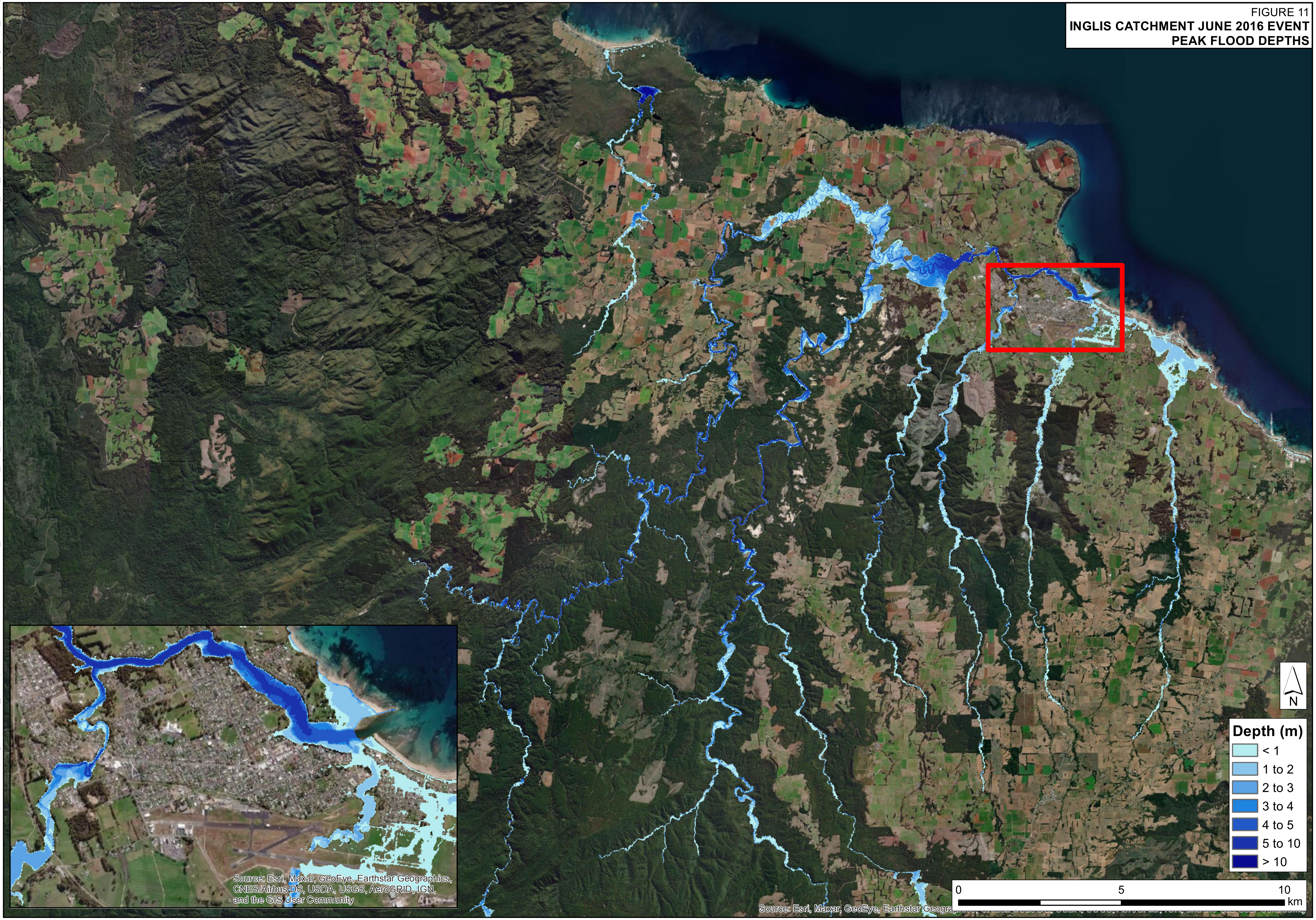
FIGURE 11
INGLIS CATCHMENT JUNE 2016 EVENT
PEAK FLOOD DEPTHS



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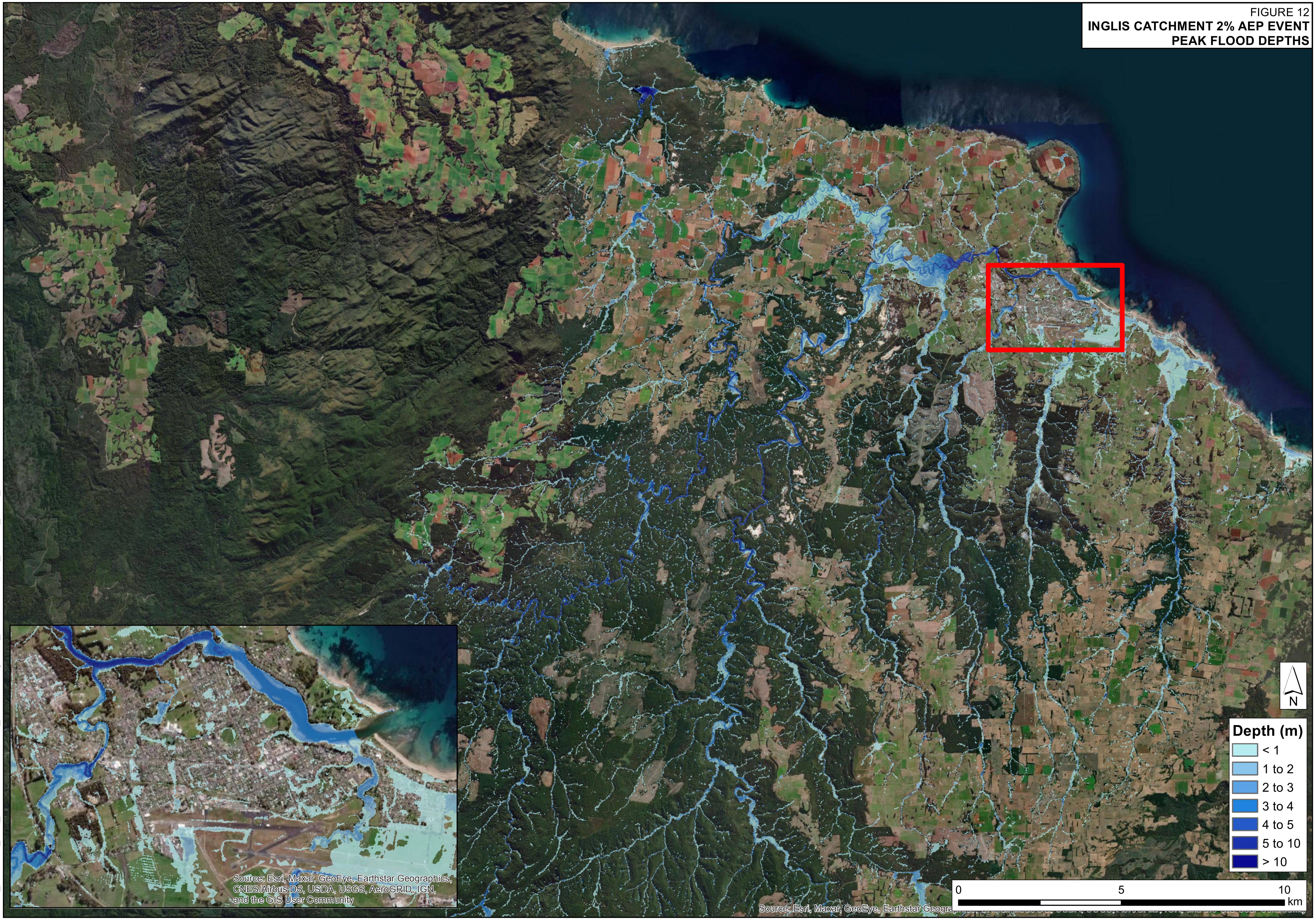

FIGURE 12
INGLIS CATCHMENT 2% AEP EVENT
PEAK FLOOD DEPTHS

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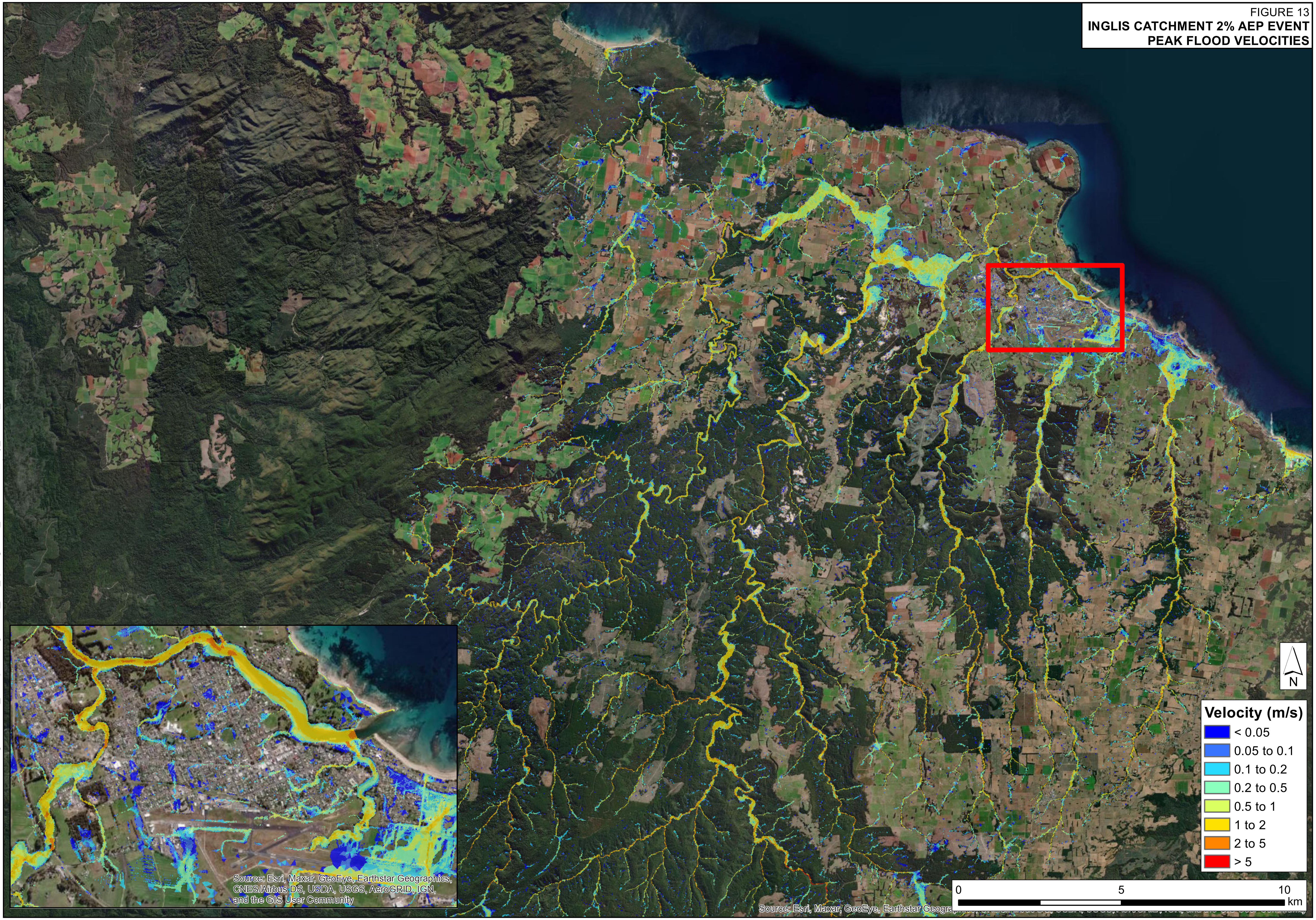
FIGURE 13
INGLIS CATCHMENT 2% AEP EVENT
PEAK FLOOD VELOCITIES



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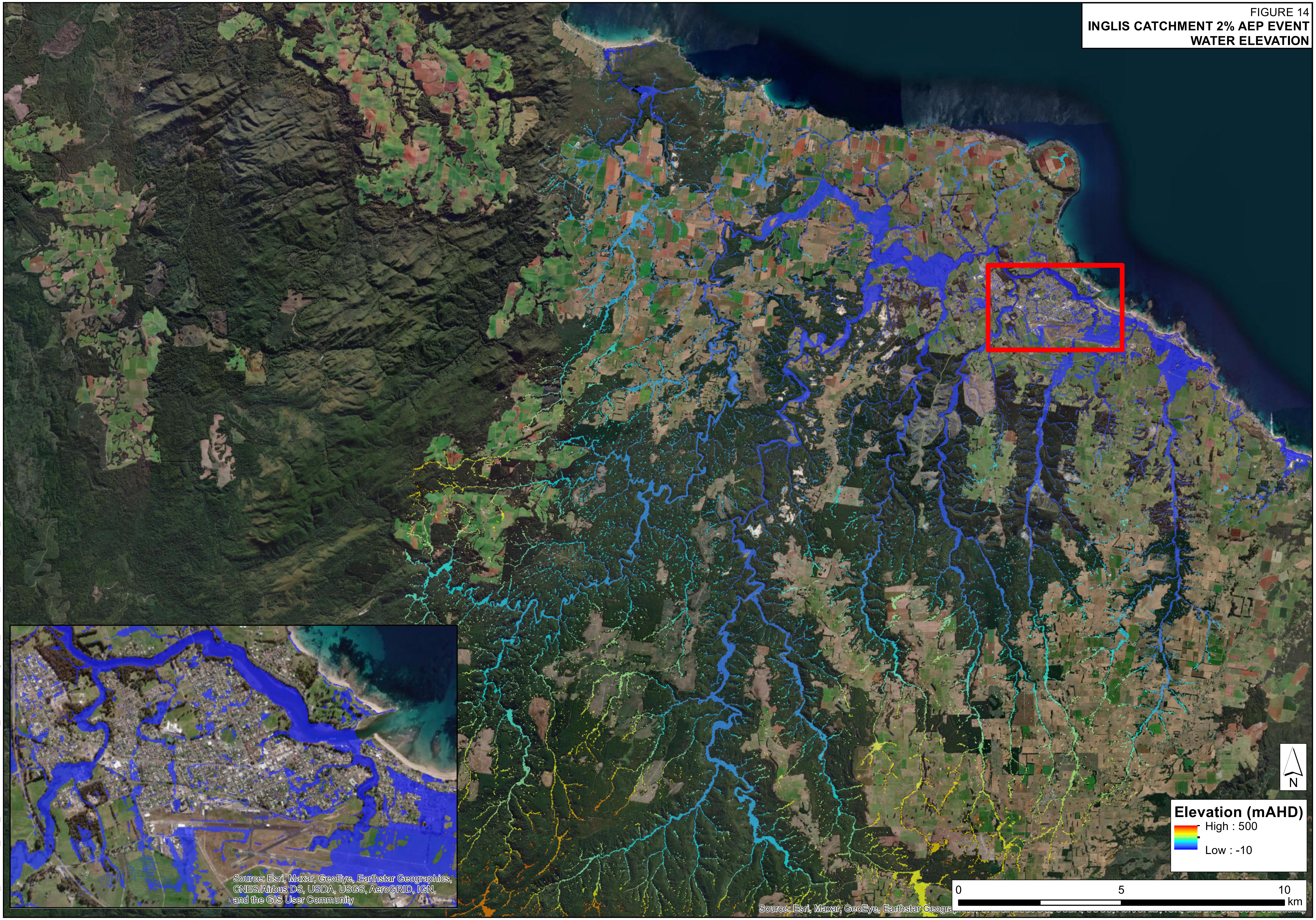

FIGURE 14
INGLIS CATCHMENT 2% AEP EVENT
WATER ELEVATION

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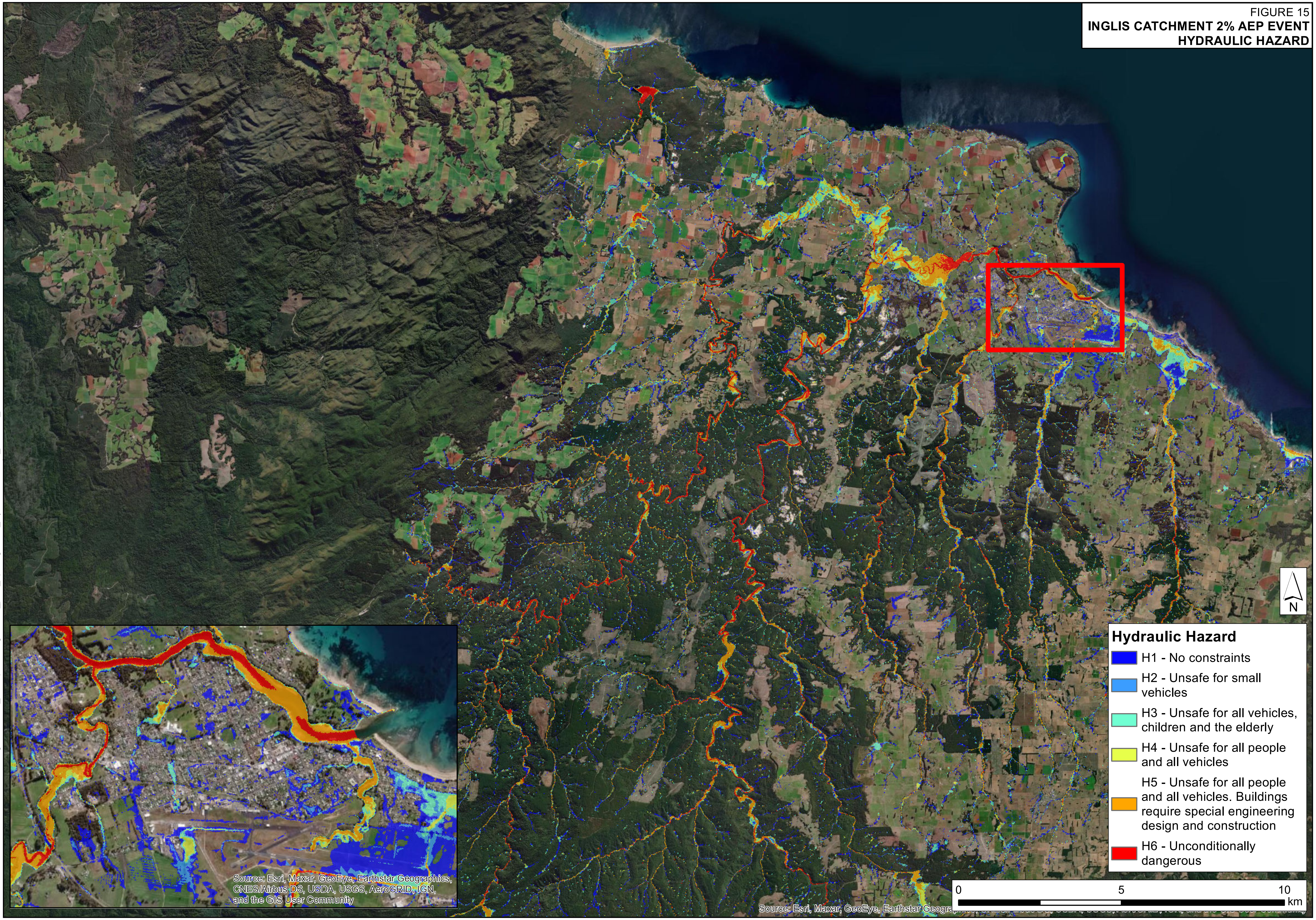

FIGURE 15
INGLIS CATCHMENT 2% AEP EVENT
HYDRAULIC HAZARD

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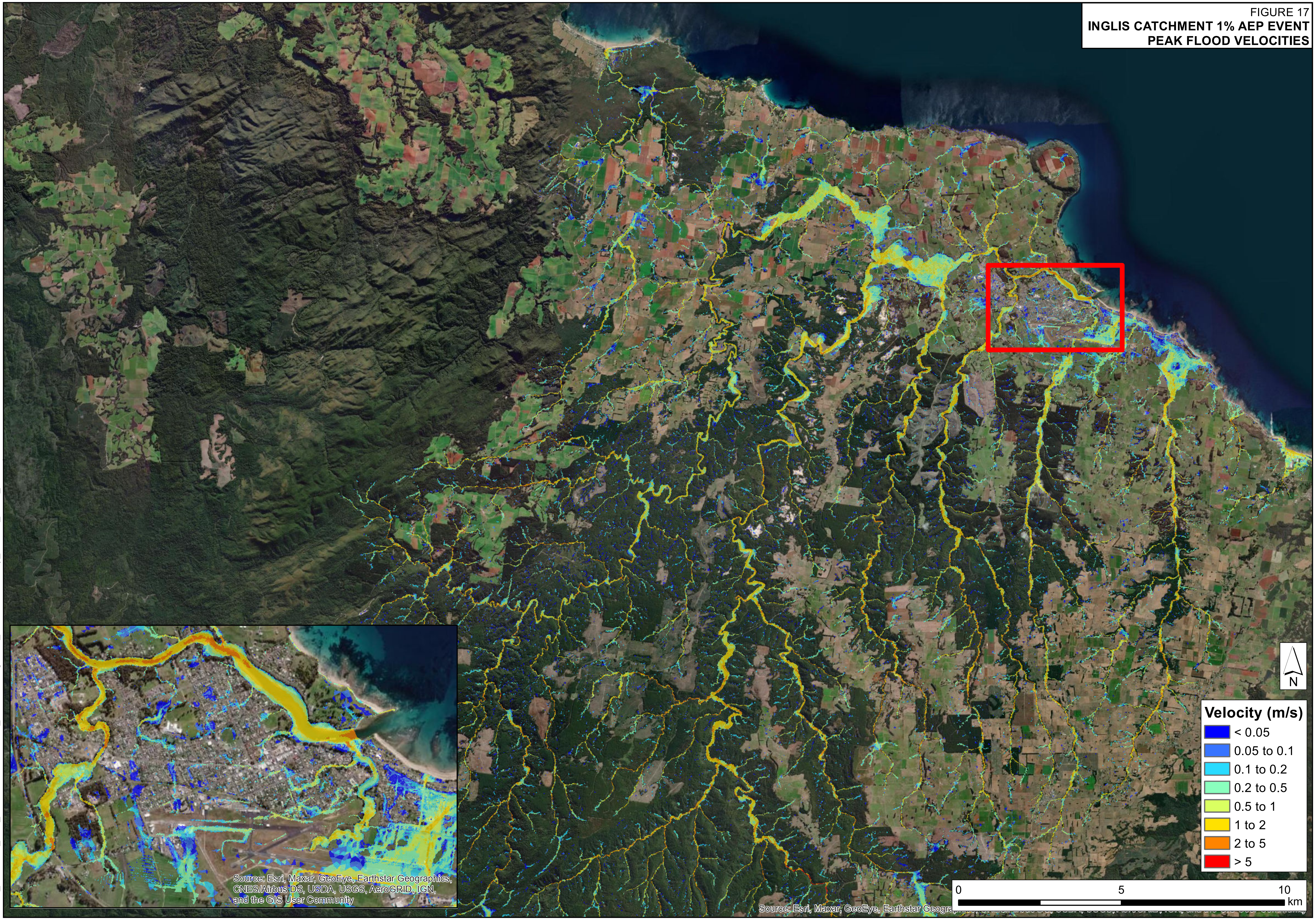

FIGURE 17
INGLIS CATCHMENT 1% AEP EVENT PEAK FLOOD VELOCITIES

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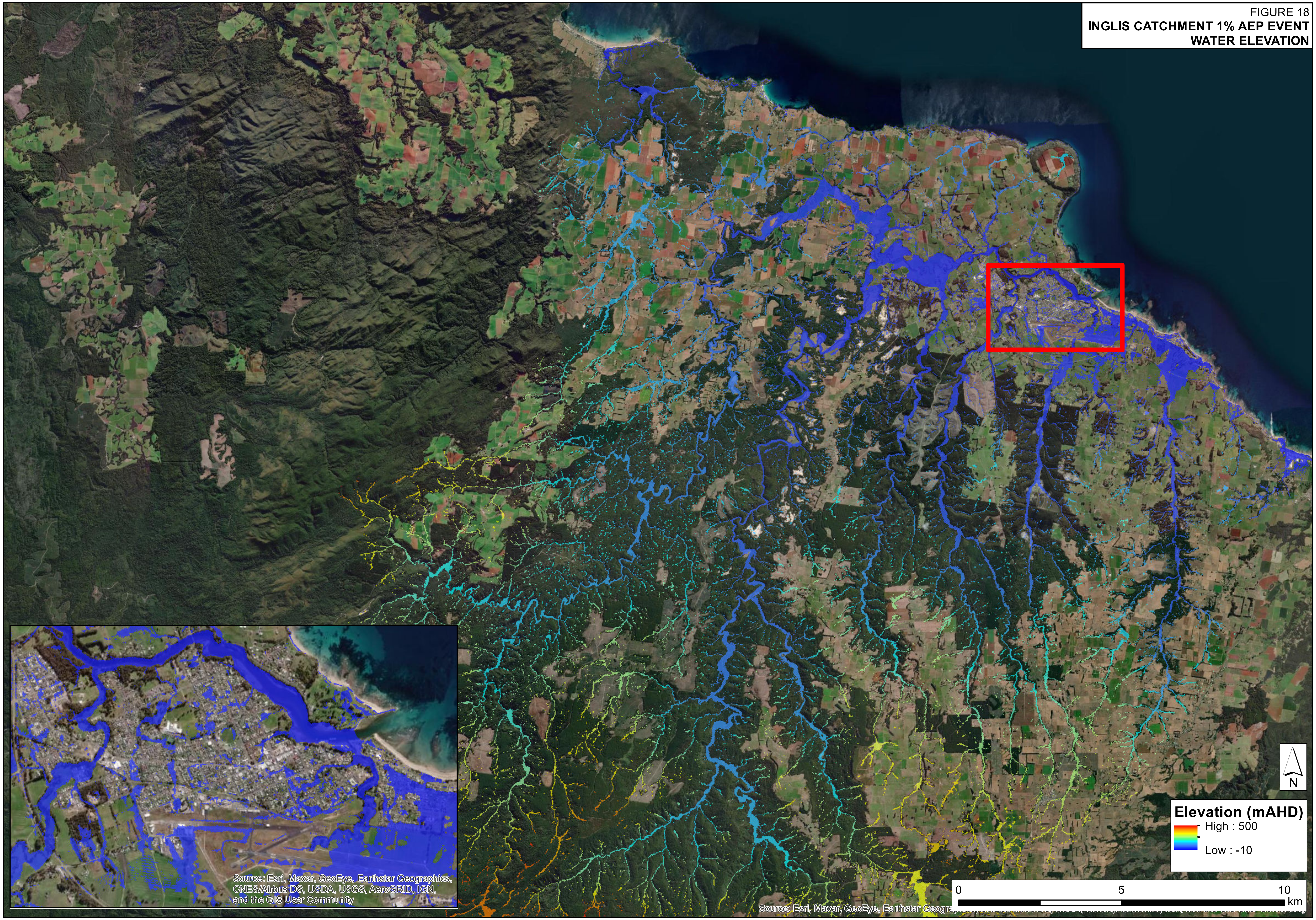

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FIGURE 19
INGLIS CATCHMENT 1% AEP EVENT
HYDRAULIC HAZARD

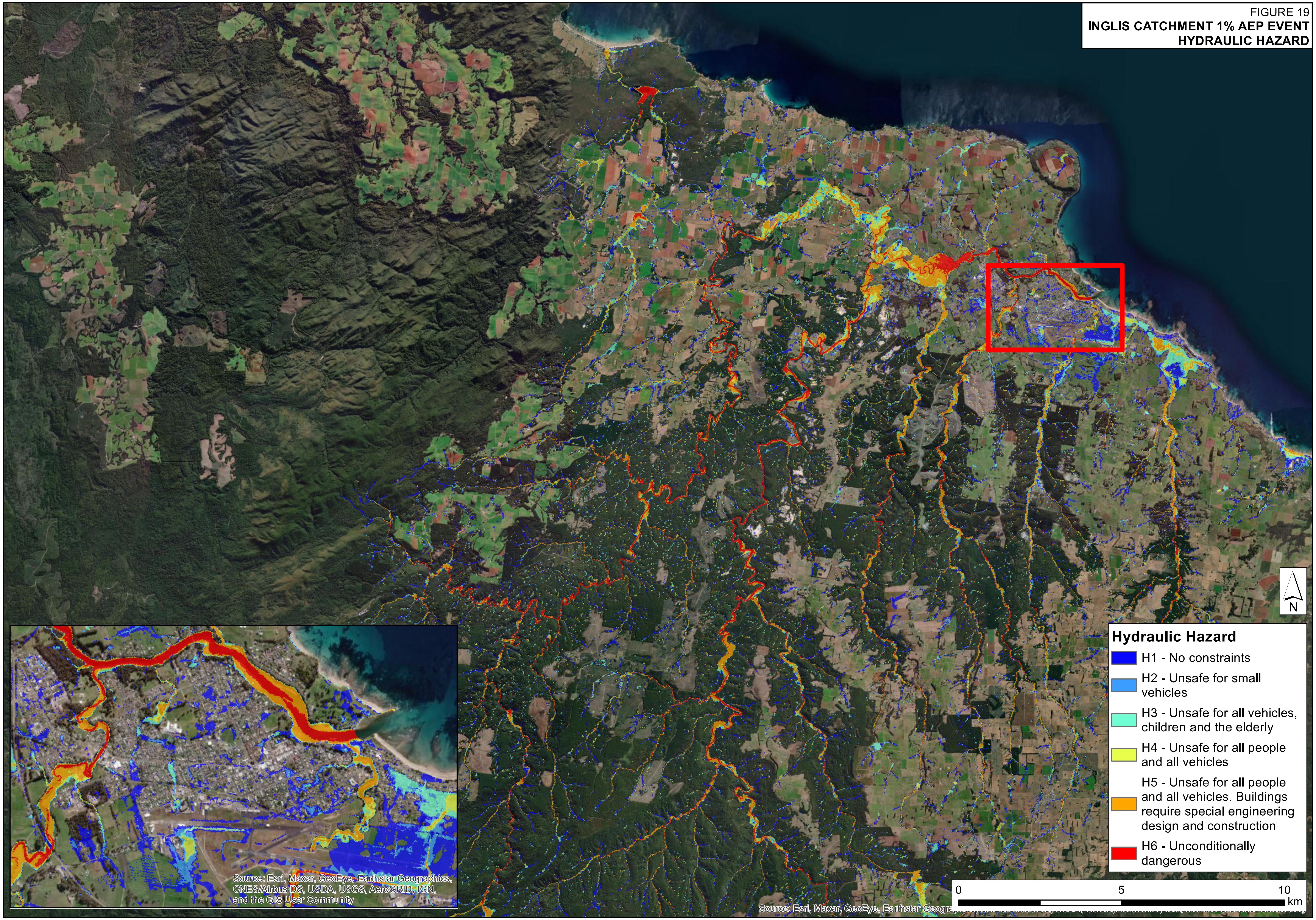

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FIGURE 20
INGLIS CATCHMENT 1% AEP EVENT
PEAK FLOOD DEPTHS
CLIMATE CHANGE SCENARIO

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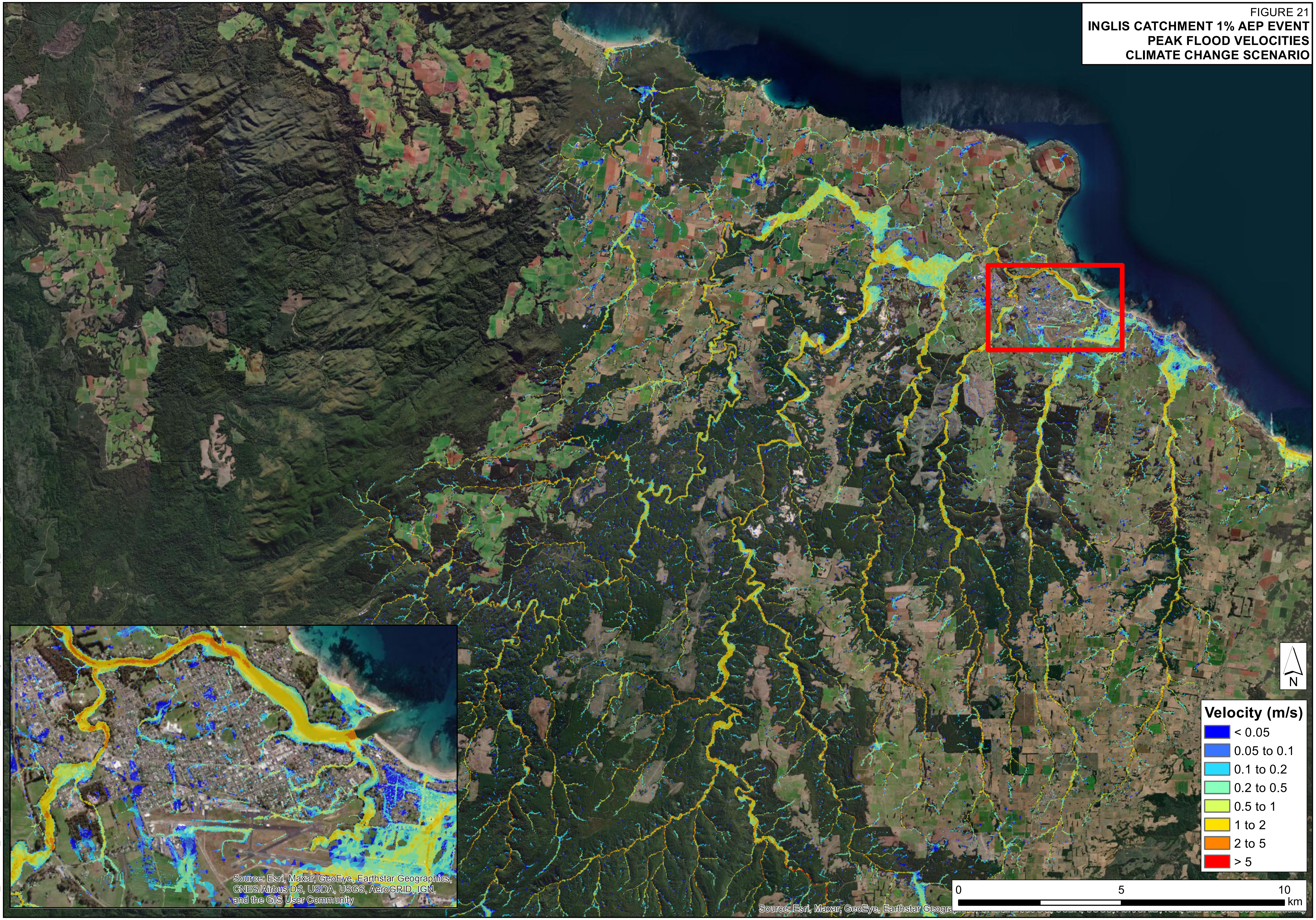
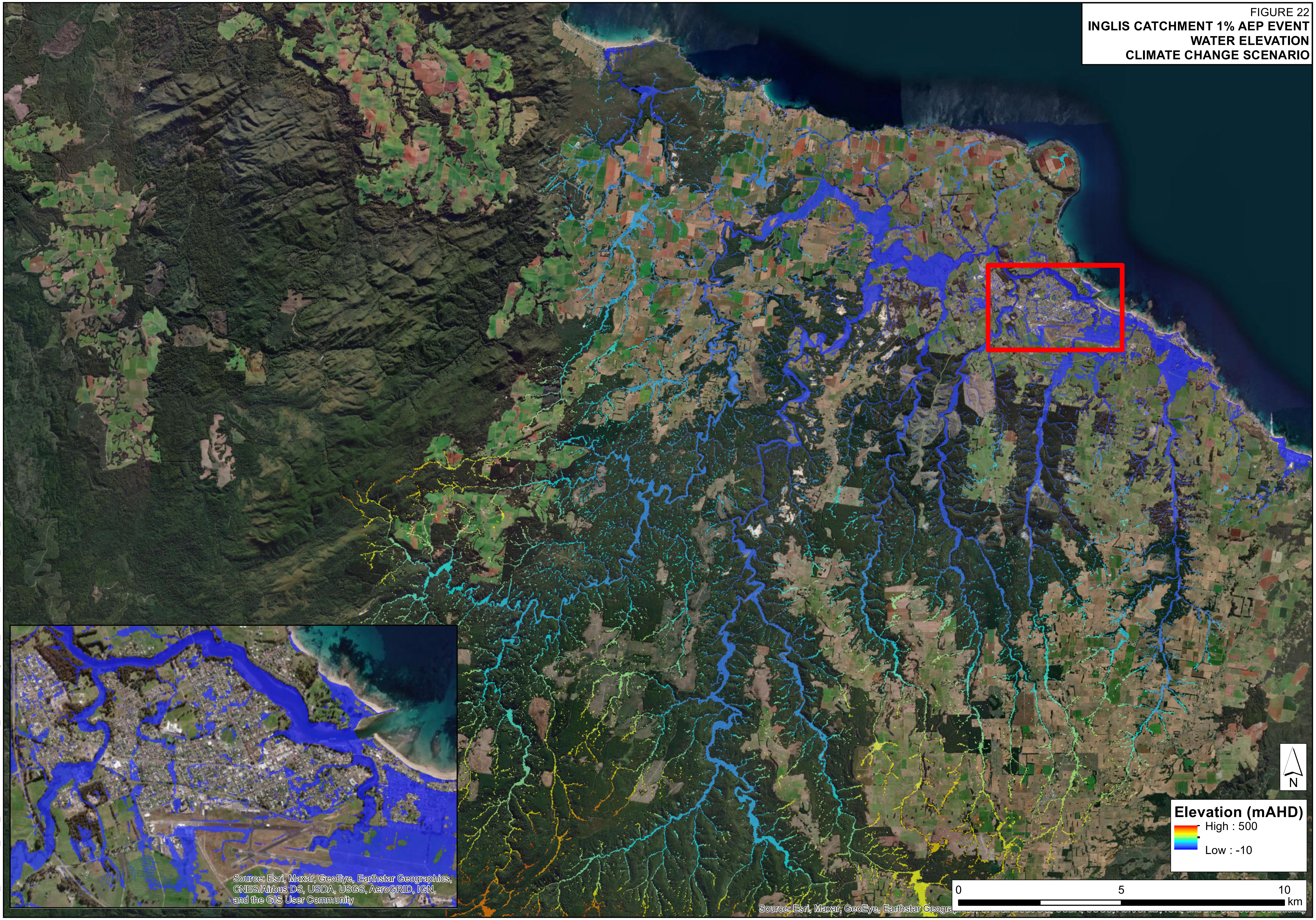


FIGURE 21
INGLIS CATCHMENT 1% AEP EVENT
PEAK FLOOD VELOCITIES
CLIMATE CHANGE SCENARIO

P:\Zac_H120038_ASC_Conversion\Combined_PDF\MXD\Figure21_PeakFloodVelocity_1%AEP_Event_CC.mxd

FIGURE 22
INGLIS CATCHMENT 1% AEP EVENT
WATER ELEVATION
CLIMATE CHANGE SCENARIO



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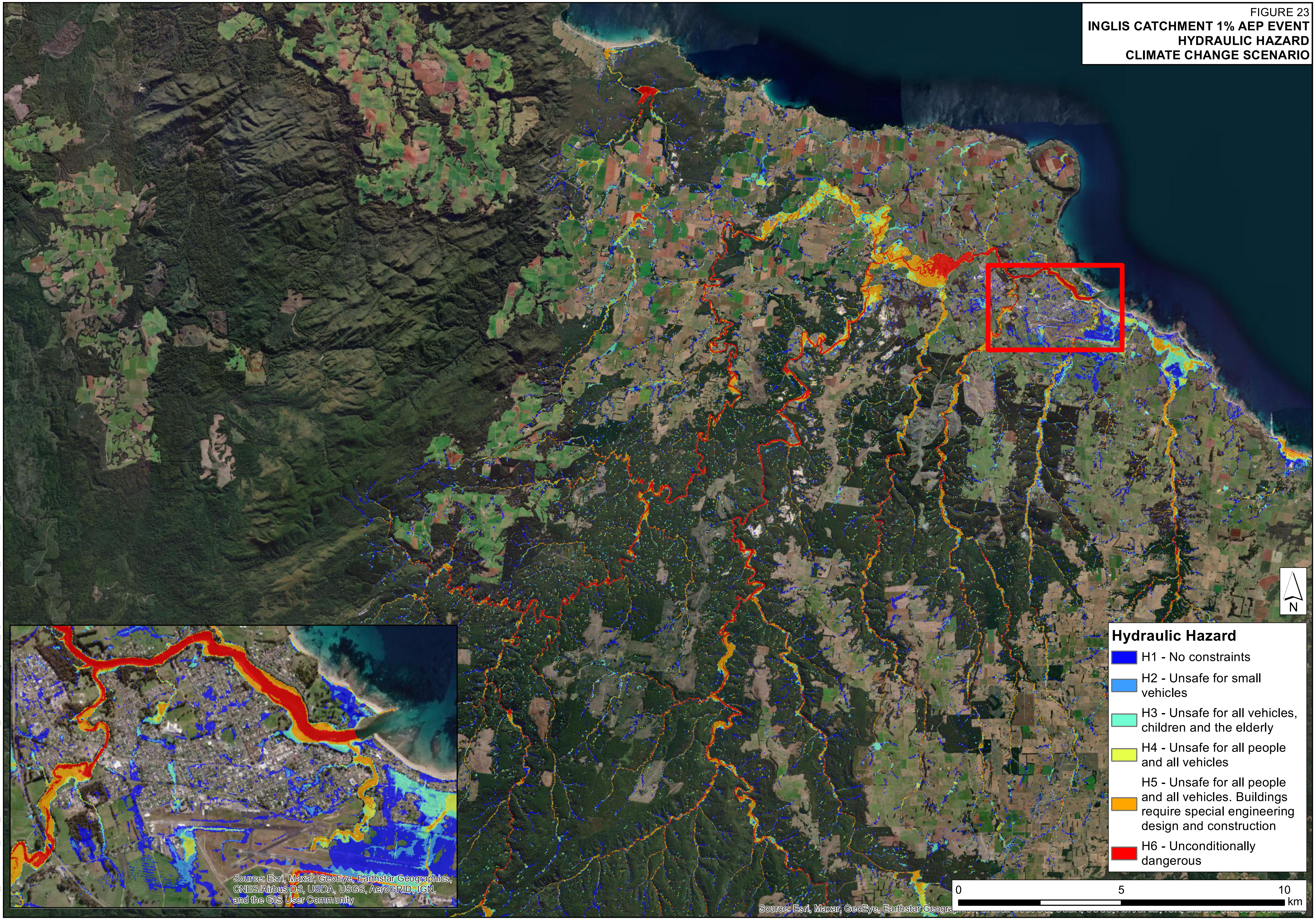

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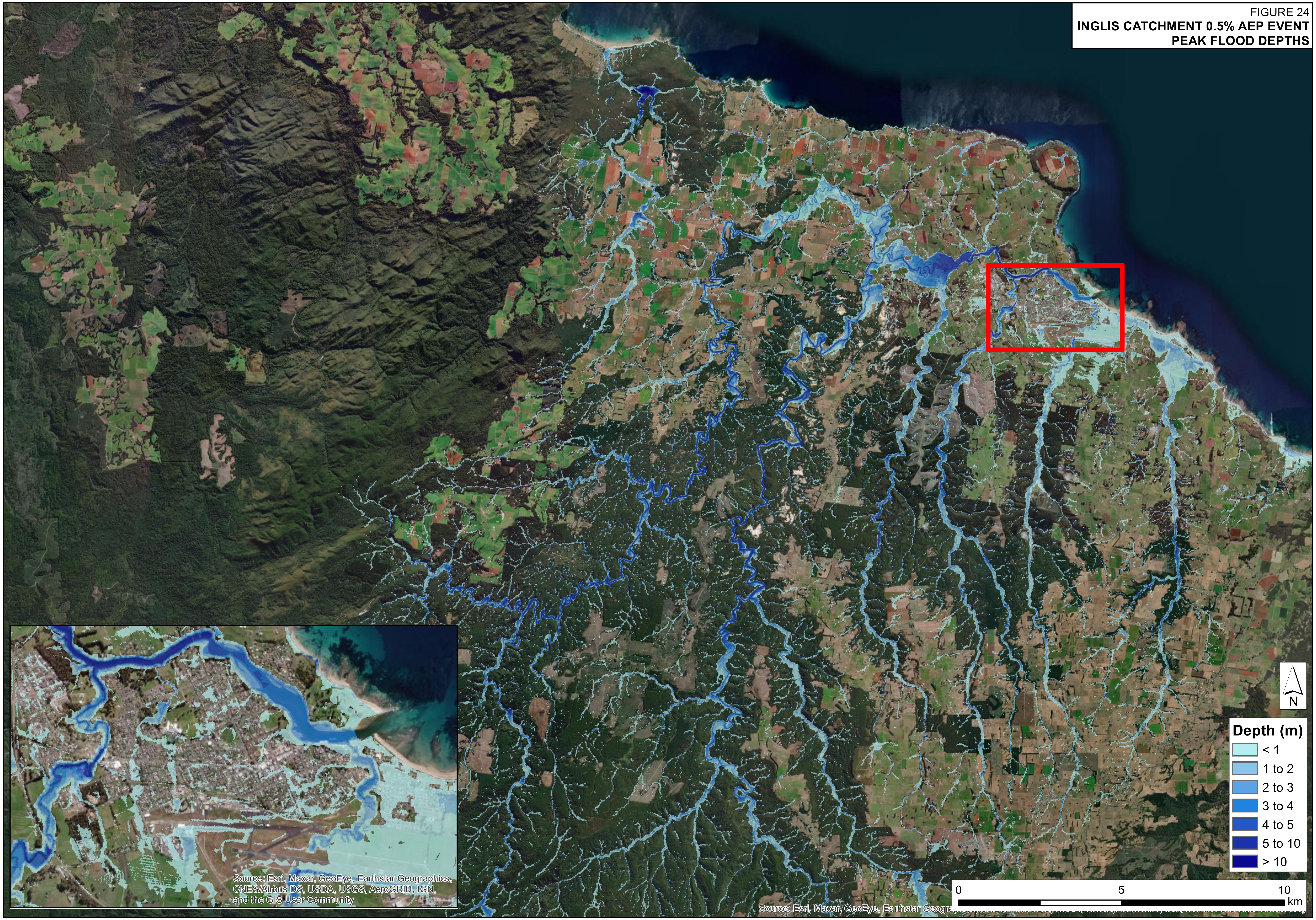

FIGURE 24
INGLIS CATCHMENT 0.5% AEP EVENT
PEAK FLOOD DEPTHS

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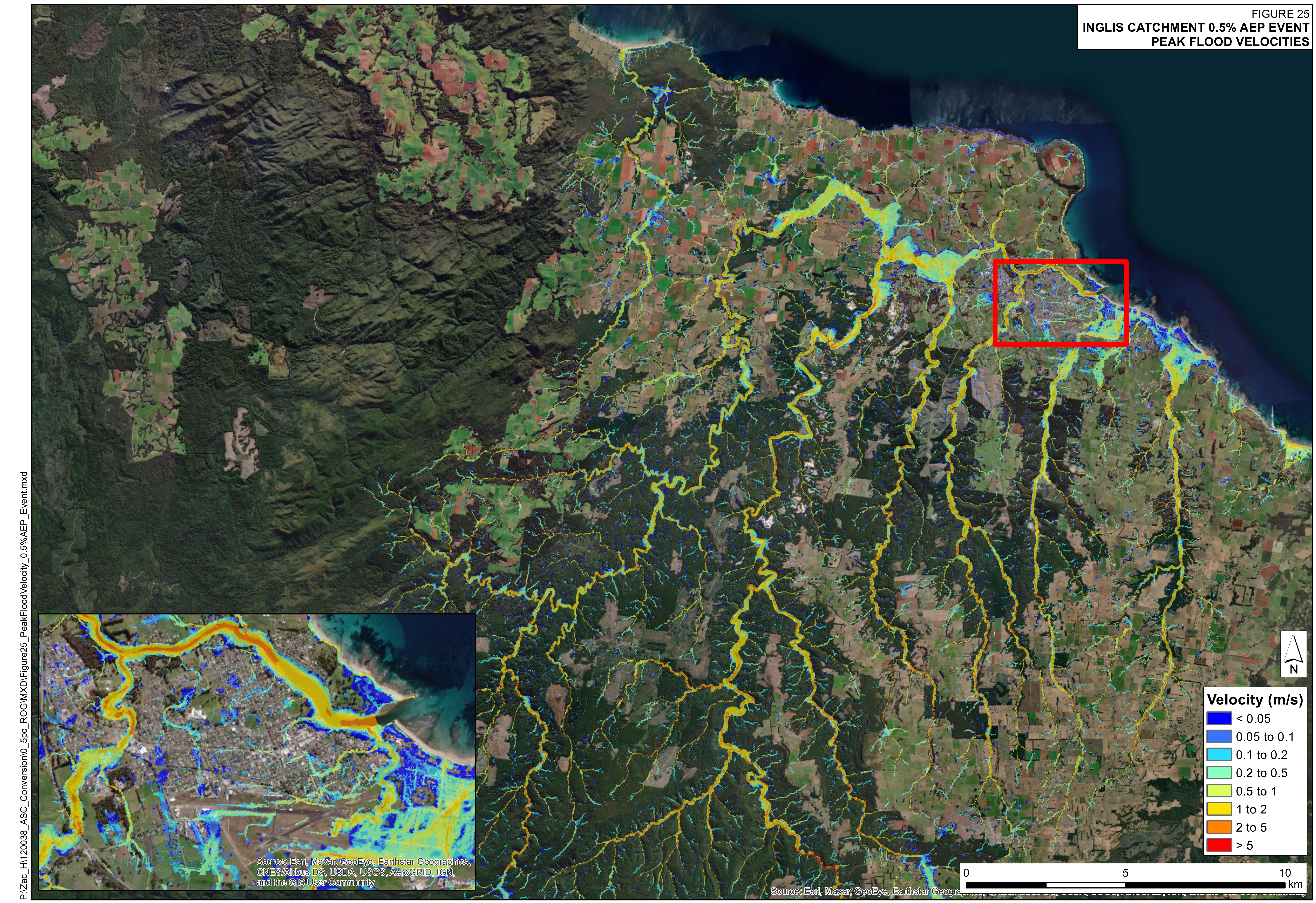
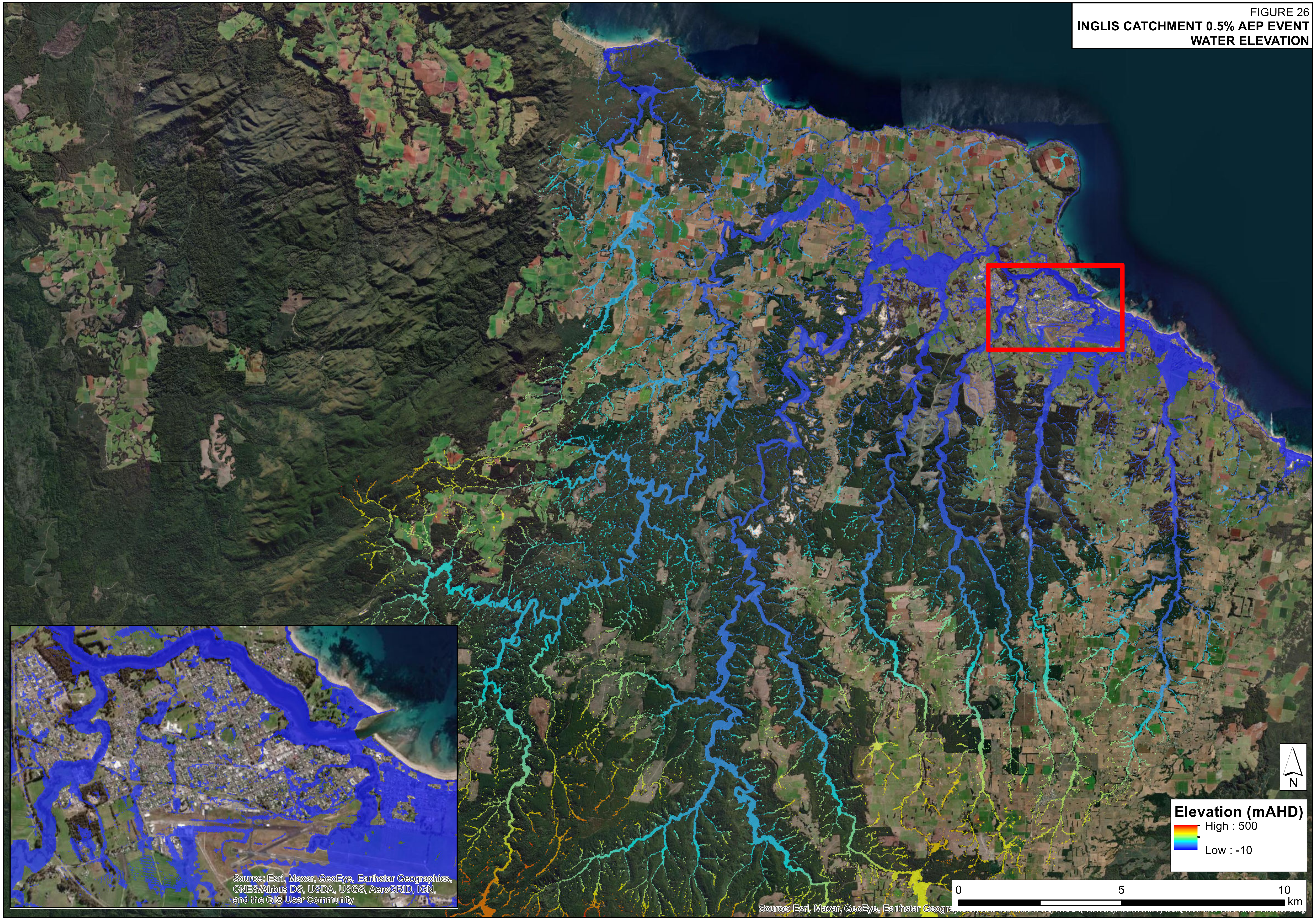


FIGURE 25
INGLIS CATCHMENT 0.5% AEP EVENT
PEAK FLOOD VELOCITIES
Velocity (m/s)
< 0.05
0.05 to 0.1
0.1 to 0.2
0.2 to 0.5
0.5 to 1
1 to 2
2 to 5
> 5
N
0
5
10
km
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
P:\Zac_H120038_ASC_Conversion\0_5pc_ROG\MXD\Figure25_PeakFloodVelocity_0.5%AEP_Event.mxd

FIGURE 26
INGLIS CATCHMENT 0.5% AEP EVENT WATER ELEVATION



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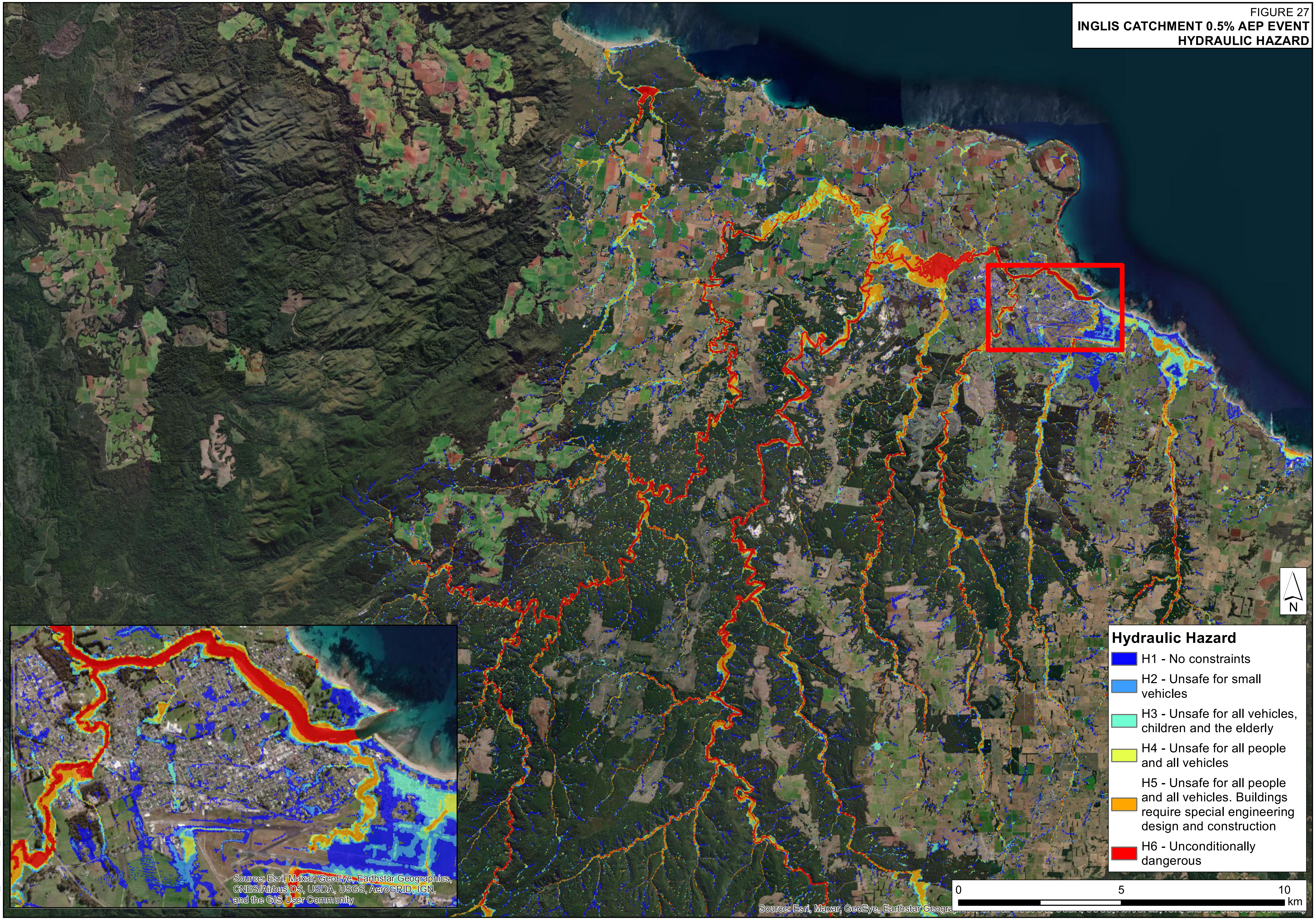

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APPENDIX A. AVALIABLE DATA

A.1. Design Event Data

FIGURE A1
DESIGN RAINFALL DEPTHS
720MIN 2%AEP

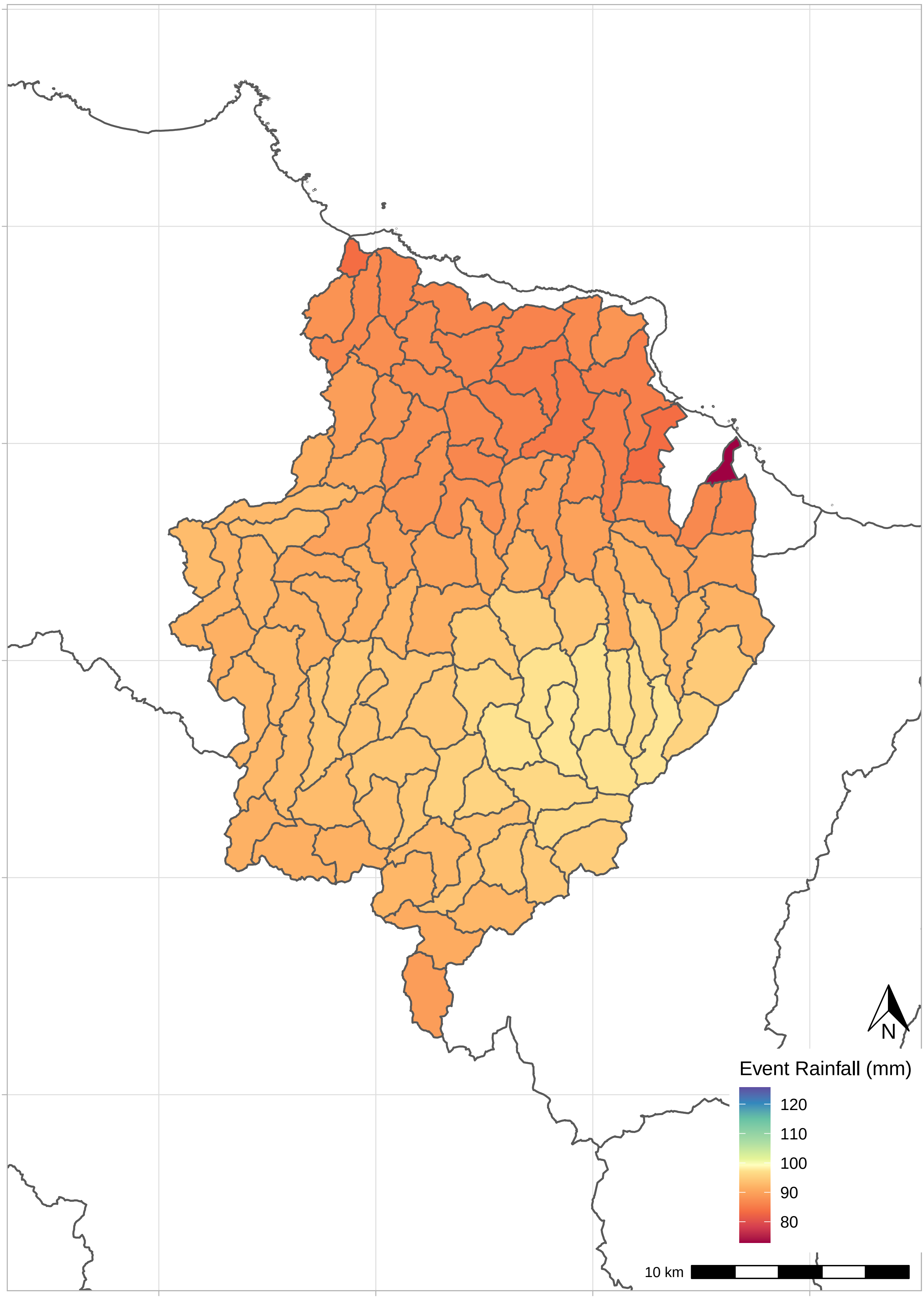

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FIGURE A2

DESIGN RAINFALL DEPTHS

720MIN 1%AEP

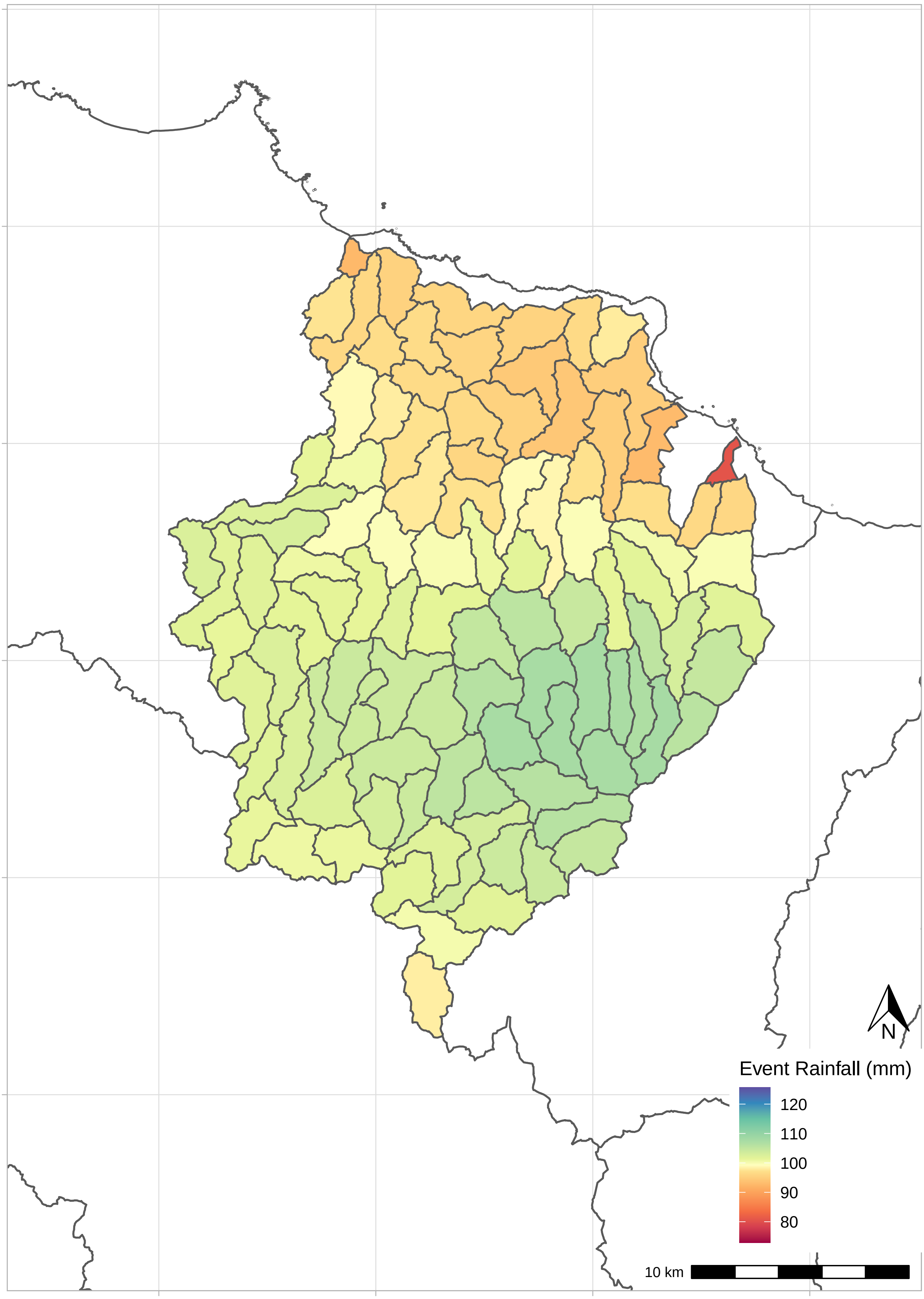

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FIGURE A3

DESIGN RAINFALL DEPTHS

720MIN 1IN200AEP

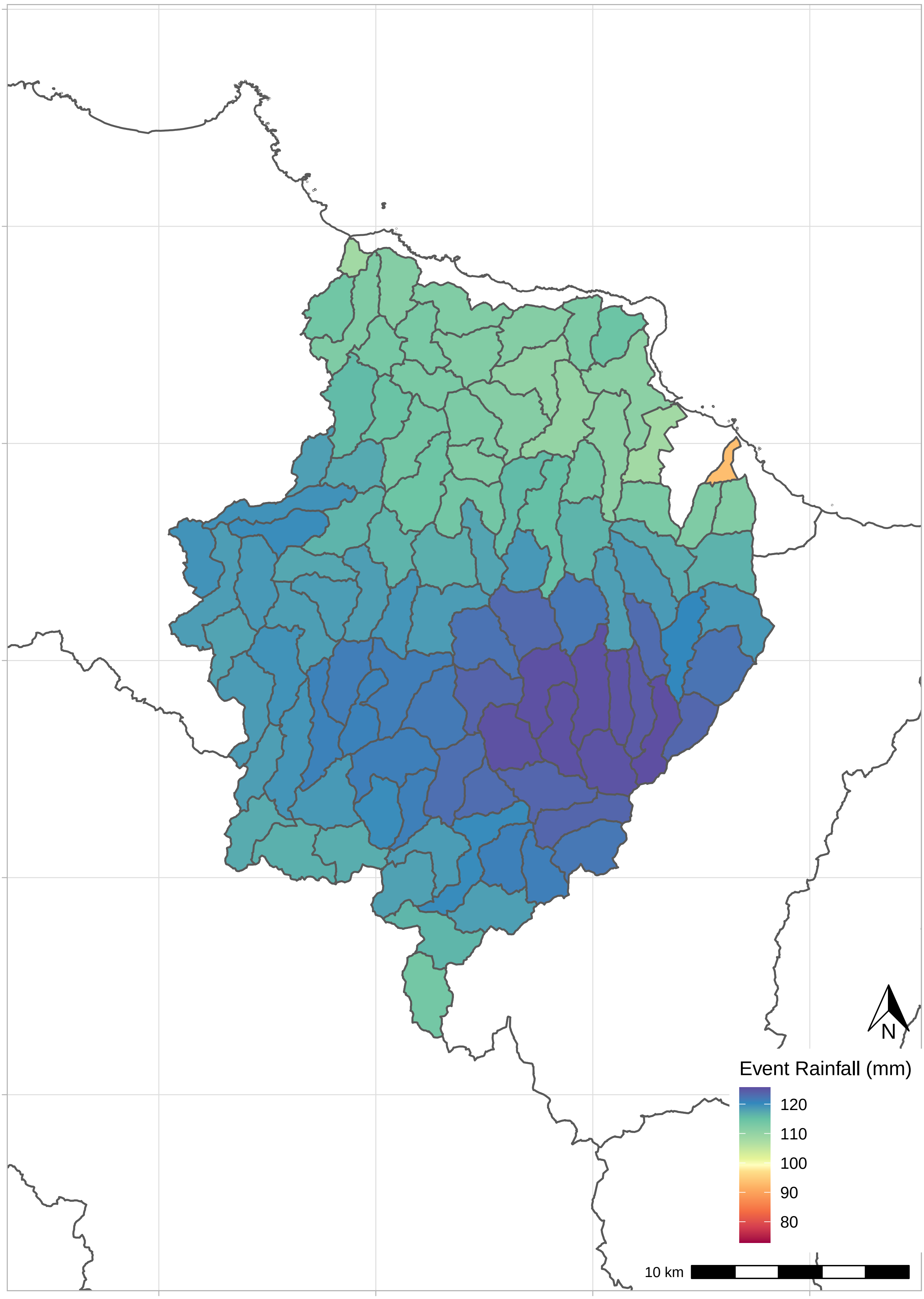

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FIGURE A4

DESIGN AREAL TEMPORAL PATTERNS

DURATIONS FROM 1 TO 12 HOURS

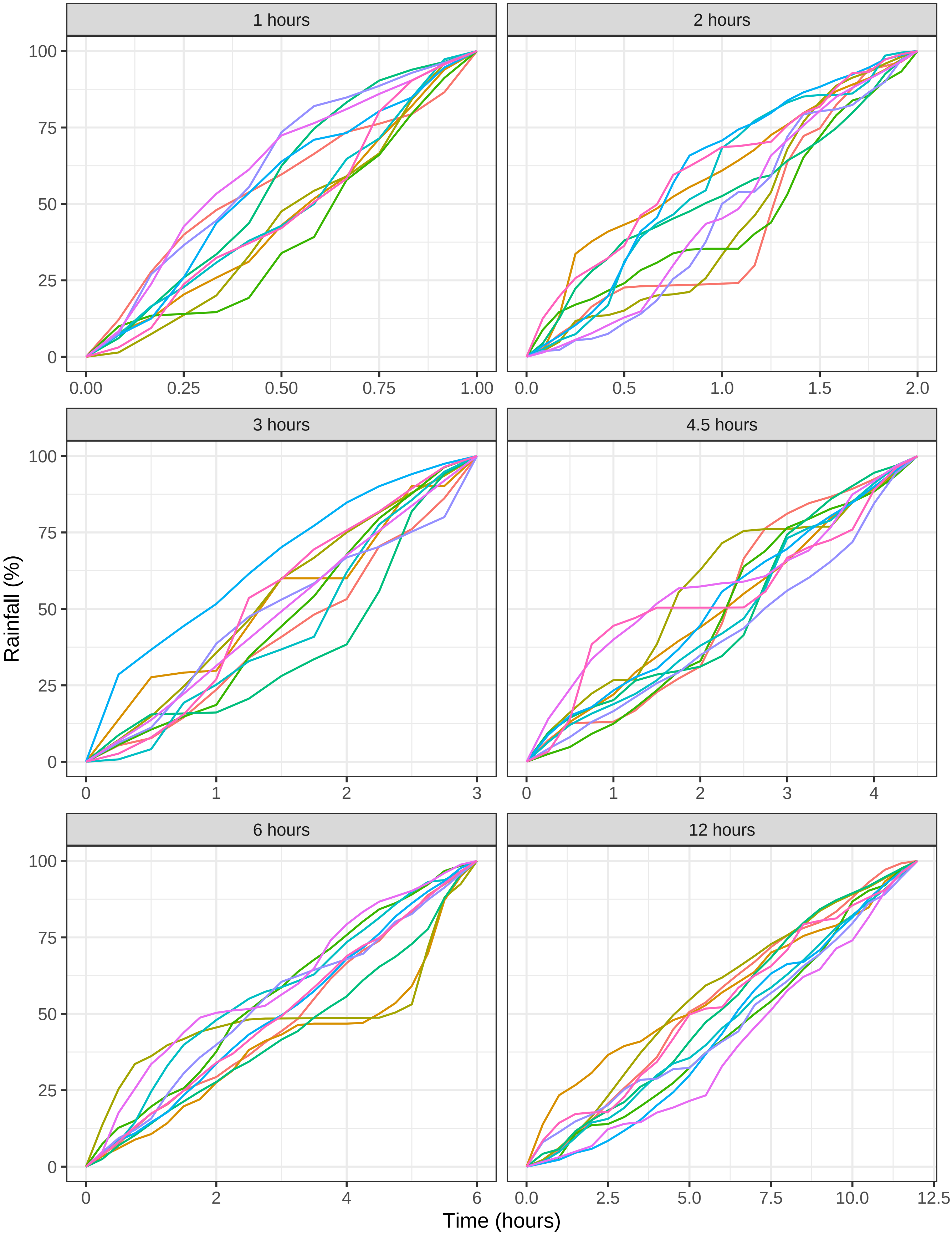

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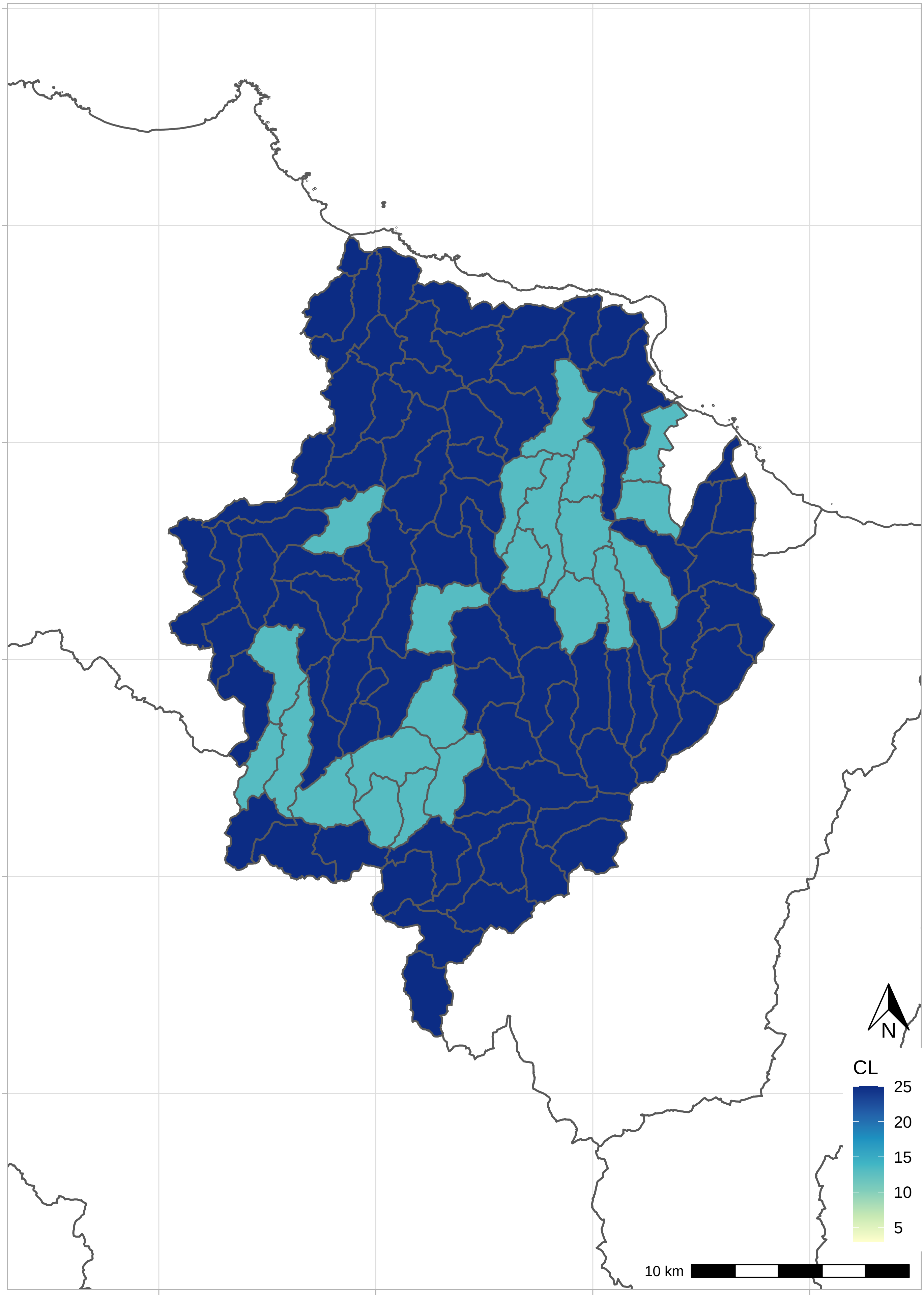
FIGURE A5

HYDROLOGICAL SOIL GROUP MAPPING

DOMINANT SUBCATCHMENT SOIL INFILTRATION RATE



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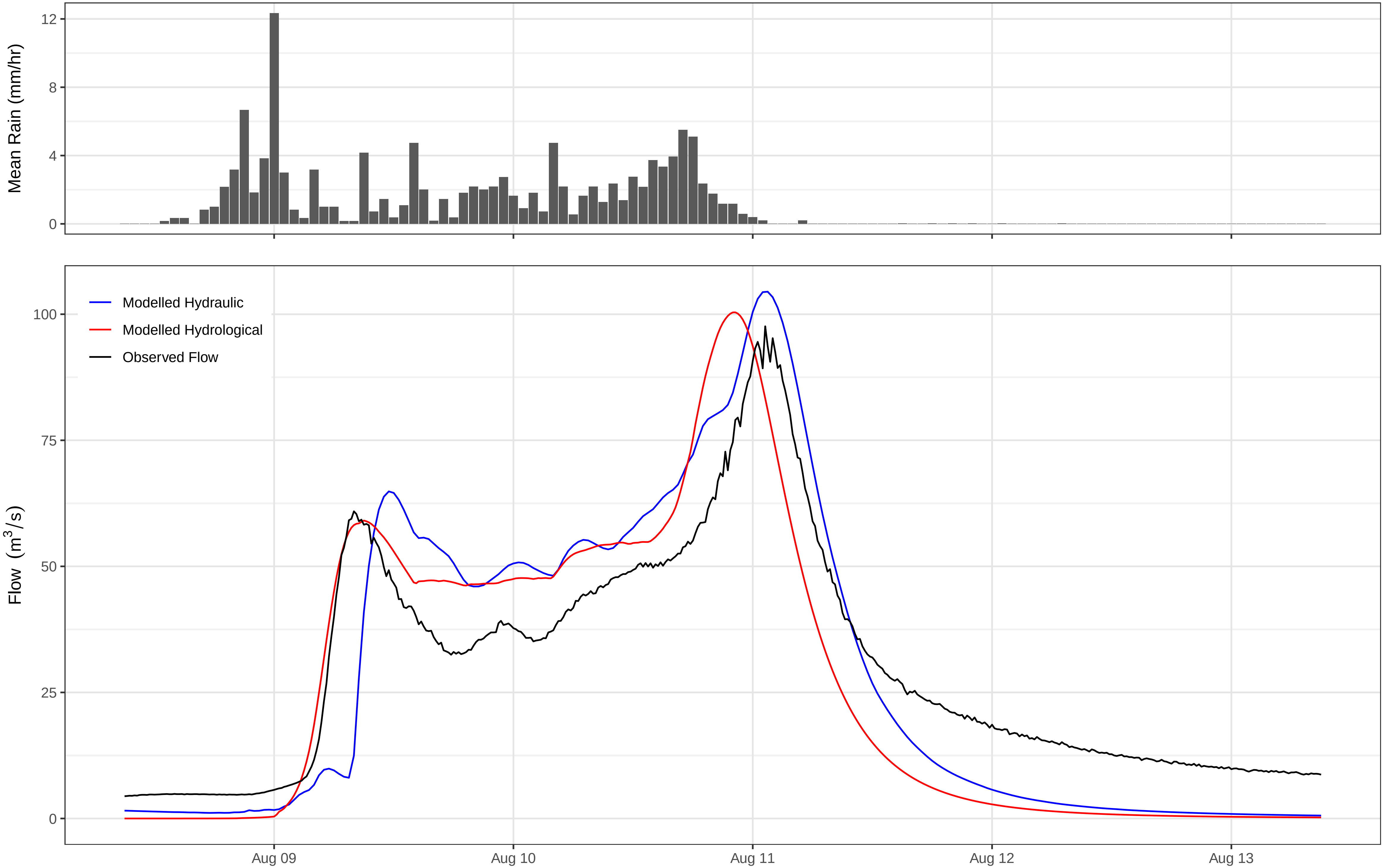
Appendix B

APPENDIX B. HYDROLOGIC MODEL

FIGURE B01
FLOWERDALE RIVER AT MOORLEAH
2007 AUG: DEFAULT ROUTING PARAMS
MEAN LOSSES IL=22 CL=0.8



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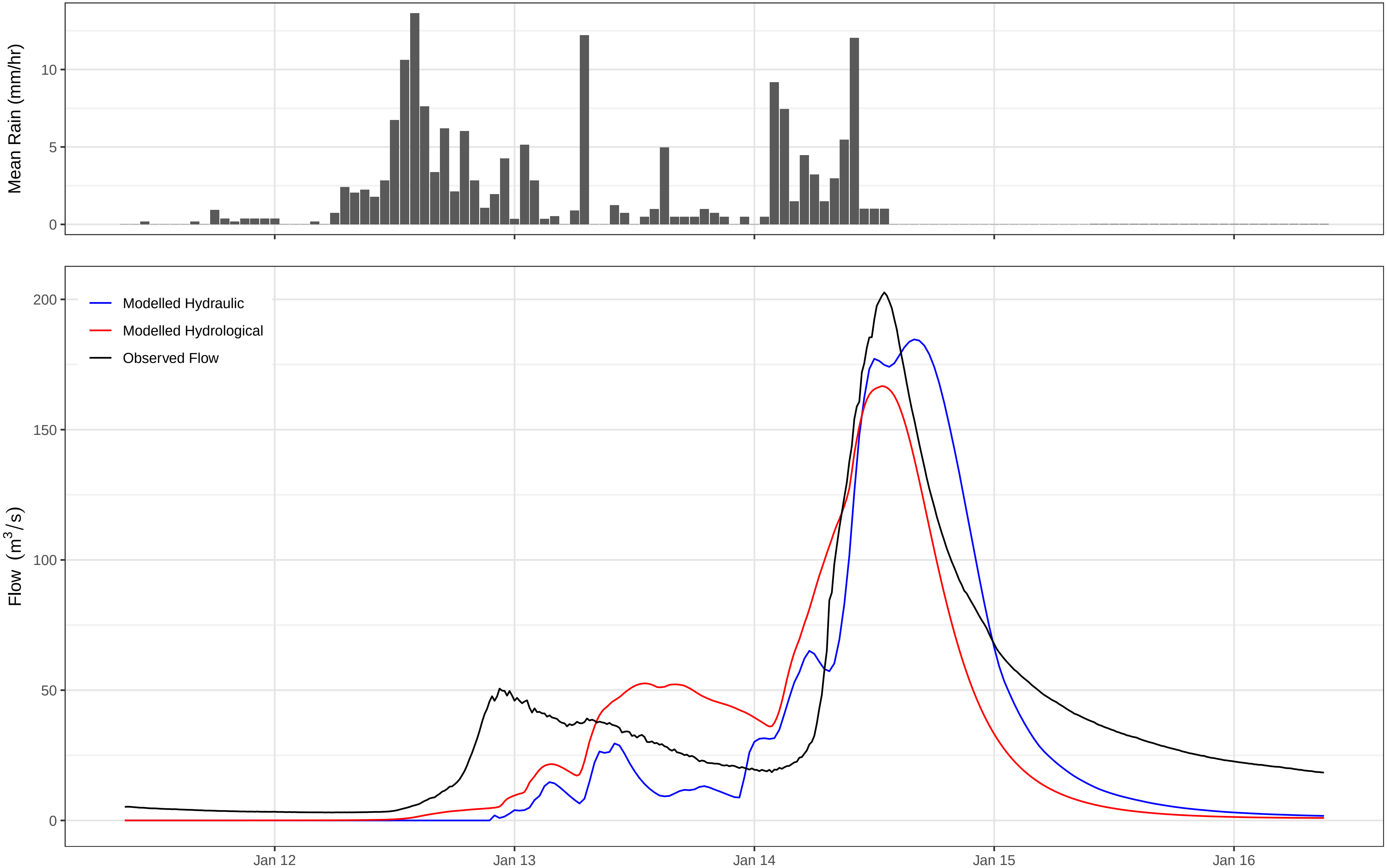
J:\Jobs\120038\Hydrology\Validation_Catchments\Calibration\Inglis_postRainfallVariation\collate_results\Report_plots_2021_05_25/FigureB01_Fwdle 2007 Aug Default Routing Params.pdf

FIGURE B02

FLOWERDALE RIVER AT MOORLEAH

2011 JAN: DEFAULT ROUTING PARAMS

MEAN LOSSES IL=89 CL=0



created by J:/Jobs/120038/Hydrology/R_scripts/Validation_Catchments/Calibration_report_plots.R
J:\Jobs\120038\Hydrology\Validation_Catchments\Calibration\Inglis_postRainfallVariation\collate_results\Report_plots_2021_05_25/FigureB03_Fwdle 2016 Jun Default Routing Params.pdf

FIGURE B03
FLOWERDALE RIVER AT MOORLEAH
2016 JUN: DEFAULT ROUTING PARAMS
MEAN LOSSES IL=80 CL=0

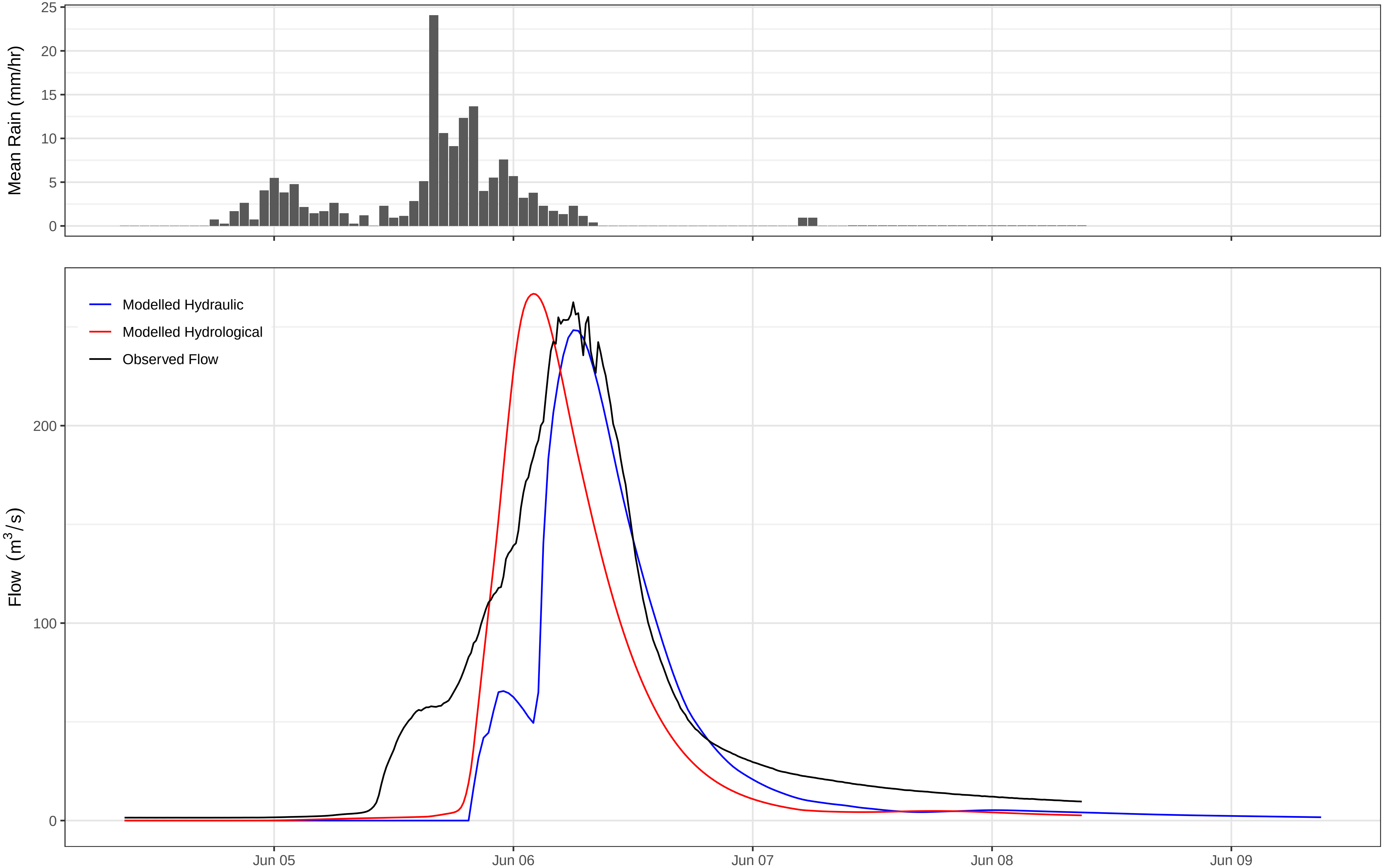
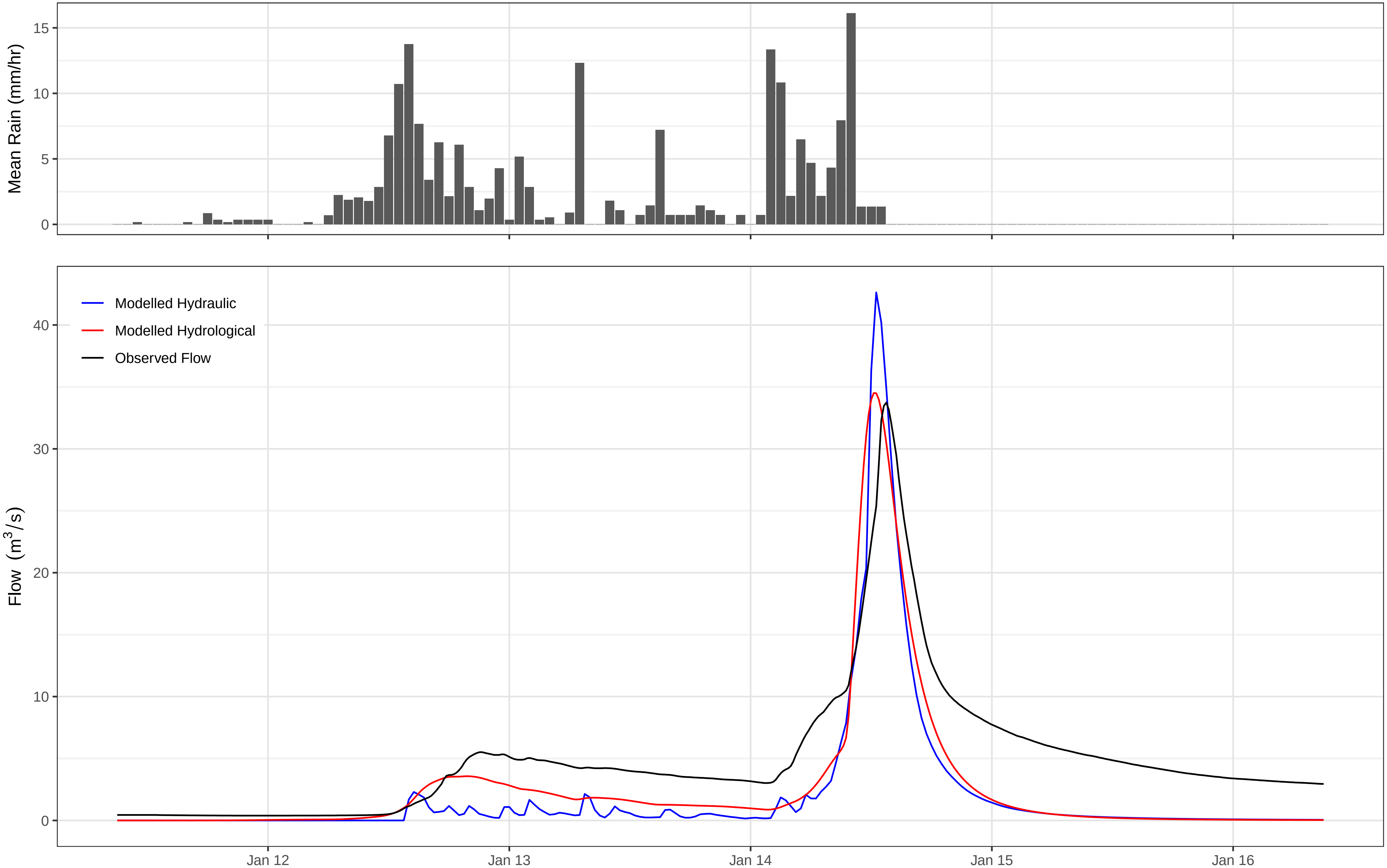


FIGURE B04

SEABROOK CREEK U/S BASS HWY

2011 JAN: DEFAULT ROUTING PARAMS

MEAN LOSSES IL=150 CL=6



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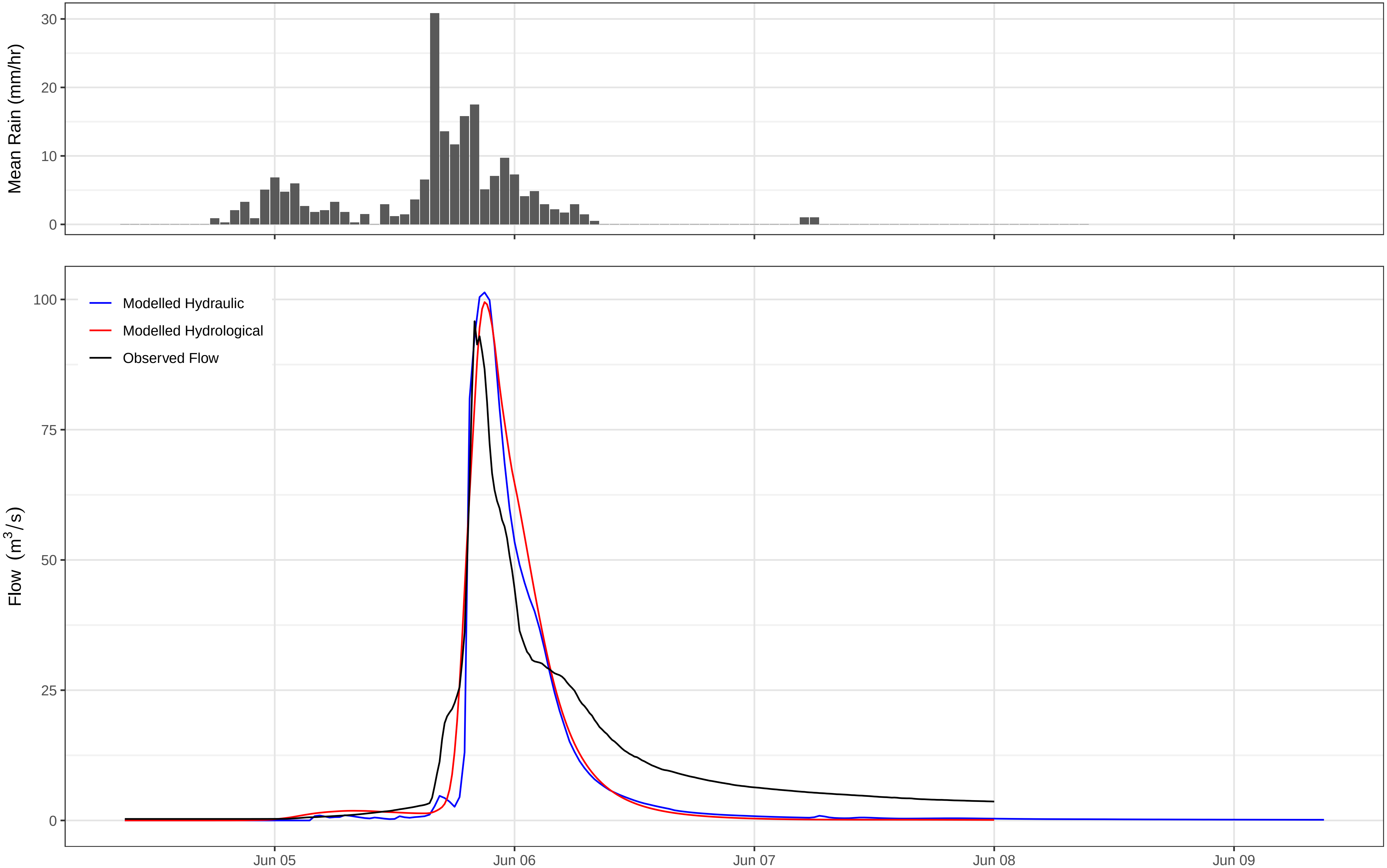
J:\Jobs\120038\Hydrology\Validation_Catchments\Calibration\Inglis_postRainfallVariation\collate_results\Report_plots_2021_05_25/FigureB04_Sbrok 2011 Jan Default Routing Params.pdf

FIGURE B05
SEABROOK CREEK U/S BASS HWY
2016 JUN: DEFAULT ROUTING PARAMS
MEAN LOSSES IL=85 CL=4.5



created by J:/Jobs/120038/Hydrology/R_scripts/Validation_Catchments/Calibration_report_plots.R
J:\Jobs\120038\Hydrology\Validation_Catchments\Calibration\Inglis_postRainfallVariation\collate_results\Report_plots_2021_05_25/FigureB05_Sbrok 2016 Jun Default Routing Params.pdf

Appendix C

APPENDIX C. UNCERTAINTY ANALYSIS

C.1. Hydrologic Model Uncertainty

Table C 1 shows the calibration event rating. The following shading is used to highlight relevant statements:

- For rainfall input quality, June 2016 and August 2007 shown in orange shading. January 2011 event shown in green shading, where different from the other events.
- For observed flows, Moorleah gauge is shown in yellow shading, Seabrook gauge in grey shading.
- For calibration events, blue shading is used.

Table C 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 300km^2 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	Calibration event is out of channel, site has been gauged during applicable rating period out of channel

				top end)	
	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 C 2 shows the hydrology calibration quality rating. The following shading is used to highlight relevant statements:

- For peak flows and hydrograph shape, June 2016 and August 2007 shown in orange shading. January 2011 event shown in green shading
- For hydrograph volumes, August 2007 is shown in yellow. June 2016 and January 2011 are shown in grey.

Table C 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

C.2. DTM Uncertainty

The DTM quality rating is shown in Table C 3 with orange shading.

Table C 3: DTM rating

Category	Rating				
	Poor	Fair	Good	Very good	Excellent
DTM definition	Low resolution	Low resolution	High resolution in HSA	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

C.3. Hydrodynamic Modelling Uncertainty

The hydrodynamic calibration event rating is shown in Table C 4, highlighted in orange. The calibration flood depths are considered fair in some areas and good in others (refer to Section 7.2.2).

Table C 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 C 5. The following shading is used to highlight relevant statements:

- For peak flows at Moorleah, orange shading is used for 2007 and 2016 events, blue is used for 2011 event.
- For peak levels, yellow shading is used for 2007 event, and grey shading is used for 2011 and 2016 events.
- For flood extents and calibration depths (June 2016 event), orange is used for areas where the surveyed flood levels and extents are considered to be good (Saunders St bridge, Fists Lane and around the confluence of the Inglis and Flowerdale) and green is used for areas where the surveyed flood levels and extents are considered to be in error (upstream of Saunders St bridge and Big Creek catchment).

Table C 5: Hydrodynamic calibration quality rating

Category	Rating				
	Poor	Fair	Good	Very good	Excellent
Hydrodynamic calibration - peak flow	Peak flow not within 20% of hydrology	Peak flow within 20% of hydrology	Peak flow within 15% of hydrology	Peak flow within 15% of hydrology	Peak flow within 10% of hydrology
Hydrodynamic calibration - peak levels	Peak level > +/- 1m of observed	Peak level within +/- 0.5m of observed	Peak within +/-0.5m of observed	Peak within +/-0.3m of observed	Peak within +/- 0.3m of observed
Hydrodynamic calibration – flood extents	Extent > 50m difference from observed	Extent lies within +/- 50m of recorded	Extent lies within +/- 20m of recorded	Extent lies within +/- 10m of recorded	Extent lies within +/- 5m of recorded
Hydrodynamic calibration - depths	Depth within > +/- 1m of Survey	Depth within +/- 1 m of Survey	Depth within +/- 0.5m of Survey	Depth within +/- 0.3m of Survey	Depth within +/- 0.3m of Survey