STATE EMERGENCY SERVICE

TASMANIAN STRATEGIC FLOOD MAP FORTH-LEVEN STUDY AREA DESIGN FLOOD MODELLING

ADDENDUM TO CALIBRATION REPORT

NOVEMBER 2022

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Project Tasmanian Strategic Flood Map Forth-Leven Study Area Design Flood Modelling	**Project Number** **120038**
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Revision History

Revision	Description	Distribution	Authors	Reviewed by	Verified by	Date
0	Addendum to calibration report	Chris Irvine, SES	Sarah Blundy, Evmen Wong	Daniel Wood	Fiona Ling	NOV 22
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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
AMS	Annual Maximum Series
ARF	Areal Reduction Factor
ARR	Australian Rainfall and Runoff
ATP	Areal Temporal Patterns
Bureau/BoM	Bureau of Meteorology
CC	Climate Change
CFEV	Conservation of Freshwater Ecosystem Values (DPIPWE/DNRE)
CL	Continuing Loss
DEM	Digital Elevation Model
DPIPWE	Department of Primary Industries, Water and Environment
DNRE	Department of Natural Resources and Environment Tasmania (formerly DPIPWE)
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
HAT	Highest Astronomical Tide
HSA	Human Settlement Area
ICM	Infoworks ICM software (Innovyze)
IL	Initial Loss
IFD	Intensity, Frequency and Duration (Rainfall)
ISIS	ISIS 2D modelling software
LiDAR	Light Detection and Ranging
mAHD	meters above Australian Height Datum
NTC	National Tide Centre
PERN	Catchment routing parameter in RAFTS
Pluvi	Pluviograph – Rain gauge with ability to record rain in real time
PTP	Point Temporal Patterns
R	Channel routing param in WMAWater RAFTS WBNM hybrid model
RAF	RAFTS Adjustment Factor
RAFTS	hydrologic model
RCP	Representative Concentration Pathways (RCPs) (CC scenarios)
RORB	RORB hydrological modelling software
SES	State Emergency Service
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software (hydrodynamic model)
TP	Rainfall Temporal Patterns

1. INTRODUCTION

This report is an addendum to the Tasmanian Strategic Flood Map Forth-Leven Study Area Calibration Report (WMAwater, 2022). The study area, available data, model calibration, limitations and uncertainty statements are provided in the calibration report.

This report outlines the data, methodology and the results of modelling the design flood events for the Forth-Leven Study Area.

2. DATA

2.1. Previous Flood Studies

Previous flood studies in the study area were provided to WMAwater as part of the project data library. The studies that include modelling of the 1% AEP event are listed in Table 1.

Table 1: Previous flood studies

Flood study name	Study year	Study area	Flood extents and layers available
Forth Flood Plan – Hydraulic Modelling Report (Entura)	2014	Forth River (between Forth Road and Bass Highway)	Some design flows and levels contained in the report.
Forth Flood Plan – Hydraulic Modelling Report Addendum (Entura)	2015	Forth River (between Forth Road and Bass Highway)	Some flood mapping available (PDF format only)

2.2. Flow Data

Flood Frequency Analysis (FFA) was performed on annual maximum series (AMS) from flow gauges within the catchment. The gauges used for FFA are shown in Table 2. The other gauges in the study area were not included in the FFA due to insufficient record length, being highly influenced by upstream dams, inconsistent datasets and/or unreliable rating curves. More detail on the quality of the gauge data is provided in the calibration report (WMAwater, 2022).

A local hydrodynamic model was used to create theoretical rating curves at the Leven River at Bannons Bridge gauge (WMAwater, 2021c). This rating was largely similar to the more recent DNRE ratings below 5m local stage height, so the original ratings were maintained for these events, where more gaugings are available to inform historical ratings. The revised rating curve was applied to the four largest events on record (including the three calibration events) as the rating showed significant variance and the water levels are outside the range of historic gaugings. The supplied rating curve for Forth River a/b Lemonthyme is believed to be good with high flow gaugings available. However, as discussed in the calibration report the river bathymetry in the DEM did not provide enough definition for the modelled rating curve to match historic rating curves at the site.

Table 2: Flow gauges used for FFA

Gauge number	Gauge name	River	Period of record	Number of points in AMS
450-1	Forth River a/b Lemonthyme	Forth River	1963-2020	57
14207-1	Leven River at Bannons Bridge	Leven River	1963-2020	55

2.3. Design Inputs

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

2.3.1. 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 A 1 to Figure A 3.

2.3.2. 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 the flood frequency analysis, 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. Temporal patterns were filtered for embedded bursts and in some cases patterns with large, embedded bursts causing significant outliers were removed. When assessing the reference critical flow for each sub-catchment (as described in the Hydrology Methods Report (WMAwater, 2021a)), 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).

2.3.3. Pre-burst

Pre-burst rainfall depths were taken from the ARR Data Hub as a ratio of the IFD depths. As ILs calibrated to the FFA were greater than 0 there was no need to include sensitivity to adding a pre-burst temporal pattern for this study area, as the pre-burst has effectively been removed from the IL with some IL depth remaining.

2.3.4. 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).

2.3.5. 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), where baseflows of less than 5% are considered a small component compared to runoff, a simplified approach to baseflow calculations was 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 a small component of the hydrograph for the AEPs of interest (2%, 1% and 0.5%) and therefore baseflow was not included in the design events.

2.3.6. Direct Rainfall

Two hour direct rainfall storms were created using each sub-catchment's IFD depths using the method described in the Hydrodynamic Methods Report (WMAwater, 2021b).

2.3.7. Climate Change

2.3.7.1. 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% to the IFDs.

2.3.7.2. 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 0.82 m for the Central Coast Council area.

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

3. OVERVIEW OF METHODOLOGY

The hydrological and hydrodynamic design modelling 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 for the design events includes the following steps.

- Data preparation
    - Fitting FFA to suitable flow records
    - Extraction of design data – IFDs, temporal patterns, pre-burst rainfalls from ARR DataHub (automated in the modelling process), derivation of direct rainfall storms
- 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 hydrodynamic model.
- Hydrodynamic modelling
    - Run design events and direct rainfall through the calibrated hydrodynamic model with the applicable downstream boundary levels and dam initial conditions.
    - Output design event and direct rainfall results for processing.
- Mapping
    - Convert design event and direct rainfall results to a grid format with a grid resolution of at least 10 m.
    - Envelope design event results to produce the maximum envelope of the inputs.
    - Filter direct rainfall results using a peak flood depth filter of 0.1 m. Clip direct rainfall results to the design event envelope.
    - Map the design event envelope and filtered direct rainfall results.

During the design event selection process, it was discovered that the standard selection process could not select a small number of patterns which were viable across the catchment without the patterns with small ARFs (i.e. higher rainfalls) drowning out all patterns with more appropriate ARF factors in the lower catchment. The selected patterns were therefore forcibly applied to their respective regions through the cropping of the design event results prior to the enveloping.

It is acknowledged that the cropping may result in abrupt changes in levels at the boundaries of the selected patterns in the design mapping. Where possible, the boundaries of the selected patterns were located away from human settlement areas and major infrastructure to minimise the impact of the cropping. Discontinuities in the design mapping in isolated areas should still be expected, however this was deemed to be an acceptable compromise in achieving a better representation in the design mapping across the remainder of the study area.

4. CALIBRATION OF DESIGN LOSSES

FFA was undertaken at the gauges identified in Table 2. The results of the FFA are shown in Figure 1 and Figure 2. The fitting method and distribution that provided the best fit to the data at each site is shown in Table 3.

Table 3: Fitting method and distribution used for FFA

Gauge number	Gauge name	Fitting method	Distribution
450-1	Forth River a/b Lemonthyme	Bayesian	Log Pearson III
14207-1	Leven River at Bannons Bridge	Bayesian	Log Pearson III

The calibrated external hydrologic model for each study area 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 the FFA curve. The catchment-average continuing loss was distributed across the study area using the hydrological soil group final infiltration rates.

The percentage differences between the FFA and the modelled peak flow for the 2%, 1%, and 0.5% AEP events are shown in Table 4. The modelled data provided a good fit to the 2% and 1% AEP FFA peak flows. As has been found across the state the IFD curves increase in gradient at the 1% AEP rainfall and therefore the 0.5% AEP flows are overestimated.

Table 4: FFA and modelled peak flows

	Forth ab Lemonthyme			Leven River		
Parameter	**2% AEP**	**1% AEP**	**0.5% AEP**	**2% AEP**	**1% AEP**	**0.5% AEP**
Modelled peak flow (m^3/s)	415	471	592	586	682	855
FFA peak flow (m^3/s)	420	472	527	595	690	792
Peak flow difference (%)	-1%	-0.1%	12%	-2%	-1%	8%

The adopted loss values are shown in Table 5, and comparisons to site FFAs are shown in Figure 1 and Figure 2.

Table 5: Adopted losses

Initial Loss (mm)	Continuing Loss (mm/h)			
	Soil Type A	**Soil Type B**	**Soil Type C**	**Soil Type D**
14	2	1.04	0.48*	0.24*

*Soil type C and D make up less than 1% of the catchment area each

5. DESIGN EVENT MODELLING

5.1. 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 the number of sub-catchments best represented by each are shown in Table 6. The temporal patterns for each selected run are shown in Figure 3.

In some parts of the study area, the smaller ARF patterns were drowning out the more appropriate bins. Therefore, in some places the resulting grids were cropped to the appropriate areas, as detailed in Section 3.

Table 6: 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%	720	75	60
2%	1440	800	9
2%	2160	450	22
2%	2160	1200	5
1%	720	75	61
1%	1440	800	9
1%	2160	450	22
1%	2160	1200	5
0.5%	720	75	58
0.5%	1440	800	9
0.5%	2160	450	22
0.5%	2160	1200	5

Diagram 1 shows which ARF-duration-TP set gives representative flows for each sub-catchment for the 1% AEP event. Headwater sub-catchments where only direct rainfall is applied are also shown. In the headwater catchments, direct rainfall was defined as the dominating event, with the rainfall intensities factored to account for losses via a runoff coefficient. For this study area, a runoff coefficient of 65% was adopted. Although direct rainfall is applied to all sub-catchments, the mapping process detailed in Section 3 ensures that primary flow paths are not defined by this event.

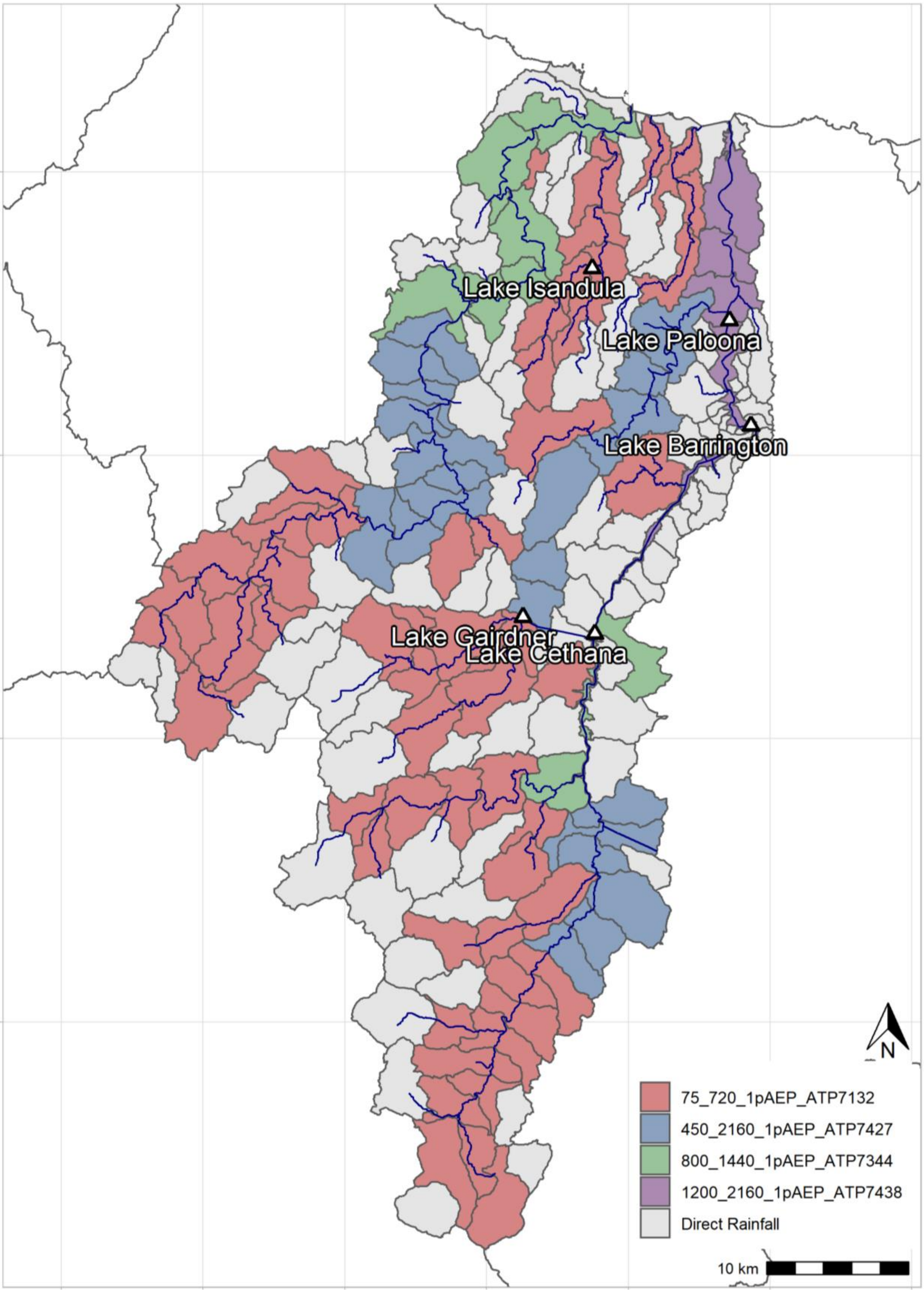

Diagram 1: ARF set relevant for each sub-catchment for the 1% AEP event

The selection of four ARF-duration-TP sets per AEP does introduce errors when compared to running the ideal ARF-duration-TP set through the hydrodynamic model for each sub-catchment, however running thousands of runs of the hydrodynamic model is not computationally feasible.

The percentage errors for each sub-catchment are shown in Figure B 1 to Figure B 3 and a summary of the magnitude of the errors is shown in Table 7. 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 as shown in Diagram 1

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

Table 7: Sub-catchment errors using the ARF-TP-duration sets shown in Table 6 for each AEP

AEP	Absolute sub-catchment error		
	Mean across sub-catchments	**90th %ile across sub-catchments**	**Max of all sub-catchments**
2%	-3%	2%	7%
1%	-3%	2%	7%
0.5%	-2%	3%	10%

The selected storms and direct rainfall were then run through the calibrated hydrodynamic model as documented in the calibration report (WMAwater, 2022). For the design event modelling, the downstream boundary adopts a static tailwater level set to the highest astronomical tide (HAT). This data was provided by the National Tide Centre (NTC) in 5 km² grid cells and was extracted off the coast of Ulverstone.

Table 8 below summarises the downstream boundary levels and dam initial conditions for each design event.

Table 8. Downstream boundary levels and dam initial conditions for each AEP

<table>
<tr><th>AEP</th><th>Downstream boundary</th><th>Lake Gairdner</th><th>Lake Cethana</th><th>Lake Barrington</th><th>Lake Paloona</th><th>Lake Isandula</th></tr>
<tr><td>2%</td><td rowspan="3">HAT
(1.83 mAHD)</td><td rowspan="4">FSL
(472.44 mAHD)</td><td rowspan="4">FSL
(220.98 mAHD)</td><td rowspan="4">FSL
(121.92 mAHD)</td><td rowspan="4">FSL
(53.34 mAHD)</td><td rowspan="4">FSL
(131.79 mAHD)</td></tr>
<tr><td>1%</td></tr>
<tr><td>0.5%</td></tr>
<tr><td>1% CC</td><td>HAT + sea level rise
(2.65 mAHD)</td></tr>
</table>

5.2. Design Event Results

The results of the design event modelling are shown in Figure 4 to Figure 19 in terms of peak flood level, depth, velocity, and hydraulic hazard for the 2%, 1%, 1% CC, and 0.5% AEP design events. The results shown are of the design event envelope and filtered direct rainfall results, as detailed in Section 3. A critical event plot for the 1% AEP design event is provided in Figure 20.

For direct rainfall only, in some areas the peak flow for headwater catchments was found to be higher in the hydrodynamic model than in the external hydrologic model. To ensure that the overestimation of these peak flows in the headwater catchments would not impact the design results, the direct rainfall results were clipped to the design event envelope.

The outcomes of the design event modelling have been reviewed against the gauge FFA and the previous flood studies.

5.2.1. Review of Results at Forth River a/b Lemonthyme

A review of the design flows produced from the hydrodynamic model at Forth River a/b Lemonthyme was undertaken, by comparing to the flows derived from the FFA. The modelled peak flows show a good match to the FFA peak flows at this location (Table 9).

Table 9: Design flows at Forth River a/b Lemonthyme

Parameter	2% AEP	1% AEP	1% AEP CC	0.5% AEP
Modelled peak flow (m^3/s)	403	465	561	555
FFA peak flow (m^3/s)	420	472	n/a	527
Peak flow difference (%)	-4%	-1%	n/a	+5%

5.2.2. Review of Results at Leven River at Bannons Bridge

A review of the design flows produced from the hydrodynamic model at Leven River at Bannons Bridge was undertaken, by comparing to the flows derived from the FFA. The modelled peak flows show a reasonable match to the 2% AEP and 1% AEP FFA peak flows at this location (Table 10). As has been seen across the state, there is a notable change in slope in the IFD rainfalls at 1% AEP which is contributing to the overestimation of flows at 0.5% AEP (Diagram 2).

Table 10: Design flows at Leven River at Bannons Bridge

Parameter	2% AEP	1% AEP	1% AEP CC	0.5% AEP
Modelled peak flow (m^3/s)	638	741	907	908
FFA peak flow (m^3/s)	595	690	n/a	792
Peak flow difference (%)	+7%	+7%	n/a	+15%

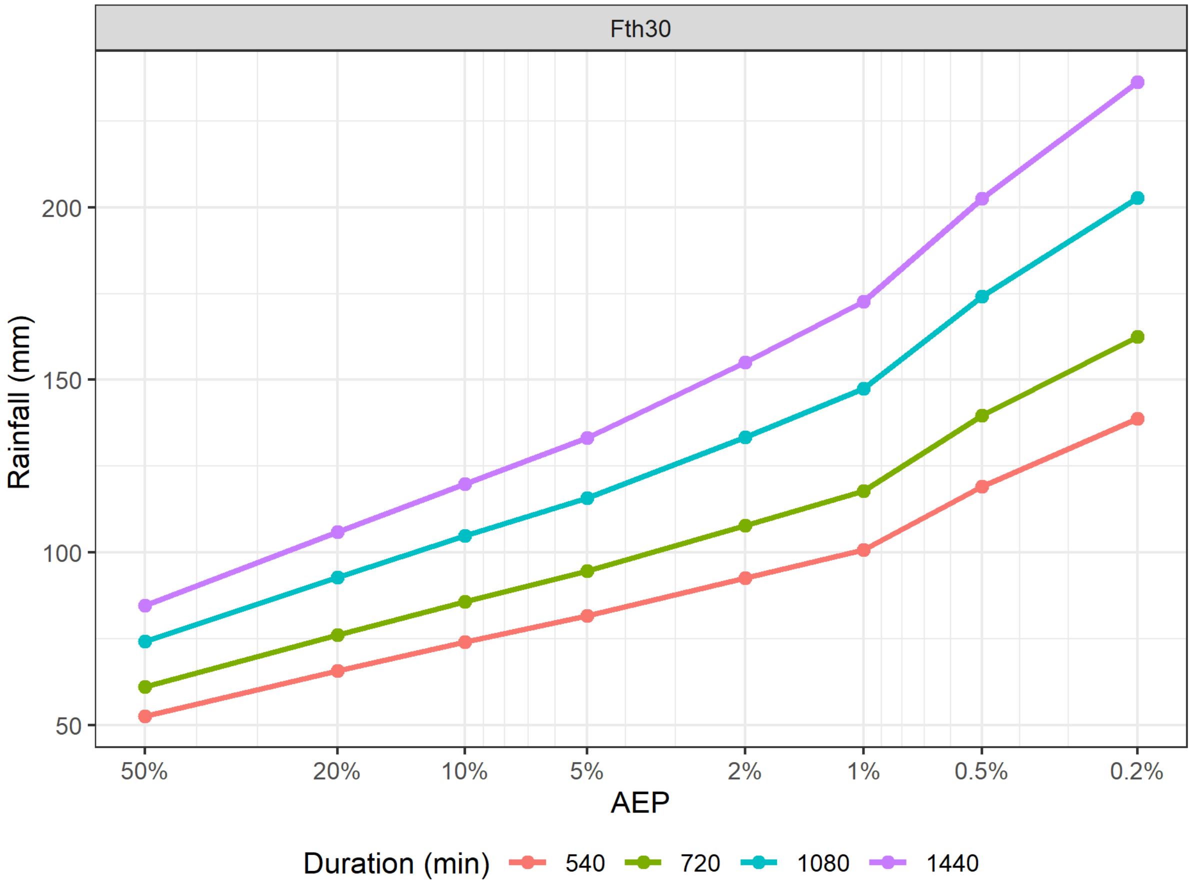

Diagram 2 IFD rainfall totals at an example sub-catchment in the Leven catchment showing the change in slope at 1%

5.2.3. Comparison to Previous Flood Studies

A flood study of the lower reaches of Leven River was undertaken by Entura in 2014 and an addendum was produced in 2015. As noted in Table 1, the flood study reports contained some references to the estimated design flows and design levels. The flood study reports also contained some flood mapping, which was georeferenced to enable a visual comparison of the estimated design extent.

The 2014 study involved the estimation of the 1% AEP design flows and levels from flood frequency analysis. It is noted that the design flows presented in the 2014 study are higher than those of the present study (1% AEP design flow of 990 m^3/s (2014 study), and 950 m^3/s (present study), at Forth River b/l Wilmot River).

A comparison of the 1% AEP design levels between the 2014 study and present study is shown in Table 11. The location of the comparison points, and a comparison of the 1% AEP flood extent between the 2014 study and present study are shown in Diagram 3.

Table 11. Design levels along Forth River (mAHD)

Comparison Point	1% AEP		
	2014 Study*	Present Study	Difference (m)
A	4.98	5.91	+0.93
B	3.23	3.46	+0.23
C	2.52	2.92	+0.40
D	2.45	2.76	+0.31
E	1.81	2.06	+0.25

* Taken from Entura, 2014

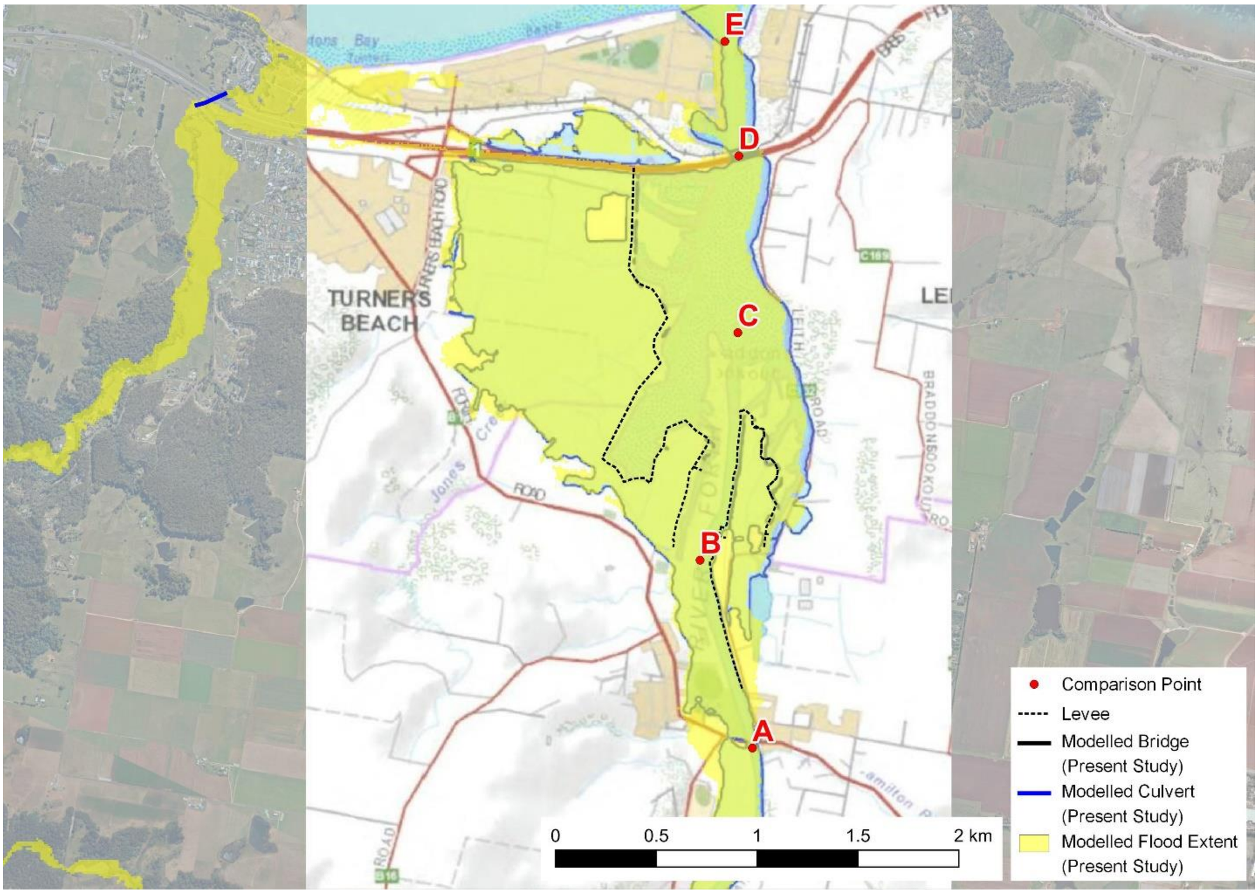

Diagram 3. Modelled flood extent for the 1% AEP design event (2014 study shown in the background from Entura, 2015)

Although the 1% AEP design flows in the present study are lower than those of the present study, the design levels are higher. As discussed in the calibration report, calibration to flow and level was not possible due to the lack of river bathymetry in the DEM used for the present study. For the design event scenarios, a match to flow rather than level was undertaken to ensure the validity of the selected design events and to ensure the design levels are conservative.

6. LIMITATIONS

A detailed uncertainty assessment of the data, hydrological calibration and hydrodynamic model is contained in the Forth-Leven Calibration Report (WMAwater, 2022). In line with the calibration report there are some areas where the lack of bathymetry or LiDAR may have impacted the modelled flood levels. If LiDAR or bathymetry were made available this model would benefit from being re-run with this information.

The selection of limited duration-TP-ARF sets introduces some errors across the catchment as described in Section 5.1. This is appropriate for a regional method, however site-specific ARFs, critical durations and TP selection should be used for detailed design modelling at specific locations.

As discussed in Section 5.2 there is some uncertainty introduced by the direct rainfall application on the headwater catchments. While the method used is appropriate for broad scale mapping, a full design event assessment should be undertaken for any future focussed studies in this area.

7. REFERENCES

Babister, M., Trim, A., Testoni, I. & Retallick, M (2016): The Australian Rainfall & Runoff Datahub 37th Hydrology and Water Resources Symposium Queenstown NZ, 2016 available at http://data.arr-software.org/

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (2019): Editors Australian Rainfall and Runoff: A Guide to Flood Estimation Commonwealth of Australia, Australia, 2019

Bureau of Meteorology (2019). 2016 Rainfall IFD Data System. Bureau of Meteorology, Victoria, Australia URL: http://www.bom.gov.au/water/designRainfalls/revised-ifd/

Bureau of Meteorology (2020). Rainfall Map Information. Bureau of Meteorology, Victoria, Australia URL: http://www.bom.gov.au/climate/austmaps/about-rain-maps.shtml

Entura (2014). Forth Flood Plan – Hydraulic Modelling Report. Report for Central Coast Council, Tasmania.

Entura (2015). Forth Flood Plan – Hydraulic Modelling Report Addendum. Report for Central Coast Council, Tasmania.

DPIPWE (2019) Hydrologic Soil Groups of Tasmania (Unpublished). Department of Primary Industries and Water, Hobart, Tasmania. Created March 2019

WMAwater (2021a): Tasmanian Strategic Flood Map Hydrology Methods Report, August 2021. Report for State Emergency Service, Tasmania.

WMAwater (2021b): Tasmanian Strategic Flood Map Hydrodynamic Methods Report, August 2021. Report for State Emergency Service, Tasmania.

WMAwater (2021c): Tasmanian Strategic Flood Map, Flow Gauge Rating Revision, Draft, Dec 2021.

WMAwater (2022): Tasmanian Strategic Flood Map Forth-Leven Catchment Model Calibration Report, October 2022. Report for State Emergency Service, Tasmania.

Figures

Forth River above Lemonthyme

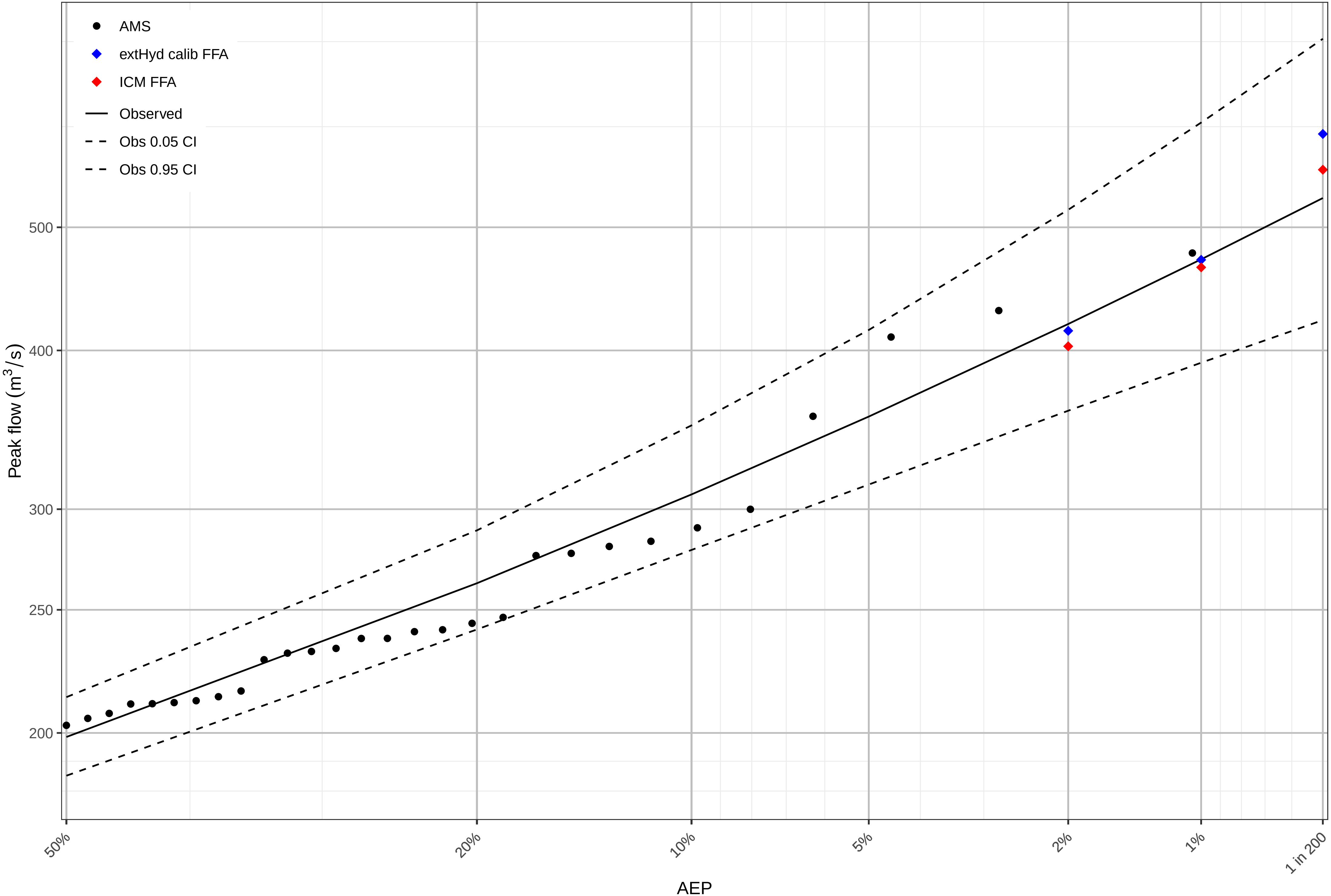

FIGURE 2

Leven River at Bannons Bridge

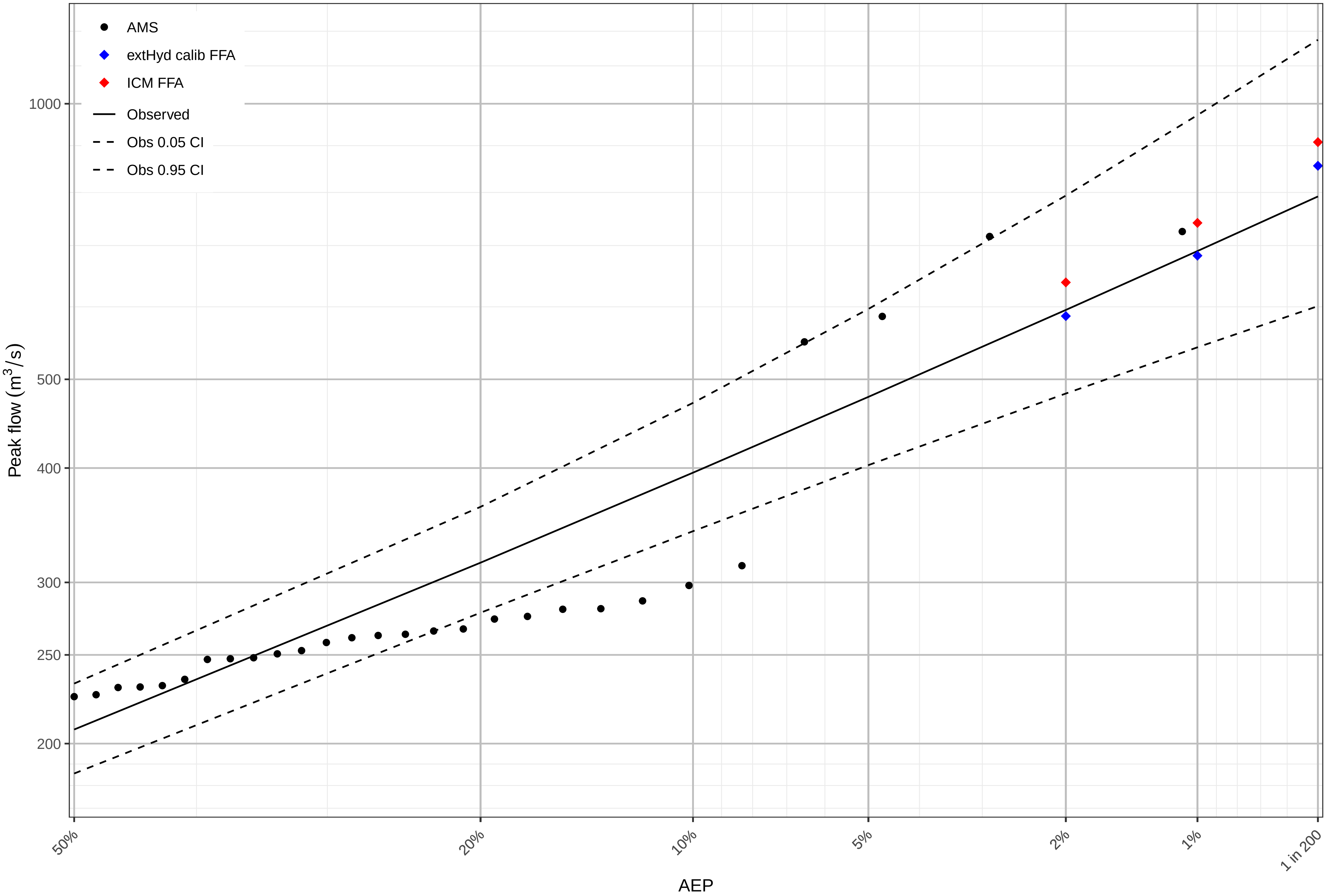

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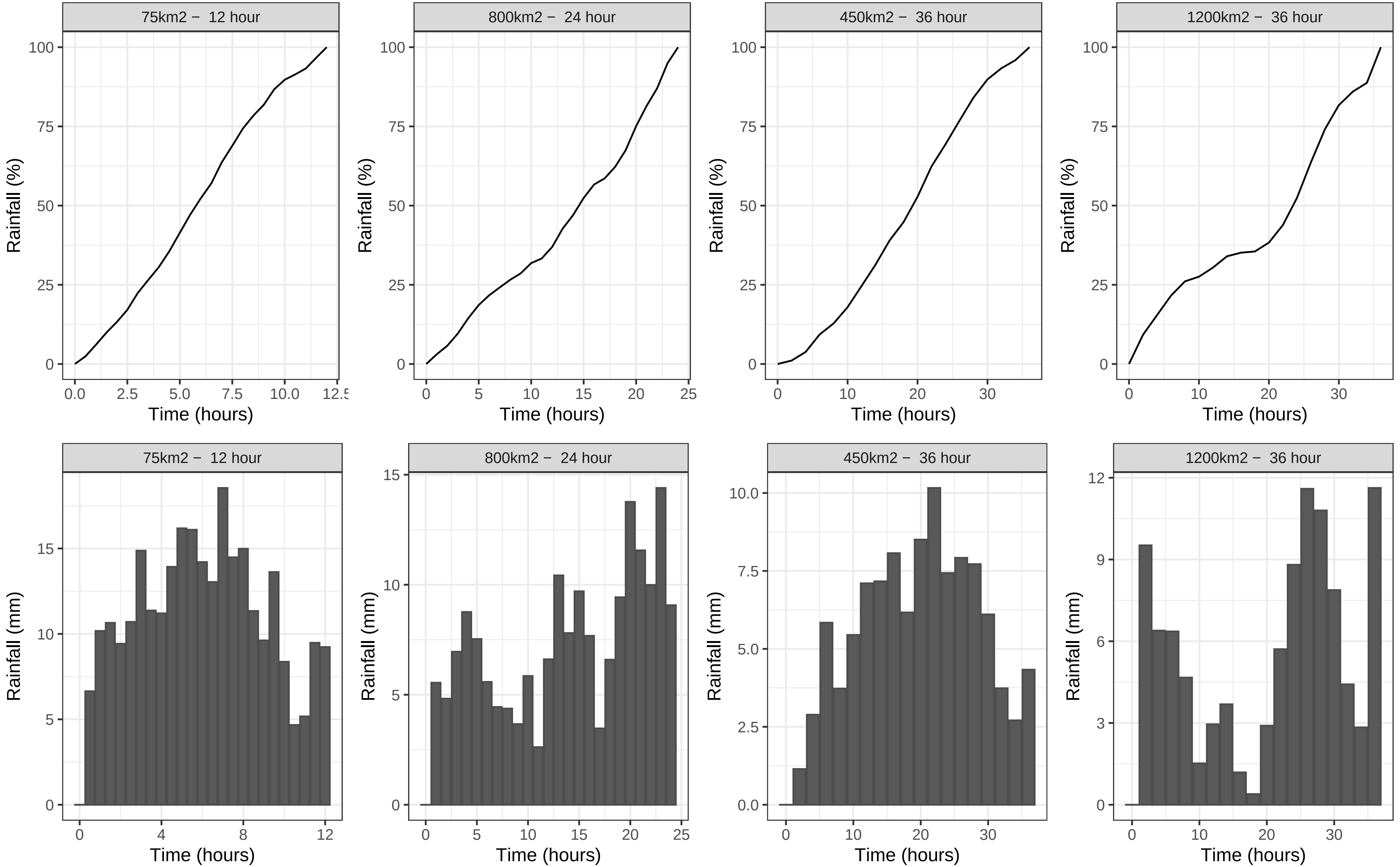
FIGURE 3
SELECTED DESIGN TEMPORAL PATTERNS ALL AEPS BY STORM DURATION AND ARF AREA



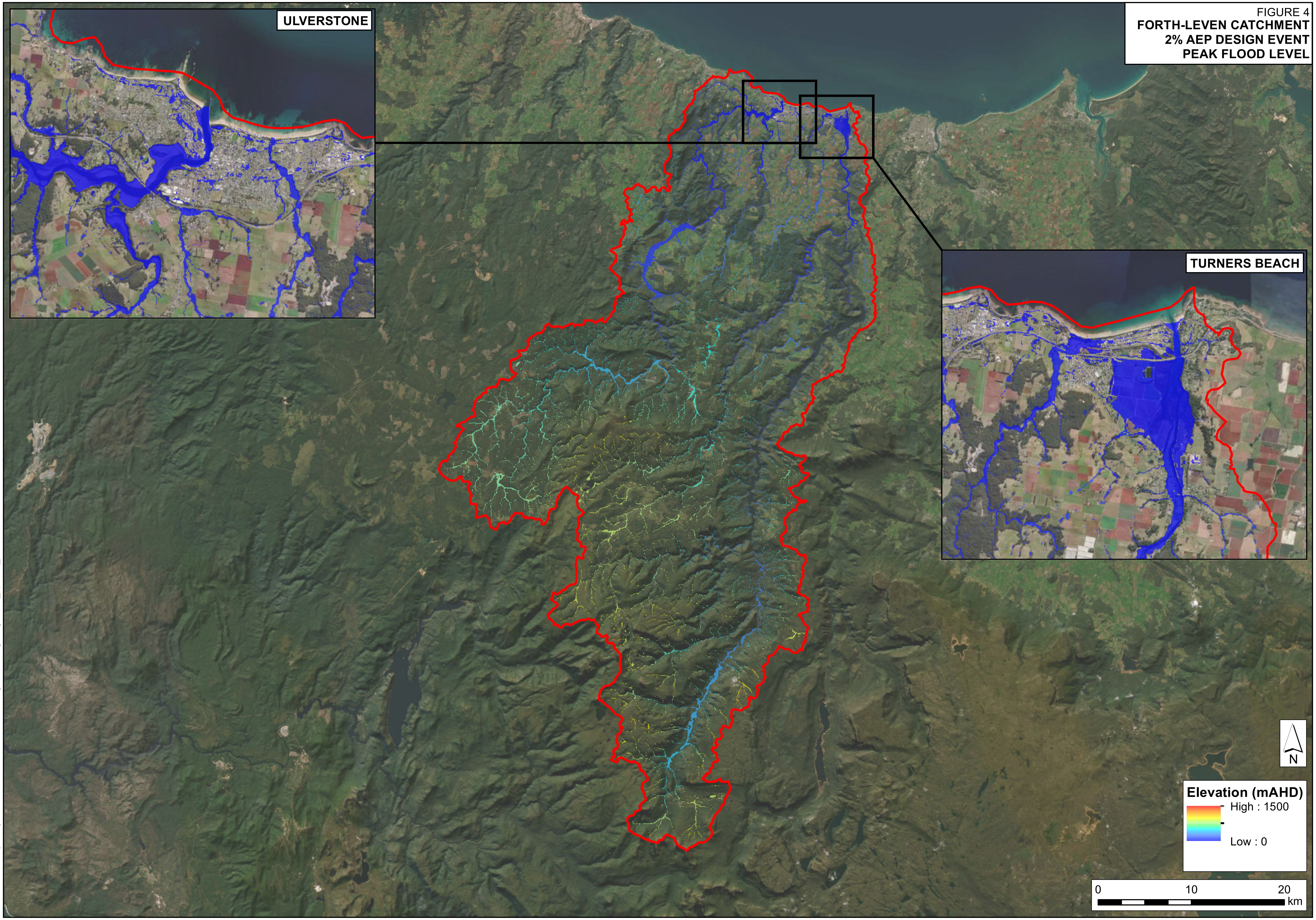


FIGURE 4
FORTH-LEVEN CATCHMENT
2% AEP DESIGN EVENT
PEAK FLOOD LEVEL

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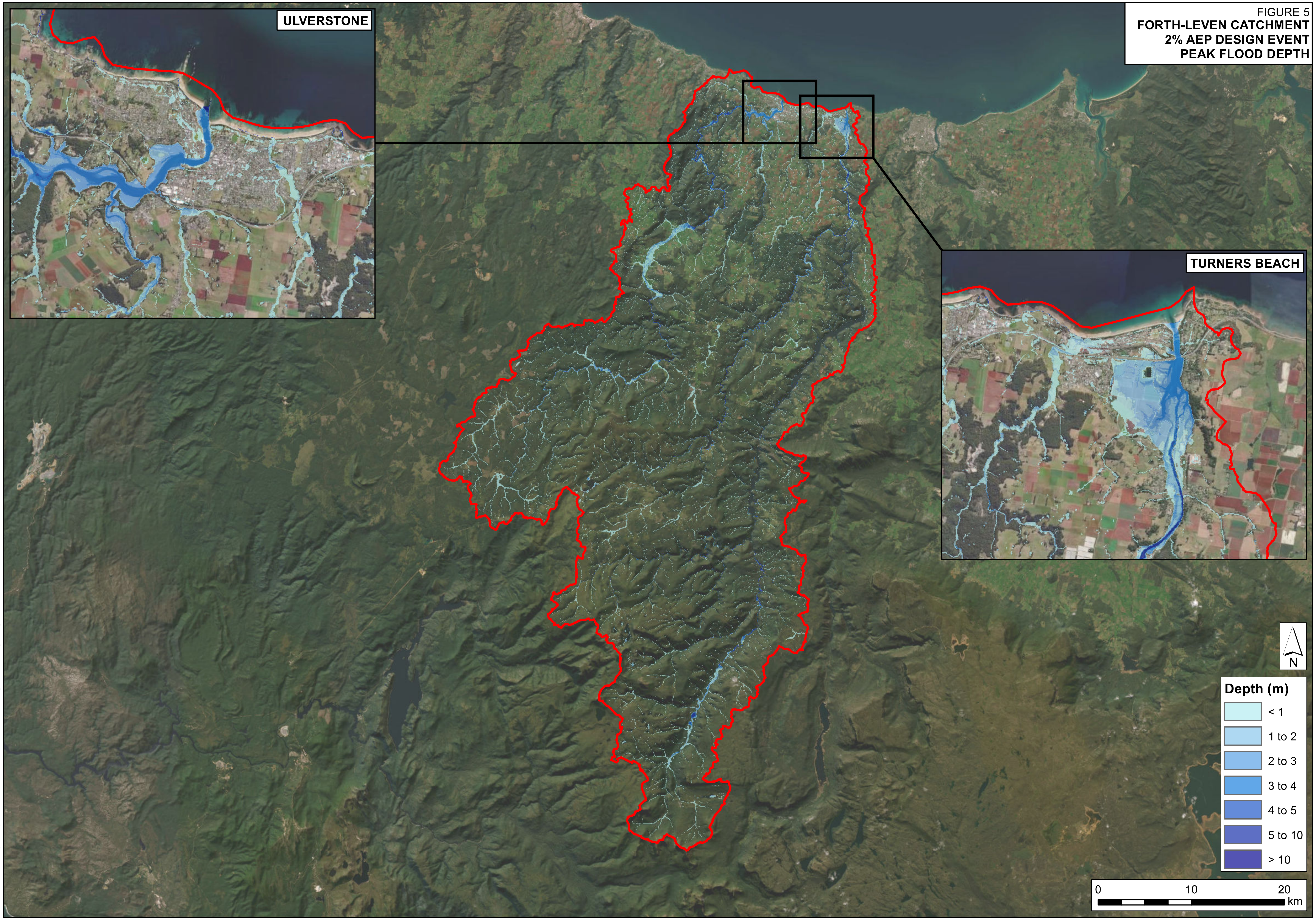

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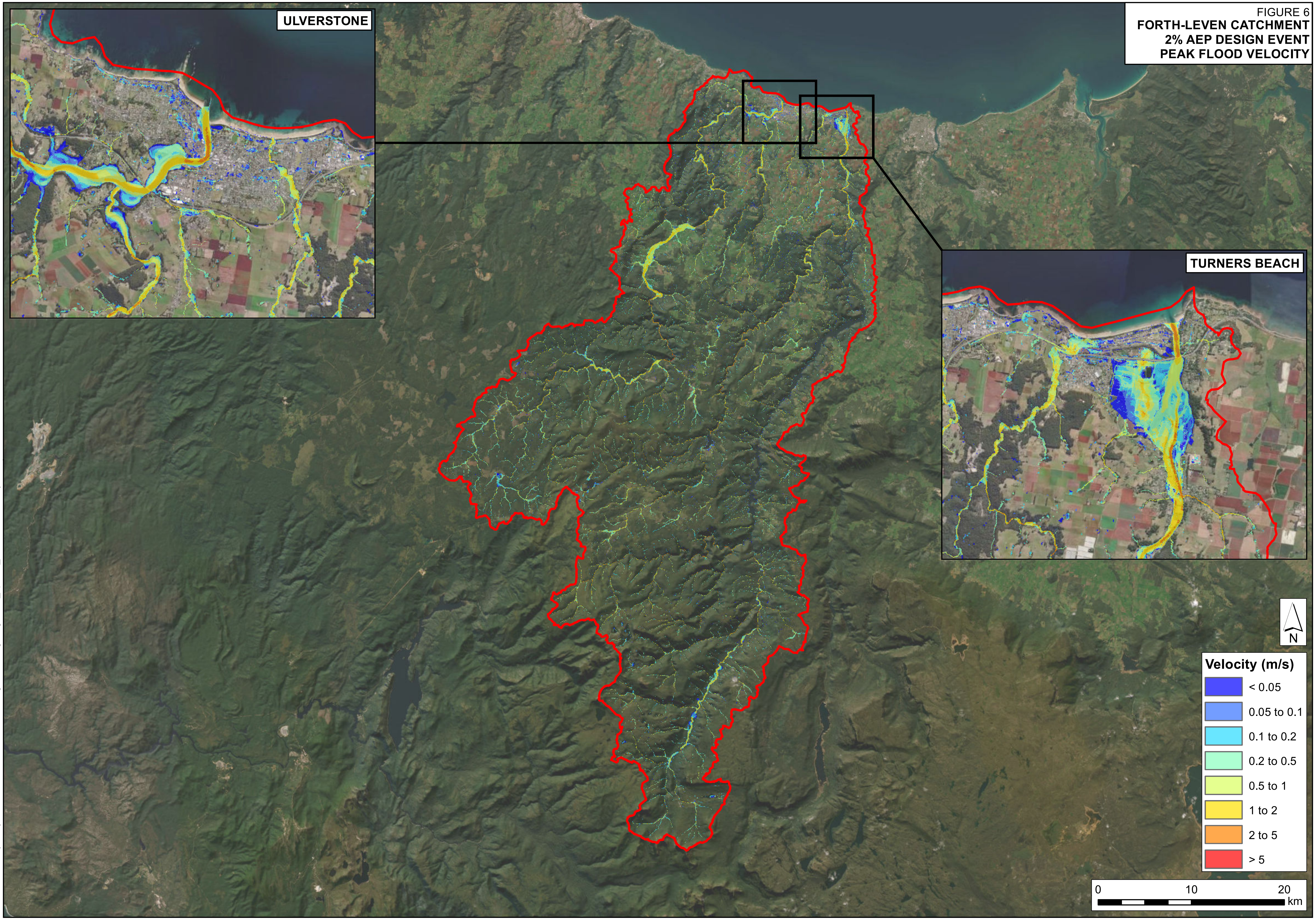
FIGURE 6
FORTH-LEVEN CATCHMENT
2% AEP DESIGN EVENT
PEAK FLOOD VELOCITY
ULVERSTONE
TURNERS BEACH
N
Velocity (m/s)
< 0.05
0.05 to 0.1
0.1 to 0.2
0.2 to 0.5
0.5 to 1
1 to 2
2 to 5
> 5
0
10
20
km
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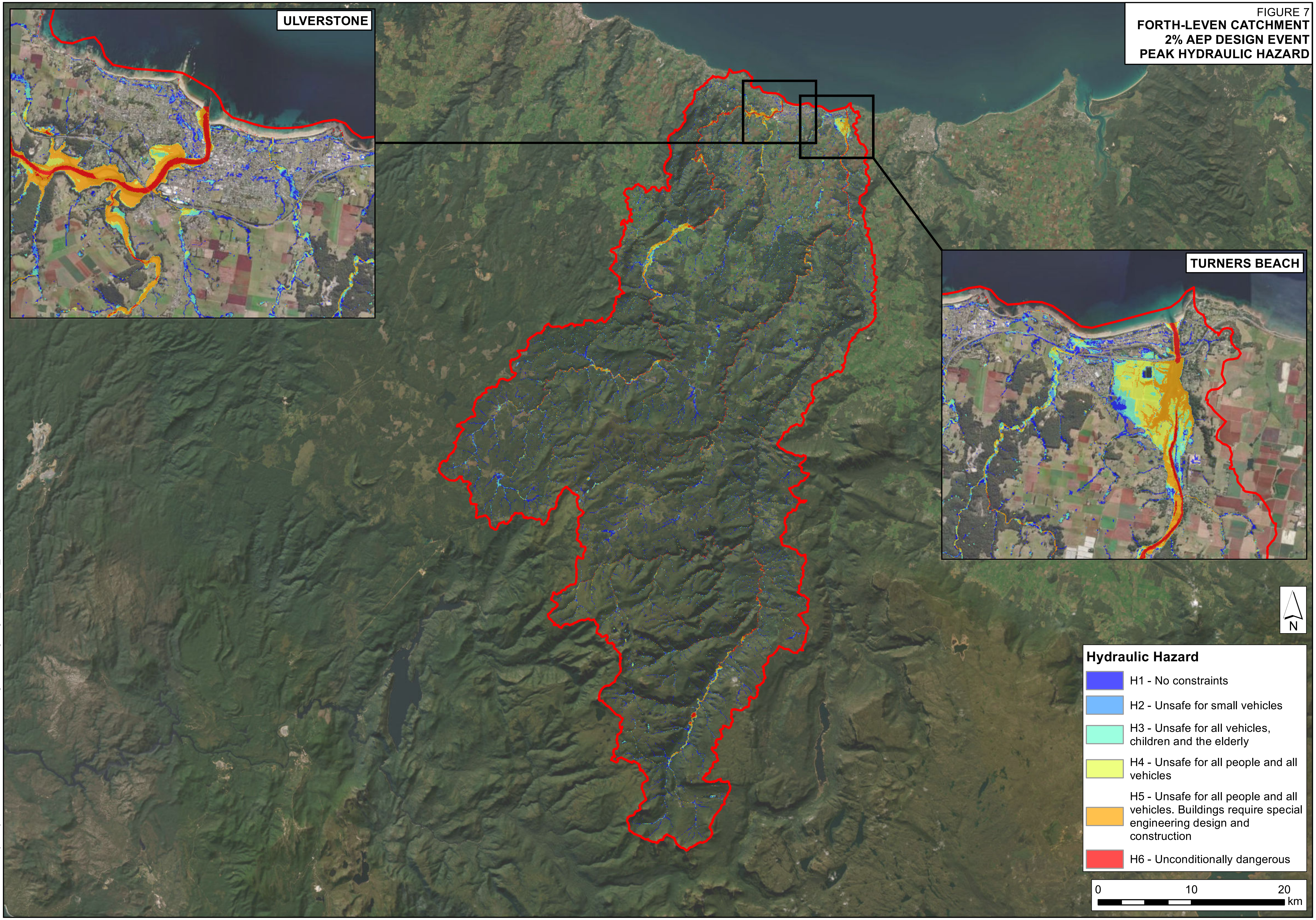
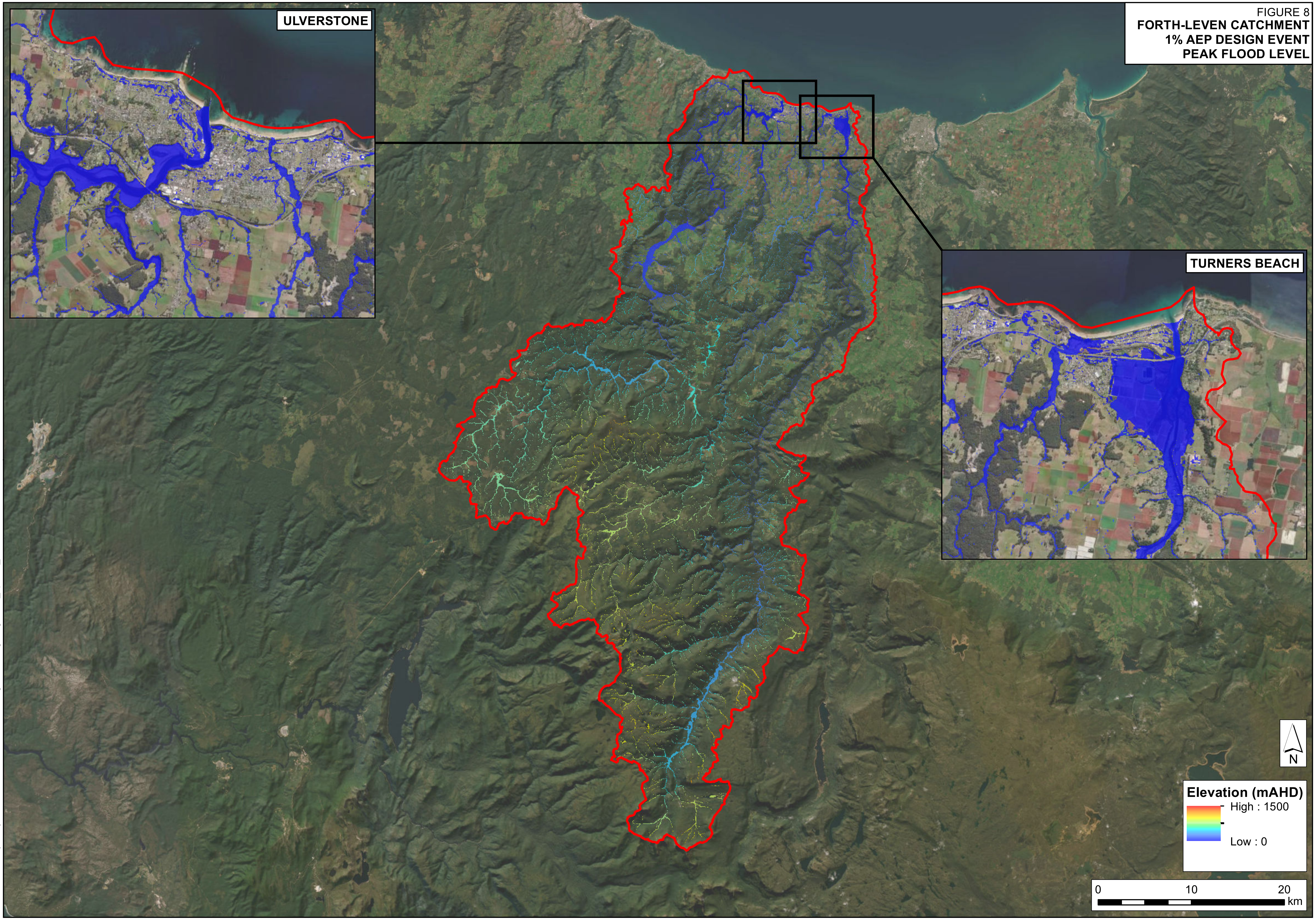


J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Design\Figure07_2pAEP_PeakHydraulicHazard.mxd

FIGURE 8
FORTH-LEVEN CATCHMENT 1% AEP DESIGN EVENT PEAK FLOOD LEVEL



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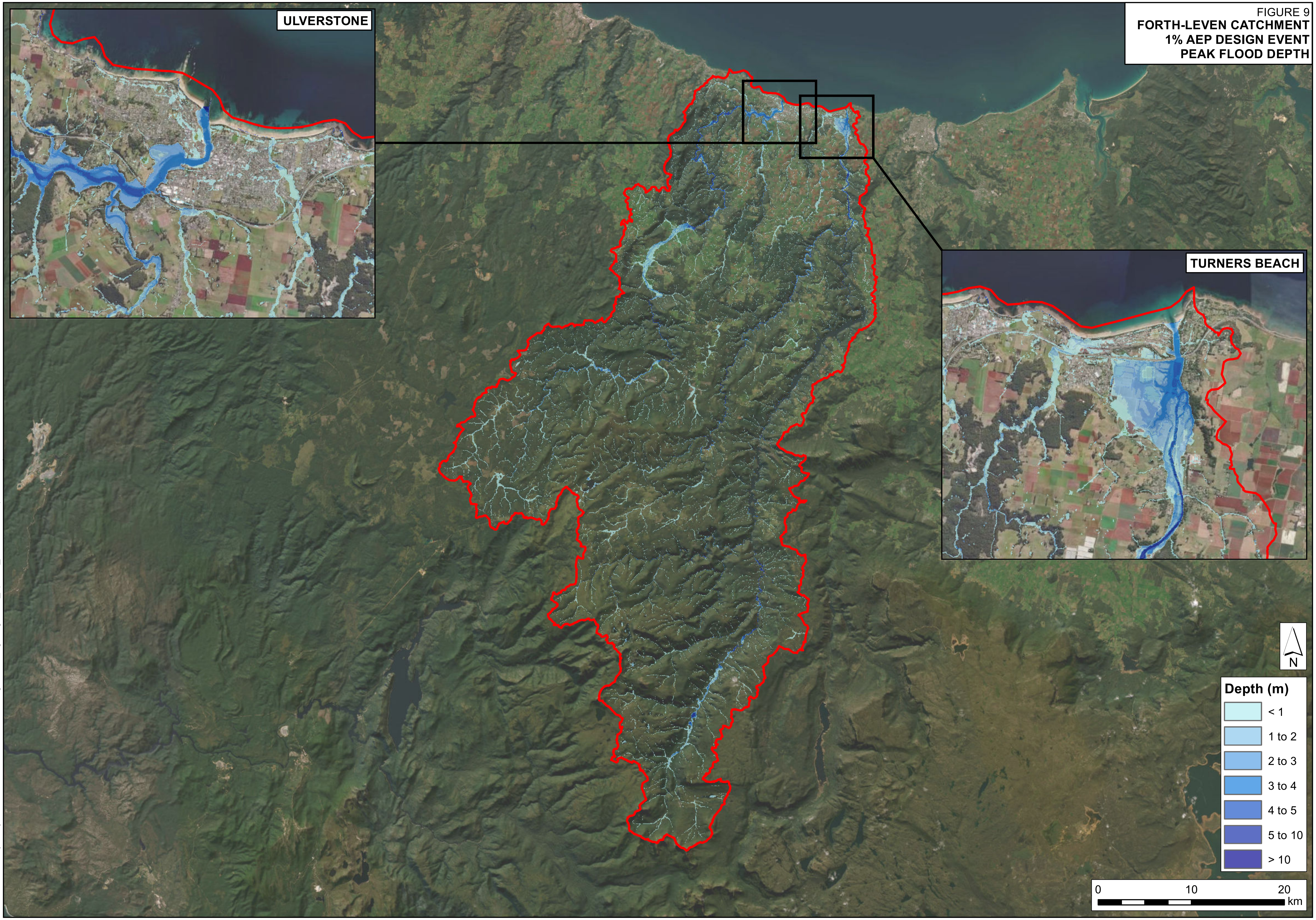
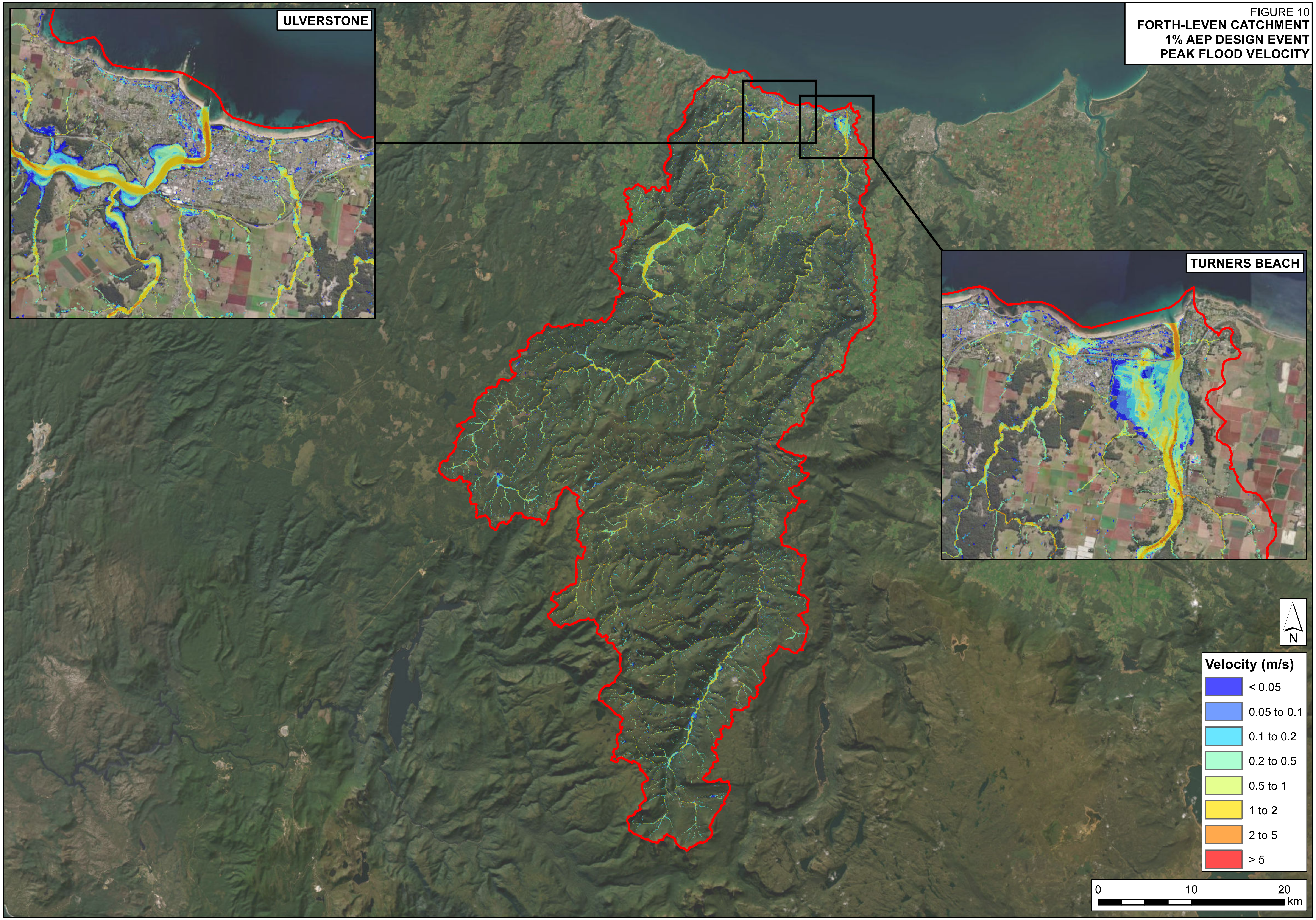


J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Design\Figure09_1pAEP_PeakFloodDepth.mxd



J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Design\Figure10_1pAEP_PeakFloodVelocity.mxd

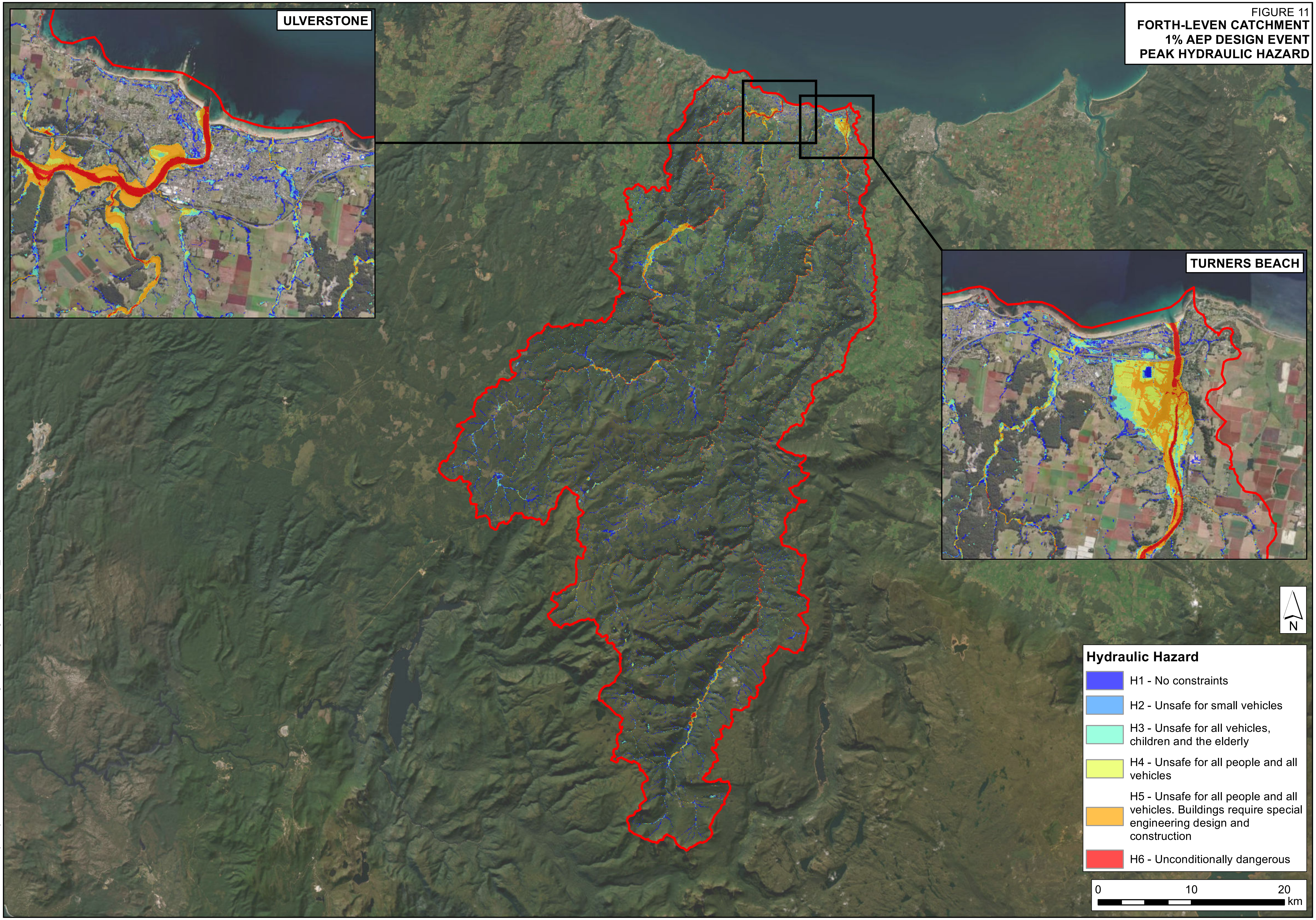
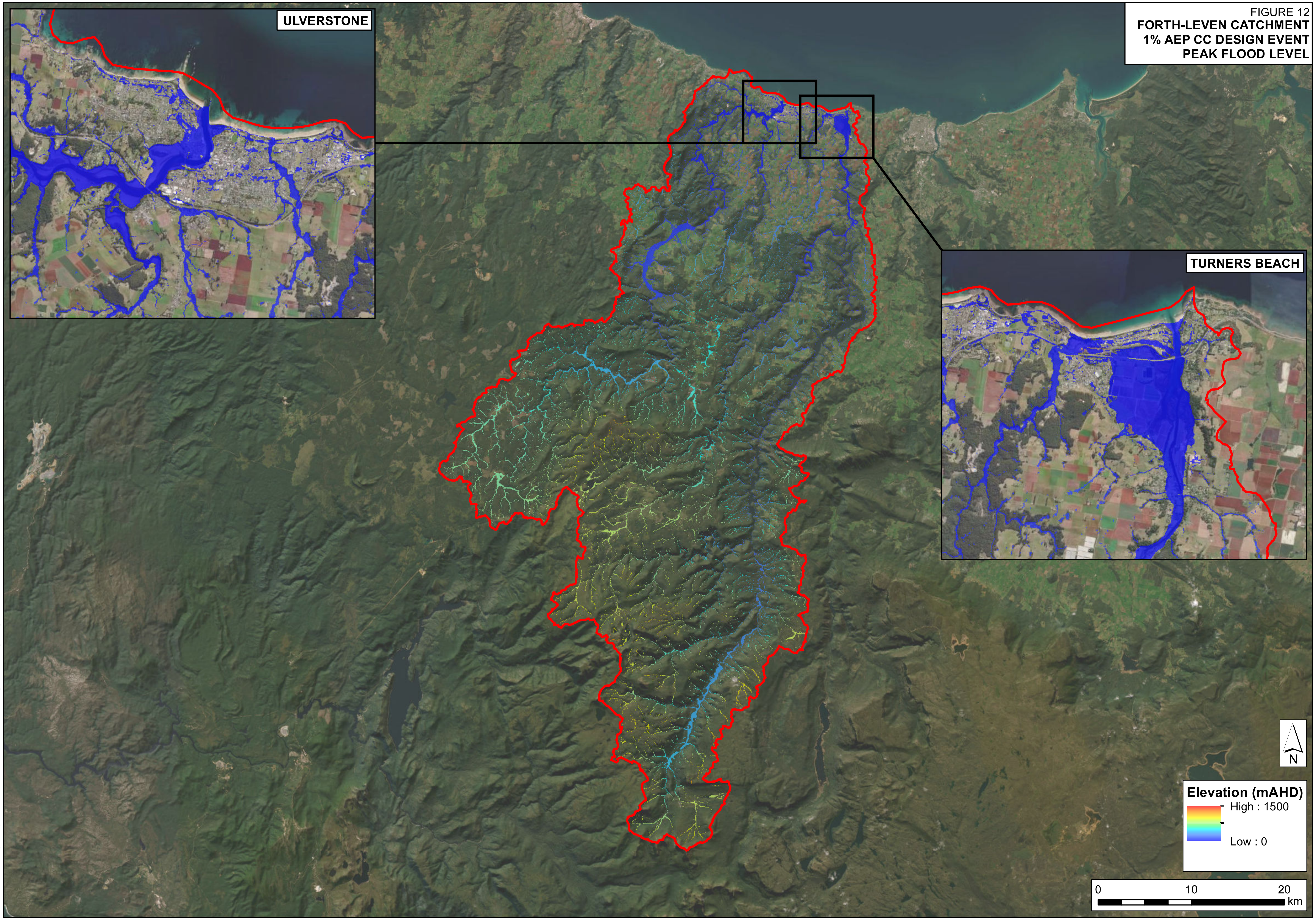
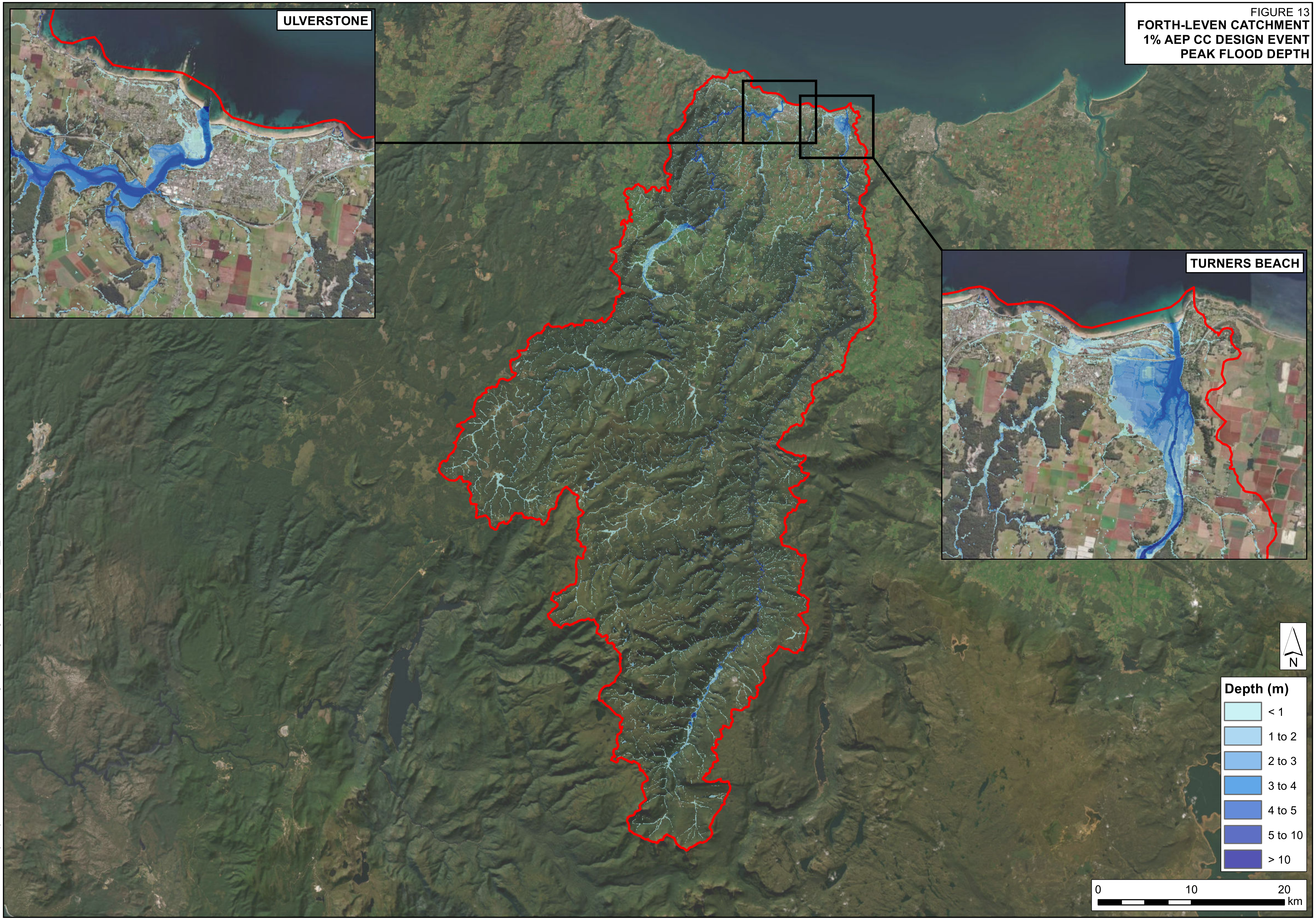


FIGURE 11
FORTH-LEVEN CATCHMENT
1% AEP DESIGN EVENT
PEAK HYDRAULIC HAZARD
ULVERSTONE
TURNERS BEACH
N
Hydraulic Hazard
H1 - No constraints
H2 - Unsafe for small vehicles
H3 - Unsafe for all vehicles, children and the elderly
H4 - Unsafe for all people and all vehicles
H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction
H6 - Unconditionally dangerous
0
10
20
km
J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Design\Figure11_1pAEP_PeakHydraulicHazard.mxd



J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Design\Figure12_1pAEP_CC_PeakFloodLevel.mxd



J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Design\Figure13_1pAEP_CC_PeakFloodDepth.mxd

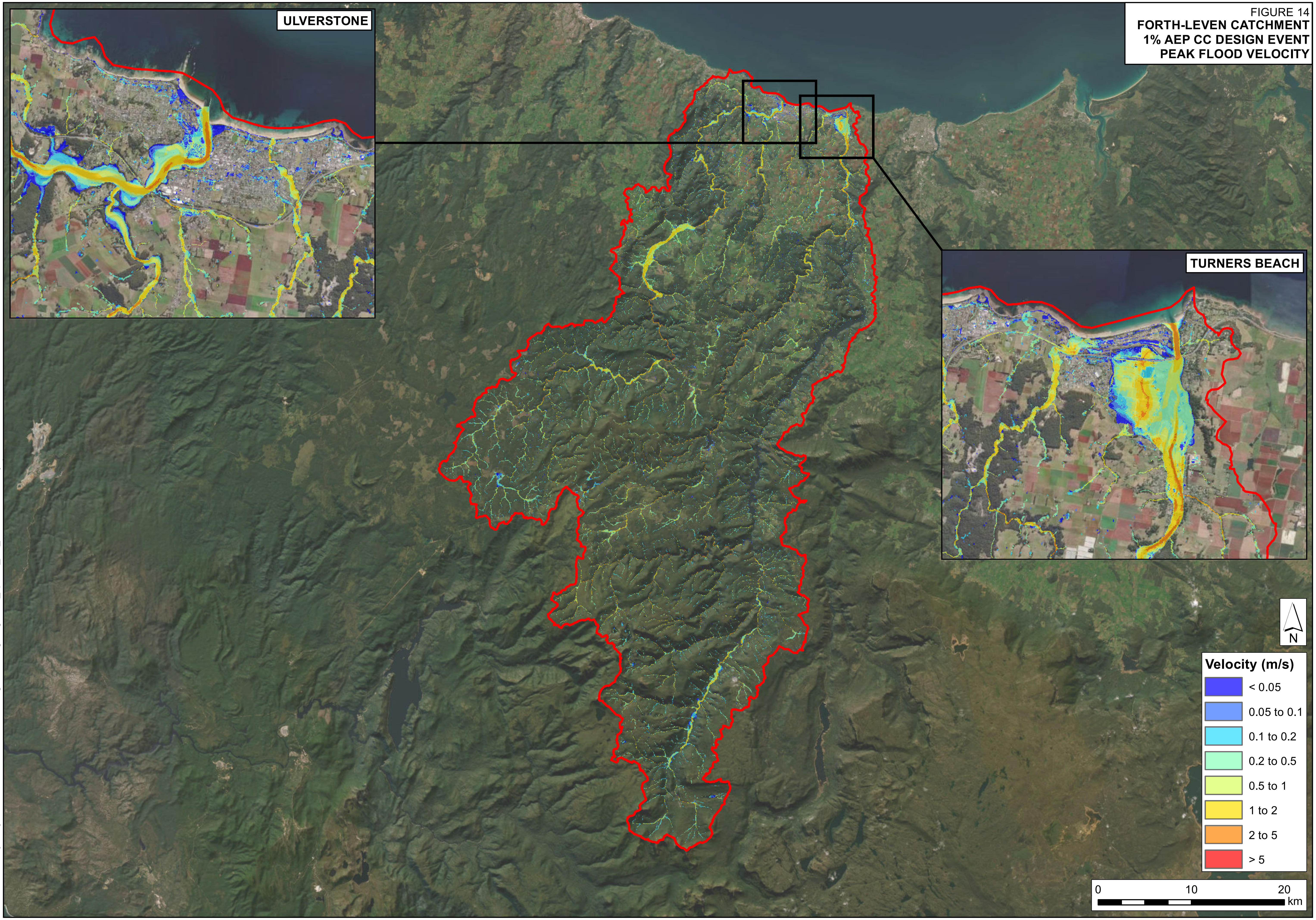
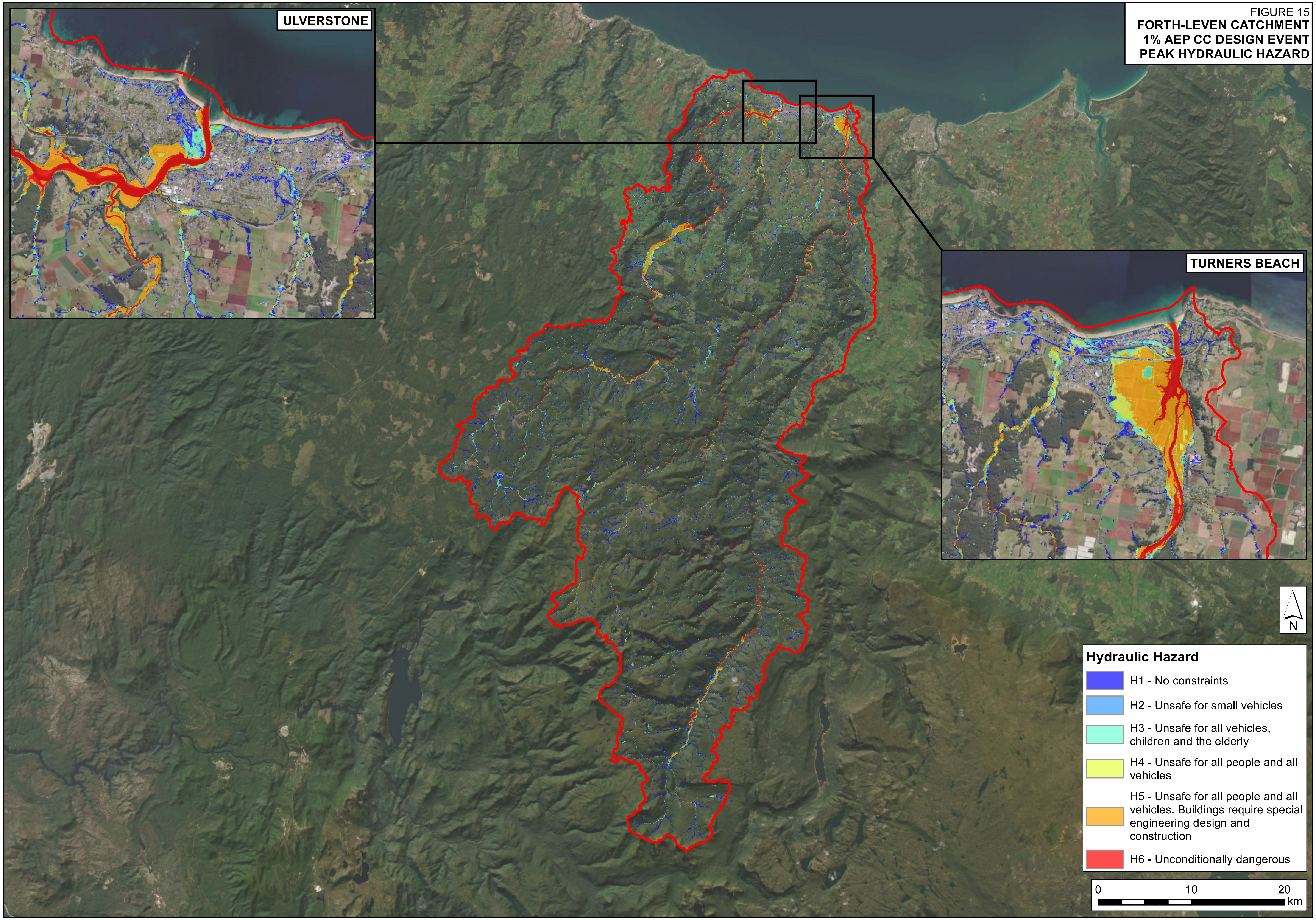
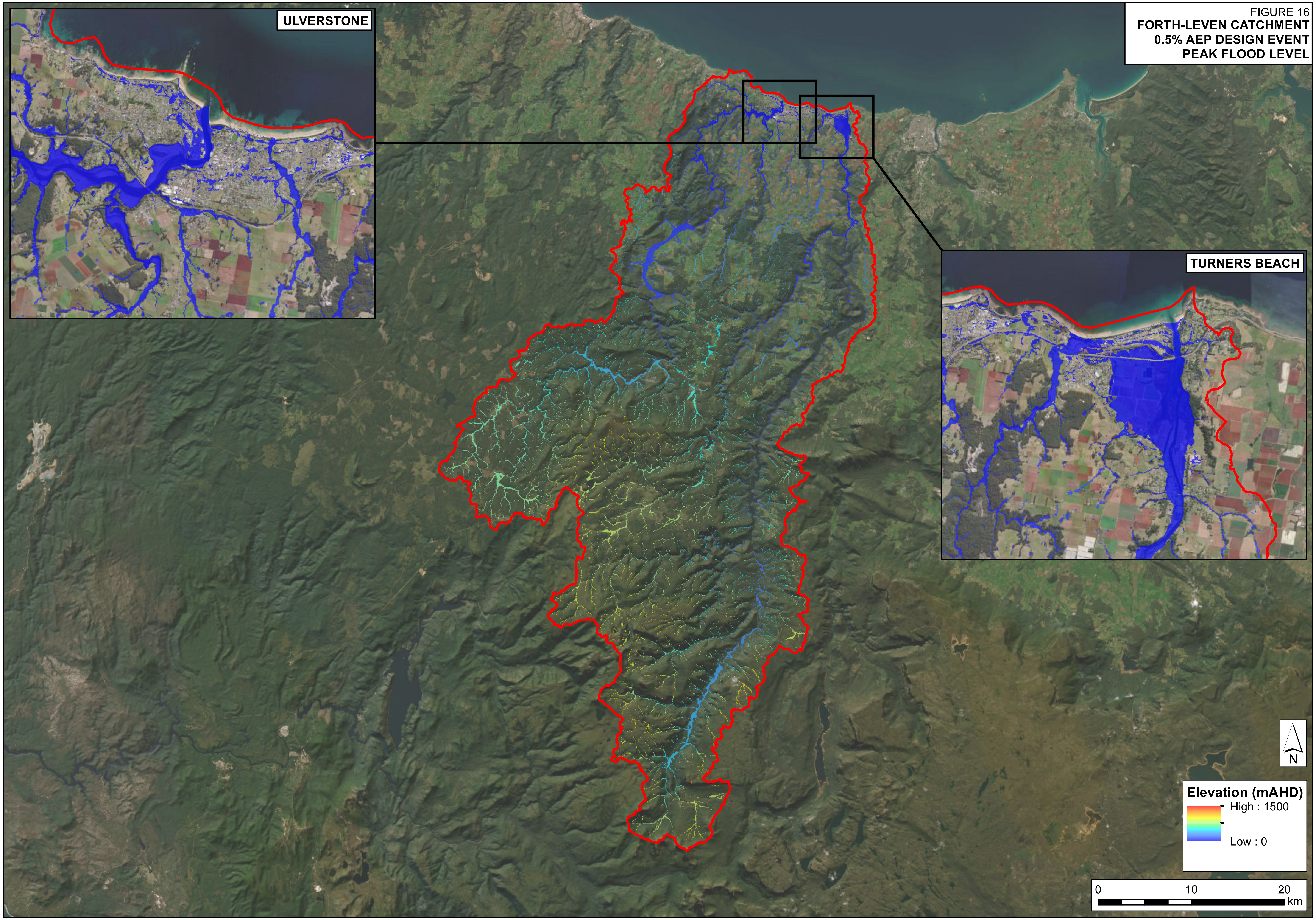


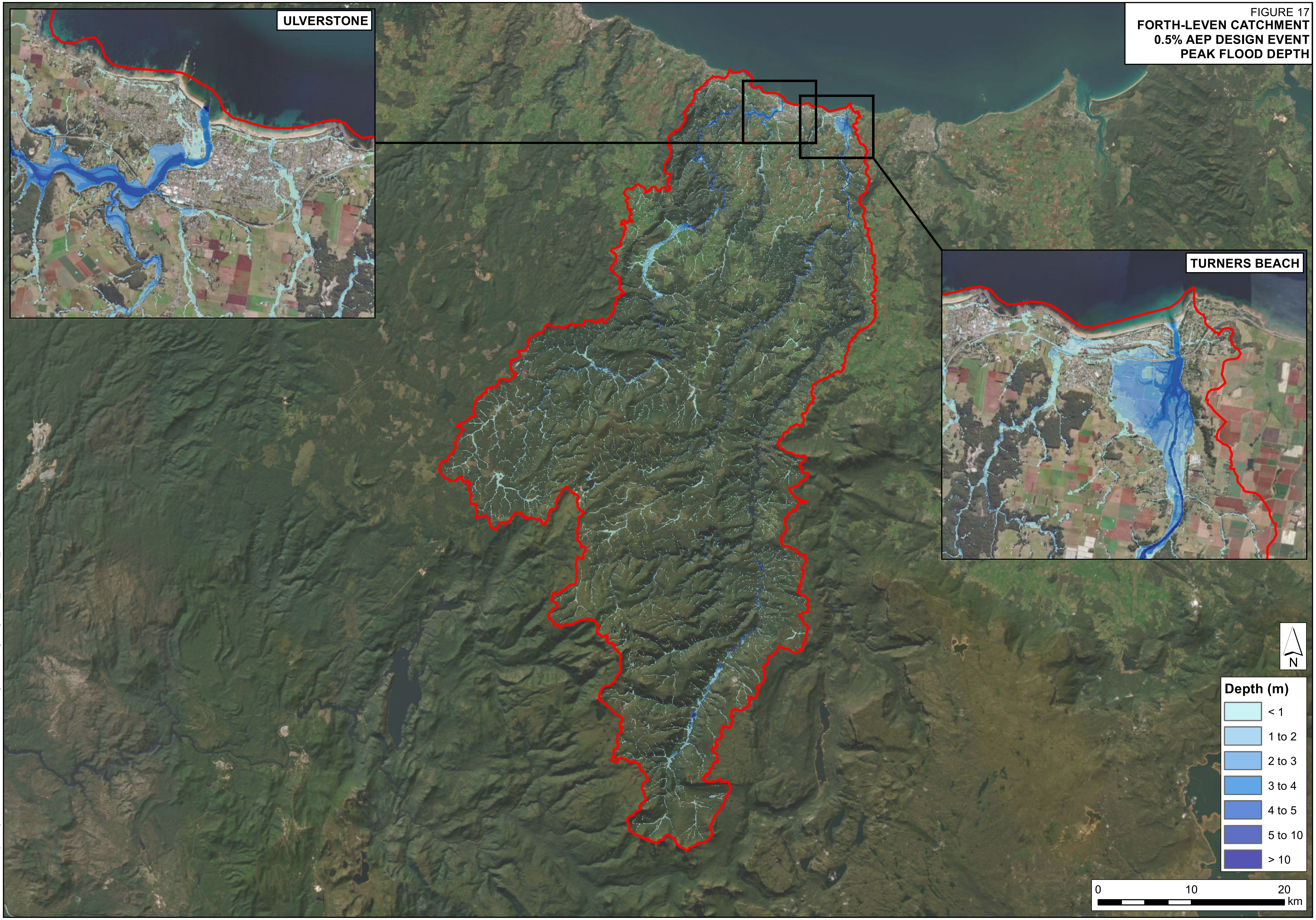
FIGURE 14
FORTH-LEVEN CATCHMENT
1% AEP CC DESIGN EVENT
PEAK FLOOD VELOCITY
ULVERSTONE
TURNERS BEACH
N
Velocity (m/s)
< 0.05
0.05 to 0.1
0.1 to 0.2
0.2 to 0.5
0.5 to 1
1 to 2
2 to 5
> 5
0
10
20
km
J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Design\Figure14_1pAEP_CC_PeakFloodVelocity.mxd



J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Design\Figure15_1pAEP_CC_PeakHydraulicHazard.mxd



J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Design\Figure16_0.5pAEP_PeakFloodLevel.mxd



J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Design\Figure17_0.5pAEP_PeakFloodDepth.mxd

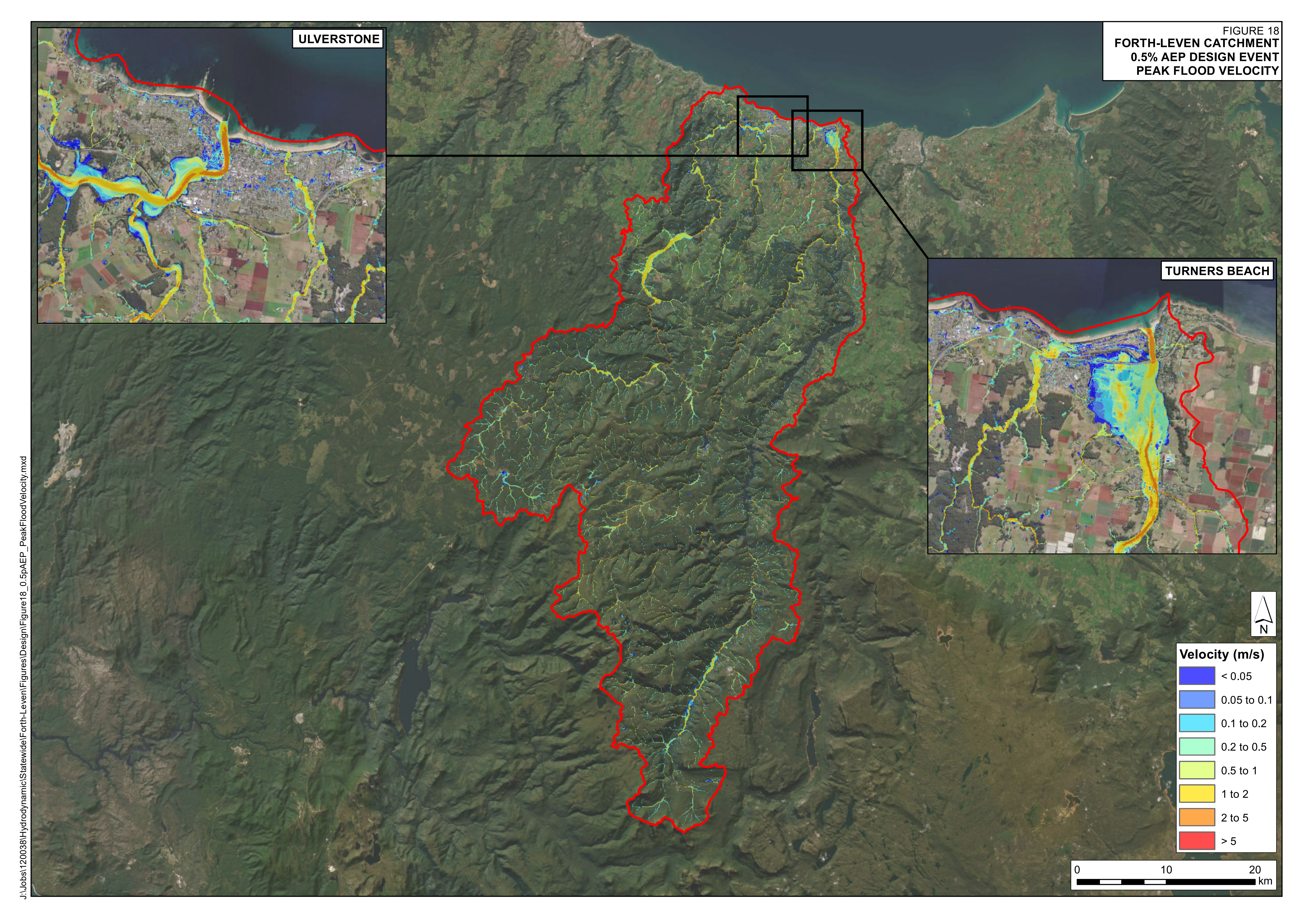
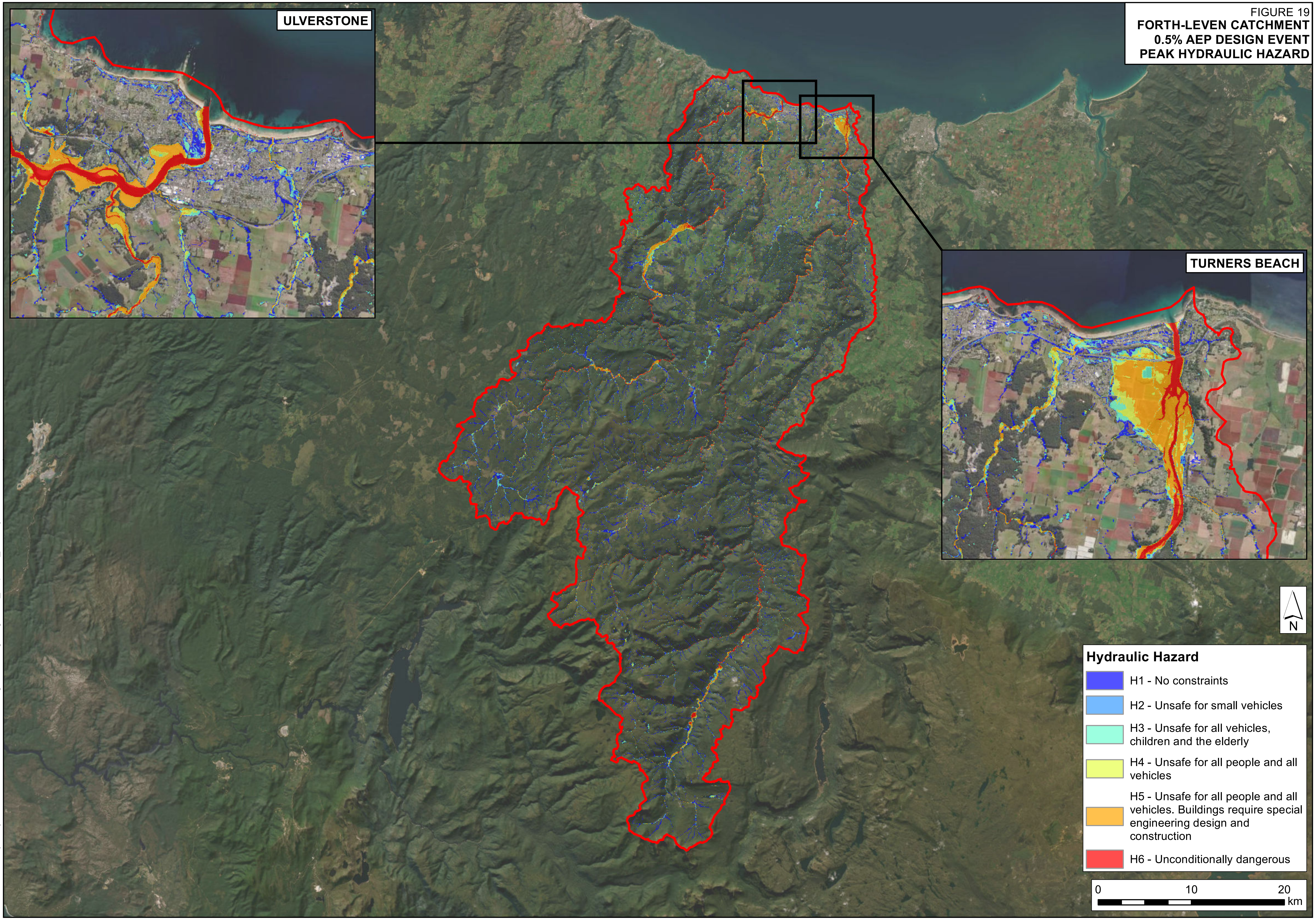


FIGURE 18
FORTH-LEVEN CATCHMENT
0.5% AEP DESIGN EVENT
PEAK FLOOD VELOCITY
ULVERSTONE
TURNERS BEACH
N
Velocity (m/s)
< 0.05
0.05 to 0.1
0.1 to 0.2
0.2 to 0.5
0.5 to 1
1 to 2
2 to 5
> 5
0
10
20
km
J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Design\Figure18_0.5pAEP_PeakFloodVelocity.mxd



J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Design\Figure19_0.5pAEP_PeakHydraulicHazard.mxd

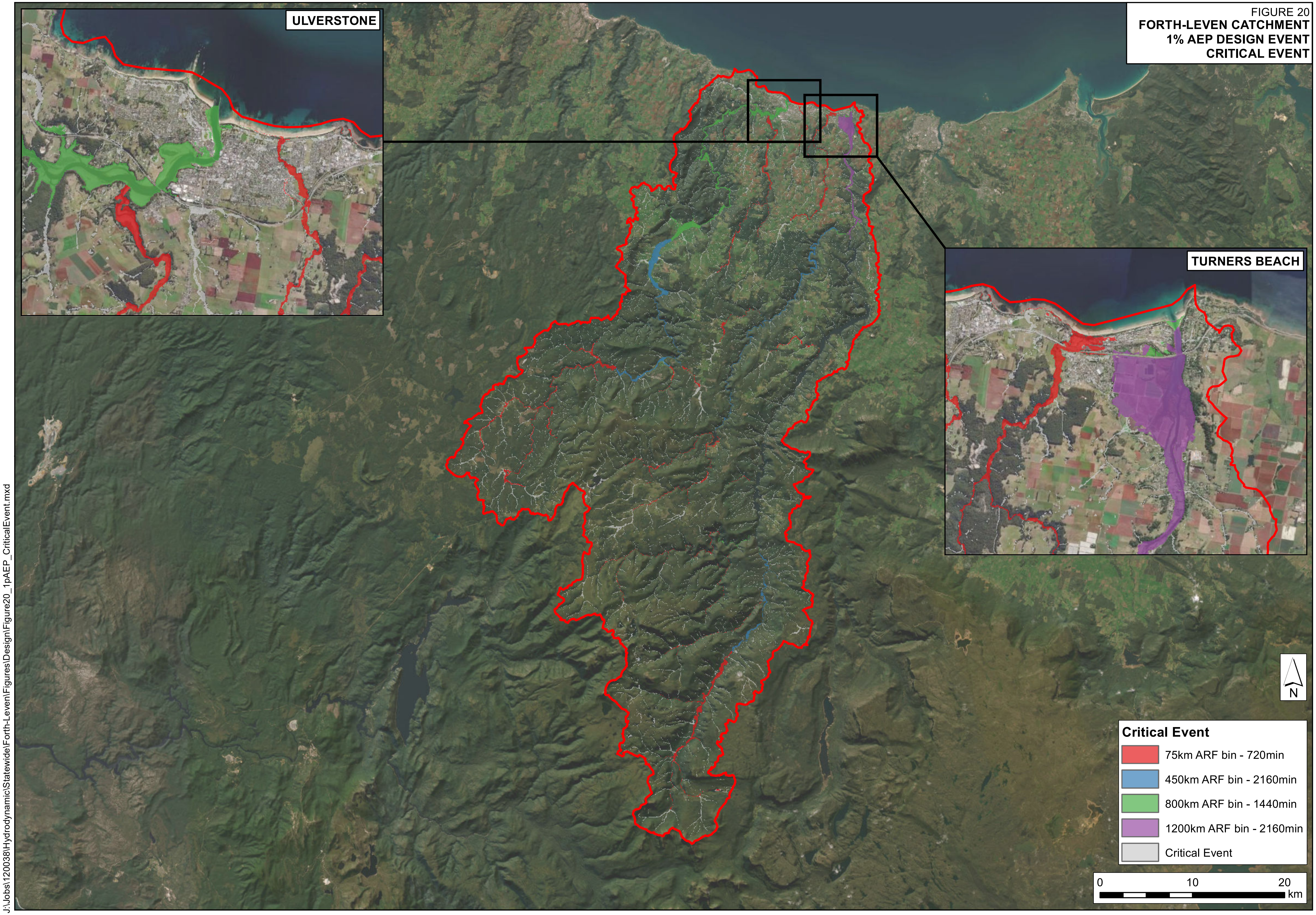
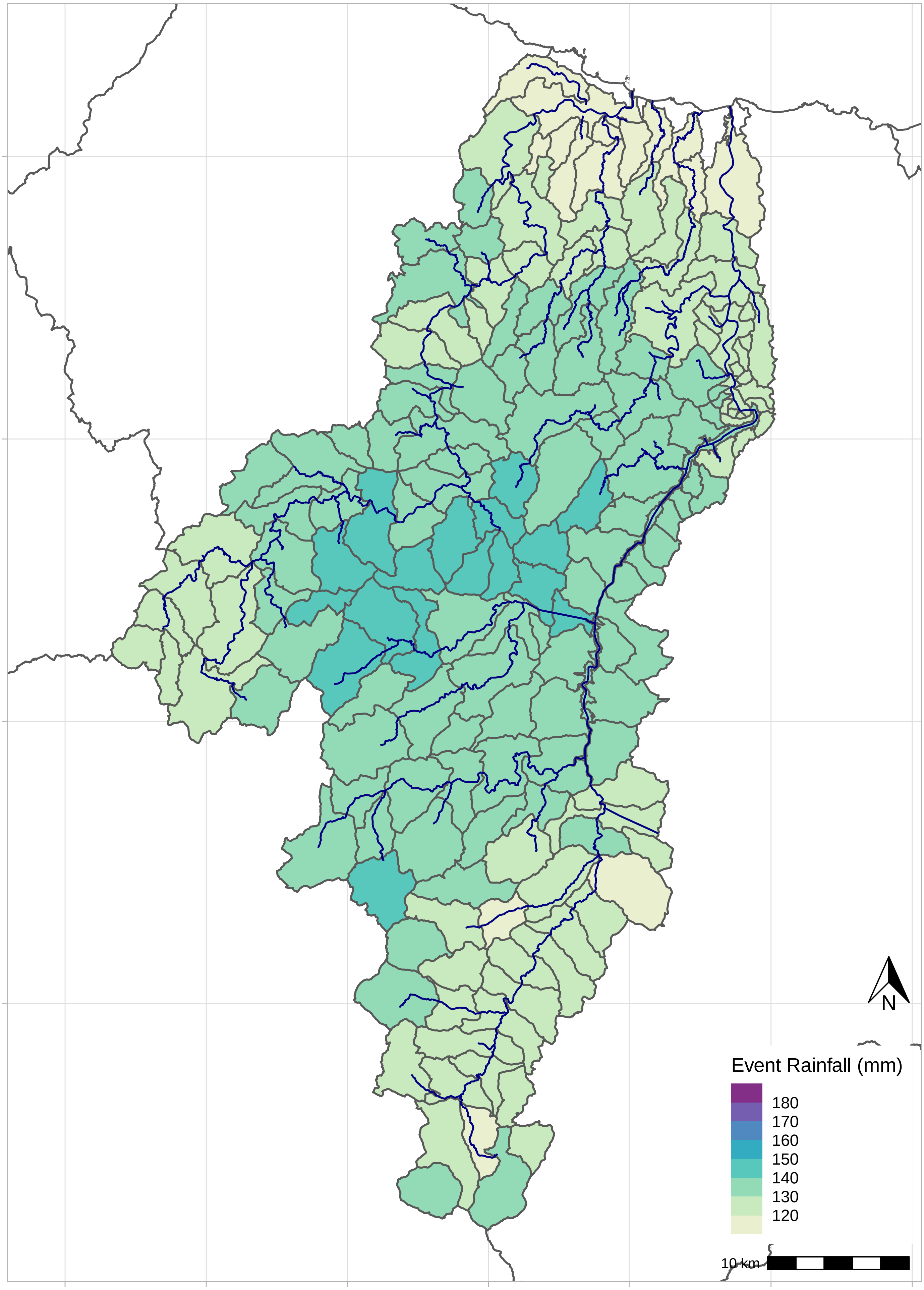


FIGURE 20
FORTH-LEVEN CATCHMENT
1% AEP DESIGN EVENT
CRITICAL EVENT
ULVERSTONE
TURNERS BEACH
N
Critical Event
75km ARF bin - 720min
450km ARF bin - 2160min
800km ARF bin - 1440min
1200km ARF bin - 2160min
Critical Event
0
10
20
km
J:\Jobs\120038\Hydrodynamic\Statewide\Forth-Leven\Figures\Design\Figure20_1pAEP_CriticalEvent.mxd

Appendix A

APPENDIX A. DESIGN EVENT DATA

FIGURE A1
DESIGN RAINFALL DEPTHS
1440MIN 2%AEP



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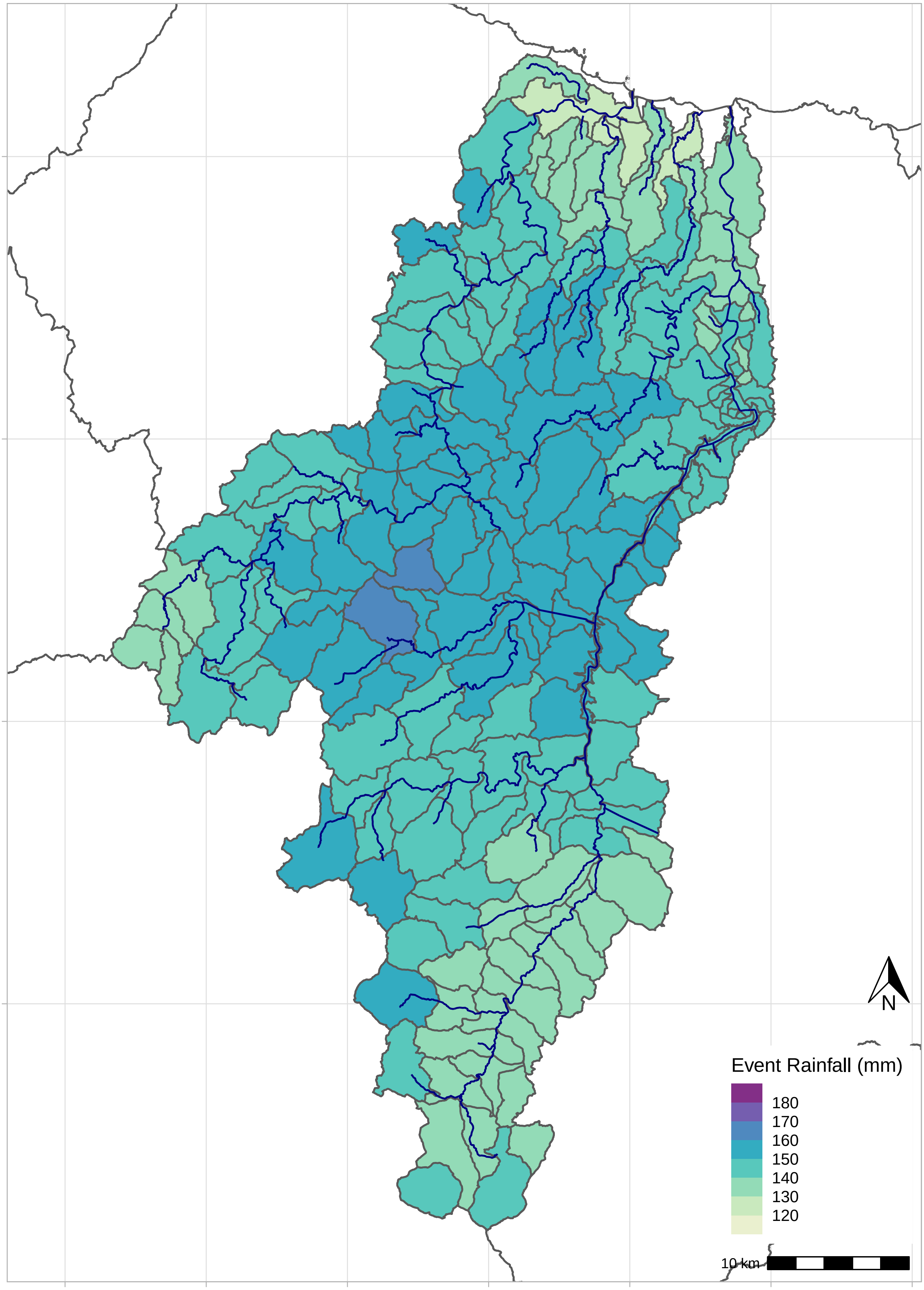
J:/Jobs/120038/Hydrology/Statewide/Design_Events/Forth−Leven/Forth−Levenv1/Report_Figures/FigureA1_1440_2pAEP_same_scale.pdf

FIGURE A2

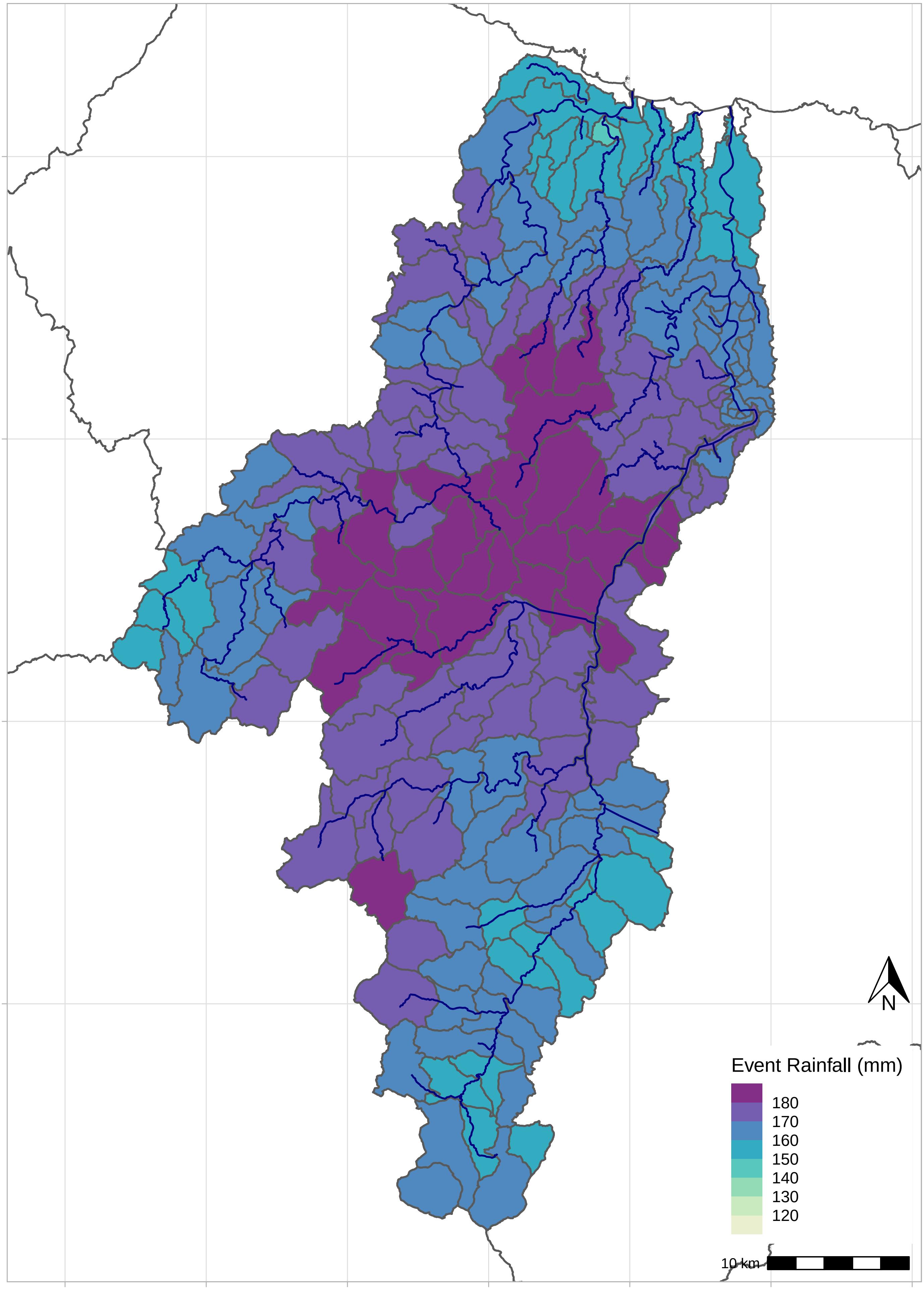
DESIGN RAINFALL DEPTHS

1440MIN 1%AEP



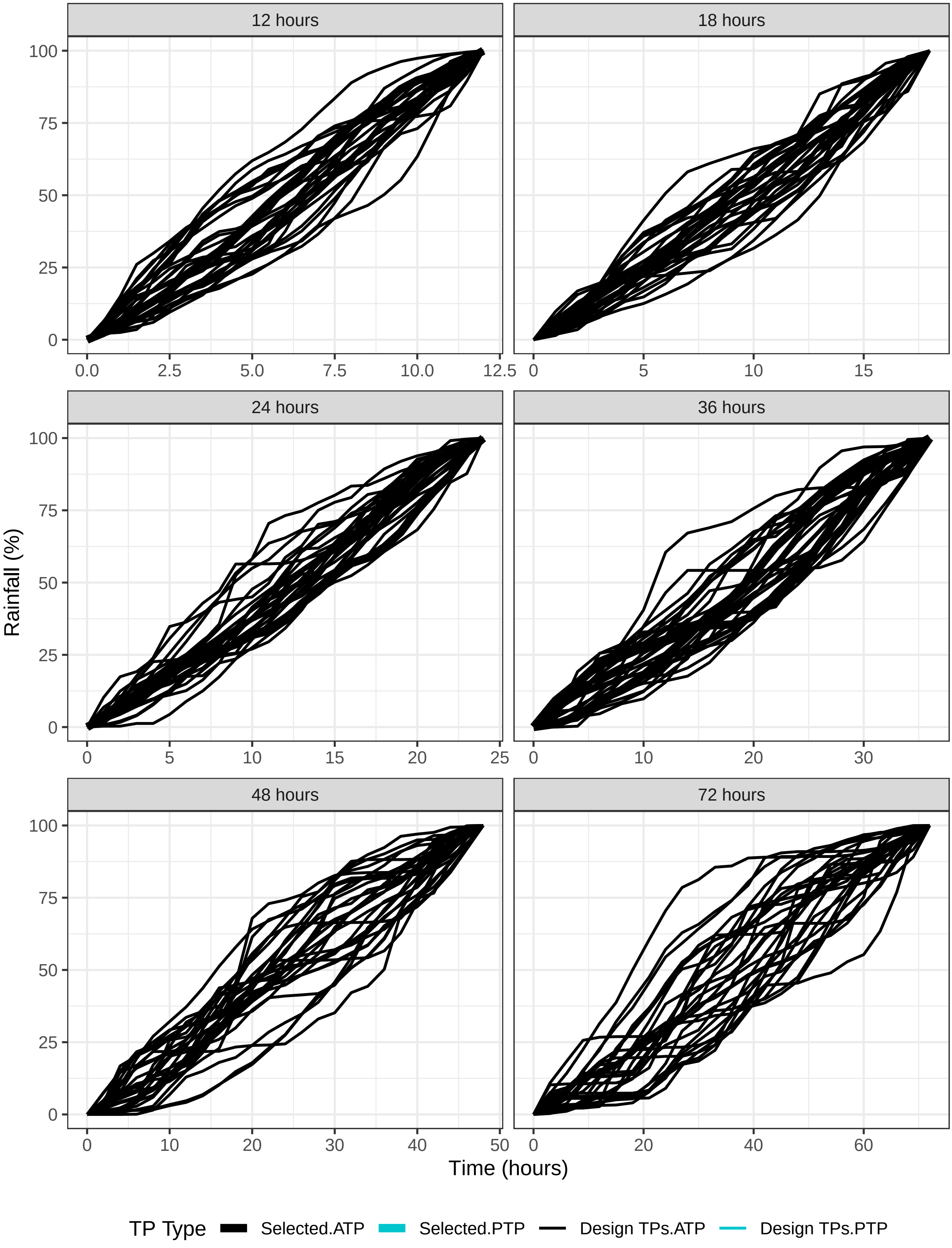
created by J:/Jobs/120038/Hydrology/Statewide/Design_Events/Forth−Leven/Forth_Leven_7_Design_Report_Plots.R
J:/Jobs/120038/Hydrology/Statewide/Design_Events/Forth−Leven/Forth−Levenv1/Report_Figures/FigureA2_1440_1pAEP_same_scale.pdf

FIGURE A3
DESIGN RAINFALL DEPTHS
1440MIN 0.5%AEP



created by J:/Jobs/120038/Hydrology/Statewide/Design_Events/Forth−Leven/Forth_Leven_7_Design_Report_Plots.R
J:/Jobs/120038/Hydrology/Statewide/Design_Events/Forth−Leven/Forth−Levenv1/Report_Figures/FigureA3_1440_1in200AEP_same_scale.pdf

FIGURE A4
DESIGN TEMPORAL PATTERNS
DURATIONS FROM 12 TO 72 HOURS



created by J:/Jobs/120038/Hydrology/Statewide/Design_Events/Forth−Leven/Forth_Leven_7_Design_Report_Plots.R

Appendix B

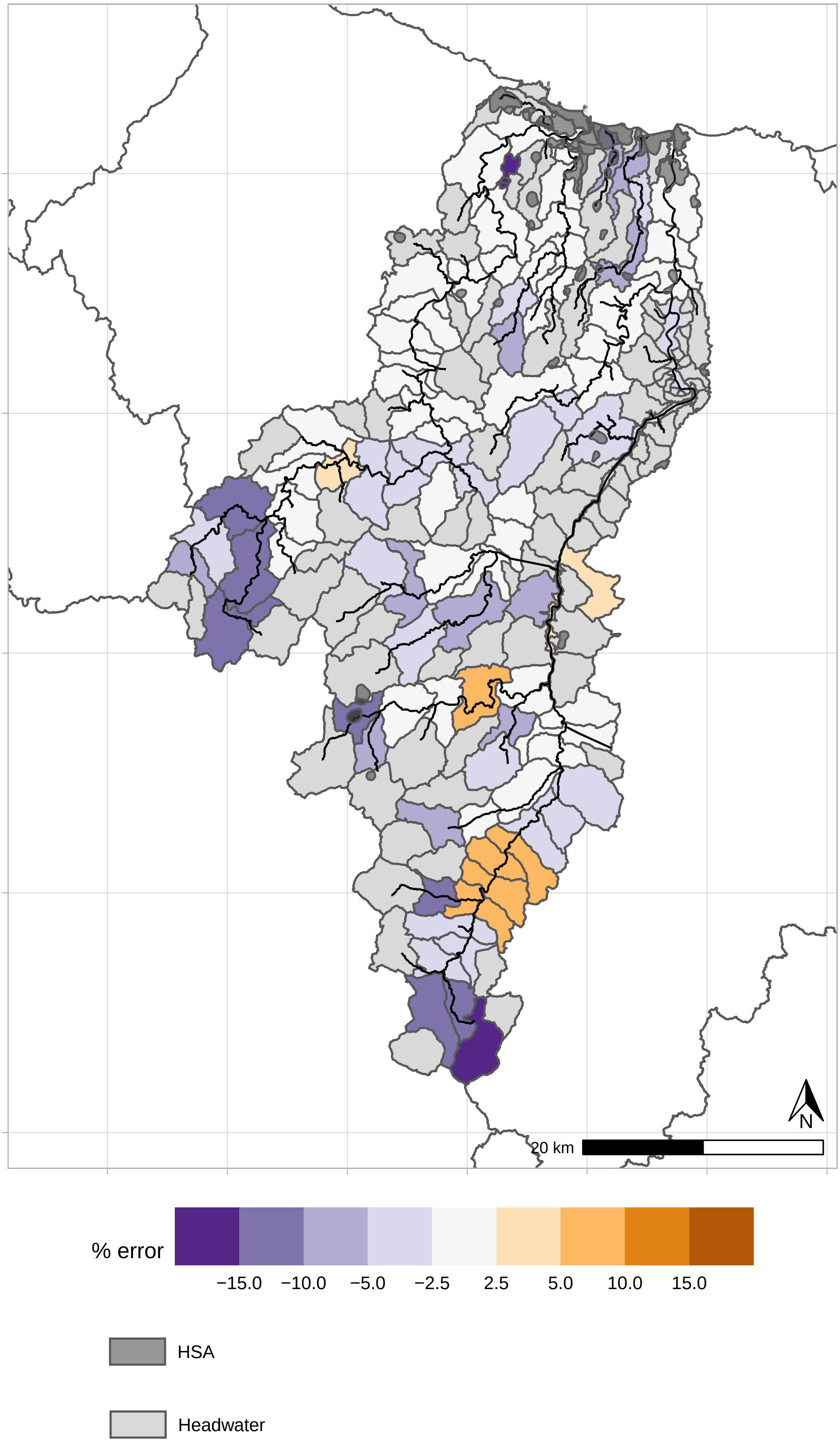
APPENDIX B. DESIGN PEAK ERRORS

Figure B1

Forth−Leven Catchment

Percentage error in peak flows using selected runs

2%AEP



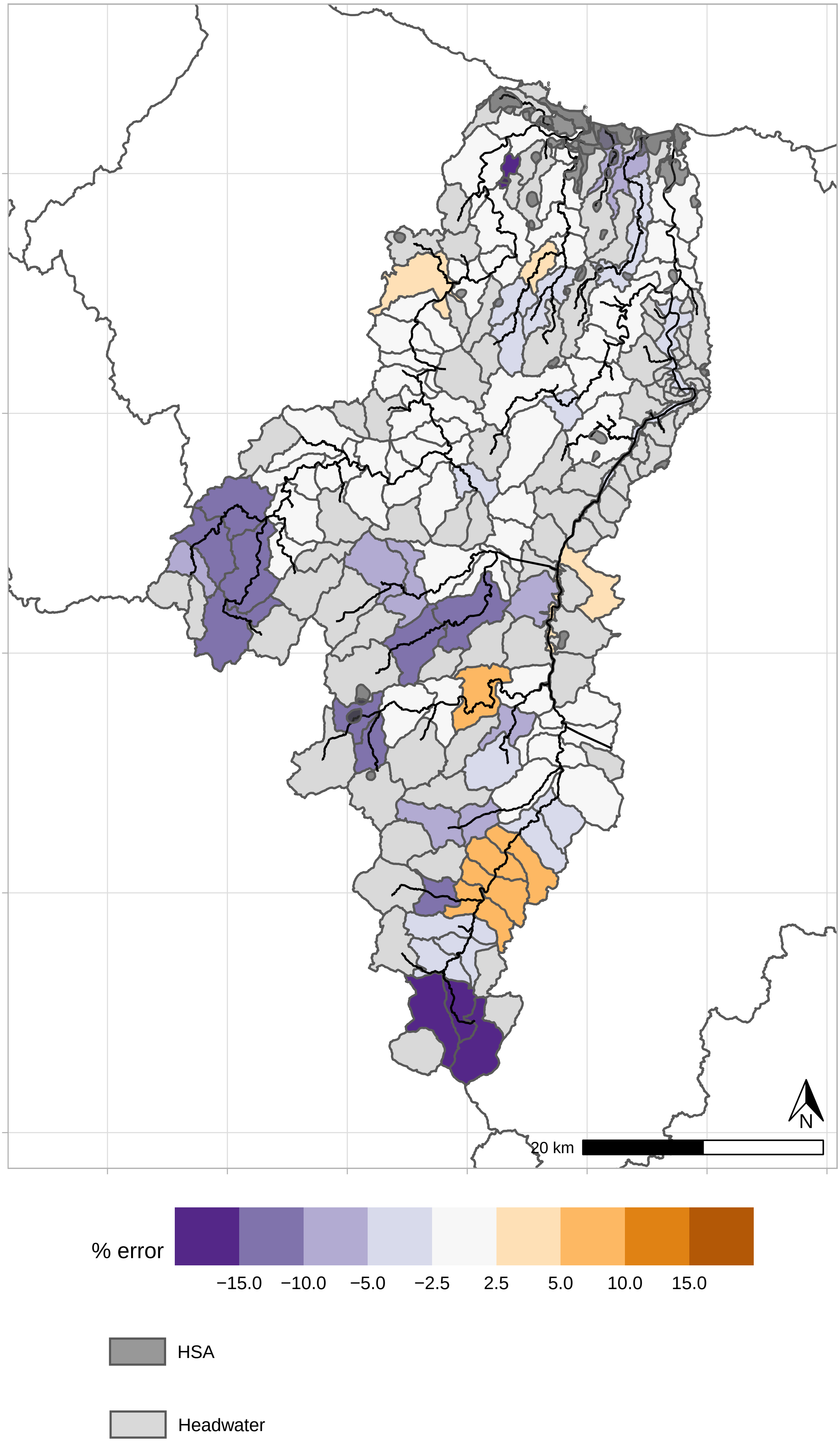
created by J:/Jobs/120038/Hydrology/Statewide/Design_Events/Forth−Leven/Forth_Leven_7_Design_Report_Plots.R

Figure B2

Forth−Leven Catchment

Percentage error in peak flows using selected runs

1%AEP



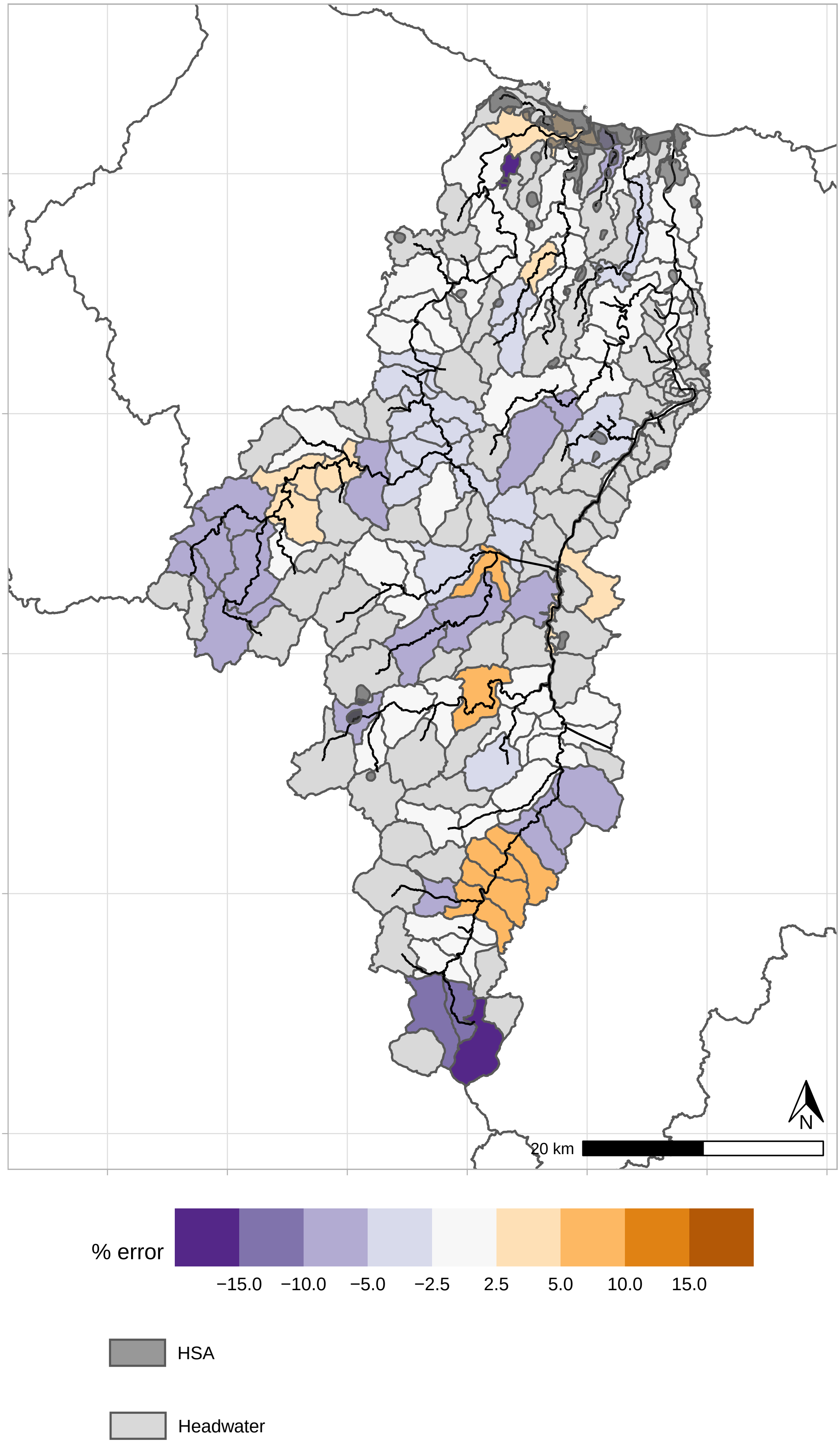
created by J:/Jobs/120038/Hydrology/Statewide/Design_Events/Forth−Leven/Forth_Leven_7_Design_Report_Plots.R

Figure B3

Forth−Leven Catchment

Percentage error in peak flows using selected runs

0.5%AEP



created by J:/Jobs/120038/Hydrology/Statewide/Design_Events/Forth−Leven/Forth_Leven_7_Design_Report_Plots.R