Lower Clarence Flood Model Update 2022

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Document Control

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Amendment Record

The Amendment Record below records the history and issue status of this document.

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Executive Summary

The Lower Clarence Flood Model extends from Mountain View, upstream of Grafton, to the ocean at Yamba and simulates and maps flood behaviour on the lower Clarence River floodplain. The model last went through a major revision for Clarence Valley Council in 2013. Since that time there have been improvements in modelling software, significant infrastructure developments within the floodplain and updated flood study guidelines. The February/March 2022 flood event also provides an opportunity to recalibrate the model to a recent event that has a good availability of calibration data.

This study updates the local Clarence Flood Model to provide improved definition and understanding of floodplain behaviour within the Lower Clarence Valley. The resulting model also provides a consistent platform that can be used for any future flood assessments.

The updated model has been calibrated to the flood events of January 2013, March 2021 and February/March 2022 and a good match to recorded flood levels has been achieved for all events.

The design flood events, expressed in terms of their annual exceedance probability (AEP) have been updated and revised design flood maps presented. The key updates with regards to the design flood events are as follows:

- Revisions to the design storm tide boundary so that it is consistent with boundaries derived for coastal-specific assessments undertaken for Council by others and compatible with current guidelines.
- The flood frequency assessment at Grafton has been updated to account for the full period of record to the present day, including the events of 2009, 2011, 2013 and 2022.
- Additional design floods have been modelled including the 0.5% and 0.2% AEP events.
- The assumptions regarding the extreme flood event have been updated to accord with current best practice.
- Two climate change scenarios have been modelled representing an intermediate (CC1) and a worst-case (CC2) scenario. The scenarios include 12% and 21.5% increases in rainfall for CC1 and CC2 respectively and allowances for sea level rise.

Table 1 presents the updated design peak flood levels at selected river gauges. Flood levels from the significant historic events of January 2013 and February/March 2022 are also included in Table 1.

Table 1. Updated Flood Model Results at Selected Gauges

Flood Event	Peak Flood Level (m AHD)				
	Grafton (Prince St Gauge)	Ulmarra	Brushgrove	Maclean	Yamba
5% AEP	8.11	6.15	5.14	3.18	1.34
1% AEP	8.44	6.42	5.66	3.55	1.85
1% AEP (CC1)	8.78	6.73	6.31	4.07	2.65
1% AEP (CC2)	9.05	7.11	6.78	4.46	3.05
Extreme Flood	13.58	12.71	12.50	8.56	6.07

Flood Event	Peak Flood Level (m AHD)				
	Grafton (Prince St Gauge)	Ulmarra	Brushgrove	Maclean	Yamba
January 2013	8.09	6.08	4.79	3.11	1.23
February/March 2022	7.67	6.06	5.16	3.36	1.60

*CC1 = Climate Change Scenario 1 (SSP 2 / 4.5) – 12% increase in rainfall; sea level rise of 0.76m from present day

**CC2 = Climate Change Scenario 2 (SSP 5 / 8.5) – 21.5% increase in rainfall; sea level rise of 1.09m from present day

The model outputs are presented as a series of maps and are also supplied digitally for upload onto Council's website.

The model outputs are provided at a higher resolution than was previously available giving a more refined flood extent. In addition to the mapped outputs provided, animations have been supplied for Grafton, Maclean and Yamba which can be viewed to highlight where the onset of flooding may first occur.

Contents

1 Introduction

1.1 Introduction

The Lower Clarence Flood Model extends from Mountain View, upstream of Grafton, to the Ocean at Yamba and is used to simulate the flood behaviour of the lower Clarence River and to determine design flood levels which are used for planning purposes.

Clarence Valley Council's (Council) current adopted model was last updated for Council in 2013 as part of the Lower Clarence Flood Model Update (BMT WBM, 2013). Since publication of that study, more recent versions of the model were developed for specific infrastructure projects, most notably the second crossing of the Clarence River at Grafton and the Pacific Highway upgrade.

Following the significant flood event of February/March 2022, Council engaged BMT to update and re-calibrate the Lower Clarence Flood Model. The model update accounts for notable changes to the floodplain such as the Pacific Highway upgrade and incorporates the latest available datasets. The update also takes advantage of significant advancements in modelling software and computing power since the time of the 2013 study, allowing the floodplain to be modelled and mapped to a higher resolution than was previously feasible. The update also presented an opportunity to revisit some of the modelling assumptions thereby ensuring that the model is compatible with current guidelines and accepted best practice.

The modelling documented in this report covers Clarence River flood events. Tributaries of the lower Clarence River are only represented in the model in so far as allowing backwater from the Clarence River to extend into the tributary catchments.

1.2 Design Flood Terminology

Design flood events are hypothetical flood events with a given probability of occurrence. This probability of occurrence is the chance that the flood may occur or be exceeded in any one year and is termed the Annual Exceedance Probability (AEP). A 1% AEP flood is a flood that statistically has a 1% chance of occurring or being exceeded in any given year. This is also sometimes stated as a '1 in 100' chance of occurrence with the two terms being interchangeable. Use of the AEP terminology for describing design floods is in accordance with current best practice as described in Australian Rainfall and Runoff 2019 (ARR2019).

Table 1.1 lists the AEP floods considered by this study in both the percentage and ratio forms. In this report the AEP terminology expressed as a percentage, has been used to describe probability of occurrence.

Table 1.1 Design Flood Terminology

AEP (%)	AEP (1 in Y)
20	5
5	20
2	50
1	100
0.5	200
0.2	500

In addition to the design floods listed in Table 1.1, an Extreme Flood has been modelled. The term ‘Extreme Flood’ is contained within the NSW Floodplain Development Manual and, for all intents and purposes, can be considered the same as the probable maximum flood (PMF). It is referred to as an Extreme Flood rather than a PMF as it is not derived from estimating catchment runoff from a probable maximum precipitation (PMP). It does however seek to replicate the magnitude of a PMF flood and so should be considered as such when a PMF event is required for planning or emergency management considerations.

1.3 Project Objectives

This study, referred to as the ‘Lower Clarence Flood Model Update 2022’ represents an update to Council’s adopted flood model, last updated for Council in 2013 (BMT WBM, 2013). The main objectives of the 2022 update are to:

- Update the Lower Clarence Flood Model to use more advanced software and to delineate flood mapping at a higher resolution.
- Calibrate the updated model to recent flood events.
- Revisit the flood frequency analysis at Grafton and update this assessment to use the record to the present day.
- Review the model downstream boundary and revise to reflect the latest applicable guidelines.
- Use the updated model to generate an updated set of design flood outputs.

2 Background

2.1 Study Area

The Clarence River catchment, on the far north coast of New South Wales (NSW), is one of the largest catchments on the east coast of Australia, with an area of approximately 22,000km^2. The study area is shown in Figure 2.1 and comprises the lower Clarence River floodplain from Mountain View, upstream of Grafton, down to the ocean at Yamba. The study area covers approximately 500km^2 of floodplain and includes the communities of Grafton, South Grafton, Maclean and Yamba along with several smaller towns and villages.

The lower Clarence River floodplains include numerous levee systems designed to provide a degree of protection from Clarence River floods. The most significant levee systems are located at Grafton, South Grafton and Maclean. These levee systems were initially constructed in the 1960's in response to the significant flood of 1950 and have been extended and raised at various points in time.

2.2 Model History

This study builds upon flood modelling of the lower Clarence River which has been developed over many years. The following key studies have involved major flood model updates and derived some of the key modelling assumptions retained in Council's current adopted model.

Lower Clarence River Flood Study (1988)

BMT (then trading in NSW as WBM Oceanics) completed the Lower Clarence River Flood Study for the Public Works Department in December 1988 (PWD, 1988). This study developed a one-dimensional (1D) dynamic flood model of the entire floodplain downstream of Grafton.

The main Clarence River inflows were based on a flood frequency analysis (FFA) of the Clarence River at Grafton and were provided to WBM Oceanics by the Public Works Department. The shape of the 1974 flood hydrograph was determined as being a typical hydrograph shape at Grafton and was scaled to fit the peak flow estimates derived by the FFA.

Hydrologic models of the tributary catchments of the floodplain (e.g. Sportsmans Creek, Glenugie Creek, Coldstream River) were also created based on a unit hydrograph technique and application of design rainfall based on Australian Rainfall and Runoff 1977 (ARR1977). Rainfall falling directly onto the lower Clarence River floodplain was accounted for by applying inflows to nodes in the model based on the floodplain area.

The ocean (storm tide) boundaries were supplied by the Public Works Department and included a 1% AEP storm tide peak level of 2.6mAHD. The study investigated a number of scenarios in which the relative timing of the storm tide peak and catchment runoff peak was varied. The study adopted an assumption whereby the peak of the storm tide coincided with the peak of the rainfall on the tributary catchments but which occurred before the peak of the main Clarence River catchment runoff.

Lower Clarence River Flood Study Review (2004)

The Lower Clarence River Flood Study Review (WBM Oceanics, 2004) updated the Lower Clarence Flood Model by converting it from a 1D model to a 2D model allowing the floodplain behaviour to be captured in much greater detail. The model was also extended approximately 10km upstream of Grafton to Mountain View. The 2D model used a digital terrain model (DEM) composed of various sources, predominantly ground contour information. The model sampled this DEM at a 60m grid resolution. A key part of the study involved a review of the modelled Clarence River inflows. To do this the study developed a series of rating curves representing different historical conditions and used these to convert recorded flood levels at Grafton to peak flow estimates at Mountain View. An updated flood frequency analysis was then performed on the series of peak flows to provide design flow estimates. The updated peak design flows were then applied to the shape of the 1974 flood hydrograph as per the 1988 study and used to map design floods for the 20%, 5%, 1% and 0.2% AEP events.

The hydrologic (unit hydrograph) models developed for the tributaries entering the floodplain downstream of Grafton were retained from the 1988 study but updated to use design rainfall from the more recent Australian Rainfall and Runoff 1987 (ARR1987).

The storm tide magnitude and assumptions on timing were retained from the 1988 study, i.e. a peak 1% AEP storm tide of 2.6mAHD was timed to occur at the time of peak rainfall and before the time of peak catchment runoff.

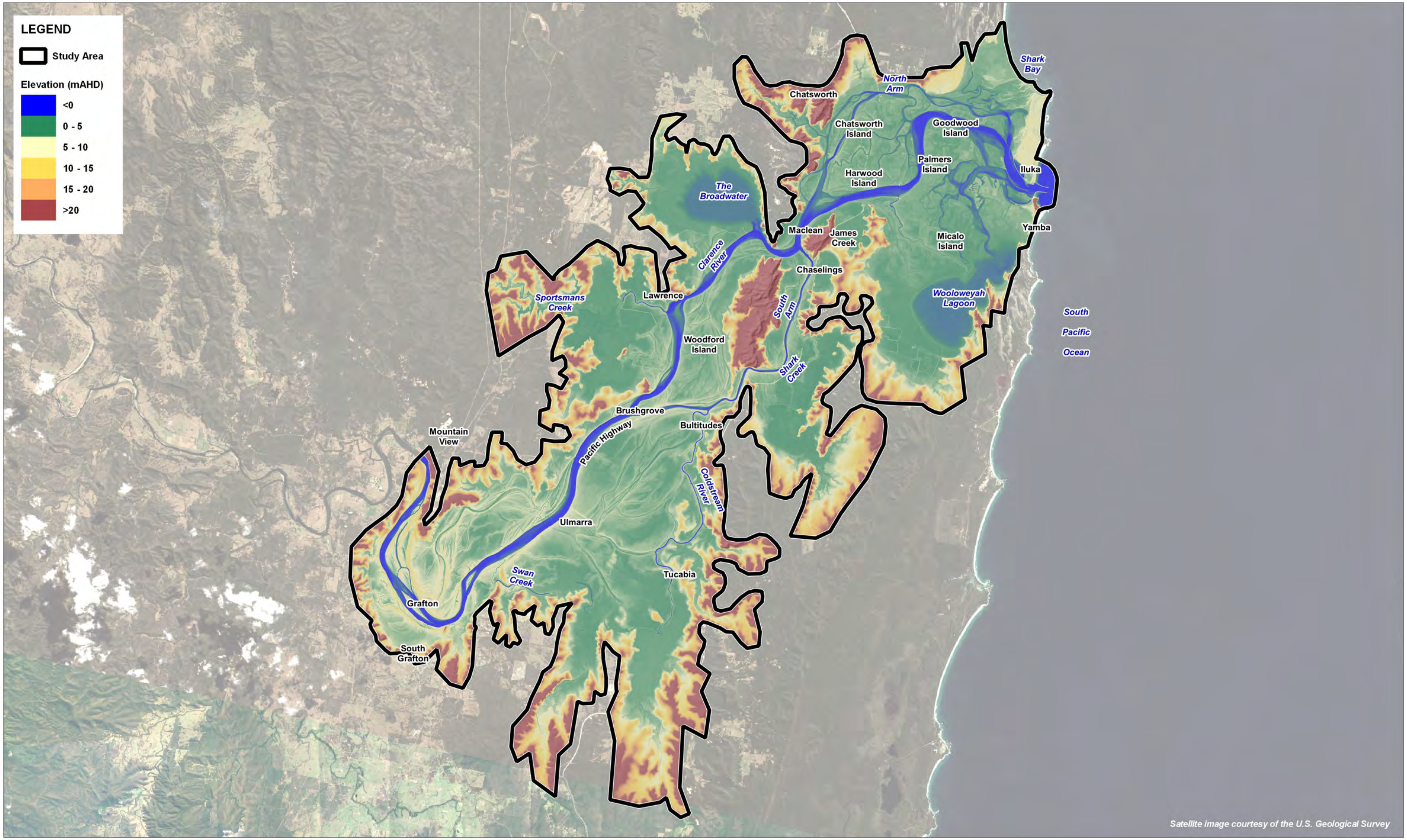
The study included the derivation of an extreme flood. This was obtained by applying a scaling factor of 1.53 to the 1% AEP inflows. The scaling factor was derived from the ratio of the 72 hour Probable Maximum Precipitation (PMP) depth estimate of 660mm and the 72 hour 1% AEP rainfall depth of 430mm. A second extreme flood using a 1% AEP scaling factor of 3.0 was also modelled.

Lower Clarence Flood Model Update (2013)

The Lower Clarence Flood Model Update 2013 (BMT WBM, 2013) further refined the 2D model of the Lower Clarence floodplain. The study retained the same model extent as used for the 2004 study but improved the representation of terrain in the model by using LiDAR data captured in 2010 along with a detailed survey of the Grafton and South Grafton levee systems. The LiDAR data significantly improved the modelled definition of the floodplain. The model was also updated to use multiple 2D domains whereby higher resolution domains (10m grid) were specified in Grafton and Maclean. Outside of these areas the majority of the modelled area retained a 60m model grid.

During the study, the significant flood event of January 2013 occurred. The updated model included a calibration to this event along with previous historic events.

The design flood model inflows, storm tide boundaries and associated assumptions were retained from the 2004 study. The model was used to map design flood events for the 20%, 5%, 2% and 1% AEPs. The Extreme Event was also modelling using a 1%AEP scaling factor of 1.53 which was retained from the 2004 study. Of note, the 0.2% AEP and the second Extreme Event (3.0x scaling factor) were not included in the assessment. The study also included three 1% AEP climate change scenarios, all with a 10% increase in rainfall and with varying allowances for sea level rise. The sea level rise amounts of 0.4m and 0.9m were applied on top of the 1% AEP storm tide peak of 2.6mAHD.



Title:
Study Area

Figure: 2.1

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3 Flood Model Update

3.1 Introduction

Clarence Valley Council's current adopted flood model of the lower Clarence was last updated by BMT in 2013 (see Section 2). It is a 2D hydraulic model developed using TUFLOW software and extends from Mountain View, upstream of Grafton, to the ocean at Yamba. Much of the modelled area is represented as a 60m grid with parts of Grafton and Maclean modelled at finer 30m and 10m grid resolutions. Full details of the model development are provided in the report 'Lower Clarence Flood Model Update 2013' (BMT WBM, 2013).

Since 2013 there has been ongoing development within the floodplain, including the construction of the second Grafton Bridge and the Pacific Highway Upgrade. There have also been significant advancements in the modelling software along with updated modelling guidance. Furthermore, the flood event of February/March 2022 was significant and offers an opportunity to calibrate the flood model with the recent floodplain development in place.

The opportunity has therefore been taken to update the model and to recalibrate the model to recent flood events. The updates made to the model fall within two general categories as follows:

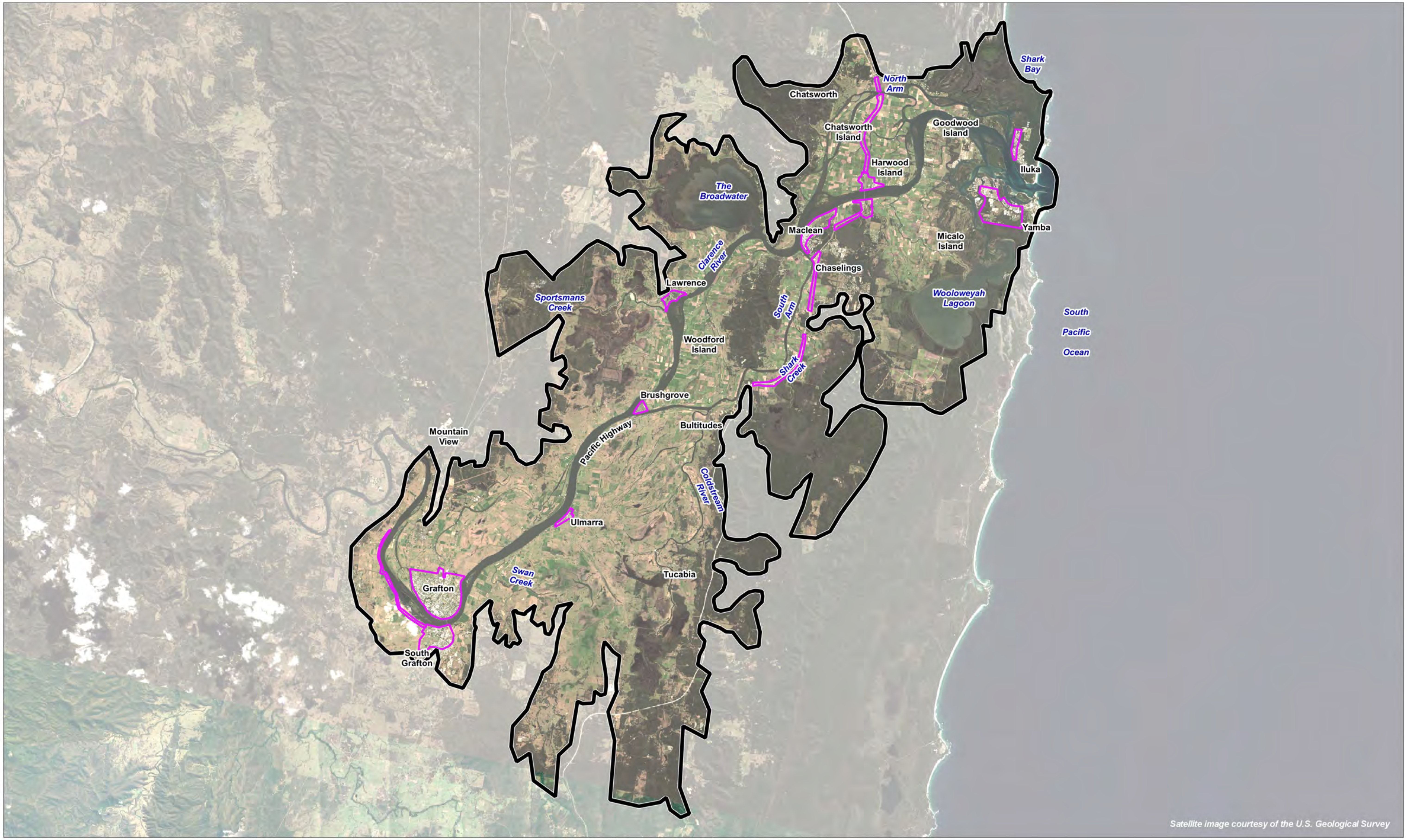
- Software and model schematisation updates
- Updates to model input data and assumptions.

These updates are summarised below. Together, the updates represent a major upgrade to the Lower Clarence Flood Model which then warranted a revisit of the model calibration. This has been undertaken using the historic events of January 2013, March 2021 and February/March 2022. This is documented in Section 4.

3.2 Software and Schematisation Updates

Since the adoption by Council of the 2013 flood study, there have been significant advancements in the TUFLOW modelling software. This includes the ability for the software to run models on high performance Graphics Processing Units (GPUs). This in turn allows for faster simulation times or comparable simulation times but at a finer model grid resolution.

The Lower Clarence River Flood Model has therefore been updated to take advantage of these improvements which includes use of TUFLOW's Quadtree feature to vary the model grid size. The model now utilises a model grid size of 20m in rural areas and 10m in both urban areas and along key floodplain features such as the Pacific Highway. The model is designed such that additional areas of high resolution can be incorporated with relative ease, for example when using the model for a site specific assessment. Figure 3.1 shows the model extent and the areas of higher model resolution.



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10m resolution

Model extent (20m resolution)

Title:

Model Extent and Resolution

Figure: 3.1

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3.3 Model Topography

The base topography uses LiDAR data captured in 2010 as this is the latest LiDAR dataset available for the lower Clarence River floodplain. This base topography is the same as that applied in the modelling for the 2013 flood study although it is now sampled at a higher resolution within the model. The in-bank bathymetry has been defined based on the Clarence River hydro-survey used by the original Lower Clarence River Flood Study (WBM Oceanics, 2004). Where more current bathymetry is available, such as near Grafton, this has been incorporated into the model. During a flood event, changes to the channel bed may occur due to scour or deposition of sediment. The model assumes a fixed bathymetry based on available survey data. During extreme events, this limitation may impact on model results (this is explored further for the Extreme Flood event in Annex D).

In addition to the topographic features represented in the 2013 flood study version of the model, the following additions have also been made:

- A 2015 levee survey of the Grafton and South Grafton levees captured for the Grafton Bridge project. Works as executed survey was also included for those parts of the levee that were updated
- A 2017 levee survey of the Maclean levee captured for the Pacific Highway Upgrade project
- Incorporation of embankments and drainage enforcement input layers from the Pacific Highway Upgrade (Roads and Maritime, 2017)
- Filling within the West Yamba Urban Release Area (fill as at 2022).
- Big River Way survey, captured by TfNSW in June 2020
- River bank survey south (upstream) of Ulmarra captured by TfNSW in 2018
- Goodwood Island – survey of levees and adjoining natural high ground (captured by Council in 2017)
- Ground survey of a levee near Sportsmans Creek (captured by Council in 2015)
- Taloumbi levee survey at Lake Wooloweyah (captured by Macro Consulting Surveyors in 2018 for Council)
- Survey of a key floodplain spill location along Old Coldstream Road (captured by Council in 2020)
- Kings Creek Levee (captured by Council in 2020)
- Ashby Island Levee (captured by Council in 2020)
- Iluka levee (survey date unknown)

For levees and embankments within the floodplain for which no ground survey exists, breaklines were included to ensure that the crest level of these features is represented in the model.

The model was also extended on some of the Lower Clarence River tributaries to fully allow backwater to propagate into those tributary catchments. Extensions were also made to the model to allow for additional outlets to the ocean across the dune systems during extreme flood events.

3.4 Model Boundaries

The 2013 model included four main types of model boundary as follows:

- Flood inflows for the Clarence River at Mountain View;
- Flood inflows for the Clarence River tributaries downstream of Mountain View;
- Runoff resulting from direct rainfall onto the lower floodplain; and

- Ocean water levels

For this update, the main Clarence River inflow location and the ocean boundary location have been retained in the model. A significant update has been to develop a separate hydrologic (WBNM) model of the Lower Clarence floodplain. This replaces both the tributary inflow unit hydrograph models and the floodplain rainfall runoff inputs from the 2013 study. The WBNM model allows for improved hydrologic routing of tributary inflows and allows runoff generated within the Lower Clarence Floodplain to be applied to the hydraulic model in a more distributed manner. It also provides for a consistency of approach and improves the ease of use of the model for simulating design flood events. Figure 3.2 shows the location of the hydrologic model subareas across the lower Clarence floodplain.

As discussed in Section 3.3, additional ocean boundaries have been applied on the ocean side of dune systems to the north of Iluka, near Shark Bay. This allows catchment runoff to pass into the ocean during extreme flood events.

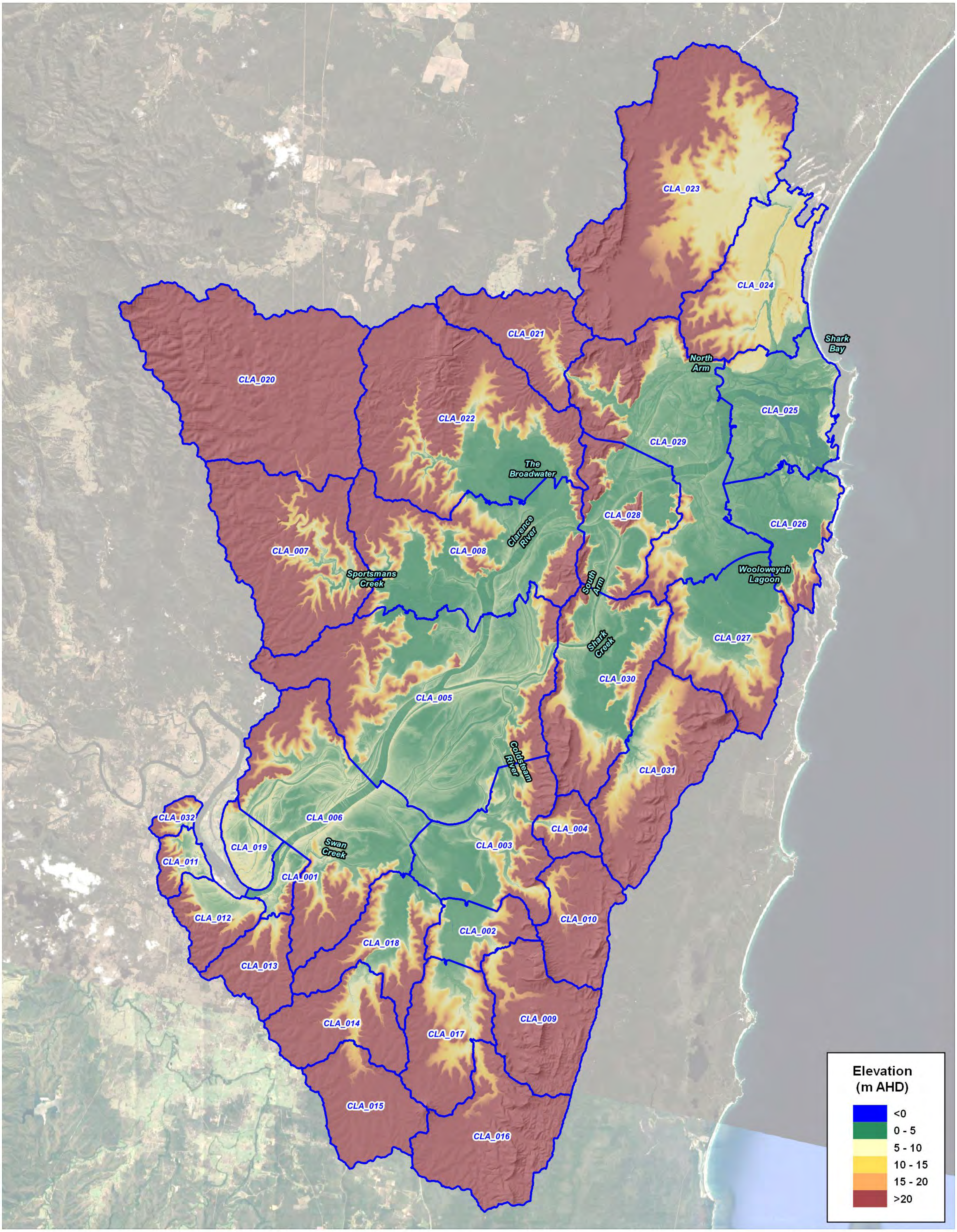
3.5 Land use Delineation

Land use mapping is used by the hydraulic model to represent the associated hydraulic resistance or roughness (Manning's n values) within the floodplain. The land use types and associated roughness values remain largely as defined for the 2013 study. Updates have been made to represent new floodplain features, such as the Pacific Highway upgrade or where the model has been extended from that used in the 2013 study.

During model calibration, the Manning's n values for the river were reviewed and only minor changes to values were required. This included a revised (smoother) Manning's n value for the river downstream of Maclean to reflect the more estuarine fine sediment. The Manning's n values applied in the model for different land use types are provided in Table 3.1 and are shown in Figure 3.3.

Table 3.1 Hydraulic Model Land Use Categorisation

Land Use Category	Manning's n coefficient
River (upstream of Maclean)	0.025
River (downstream of Maclean)	0.022
River Bank	0.06
Island Vegetation	0.08
Pasture	0.06
Sugar Cane	0.15
Crops	0.1
Forest	0.2
Urban Blocks	0.3
Parks	0.04
Roads (accounting for buffered strip)	0.02



Legend

Subcatchments

Title:

Hydrologic Model Subareas

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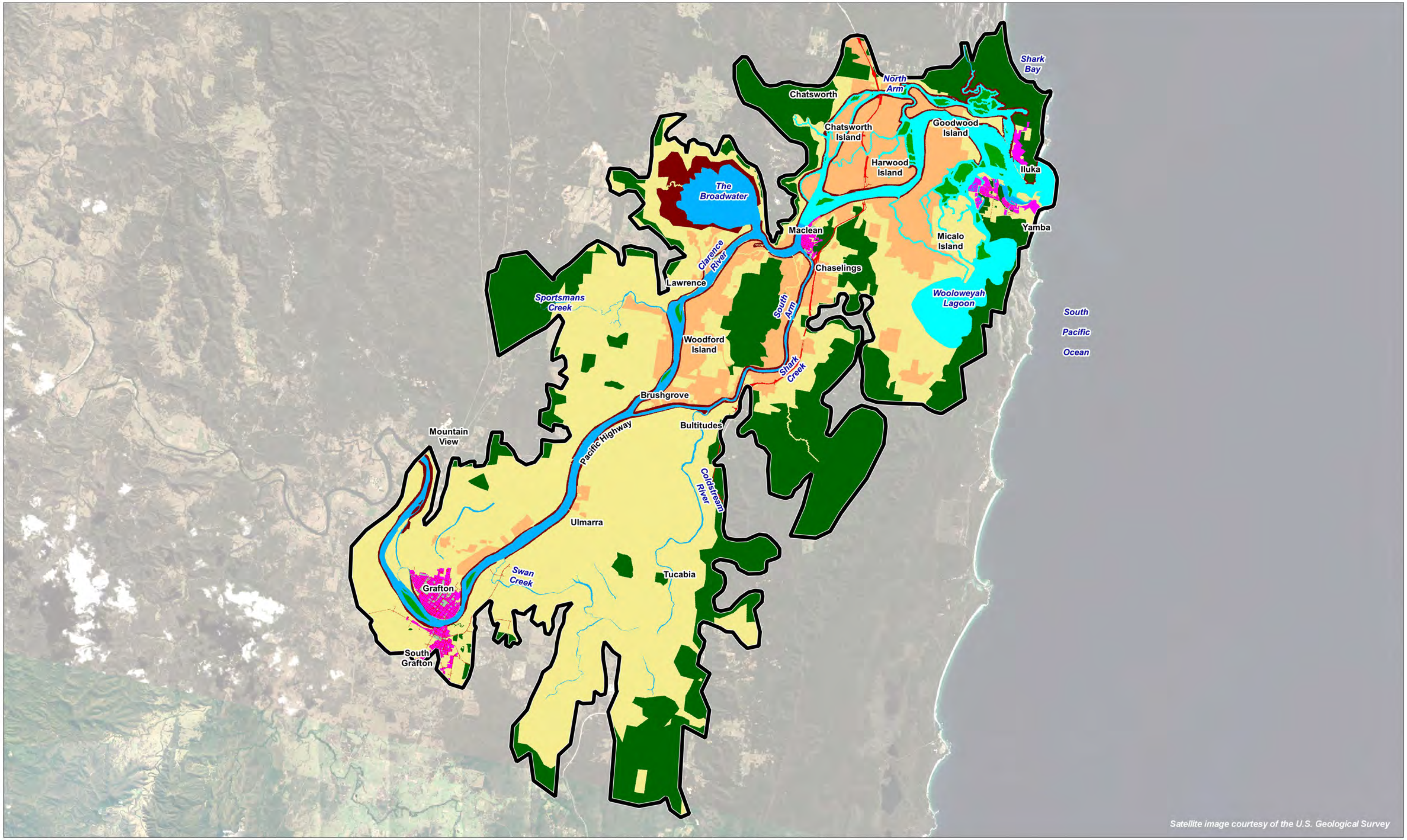

LEGEND

Model extent (20m resolution)

Land Use

- River (upstream of Maclean)
- River (downstream of Maclean)
- River Bank
- Island Vegetation
- Pasture
- Sugar Cane
- Forest
- Urban Blocks
- Parks
- Roads (accounting for buffered strip)

Title:

Model Land Use

Figure: 3.3

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4 Model Calibration

4.1 Overview

Model calibration is the process by which model parameters are adjusted within acceptable bounds until the model is deemed to adequately represent real world behaviour. Historical flood events are used as the basis for achieving this with the goal of having modelled flood behaviour matching closely with recorded flood data.

Three historic events have been used for the purposes of calibrating the updated flood model. These events are January 2013, March 2021 and February/March 2022. The events were selected as they are significant, relatively recent and have good availability of calibration data (rainfall and river levels). The 2021 and 2022 events also provide an opportunity to calibrate the model with the new Grafton Bridge and the Pacific Highway upgrade in place.

Table 4.1 compares the peak recorded river levels for each of the three calibration events at key gauges along the Clarence River[1]. Figure 4.1 presents a comparison plot of the event flood hydrographs at the Ulmarra gauge. The timing of the flood peaks have been aligned for ease of comparison. Figure 4.2 shows the locations of all gauges referred to in Table 4.1.

The following points are noted about these events:

- The January 2013 event is the highest level recorded of the three events at Grafton.
- At Ulmarra, the January 2013 and February/March 2022 events were of a similar peak magnitude (see Figure 4.1).
- Downstream of Ulmarra, the February/March 2022 event is the largest of the three calibration events.
- The February/March 2022 event contained significantly more volume than the January 2013 flood as evidenced by the wider shape of the stage hydrograph.
- The March 2021 event is the smallest of the three events at all presented gauge locations.

During the February/March 2022 event a significant amount of rain fell on the lower Clarence River catchment downstream of Grafton. Therefore, whilst the 2013 event was larger at Grafton, the 2022 event was larger for areas downstream of Ulmarra. The 2022 event is therefore a good event to assess the performance of the WBNM hydrologic model for its ability to represent the lower catchment response.

[1] The river gauges record water level over time. Where an estimate of flow is required e.g for use in flood frequency analysis a rating curve is typically used to convert recorded levels to flows.

Table 4.1 Recorded Flood Levels at selected Clarence River Gauges (m AHD)

Gauge	Jan 2013	Mar 2021	Feb/Mar 2022
Grafton (Prince St)	8.09	6.58	7.67
Ulmarra	6.08	5.14	6.03
Brushgrove	4.79	4.27	5.16
Lawrence	4.40	3.82	4.71
Maclean	3.11	2.66	3.36
Palmers Island Bridge	2.55	2.11	2.79
Lake Wooloweyah	1.21	1.06	1.73
Yamba	1.23	1.17	1.60

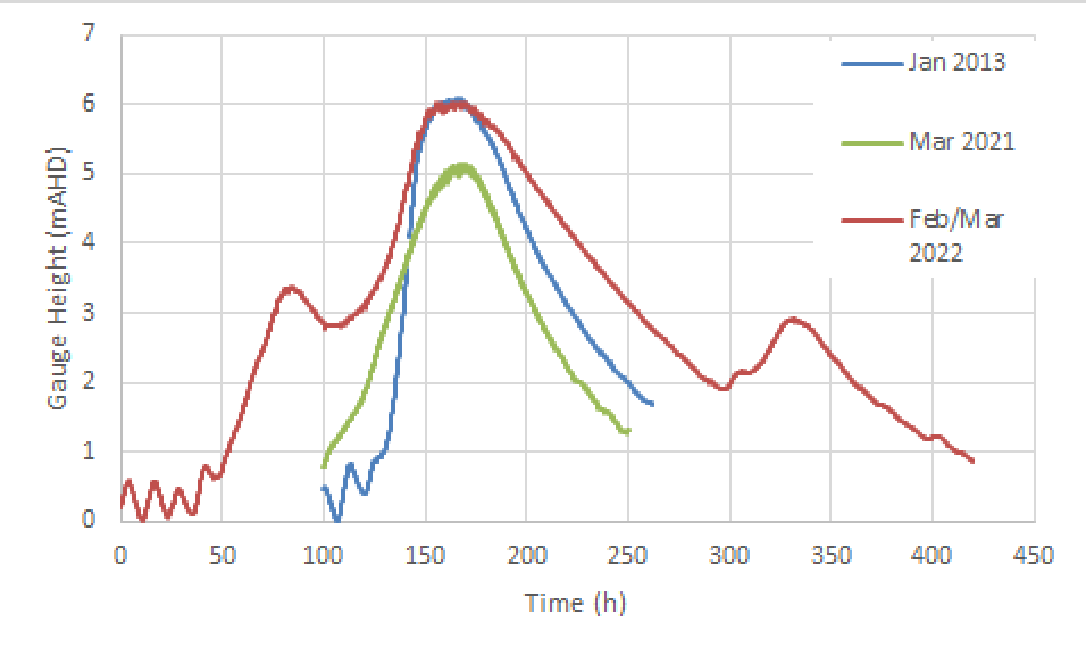
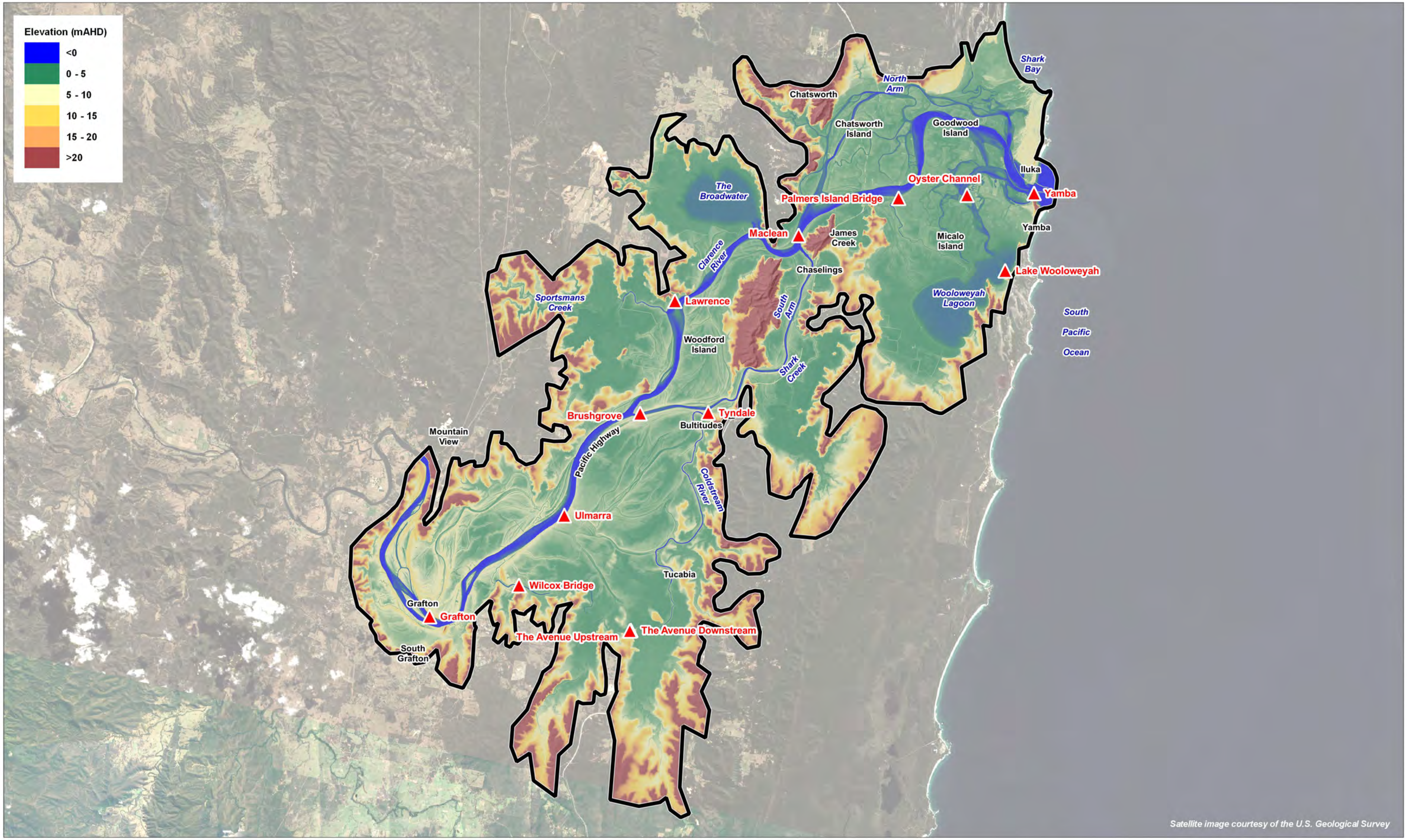


Figure 4.1 Comparison of Flood Level Hydrographs at Ulmarra (time of peak aligned)



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River Level Gauges

Study Area

Title:

Lower Clarence River Level Gauge Locations

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4.2 Calibration event boundary conditions

The calibration event boundary conditions were derived as follows:

- **Clarence River Inflows:** Generated by using the updated hydraulic model to generate the flow hydrograph from application of the recorded water level hydrograph as a model boundary at Grafton[2]. The resulting flow hydrograph was then applied at the upstream model boundary at Mountain View with an adjustment for travel time between Mountain View and Grafton and minor adjustments made to the hydrograph shape. The modelled water level hydrograph at Grafton was checked against the recorded data with further adjustments to the inflow made if needed.

- **Tributary Inflows and lower catchment runoff:** Locally recorded event rainfall data was applied within the hydrologic WBNM model to generate model inflows across the lower Clarence floodplain.

- **Ocean boundary:** Conditions were defined using recorded tide data at Yamba supplied by Manly Hydraulics Laboratory.

4.3 Calibration Results

The results for the flood model calibration are summarised in Table 4.2 for the river gauge locations shown in Figure 4.2.

Annex A includes plots of the recorded and modelled water levels at gauges for each of the three calibration events. For the 2013 event, the modelled results from the previous flood study are also shown. Also shown in Annex A are the modelled flood extents and comparisons of modelled water levels to recorded levels at flood marks for the 2013 and 2022 events. No flood marks were available for the 2021 event and so only the modelled flood extent is shown. Flood marks which had a recorded level that was clearly not the maximum peak level were removed from the dataset. These were identified, for example if a number of neighbouring flood marks had significantly higher recorded peak levels.

The model results show good agreement with the recorded gauge data. It is noted in particular that the 2022 event shows a good calibration against gauge records. This event had a significant amount of inflows from tributaries downstream of Grafton and the calibration demonstrates that the hydrologic WBNM model is representing this runoff generation well.

The gauges located within the Swan/Coldstream basins and not on the main river include The Avenue (upstream and downstream) and Wilcox Bridge. The calibration to the recorded hydrographs at these locations is more challenging as the levels are sensitive to both runoff from within the basins themselves along with the overtopping volume from the Clarence River. For the 2022 event, the model replicates the overall shape and timing of the hydrographs at these three gauges very well. For the 2013 event a reasonable representation is achieved with an improvement to the overall modelled shape compared to the 2013 flood study result, noting that the Wilcox Bridge gauge was not installed at the time of this event. In the 2021 event the model does not replicate the levels at these three gauges particularly well but this is not surprising given the smaller nature of the event where local drainage features and runoff from local catchments will tend to dominate the response.

Overall the results indicate that the updated model provides a sound representation of flood behaviour for current catchment conditions.

[2] The hydraulic model includes a water level boundary (type HT) at the Prince Street gauge which is used for the interim purpose of deriving historic event flows from recorded levels at the gauge.

Table 4.2 Flood Model Calibration Results: Peak Flood Level

	Jan 2013		Mar 2021		Feb/Mar 2022	
Gauge	Recorded (mAHD)	Modelled (mAHD)	Recorded (mAHD)	Modelled (mAHD)	Recorded (mAHD)	Modelled (mAHD)
Grafton (Prince St)	8.09	8.04	6.58	6.51	7.67	7.65
Ulmarra	6.08	6.07	5.14	5.25	6.03	6.07
Wilcox Bridge	n/a	4.78	3.32	2.78	5.11	4.86
The Avenue (u/s)	4.02	3.76	3.34	2.78	5.44	4.78
The Avenue (d/s)	4.01	3.76	3.32	3.01	5.15	4.78
Brushgrove	4.79	5.04	4.27	4.39	5.16	5.15
Tyndale	4.39	4.43	n/a	4.07	5.05	4.76
Lawrence	4.40	4.50	3.82	3.77	4.71	4.68
Maclean	3.11	3.06	2.66	2.60	3.36	3.26
Palmers Island Bridge	2.55	2.52	2.11	2.10	2.79	2.73
Oyster Channel	1.34	1.35	1.15	1.17	1.80	1.81
Lake Wooloweyah	1.21	1.22	1.06	1.04	1.73	1.79
Yamba	1.23	1.32	1.17	1.20	1.60	1.69

5 Flood Frequency Analysis

5.1 Introduction

The main Clarence River inflow is based on a flood frequency analysis (FFA) of the Clarence River at Grafton. There is a record of peak flood levels at Grafton (Prince Street) which dates back to 1839 resulting in a 184 year period within which peak flood levels were recorded to present day (2022). This record can be converted to peak flow estimates and then statistically analysed to provide the most reliable way of estimating design flood flows at Grafton.

The Clarence River inflows to the 2013 flood study were based on an FFA at Grafton which was undertaken in 2002 and presented in the 2004 flood study. The current model update provides an opportunity to update the FFA using an additional 20 years of data that have been recorded since that time.

5.2 Previous FFA

The last FFA undertaken at Grafton for Clarence Valley Council was detailed in the 2004 Lower Clarence River Flood Study Review (WBM Oceanics, 2004). This FFA was prepared in 2002 and covered a period of 163 years including the years of missing data.

The study derived a series of four historical rating curves representing four distinct floodplain states. These were used to convert peak recorded flood levels at Grafton (Prince Street gauge) to peak flow estimates at Mountain View, approximately 10km upstream of Grafton. The distinct floodplain states were largely determined through the extent of levee works in Grafton and South Grafton at the time. The rating curves are detailed in Table 5.1 and shown in Figure 5.1.

Table 5.1 Historical Rating Curves

Rating Curve	Description	Applicable Period of Record
1	Natural State	1839 to 1909
2	Works in place at 1910	1910 to 1973
3	Works in place at 1974	1974 to 1995
4	Works in place at 1996	1996 to present

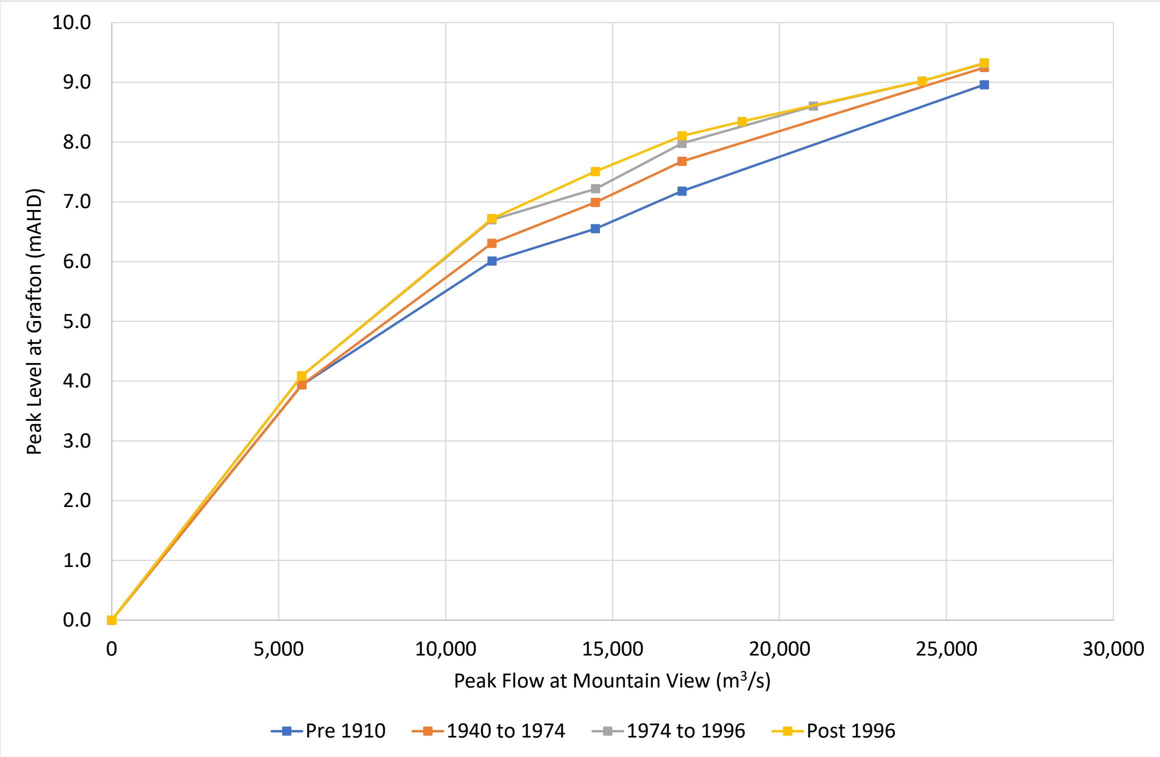


Figure 5.1 Historical Rating Curves derived for Grafton

The 2013 flood study retained the FFA derived peak flow estimates from the 2004 flood study. These peak design flood estimates (derived in 2002) are provided in Table 5.2.

Table 5.2 2004 Flood Study FFA Peak Flow Estimates at Mountain View

AEP (%)	Peak FFA Flow (Mountain View) (m^3/s)
20	9,360
10	13,710
5	16,280
2	18,220
1	19,060
0.5	19,590
0.2	20,000

5.3 Revised Rating Curve

The current assessment has resulted in significant updates to the hydraulic model. This has the potential to affect the rating curve relating peak levels at Grafton (Prince Street) to the model inflow at Mountain View. For this reason, the rating curve representing current catchment conditions (rating curve 4 – post 1996) was regenerated using the updated model. Figure 5.2 plots the updated rating curve against the previous one. Overall, the two rating curves are similar with only relatively minor differences apparent. For this reason, the remaining three historical rating curves have not been revisited. The updated rating curve 4 has been incorporated into the assessment for generating peak flow estimates post 1996.

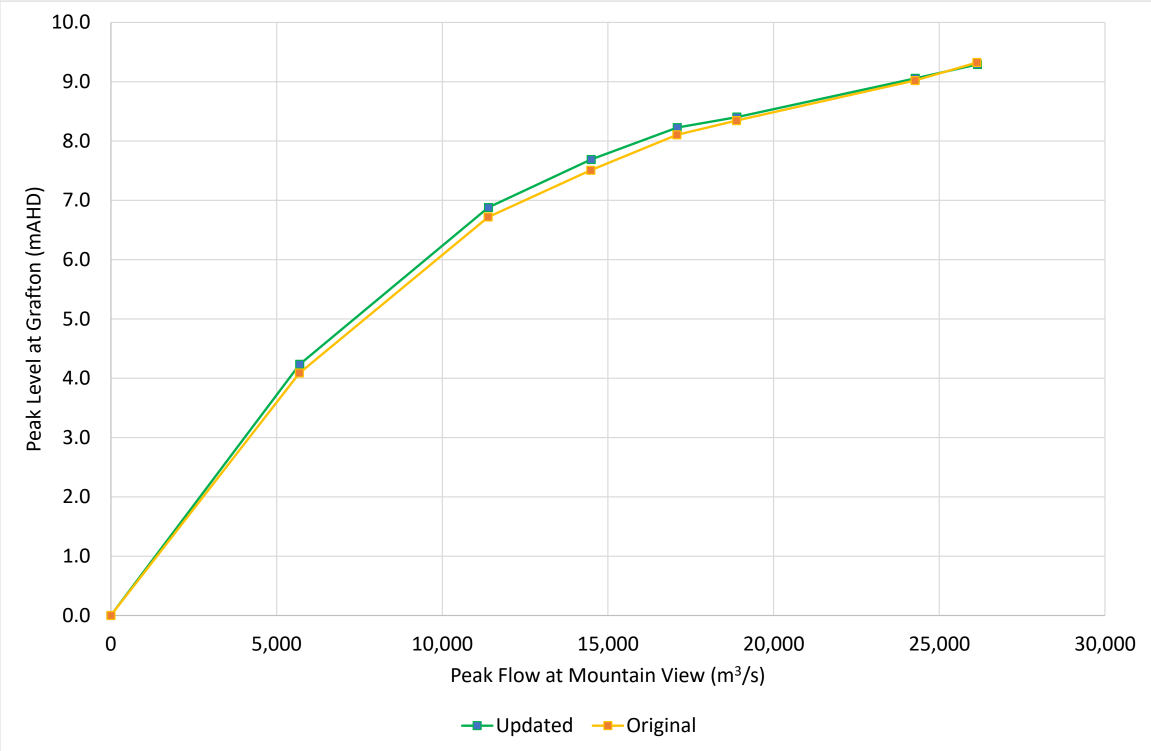


Figure 5.2 Updated Post-1996 Rating Curve

5.4 Revised Flow Series

Annex B contains the updated peak annual maximum flow series derived from rating curves and also includes the peak levels at the Grafton, Prince Street Gauge upon which those flow estimates are based. The top 10 events in terms of peak flow are summarised in Table 5.3. Of note, the January 2013 event was the largest on record in terms of peak flood level at Prince Street but is only 9th largest in terms of its flow magnitude. It achieves the highest level due to the containing effect of the Grafton levee system which was not present for the majority of the other top 10 events.

Table 5.3 Top 10 Peak Flows at Mountain View

Rank (for peak flow)	Event Year	Peak Level at Grafton (mAHD)	Peak Flow (Mountain View) (m^3/s)
1	1890	7.83	20,411
2	1887	7.78	20,157
3	1893	7.68	19,648
4	1876	7.43	18,377
5	1950	7.73	17,408
6	1954	7.67	17,068
7	1963	7.58	16,728
8	1967	7.55	16,614
9	2013	8.09	16,433
10	1863	6.90	15,945

5.5 Flood Frequency Analysis

The FFA was undertaken on an annual maximum series of peak flows dating back to 1839. The record is incomplete and an assumption has been made that missing years, assumed to have no flood, have peak flows of less than 3,000m^3/s. In total, 115 missing years were treated in this way. A further two years had recorded flows below 3,000m^3/s (1934 and 1983). These years were also treated as censored data below a threshold of 3,000m^3/s. The remaining 67 years in the period of record have peak flow estimates.

The analysis of the data was undertaken using TUFLOW-FLIKE software which is software suggested for use by ARR2019. A Bayesian approach was applied within the software and results were fitted to a generalised extreme value (GEV) model.

Table 5.4 presents the results of the updated FFA and Figure 5.3 presents the fit of the GEV distribution along with the upper and lower confidence limits. A copy of the TUFLOW-FLIKE output file is included in Annex C.

Table 5.4 Updated FFA Peak Flow Estimates at Mountain View

AEP (%)	Peak FFA Flow (Mountain View) (m^3/s)
20	9,240
10	13,670
5	16,380
2	18,500
1	19,460
0.5	20,080
0.2	20,590

The following observations are noted:

- Almost all the data falls within the 90% confidence limits
- The GEV has an upper bound of 21,255m^3/s due to its strong negative skewness. This can impact on the magnitude of flows for AEPs rarer than the 1% AEP. An alternative approach has therefore been used to derive the 0.5% ad 0.2% AEP peak flows (see Section 6.1).
- The results remain broadly similar to those presented in the 2004 Flood Study (see Table 5.2). Whilst there have been some sizeable floods since 2004 eg 2009, 2013, 2022, there have also been a number of years with no floods.

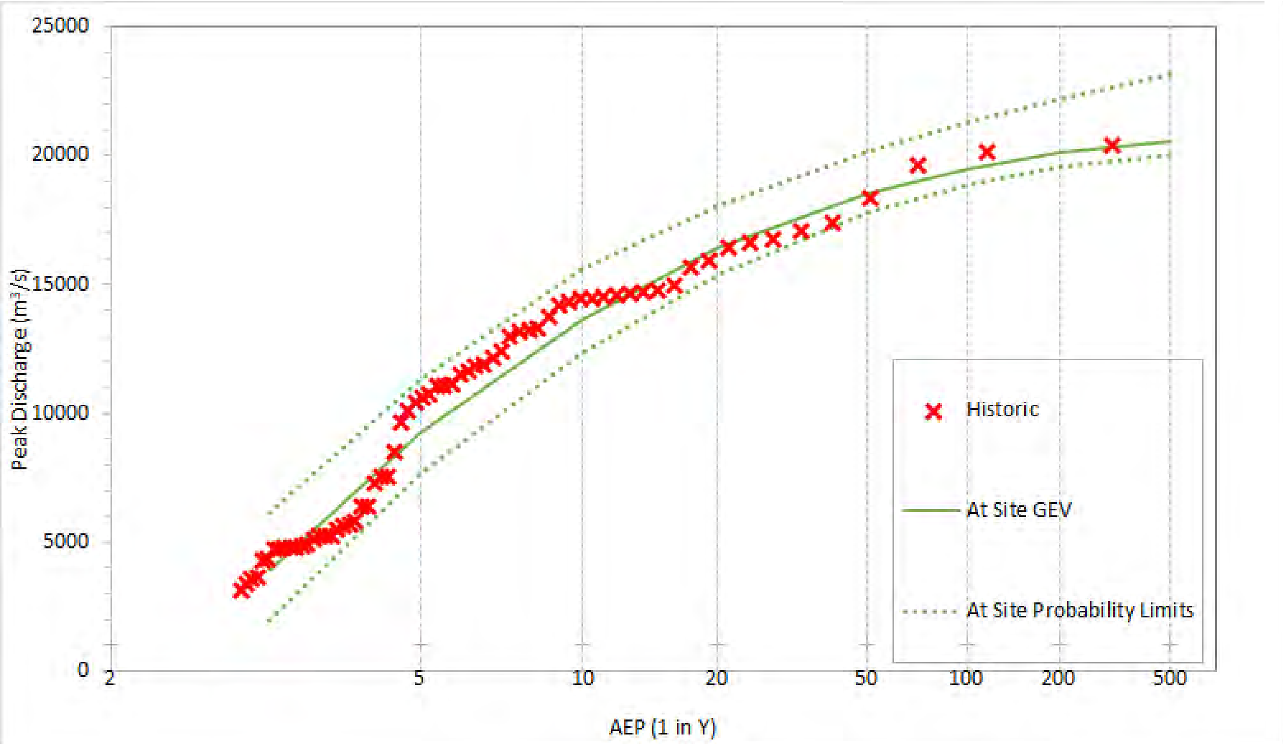


Figure 5.3 Flood Frequency Plot: Mountain View Inflow

6 Design Event Simulation

6.1 Model Inflows

Clarence River Inflow

The main inflow to the model is the Clarence River inflow at Mountain View, 10km upstream of Grafton. The peak inflow values for AEPs up to and including the 1% AEP are taken from the FFA (see Section 5). FFA is the recommended approach in ARR2019 to deriving peak design flow estimates where adequate data of sufficient quality is available. For previous versions of the Lower Clarence River Flood Model (1988, 2004 and 2013) the peak flow was also derived from FFA and was fitted to the shape of the 1974 event flood hydrograph by scaling the hydrograph to match the design peak flows. The 1974 flood hydrograph was selected as being “typical of the stage hydrographs observed at the Prince Street gauge for a number of floods”.

The shape of the hydrograph has been revisited for this study given that there have been a number of significant floods in the vicinity of Grafton since 1988, for example 2001, 2009, 2013 and 2022. Figure 6.1 presents a plot of the recorded hydrograph shapes at the Prince Street gauge in Grafton for notable recent events. The hydrograph shape of the 1974 event (adopted for previous studies) is also shown in bold. These have been made dimensionless in terms of flow and the timing of the peaks have been aligned so that the shapes can be easily compared.

It can be seen that the shapes of the flood hydrographs are broadly similar. The following is noted:

- The 2022 event had an earlier, smaller peak which is not seen for the other events.
- The 2013 shape has less volume compared to other event hydrograph shapes.
- The 1974 flood shape is broadly representative of the other flood events for the main peak and is slightly conservative in that it has more volume than the majority of the other hydrographs.

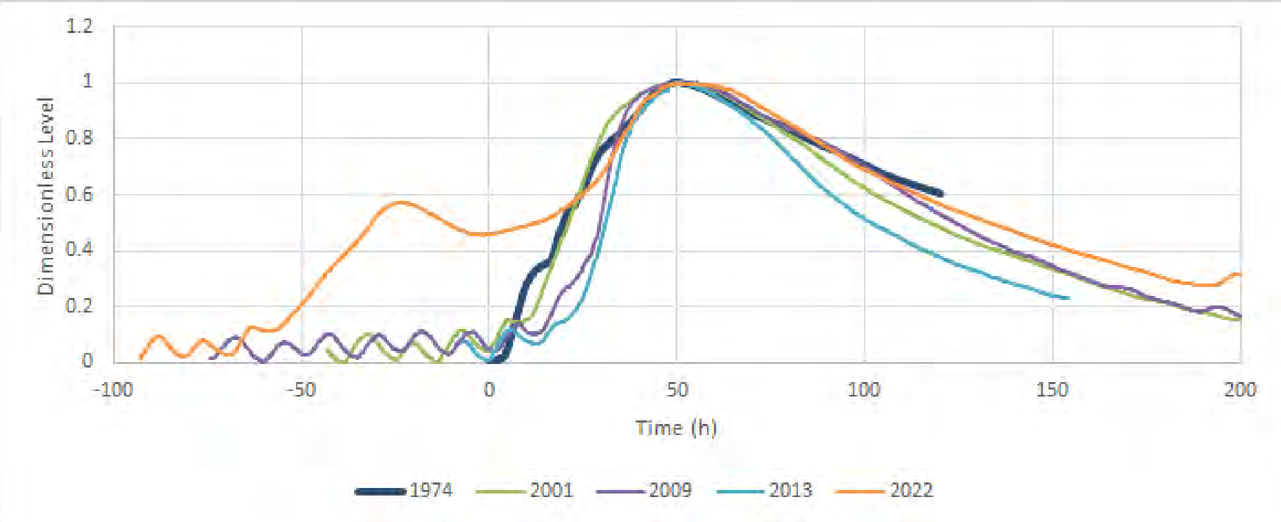


Figure 6.1 Historical Event Stage Hydrograph Shapes: Prince Street Gauge, Grafton

Based on this assessment it was considered appropriate to retain use of the 1974 flood hydrograph shape for use in design event modelling. The peak inflows derived from the FFA were therefore fitted to the 1974 event hydrograph shape.

Lower Floodplain Inflows

Inflows from tributaries of the Clarence River entering the floodplain downstream of Grafton along with direct rainfall onto the lower floodplain have been represented in the model using flows derived from the WBNM model (see Section 3.4).

Whilst the magnitude of the tributary inflows are minor relative to the Clarence River inflow, they are still significant in their own right and can influence the design flood behaviour by filling or partially filling some of the available storage within the Lower Clarence floodplain.

The assumptions from previous modelling have been maintained for the lower floodplain inflows whereby the tributary inflows are based on design rainfall for a 72 hour duration storm and the initial and continuing design rainfall losses are 30mm and 2mm/hr respectively. The peaks of the inflows are also timed to occur prior to the peak of the Clarence River inflow as would be expected given the large size of the Clarence River catchment relative to the lower tributary catchments. The design rainfall depths applied for the lower floodplain inflows have been maintained from previous studies. These are based on ARR1987 intensity, frequency duration (IFD) data and have been applied with the ARR1987 temporal pattern. Use of ARR2019 rainfall depths would have no material bearing on the outputs given that the rainfall depths are similar[3]. Furthermore, the assessment is for Clarence River flood events and so the tributary flows should not be taken to be representative of critical design flows on those tributaries. If design flows on the tributaries are required then the WBNM model should be simulated using ARR2019 temporal patterns and rainfall depths and a separate critical duration analysis undertaken. This is outside the scope of the regional model update.

Very Rare and Extreme Flood Inflows

Very rare flood events are a category of floods considered in ARR2019 to be rarer than a 1% AEP event. These are then termed extreme floods once the credible limit of extrapolation is exceeded (typically beyond a 0.05% or 1 in 2000 AEP flood).

The probable maximum flood (PMF) falls within the extreme flood category and is defined as the largest flood that could conceivably occur at a particular location. It is used as an upper bound for flood risk planning purposes when defining the extent of flood prone land. The PMF is typically derived through application of a probable maximum precipitation (PMP) within a hydrologic model. For catchments that do not have a hydrologic model and rely on flood frequency techniques to derive design inflows, such as the Clarence River, it is not possible to model a PMP and the approach typically adopted is to scale up the 1% AEP design flow by a determined factor. The resulting flood is termed the ‘Extreme Flood’ as it is not a PMF flood derived from simulation of the PMP rainfall.

The most recent estimate of the Extreme Flood on the lower Clarence River was undertaken for the 2004 flood study and was retained for use in the 2013 flood study.

The 2004 study simulated two extreme floods as follows:

- Extreme Flood 1 – based on a scaling factor of 1.53 applied to the 1% AEP inflows
- Extreme Flood 2 – based on a scaling factor of 3.0 applied to the 1% AEP inflows.

The scaling factor for Extreme Flood 1 of 1.53 was based on the ratio of the 72 hour PMP depth, then calculated at 660mm, and the 1% AEP 72 hour rainfall depth of 430mm. The scaling factor of 3.0 used for Extreme Flood 2 was noted as being typically used as an extreme flood scaling factor on other large

[3] For example the differences between the ARR2019 and ARR1987 72 hour design rainfall depths at Grafton (-29.686, 152.940) are less than 1% for the 5%, 2% and 1% AEP events.

catchments on the NSW coast. Only Extreme Flood 1 was taken forward for use in the 2013 flood study. Of note, the current catchment average 0.05% (1 in 2000) AEP, 72 hour rainfall depth is 614mm which is comparable to the previous PMP depth. Use of a scaling factor of 1.53 applied to the 1% AEP inflows would therefore result in a flood which is closer to the 0.05% AEP than the PMF by current standards.

Since the PMP was derived for the 2004 study, there have been revised guidelines on how to calculate the PMP. Due to the location and size of the Clarence River catchment, the generalised tropical storm method (revised) (GTSMR) is applicable (Walland et al, 2003). Using this method, an updated estimate of the 72 hour PMP depth is 1120mm. The current ARR2019 IFDs give a catchment average 1% AEP, 72 hour rainfall depth of 422mm to Grafton which becomes 333mm after application of an areal reduction factor applicable for the upstream catchment to Grafton. The ratio of the updated PMP depth to the updated 1% AEP areal rainfall depth is approximately 3.3 and so a scaling factor of 3.0 is more appropriate than 1.53.

A scaling factor of 3.0 has therefore been applied to the main Clarence River 1% AEP inflow and all the lower floodplain tributary inflows to derive the updated inputs for the Extreme Flood.

The updated Extreme Flood inflow represents a significant increase in flow compared to what was previously used. Such a flow would likely cause significant scouring of the floodplain and would likely result in significant morphological change including additional breakouts into the ocean. This in turn would help to moderate (lower) flood levels in the downstream parts of the catchment. Such morphological changes are not simulated in the flood model which assumes a static terrain. Annex E presents results of a sensitivity test in which the Extreme Flood is simulated in the model with additional breakouts to the ocean.

The Extreme Flood estimate is therefore likely to be very conservative in terms of peak flood levels but is considered suitable for defining a physical upper limit for flooding. Given its conservatism, Council may which to consider using a very rare flood event flood event in place of the Extreme Flood for the purpose of risk planning. This should be investigated further in a flood risk management study.

The 0.5% AEP and 0.2% AEP floods are two events modelled in this study that fall within the Very Rare category of floods. To determine the main river inflow for these events a procedure from ARR2019 was followed whereby a log-normal approximation is made using the 1% AEP and PMF (Extreme Flood) peak flow estimates. The procedure requires an estimate of the AEP of the PMF which, for the purposes of the procedure, is assumed to be the same as the AEP of the PMP. The AEP of a PMP estimate is considered to vary solely as a function of catchment area. The 22,000km^2 area of the Clarence River catchment results in an AEP of 1 in 100,000 (0.001%) which has been assigned to the Extreme Flood. Log-normal interpolated estimates of the main Clarence River inflow for the 0.5% and 0.2% AEPs have been applied in this study. Lower floodplain inflows for the 0.5% and 0.2% AEPs are based on hydrology model outputs from applying equivalent design rainfall depths for those AEPs.

6.2 Downstream Boundary

Overview

The downstream boundary has been updated from that used in the 2013 flood study. The updates align the boundary assumptions to those recommended in current guidelines and provide consistency with recent coastal investigations undertaken for Council.

Peak Storm Tide

A peak 1% AEP storm tide of 1.62mAHD has been applied in this study. This peak storm tide was determined from a storm tide investigation assessment undertaken for Council in 2021 (Risk Frontiers, 2021). It is also similar to the peak 1% AEP storm tide suggested by state guidelines (OEH, 2015) of 1.55mAHD[4]. As the peak level derived from the Risk Frontiers study is specific to the Clarence River, this has been used over the more generalised peak level from the state guidance.

The 5% AEP storm tide is also required for the study. This has been derived by noting the difference between the 1% and 5% AEP storm tide peak levels in the state guidance and subtracting this difference from the Clarence Estuary 1% AEP storm tide peak to give a 5% AEP storm tide peak level of 1.57mAHD.

[4] Based on a ‘Type A’ entrance type north of Crowdy Head. Type A includes an estuary with training walls which is navigable for large vessels.

Coincidence of Catchment/Oceanic Inundation

The storm tide boundary is modelled as a dynamic (tidal) boundary. Because the boundary is dynamic, the relative timing of the catchment runoff peak flow and the storm tide peak needs to be considered. The adopted approach follows the recommended approach provided in state guidelines in which the catchment runoff peak is timed to coincide with the storm tide peak at the location of interest. For the purposes of this study, the location of interest with regards to the storm tide considerations is the lower Clarence between Maclean and Yamba/Iluka.

The combinations of catchment and oceanic inundation scenarios suggested in the state guidance (OEH, 2015) have been used for this study and are summarised in Table 6.1.

Table 6.1 Combinations of catchment flooding and storm tide inundation

Design AEP for Study	Catchment Flood AEP	Storm tide AEP
20%	20%	HHWS(SS)*
5%	5%	HHWS(SS)
2%	2%	5% AEP
1%**	1%	5% AEP
0.5%	0.5%	1%
0.2%	0.2%	1%
Extreme	Extreme	1%

*High High Water Springs (Solstice Spring) taken to be 1.13mAHD for the Clarence Estuary

** The OEH guideline suggests an enveloping approach by also using the 5% AEP catchment flood with a 1% AEP storm tide and taking the maximum level from the two scenarios. Testing showed that the 1% AEP catchment flood with a 5% AEP storm tide dominated the maximum levels for all areas of interest and so was adopted for the 1% AEP design event.

6.3 Climate Change Scenarios

When considering increases to flooding due to future climate change, the approach has been informed by climate scenarios defined by the Intergovernmental Panel on Climate Change (IPCC) in its Sixth Assessment Report (IPCC, 2021). These climate scenarios are based on differing sets of input projections termed ‘shared socioeconomic pathways’ (SSP). SSP scenarios expand on the ‘Relative Concentration Pathways’ (RCPs) used in the IPCC Fifth Assessment Report. The two SSP scenarios used in this study can be summarised as follows:

- SSP2/4.5 – an intermediate scenario with a predicted warming of ~2.4°C by 2100 (analogous to RCP4.5). This modelled scenario has been termed **CC1** for this assessment.
- SSP5/8.5 – a ‘worst case’ scenario which assumes a predicted warming if 4.3°C by 2100 (analogous to RCP8.5). This modelled scenario has been termed **CC2** for this assessment.

Climate change has been represented in the model in the following two ways:

- Increases in rainfall/flow
- Increases in sea level

The increases in rainfall/flow and increases in sea level have been applied to the 1% AEP event for the two SSP scenarios described above. Details of the changes made to the model are provided below.

Increases in Rainfall/Flow

The approach to deriving the main Clarence River inflow is in general accordance with NSW Floodplain Risk Management Guidelines (OEH, 2019). This recommends a 5% increase in design rainfall intensity per °C of projected warming. Predicted warming values to the year 2100 of 2.4°C and 4.3°C have been assumed for SSP2/4.5 and SSP5/8.5 respectively. These equate to increases in design rainfall intensity of 12% and 21.5% for the two respective SSP scenarios. As the main Clarence River inflow is derived from a flood frequency analysis, and not through rainfall runoff modelling, the inflow has been factored up by 12% for SSP2/4.5 (CC1) and 21.5% for SSP5/8.5 (CC2).

For the lower floodplain inflows, the design rainfall has been increased by 12% for SSP2/4.5 (CC1) and 21.5% for SSP5/8.5 (CC2).

Sea Level Rise

To inform the storm tide boundary under climate change scenarios, information has been obtained from the Stage 2 report of Council's Coastal Management Program (CMP). This report provides sea level rise estimates for two climate scenarios. The climate scenarios are associated median sea level rise projections for a planning horizon in the year 2123 derived for the CMP and based on data from the IPCC Sixth Assessment Report for the two SSP scenarios are as follows:

- SSP2/4.5 (CC1) – sea level rise of 0.76m from present day.
- SSP5/8.5 (CC2) – sea level rise of 1.09m from present day.

These sea level rise values have been added to the present day storm tide boundaries to obtain peak storm tide values for planning horizon 2123.

Summary of Climate Change Allowances

Table 6.2 summarises the climate change allowances adopted for this study along with those used for the existing climate for comparison.

Table 6.2 Climate Change Allowances

Variable	Existing Climate	2123 SSP2/4.5 (CC1)	2123 SSP5/8.5 (CC2)
Rainfall/flow increase (1% AEP)	-	12%	21.5%
Storm tide peak (5% AEP)*	1.57 mAHD	2.33 mAHD	2.66 mAHD
Storm tide peak (1% AEP)	1.62 mAHD	2.38 mAHD	2.71 mAHD

*Applied for a 1% AEP catchment runoff event (see section 6.2)

6.4 Summary of Modelled Events

Table 6.3 provides a summary of the modelled events including the peak Clarence River inflow at Mountain View and the peak level of the applied storm tide.

Table 6.3 Summary of Design Flood Events

Event	Peak River Inflow (m3/s)	Peak Storm Tide (mAHD)
20% AEP	9,240	1.13
5% AEP	16,380	1.13
2% AEP	18,500	1.57
1% AEP	19,460	1.57
0.5% AEP	22,420	1.62
0.2% AEP	26,610	1.62
Extreme Flood	58,390	1.62
1% AEP (CC1)	21,800	2.33
1% AEP (CC2)	23,650	2.66

6.5 Design Flood Results

Design flood results are presented as maps of peak flood levels, depths, velocities and classified flood hazard for the 20%, 5%, 2%, 1%, 0.5% and 0.2% AEP. Additionally the ‘Extreme Flood’ has been mapped along with two 1% AEP climate change scenarios for an intermediate and a worst case.

The map outputs are included in Annex C and are supplied digitally with this report. The peak flood levels at river gauges are summarised in Table 6.4.

Table 6.4 Peak Design Flood Levels at Gauges (mAHD)

Gauge	20% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	Extreme	1% AEP (CC1)	1% AEP (CC2)
Grafton (Prince St)	6.27	8.11	8.38	8.44	8.87	9.39	13.58	8.78	9.05
Ulmarra	5.08	6.15	6.38	6.42	6.77	7.53	12.71	6.73	7.11
Brushgrove	4.24	5.14	5.40	5.66	6.35	7.21	12.50	6.31	6.78
Tyndale	3.91	4.61	5.25	5.50	6.14	6.99	12.34	6.11	6.59
Lawrence	3.51	4.65	4.89	5.14	5.81	6.69	12.10	5.79	6.29
Maclean	2.41	3.18	3.41	3.55	3.98	4.59	8.56	4.07	4.46
Palmers Island Bridge	1.96	2.59	2.86	2.99	3.37	3.93	7.77	3.56	3.95
Oyster Channel	1.08	1.41	1.94	2.07	2.55	3.21	7.17	2.99	3.45
Lake Wooloweyah	0.88	1.32	1.92	2.08	2.58	3.25	7.20	3.01	3.47
Yamba	1.17	1.34	1.79	1.85	2.08	2.47	6.07	2.65	3.05

6.6 Comparison with Previous Study

The 1% AEP peak flood levels have been compared with the previous 1% AEP event (2013 Flood Study). Table 6.5 provides the respective flood levels and flood level differences at gauges. The results are also presented as a difference map (Figure 6.2) showing change in peak flood levels. Only differences greater than 0.1m are shown.

With the exception of parts of Grafton, South Grafton and the Lake Wooloweyah area, the overall trend is for the updated design flood levels to have reduced from what they were previously. This is due to a number of reasons including:

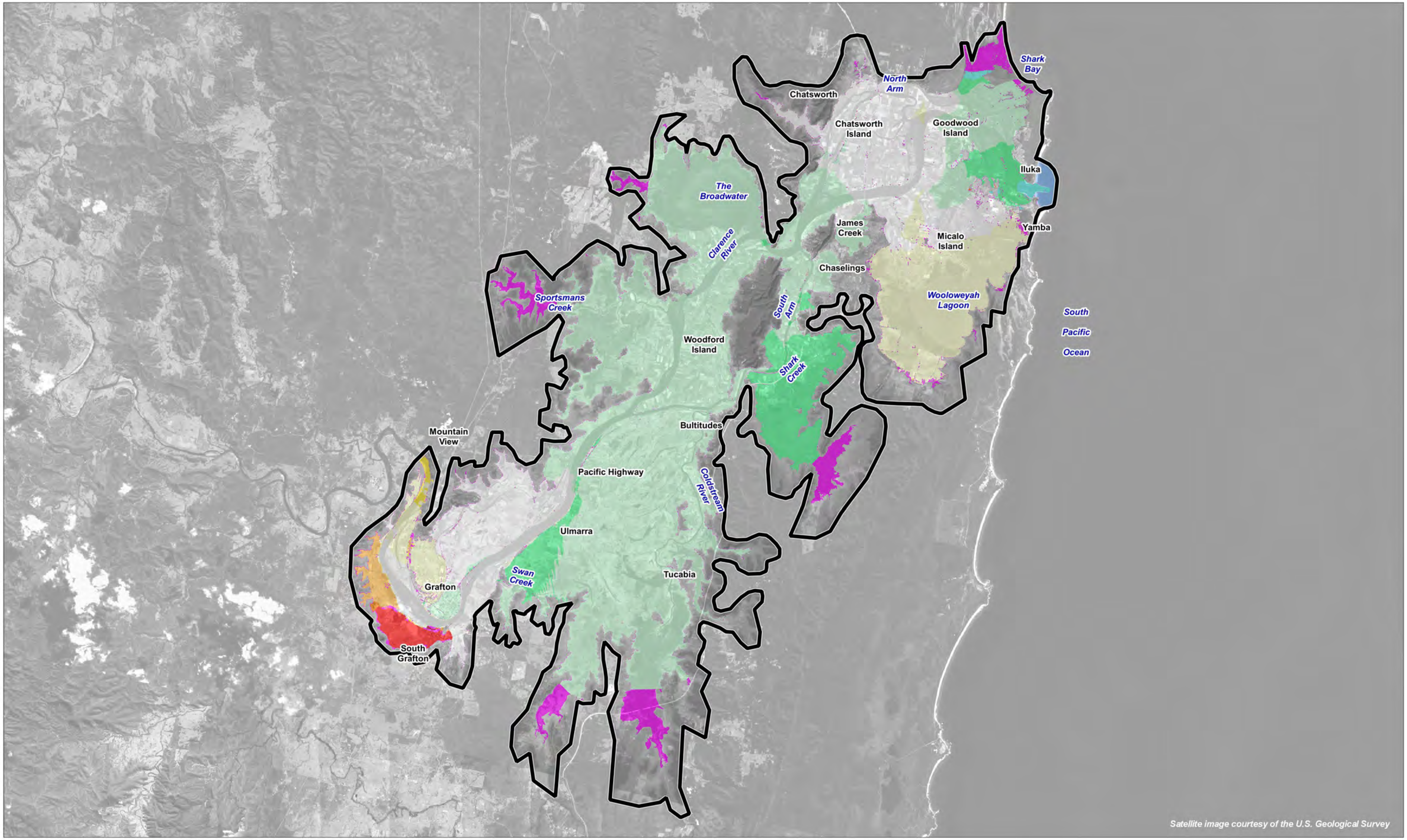
- Extension of the modelled area allowing the floodwater to fully spread out and not be constrained by the edge of the model.
- A notably lower storm tide boundary than what was previously applied.
- Minor changes (reductions) to some Manning's n values as determined through the model calibration exercise.
- The refined model resolution and updated levee surveys has also improved the estimates of volumes of water overtopping levees.

As the main 1% AEP Clarence River inflow has increased, this increases the flood levels along the Clarence River between the upstream limit of the model and Grafton. This causes additional overtopping of the levees, with most of the additional volume spilling into the South Grafton Common area. As a result, parts of South Grafton Common see the largest increase in peak 1% AEP flood level of up to 2m (refer to Figure 6.2). This is also partially attributed to the accounting of local rainfall within the South Grafton Common area which was previously not included.

The increase in peak flood level in the Lake Wooloweyah area is attributed to the greater coincidence between the peak of the catchment runoff and the peak of the storm tide. Whilst, the updated storm tide peak is lower, the increased coincidence of the peaks results in higher levels in the updated study.

Table 6.5 Peak 1% AEP Flood Level Comparison at Gauges

Gauge	Previous Level (mAHD)	Updated Level (mAHD)	Difference (mAHD)
Grafton (Prince St)	8.36	8.44	0.08
Ulmarra	6.26	6.42	0.16
Brushgrove	5.83	5.66	-0.17
Tyndale	5.67	5.50	-0.17
Lawrence	5.33	5.14	-0.19
Maclean	3.74	3.55	-0.19
Palmers Island Bridge	3.02	2.99	-0.03
Oyster Channel	2.22	2.07	-0.15
Lake Wooloweyah	1.86	2.08	0.22
Yamba	2.51	1.85	-0.66



LEGEND

Study Area

Peak Flood Level Difference (m)

<= -2.50	0.10 - 0.25
-2.00 - -1.50	0.25 - 0.50
-1.50 - -1.00	0.50 - 1.00
-1.00 - -0.50	1.00 - 1.50
-0.50 - -0.25	1.50 - 2.50
-0.25 - -0.10	> 2.50
-0.10 - 0.10	was dry now wet

Title:

1% AEP Peak Flood Level Difference (2022 update vs 2013 update)

Figure: 6.2

Rev: A

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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7 Conclusions

7.1 Model Updates

The Lower Clarence Flood Model has undergone a significant revision which has included the following:

- A higher model resolution and an ability to easily update the resolution for use in local scale assessments.
- Incorporation of significant recent floodplain development such as the Pacific Highway Upgrade and the second Grafton Bridge.
- Incorporation of recent and more accurate ground survey for numerous rural levees.
- Improvements to the representation of lower floodplain tributary inflows.

The updated model was then calibrated to the events of January 2013, March 2021 and February/March 2022 where a high level of calibration was demonstrated.

The updated model was then used to simulate design flood events. The following relevant updates were made in this regard:

- Revisions to the design storm tide boundary so that it is consistent with boundaries derived for coastal specific assessments undertaken for Council by others and compatible with current guidelines.
- The flood frequency assessment at Grafton has been updated to account for the full period of record to the present day, including the events of 2009, 2011, 2013 and 2022.
- Additional design floods have been modelled including the 0.5% and 0.2% AEP events.
- The assumptions regarding the Extreme Flood have been updated to accord with current best practice. It is noted that this does result in a highly conservative estimate of Extreme Flood levels due to static terrain assumptions in the lower Clarence River estuary.
- Two climate change scenarios have been modelled representing an intermediate and a worst-case scenario. The scenarios include increases in rainfall intensity and sea level.

7.2 Model Outputs

The model outputs are provided as a series of maps and are also supplied digitally for upload onto Council's website.

The model outputs are provided at a higher resolution than was previously available giving a more refined flood extent. In addition to the mapped outputs provided, animations have been supplied for Grafton and Maclean which can be viewed to highlight where the onset of flooding may first occur.

7.3 Future Use of the Model for Local Assessments

As the model utilises TUFLOW's Quadtree feature it is relatively straightforward to increase or decrease the model resolution as required. For local assessments that require a higher model output resolution than that provided by the regional model it is recommend that additional higher resolution domains are applied within the regional model as opposed to using a separate truncated model. This has the benefit of preserving the model boundaries and ensuring that floodplain behaviour is fully represented in the model. Higher resolutions can also be disabled elsewhere in the regional model if these areas are away from the area of interest. This will help maintain feasible simulation times. Any revisions to the regional base case model should always have the resulting flood levels compared back to those from the adopted model to ensure that the changes have resulted in no significant departures from the adopted flood levels.

8 References

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Walland D.J., Meighen J., Xuereb K.C., Beesley C.A. and Hoang T.M.T. (2003) Revision of the Generalised Tropical Storm Method for Estimating Probable Maximum Precipitation, HRS Report No. 8, Hydrology Report Series, Bureau of Meteorology Melbourne, Australia, August 2003, (78 pp).

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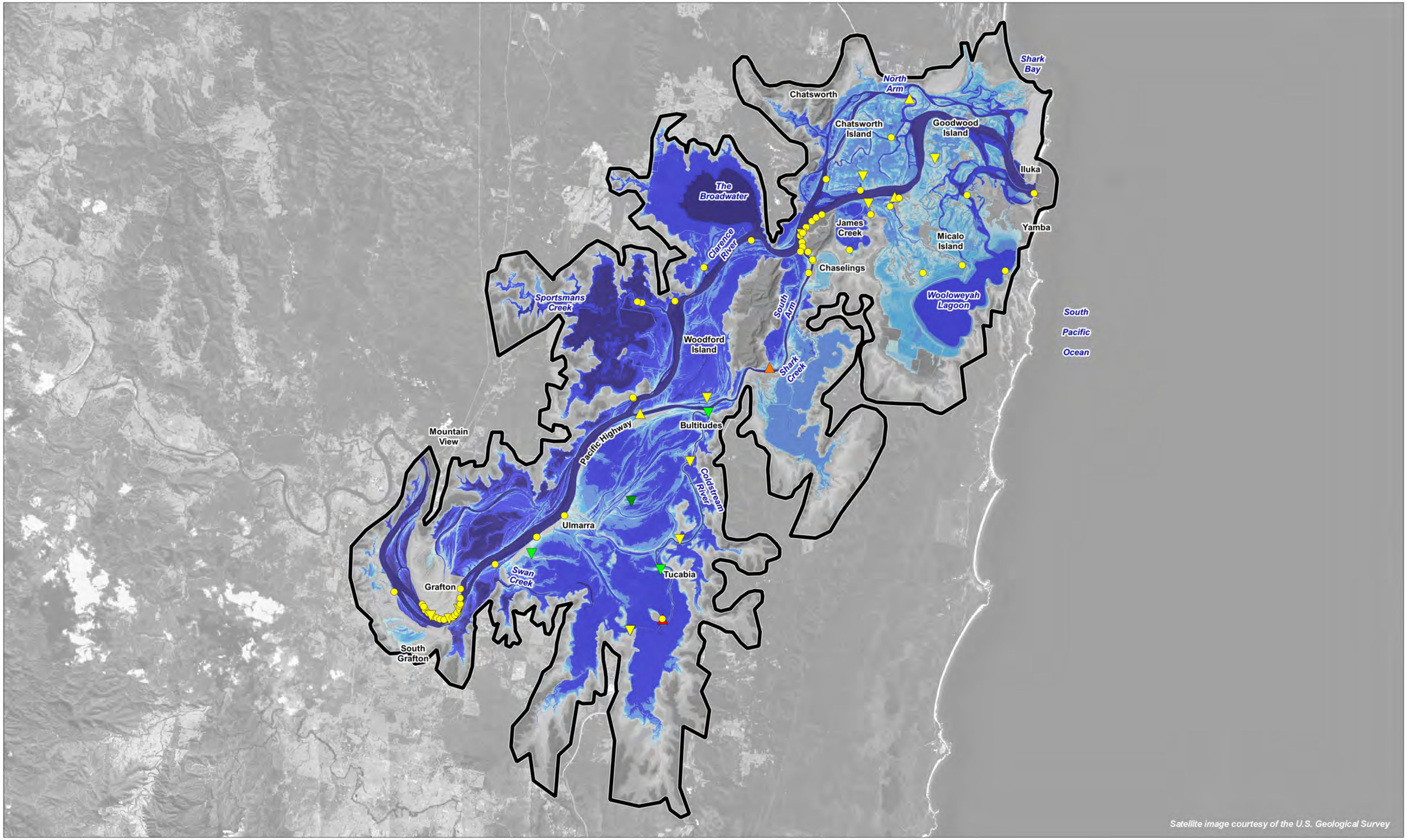
Annex A Model Calibration Plots and Maps



LEGEND

Study Area

Calibration Points (Modelled minus Recorded)

- >0.5 m
- 0.3 to 0.5 m
- 0.15 to 0.3 m
- -0.15 to 0.15 m
- -0.3 to -0.15 m
- -0.5 to -0.3 m
- <-0.5 m

Peak Flood Depth (m)

Band 1
- < 0.25
- 0.25 to 0.5
- 0.5 to 0.75
- 0.75 to 1.0
- 1.0 to 2.0
- 2.0 to 4.0
- >4.0

Title:
2013 Calibration to Flood Marks

Figure: **A-1**

Rev: **A**

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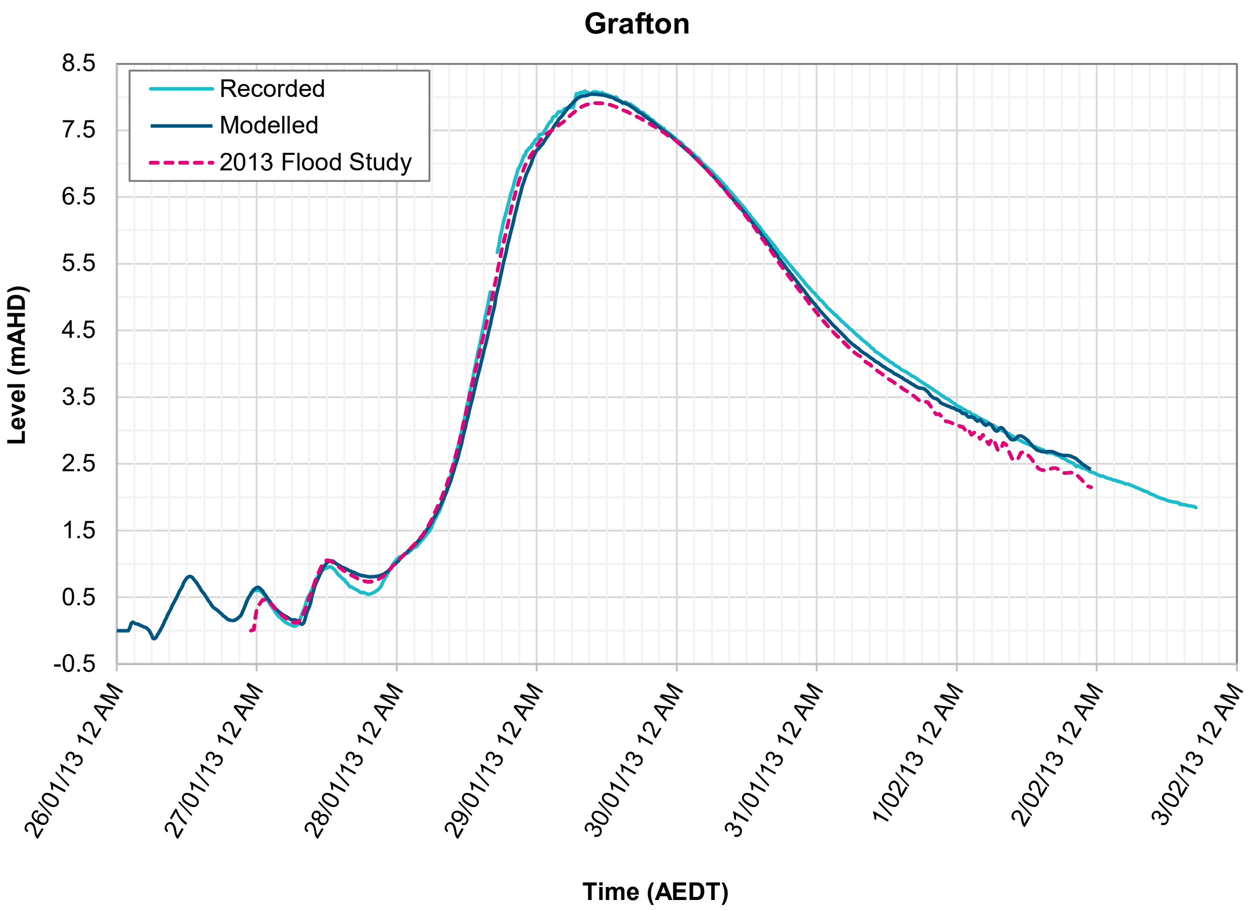
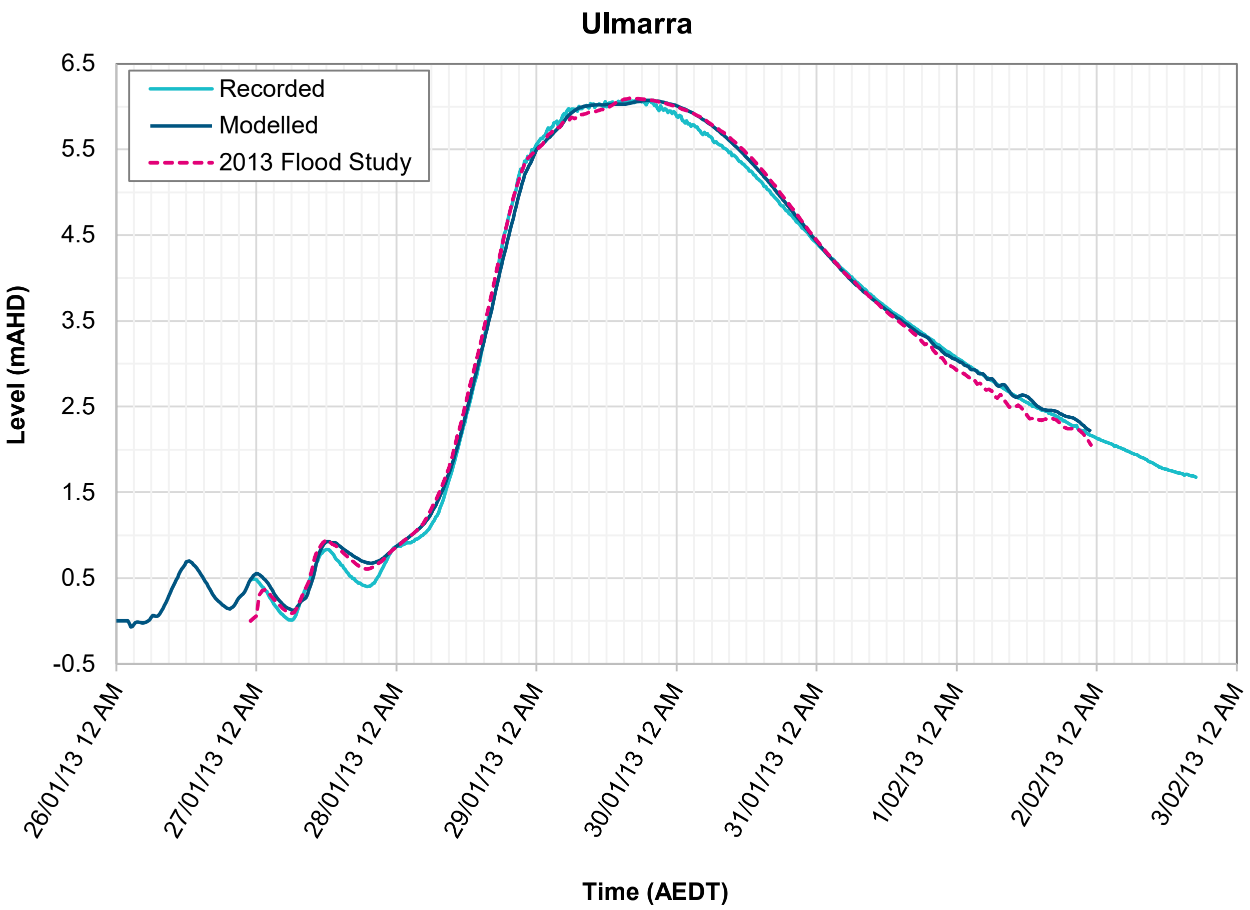
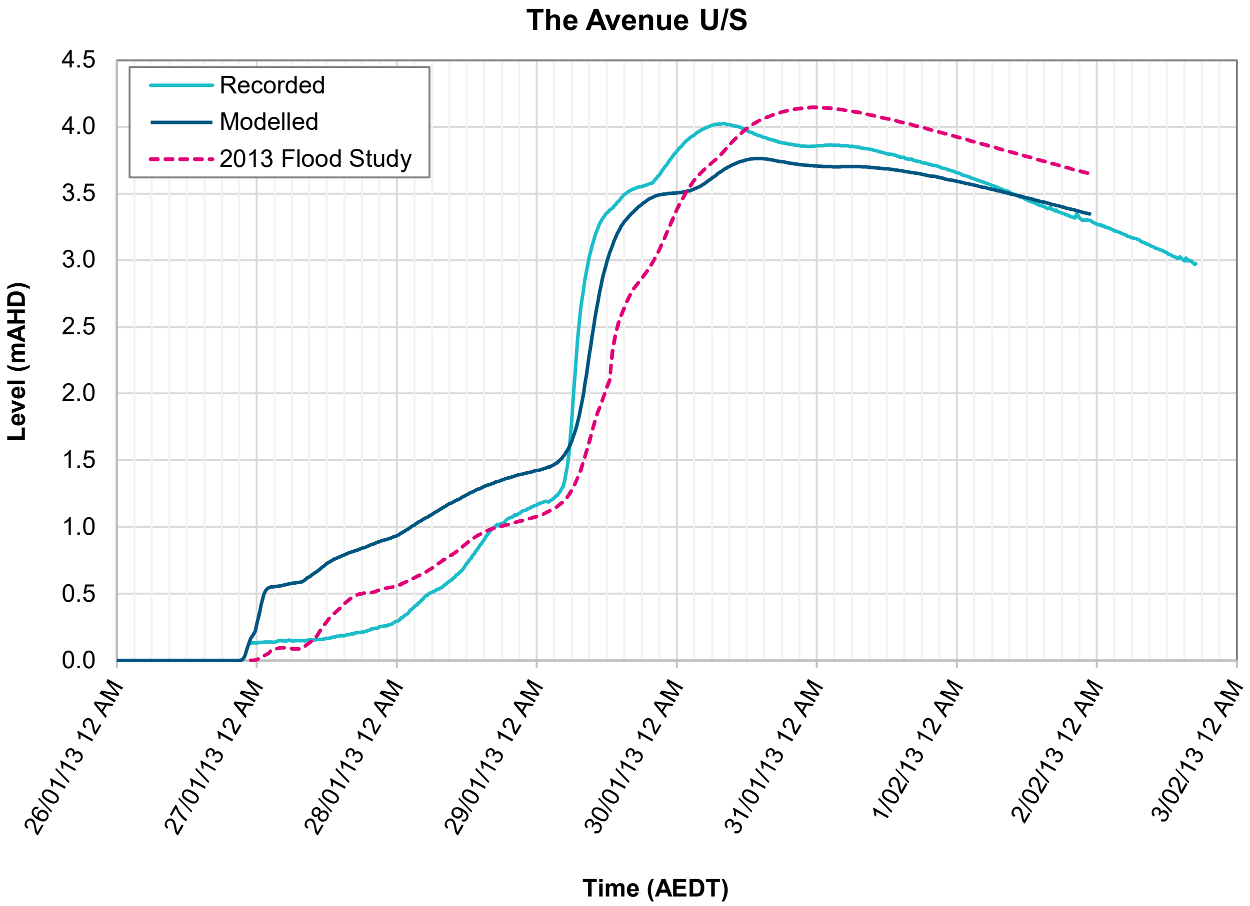
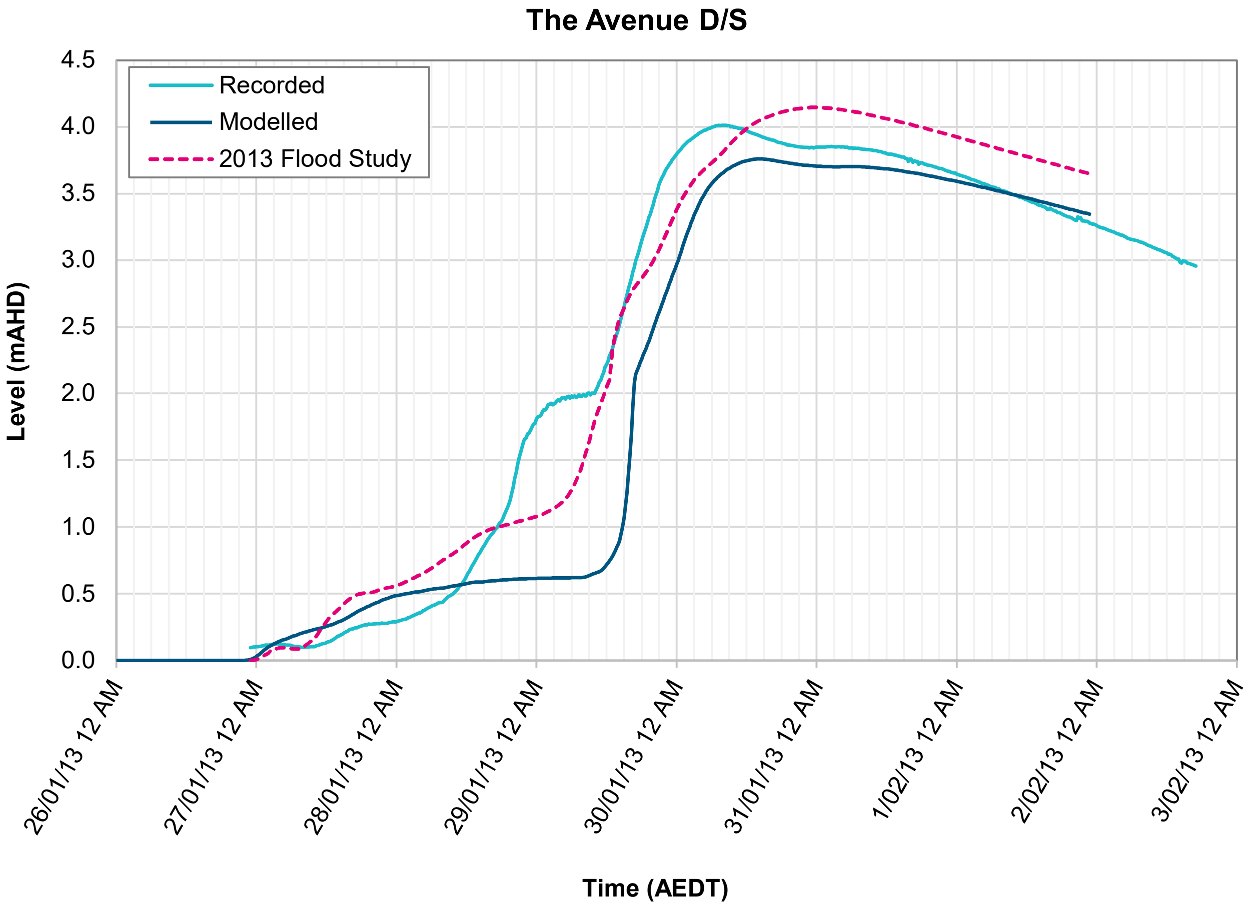
Filepath: I:\A11908_I_br_CLA\QGIS\FLD_005_221111_2013 Calibration to Flood Marks.qgz

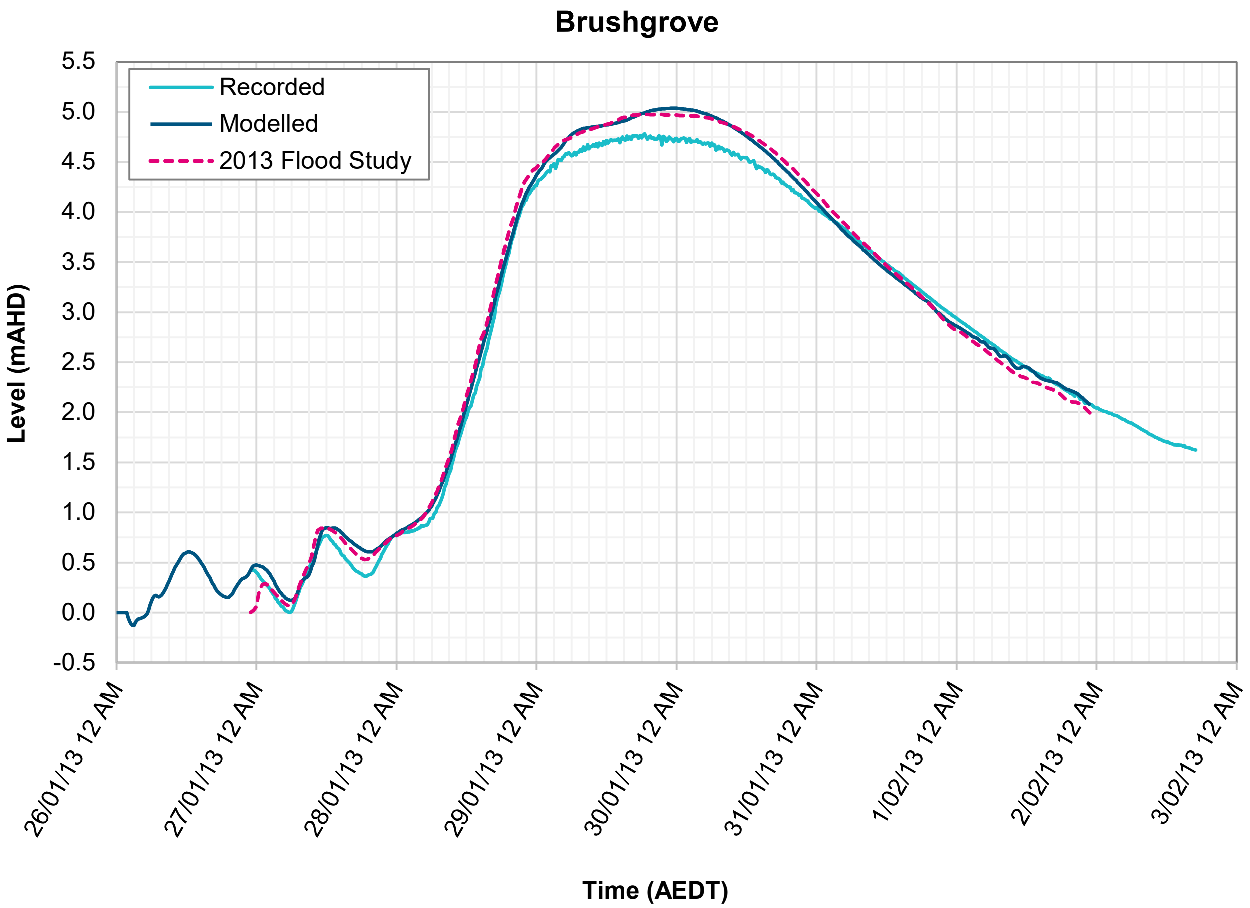


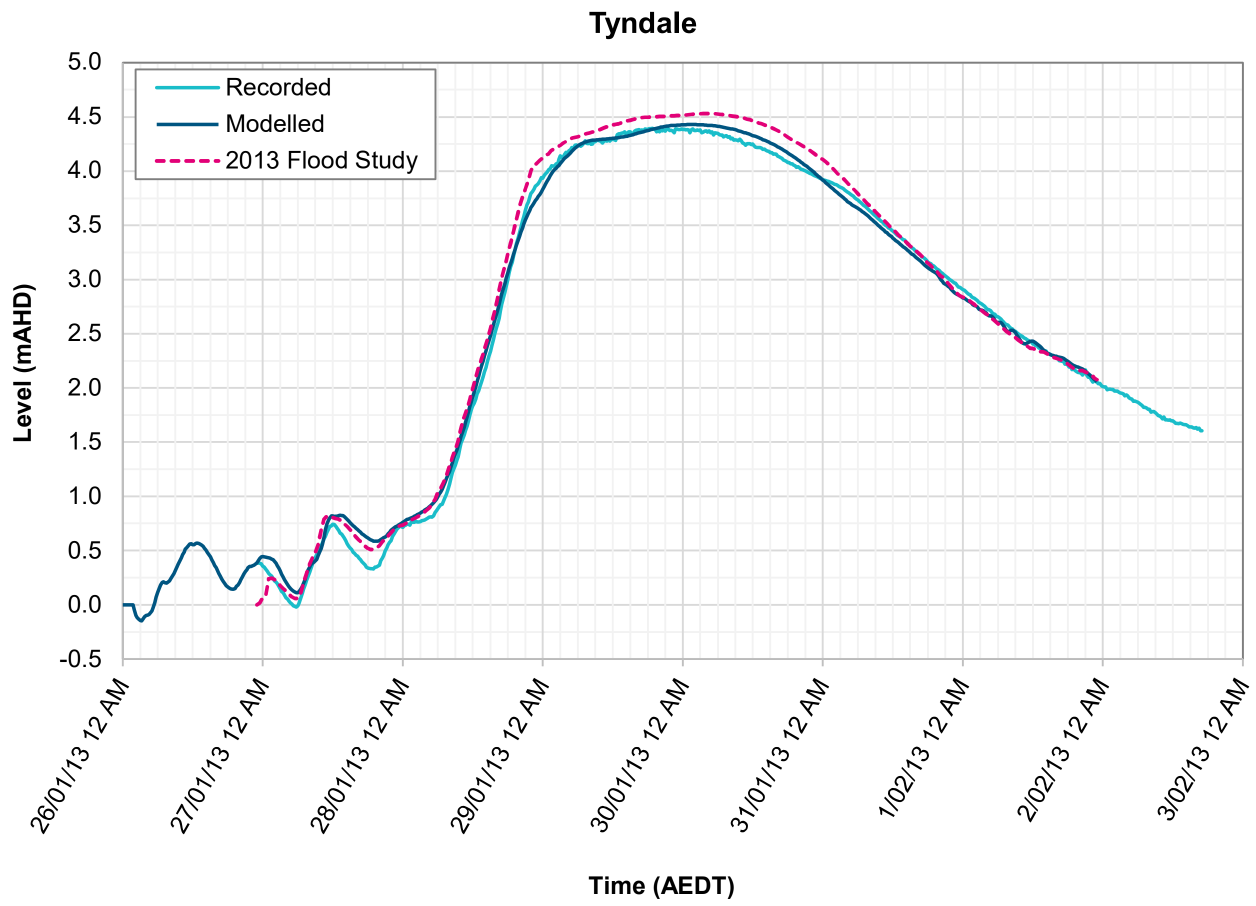


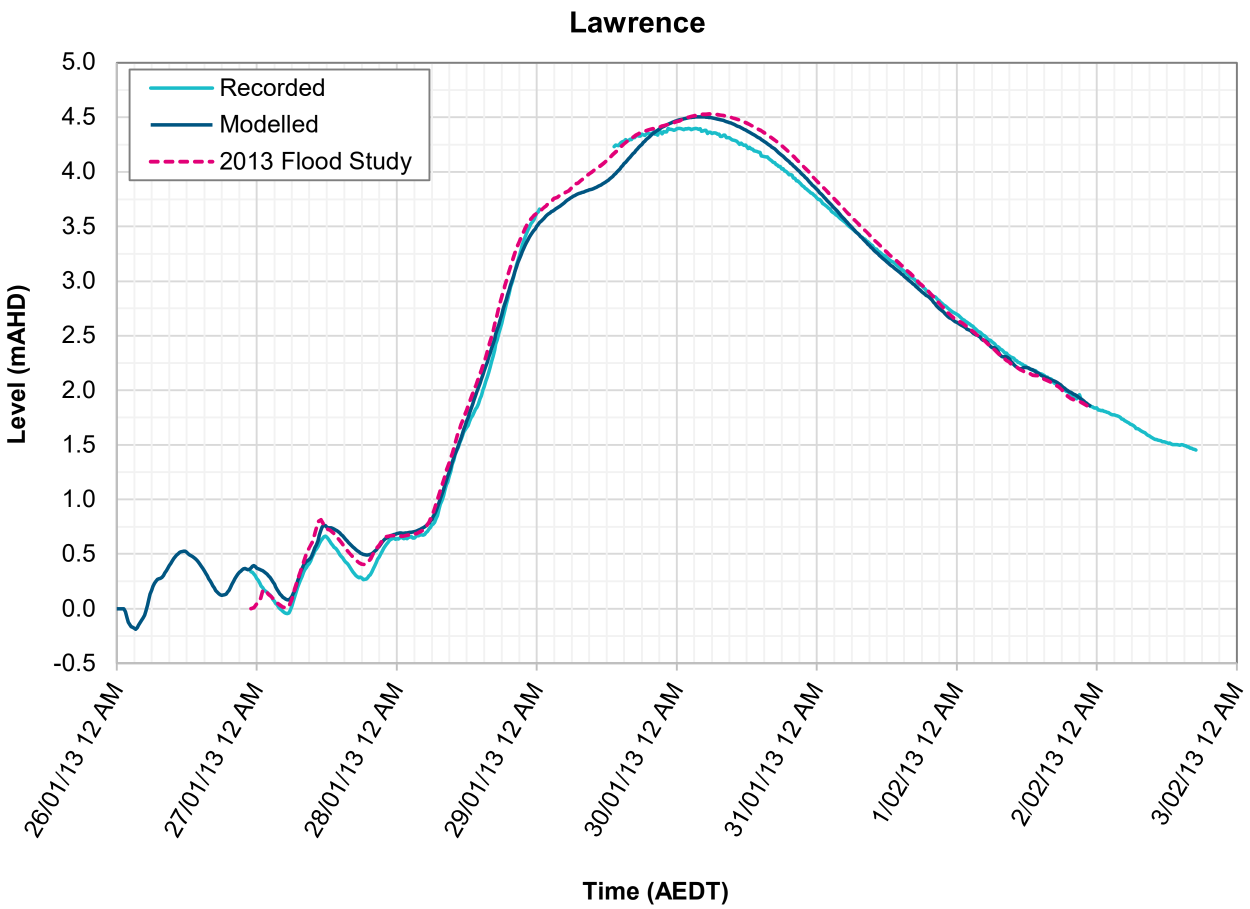


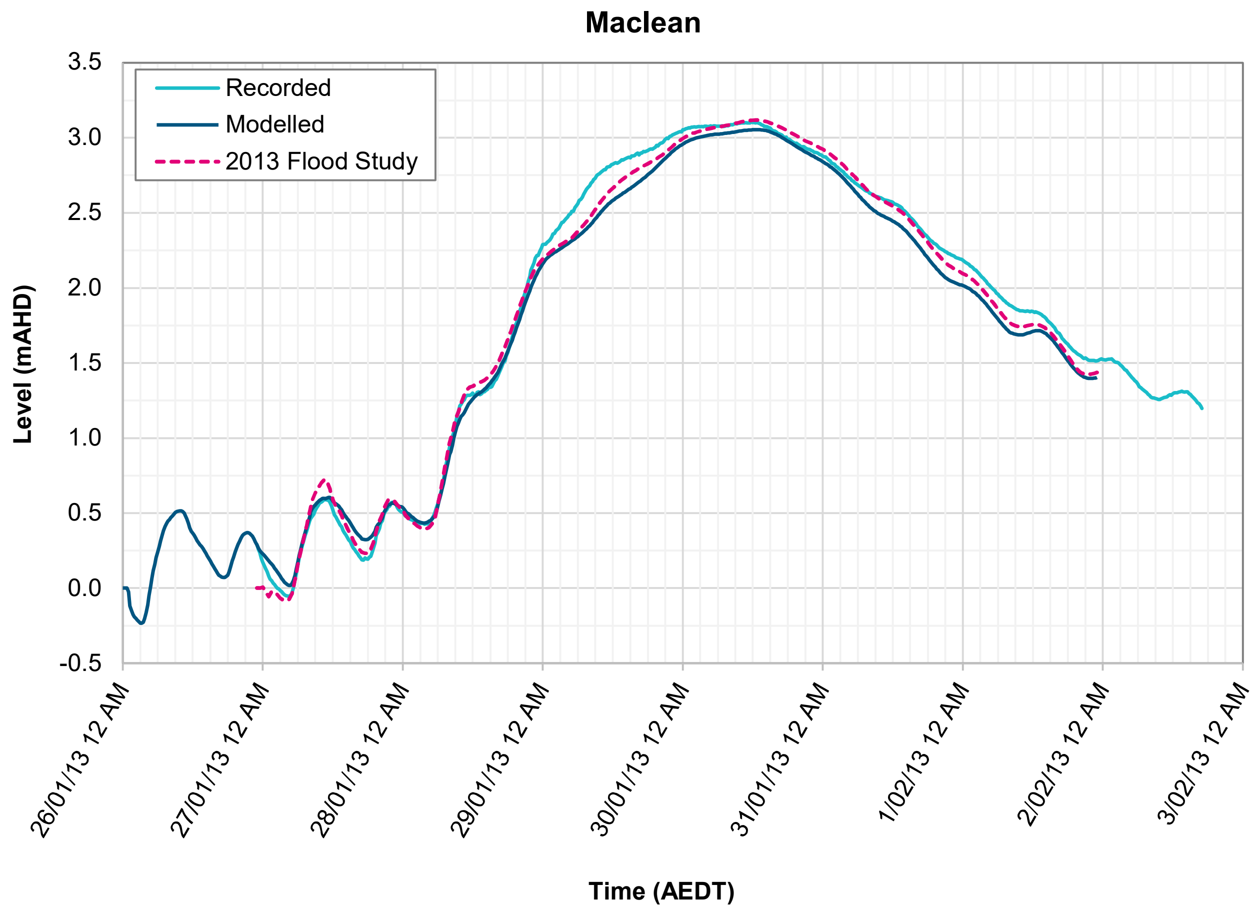


2013 Event Sheet 1

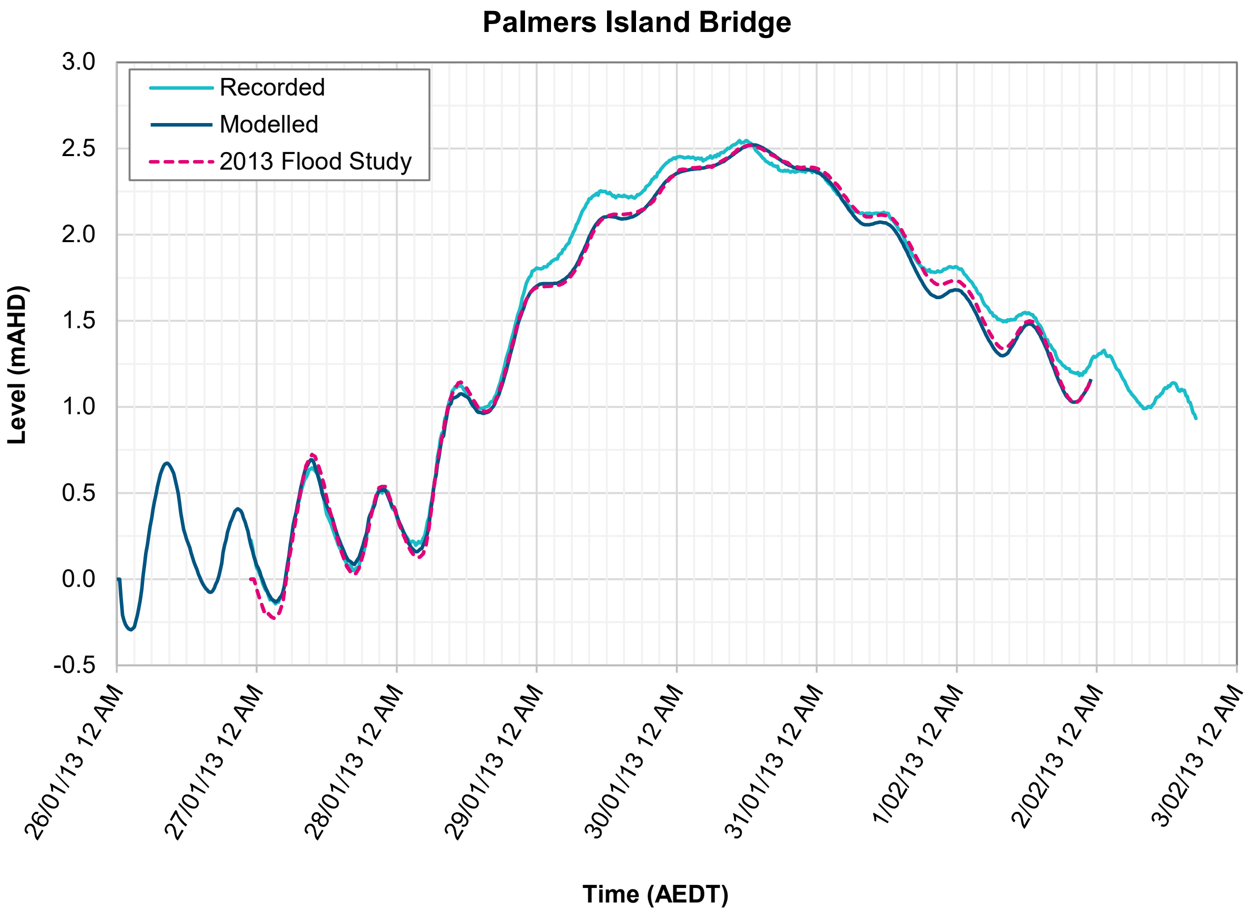


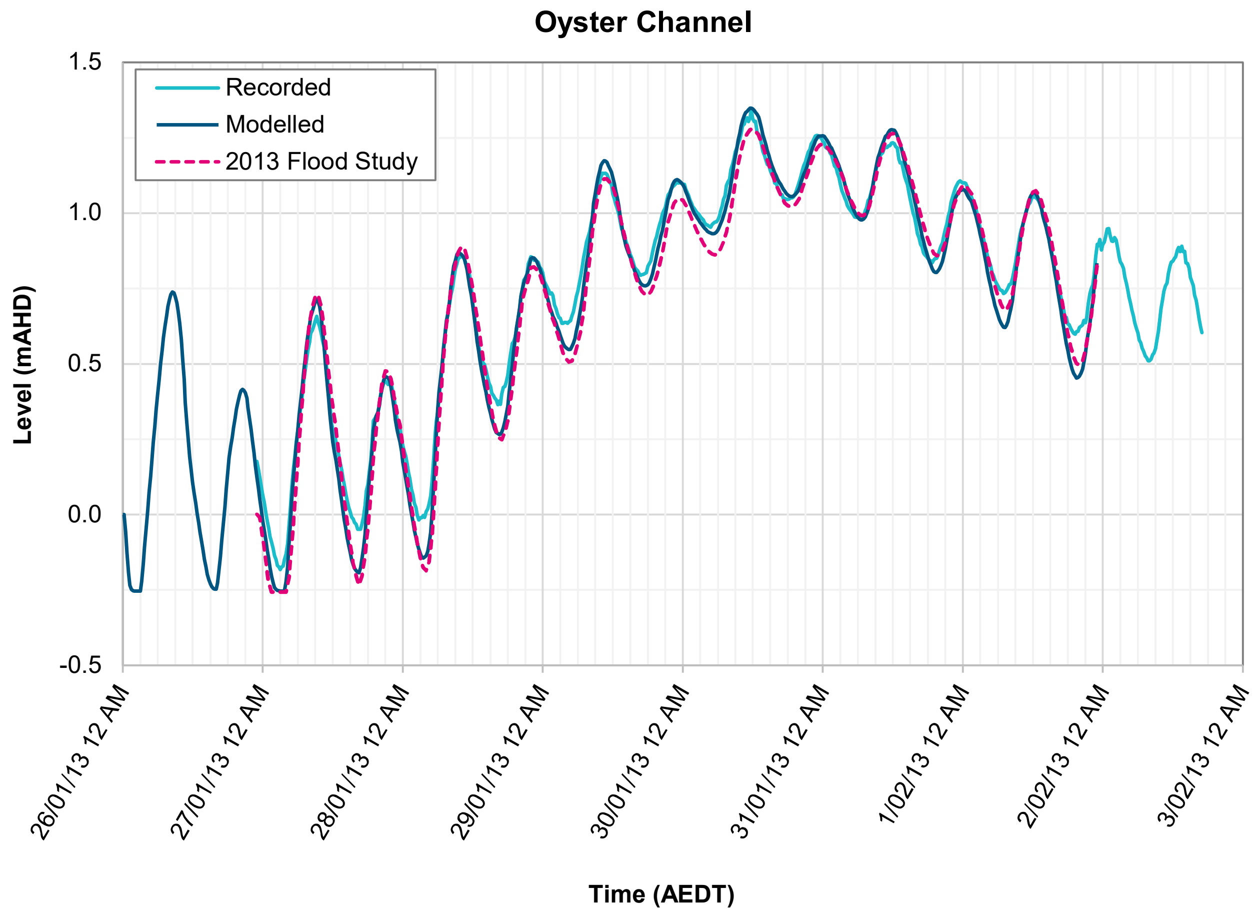


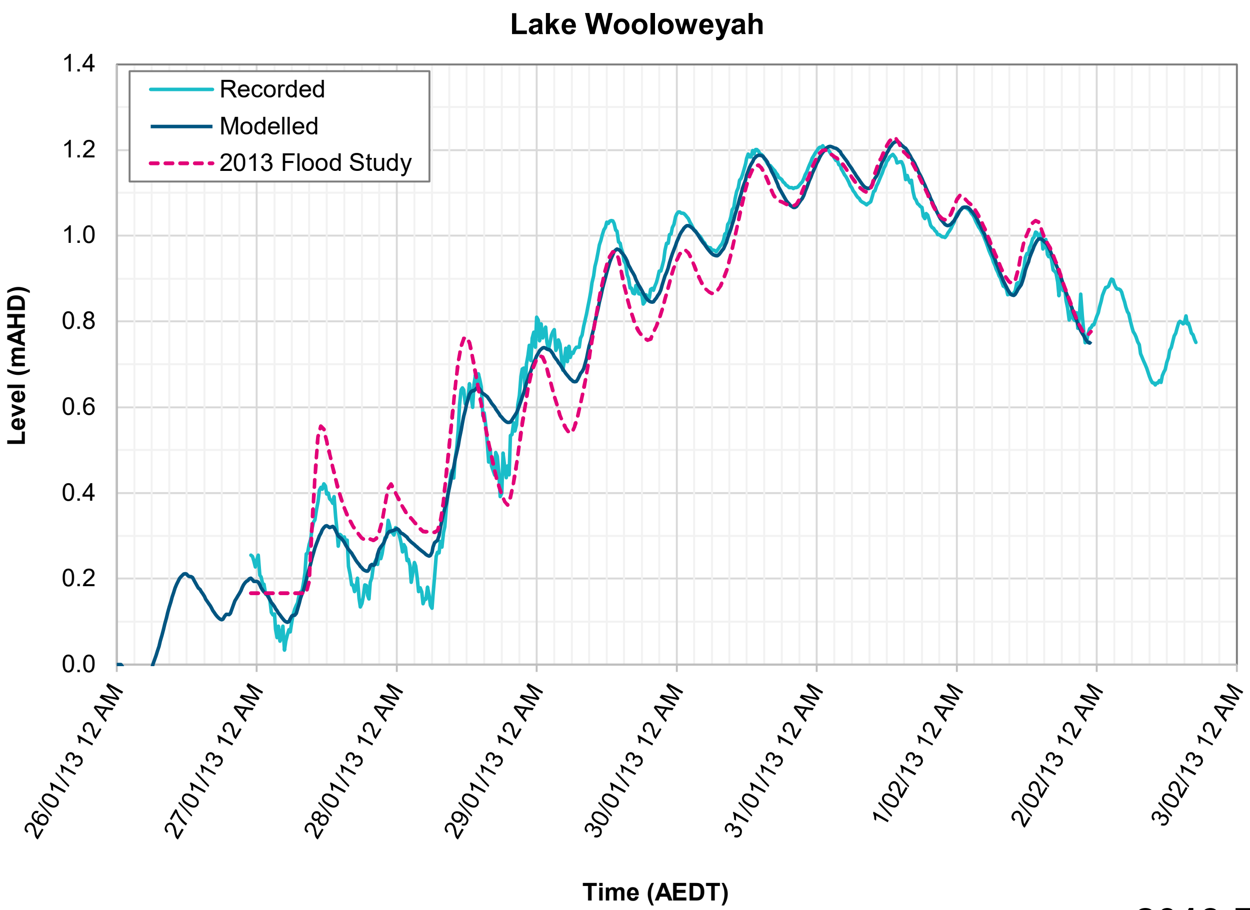


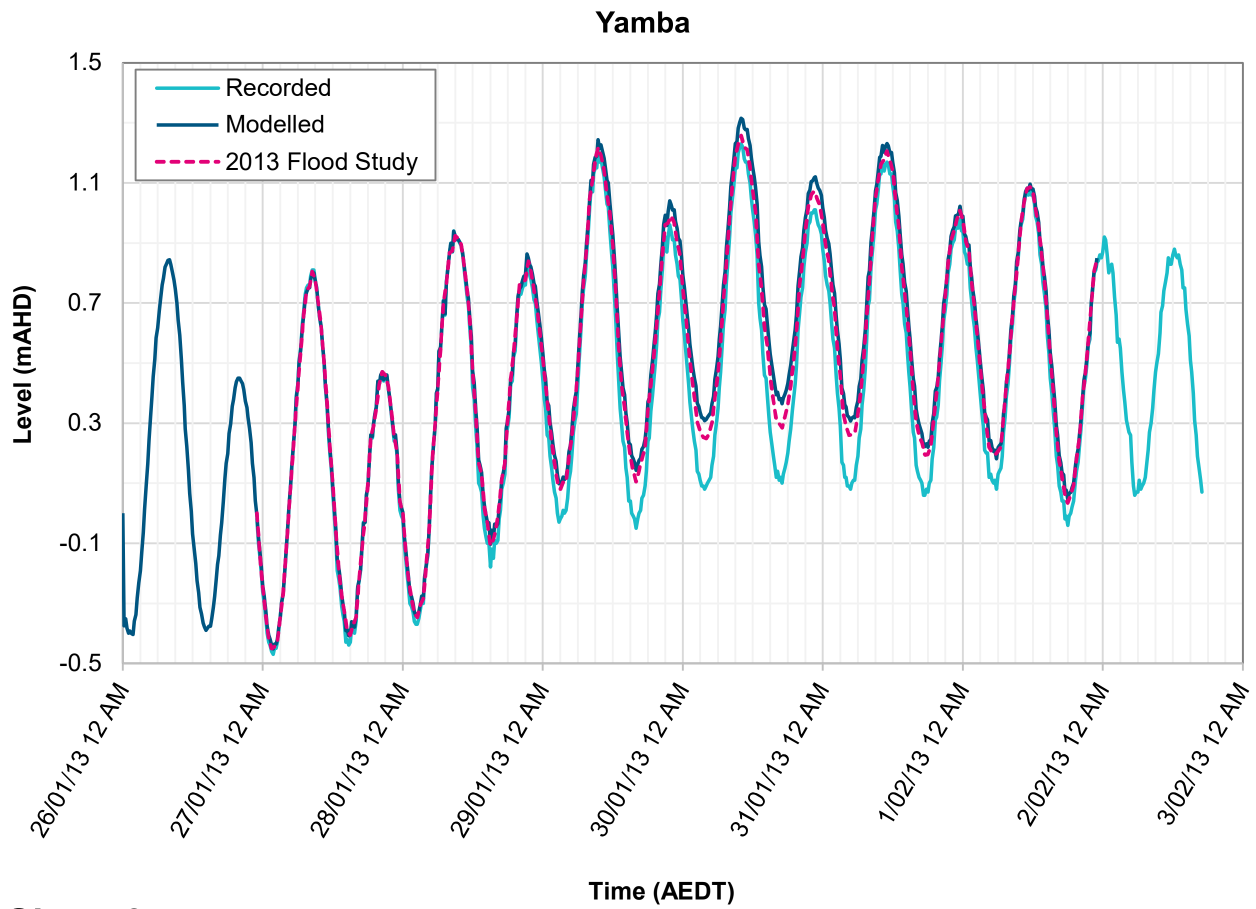


2013 Event Sheet 2









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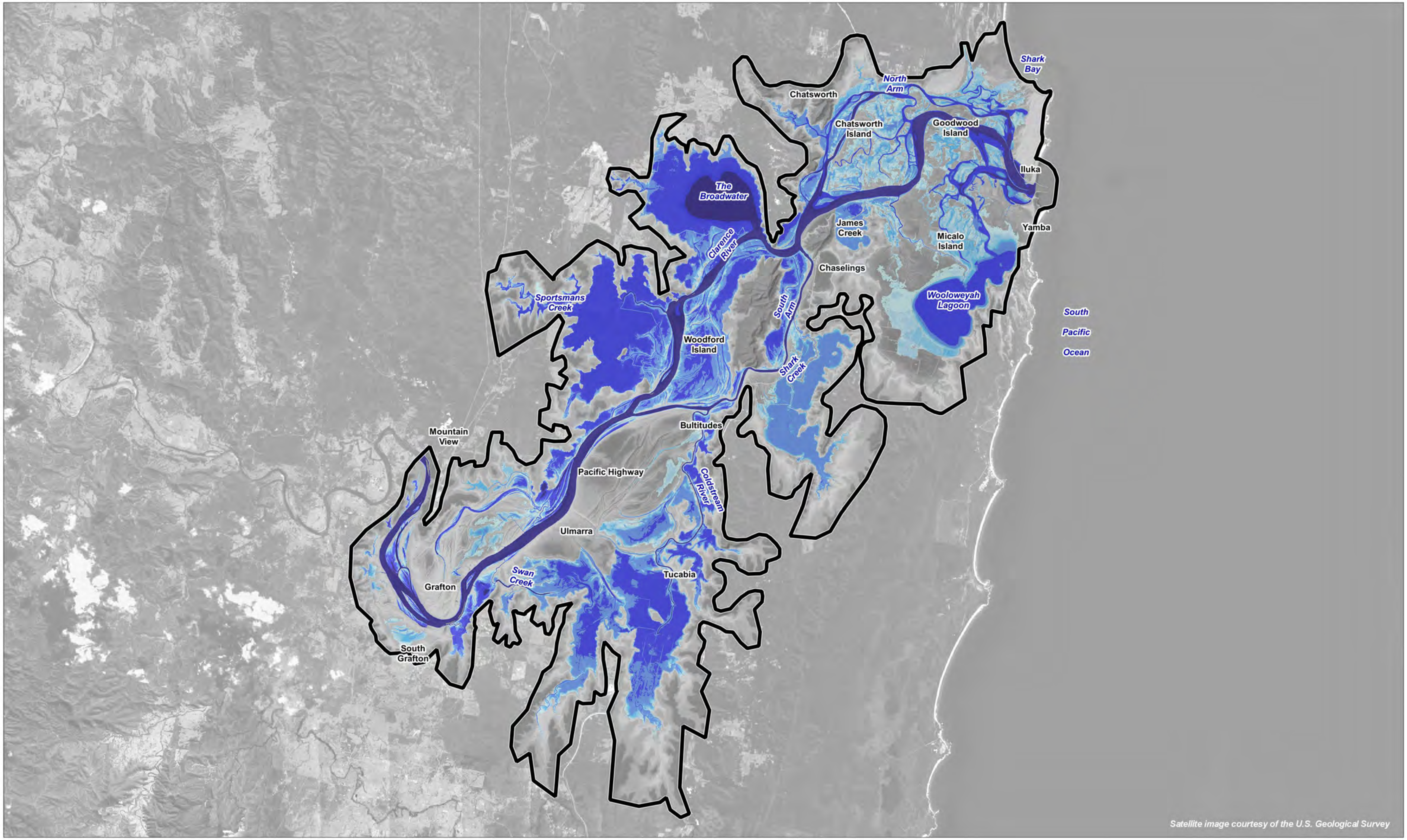

LEGEND

Study Area

Peak Flood Depth (m)

- < 0.25
- 0.25 to 0.5
- 0.5 to 0.75
- 0.75 to 1.0
- 1.0 to 2.0
- 2.0 to 4.0
- >4.0

Title:

2021 Calibration Modelled Extent

Figure: **A-2**

Rev: **A**

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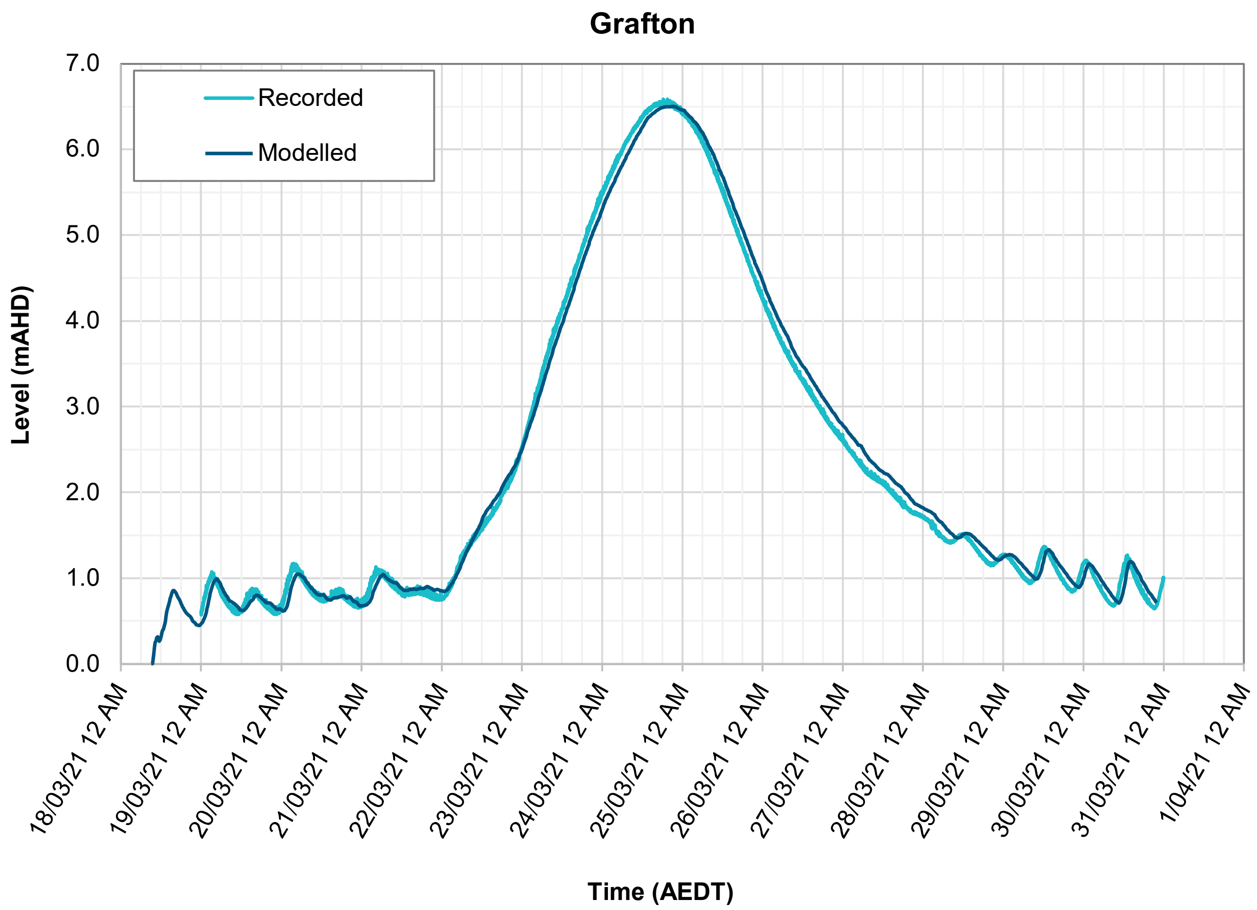
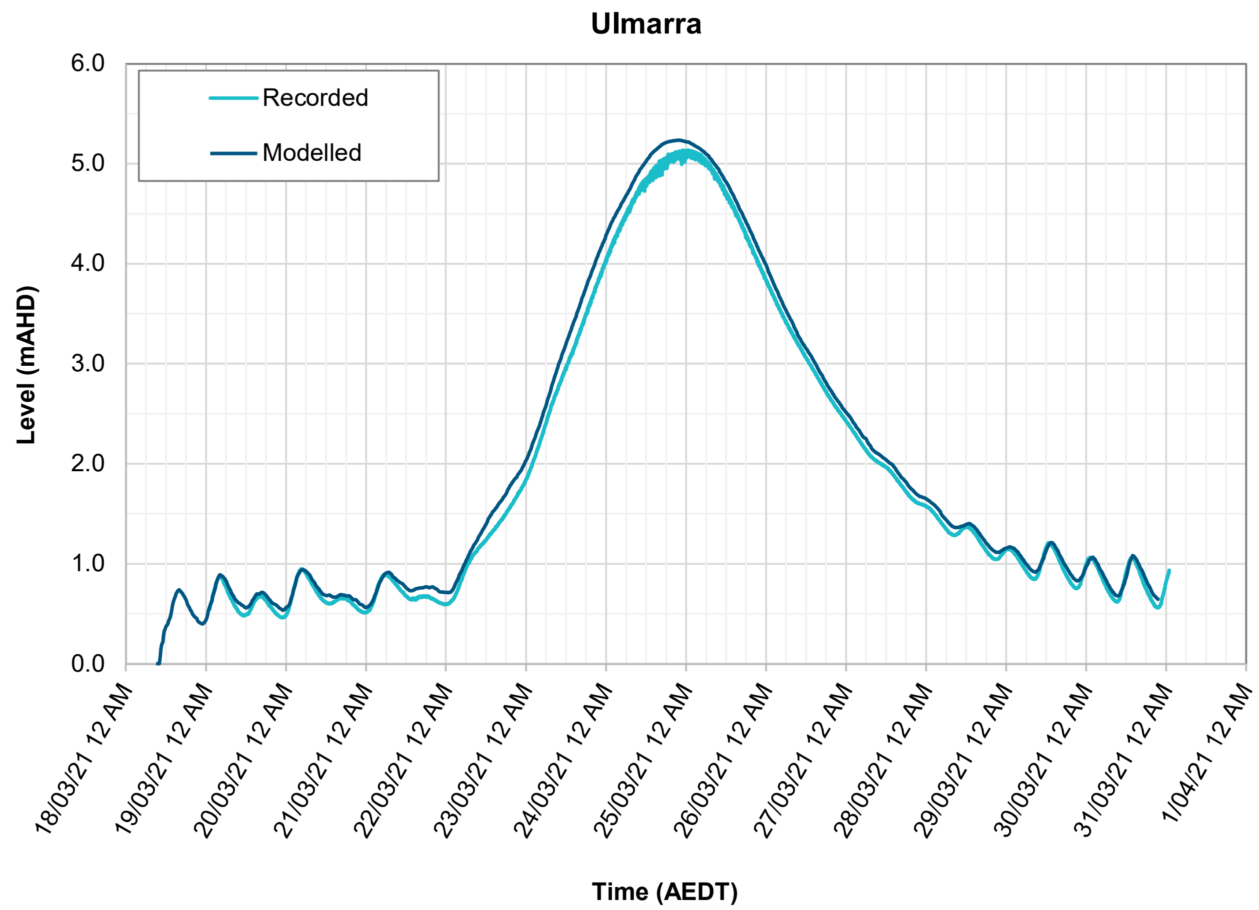
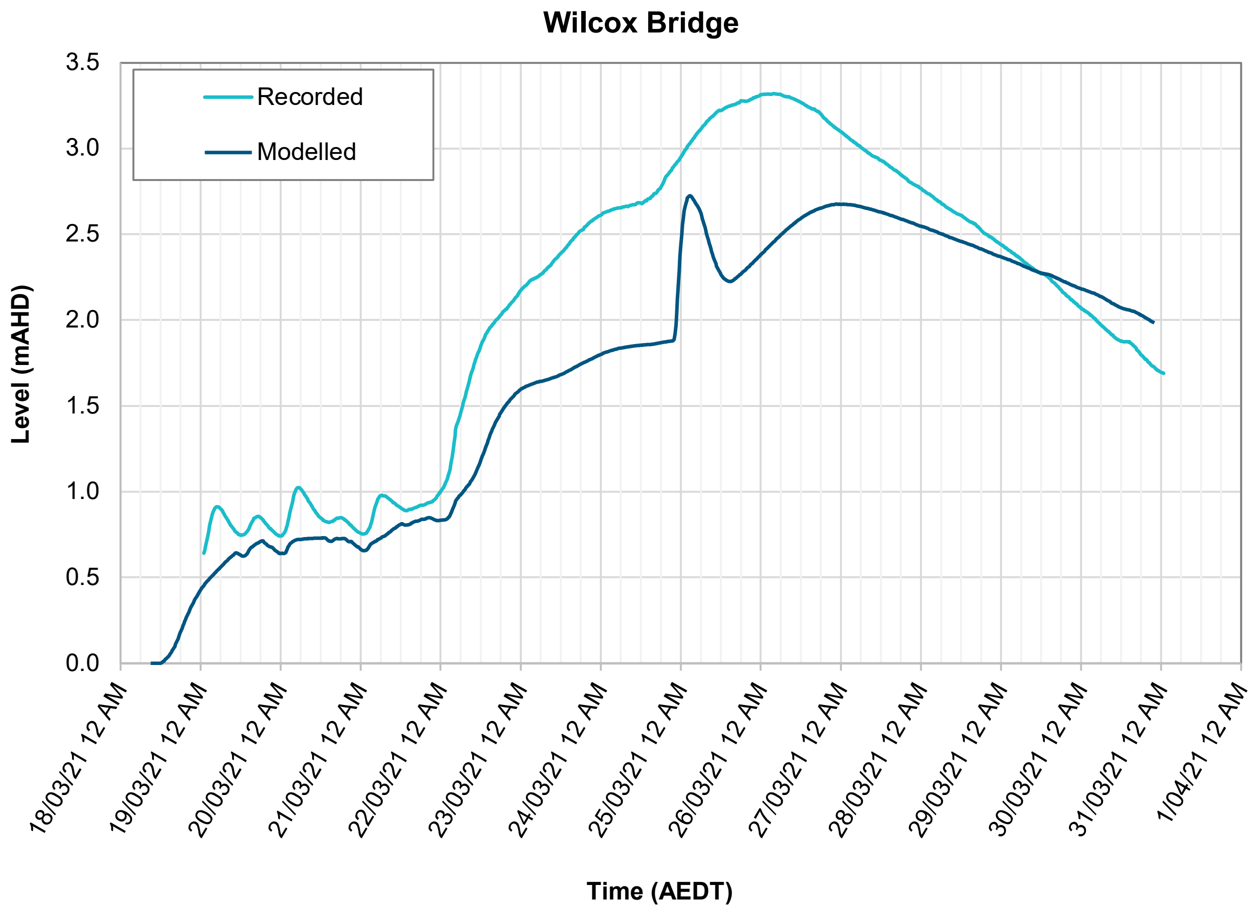
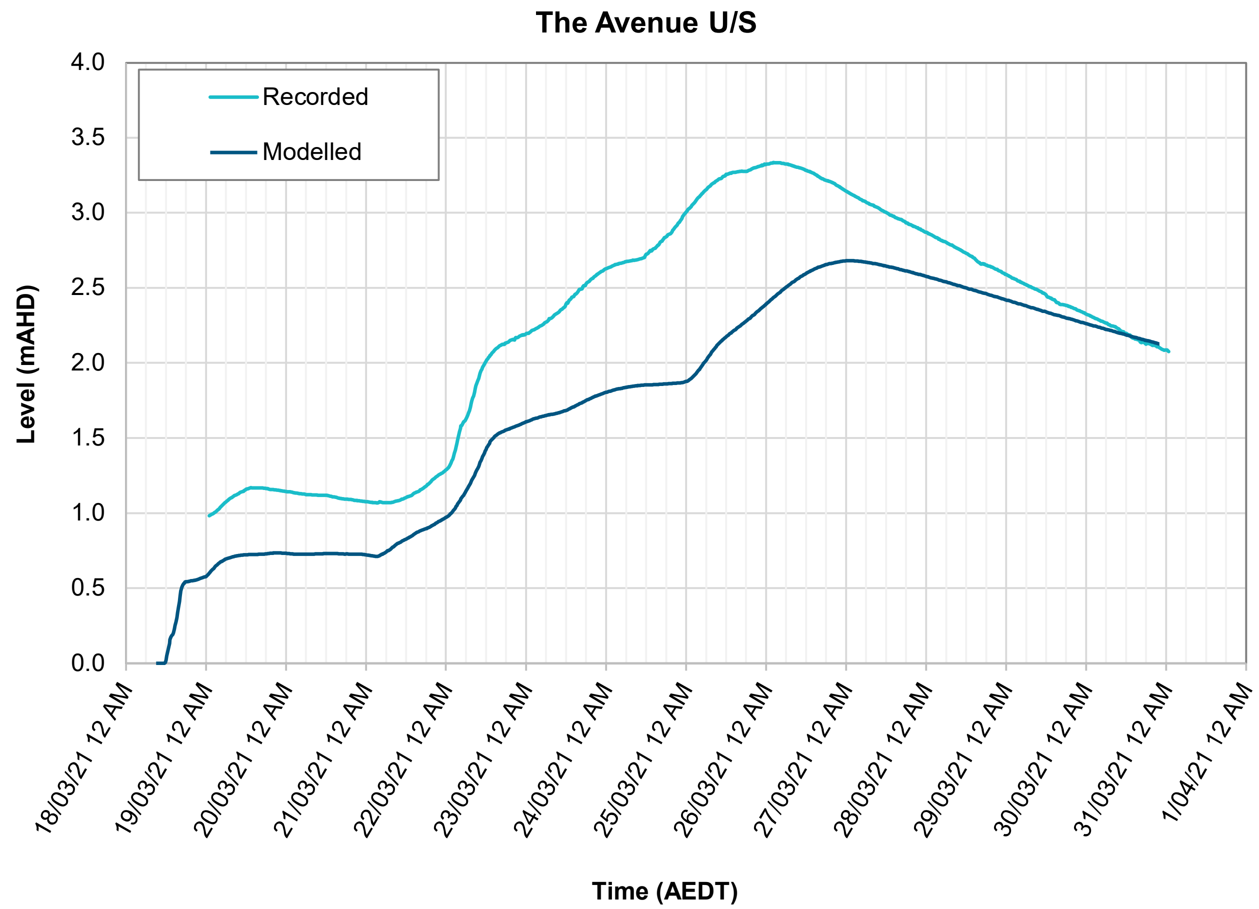
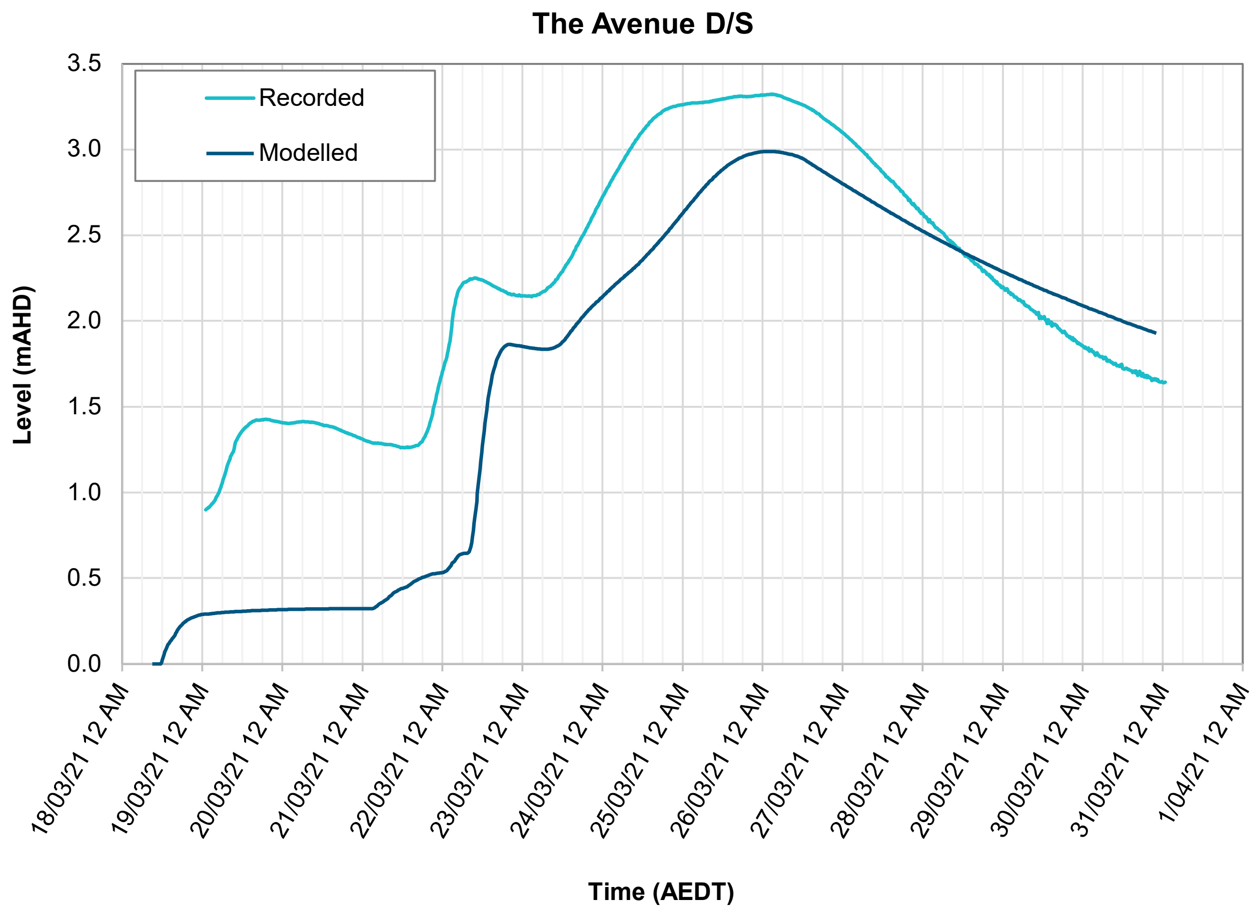


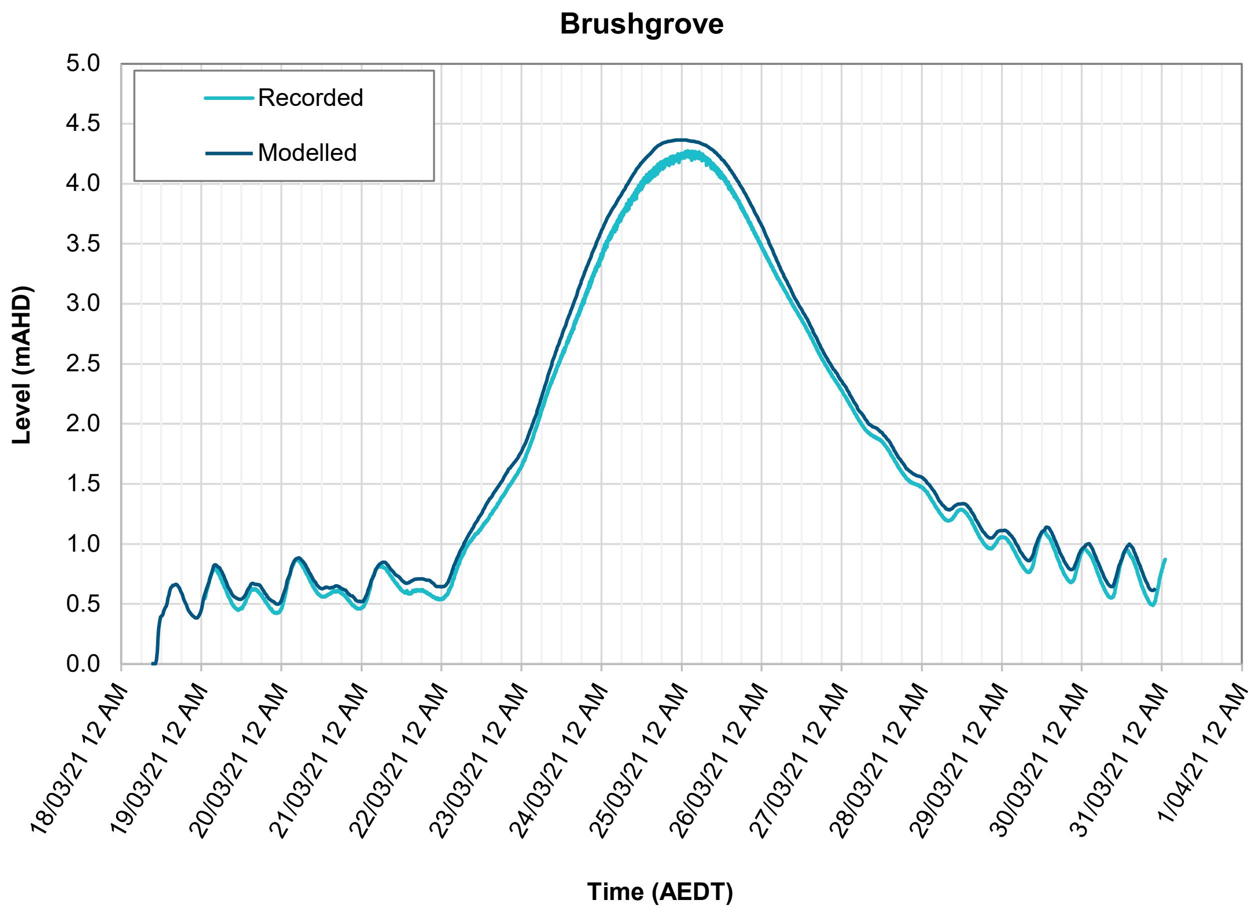


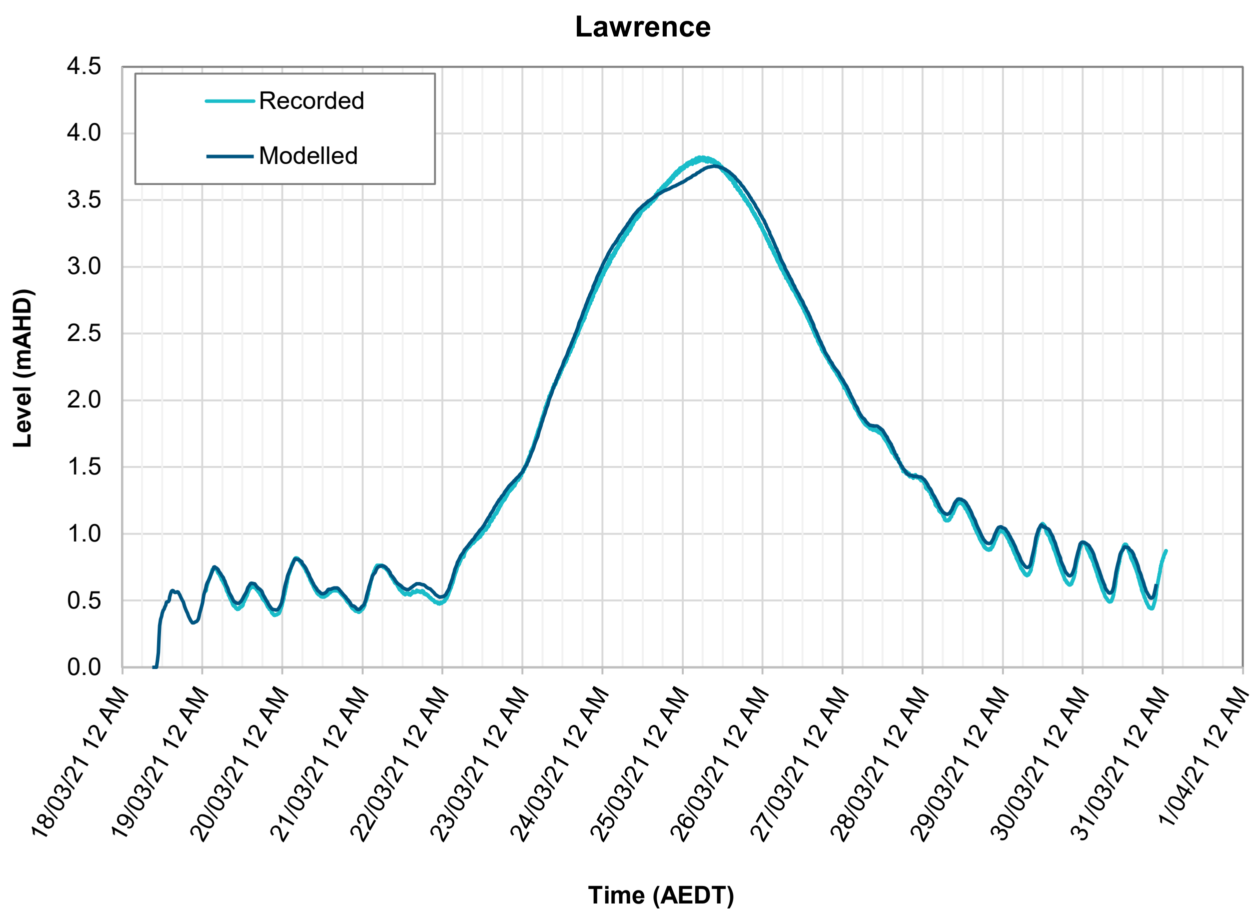


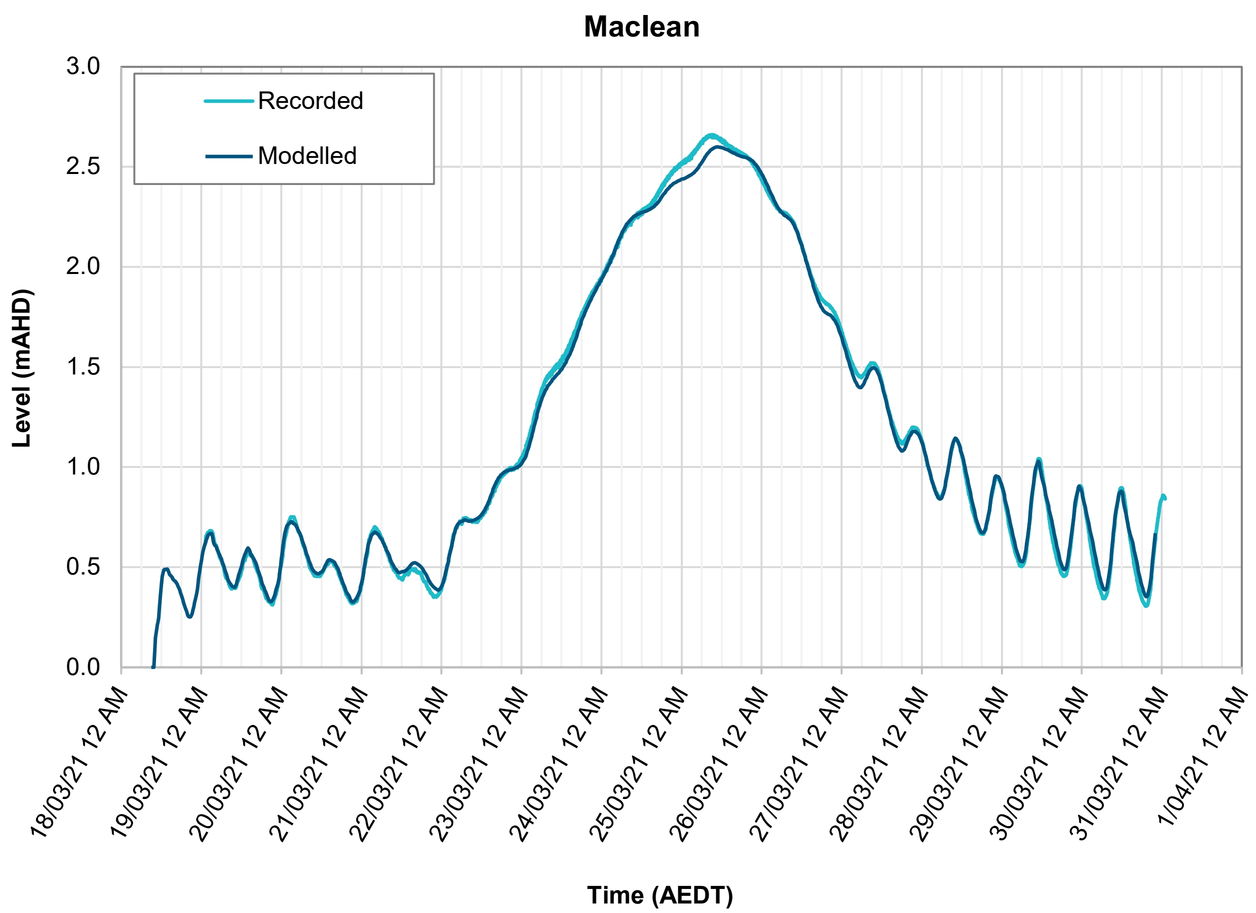


2021 Event Sheet 1

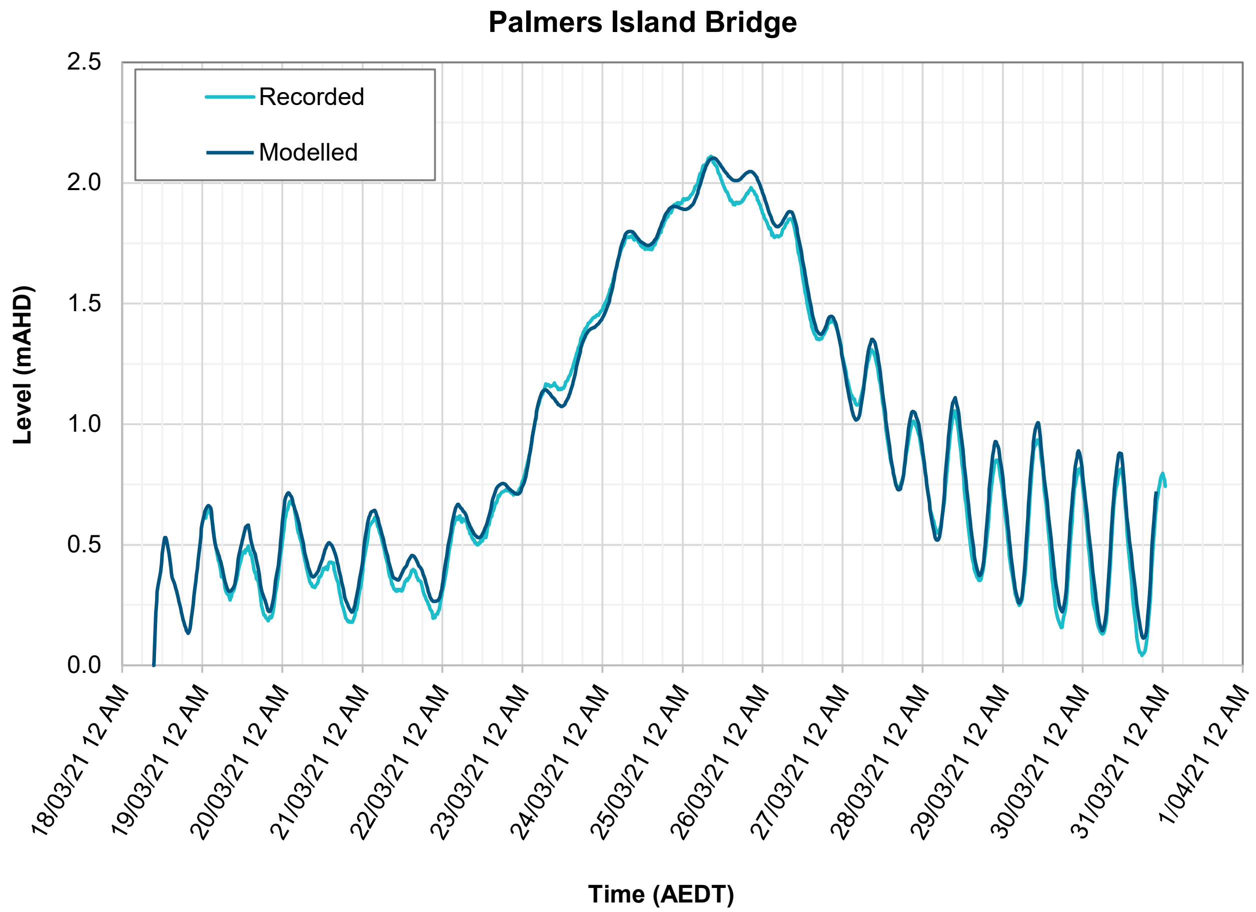


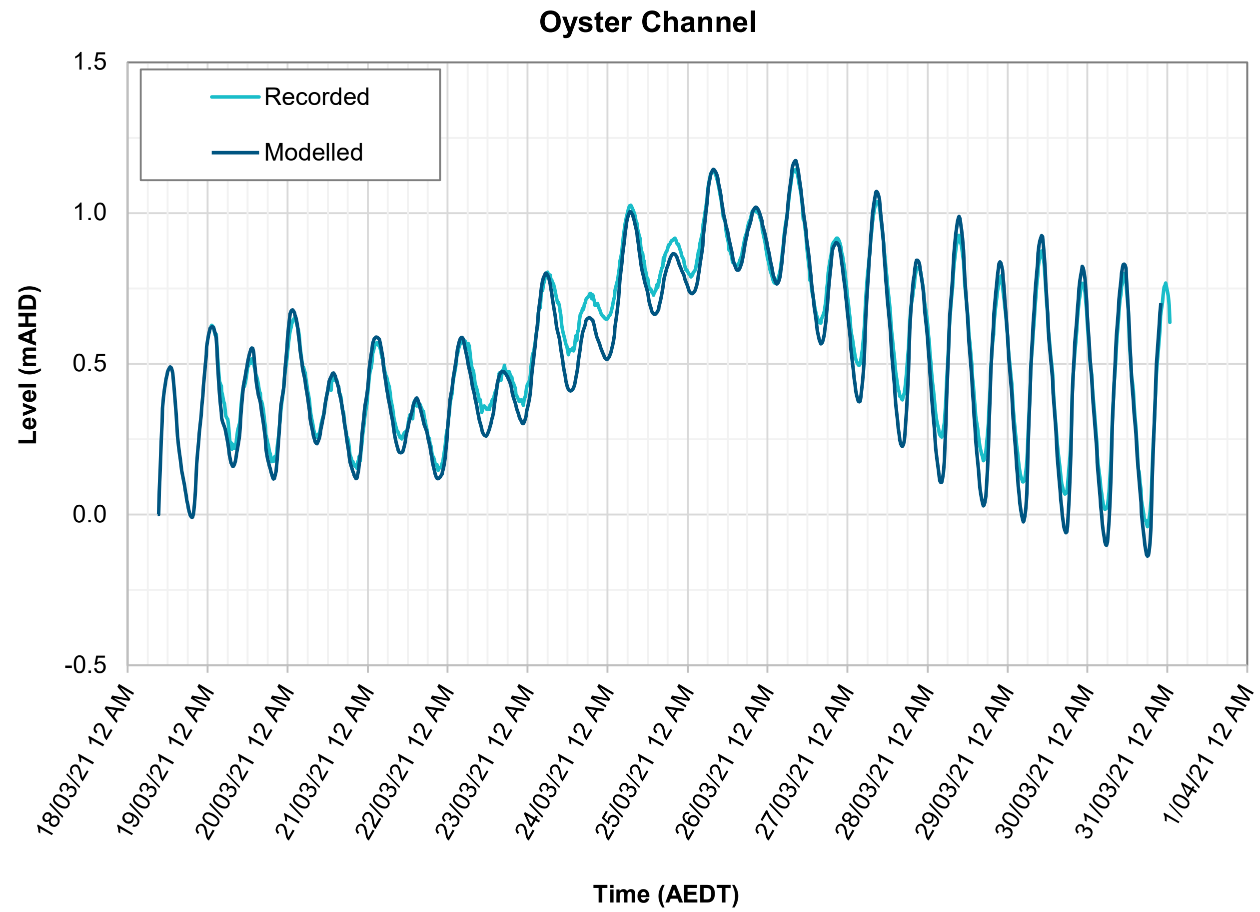


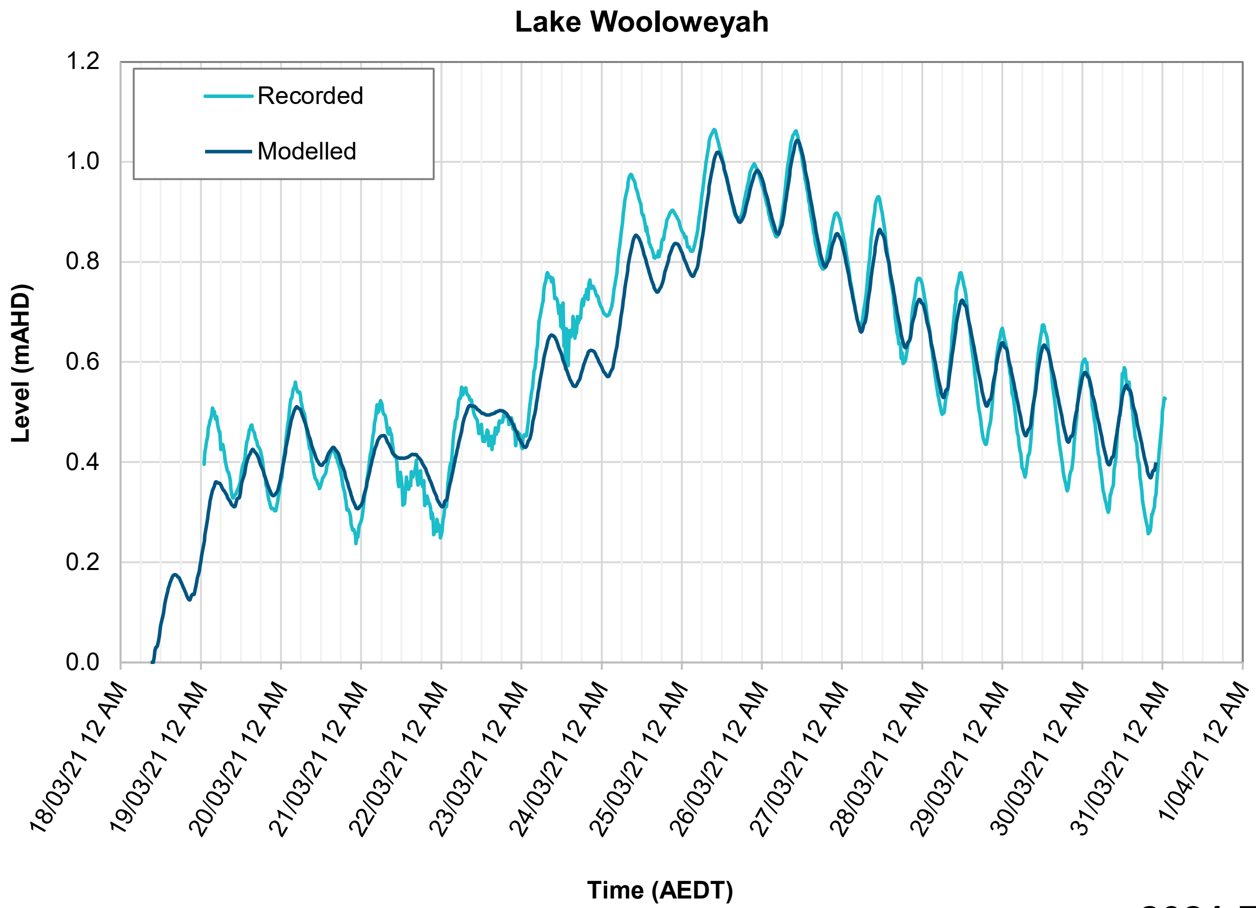


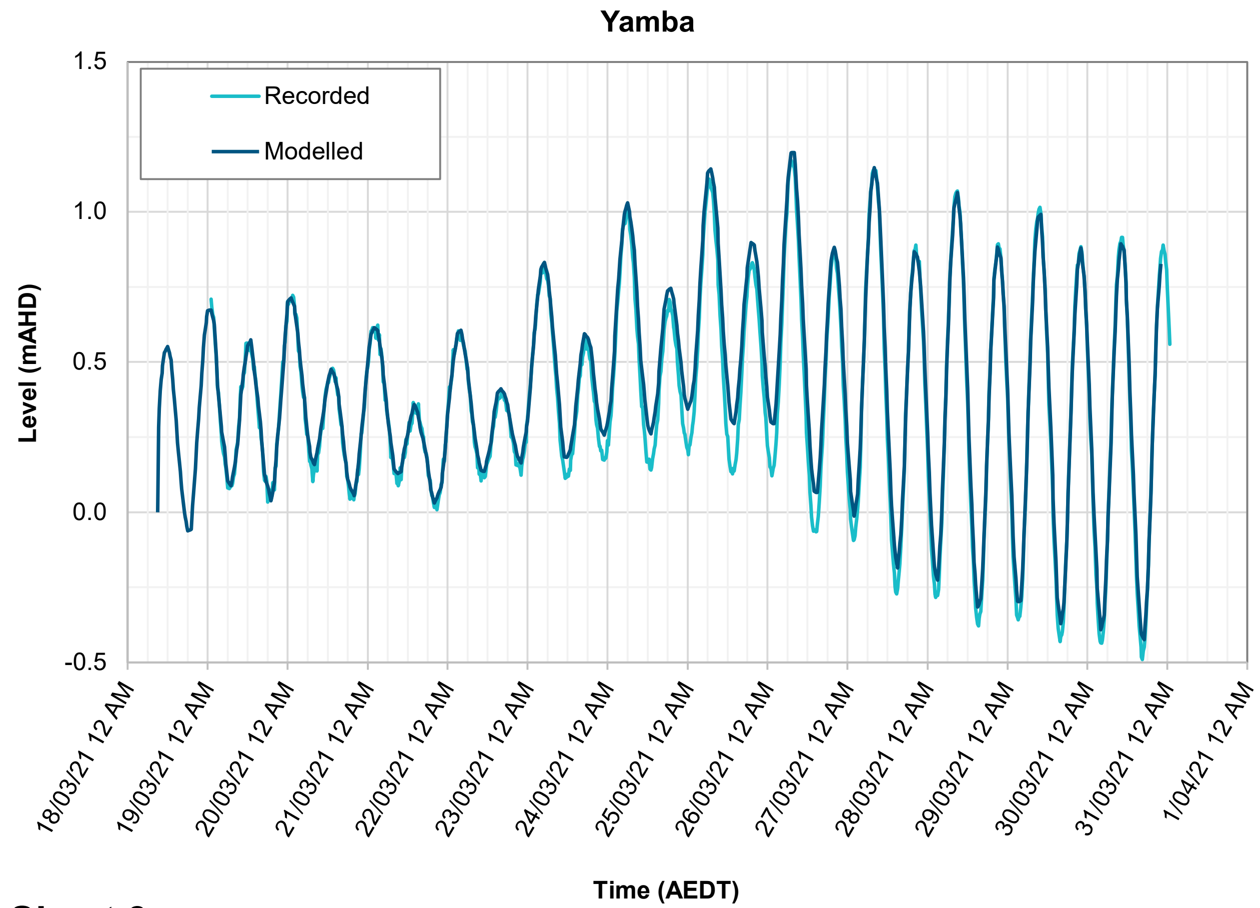


2021 Event Sheet 2

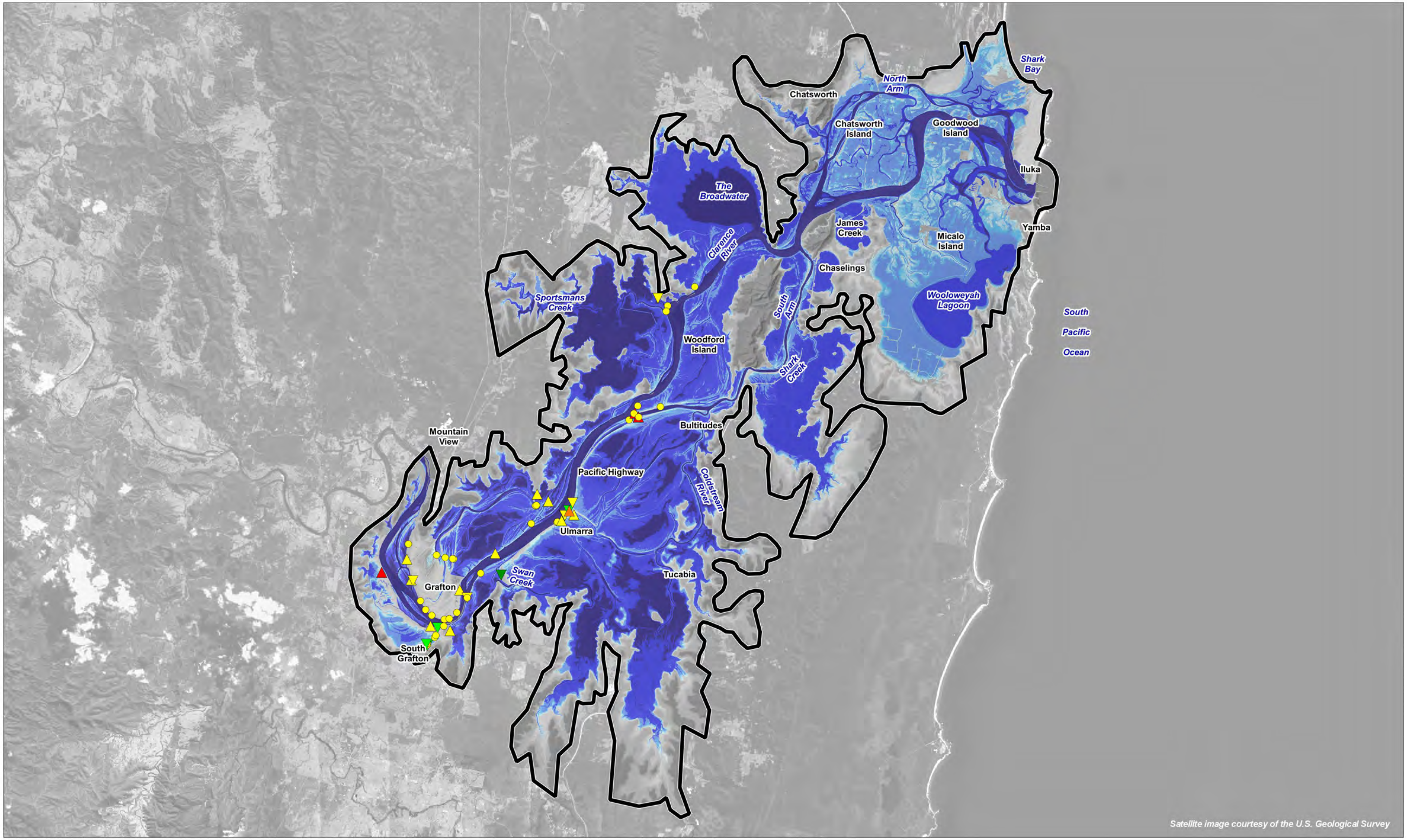








2021 Event Sheet 3



LEGEND

Study Area

Calibration Points (Modelled minus Recorded)

- >0.5 m
- 0.3 to 0.5 m
- 0.15 to 0.3 m
- -0.15 to 0.15 m
- -0.3 to -0.15 m
- -0.5 to -0.3 m
- <-0.5 m

Peak Flood Depth (m)

Band 1
- < 0.25
- 0.25 to 0.5
- 0.5 to 0.75
- 0.75 to 1.0
- 1.0 to 2.0
- 2.0 to 4.0
- >4.0

Title:

2022 Calibration to Flood Marks

Figure: A-3

Rev: A

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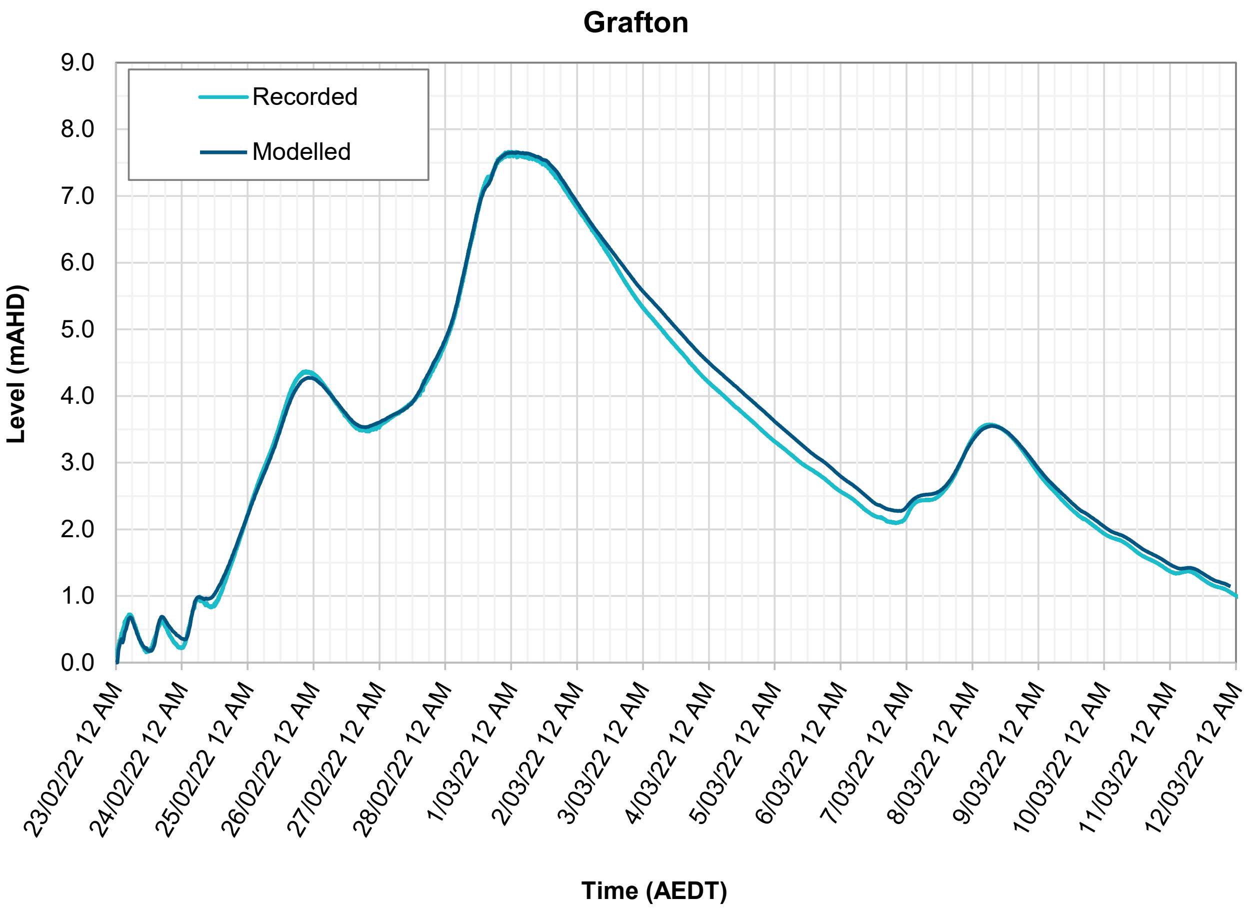
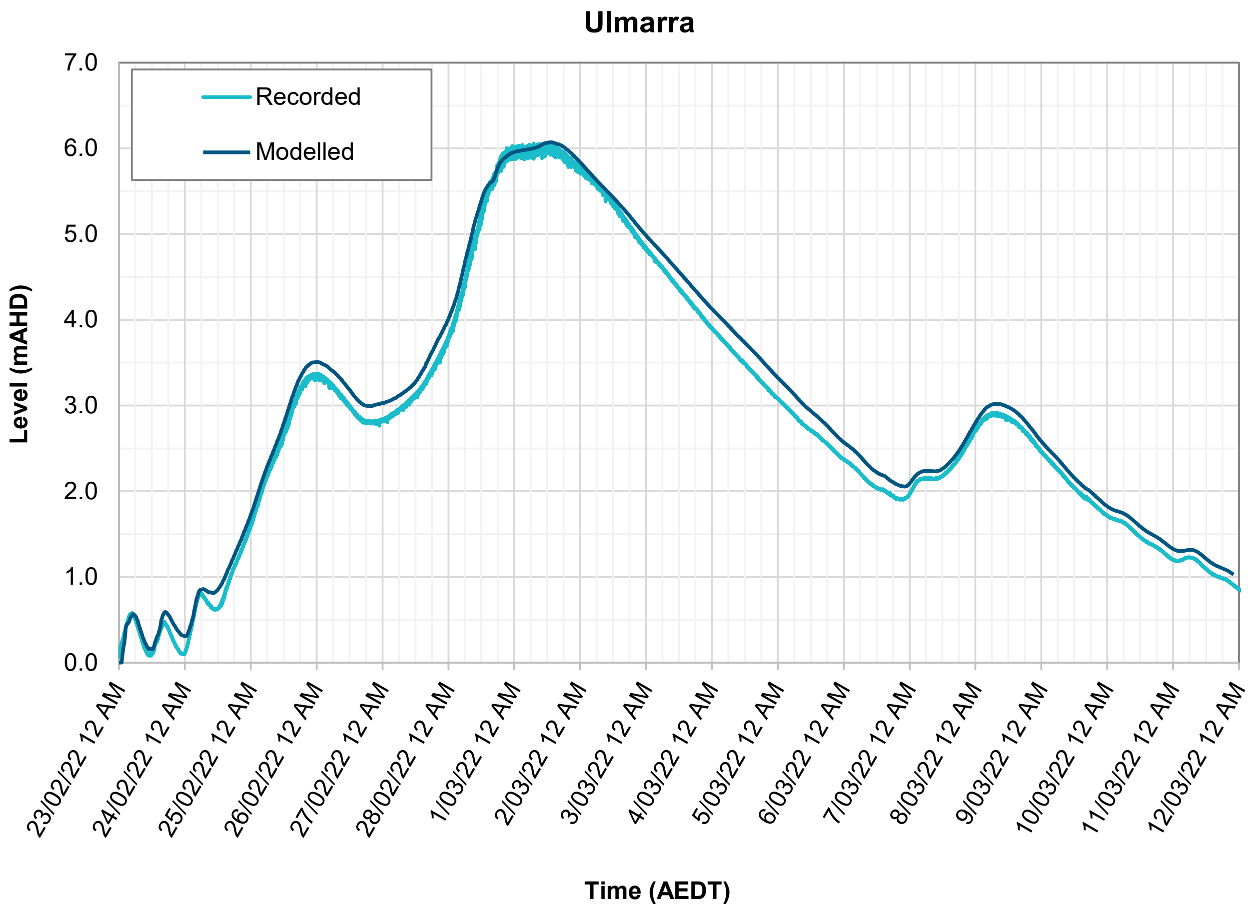
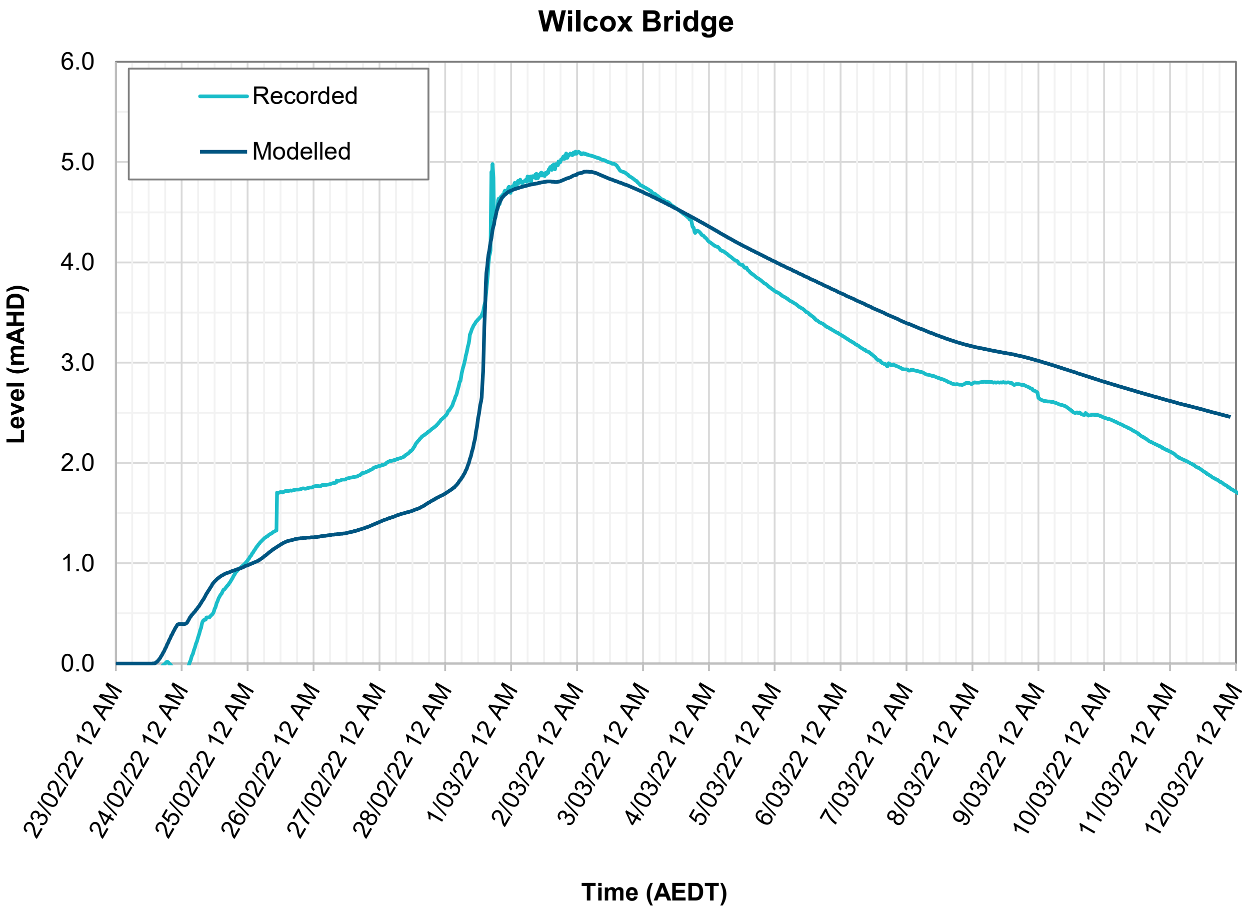
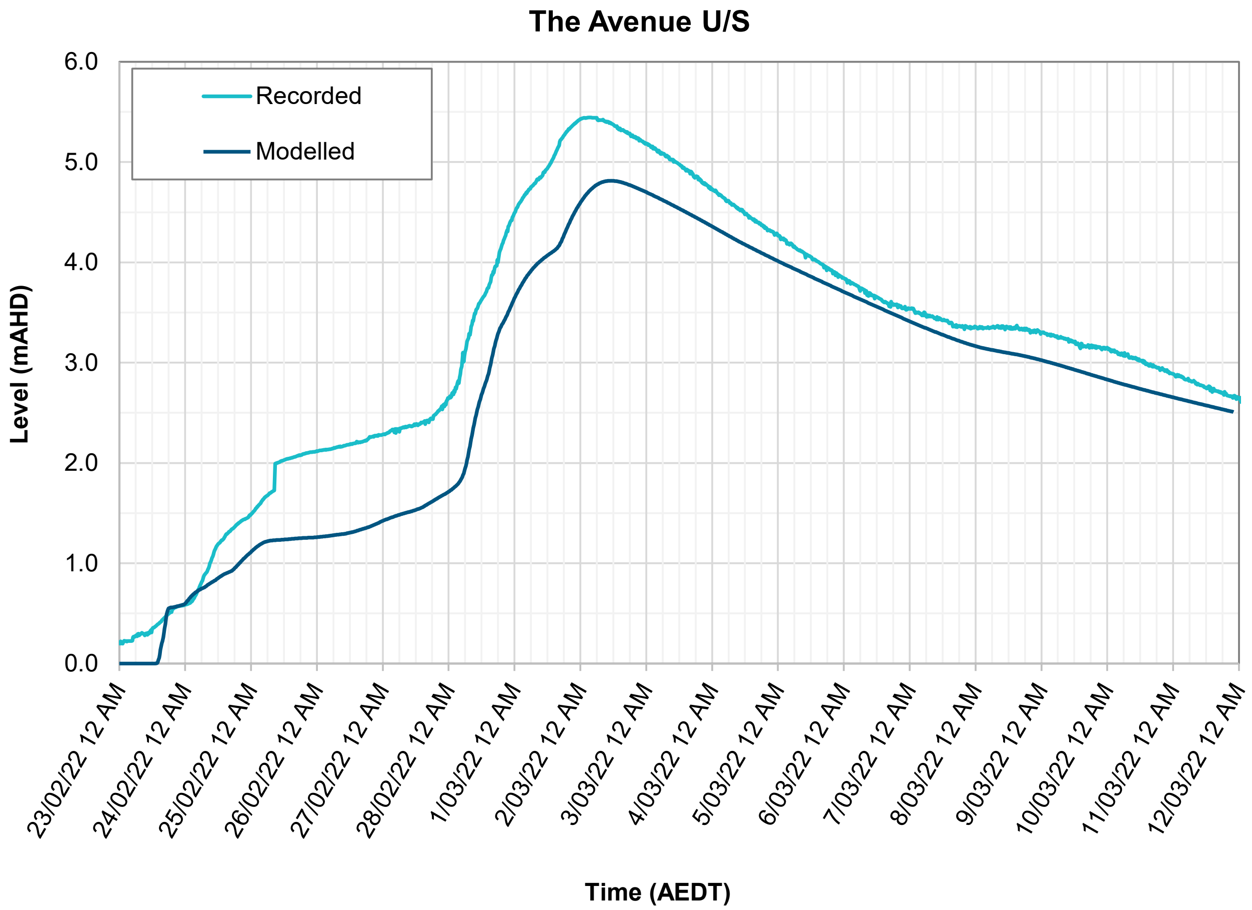
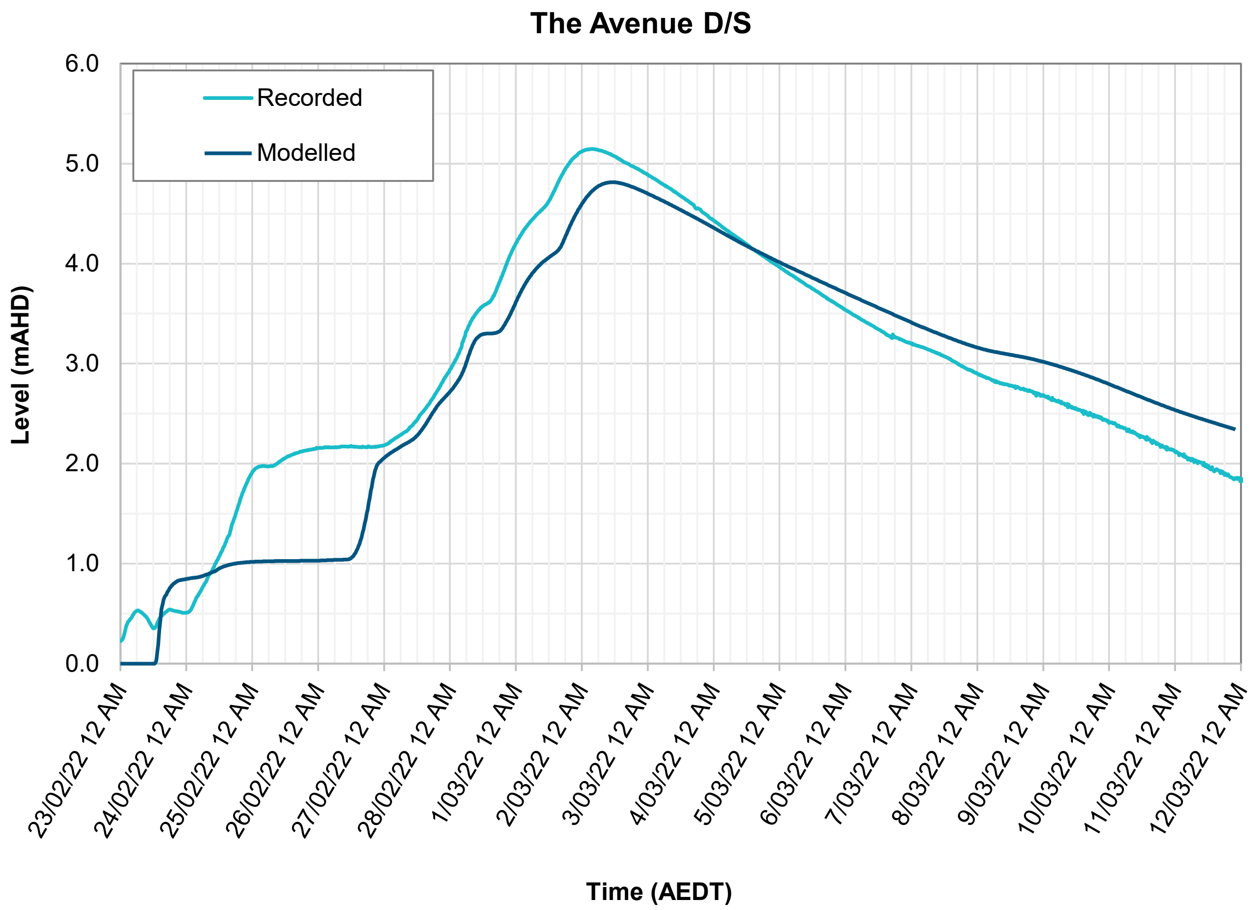


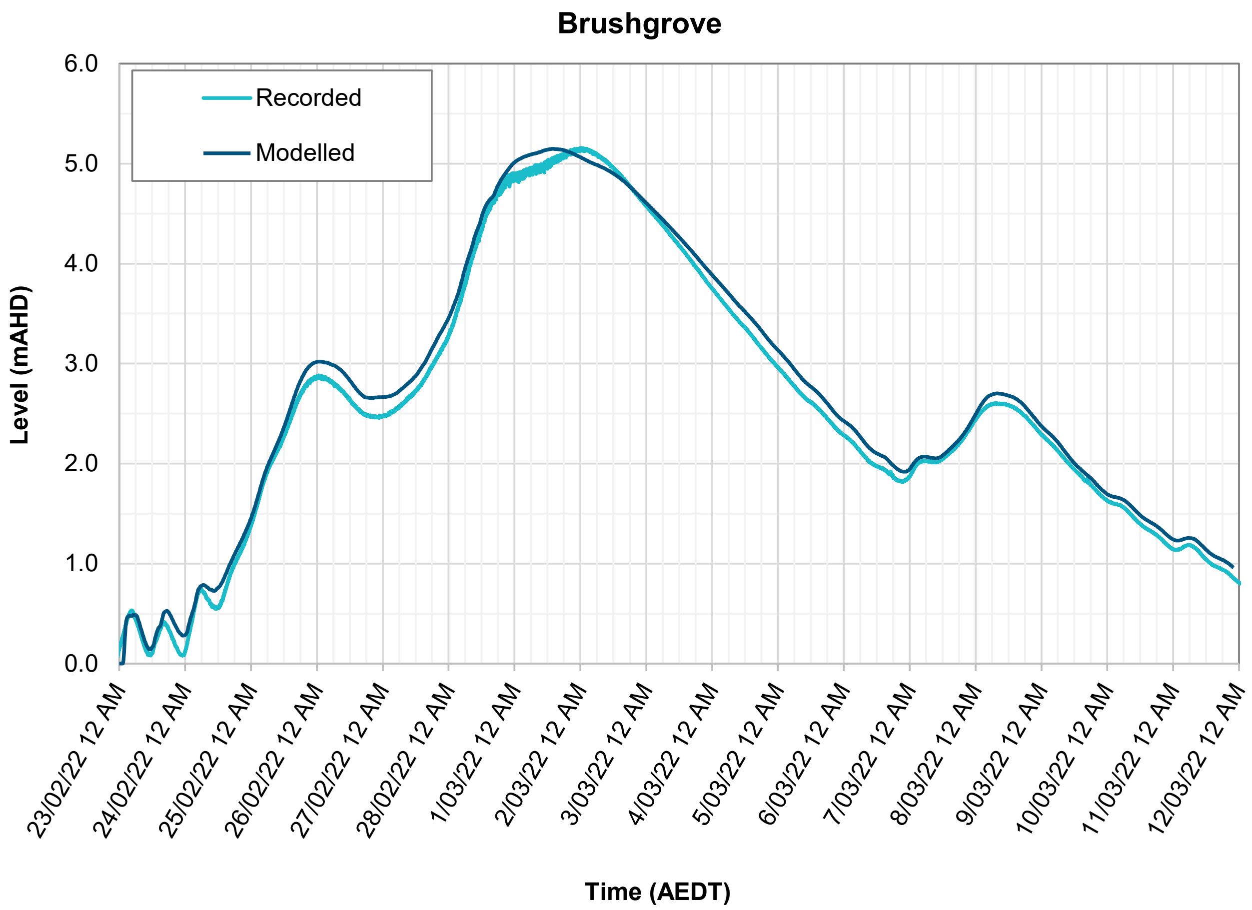


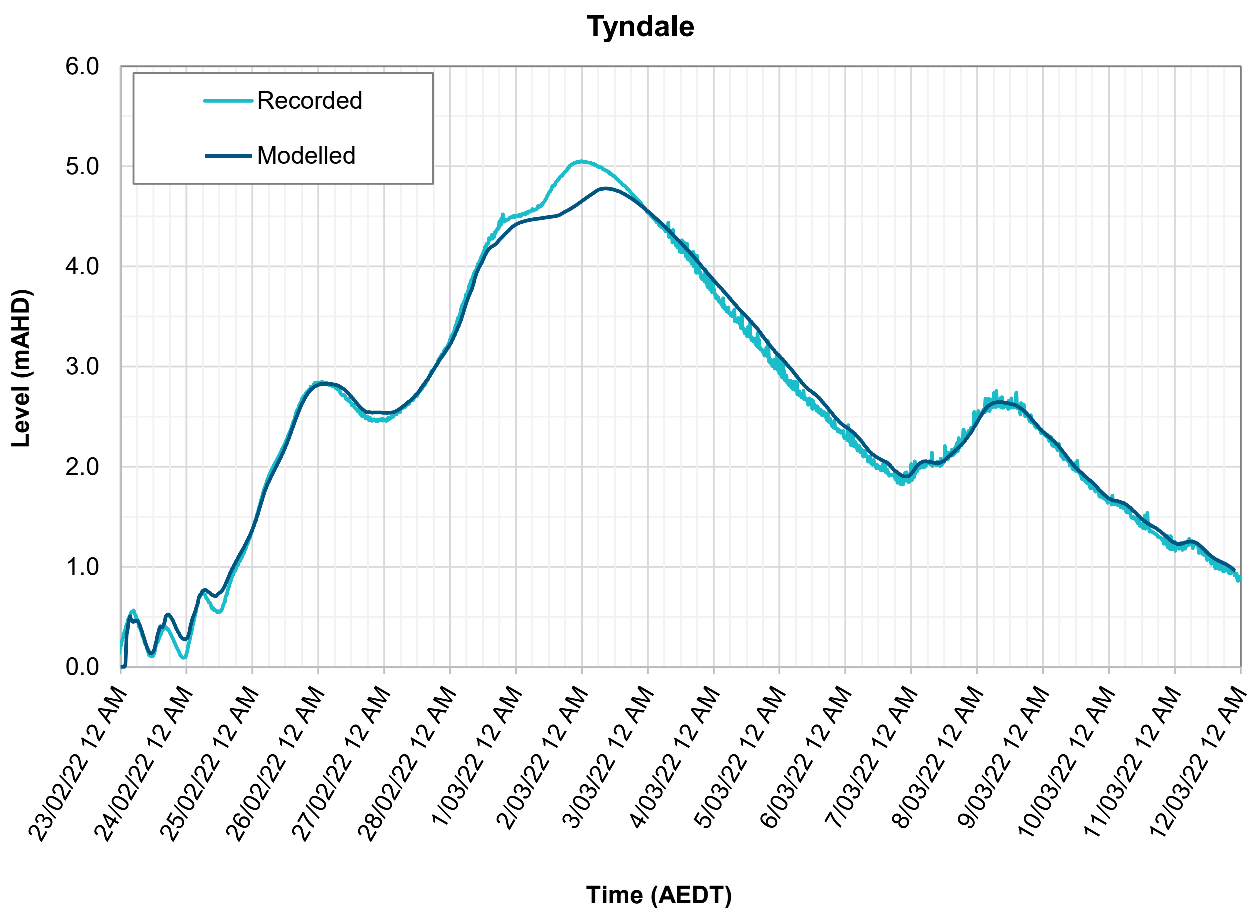


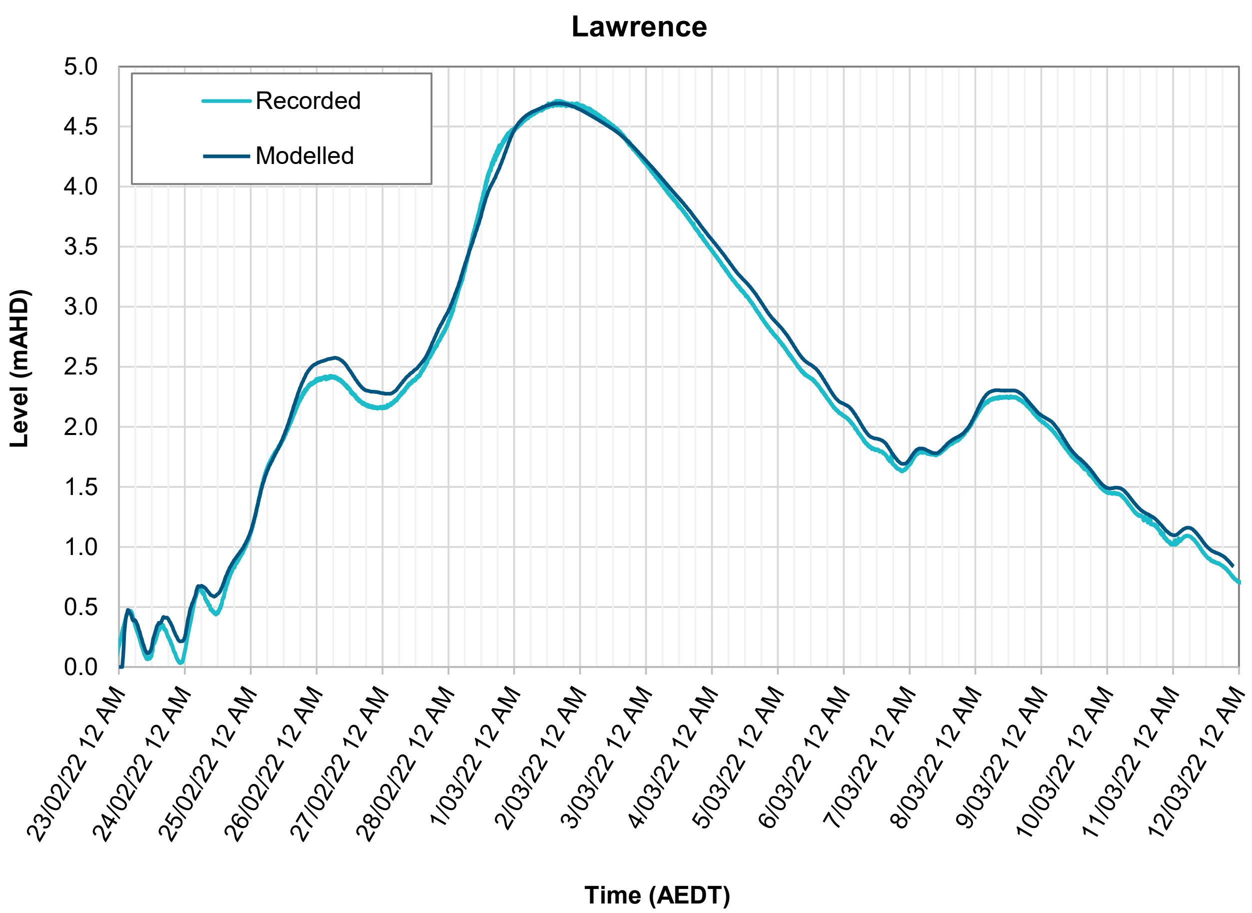


2022 Event Sheet 1

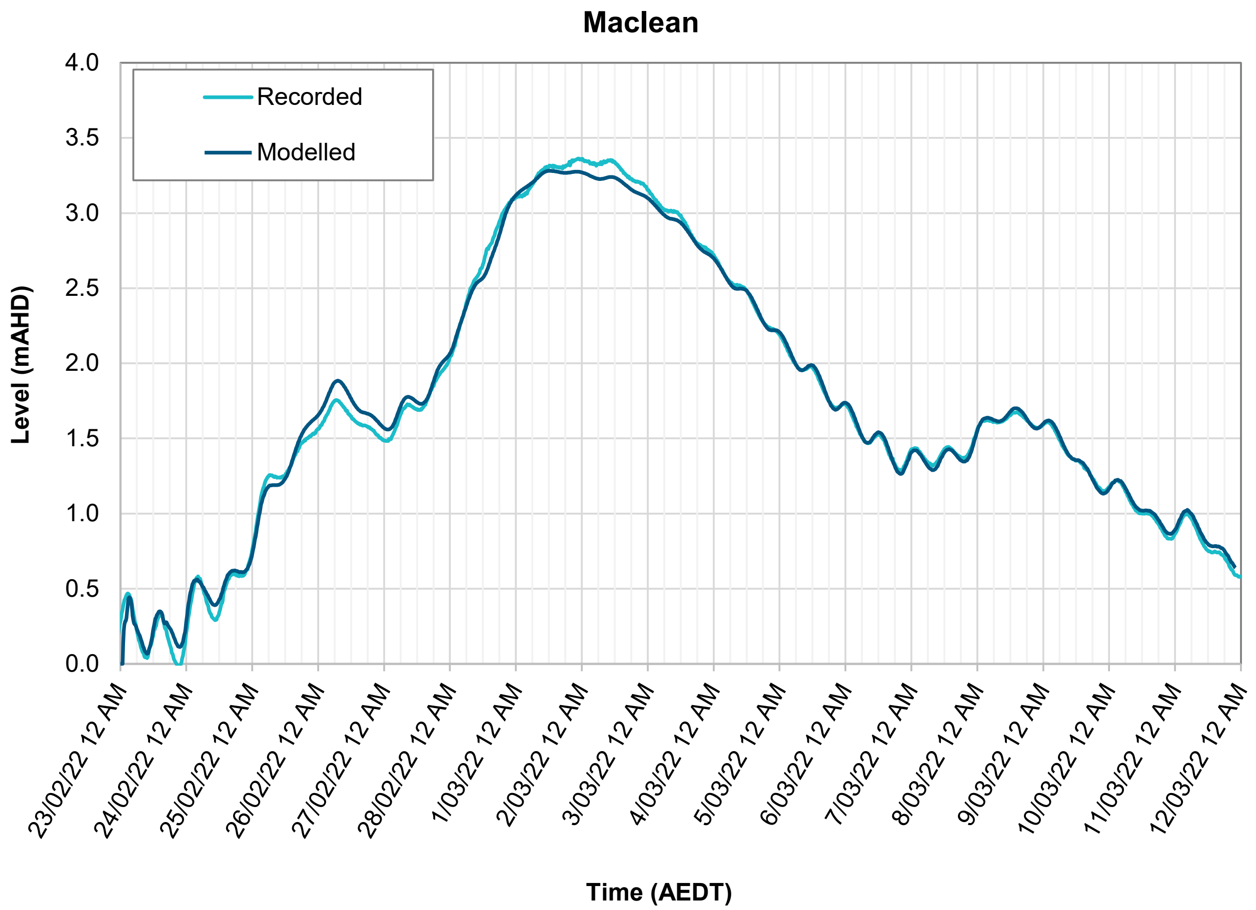


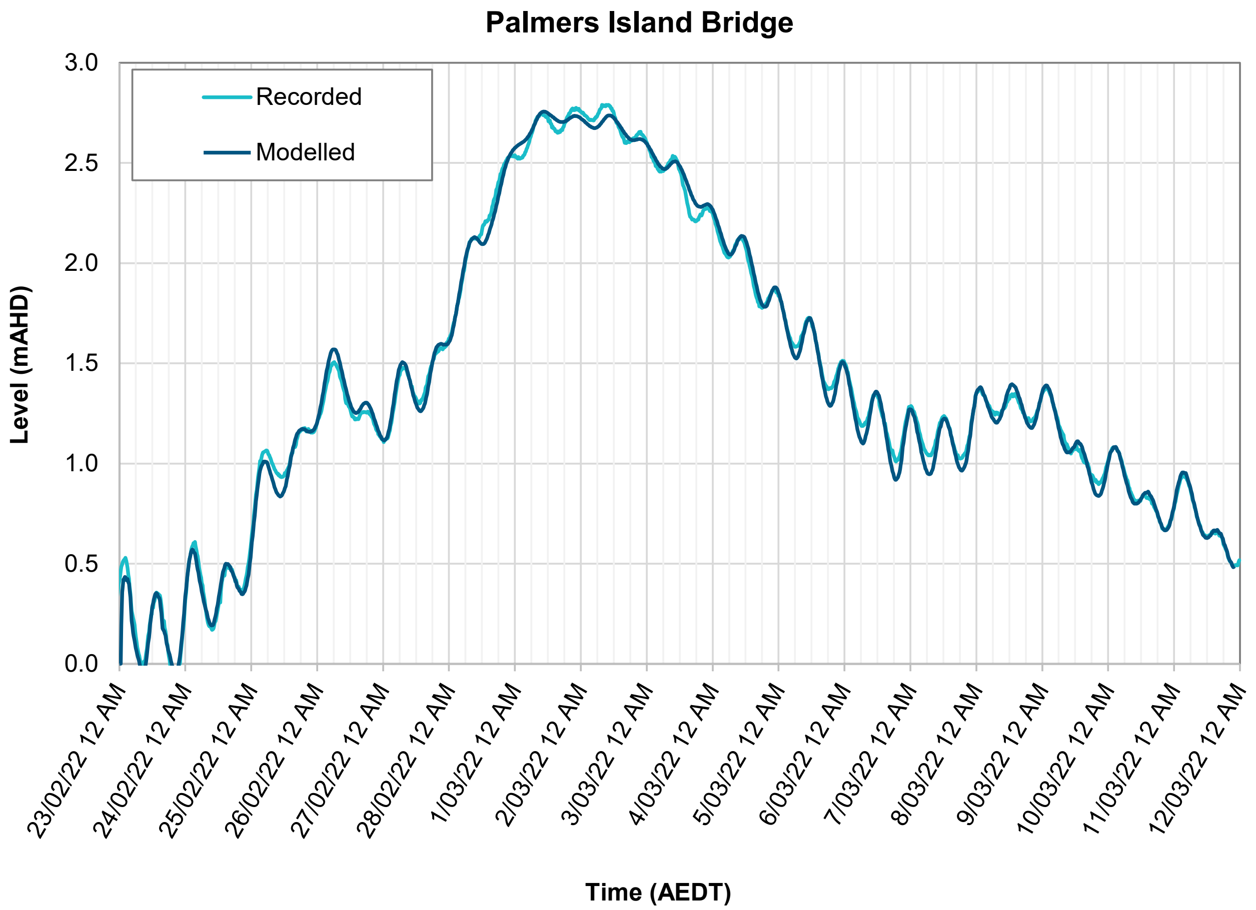


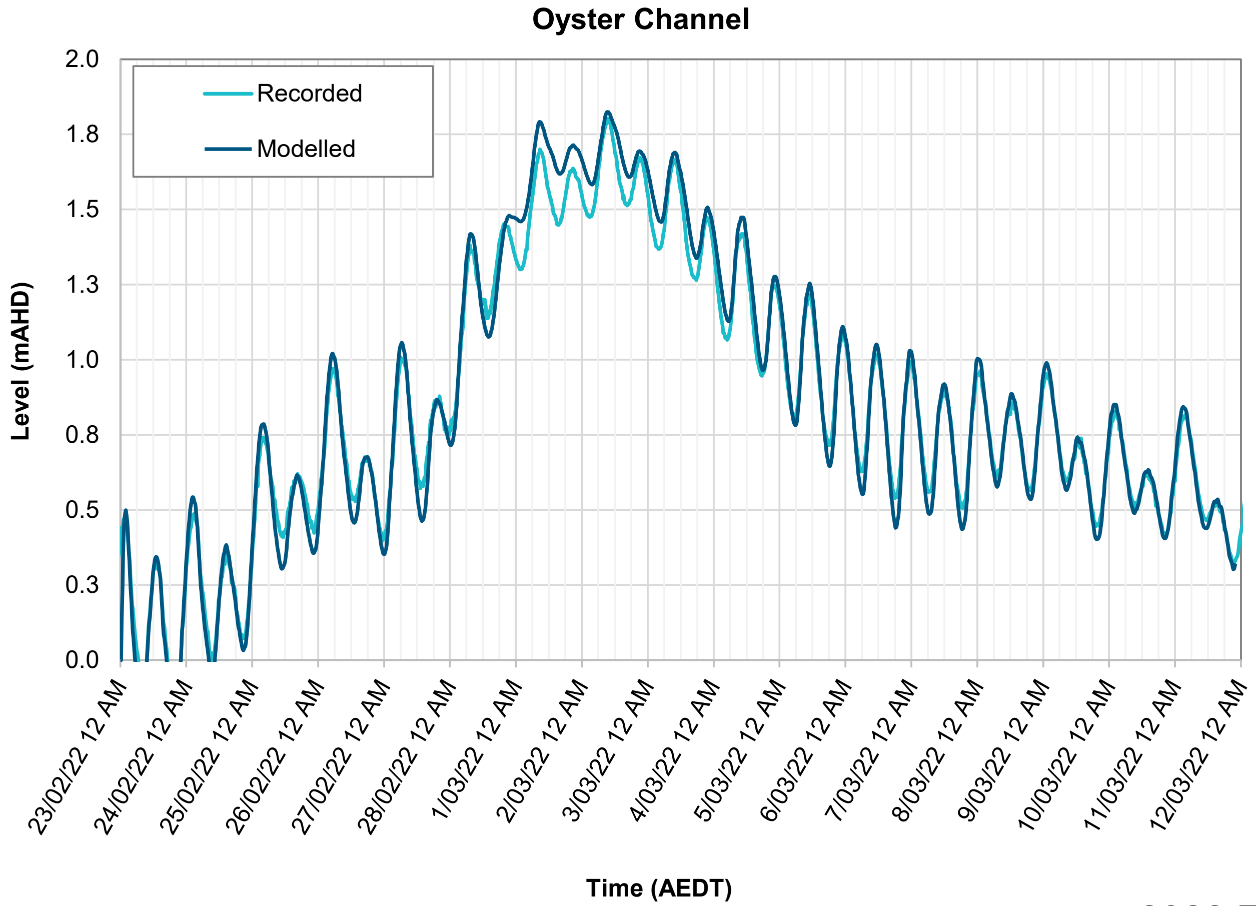


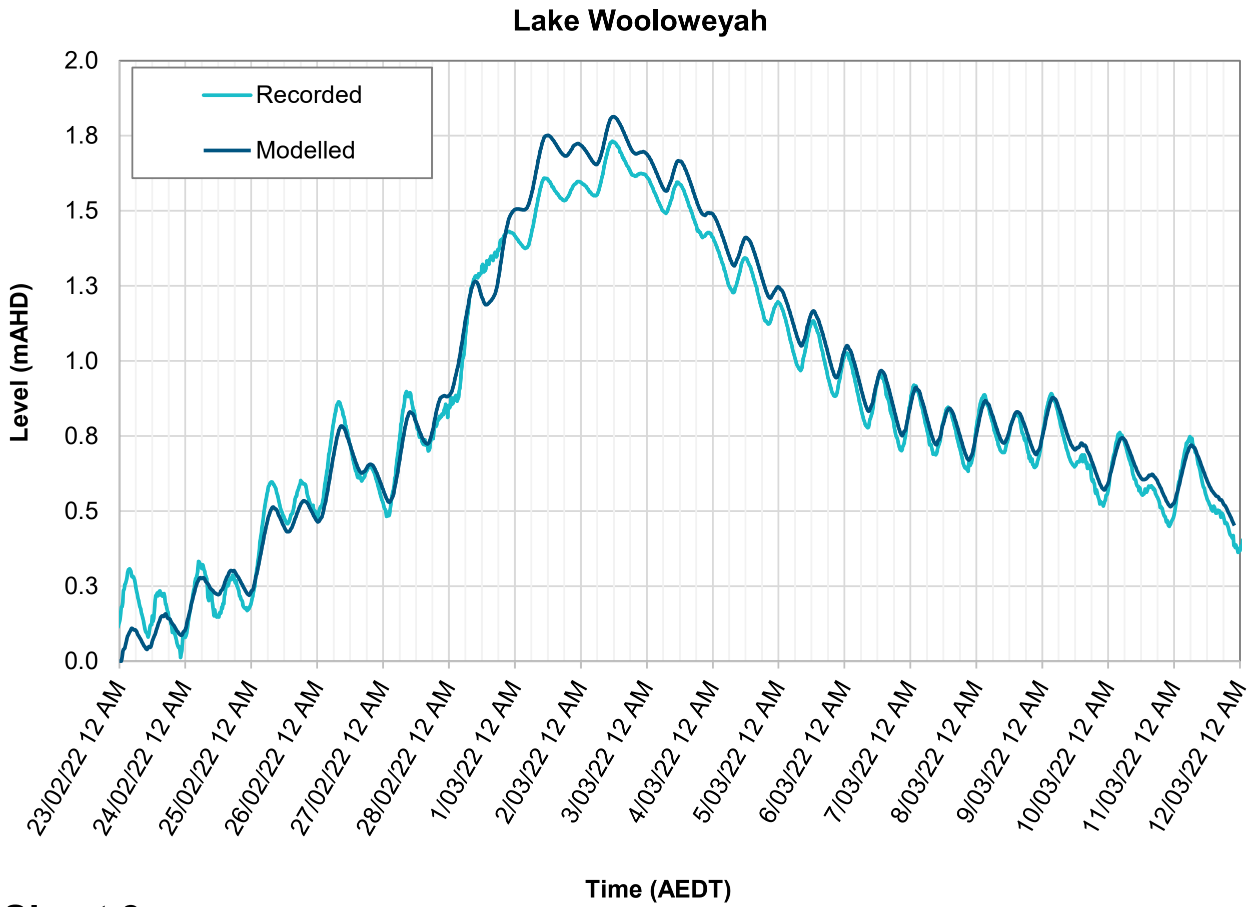


2022 Event Sheet 2

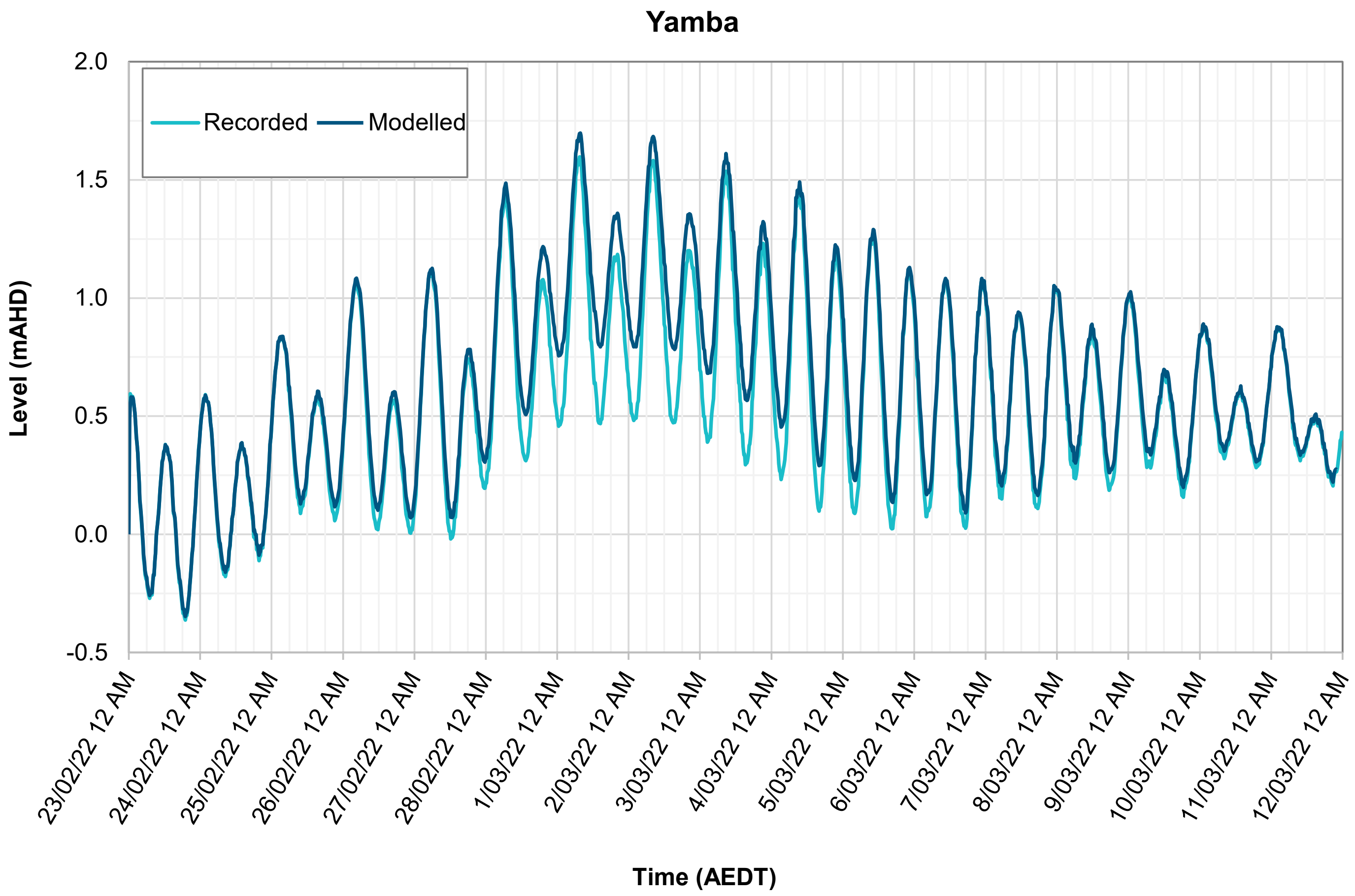








2022 Event Sheet 3



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2022 Event Sheet 4

Annex B Annual Maximum Series used for FFA

Table B.1. presents the annual maximum flow series for Mountain View based on the recorded level at the Grafton Prince Street gauge.

Table B.1. Annual Maximum Series

Year	Peak Stage (mAHD)	Peak Flow (m^3/s)	Year	Peak Stage (mAHD)	Peak Flow (m^3/s)
1839	5.65	10,414	1951	3.81	5,513
1841	5.90	11,102	1952	2.35	3,403
1845	6.05	11,651	1953	3.37	4,877
1857	6.28	12,965	1954	7.67	17,068
1861	6.03	11,537	1955	5.77	10,106
1863	6.90	15,945	1956	6.92	14,181
1864	6.54	14,451	1959	6.69	13,141
1867	6.18	12,394	1962	5.59	9,674
1875	3.30	4,776	1963	7.58	16,728
1876	7.43	18,377	1964	3.62	5,238
1887	7.78	20,157	1965	3.28	4,747
1889	6.84	15,698	1967	7.55	16,614
1890	7.83	20,411	1968	6.17	11,068
1892	6.59	14,666	1971	3.54	5,123
1893	7.68	19,648	1973	4.93	7,537
1894	3.61	5,224	1974	7.30	14,781
1895	4.52	7,304	1976	7.23	14,543
1903	3.00	4,342	1977	2.58	3,598
1917	4.22	6,379	1980	6.35	10,632
1921	6.82	13,729	1988	6.78	11,865

Year	Peak Stage (mAHD)	Peak Flow (m^3/s)	Year	Peak Stage (mAHD)	Peak Flow (m^3/s)
1925	2.16	3,128	1989	6.54	11,037
1927	3.91	5,658	1996	7.07	12,124
1928	6.71	13,231	2001	7.70	14,552
1929	4.22	6,379	2008	3.66	4,923
1933	3.94	5,706	2009	7.37	13,275
1937	4.71	7,557	2011	7.64	14,310
1938	3.61	5,224	2012	5.55	8,529
1939	3.30	4,776	2013	8.09	16,433
1944	3.30	4,776	2015	2.69	3,618
1945	6.40	11,829	2017	3.19	4,291
1946	7.05	14,723	2020	4.30	5,836
1947	3.27	4,733	2021	6.58	10,749
1948	7.12	14,988	2022	7.67	14,425
1950	7.73	17,408			

Annex C TUFLOW-FLIKE Data Output File

Report created on 21/ 9/2022 at 17:14

FLIKE program version 5.0.300.0

FLIKE file version 3.10

Data file:
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Input Data for Flood Frequency Analysis for Model: GEV

Gauged Annual Maximum Discharge Data

Obs, Discharge, Year, AEP plot position, AEP 1in Y yrs

----

1 20410.94 1890 0.99674 307.00

2 20156.65 1887 0.99131 115.12

3 19648.07 1893 0.98588 70.85

4 18376.62 1876 0.98046 51.17

5 17408.30 1950 0.97503 40.04

6 17068.28 1954 0.96960 32.89

7 16727.81 1963 0.96417 27.91

8 16614.31 1967 0.95874 24.24

9 16433.00 2013 0.95331 21.42

10 15945.30 1863 0.94788 19.19

11 15697.78 1889 0.94245 17.38

12 14987.61 1948 0.93702 15.88

13 14781.48 1974 0.93160 14.62

14 14722.79 1946 0.92617 13.54

15 14666.47 1892 0.92074 12.62

16 14552.34 2001 0.91531 11.81

17 14542.69 1976 0.90988 11.10

18 14450.68 1864 0.90445 10.47

19 14425.15 2022 0.89902 9.90

20	14310.09	2011	0.89359	9.40
21	14181.37	1956	0.88817	8.94
22	13728.99	1921	0.88274	8.53
23	13274.55	2009	0.87731	8.15
24	13231.38	1928	0.87188	7.81
25	13140.90	1959	0.86645	7.49
26	12965.07	1857	0.86102	7.20
27	12393.68	1867	0.85559	6.92
28	12123.95	1996	0.85016	6.67
29	11864.81	1988	0.84473	6.44
30	11829.00	1945	0.83931	6.22
31	11650.87	1845	0.83388	6.02
32	11536.59	1861	0.82845	5.83
33	11101.81	1841	0.82302	5.65
34	11068.25	1968	0.81759	5.48
35	11037.38	1989	0.81216	5.32
36	10748.57	2021	0.80673	5.17
37	10631.94	1980	0.80130	5.03
38	10413.76	1839	0.79587	4.90
39	10106.38	1955	0.79045	4.77
40	9673.54	1962	0.78502	4.65
41	8529.48	2012	0.77959	4.54
42	7557.41	1937	0.77416	4.43
43	7536.67	1973	0.76873	4.32
44	7303.80	1895	0.76330	4.22
45	6379.12	1929	0.75787	4.13
46	6379.12	1917	0.75244	4.04
47	5836.41	2020	0.74701	3.95
48	5705.80	1933	0.74159	3.87
49	5657.64	1927	0.73616	3.79
50	5513.09	1951	0.73073	3.71

51	5238.45	1964	0.72530	3.64
52	5224.00	1938	0.71987	3.57
53	5224.00	1894	0.71444	3.50
54	5122.81	1971	0.70901	3.44
55	4923.03	2008	0.70358	3.37
56	4877.08	1953	0.69815	3.31
57	4775.90	1944	0.69273	3.25
58	4775.90	1939	0.68730	3.20
59	4775.90	1875	0.68187	3.14
60	4746.98	1965	0.67644	3.09
61	4732.53	1947	0.67101	3.04
62	4342.25	1903	0.66558	2.99
63	4290.83	2017	0.66015	2.94
64	3618.29	2015	0.65472	2.90
65	3597.75	1977	0.64929	2.85
66	3402.68	1952	0.64387	2.81
67	3128.04	1925	0.63844	2.77

Censored Data

Obs, Threshold, Number of floods above, Number of floods below, Correlated error group, Error coefficient of variation, AEP plot position, AEP 1 in Y yrs

----

1	3000.00	0	117	2	0.000	0.63301	2.72

Summary of Prior Parameter Information

Parameter, Mean, Std dev, Correlation

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2	1.0000	0.10000E+09	0.000	1.000	
3	1.0000	0.10000E+09	0.000	0.000	1.000

Flood model: GEV

Zero flow threshold: -0.1000+101

Number of gauged flows at or below flow threshold = 0

Summary of Posterior Moments from Importance Sampling

No, Parameter, Mean, Std dev, Correlation

No	Parameter	Mean	Std dev	Correlation		
1	Location u	-8893.03236	3138.27676	1.000		
2	loge (Scale a)	9.82528	0.23030	-0.878	1.000	
3	Shape k	0.61349	0.10789	-0.655	0.924	1.000

Note: Posterior expected parameters are the most accurate in the mean-squared-error sense. They should be used in preference to the most probable parameters

Upper bound = 21255.2

AEP 1 in Y, Exp parameter quantile, Monte Carlo 90% quantile probability limits, Mean(log10(q)), Stdev(log10(q))

3.000	3927.25	1948.68	6125.5	3.5971	0.1663
5.000	9242.84	7672.27	11295.7	3.9759	0.0508
10.000	13674.83	12332.07	15580.1	4.1443	0.0303
20.000	16380.98	15348.68	18049.0	4.2221	0.0218
50.000	18503.12	17755.13	20137.2	4.2751	0.0173
100.000	19461.97	18838.63	21266.1	4.2974	0.0171
200.000	20084.91	19540.94	22189.6	4.3115	0.0185
500.000	20588.74	20045.40	23130.8	4.3229	0.0208

Flood magnitude, Expected probability, AEP 1 in Y, AEP 90% limits

----

3927.25	0.65862	2.93	2.54	3.5
9242.84	0.79240	4.82	3.98	6.1
13674.83	0.89259	9.31	7.02	13.
16380.98	0.94333	17.65	12.09	28.
18503.12	0.97481	39.70	23.48	77.

19461.97	0.98586	70.71	36.39	0.18E+03
20084.91	0.99167	120.06	48.78	0.55E+03
20588.74	0.99531	213.09	64.88	0.10E+11
20819.71	0.99646	282.14	74.33	0.10E+11
20970.59	0.99704	338.11	81.69	0.10E+11
21092.97	0.99744	390.91	88.72	0.10E+11
21149.15	0.99761	417.80	92.07	0.10E+11
21185.87	0.99771	436.29	94.46	0.10E+11
21215.67	0.99779	451.82	96.39	0.10E+11
21229.35	0.99782	459.13	97.30	0.10E+11

Annex D Design Flood Maps

Overview

Annex D presents the design flood mapping. The maps contain the following model outputs:

- Peak flood levels (mAHD)
- Peak flood depth (m)
- Peak flood velocity (m/s)
- Peak flood (classified) hazard

The classified flood hazard output has been classified in accordance with general guidance from the Australian Institute for Disaster Resilience (AIDR, 2017). Six hazard vulnerability categories are defined based on different combinations of flood depth and velocity. The categories increase in severity from category H1 to H6. The combinations of depth and velocity that define the categories are shown below.

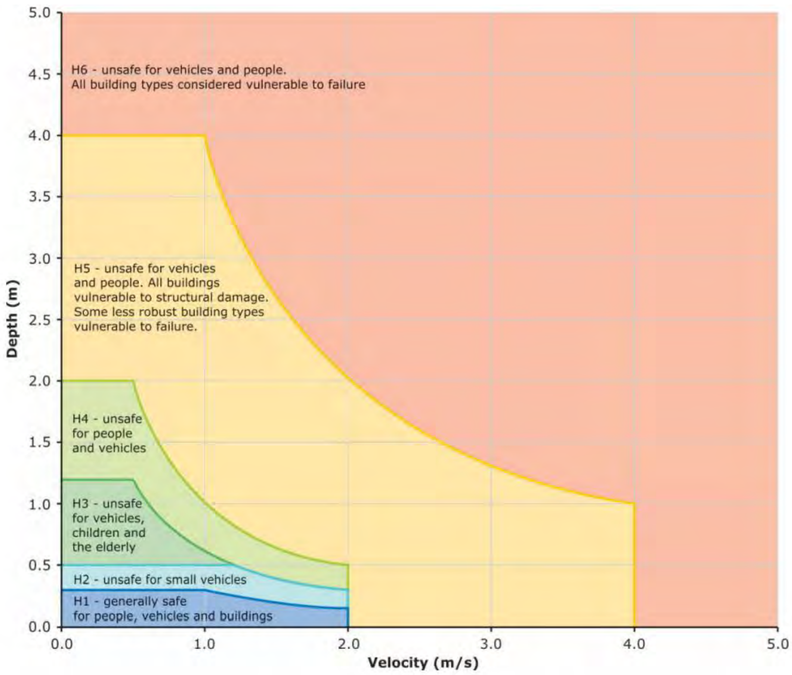
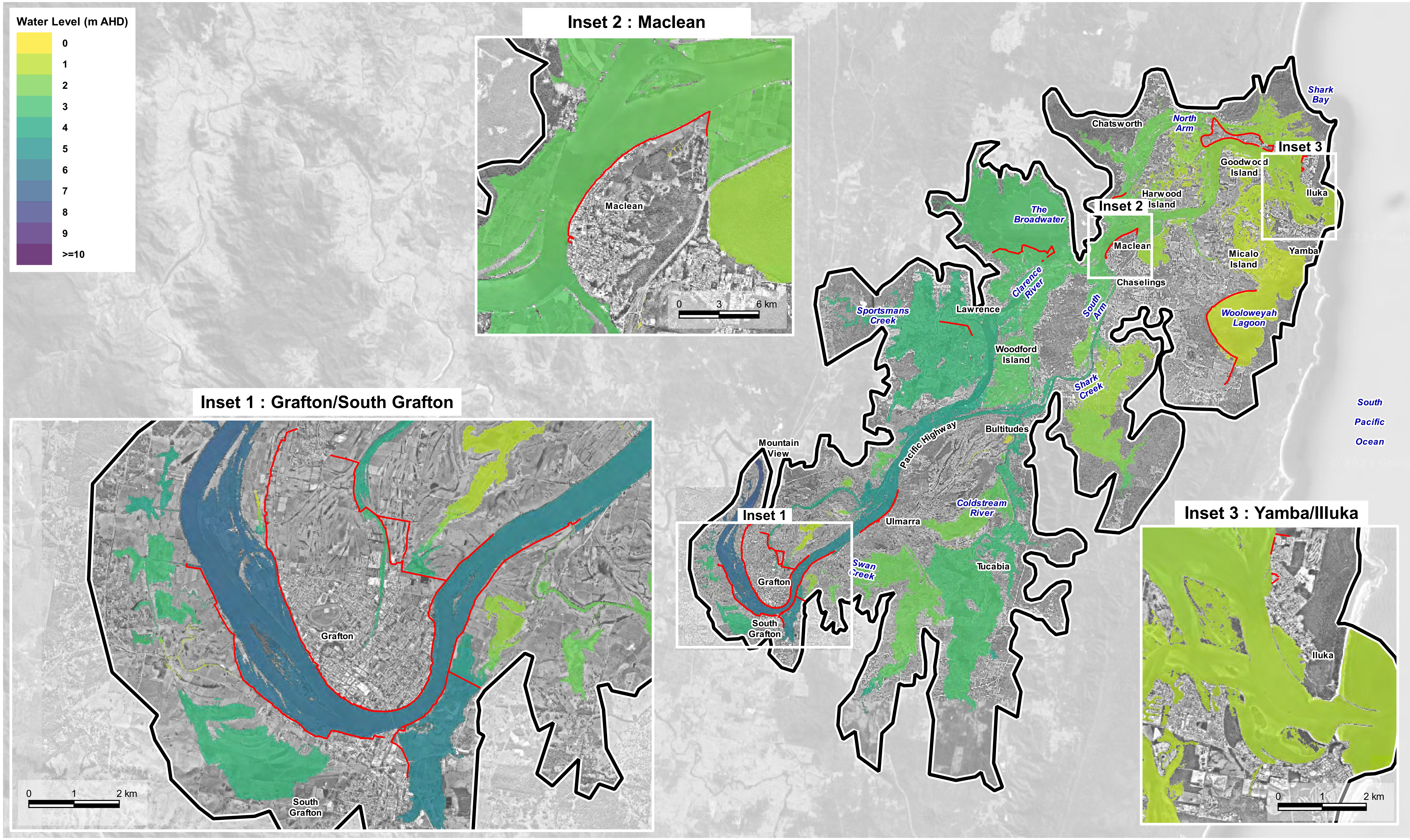


Figure D.1 General Flood Hazard Vulnerability Curves (AIDR, 2017)



LEGEND

- Levees
- Flood Model Extent

Title:

20% AEP Peak Flood Level

Drawing: **D2**

Rev: **A**

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N

0 5 10 km

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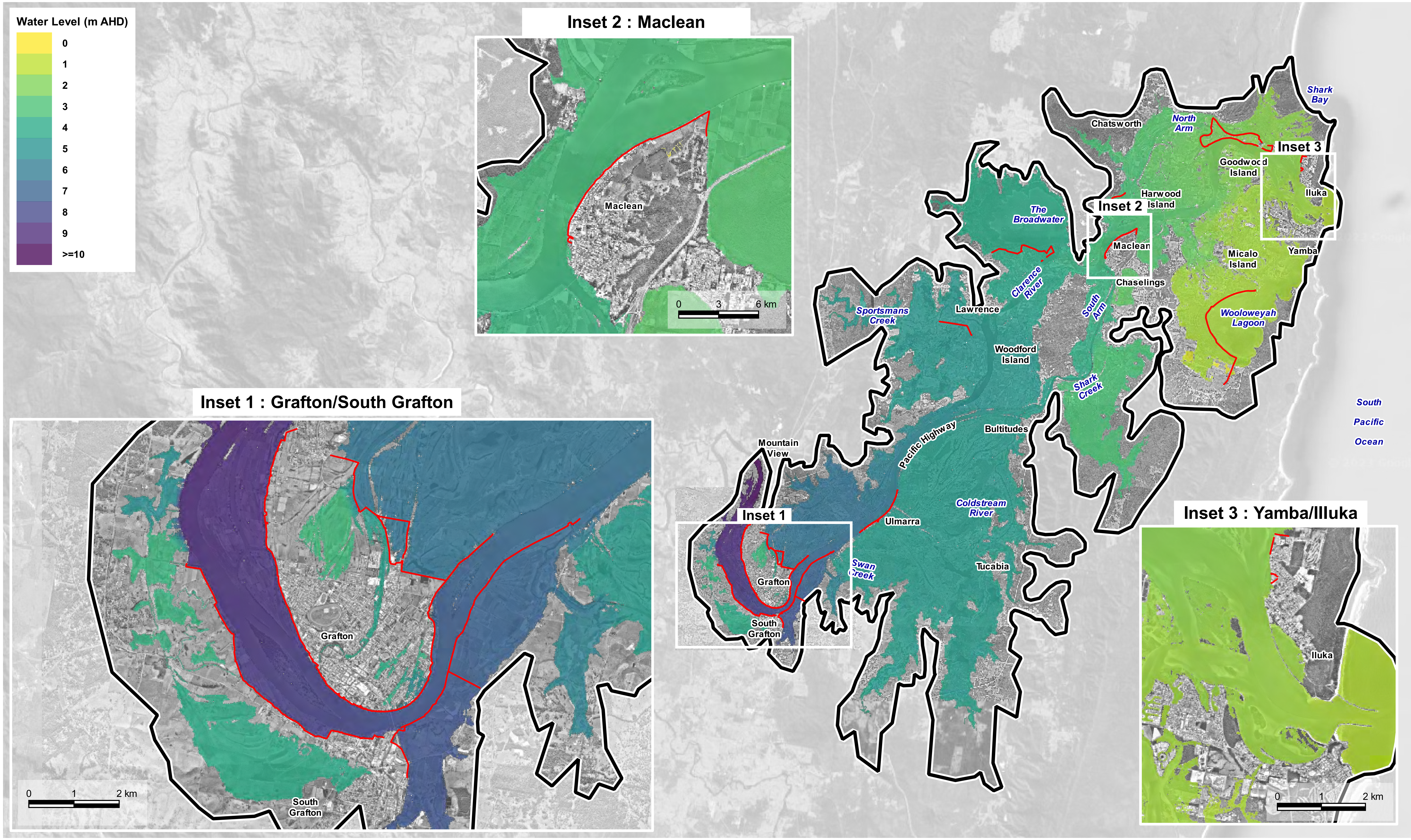

LEGEND

Levees

Flood Model Extent

Title:

5% AEP Peak Flood Level

Drawing: D3

Rev: A

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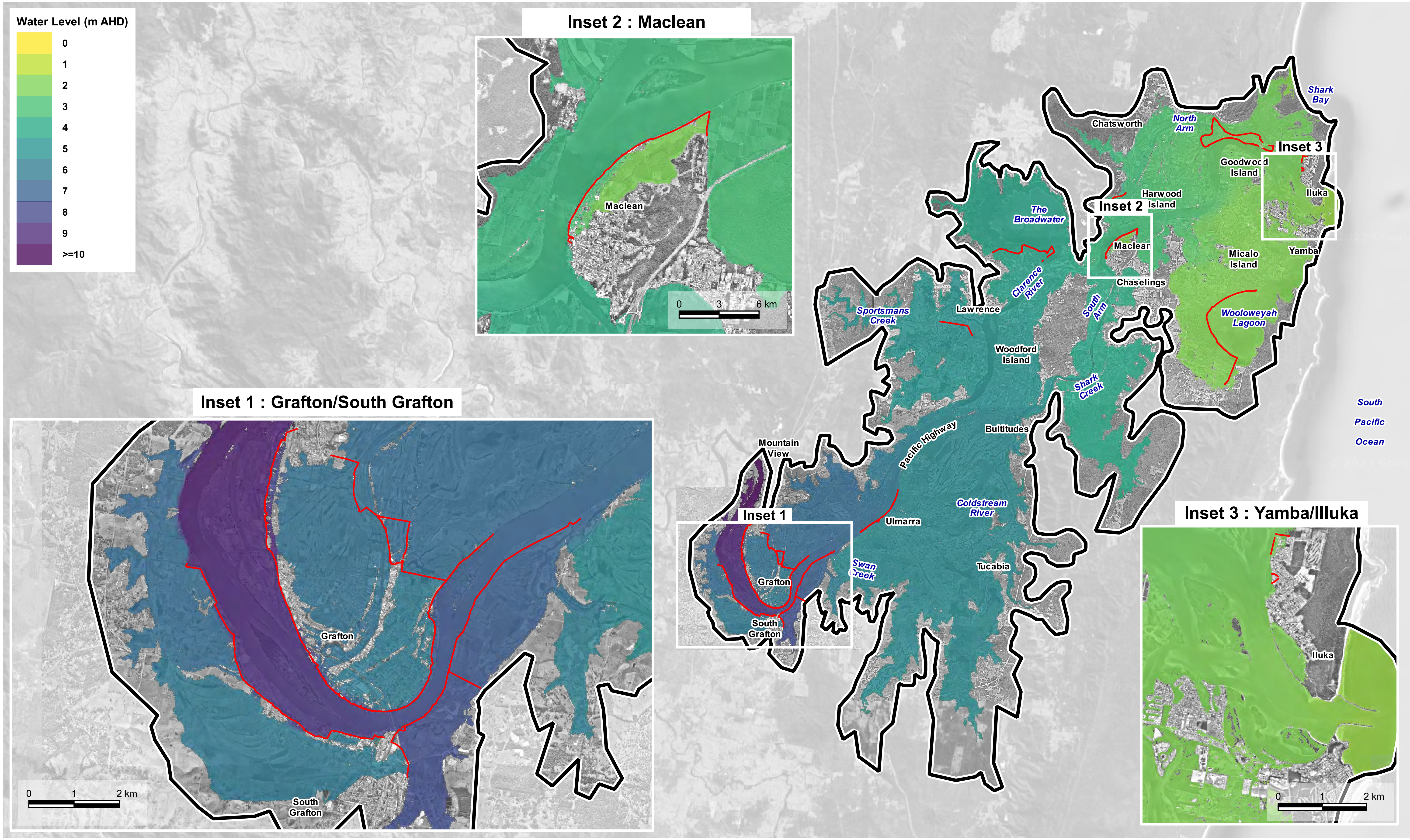

LEGEND

Levees

Flood Model Extent

Title:

2% AEP Peak Flood Level

Drawing: D4

Rev: A

N

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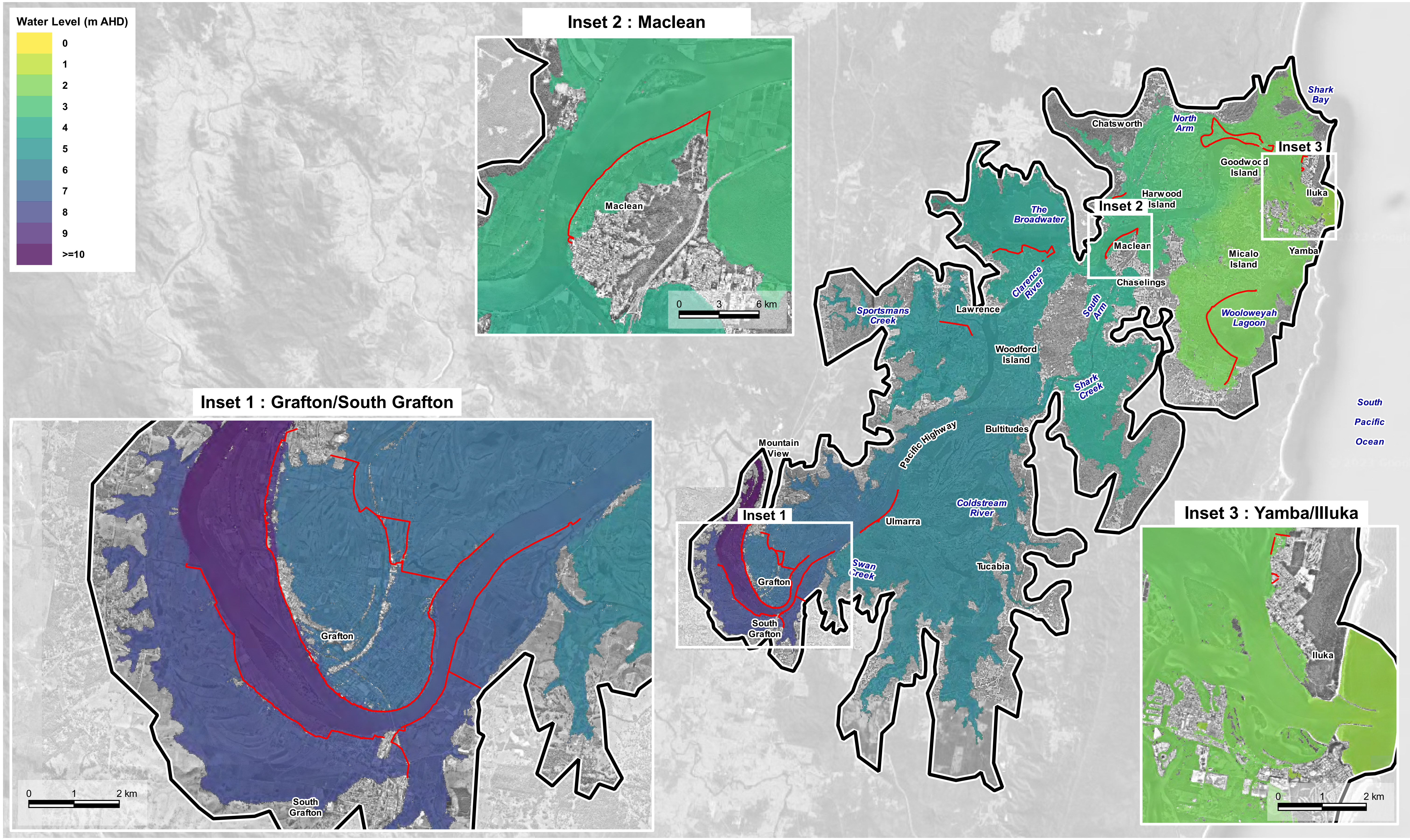

LEGEND

Levees

Flood Model Extent

Title:

1% AEP Peak Flood Level

Drawing: D5

Rev: A

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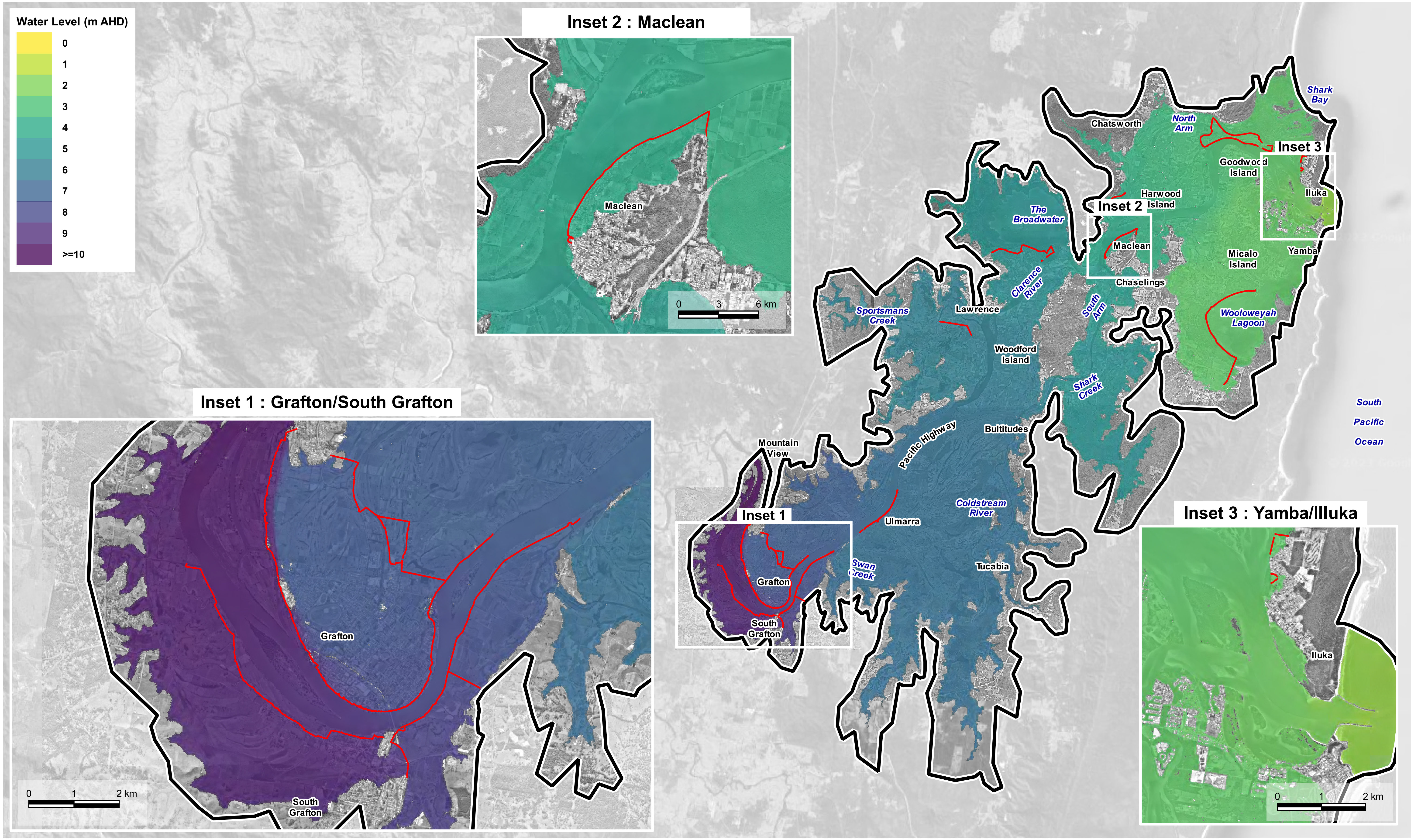

LEGEND

Levees

Flood Model Extent

Title:

0.5% AEP Peak Flood Level

Drawing: D6

Rev: A

N

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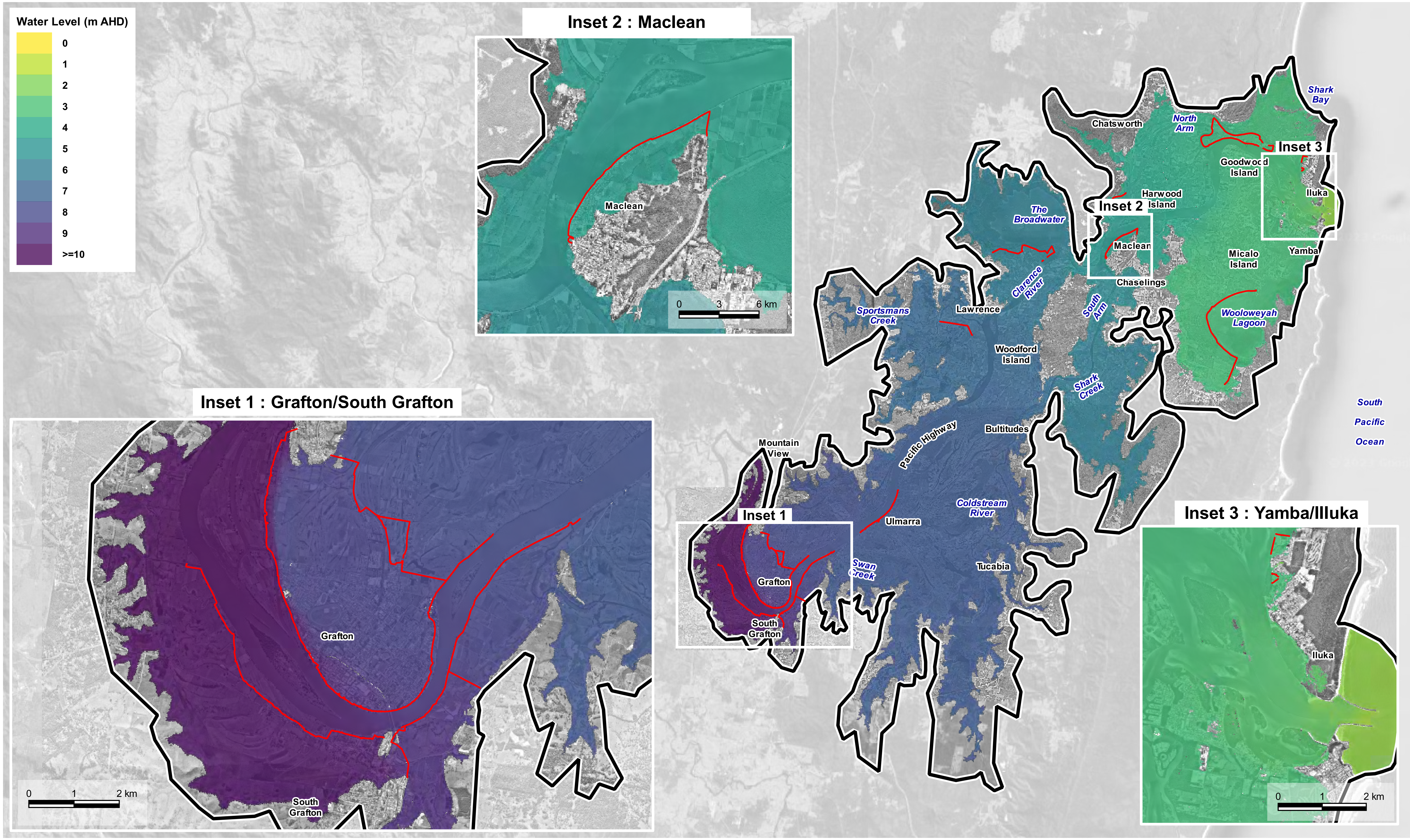

LEGEND

Levees

Flood Model Extent

Title:

0.2% AEP Peak Flood Level

Drawing: D7

Rev: A

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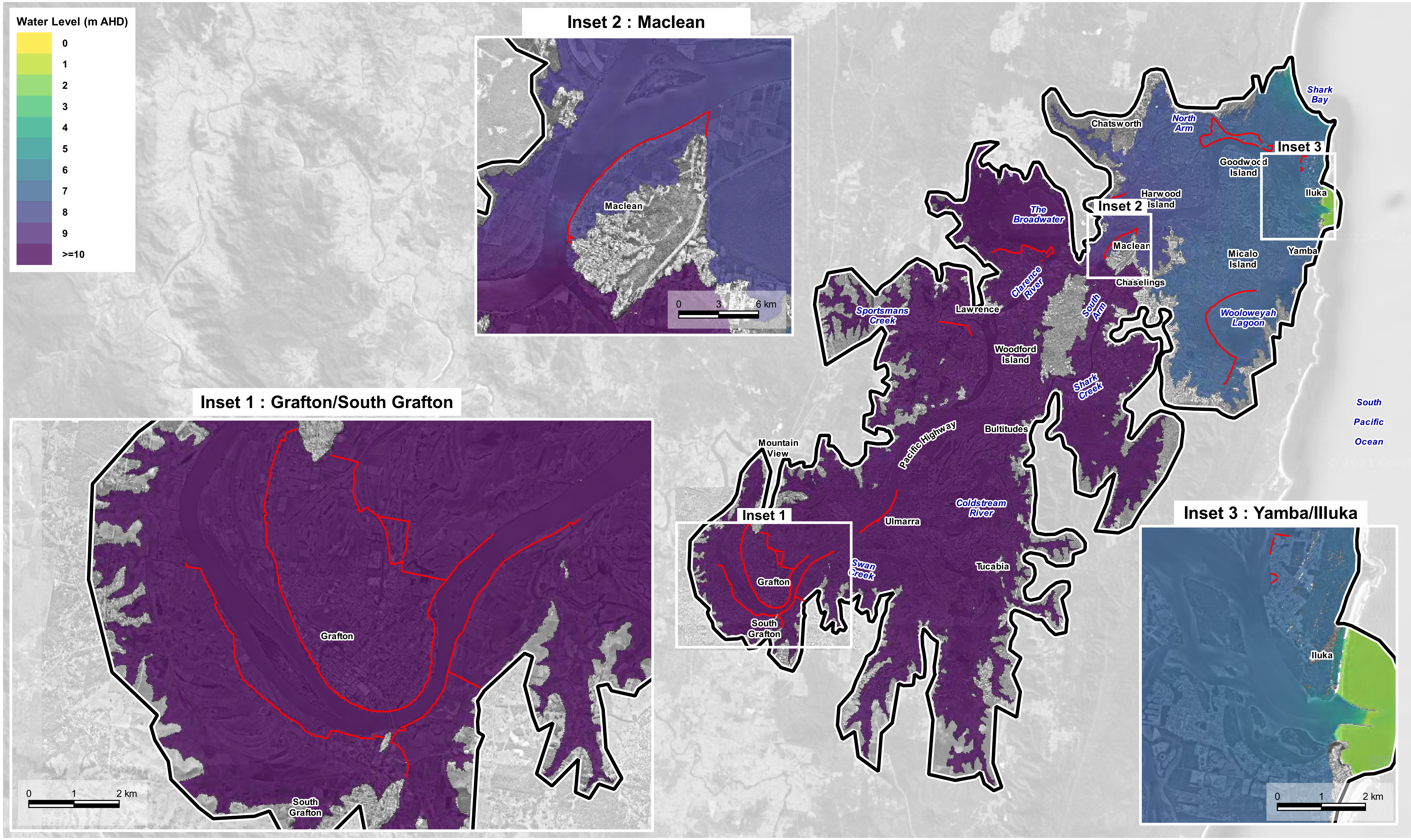

LEGEND

Levees

Flood Model Extent

Title:

Extreme Flood Peak Flood Level

Drawing: D8

Rev: A

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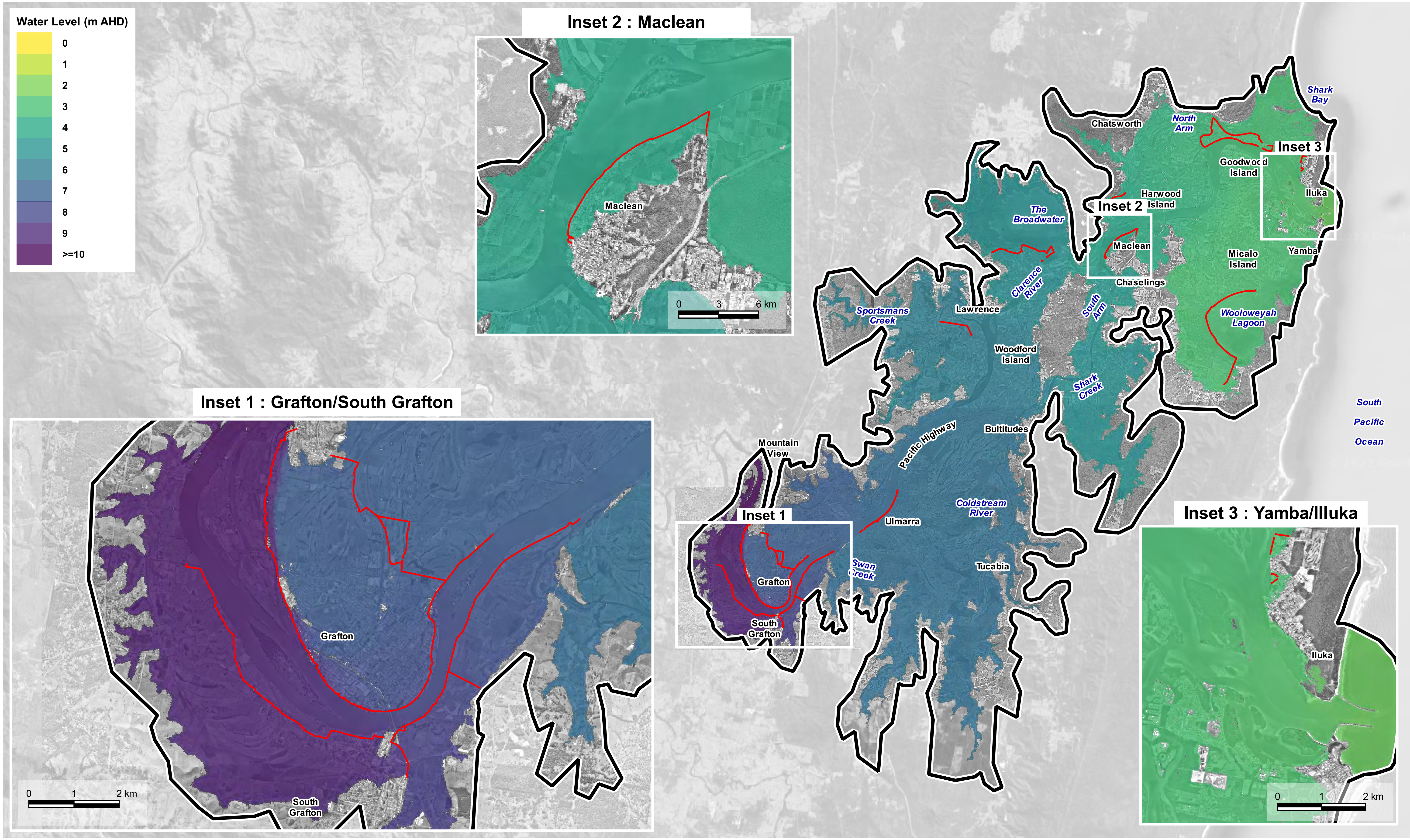

LEGEND

Levees

Flood Model Extent

Title:

1% AEP Climate Change (CC1) Peak Flood Level

Drawing: D9

Rev: A

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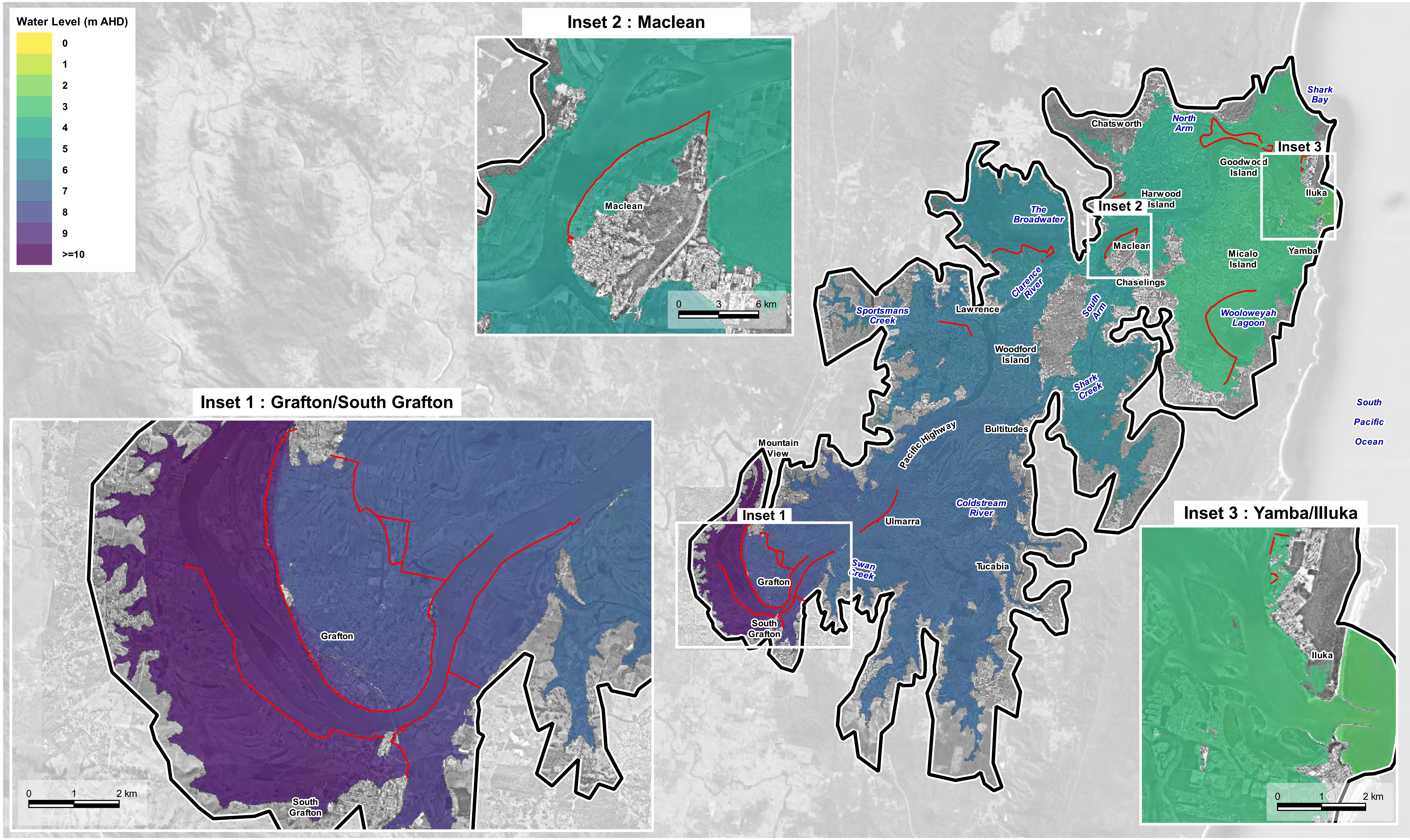

LEGEND

Levees

Flood Model Extent

Title:

1% AEP Climate Change (CC2) Peak Flood Level

Drawing: D10

Rev: A

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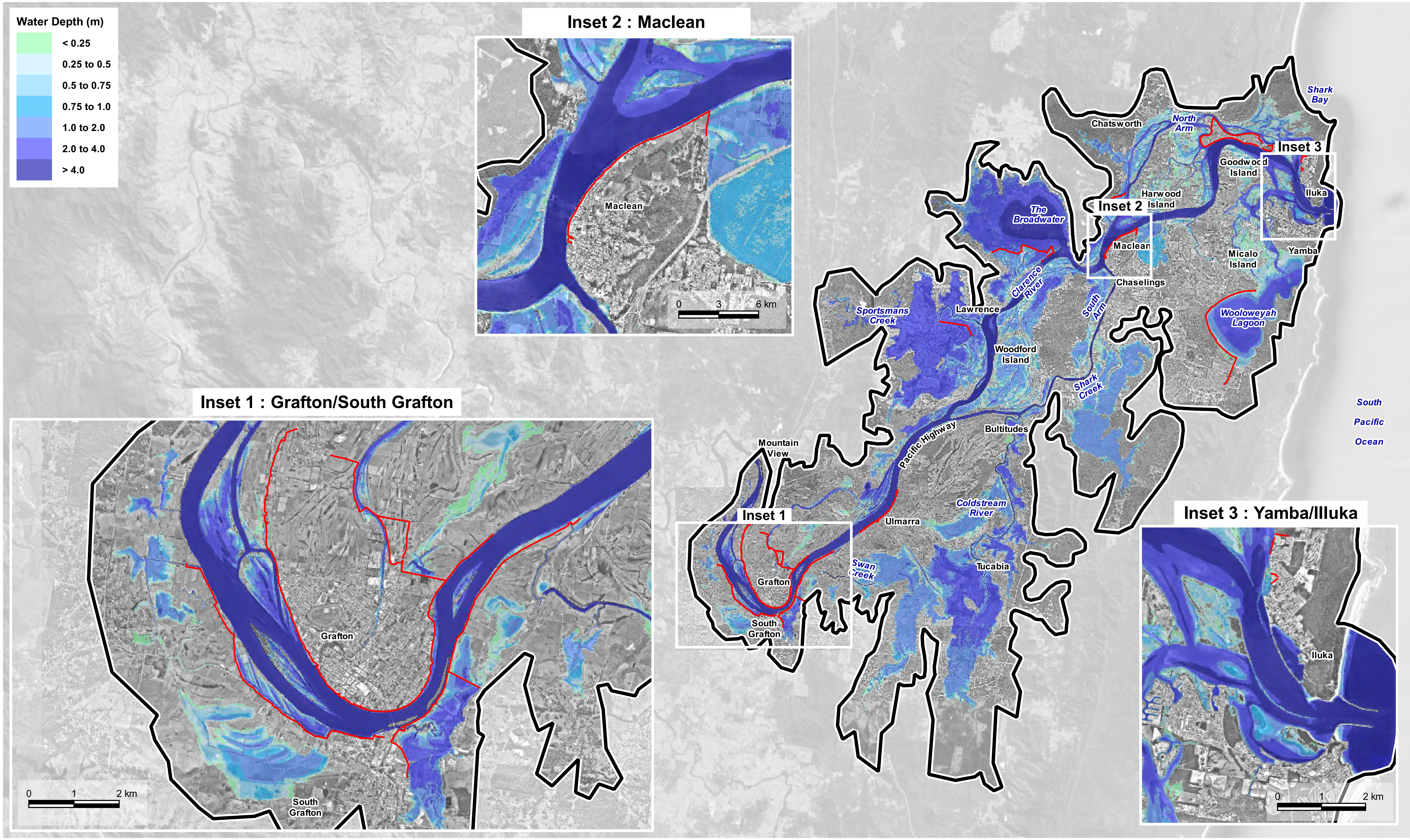

LEGEND

Levees

Flood Model Extent

Title:

20% AEP Peak Flood Depth

Drawing: D11

Rev: A

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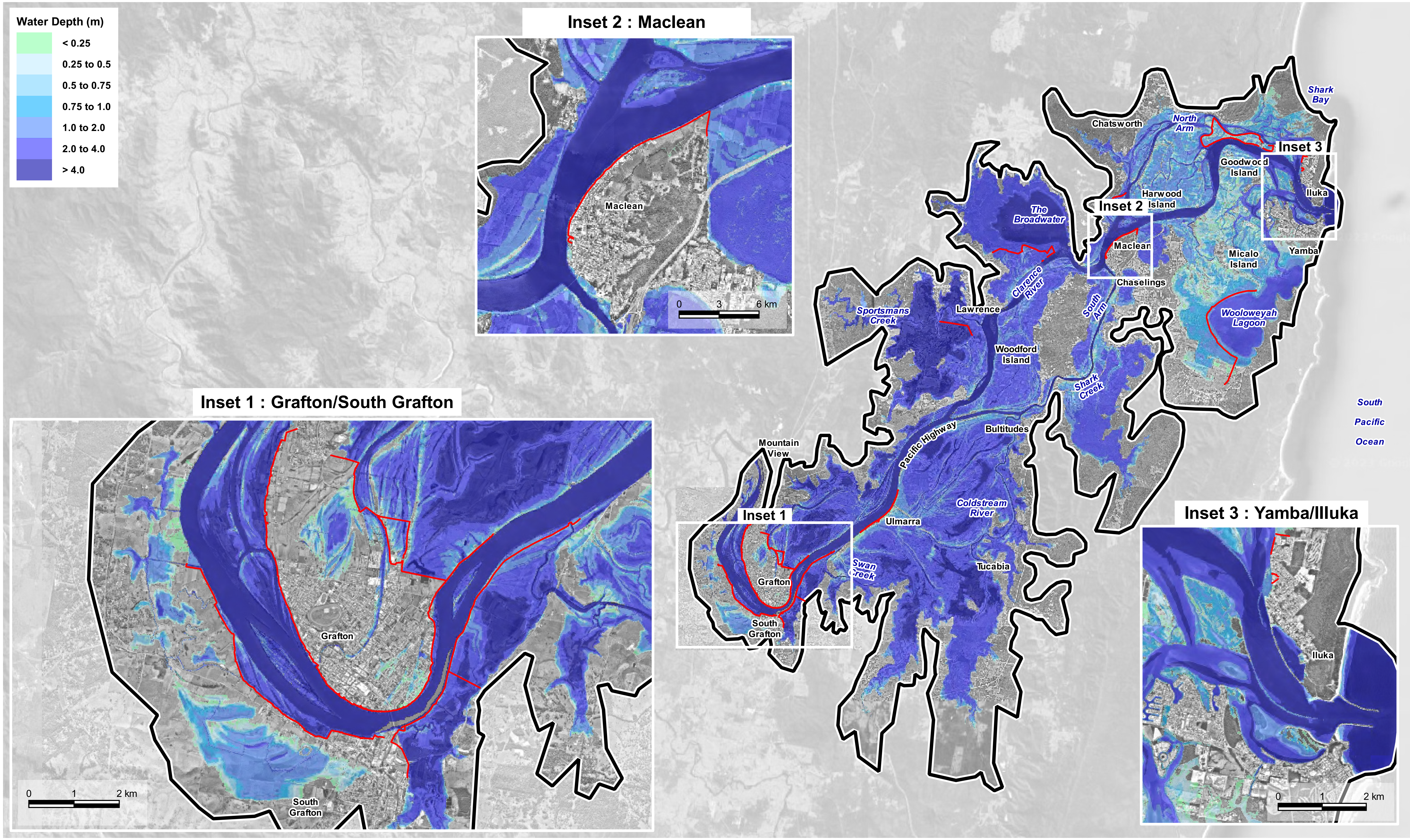

LEGEND

Levees

Flood Model Extent

Title:

5% AEP Peak Flood Depth

Drawing: D12

Rev: A

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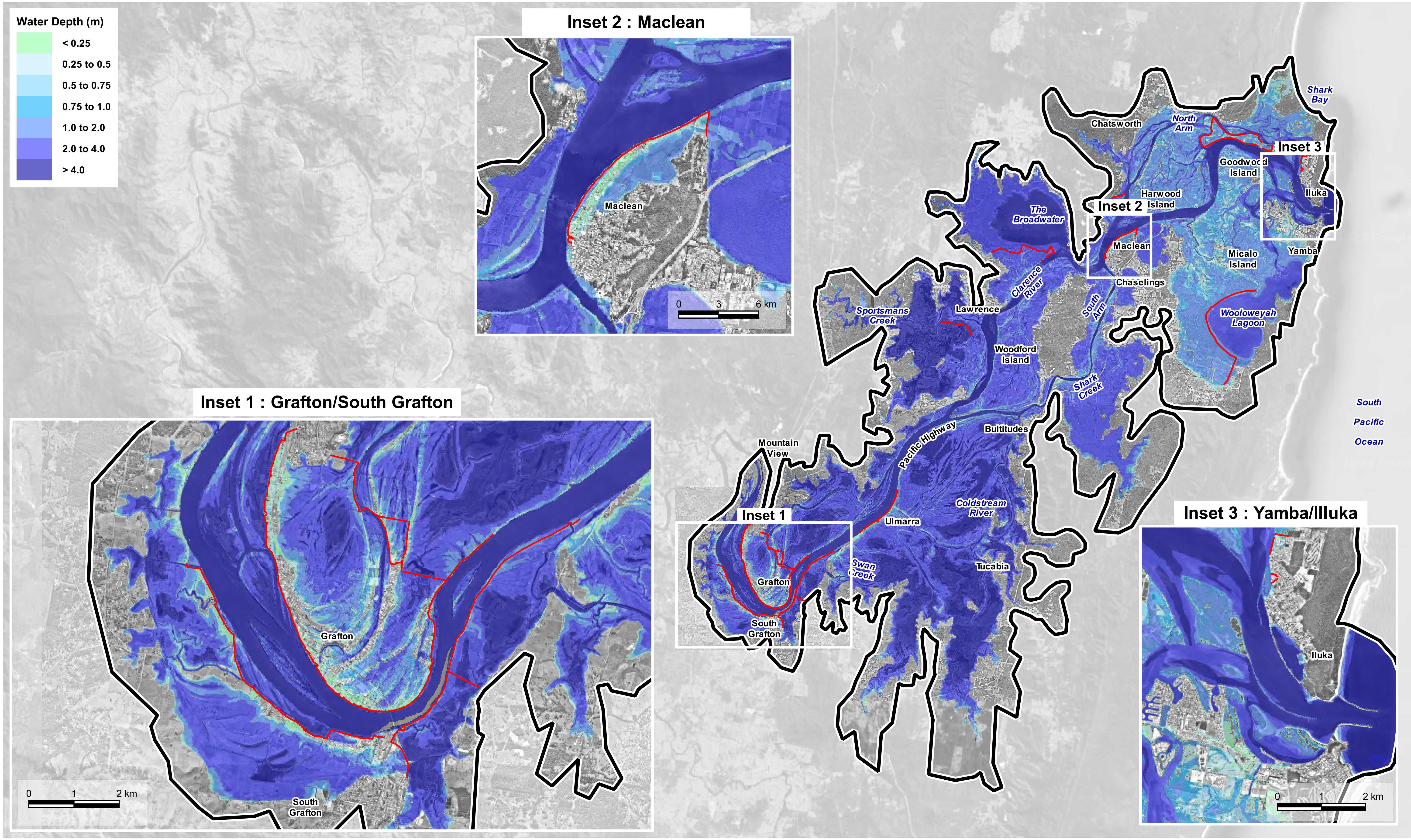

LEGEND

Levees

Flood Model Extent

Title:

2% AEP Peak Flood Depth

Drawing: D13

Rev: A

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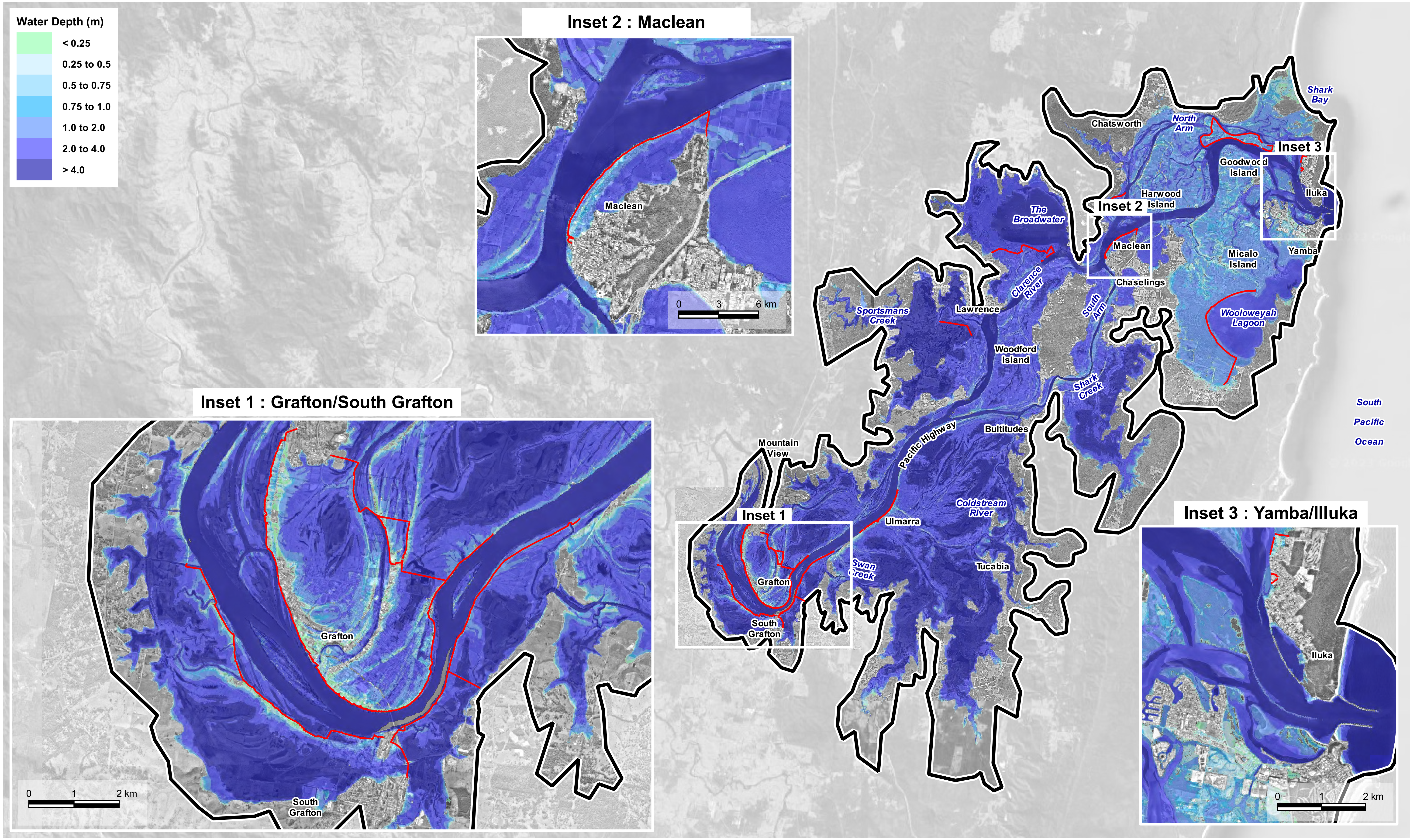

LEGEND

- Levees
- Flood Model Extent

Title:

1% AEP Peak Flood Depth

Drawing: D14

Rev: A

N

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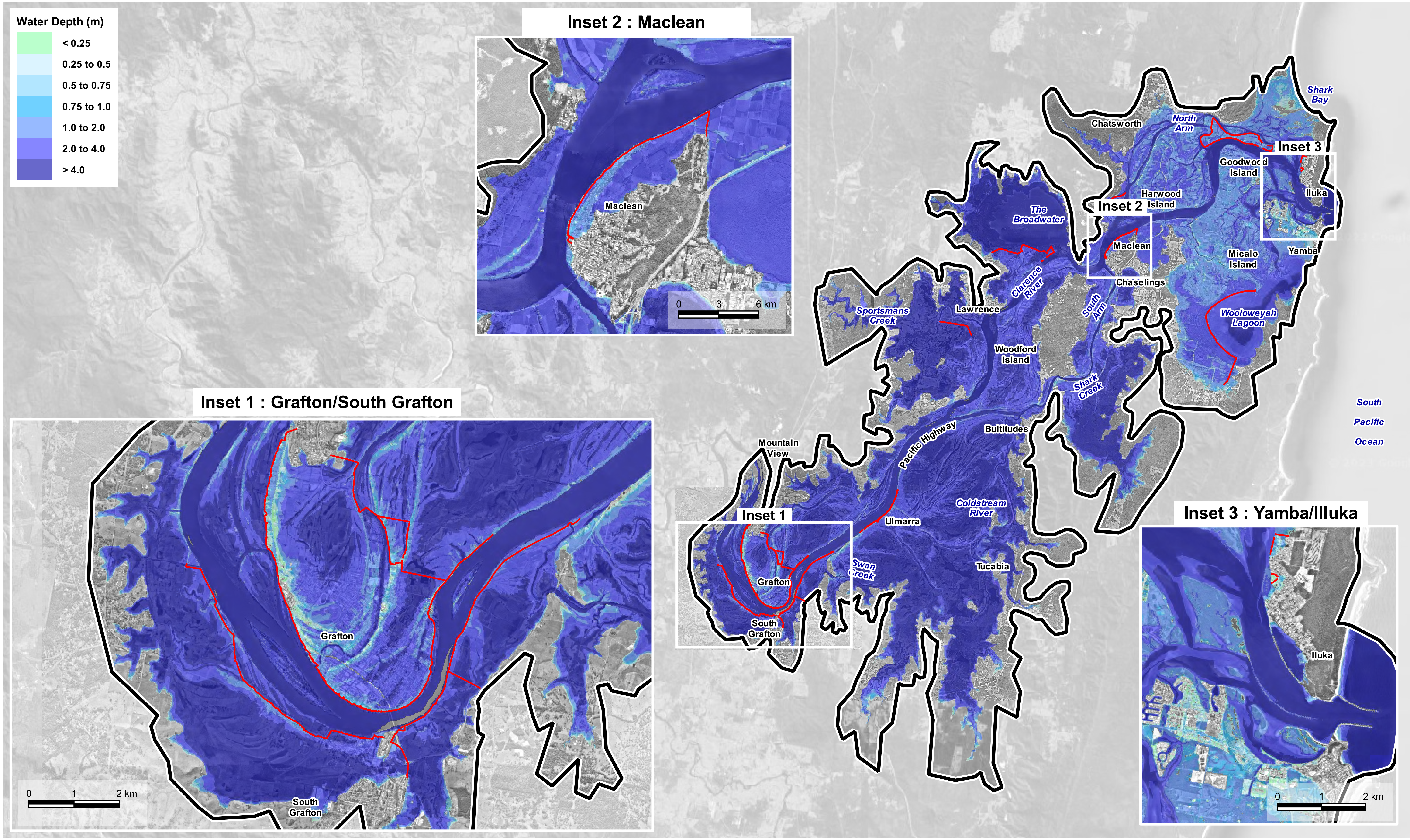

LEGEND

Levees

Flood Model Extent

Title:

0.5% AEP Peak Flood Depth

Drawing: D15

Rev: A

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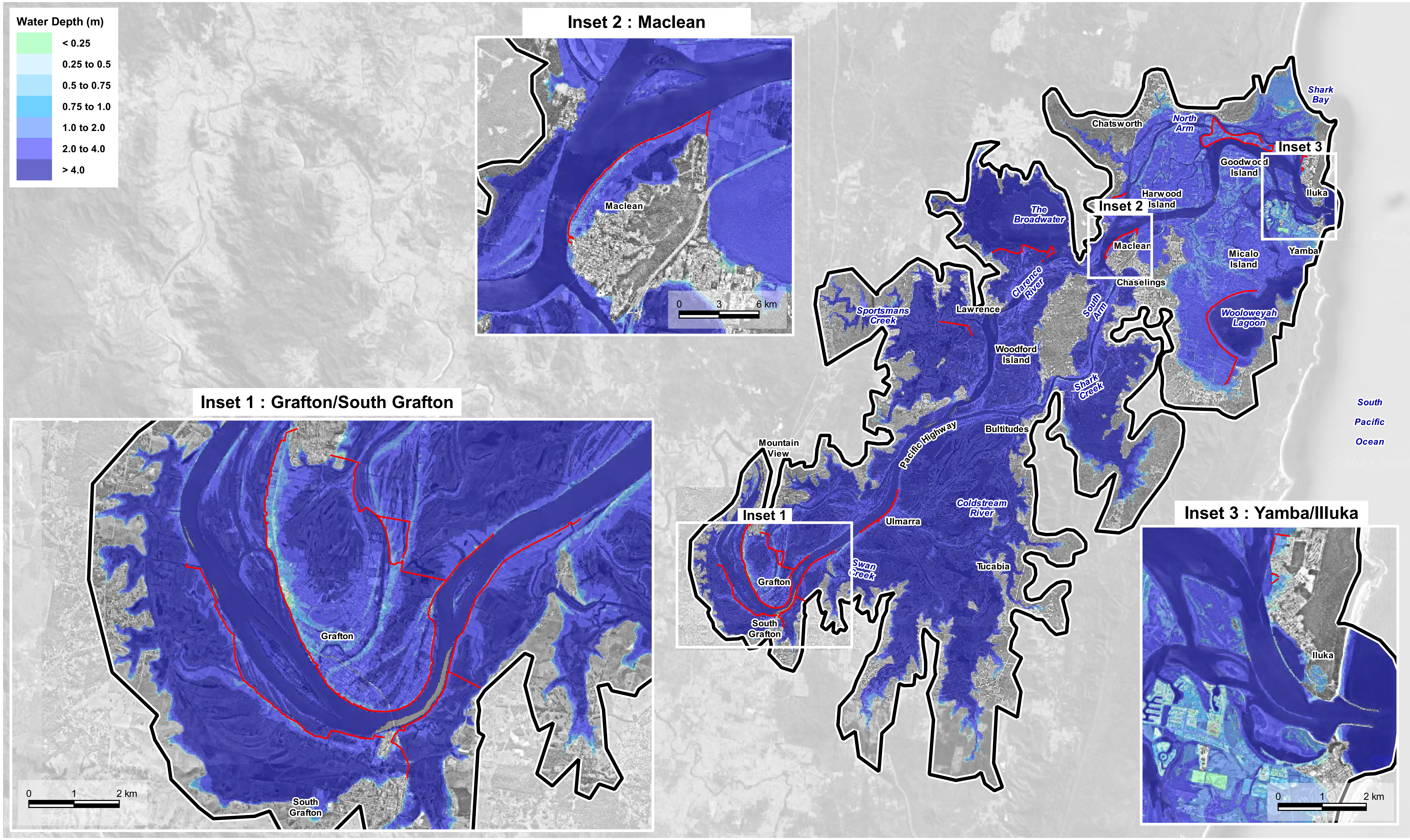

LEGEND

Levees

Flood Model Extent

Title:

0.2% AEP Peak Flood Depth

Drawing: **D16**

Rev: **A**

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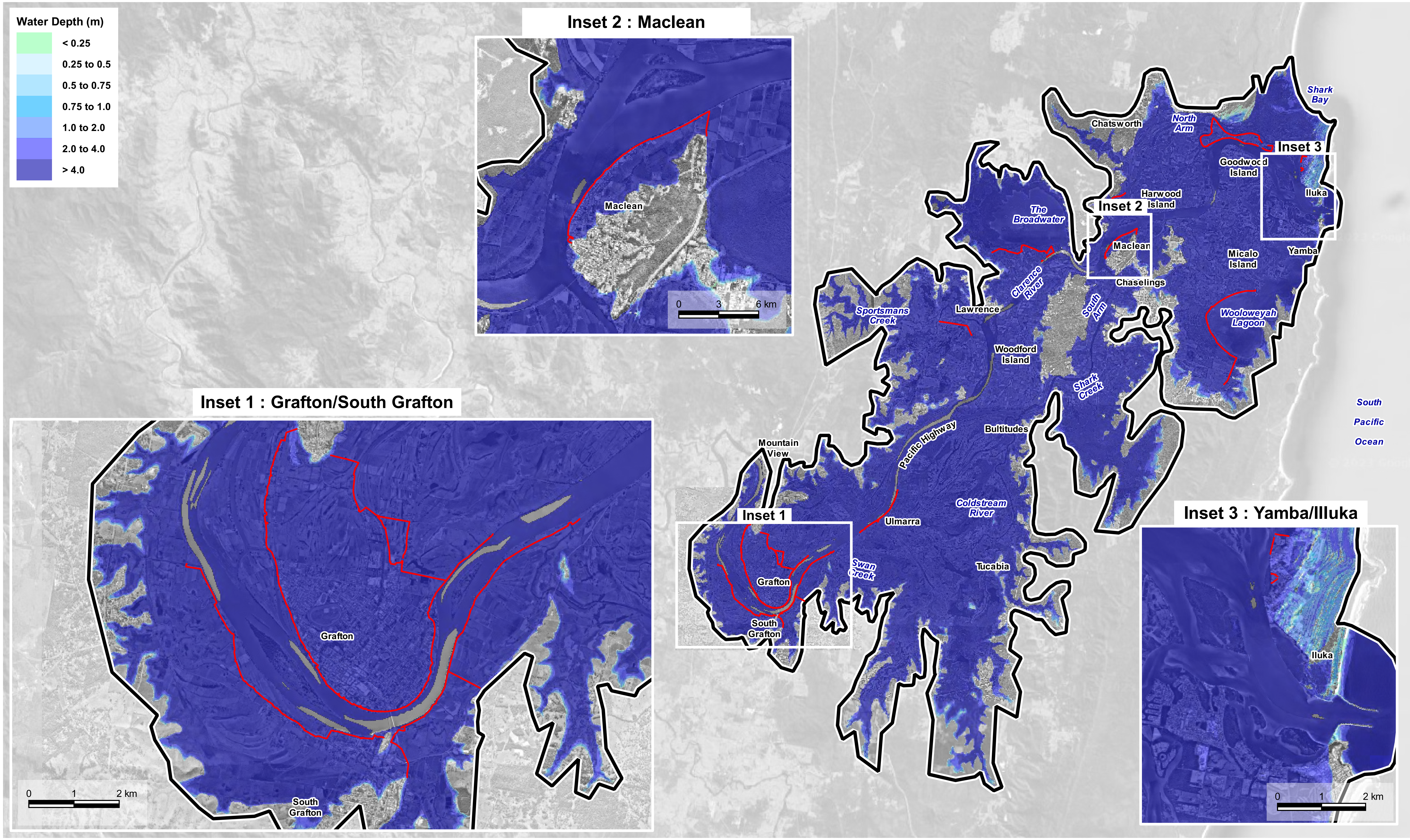

LEGEND

Levees

Flood Model Extent

Title:

Extreme Flood Peak Flood Depth

Drawing: D17

Rev: A

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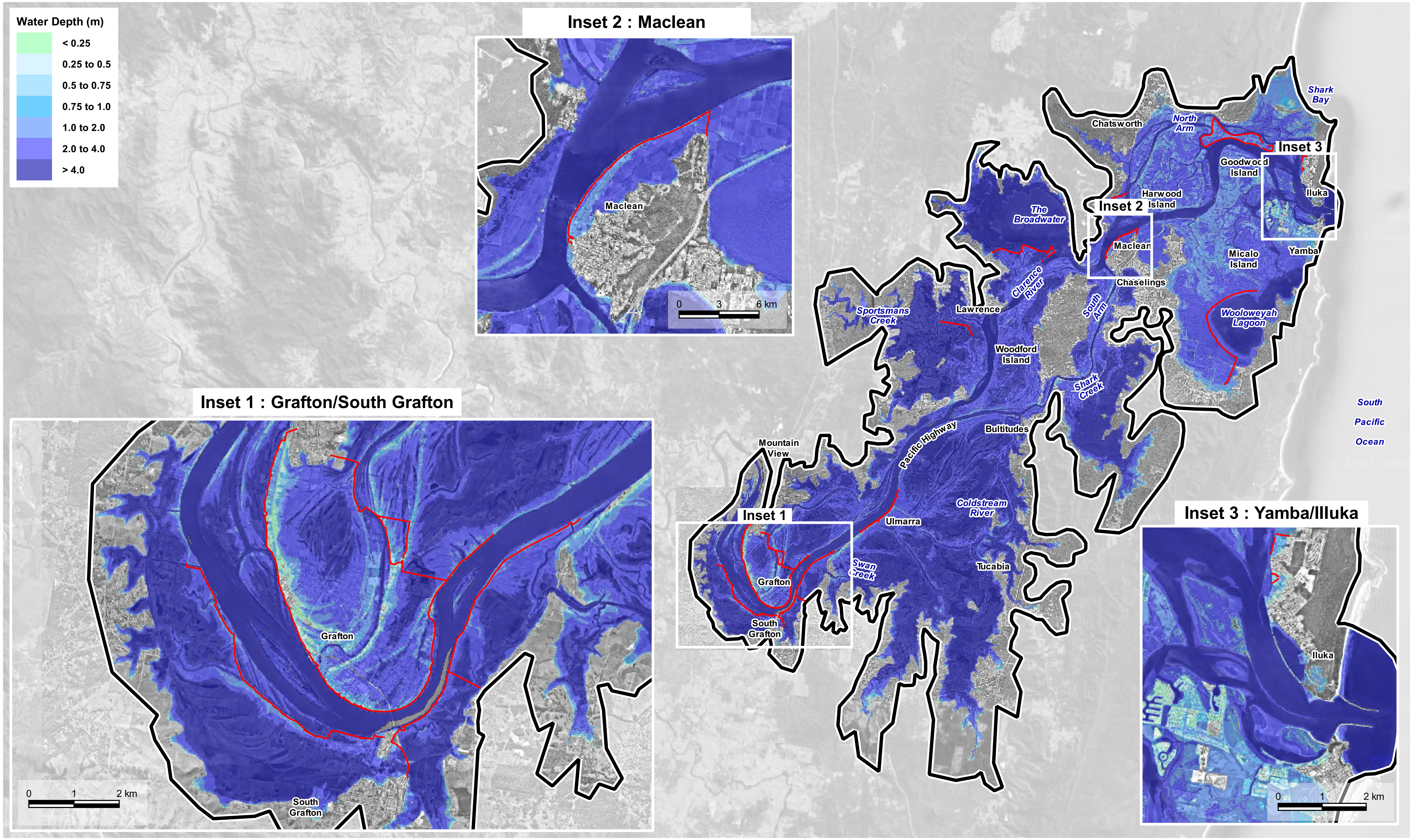

LEGEND

- Levees
- Flood Model Extent

Title:

1% AEP Climate Change (CC1) Peak Flood Depth

Drawing: **D18**

Rev: **A**

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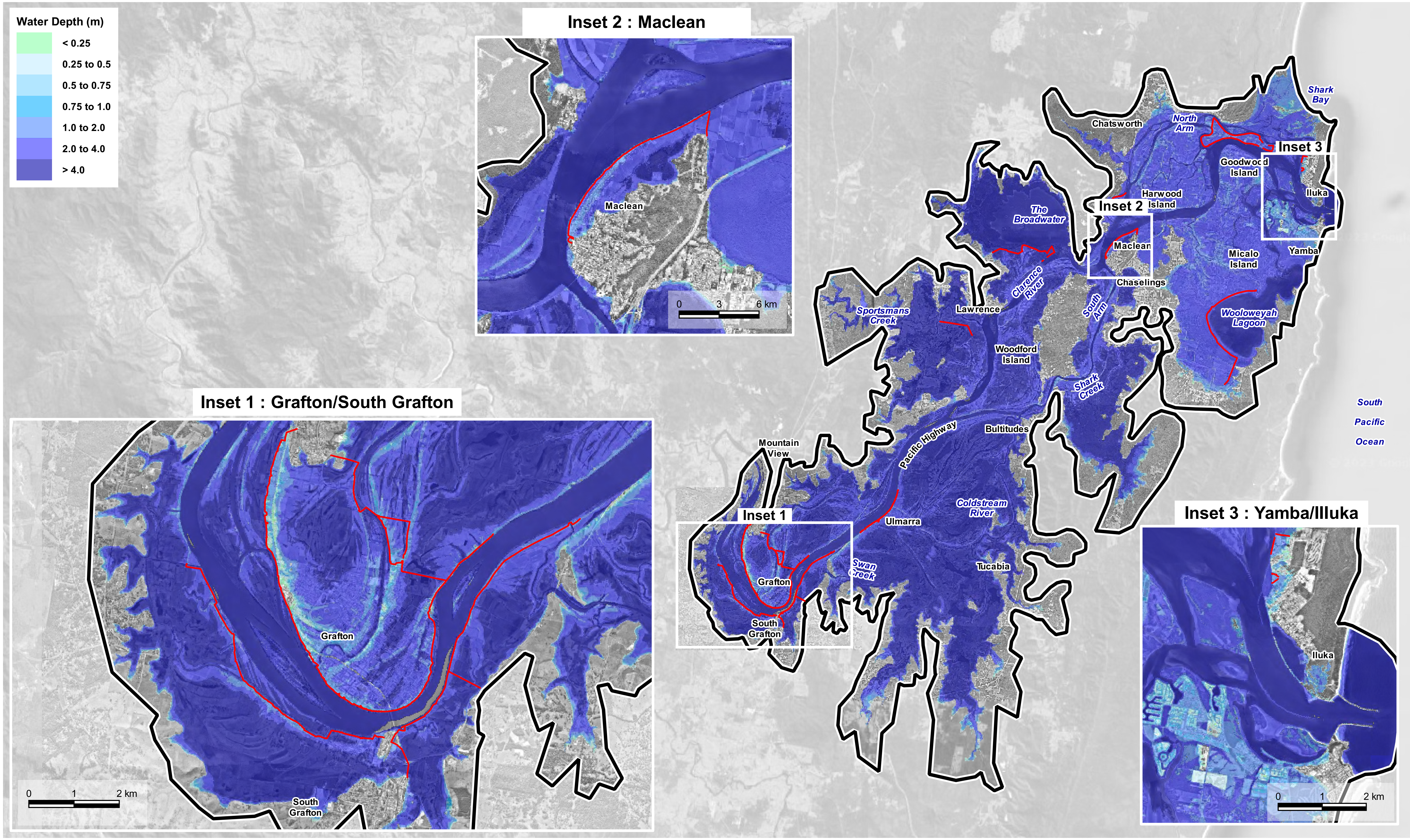

LEGEND

Levees

Flood Model Extent

Title:

1% AEP Climate Change (CC2) Peak Flood Depth

Drawing: **D19**

Rev: **A**

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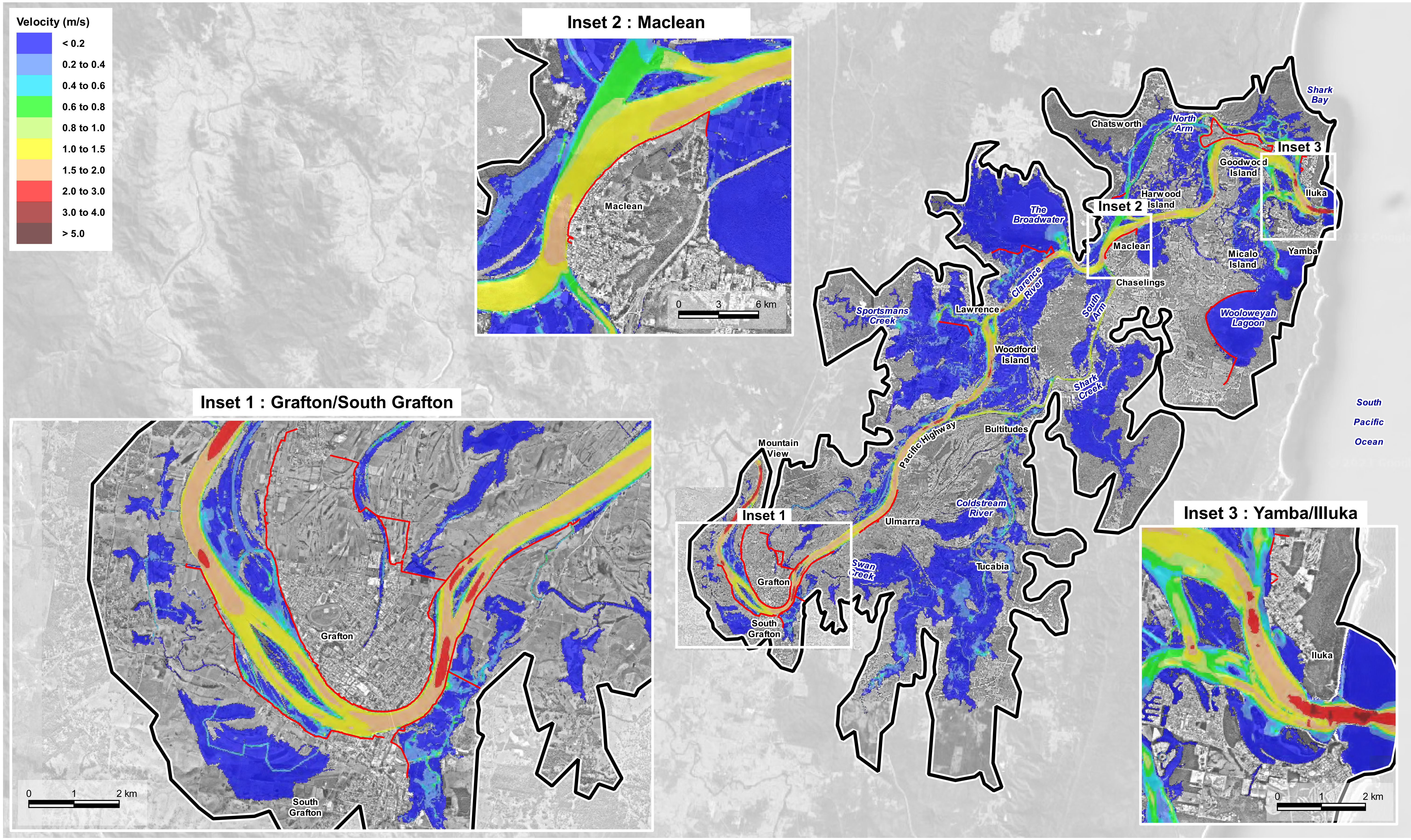

LEGEND

Levees

Flood Model Extent

Title:

20% AEP Peak Flood Velocity

Drawing: D20

Rev: A

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N

0 5 10 km

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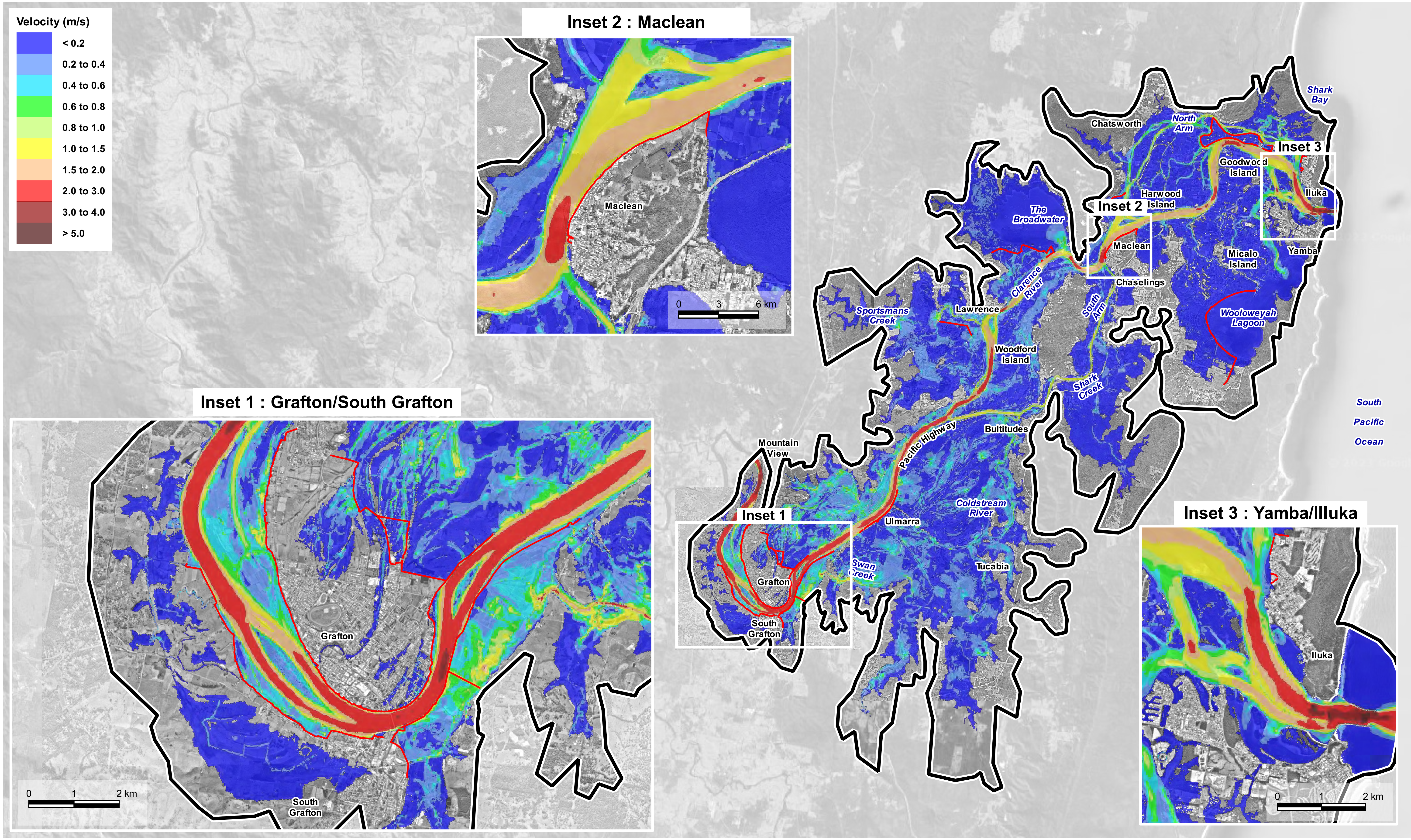

LEGEND

Levees

Flood Model Extent

Title:

5% AEP Peak Flood Velocity

Drawing: D21

Rev: A

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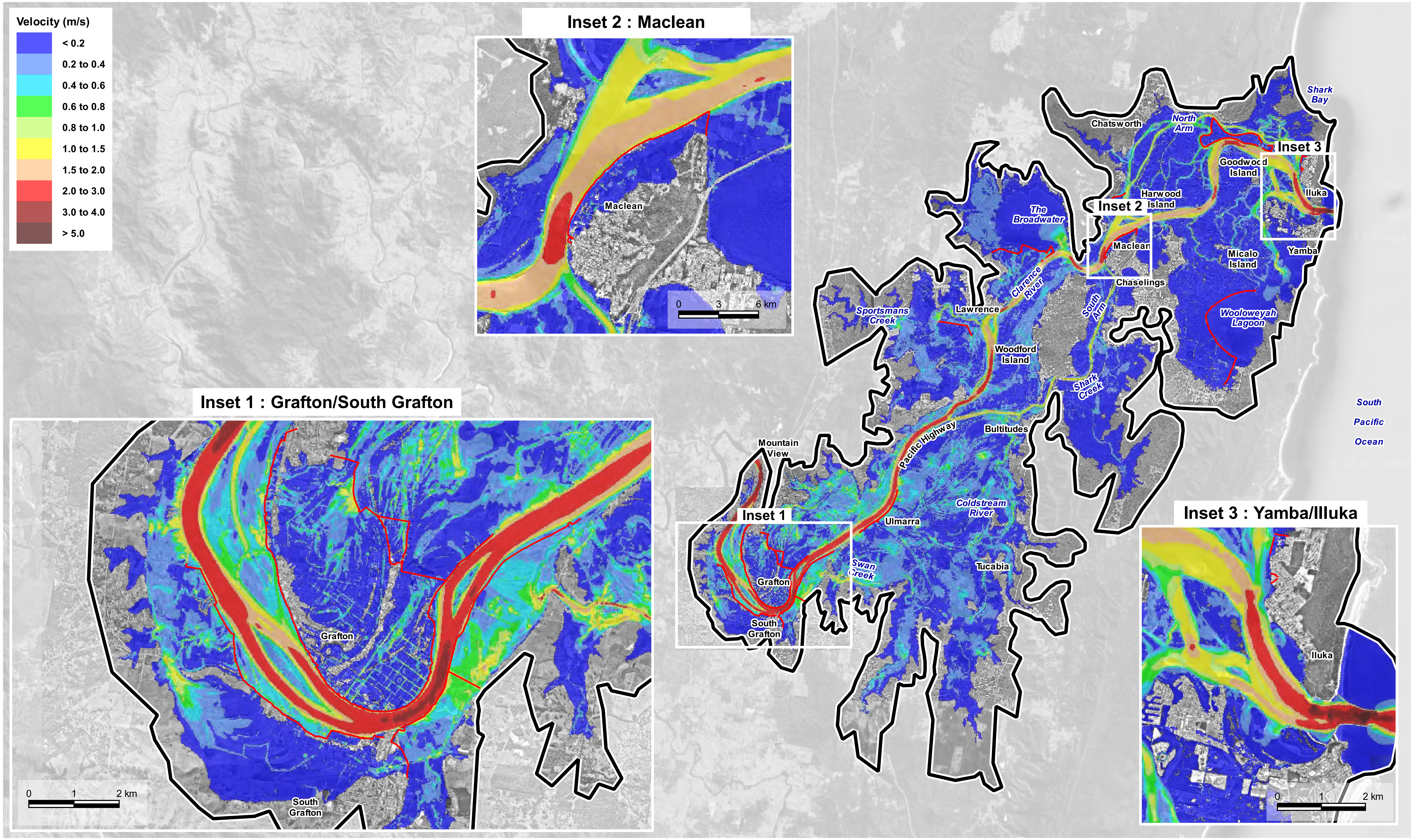

LEGEND

Levees

Flood Model Extent

Title:

2% AEP Peak Flood Velocity

Drawing: D22

Rev: A

N

0 5 10 km

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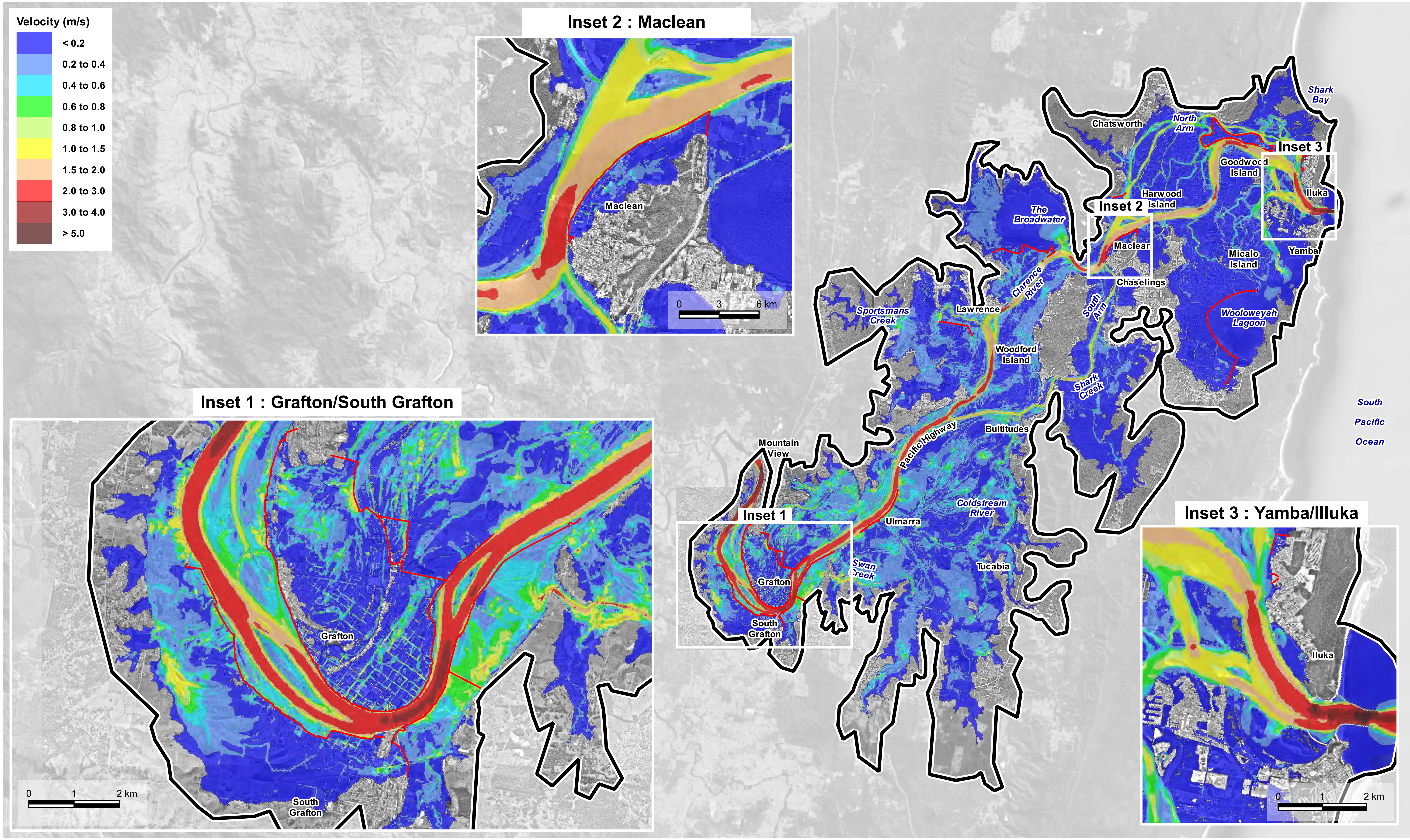

LEGEND

Levees

Flood Model Extent

Title:

1% AEP Peak Flood Velocity

Drawing: D23

Rev: A

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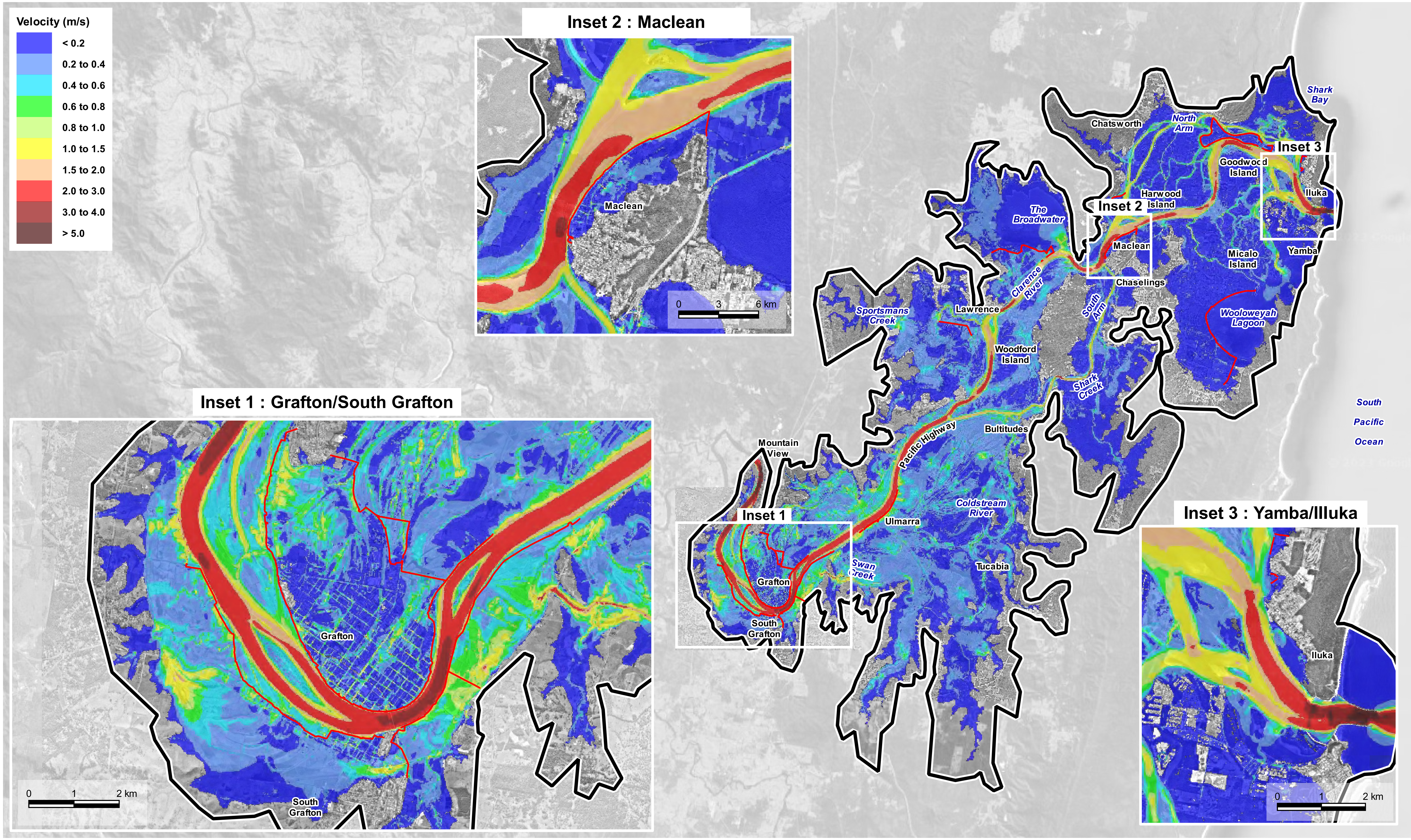

LEGEND

Levees

Flood Model Extent

Title:

0.5% AEP Peak Flood Velocity

Drawing: D24

Rev: A

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0 5 10 km

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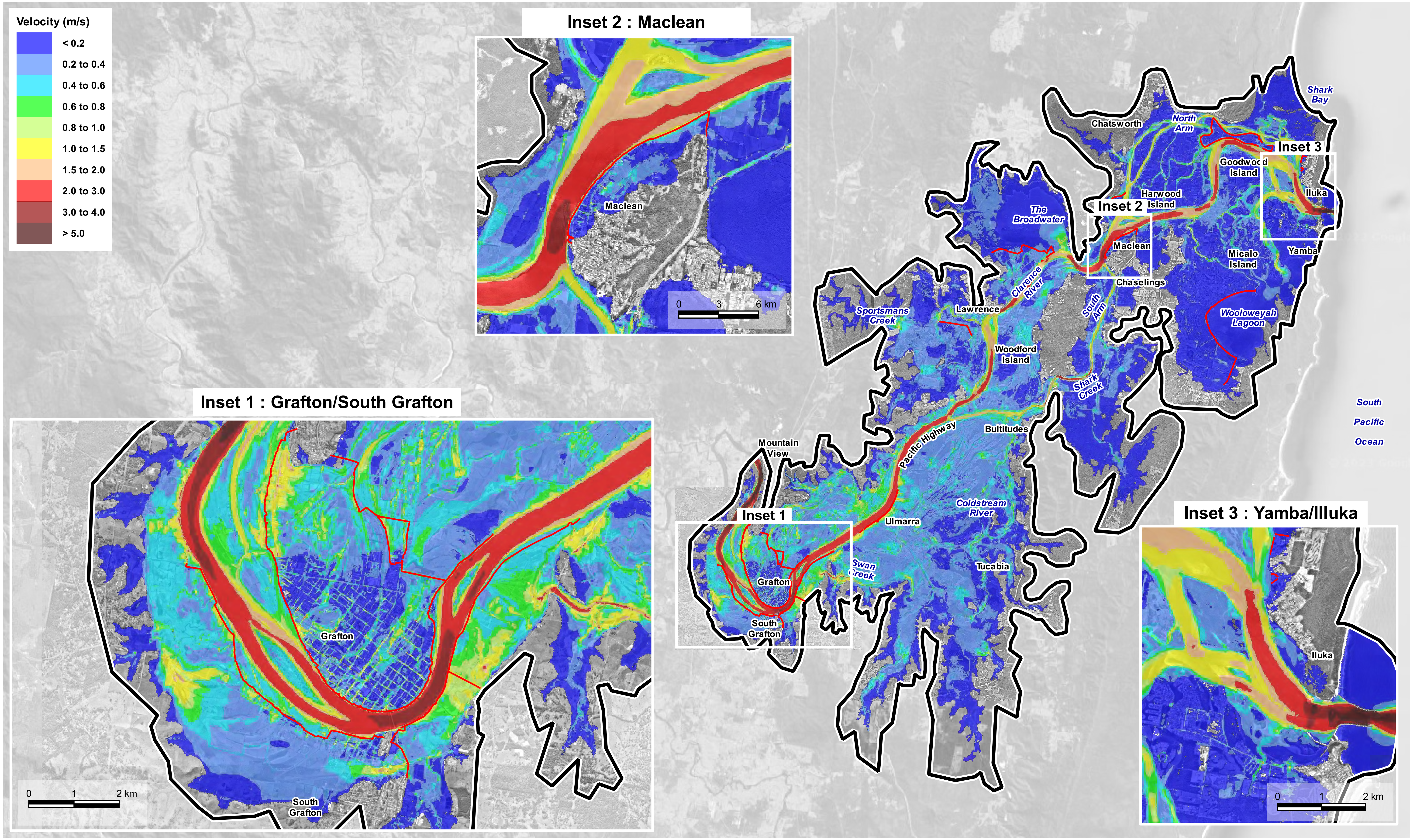

LEGEND

Levees

Flood Model Extent

Title:

0.2% AEP Peak Flood Velocity

Drawing: **D25**

Rev: **A**

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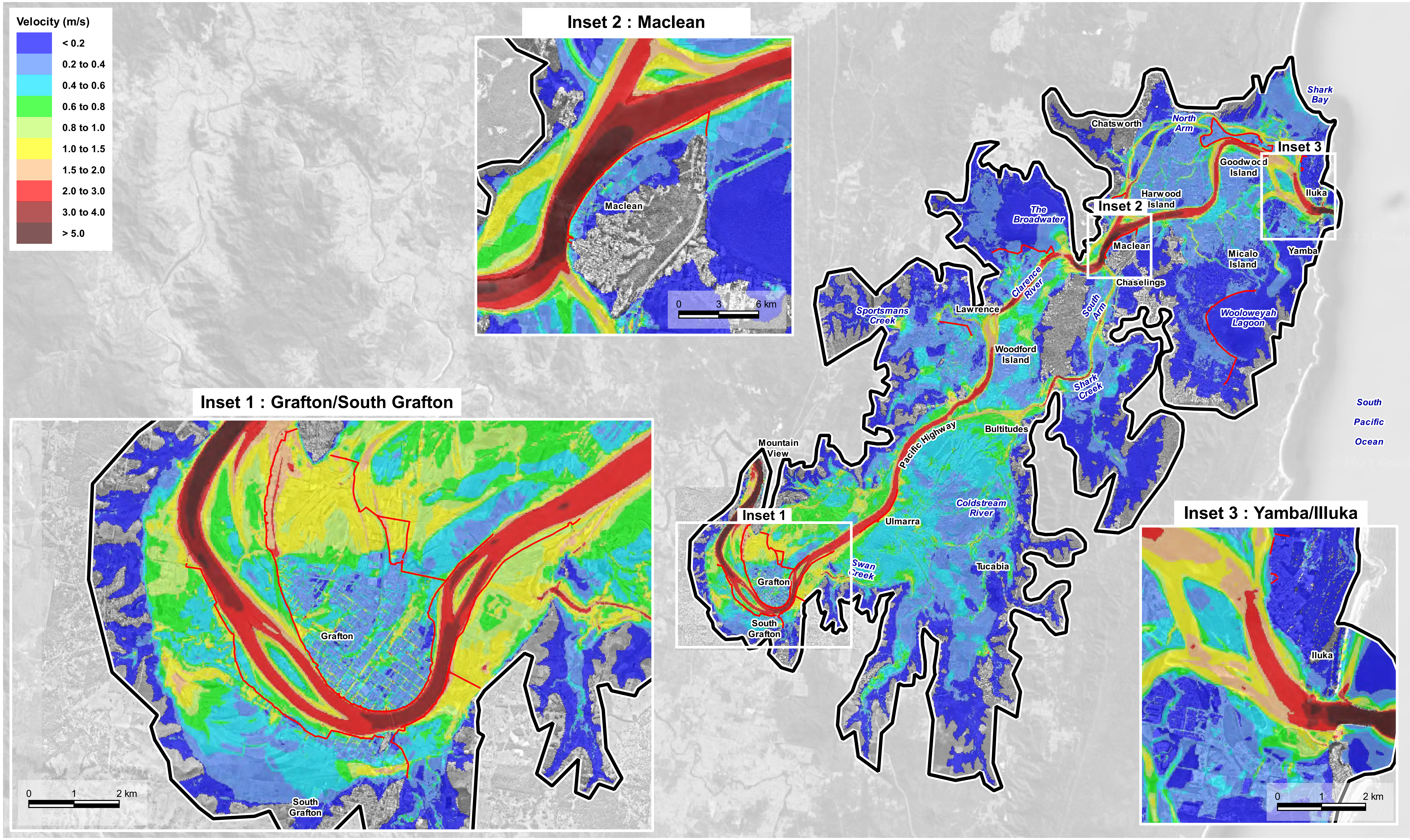

LEGEND

Levees

Flood Model Extent

Title:

Extreme Flood Peak Flood Velocity

Drawing: D26

Rev: A

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0 5 10 km

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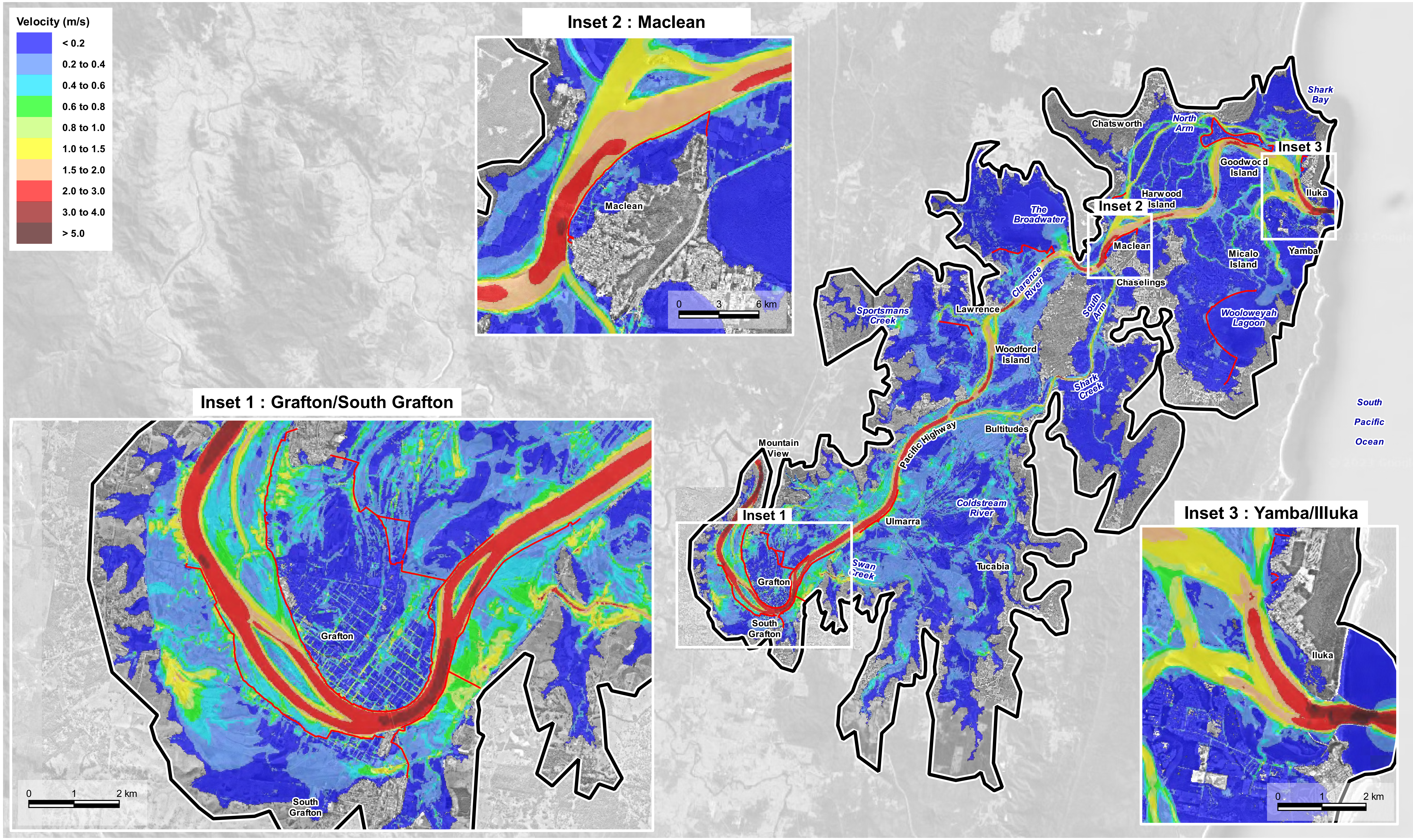

LEGEND

- Levees
- Flood Model Extent

Title:

1% AEP Climate Change (CC1) Peak Flood Velocity

Drawing: D27

Rev: A

N

0 5 10 km

BMT
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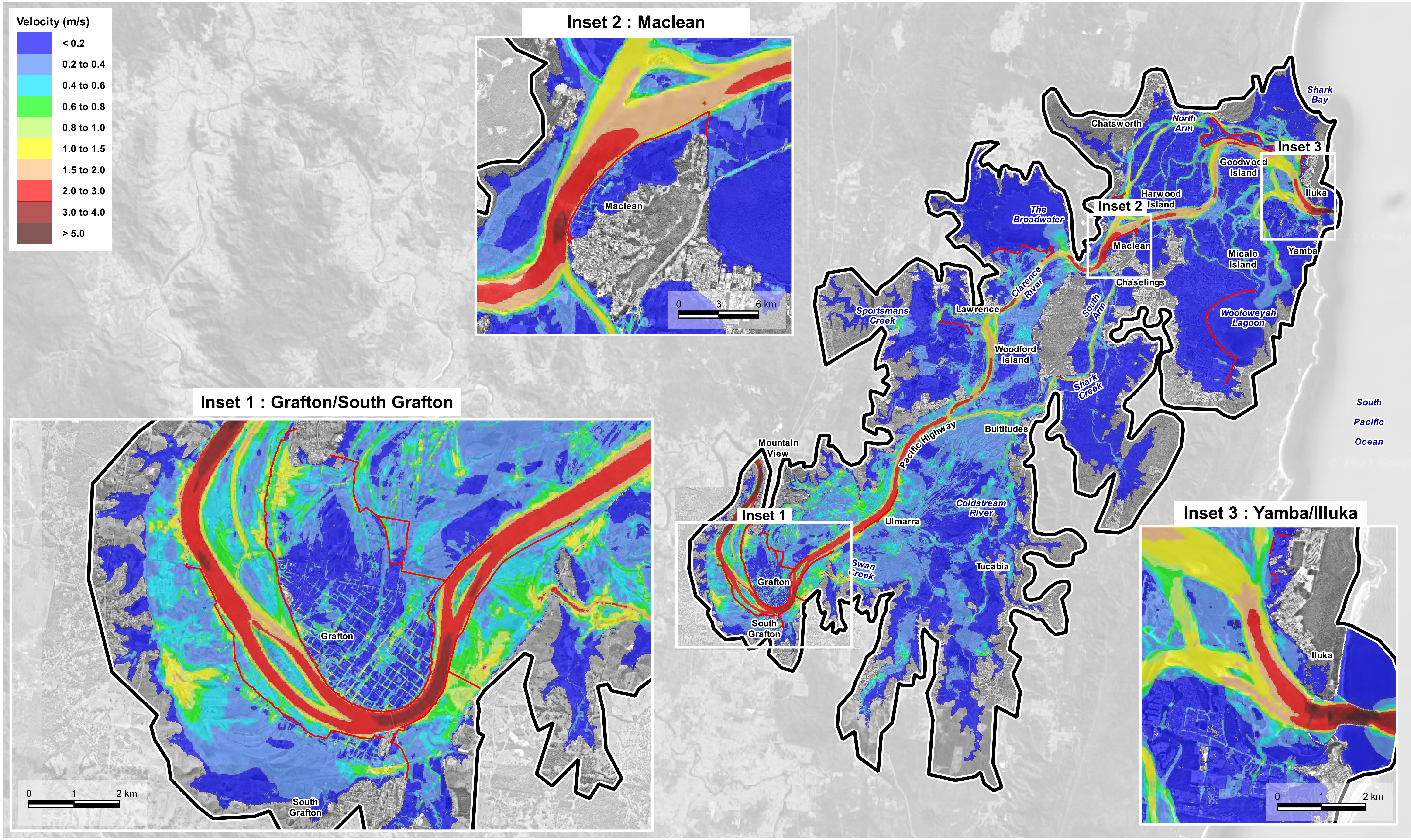

LEGEND

Levees

Flood Model Extent

Title:

1% AEP Climate Change (CC2) Peak Flood Velocity

Drawing: D28

Rev: A

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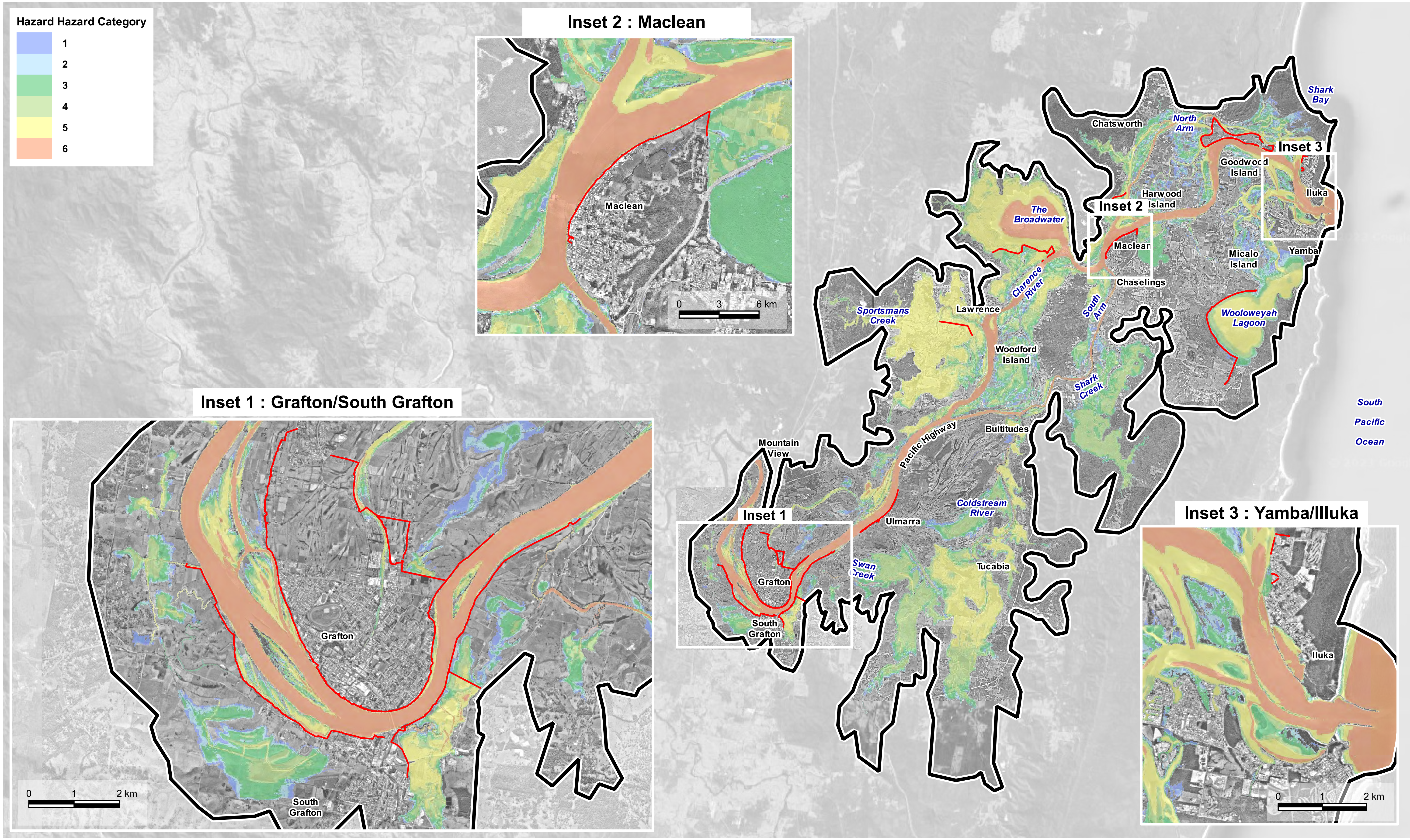

LEGEND

Levees

Flood Model Extent

Title:

20% AEP Classified Hazard

Drawing: D29

Rev: A

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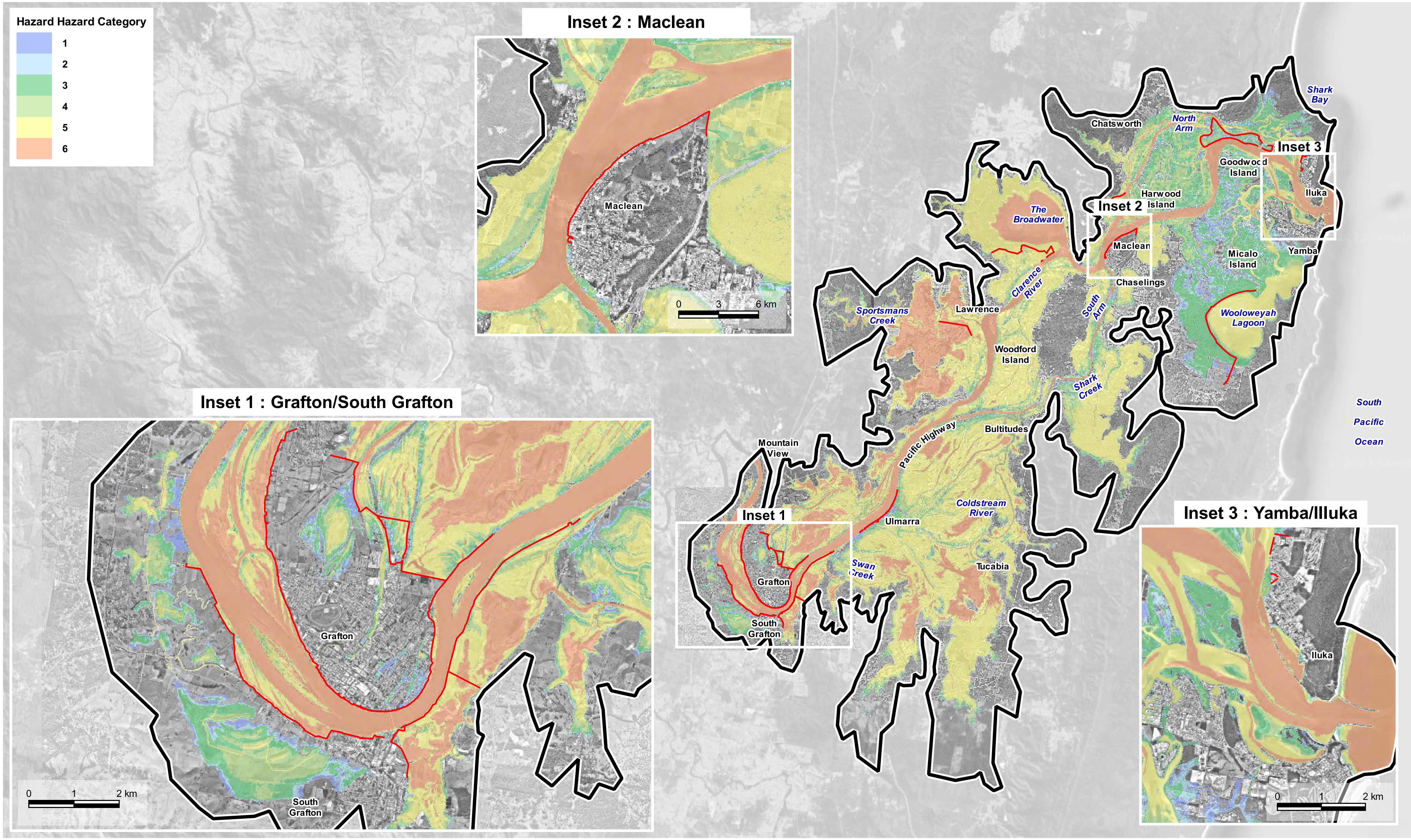

LEGEND

Levees

Flood Model Extent

Title:

5% AEP Classified Hazard

Drawing: D30

Rev: A

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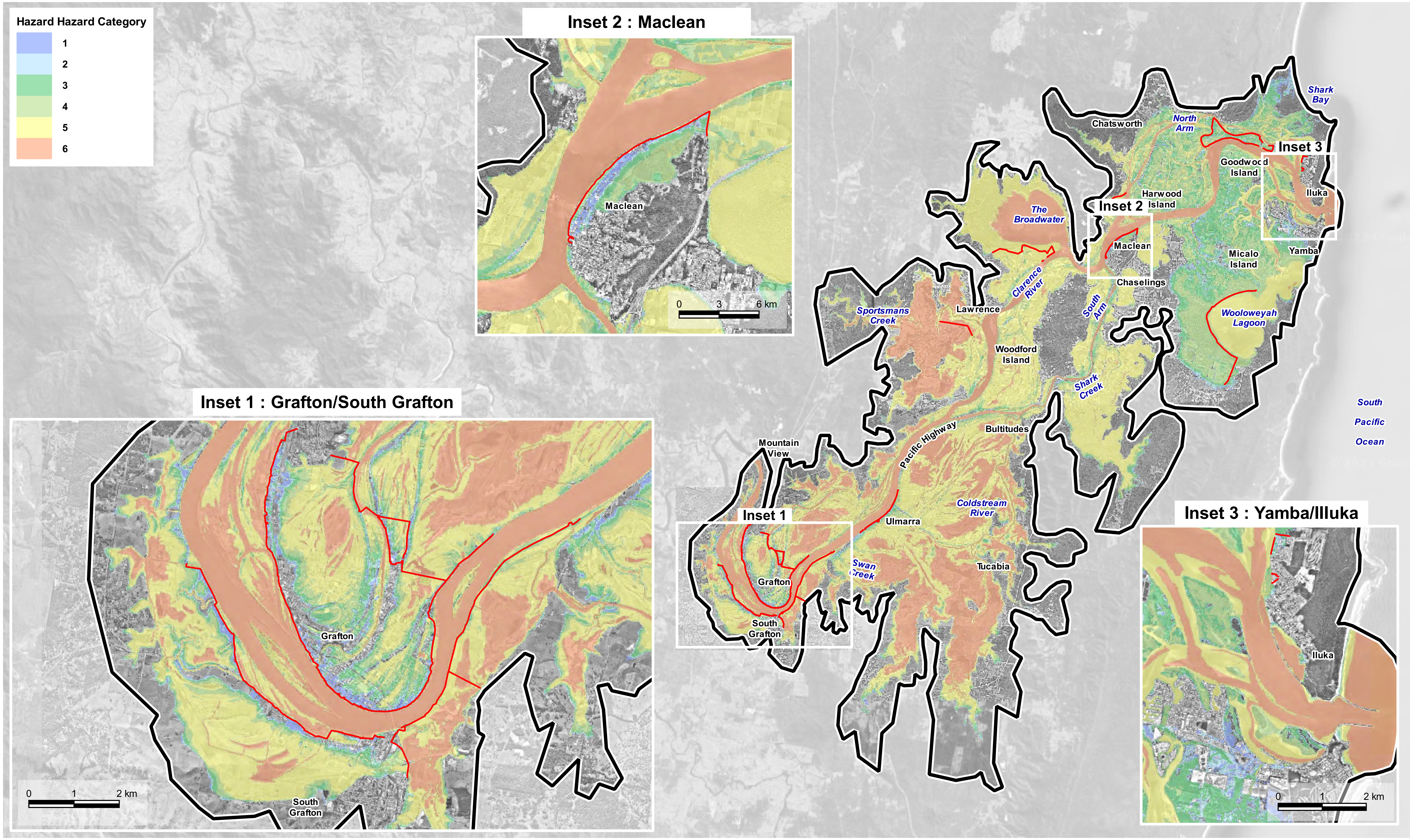

LEGEND

Levees

Flood Model Extent

Title:

2% AEP Classified Hazard

Drawing: D31

Rev: A

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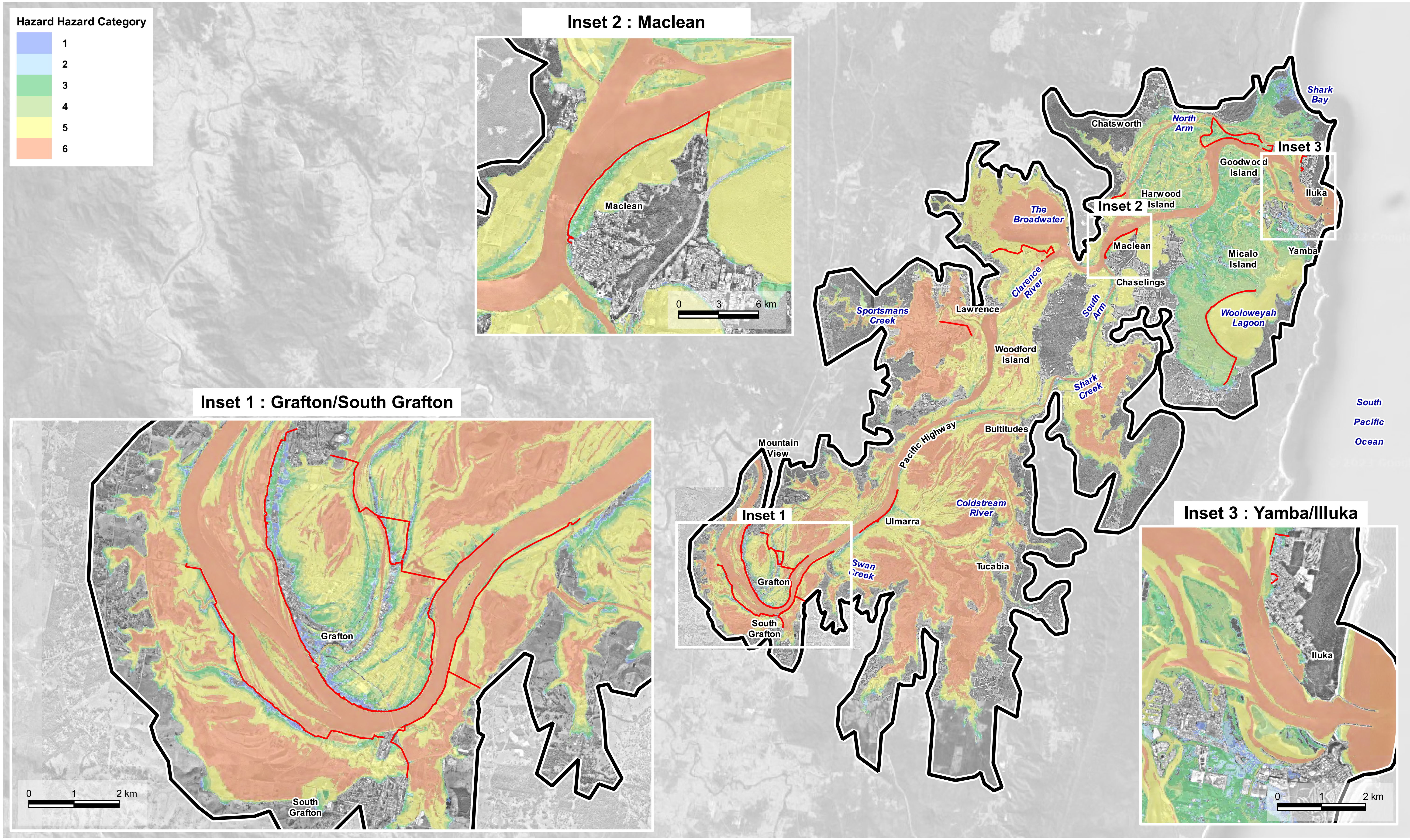

LEGEND

Levees

Flood Model Extent

Title:

1% AEP Classified Hazard

Drawing: D32

Rev: A

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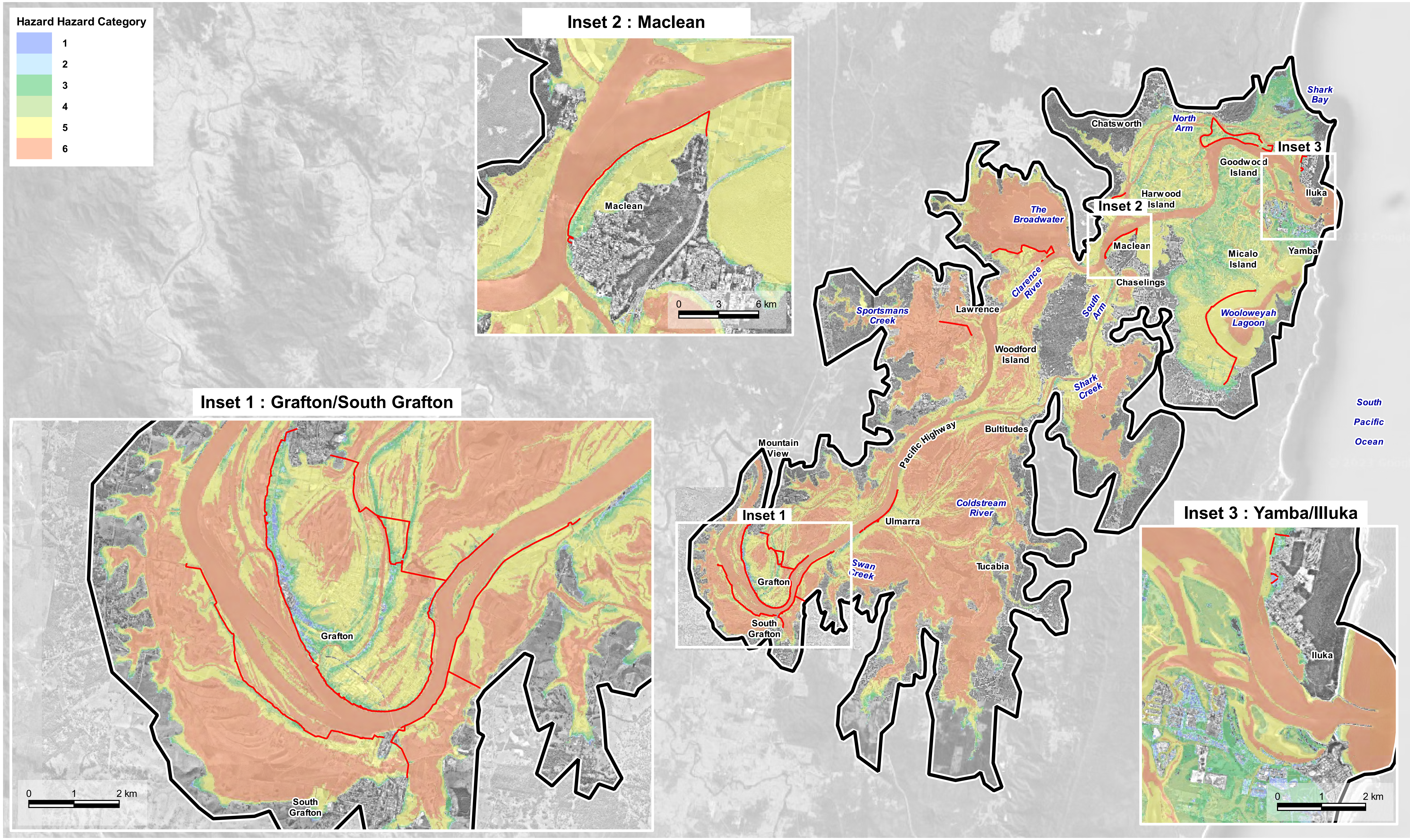

LEGEND

Levees

Flood Model Extent

Title:

0.5% AEP Classified Hazard

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0 5 10 km

Drawing: D33

Rev: A

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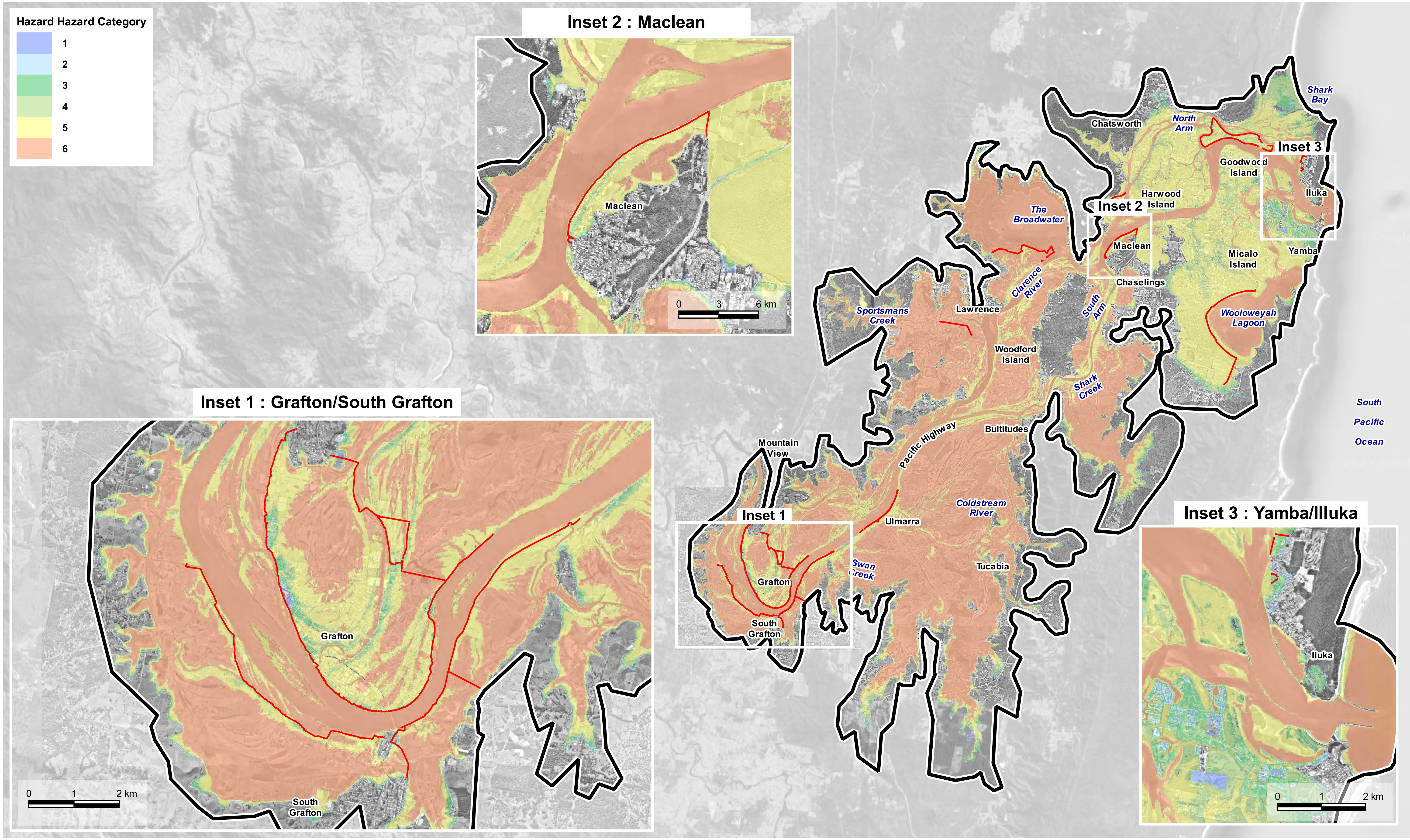

LEGEND

- Levees
- Flood Model Extent

Title:

0.2% AEP Classified Hazard

Drawing: D34

Rev: A

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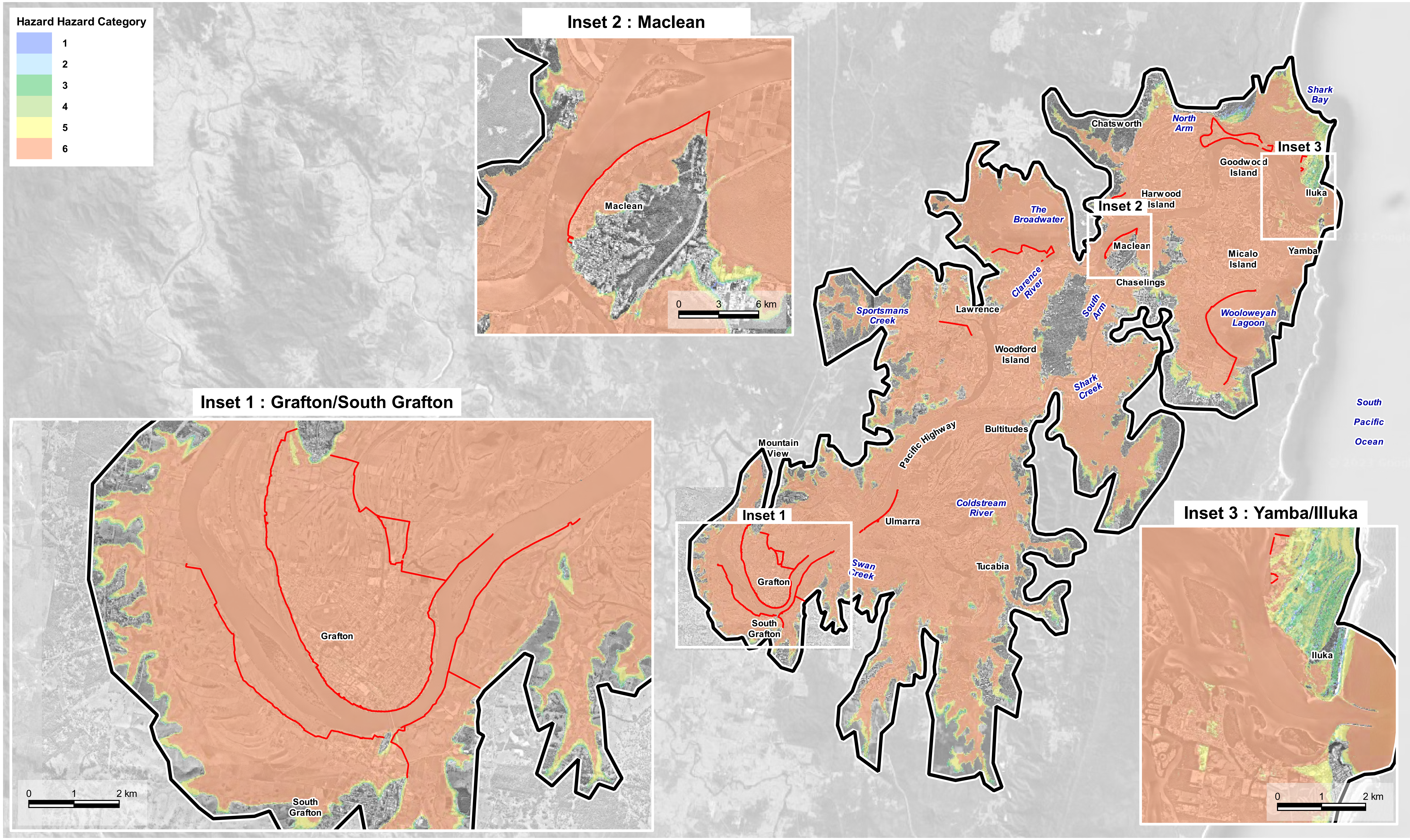

LEGEND

Levees

Flood Model Extent

Title:

Extreme Flood Classified Hazard

Drawing: D35

Rev: A

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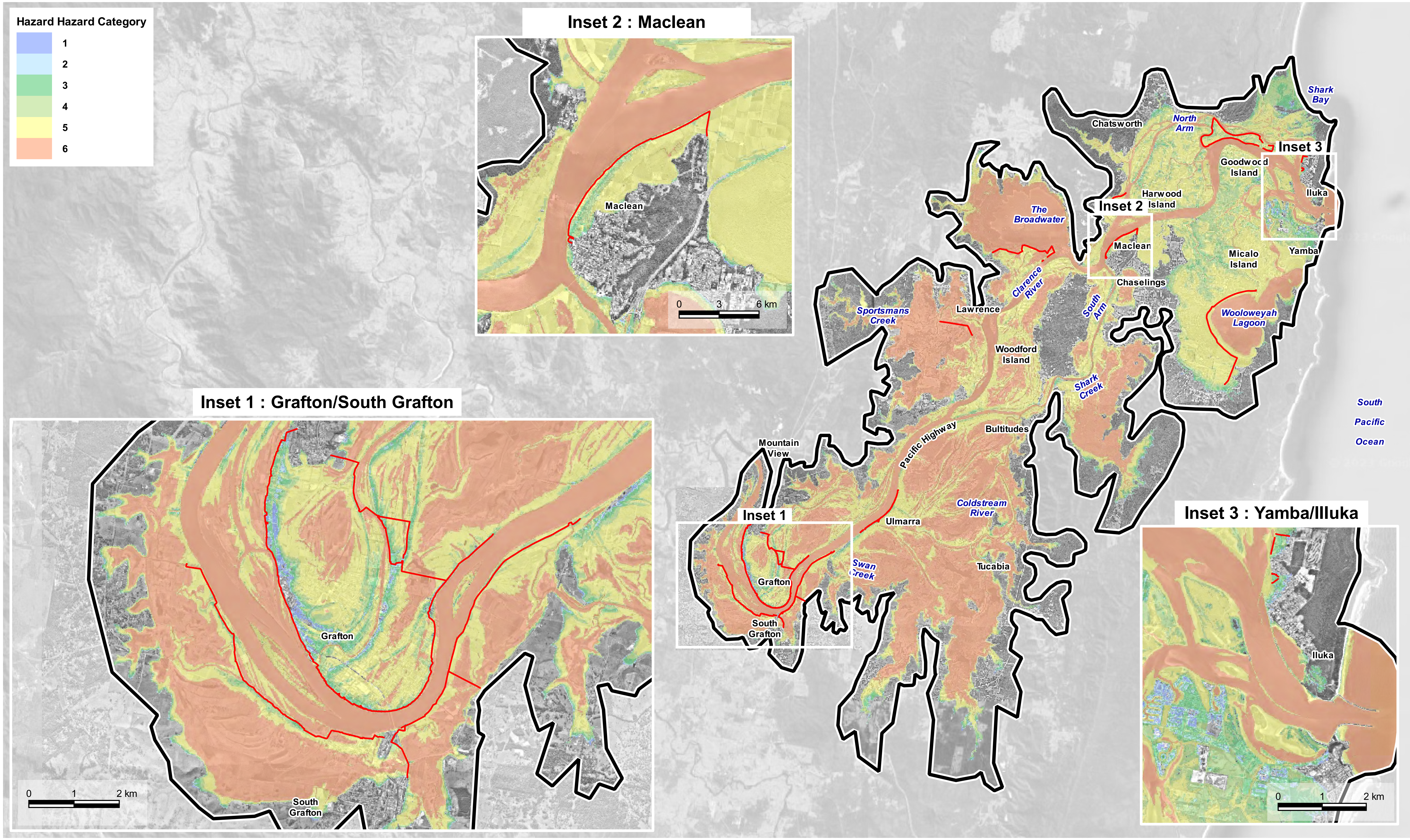

LEGEND

Levees

Flood Model Extent

Title:

1% AEP Climate Change (CC1) Classified Hazard

Drawing: D36

Rev: A

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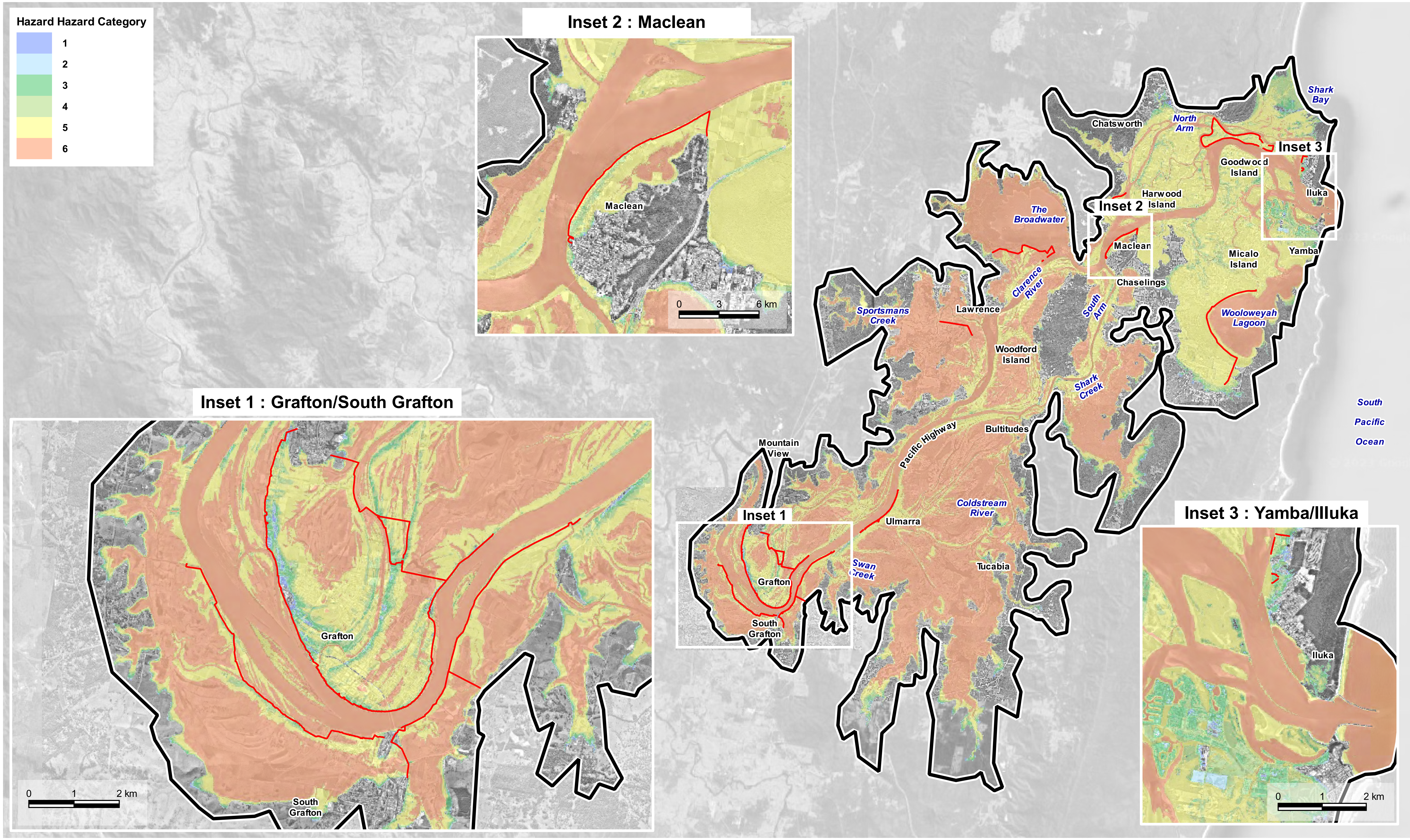

LEGEND

Levees

Flood Model Extent

Title:

1% AEP Climate Change (CC2) Classified Hazard

Drawing: D37

Rev: A

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Annex E Extreme Flood Sensitivity Assessment

Overview

The flood model assumes fixed terrain when simulating flood events. When modelling the Extreme Flood, the flows are so great that they would lead to overtopping of the dunes causing additional breakouts to the ocean. Whilst the model allows this flow to pass into the ocean, it does not allow for any erosion or scour which would likely occur under these extreme conditions. To understand the sensitivity of Extreme Flood levels to changes in terrain as a result of erosion, a sensitivity test has been simulated with additional channels carved out of the terrain, north of the current outlet to the ocean. It is recognised that the assumptions of the sensitivity scenario are subjective. The intent is to give an indication on the sensitivity of flood levels to significant erosion. The extent of the assumed breakout channel is shown in Figure E.1.

Figure E.1 Assumed New Breakout Channel (yellow cross hatching)

Results

The results of the assessment are presented as tabulated peak flood levels for the four locations shown in Figure E.1. Table E.1. shows the Extreme Flood peak levels for the baseline case and the sensitivity assessment with the additional channel.

Table E.1. Extreme Flood Sensitivity Analysis

Location	Baseline Level (mAHD)	Sensitivity Test Level (mAHD)	Change in Peak Flood Level (m)
1	5.38	4.80	-0.58
2	7.09	6.49	-0.60
3	7.08	6.43	-0.65
4	7.78	7.32	-0.46

Annex F Climate Change Background Information

Two climate change scenarios are simulated in this study, both representing the 1% AEP flood event under future climate scenarios. The scenarios differ from the 1% AEP event by assuming increases in design rainfall leading to increases in catchment runoff and increases in sea level.

The assumptions applied in determining the increases in catchment runoff and sea level draw upon available studies. Both scenarios include increases in rainfall and assume an amount of sea level rise. The scenarios, termed CC1 and CC2, are informed by the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathways (RCPs) 4.5 and 8.5 respectively. As such, the assumptions and any conservatism built into those scenarios are based on those within the RCPs.

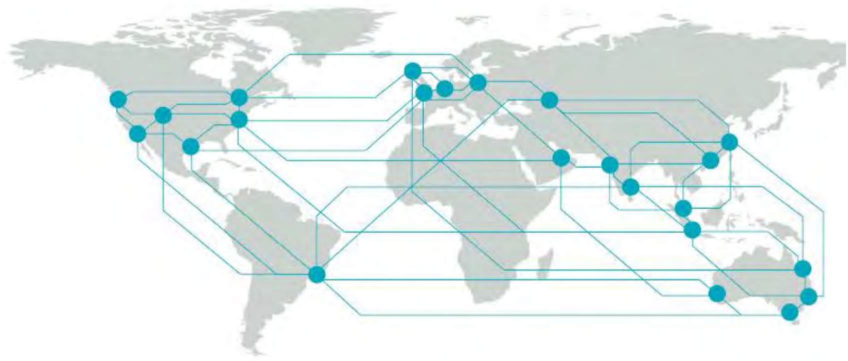
RCP4.5 is generally considered a more realistic future scenario with regards to greenhouse gas emissions whereas RCP8.5 is a more conservative scenario. RCP8.5 combines assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and GHG emissions in absence of climate change policies. RCP8.5 translates into greater sea level rise compared to RCP4.5.

The modelled storm tide for the existing climate is provided by state guidance (OEH, 2015) and increased slightly so that the peak storm tide level matches the peak level from a storm tide investigation assessment undertaken for Clarence Valley Council in 2021 (Risk Frontiers, 2021). The sea level rise component added to this for scenarios CC1 (RCP4.5) and CC2 (RCP8.5) is taken from the Stage 2 report of Council’s Coastal Management Program (CMP) under a 2123 future scenario. These sea level rise amounts are:

- 0.76m for RCP4.5
- 1.09m for RCP8.5

With regards to which scenario should be adopted for decision making purposes this can be explored further during the preparation of a floodplain risk management study which could consider factors such as:

- Will climate change result in a significant increase in frequency of exposure to hazard
- Will climate change significantly impact upon flood damages?
- Do conditions for new development need to change to reduce the potential growth in flood damages?



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