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Lower Clarence Flood Model Update 2013

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Lower Clarence Flood Model Update 2013

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Title :	Lower Clarence Flood Model Update 2013
Author :	Annabel Farr and Chris Huxley
Synopsis :	This report documents the update of the Lower Clarence River flood model.

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EXECUTIVE SUMMARY

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 20,000km^2. The lower Clarence River floodplain spans 500km^2, within which lie the towns of Grafton and Maclean. These towns are home to over 20,000 residents collectively and serve as a rural centre for the surrounding agricultural lands. Both Grafton and Maclean and are protected by levee systems which have been developed over time as a response to previous floods in the region.

This study aims to assess the flood behaviour within the Lower Clarence Valley, and in particular the characteristics of the flood flow within Grafton and Maclean when the levee systems are overtopped. These results will assist the Clarence Valley Council regarding possible future capital works on the levee systems to raise the flood immunity within both towns. Furthermore, the information will assist emergency response managers with their evacuation planning in preparation for when the respective levees are at risk of overtopping in the future.

This study is part of an ongoing process which aims to develop a greater understanding of the flood behaviour within the Lower Clarence Valley, aiding the management of flood risk within the greater catchment.

Assessment items which are addressed in this report include:

1 Update of the Lower Clarence Valley flood model with revised catchment topography data:

a) Calibration/validation of the updated flood model to the 1967, 1968, 1980, 1988, 1996, 2001, 2009 and 2013 flood events.

b) Definition of the design flood behaviour within the Lower Clarence Valley catchment for the 20%, 5%, 2%, 1% AEP and Extreme flood events. Table ES- 1 summarises peak design flood levels for a range of key catchment locations.

Table ES- 1 Design Event Results: Regional Reporting Locations

Design Flood Event	***Peak Flood Level (mAHD)***				
	Prince St Gauge (Grafton)	***Ulmarra Gauge (Ulmarra)***	***Brushgrove Gauge (Brushgrove)***	***Maclean Gauge (Maclean)***	***Iluka Gauge (Iluka)***
20% AEP	6.1	5.0	4.2	2.4	1.1
5% AEP	7.9	6.1	5.1	3.1	2.0
2% AEP	8.2	6.2	5.5	3.4	2.2
1% AEP	8.3	6.4	5.8	3.6	2.5
Extreme Event	9.7	8.4	8.0	5.1	3.5

2 A climate change assessment for the Lower Clarence Valley, accounting for projected future changes in rainfall intensity and sea level rise. The assessment considered three climate change scenarios:

i. Climate Change Scenario 1 (Rainfall intensity sensitivity testing) - 1% AEP event: 10% rainfall intensity increase + no sea level rise;

ii. Climate Change Scenario 2 (2050 planning horizon) - 1% AEP event: 10% rainfall intensity increase + 0.4m sea level rise; and

iii. Climate Change Scenario 3 (2100 planning horizon) - 1% AEP event: 10% rainfall intensity increase + 0.9m sea level rise.

Table ES- 2 summarises the climate change assessment results for a range of key catchment locations.

Table ES- 2 Climate Change Assessment Results: Regional Reporting Locations

Results	***Climate Change Scenario***	***1% AEP Event***				
		Prince St Gauge (Grafton)	***Ulmarra Gauge (Ulmarra)***	***Lawrence Gauge (Lawrence)***	***Maclean Gauge (Maclean)***	***Iluka Gauge (Iluka)***
Peak Flood Level (mAHD)	Current climate	8.3	6.4	5.4	3.6	2.5
	Scenario 1: Rainfall intensity sensitivity	8.4	6.6	5.7	3.8	2.5
	Scenario 2: 2050 planning horizon	8.4	6.7	5.7	3.8	2.8
	Scenario 3: 2100 planning horizon	8.4	6.7	5.8	3.9	3.2
Peak Flood Level Increase (m)	Scenario 1: Rainfall intensity sensitivity	0.1	0.3	0.3	0.2	0.0
	Scenario 2: 2050 planning horizon	0.1	0.3	0.4	0.3	0.3
	Scenario 3: 2100 planning horizon	0.1	0.4	0.5	0.4	0.7

3 Assessment of the drainage behaviour within the North Grafton levee system. The purpose of this assessment is to determine the approximate time required for floodwaters in North Grafton to drain following a major overtopping event. This information will assist CVC to plan and conduct the flood recovery process.

4 Revision of the flood planning levels within the Lower Clarence River catchment.

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LIST OF ABBREVIATIONS

ALS	Airborne Laser Survey
AEP	Annual Exceedance Probability
AR&R	Australian Rainfall and Runoff
ARI	Average Recurrence Interval
BoM	Bureau of Meteorology
CVC	Clarence Valley Council
DIPNR	Department of Infrastructure and Planning (now Department of Planning)
DEM	Digital Elevation Model
GIS	Geographical Information Systems
GSDM	Generalised Short Duration Method
GTSMR	Generalised Tropical Storm Method
HAT	Highest Astronomical Tide
FLP	Flood Planning Level
MHWS	Mean High Water Spring Tide
NSW DECCW	Department of Environment, Climate Change and Water NSW (now OEH)
OEH	Office of Environment and Heritage
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SES	State Emergency Services

1 INTRODUCTION

1.1 Background

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 20,000km^2. The lower Clarence River floodplain spans 500km^2, within which lie the towns of Grafton and Maclean. These towns are home to over 20,000 residents collectively and serve as a rural centre for the surrounding agricultural lands. Both Grafton and Maclean and are protected by levee systems which have been developed over time as a response to previous floods in the region.

This study aims to assess the flood behaviour within the Lower Clarence Valley. These results will assist the Clarence Valley Council (CVC) in their management of flooding risk within the catchment.

This study is part of an ongoing process[1]which aims to develop a greater understanding of the flood behaviour within the Lower Clarence Valley, aiding the management of flood risk within the greater catchment.

1.2 Project Objectives

This study, referred to as '*Lower Clarence Flood Model Update'*, represents an update to the Lower Clarence Flood Study Review (WBM, 2004) and *Grafton and Maclean Flood Levee Overtopping: Hydraulic Assessment* (BMT WBM, 2011).

The main objectives of the Flood Model Update are to:

1 Update the Lower Clarence Valley flood model with:

   a) Newly available Airborne Laser Survey (ALS) topography data of the entire study area; and

   b) Revised Grafton and South Grafton levee survey data.

2 Complete a climate change assessment for the Lower Clarence Valley, accounting for projected future changes in rainfall intensity and sea level rise.

3 Complete an assessment of the drainage behaviour within the Grafton levee system, providing CVC with the information required to plan and conduct the flood recovery process.

4 Revise the flood planning levels Lower Clarence Valley.

1.3 Previous Studies

1.3.1 Lower Clarence Flood Study (1988)

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

[1] The floodplain management process evolves over time. As assessment methodologies are improved, updated catchment/rainfall information becomes available and also in response to development needs within the catchment.

Hydrological models of the tributary catchments of the floodplain (e.g. Sportsmans Creek, Glenugie Creek, Coldstream River) were also created.

1.3.2 Lower Clarence Flood Study Review (2004)

After the completion of the Lower Clarence Flood Study (PWD, 1988), Councils within the Lower Clarence area advanced to various stages of the floodplain risk management process. Additionally, the 2001 Floodplain Management Manual also incorporated a number of changes to the 1986 manual, including a more explicit recognition of the need to consider the full range of flood sizes.

The changes described above necessitated an update to the existing Lower Clarence Flood Study (PWD, 1988). Rather than undertaking studies based on shire boundaries, the Lower Clarence Flood Study Review provided an opportunity to update the 1988 flood study for the entire Lower Clarence River area using updated flood modelling technology. The 1D model created for the Lower Clarence River Floodplain Study was updated to a two-dimensional (2D) dynamic flood model with a 60 metre grid resolution. The upstream boundary of the 1988 flood study model was revised and the model was extended upstream of Grafton to Mountain View, including the township of Grafton in the flood study review.

The flood study review examined and defined the flood behaviour of the Lower Clarence River from Mountain View (approximately 10km upstream of Grafton) to the ocean outlet at Yamba. The primary objective of the study was to define flood behaviour in the Lower Clarence River floodplain for a full range of flood events under existing catchment floodplain conditions. The events included the 5 year, 20 year, 100 year, 500 year ARI (Average Recurrence Interval) and an extreme flood event.

1.3.3 Grafton and Lower Clarence Flood Risk Management Plan (2007)

The Grafton and Lower Clarence Flood Risk Management Plan was completed by Bewsher Consulting Pty Ltd in 2007. The Plan used the flood results defined by the Lower Clarence Flood Study Review (WBM, 2004) to assess the flood risk within the Lower Clarence Valley. The plan proposed various flood risk management measures, aimed at reducing flood risk within the catchment. These measures include:

- Flood warning and emergency management planning recommendations;
- Community awareness campaigns;
- Voluntary house purchase;
- Voluntary house raising;
- Structural modification measures; and
- Future planning considerations.

In addition to the above listed measures, the Plan recommended further flood modelling of potential levee overtopping at Grafton and South Grafton. The Grafton and Maclean Flood Levee Overtopping: Hydraulic Assessment (BMT WBM, 2011) was commissioned by CVC to address this recommendation.

1.3.4 Grafton and Maclean Flood Levee Overtopping: Hydraulic Assessment (2011)

The towns of Grafton and Maclean are located within the Lower Clarence River floodplain. Results from the Lower Clarence Flood Study Review (WBM, 2004) combined with the March 2001 flood event highlighted the residual risk associated with Grafton, South Grafton and Maclean's levee systems overtopping in large flood events.

The Grafton and Maclean Flood Levee Overtopping study refined the 2D flood model developed during the Lower Clarence Flood Study Review (WBM 2004). The model was refined such that it included multiple domains, increasing the model resolution within and surrounding the urban areas of Grafton, South Grafton and Maclean. This model was used to assess the flood behaviour in Grafton and Maclean when the levee systems surrounding these towns are overtopped.

The urban areas of Grafton, South Grafton and Maclean were modelled using a 10 metre grid resolution. This degree of resolution was required within the respective urban areas to represent the complex urban flow patterns after levee overtopping has occurred.

The Clarence River adjacent to the subject areas of Grafton and South Grafton, extending upstream to Mountain View utilised a 30 grid resolution. In this location, compared with a coarser 60m grid, the 30m grid resolution improves representation of the levee and overtopping regime in Grafton and South Grafton. The remaining sections of the Clarence River floodplain downstream of Grafton were represented using a 60m grid resolution.

Using the refined flood model, the levee overtopping analysis aimed to identify locations along levees where overtopping occurs, and to approximate the frequency of overtopping. The 2011 study was not released publically as it was determined that more accurate survey data was required. The current assessment uses updated survey of the levees collected by CVC.

2 FLOOD MODEL UPDATE

2.1 Model Configuration

The refined Lower Clarence flood model developed as part of the *Grafton and Maclean Flood Levee Overtopping: Hydraulic Assessment* (BMT WBM, 2011) has been used as the base model for this study. Updates to this model are summarised in the following sections. The refined model configuration, which includes a range of grid resolutions, is presented in Figure 2-1.

2.2 Model Topography

2.2.1 Levee Survey

The Lower Clarence River model has been updated with 2012 ground survey data of the Grafton, South Grafton, Heber, Alipou, Clarenza and Ulmarra levees, obtained from CVC. These levee datasets, shown in Figure 2-1, are represented in the flood model as breaklines.

2.3 Digital Elevation Model

A Digital Elevation Model (DEM) represents the base topographic dataset used by a hydraulic flood model. The Lower Clarence River Flood Study (WBM, 2004) used a DEM which was derived from a variety of datasets, including:

- Ground contours of the floodplain developed from the Clarence River Flood Mitigation;
- Survey carried out by E. Kazimierczuk (of PWD) between 1958 and 1960;
- Clarence River hydro-survey (1963, 1978 and 1979);
- CVC survey plans;
- Road surveys; and
- 1:25,000 topographical maps.

As part of this study, all out-of-bank topography within the Lower Clarence River flood model has been updated using a DEM derived from 1m resolution Airborne Laser Survey (ALS). The ALS dataset, covering the entire Lower Clarence River catchment, was provided by CVC. This dataset is of considerably greater accuracy than the DEM used in the previous Lower Clarence studies. The in-bank bathymetry has been defined based on the Clarence River hydro-survey used by the original Lower Clarence River Flood Study (WBM 2004). For comparison, the elevation differences between the DEM used for the Lower Clarence River Flood Study (WBM 2004) and the current DEM is shown in Figure A- 1.

2.4 Landuse Delineation

Landuse mapping is used by the hydraulic model to represent the associated hydraulic resistance or roughness within the floodplain. In total, nine areas of different landuse type based on aerial photography were used. The Manning's 'n' values adopted for the various defined landuse within the hydraulic model are listed in Table 2 1. These values have been validated as part of the flood model calibration exercise, documented in Section 3.2. Figure 2-2 shows the landuse mapping defined for the hydraulic model.

Table 2-1 Hydraulic Model Landuse Categorisation

Landuse Type	***Manning's n Coefficient***
River Bank	0.08
River	0.025
Island Vegetation	0.08
Minor Tributary	0.035
Pasture	0.08
Sugar Cane	0.15
Crops	0.1
Forest	0.2
Urban Blocks	0.3
Parks	0.04
Roads (within 10m model domains)	0.02

2.5 Model Boundaries

The Lower Clarence flood model used various input boundary conditions including:

- Flood inflows for the Clarence River at Mountain View;
- Flood inflows for the Clarence River tributaries downstream of Mountain View;
- Floodplain rainfall runoff; and
- Ocean water levels.

Figure 2-1 shows the location of the catchment inflows and outflows which have been included within the flood model. The derivation of these inflow conditions for the model calibration and design event modelling undertaken for this study are provided in 3.2 and 4.2.

2.6 Software Update

The Lower Clarence flood model has been upgraded for compatibility with the latest release version of TUFLOW, V2012-05-AE.

The model was upgraded to the latest release of TUFLOW, capitalizing on the following new software features:

1 Evacuation Route Inundation Outputs, to be used during the review of the current Grafton Flood Evacuation Plan. These outputs provide the following information for defined evacuation routes:

   a. Time when a specified inundation criteria is exceeded (e.g. 0.15m depth pedestrian traffic, 0.3m hydraulic head vehicle traffic);

   b. Location along the route where inundation first occurs;

c. Duration of route inundation; and

d. Relative gauge height (gauge datum) when inundation of the route first occurs.

2 Time of initial inundation across the whole floodplain, to be used when identifying the benefits associated with the possible augmentation of the Grafton, South Grafton and Maclean levees.

3 Software compatibility with both 32 and 64 bit computer operating systems.

4 Reduction in model simulation times, reduced by approximately 50%.

LEGEND

- Model Inflows
- 60m model domain
- 30m model domain
- 10m model domain
- Railway
- Pacific Highway
- Levee

Ground Level : Metres AHD

Ground Level Inset

Title:

Lower Clarence Flood Model Configuration

Figure: **2-1**

Rev: **A**

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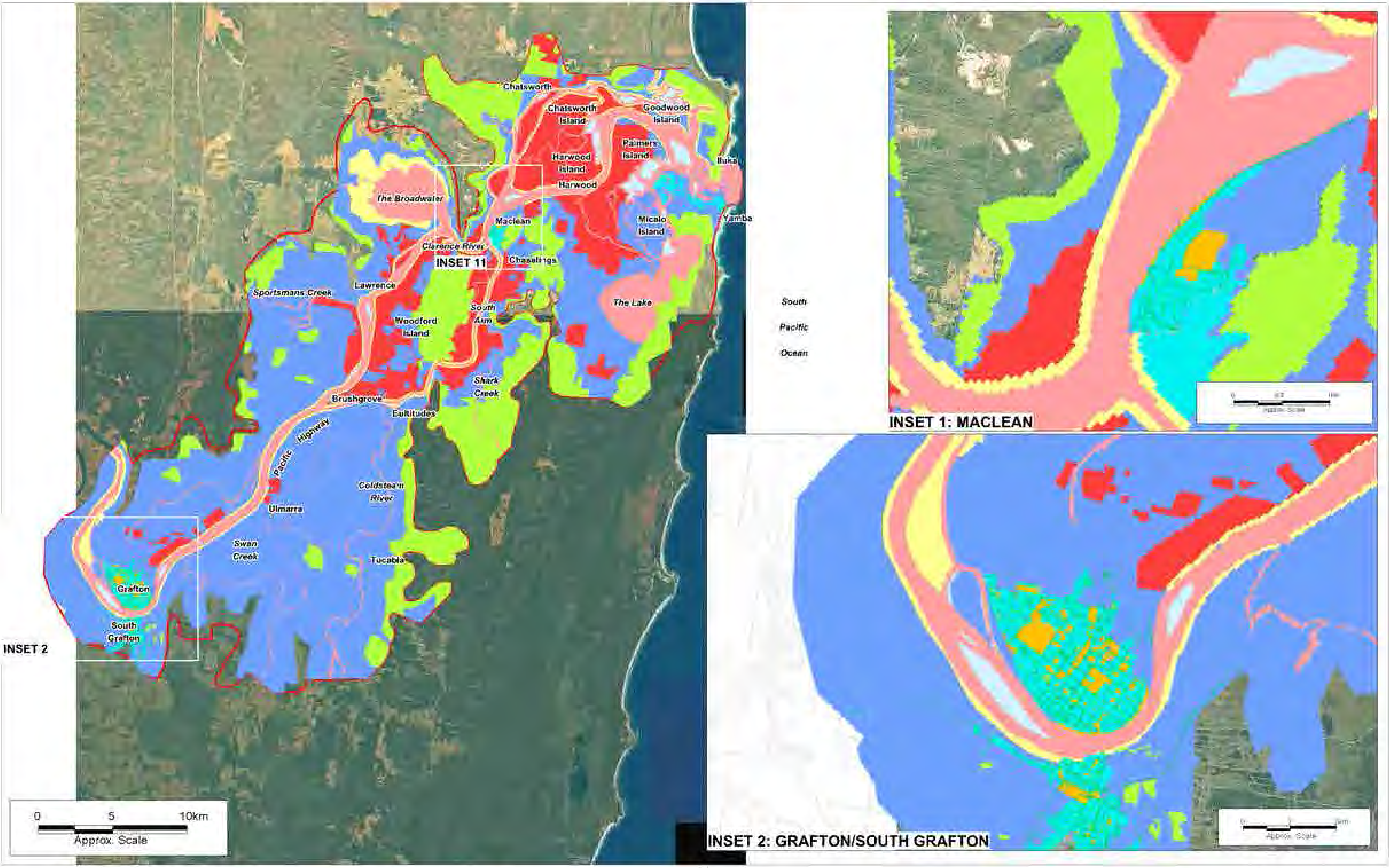

LEGEND

Model domain

Landuse Categories

- River
- River Bank
- Islands in the River
- Pasture
- Sugar Cane
- Forest
- Urban
- Parks
- Urban Roadways

Title:

Lower Clarence River Flood Model Landuse Delineation

Figure: 2-2

Rev: A

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3 HISTORIC FLOODING

3.1 Historic Recordings

The Lower Clarence Valley has a long history of flooding. Soros-Longworth & McKensie and Cameron McNamara (1980) summarised the flood history within the Lower Clarence Valley:

"Settlement on the north bank at Grafton started about 1850 and developed rapidly in the next few decades. The introduction of cane farming in 1868 and the opening of dozens of small sugar mills throughout the district gave further impetus to this early development.

The effects of floods on the new settlements before 1876 have not been ascertained but the flood heights that were recorded suggest that only two floods, those in 1863 and 1864, would have overtopped the banks near the settlements.

The next seventeen years, however, saw seven floods that would have overtopped the banks and among these was the record flood of 1890. This spate of flooding undoubtedly contributed to Grafton's reputation as a "flood city" but any anxieties about further development were probably allayed during the next three decades as the next major flood did not occur until 1921. Another major flood occurred in 1928.

Since 1945, the incidence of major flooding has been much higher, with major floods occurring in 1945, 1946, 1948, 1950, 1954, 1956, 1959, 1963, 1967, 1974 and 1976. The 1950 flood approached the height of the 1890 flood and caused widespread damage in the valley; two people were drowned and a thousand head of cattle were lost, while several thousand homes and farms were damaged. The frequent major flooding from 1946 to 1956 had major effects on the economy of the valley and aroused public interest in measures to reduce those effects.

Several reports were presented by the Department of Public Works from 1950 to 1961, including proposals for a dam at the Gorge and for a system of levees and drainage works in the lower valley.

The flood mitigation construction program which followed those reports was accelerated by the formation of the Clarence River County Council in 1959. The injection of Commonwealth Government aid from 1963 onwards greatly assisted the efforts of the N.S.W. Government and further accelerated the progress of the works.

The existing works on the Clarence River now provide high level protection for urban areas and a lower level of protection for agricultural areas to prevent frequent nuisance flooding up to about the 1 in 3 year flood level.

Table 3-1 summarises the recorded flood data for the Prince Street Gauge in Grafton. Since the Soros-Longworth & McKensie and Cameron McNamara (1980) study, major flood events have occurred in 1988, 1989, 1996, 2001, 2009, 2011 and most significantly in 2013. The largest of these more recent events, occurring in 2001, 2011 and 2013, almost resulted in the overtopping of the Grafton levees. During 2001, peak flood levels came within 0.2m of overtopping the levee. In response to the significant risks associated with flooding within Grafton following overtopping, appropriately, the SES ordered a partial evacuation of Grafton. During the 2013 flood event, overtopping was only prevented by strategic sandbagging by the SES at Fry Street prior to the peak of the flood event.

Table 3-1 Historic Flood Levels – Prince Street Gauge

Year	*Prince Street Gauge*		*Year*	*Prince Street Gauge*	
	Peak Flood Level (mAHD)	*Data Source*		*Peak Flood Level (mAHD)*	*Data Source*
1839	5.75	Clarence River Historical Society Records	1946	6.97	Prince Street Gauge recording
1841	5.90		1947	3.27	
1848	6.05		1948	7.02	
1857	5.82		1950	7.69	
1861	6.14		1951	3.08	
1863	7.26		1952	2.41	
1864	6.92		1953	3.37	
1867	6.56		1954	7.67	
1875	4.83		1955	5.77	
1876	7.16		1956	6.92	
1887	7.53		1959	6.69	
1889	6.56		1959	3.01	
1890	8.19		1962	5.59	
1892	6.43		1963	7.58	
1893	7.40		1964	3.62	
1894	3.62		1965	3.28	
1895	4.53		1967	7.55	
1903	3.01		1968	6.17	
1917	4.22		1971	3.54	
1921	6.82	Calculated based on correlation with neighbouring river gauges (Lilydale and/or South Grafton Railway) [2]	1972	4.92	
1925	2.16		1974	7.30	
1927	3.91		1976	7.22	
1928	6.69		1977	2.58	
1929	4.22		1980	6.35	
1933	3.94		1983	1.37	
1934	1.76		1988	6.73	
1937	4.71		1989	6.49	
1938	3.61		1996	6.98	
1939	3.30		2001	7.70	
1944	3.30		2009	7.33	
1945	6.40		2011	7.64	
-	-		2013	8.09	

[2] (Soros-Longworth & McKensie and Cameron McNamara, 1980)

3.2 Flood Model Calibration

Calibration is an essential part of the flood modelling process, investigating the validity of the model, underlying data and assumptions. The Lower Clarence flood model has been calibrated against eight historical flood events, from 1967 to 2013. These events are summarised in Table 3-2. Appendix B contains the historical rating curves used to derive the inflows from the recorded peak flood level.

Table 3-2 Flood Model Calibration Events

Historic Flood Event	***Prince Street Gauge***		
	Peak Flood Level (mAHD)	***Approximate ARI Event Equivalent***	***Comment***
June 1967	7.55	25 year ARI event	Pre 1974 catchment condition rating curve WBM (2004) – refer to Figure B-1
January 1968	6.17	8 year ARI event	
May 1980	6.35	7 year ARI event	1974 -1996 catchment condition rating curve WBM (2004) – refer to Figure B-1
April 1988	6.73	9 year ARI event	
May 1996	7.03	10 year ARI event	
Mar 2001	7.70	14 year ARI event	Post 1996 catchment condition rating curve WBM (2004) – refer to Figure B-1
May 2009	7.33	12 year ARI event	
January 2013	8.09	27 year ARI event	

These historic events were selected for the flood model calibration following consideration of the following factors:

1 Data Availability: Sufficient recorded rainfall and water level data with good spatial coverage of the catchment.

2 Event Magnitude: Events of varying flood magnitude have been selected for the calibration. This approach ensures the model best represents both the conveyance within the main river channels (dominant during minor flood events) and also the flood storage areas within the floodplain (dominant during major flood events).

3 Event Recency: Where possible, recent events have been used for the model calibration to best represent current catchment conditions for future planning and decision making.

Since settlement, many parts of the community (urban, dairy, sugar, grazing communities) have spent considerable effort in dealing with regular flooding of the area. Local authorities have constructed many levees, floodgates and other features to change the behaviour of floods and to reduce flooding impacts. The construction of levees has been a gradual process. Appendix B documents the development of the flood protection network between Mountain View and Ulmarra. These alterations to the catchment have been represented within the calibration event flood models, as summarised in Table B- 1.

3.2.1 Flood Model Update

Following update of the model topography, summarised in Section 2.2, model parameters adopted during the previous WBM (2004) study were reviewed as part of this model calibration exercise. The review found that the previous model parameters were suitable, not requiring adjustment. As such, subsequent improvements in the flood model calibration have occurred as a result of improved accuracy in the underlying topographic data within the model.

3.2.2 Calibration Event Model Boundary Conditions

The inflows used for the model calibration are presented in Table 4-2. The derivation and application of each of these inputs is outlined below.

- Clarence River Inflows: Calculated from recorded flood level data at the Prince Street Gauge and a rating curve. The time varying rating curves developed during the Lower Clarence Valley Flood Study (WBM, 2004) have been used for this purpose.
- Tributary Inflows: Locally recorded rainfall data has been used to calculate tributary inflows using the unit hydrograph hydraulic assessment method, as prescribed in Australian Rainfall and Runoff (1987).
- The rainfall on the floodplain was simulated as runoff to the 2D flood model by simulating ponding of the rainfall immediately on the floodplain without any flood routing. These rainfall runoff volumes were estimated based on recorded rainfall totals within the catchment.

Ocean boundary conditions have been defined using recorded tidal data supplied by the Manly Hydraulics Laboratory.

Table 3-3 Lower Clarence Flood Model Historic Event Inflows

Historic Flood Event	Clarence River Inflow (m^3/s)	Tributary Inflows (m^3/s)							Peak Ocean Boundary Level (mAHD)
		Glenugie Creek	Coldstream River	Shark Creek	Sportsmans Creek	Great Estuary Creek	Cowley Creek	Esk River	
1967	16,610	417	776	156	639	235	271	785	0.64
1968	11,070	97	48	10	263	63	17	141	0.81
1980	10,630	147	283	51	166	64	106	201	0.75
1988	11,570	100	241	56	267	90	114	355	0.76
1996	12,410	249	536	145	344	223	345	1,228	1.05
2001	14,740	300	630	88	718	176	216	816	1.36
2009	13,910	223	440	107	506	327	165	314	1.45
2013	17,780	89	153	33	553	181	96	422	1.23

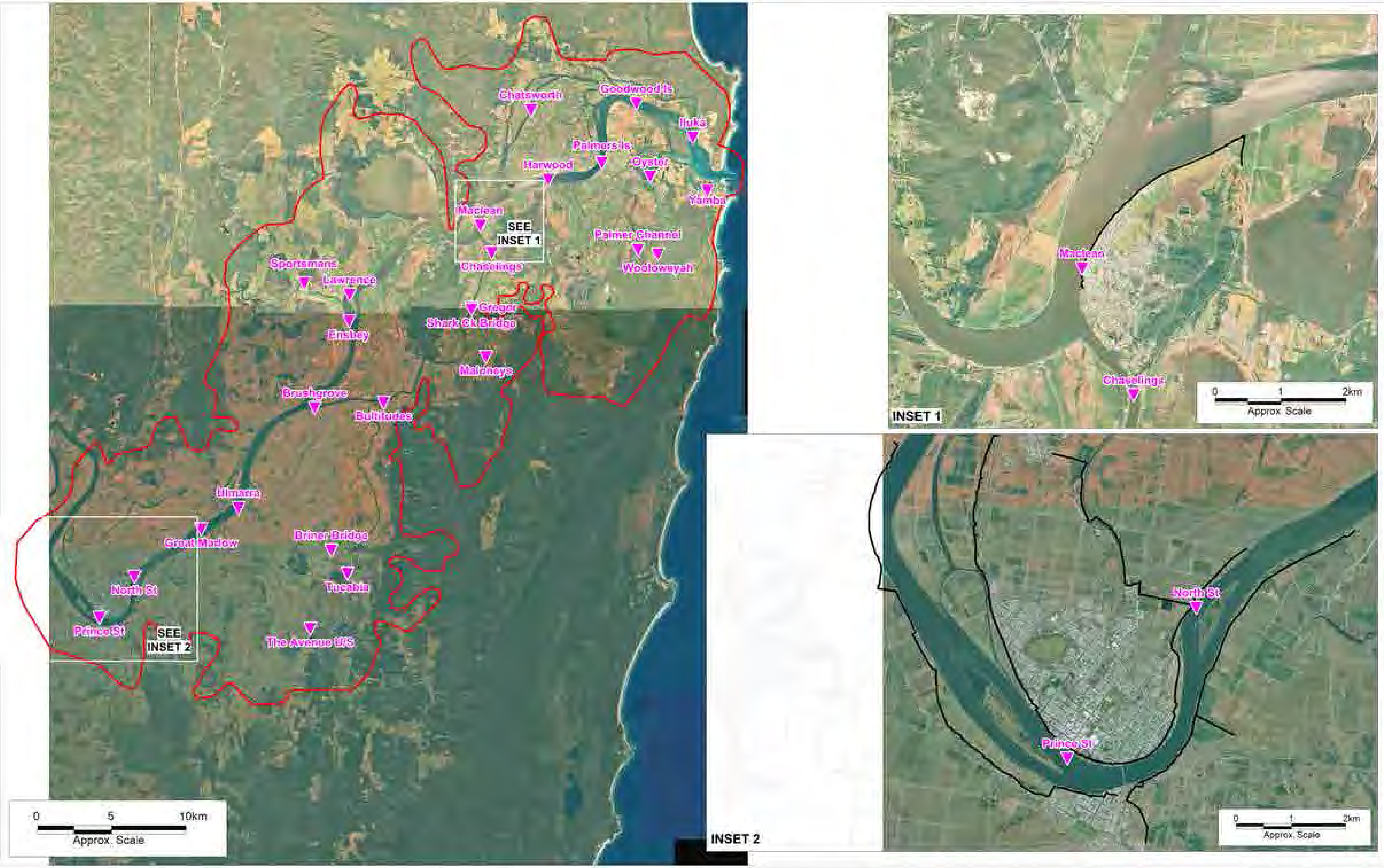
3.2.3 Calibration Results

The results for the flood model calibration are summarised in Table 3-4 to Table 3-5 for the river gauge locations presented in Figure 3-1.

Additionally, peak flood level recordings within the floodplain and time series results for the gauges listed in Table 3-4 to Table 3-5 are compared against modelled flood levels in Appendix B. Overall, the model results are in good agreement with the recorded gauge data. These results indicate that the model provides a sound representation of flood behaviour.

3.2.4 Conclusion

The calibration and verification results presented above indicate that the model is capable of accurately representing the catchment flood behaviour for a range of flood events.



LEGEND

- Flood Model Extent
- Gauge Location

Title:

Lower Clarence Rive Gauge Locations

Figure: **3-1**

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Table 3-4 Flood Model Calibration Results (1967-2013): Peak Flood Level

Gauge	1967		1968		1980		1988	
	Recorded (mAHD)	Modelled (mAHD)	Recorded (mAHD)	Modelled (mAHD)	Recorded (mAHD)	Modelled (mAHD)	Recorded (mAHD)	Modelled (mAHD)
Prince St Grafton	7.6	7.5	6.2	6.3	6.4	6.4	6.8	6.8
North St Grafton			5.7	5.6	5.9	5.8		
Great Marlow	6.6	6.2	5.1	5.2				
Ulmarra	5.9	5.9	4.8	4.9	4.9	5.1	5.5	5.5
Brushgrove	5.1	5.1	3.8	4.1				
Bultitudes	5.1	5.0	3.7	3.9	4.0	4.0		
The Avenue								
Tucabia	5.2	5.2	2.5	2.3	3.0	2.5	3.6	3.2
Briner Bridge			3.0	2.5				
Ensby	4.7	4.7	3.3	3.5	3.6	3.6		
Lawrence							4.1	3.8
Sportmans Ck Weir					3.5	3.6		
Maloneys					2.6	2.5		
Shark Creek Bridge								
Gregor			3.2	2.7	2.9	2.8		
Chaselings	3.7	3.5	2.5	2.5				
Maclean	3.3	3.2	2.2	2.3	2.5	2.5	2.8	2.8
Chatsworth	3.0	2.8			2.2	2.2		
Harwood					2.2	2.0		
Palmers Island	2.6	2.6	1.8	1.6	2.0	1.7		
Palmers Channel								
Wooloweyah	1.5	1.1	0.9	0.6	1.2	0.8		
Oyster Channel								
Iluka	1.5	1.3	1.1	1.0				
Yamba							1.0	0.9

Table 3-5 Flood Model Calibration Results (1996-2013): Peak Flood Level

Gauge	1996		2001		2009		2013	
	Recorded (mAHD)	Modelled (mAHD)	Recorded (mAHD)	Modelled (mAHD)	Recorded (mAHD)	Modelled (mAHD)	Recorded (mAHD)	Modelled (mAHD)
Prince St Grafton	7.0	7.0	7.6	7.7	7.3	7.5	8.1	8.0
North St Grafton								
Great Marlow								
Ulmarra	5.7	5.7			5.8	5.8	6.1	6.2
Bushgrove	4.9	4.8	4.8	5.0	4.7	4.5	4.8	5.0
Bultitudes					4.3	4.2		
The Avenue							4.0	4.4
Tucabia					4.2	4.2		
Briner Bridge								
Ensby								
Lawrence	4.3	4.1			4.3	4.2	4.4	4.6
Sportmans Ck Weir			4.6	4.6				
Maloneys								
Shark Creek Bridge								
Gregor								
Chaselings								
Maclean	3.0	3.1	3.2	3.1	3.2	3.1	3.1	3.0
Chatsworth								
Harwood								
Palmers Island					2.3	2.6	2.5	2.5
Palmers Channel								
Wooloweyah	1.3	1.2						
Oyster Channel					1.6	1.5	1.3	1.3
Iluka					1.9	1.7		
Yamba					1.4	1.5	1.2	1.3

4 DESIGN EVENT MODELLING

Design rainfall events represent hypothetical floods used for planning and floodplain management investigations. They are based on having a probability of occurrence typically specified either as:

- Average Recurrence Interval (ARI) expressed in years; or
- Annual Exceedance Probability (AEP) expressed as a percentage.

Throughout this report the AEP terminology has been used. A comparison and description of the design events assessed during this study is outlined in Table 4-1.

Table 4-1 Design Flood Terminology

ARI	*AEP*	*Comments*
2 years	50%	A hypothetical flood event likely to occur on average once every 2 years. This event has a 50% probability of occurring in any given year.
5 years	20%	A hypothetical flood event likely to occur on average once every 5 years. This event has a 20% probability of occurring in any given year.
10 years	10%	A hypothetical flood event likely to occur on average once every 10 years. This event has a 10% probability of occurring in any given year.
20 years	5%	A hypothetical flood event likely to occur on average once every 20 years. This event has a 5% probability of occurring in any given year.
50 years	2%	A hypothetical flood event likely to occur on average once every 50 years. This event has a 2% probability of occurring in any given year.
100 years	1%	A hypothetical flood event likely to occur on average once every 100 years. This event has a 1% probability of occurring in any given year.
200 years	0.5%	A hypothetical flood event likely to occur on average once every 100 years. This event has a 0.5% probability of occurring in any given year.
500 years	0.2%	A hypothetical flood event likely to occur on average once every 100 years. This event has a 0.2% probability of occurring in any given year.
Extreme	-	Refer to Section 4.1

4.1 Extreme Flood Event

The Probable Maximum Flood (PMF) is the largest flood that could reasonably be expected to occur in a catchment based on the Probable Maximum Precipitation (PMP). The theoretical definition of the PMP is the “greatest depth of precipitation for a given duration meteorologically possible for a given storm size area at a particular location at a particular time of year, with no allowance made for long-term climatic trends” (WMO, 1986).

Review of the PMF event was carried out during the WBM (2004) study. The review identified that past work completed by Willing and Partners (PWD, 1984) represented the most recent study of the PMF for the Clarence River. Due to significant advances in PMP assessments since 1984, the validity of the 1984 study result was questioned. Due to this uncertainty, the WBM (2004) study estimated an ‘Extreme’ event, based on the methodologies prescribed in Australian Rainfall and Runoff (1998 - Draft revision of Book VI).

“There have been a number of advances in the estimate of extreme floods in the past decade. There now exists a quick method for obtaining PMP estimates derived from the latest edition of Australian

Rainfall and Runoff (1998 - Draft revision of Book VI). The estimate uses an empirical equation involving basic catchment parameters (area, latitude, etc.) and the 50 year ARI 72 hour rainfall intensity. This approach produced a rainfall total of 660mm for the 72 hour duration PMP event.

This PMP total was compared with the 100 year ARI 72 hour rainfall total derived from Australian Rainfall and Runoff (1987) of 430mm. Hence, a factor of 1.53 was derived between PMP rainfall and 100 year ARI rainfall.

This factor was then applied to the 100 year ARI peak inflow (derived from the flood frequency analysis) of 19,060 m3/s. The resulting peak inflow of 29,160 m3/s was then used to simulate an extreme flood event in the 2D model. A similar factor of 1.53 was applied to the 100 year ARI inflows from the tributary catchments and the rain falling directly onto the floodplain." (WBM, 2004).

The above WBM (2004) extreme event definition, and associated model inflows, has been adopted for this study.

4.2 Design Event Model Boundary Conditions

The design inflows used for the Clarence River Flood Study Review (WBM, 2004) are presented in Table 4-2. These design inflows have been adopted for this study. The derivation and application of each of these inputs during the design event modelling is outlined in the following sections.

Table 4-2 Lower Clarence Flood Model Peak Design Flood Inflows

Design Flood Event	*Clarence River Inflow (m^3/s)*	*Tributary Inflows (m^3/s)*						
		Glenugie Creek	*Coldstream River*	*Shark Creek*	*Sportsmans Creek*	*Great Estuary Creek*	*Cowley Creek*	*Esk River*
20% AEP	9,360	223	486	66	458	192	209	780
5% AEP	16,280	326	708	96	658	276	300	1,110
2% AEP	18,220	407	877	118	813	341	370	1,361
1% AEP	19,060	445	957	127	884	367	401	1,462
Extreme Event	29,162	715	1538	201	1438	587	641	2,330

4.2.1 Clarence River Inflows

As part of the Lower Clarence River Flood Study Review (WBM, 2004) the inflows used for the Clarence River at Mountain View in the preceding Lower Clarence Flood Study (PWD, 1988) were reviewed. The basis of this review was the development of rating curves for the Clarence River at Grafton to cover the varying catchment states from the start of records in 1839 to the present.

Four "historical" rating curves were derived to represent four distinct floodplain states, presented in Figure B 1. These rating curves were then used to derive revised peak inflows based on the recorded flood levels at Prince Street Gauge over more than 150 years.

An annual maximum flood frequency analysis of the 150 years of revised peak inflows was completed using the flood frequency analysis program "FLIKE". As part of the flood frequency analysis two distributions were produced. These were the Generalised Extreme Value (GEV) and Log Pearson 3 (LP3) distributions. Comparing the two methods, the GEV distribution was found to provide the best results. For ARI's greater than 5 years the GEV fits the data satisfactorily. Almost all the data fall within the 90% confidence limits. Figure 4-1 shows the results of the GEV flood frequency analysis.

Based on the design flows calculated using the flood frequency analysis, the WBM (2004) study scaled Clarence River inflows at Mountain View using a flood hydrograph corresponding to recorded data for a historic 1974 flood event. The 1974 flood event was chosen as the hydrograph input for this purpose as comparisons with other recorded historic events indicated its shape represented a typical stage hydrograph at the Prince Street Gauge.

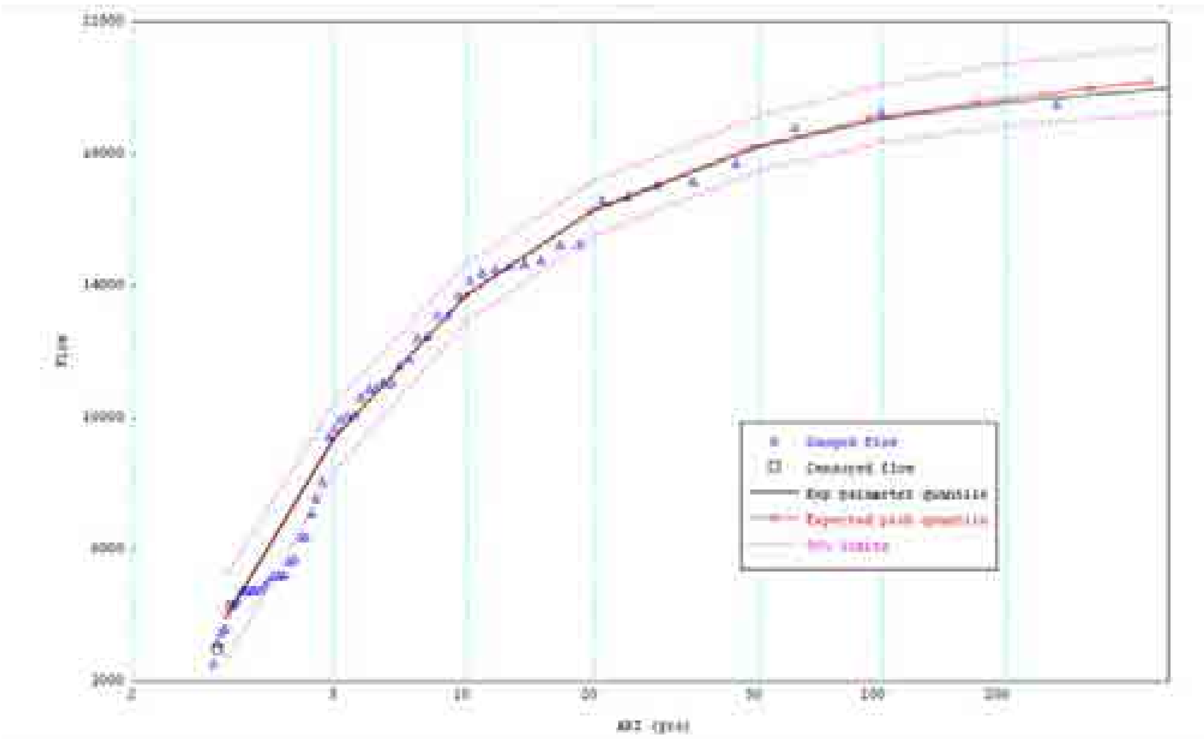


Figure 4-1 Flood Frequency Curve using GEV (Annual Series of Flows from 1839 to 2000)

The 2004 (WBM) flood frequency analysis adopted a methodology which is consistent with current *recommendations outlined in the draft Australian Rainfall and Runoff update, "Book 4 Estimation of Peak Discharge"* (Kuczera G and Frank S, 2012). The assessment:

1 Accounts for non-homogeneity within the recorded flood population, including:

   a. Changes in catchment conditions[3] which may have a significant impact on the gauge rating curve; and

   b. Changes in gauge datum – from South Grafton Railway gauge datum to Australian Height datum (mAHD).

[3] For example, the construction of levees containing flow within the river channel.

2 Uses a sufficient length of record data to reduce uncertainty associated with the extreme value estimates (162 years).

Due to these consistencies with current guidelines, the flood frequency design flows derived during the 2004 (WBM) study have been adopted for this study[4].

The smallest design flood event which is being considered for this study is the 20% AEP design event. It should be recognised that this event represents the lower limit of applicability for the Annual Maximum flood frequency analysis method. If events are required for assessment with lesser magnitudes than the 20% AEP event (e.g. 40% AEP event), peak flows should be derived using the Peak Over Threshold (POT) method, as shown in Figure 4-2.

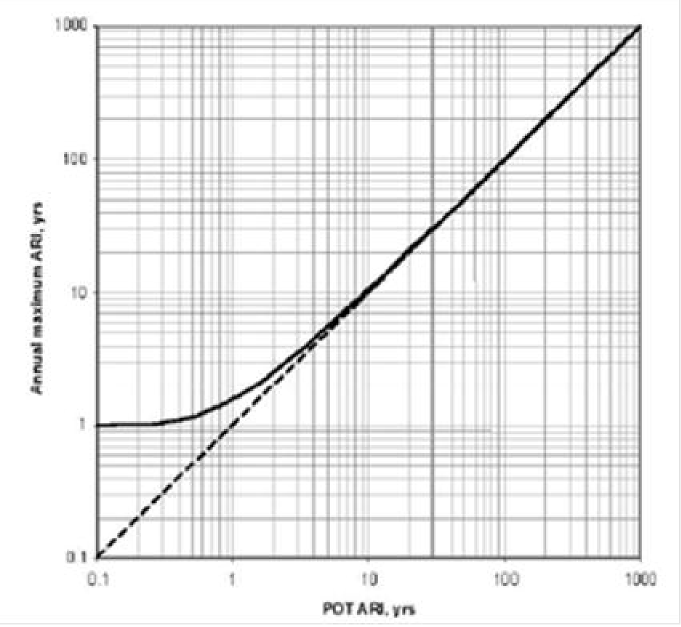


Figure 4-2 Relationship between Annual Maximum and Peak Over Threshold Average Recurrence Intervals (Kuczera G and Frank S, 2012)

4.2.2 Tributary Inflows

The design rainfall and temporal patterns for the tributary catchments for the 72 hour design storm, as recommended in Australian Rainfall and Runoff (1987), were used as input to the hydrologic models of these catchments. The 72 hour design storm was adopted because as at the time of writing it was the longest duration event with defined temporal pattern guidance provided by Australian Rainfall and Runoff. Compared to other temporal patterns, the 72 hour event provides the highest flood levels throughout the catchment. The adopted design rainfall and temporal patterns will be reviewed with the release of the forthcoming Australian Rainfall and Runoff update. For the initial and continuing rainfall losses, values of 30mm and 2mm/h were used. These losses are typical of values used for design flood assessments of NSW coastal rivers.

4 It should however be noted that the design flow estimate statistics currently do not include peak flow information associated with the events which have occurred since 2004. As such, it does not include details for the major flood events which occurred in 2009, 2011 and 2013.

4.2.3 Floodplain Runoff

The rainfall on the floodplain was simulated as runoff to the 2D flood model by simulating ponding of the rainfall immediately on the floodplain without any flood routing. Similar for the above inflows, for the initial and continuing rainfall losses, values of 30mm and 2mm/h were used.

4.2.4 Ocean Boundary Condition

WBM (2004) adopted design flood ocean levels defined by the Lower Clarence River Flood Study (PWD, 1988). These ocean boundaries, shown in Figure 4-3 have subsequently been adopted for this study. The adopted design flood ocean levels will be reviewed with the release of the forthcoming Australian Rainfall and Runoff update.

These peak tidal boundary levels approximate guideline values specified within ‘Floodplain Management Guideline No5 Ocean Boundary Conditions’ (DIPNR, 2004). The shape of the boundary condition does however vary from the guideline values. This variation reflects site specific tidal conditions at the Clarence River.

This study assumes that peak rainfall on the main and tributary catchments coincides with the storm tide peak, representing a slow moving storm which crosses the coast and moves inland. This boundary configuration results in backwater storm tide inundation prior to the arrival of catchment flooding in the lower catchment, as demonstrated in Figure 4-4.

Due to the significant size of the Clarence, and the associated delayed catchment response, coincident timing of equivalent storm tide and catchment flooding peaks at the river entrance has not been assessed. Such a scenario is overly conservative, corresponding to a significantly rarer event than the associated average recurrence interval represents. This assumption is consistent with the results of a research study completed by Collins et al (2012) for the current draft Australian Rainfall and Runoff update. The study found a low level of coincidence between catchment flood event peaks in the Clarence River and elevated ocean levels.

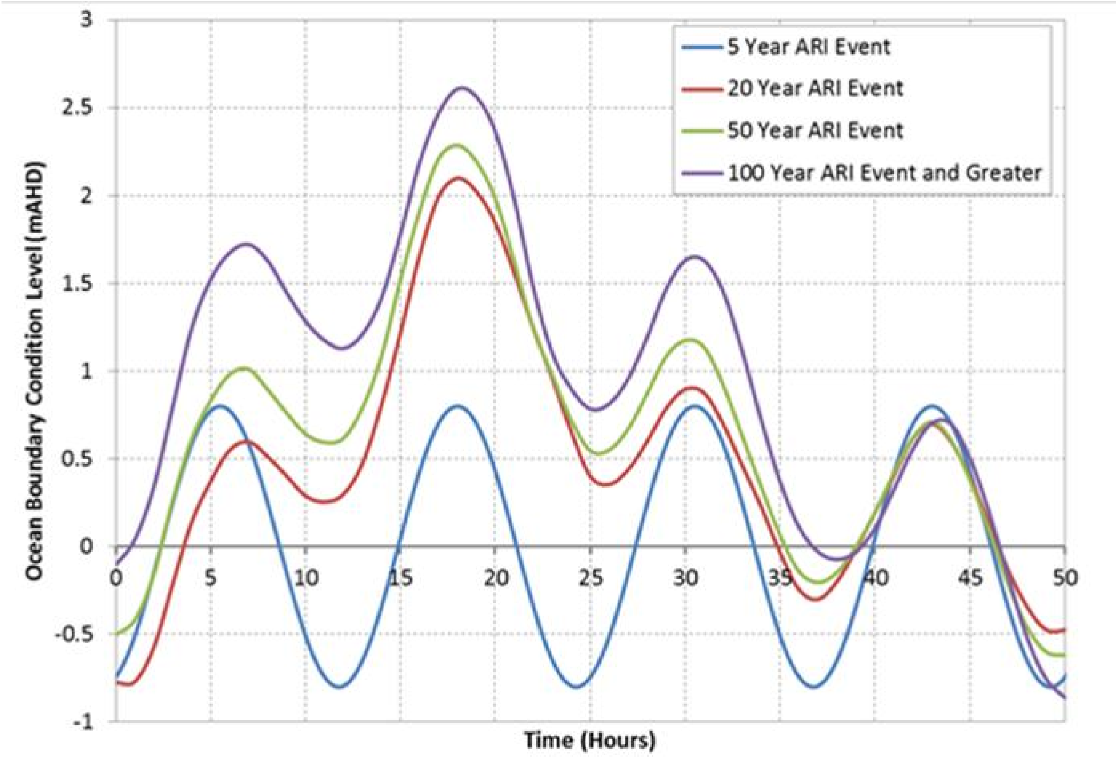


Figure 4-3 Lower Clarence Flood Model Design Tidal Boundaries

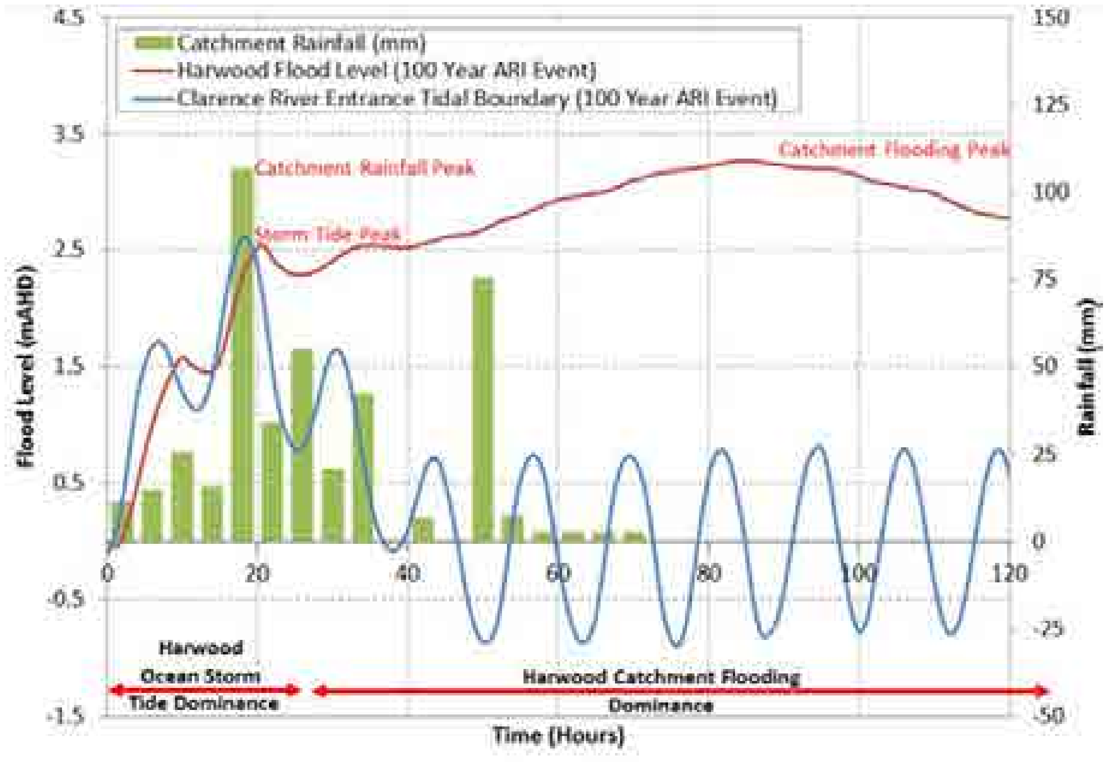


Figure 4-4 Storm Tide/Catchment Flooding Response Time (Harwood)[5]

[5] Harwood is located downstream of Maclean on the main branch of the Clarence River

4.2.5 Model Boundary Condition Revision

Various state and national flood hydraulic/hydrologic guideline documents are currently being updating. This includes:

- Australian Rainfall and Runoff (Engineers Australia):
  - Flood frequency guidelines;
  - Design event rainfall intensity estimates; and
  - Design event temporal patterns.
- Design event ocean boundary conditions (Office of Environment and Heritage).

Review of the Lower Clarence flood model boundary conditions is recommended following publication of these revised guidelines (due late 2014).

4.3 Uncertainty in Design Flood Levels

All design floods are based on statistical analyses of recorded data such as rainfall and flood levels. The longer the period of recordings, the greater the certainty, and vice versa. For example, derivation of the 1% AEP rainfall from 20 years of recordings would have a much greater error margin than from 100 years of recordings.

Similarly, the accuracy of the hydrologic and hydraulic computer models is dependent on the amount and range of reliable rainfall and flood level recordings for model calibration. An uncalibrated model's results have a greater error margin than a calibrated model. However, by using standard model parameters and carrying out sensitivity tests, which vary these parameters within conventional bounds, an uncalibrated model can still be used with confidence by experienced modellers aware of its associated uncertainty and limitations.

The error margin in this study is regarded as better than moderate due to:

1 High quality, high resolution topographic data;

2 A large amount of historic flood level data being used to define the main inflow into the model;

3 Calibration of the flood model to seven historical events of varying magnitude; and

4 The model parameters generally representing industry standard values.

4.4 Design Event Assessment Results

Figure 4-5 to Figure 4-24 present the peak flood level, depth, velocity and velocity depth product results for the 20%, 5%, 2%, 1% AEP and Extreme flood events. The peak flood level results are also reported in Table 4-3 and Table 4-4 for specific regional and urban locations within the study area.

Due to the size of the Clarence River catchment upstream of Grafton, relative to its various tributary catchments, the flooding behaviour of the Lower Clarence River floodplain is dominated by the flow originating from upstream of Grafton/Mountain View in terms of both peak flood levels and duration of inundation. The flow typically contributes 80% to 90% of the total volume of floodwaters that enters the lower floodplains, and flow can be sustained for several days to weeks. Clarence River floods typically occur from low rainfall intensity events that last several days or even weeks.

On the Clarence River floodplain, the inflows from the smaller tributary catchments downstream play only a minor role in flood behaviour. Even much of the Coldstream River portion of the floodplain, which has an area of almost 300 km^2, is dominated by floodwaters from the Clarence River backing up the Coldstream and inundating the Coldstream basin.

Acknowledging that the river flows originating from upstream of Grafton dominate flooding in the Lower Clarence Valley, the flood behaviour downstream of Grafton is quite complex. A general description of the flooding behaviour, from upstream to downstream, can be described as follows:

- In moderate to large flood events (e.g. a 5% AEPflood), the Grafton and South Grafton levees are overtopped.
- Downstream of Grafton, river flows and elevated river levels result in reverse/backflow up Swan Creek (in large and small floods). This flow then enters the Coldstream Basin. This basin plays an important role in attenuating the flows in the river.
- Inundation of the Coldstream Basin is accompanied by flows from local catchments (e.g. Coldstream River, Glenugie Creek and Pillar Valley Creek). The flood levels within the basin rises slowly (including some minor reverse / backflow through the mouth of the Coldstream River).
- In large flood events (e.g. greater than 2% AEP flood) significant flows enter the Coldstream Basin by overtopping the natural and man-made levees along the Clarence River Bank. These flows re-enter the south arm of the Clarence River via the mouth of the Coldstream River.
- At Cowper / Brushgrove, the river splits into the main Clarence River and the South Arm. The main river and its associated floodplain accommodate approximately 90% of the total flow. The remaining 10% passes along the South Arm and its associated floodplain.
- The South Arm floodplain includes the Shark Creek floodplain area. This area plays a similar (but much smaller role) to that of the Coldstream Basin as described above. However, very little flow short cuts through this area. The flows are generally backflow up Shark Creek, resulting in floodplain storage and subsequent outflow though Shark Creek.
- North of the Shark Creek Basin is the Chaselings / Gulmarrad Basin which initially fills with floodwaters from the local catchment that is unable to drain to the river when river levels rise and shut the floodgates. The area then fills from overtopping of the riverbank and flood levels rise quickly to the same level as the river.
- At Maclean, the two arms of the Clarence River converge for a short length. In large flood events (e.g. greater than 2% AEP flood), the Maclean levees are overtopped.
- Downstream of Maclean, the river again splits into the main river and the North Arm. The majority of the flow is contained within the main river channel. There is a significant width of floodplain between the two channels which is comprised of Harwood Island and Chatsworth Island. These islands are divided by a narrow tidal channel called Serpentine Channel.
- At the mouth of the river system, training walls confine the outflow to a well-defined channel. Storm surges can also result in significant inflows (i.e. reverse flow) into the river system resulting in inundation usually prior to fluvial runoff inundation described above.
- The topographic updates which have been undertaken as part of this update study (regional ALS and urban levee survey) have resulted in changes to the Lower Clarence Valley design flood

levels. A figure showing the changes from WBM (2004) to the current study is provided in Appendix A.

- Regionally, the difference in peak 1% AEP event flood levels are typically within ±0.2m.
- Peak 1% AEP event flood level differences within the Grafton and South Grafton levee systems are larger than the above mentioned regional variation:
    - Peak flood levels in Grafton have increased by up to 2.1m; and
    - Peak flood levels in South Grafton have decreased by 0.3m.

Due to the extensive length of the Grafton and South Grafton levees, slight changes in flood level within the main Clarence River (even as little as 0.01m) have the potential to significantly alter the volume of water overtopping the levee. Flood levels within Grafton and South Grafton are in turn dominated by the volume of flow overtopping the respective levee systems. Therefore, minor changes in levee crest information alter the volume of flow which overtops the levees within the flood model, directly impacting the peak flood levels within the levees.

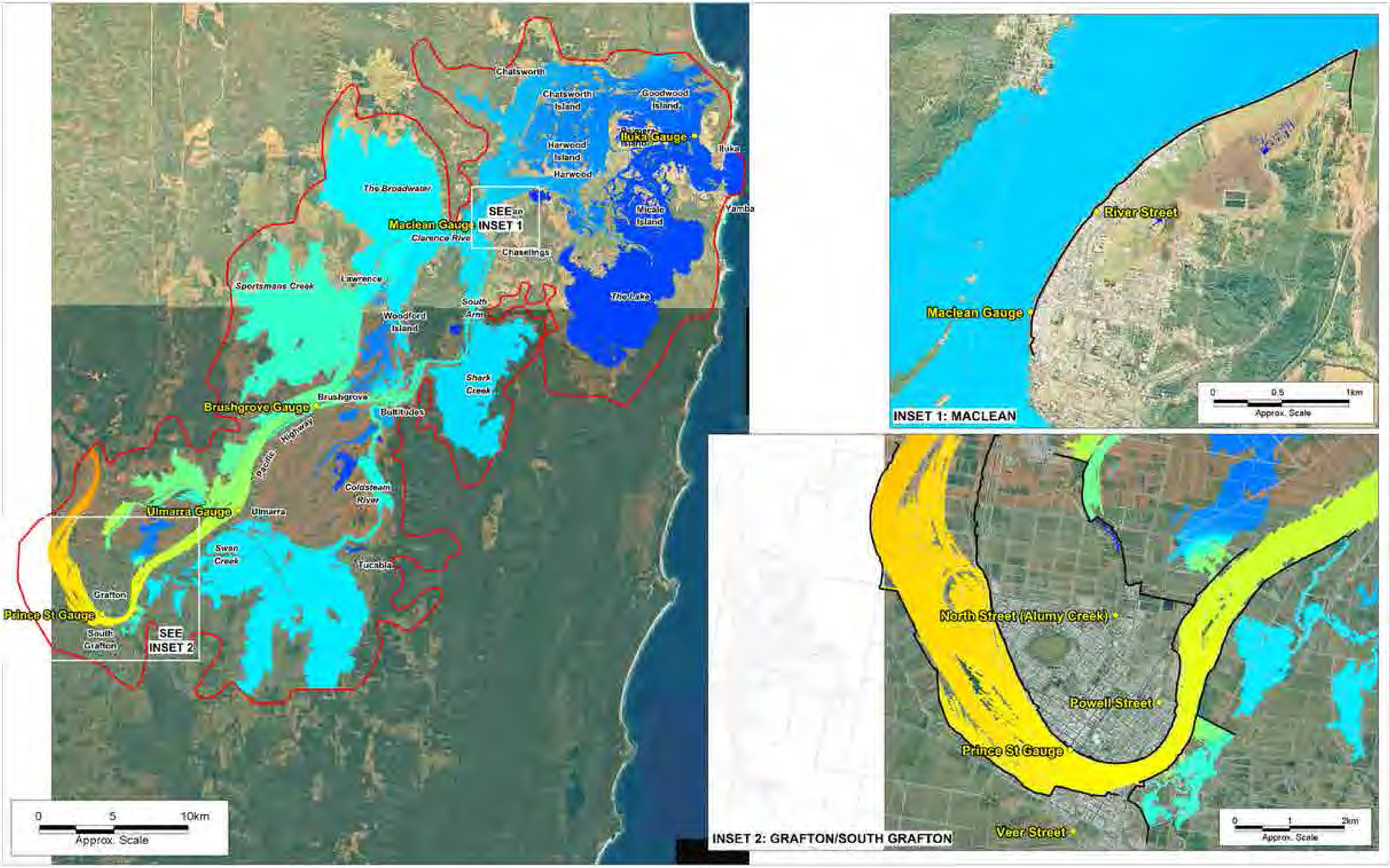
The WBM (2004) study used a variety of design and as constructed plans to define the levee crest information within the flood model. To reduce uncertainty associated with the levee data used in the WBM (2004) study, this study has replaced the 2004 levee information with detailed ground survey information (surveyed by CVC in 2012). Replacing this dataset within the model significantly increases the accuracy of the flood modelling results within the urban areas of Grafton and South Grafton.

Table 4-3 Design Event Results: Regional Reporting Locations

Design Flood Event	*Peak Flood Level (mAHD)*				
	Prince St Gauge (Grafton)	*Ulmarra Gauge (Ulmarra)*	*Brushgrove Gauge (Brushgrove)*	*Maclean Gauge (Maclean)*	*Iluka Gauge (Iluka)*
20% AEP	6.1	5.0	4.2	2.4	1.1
5% AEP	7.9	6.1	5.1	3.1	2.0
2% AEP	8.2	6.2	5.5	3.4	2.2
1% AEP	8.3	6.4	5.8	3.6	2.5
Extreme Event	9.7	8.4	8.0	5.1	3.5

Table 4-4 Design Event Results: Urban Reporting Locations

Design Flood Event	*North St (Alumy Creek) Grafton*	*Powell Street Grafton*	*Veer St South Grafton*	*River Street Maclean*
20% AEP	flood free			
5% AEP	3.6	3.8	flood free	
2% AEP	6.0	6.4	3.8	2.6
1% AEP	6.5	7.1	5.9	3.7
Extreme Event	8.9	9.0	10.0	5.1



LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Level (m AHD)

0.0 to 1.0	7.0 to 8.0
1.0 to 2.0	8.0 to 9.0
2.0 to 3.0	9.0 to 10.0
3.0 to 4.0	10.0 to 11.0
4.0 to 5.0	11.0 to 12.0
5.0 to 6.0	12.0 to 13.0
6.0 to 7.0	Greater than 13.0

Title:

20% AEP Design Event: Peak Flood Level

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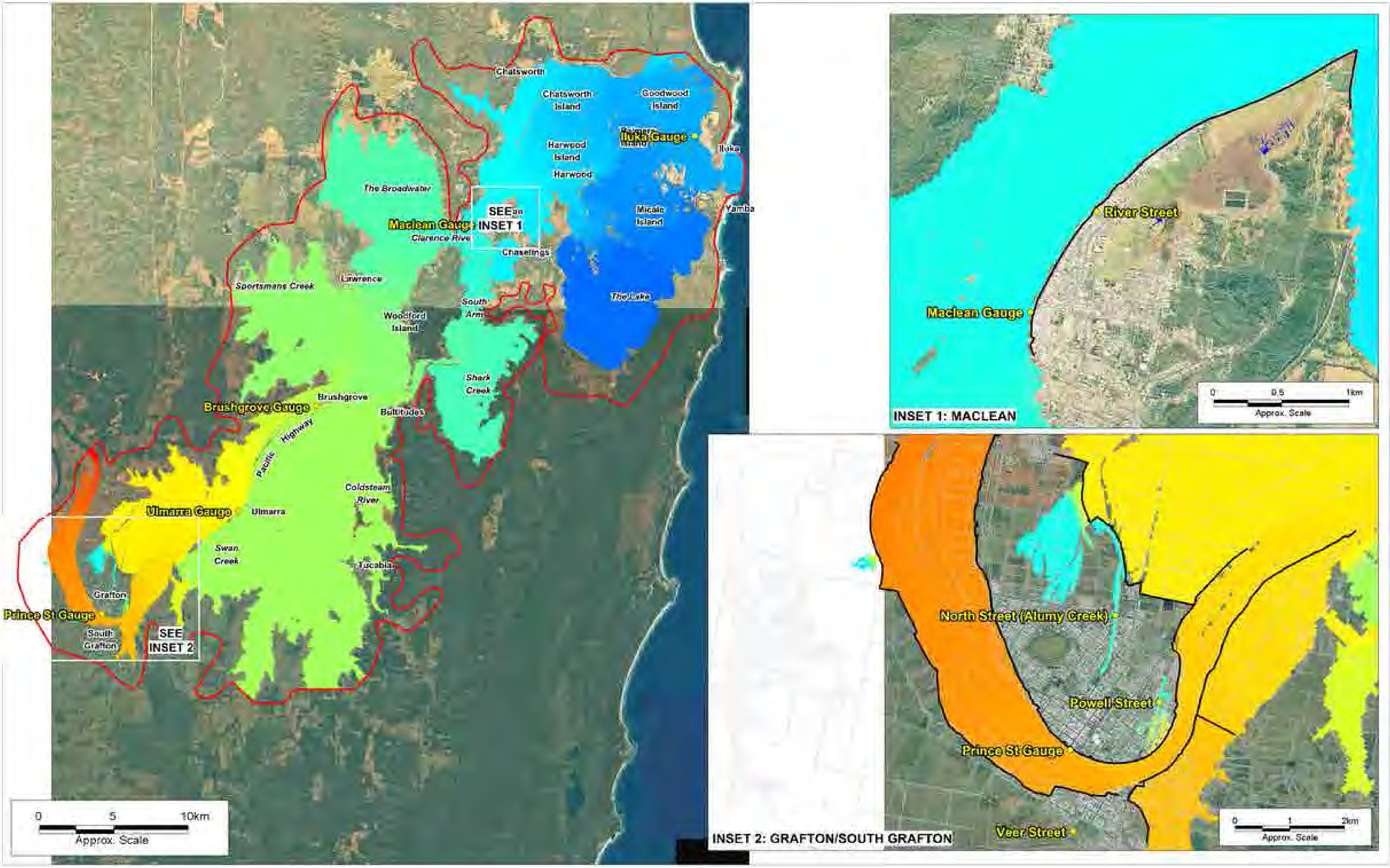

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Level (mAHD)

0.0 to 1.0	7.0 to 8.0
1.0 to 2.0	8.0 to 9.0
2.0 to 3.0	9.0 to 10.0
3.0 to 4.0	10.0 to 11.0
4.0 to 5.0	11.0 to 12.0
5.0 to 6.0	12.0 to 13.0
6.0 to 7.0	Greater than 13.0

Title:

5% AEP Design Event: Peak Flood Level

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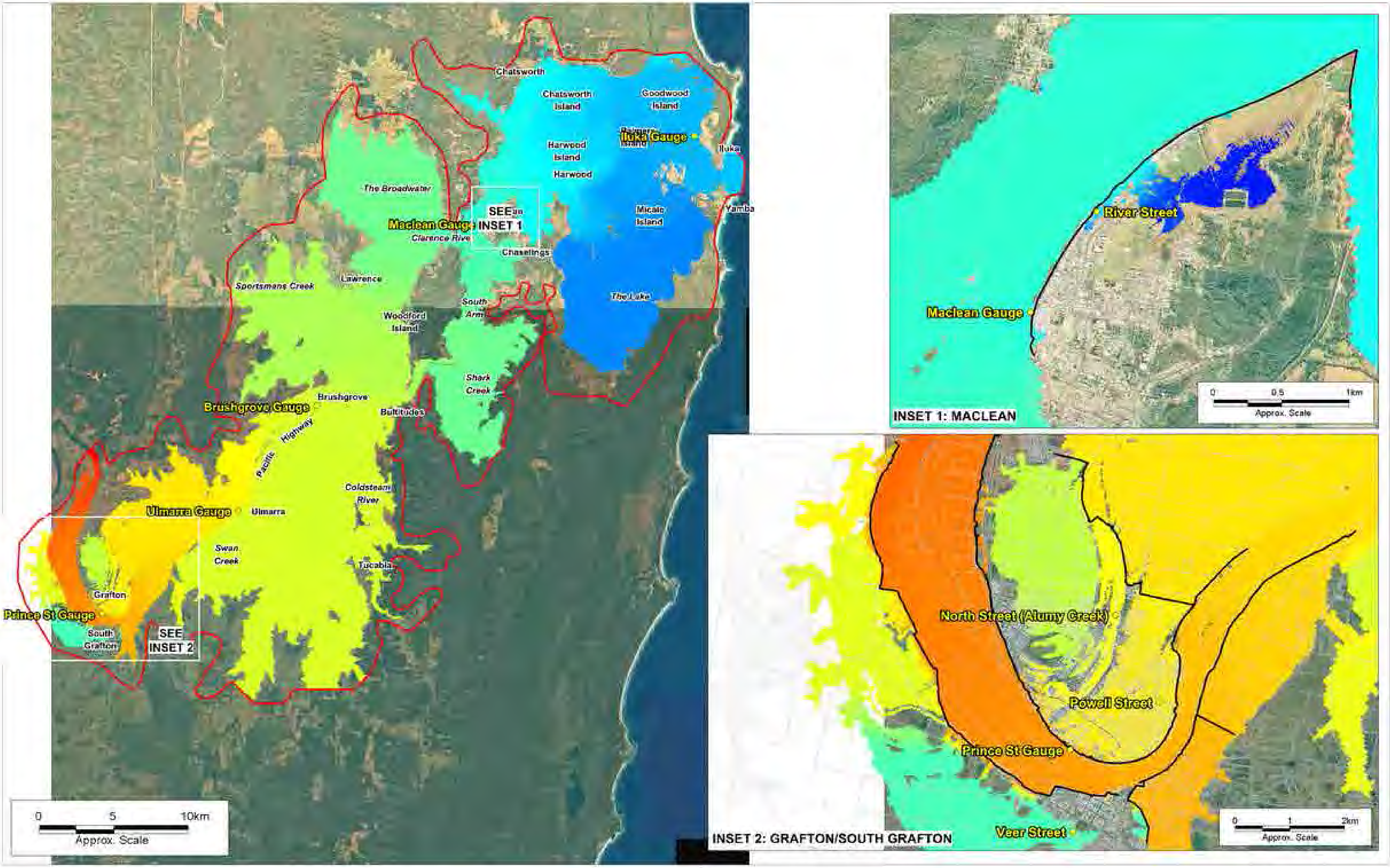

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Level (mAHD)

- 0.0 to 1.0
- 1.0 to 2.0
- 2.0 to 3.0
- 3.0 to 4.0
- 4.0 to 5.0
- 5.0 to 6.0
- 6.0 to 7.0
- 7.0 to 8.0
- 8.0 to 9.0
- 9.0 to 10.0
- 10.0 to 11.0
- 11.0 to 12.0
- 12.0 to 13.0
- Greater than 13.0

Title:
2% AEP Design Event: Peak Flood Level

Figure: 4-7

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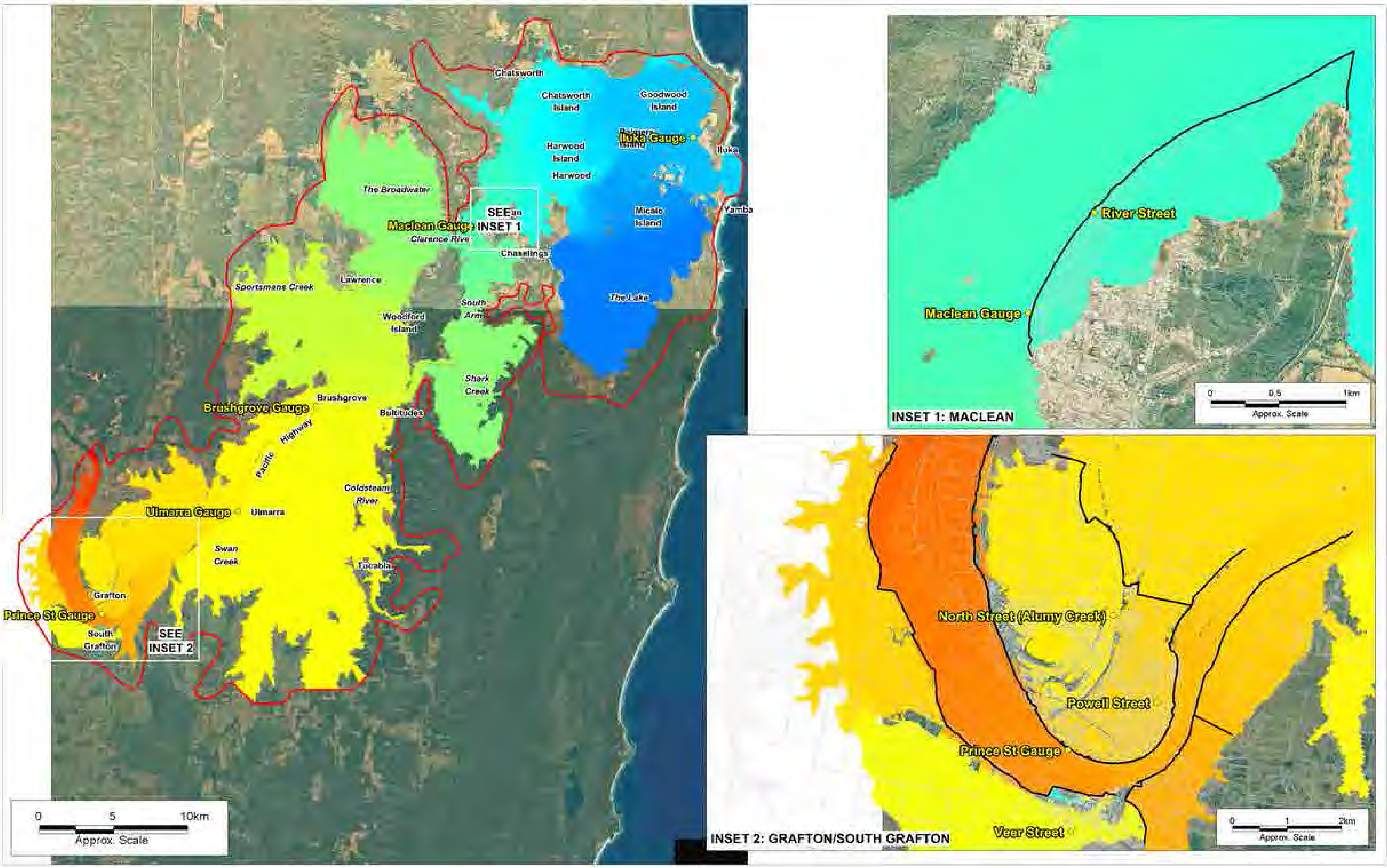

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Level (m AHD)

0.0 to 1.0	7.0 to 8.0
1.0 to 2.0	8.0 to 9.0
2.0 to 3.0	9.0 to 10.0
3.0 to 4.0	10.0 to 11.0
4.0 to 5.0	11.0 to 12.0
5.0 to 6.0	12.0 to 13.0
6.0 to 7.0	Greater than 13.0

Title:

1% AEP Design Event: Peak Flood Level

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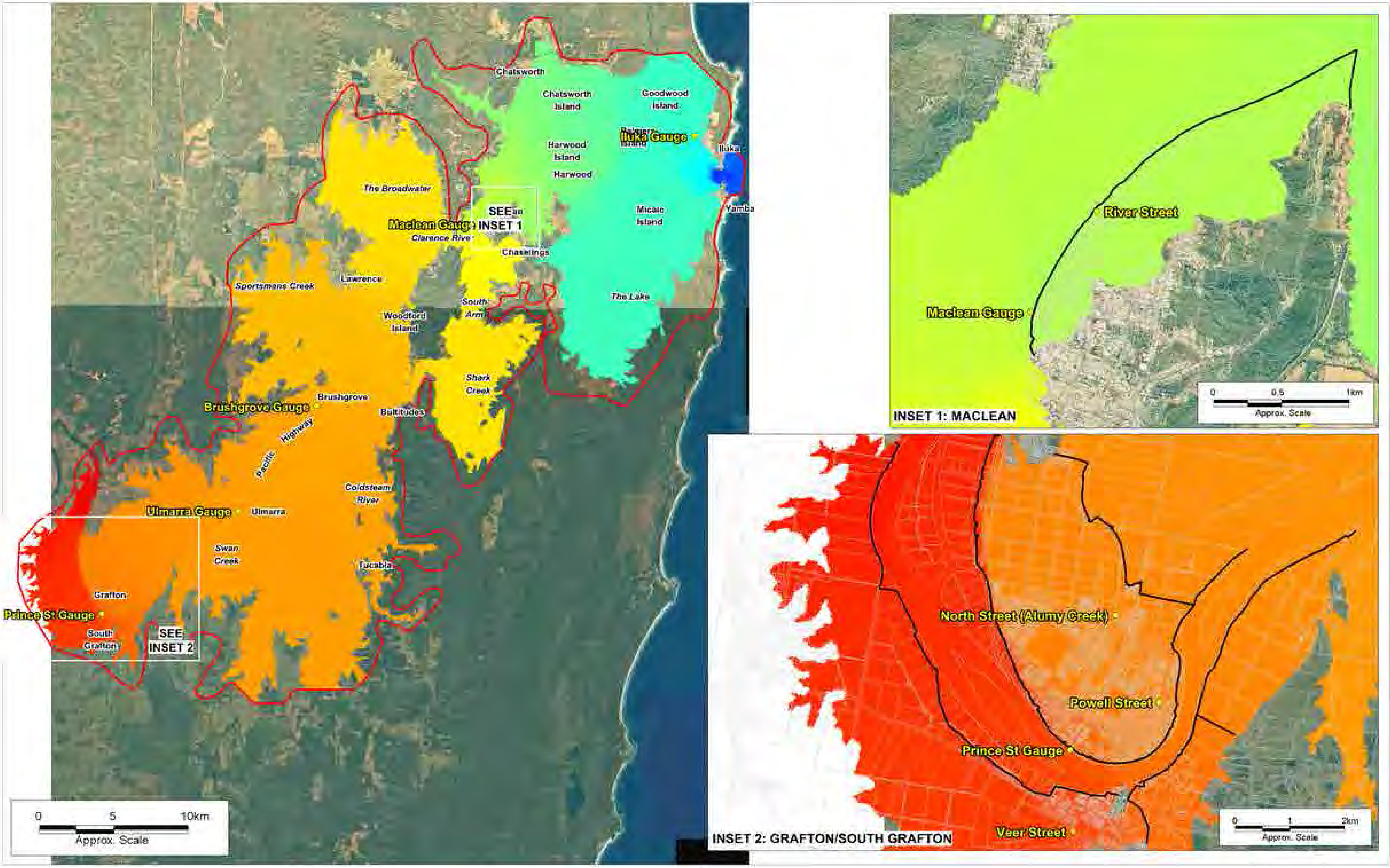

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Level (mAHD)

0.0 to 1.0	7.0 to 8.0
1.0 to 2.0	8.0 to 9.0
2.0 to 3.0	9.0 to 10.0
3.0 to 4.0	10.0 to 11.0
4.0 to 5.0	11.0 to 12.0
5.0 to 6.0	12.0 to 13.0
6.0 to 7.0	Greater than 13.0

Title:

Extreme Event: Peak Flood Level

Figure: 4-9

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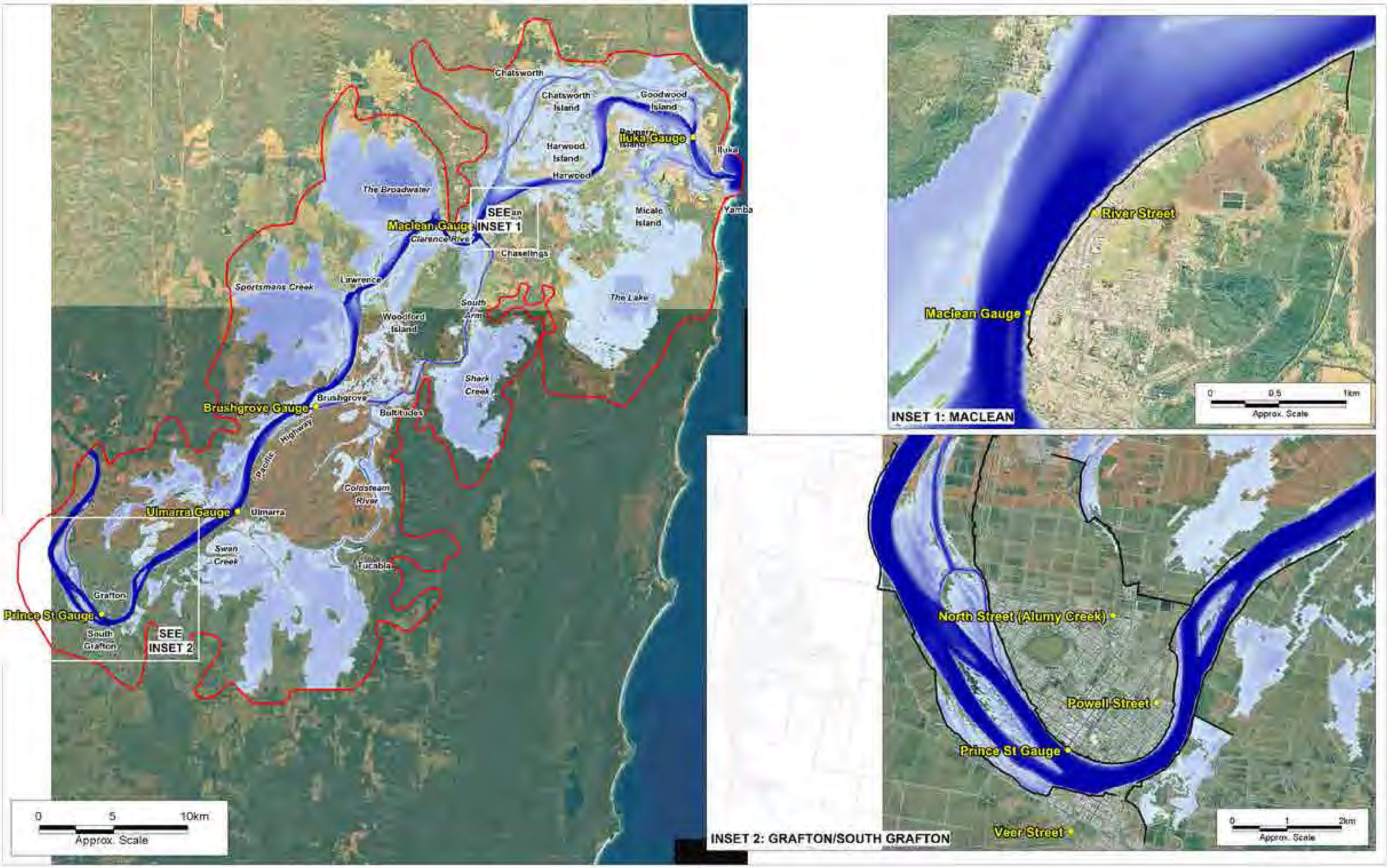

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Depth (m)

- 0.0 to 1.0
- 1.0 to 2.0
- 2.0 to 3.0
- 3.0 to 4.0
- 4.0 to 5.0
- 5.0 to 6.0
- 6.0 to 7.0
- 7.0 to 8.0
- 8.0 to 9.0
- 9.0 to 10.0
- Greater than 10.0

Title:

20% AEP Design Event: Peak Flood Depth

Figure: 4-10

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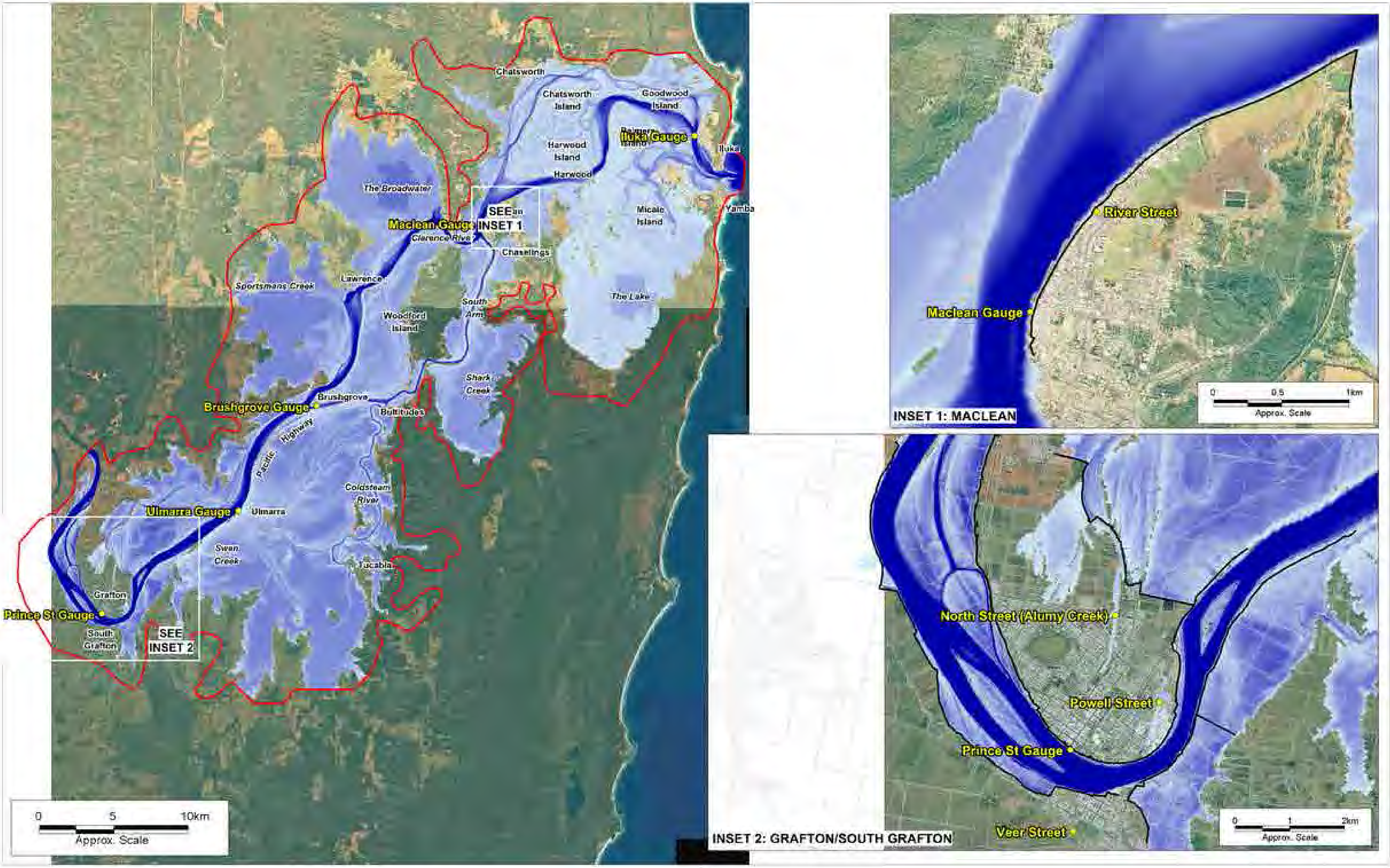

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Depth (m)

- 0.0 to 1.0
- 1.0 to 2.0
- 2.0 to 3.0
- 3.0 to 4.0
- 4.0 to 5.0
- 5.0 to 6.0
- 6.0 to 7.0
- 7.0 to 8.0
- 8.0 to 9.0
- 9.0 to 10.0
- Greater than 10.0

Title:

5% AEP Design Event: Peak Flood Depth

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Figure: 4-11

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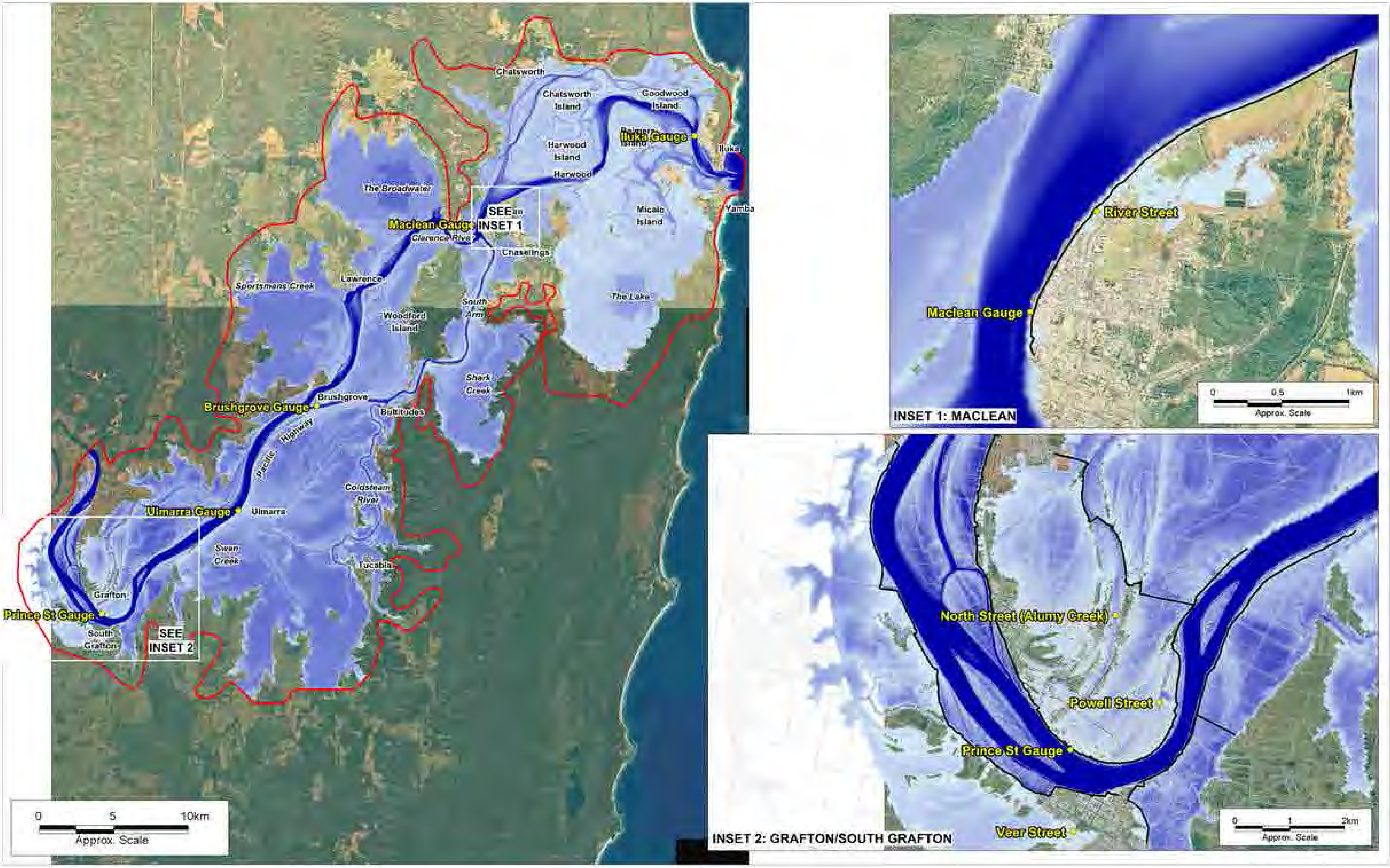

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Depth (m)

- 0.0 to 1.0
- 1.0 to 2.0
- 2.0 to 3.0
- 3.0 to 4.0
- 4.0 to 5.0
- 5.0 to 6.0
- 6.0 to 7.0
- 7.0 to 8.0
- 8.0 to 9.0
- 9.0 to 10.0
- Greater than 10.0

Title:

2% AEP Design Event: Peak Flood Depth

Figure: 4-12

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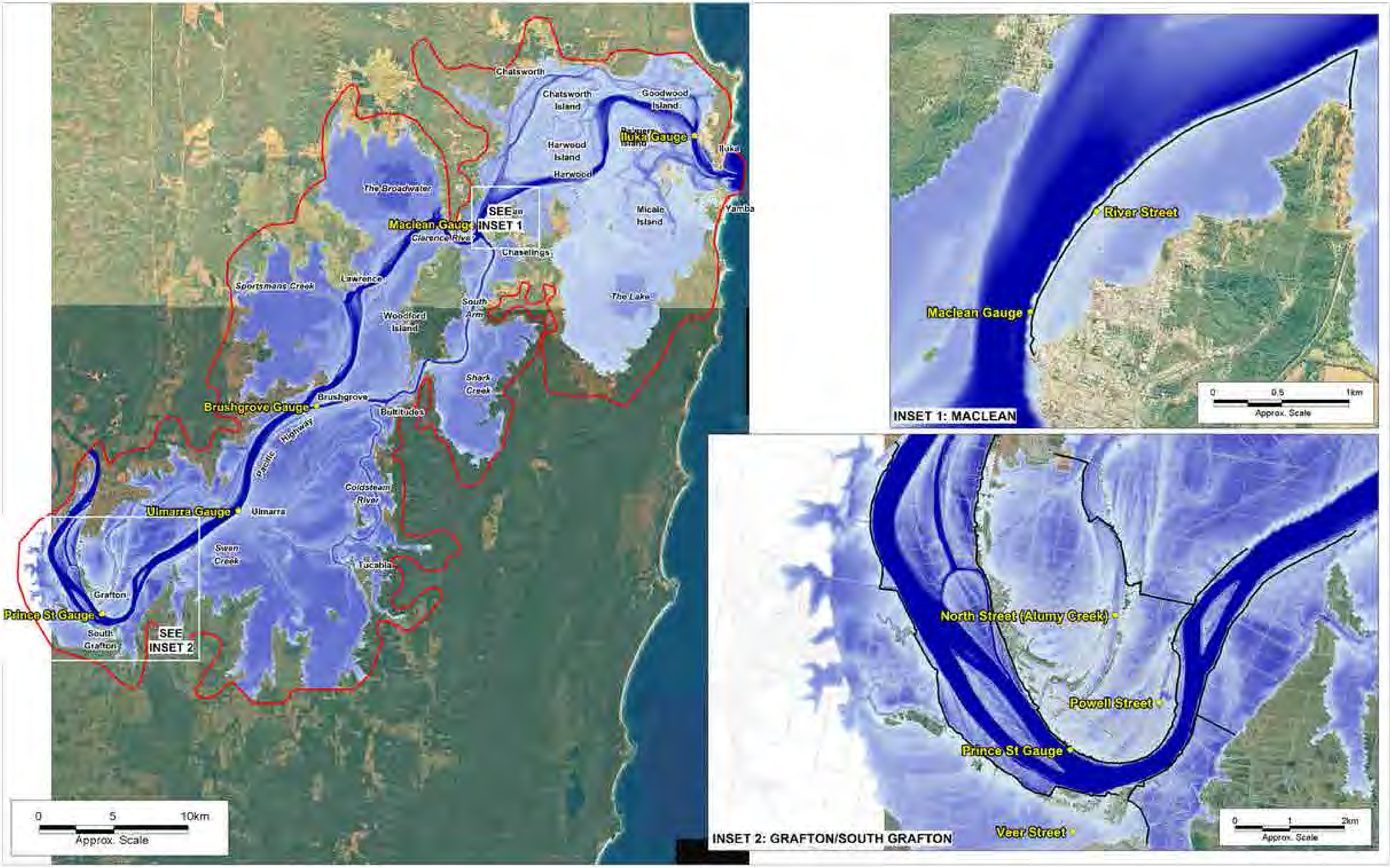

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Depth (m)

- 0.0 to 1.0
- 1.0 to 2.0
- 2.0 to 3.0
- 3.0 to 4.0
- 4.0 to 5.0
- 5.0 to 6.0
- 6.0 to 7.0
- 7.0 to 8.0
- 8.0 to 9.0
- 9.0 to 10.0
- Greater than 10.0

Title:
1% AEP Design Event: Peak Flood Depth

Figure: 4-13

Rev: A

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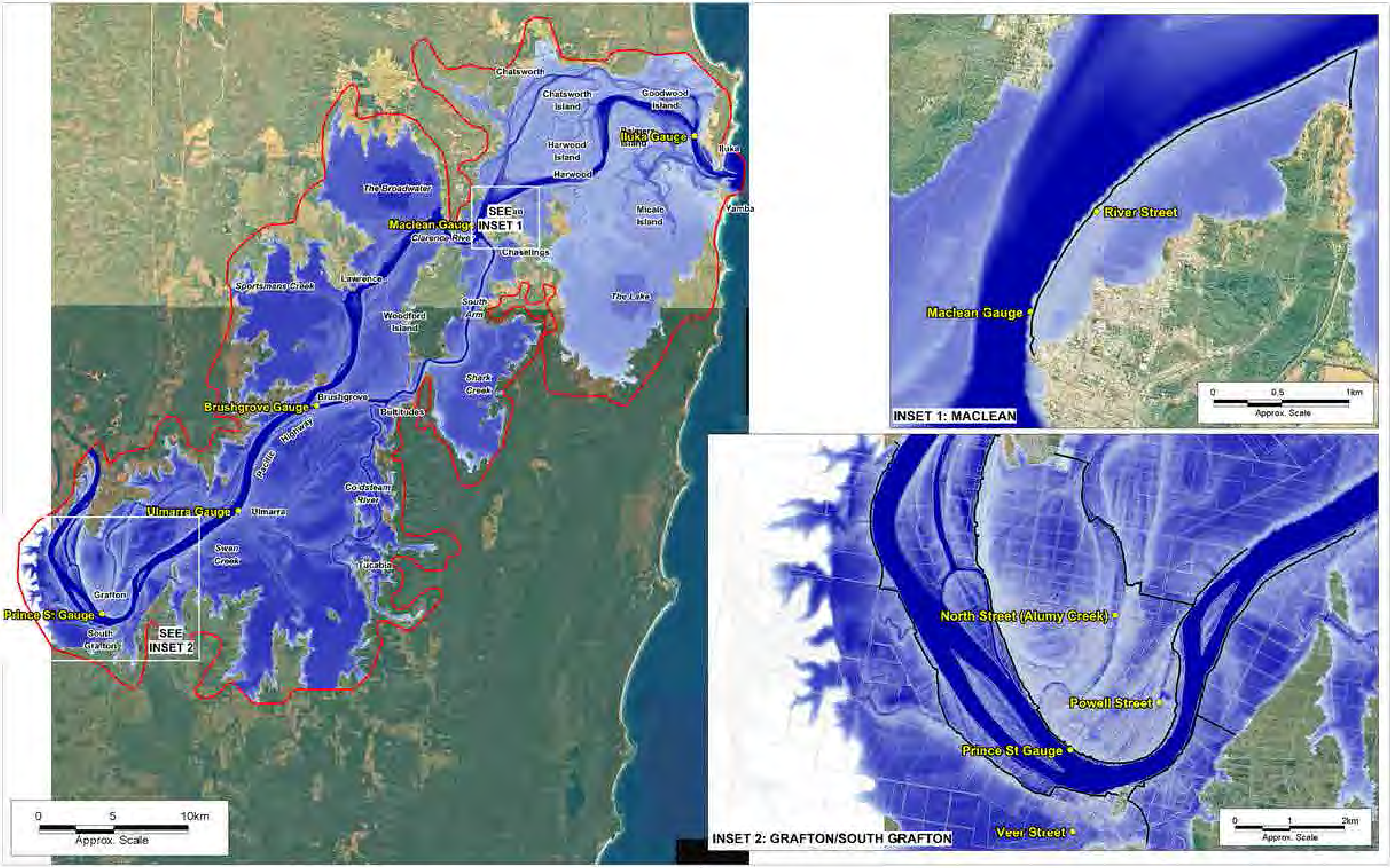

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Depth (m)

- 0.0 to 1.0
- 1.0 to 2.0
- 2.0 to 3.0
- 3.0 to 4.0
- 4.0 to 5.0
- 5.0 to 6.0
- 6.0 to 7.0
- 7.0 to 8.0
- 8.0 to 9.0
- 9.0 to 10.0
- Greater than 10.0

Title:

Extreme Event: Peak Flood Depth

Figure: **4-14**

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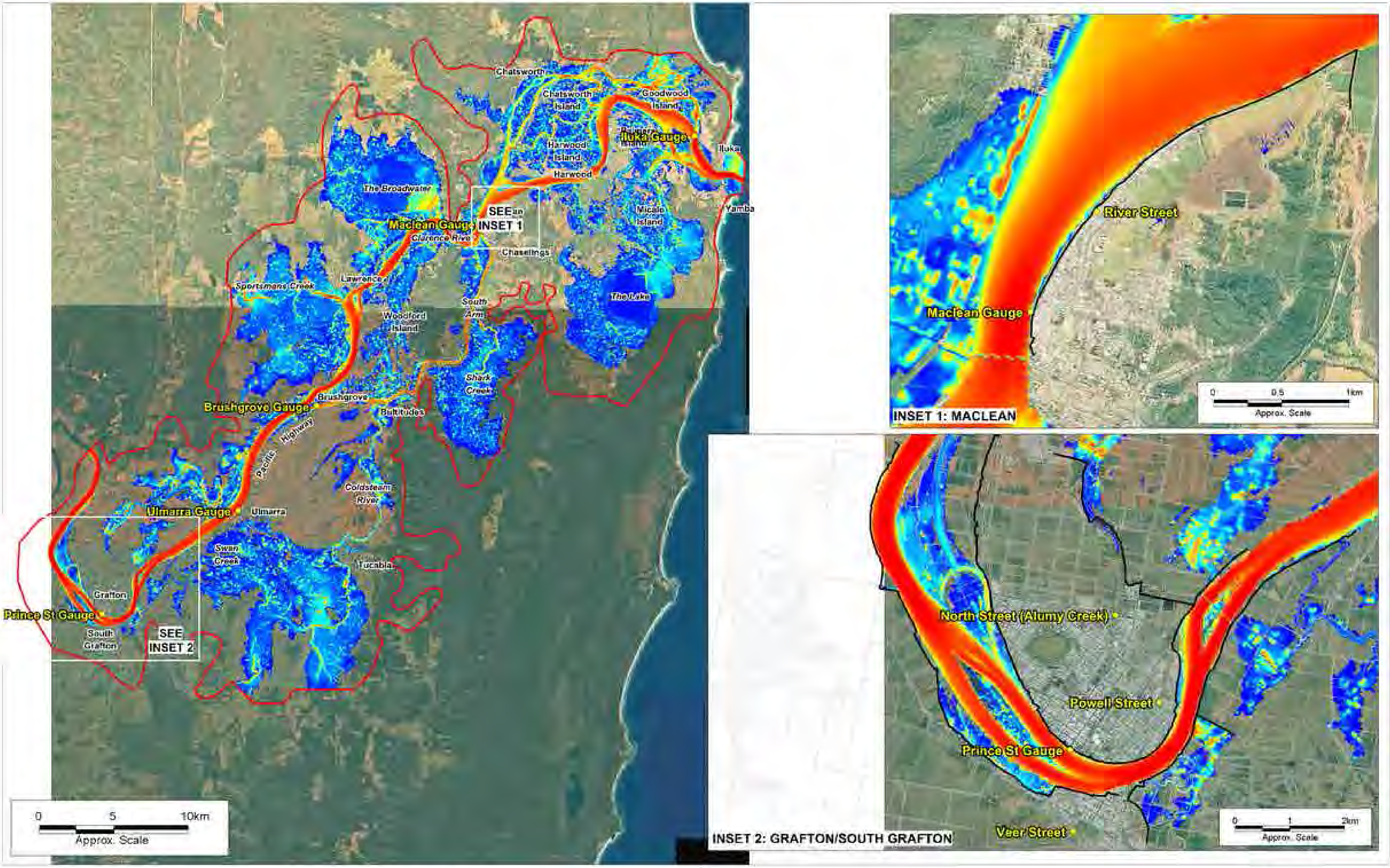

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Velocity (m/s)

- 0.0 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1.0
- 1.0 to 1.2
- 1.2 to 1.4
- 1.4 to 1.6
- 1.6 to 1.8
- 1.8 to 2.0
- Greater than 2.0

Title:

20% AEP Design Event: Peak Flood Velocity

Figure: 4-15

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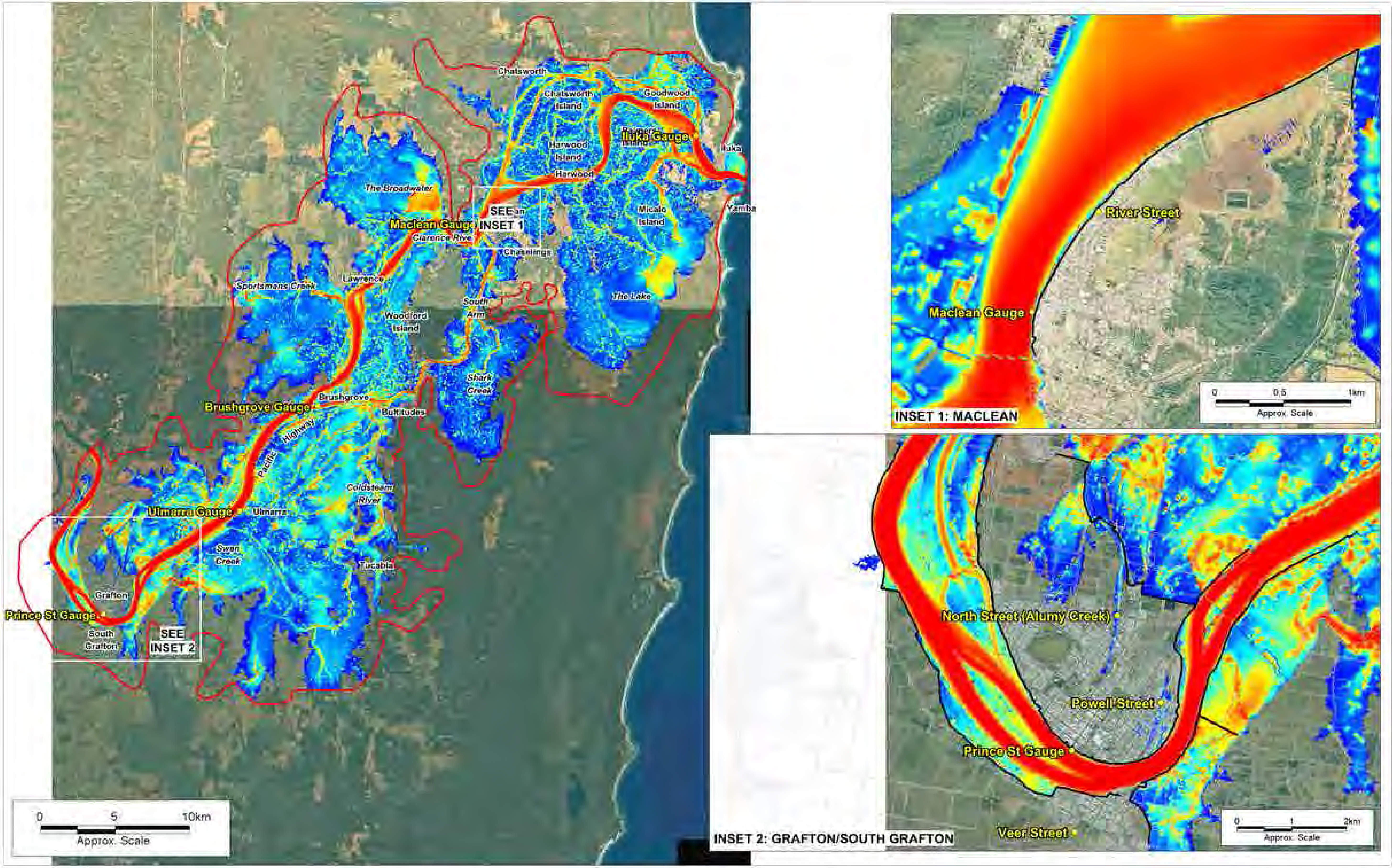

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Velocity (m/s)

- 0.0 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1.0
- 1.0 to 1.2
- 1.2 to 1.4
- 1.4 to 1.6
- 1.6 to 1.8
- 1.8 to 2.0
- Greater than 2.0

Title:
5% AEP Design Event: Peak Flood Velocity

Figure: 4-16

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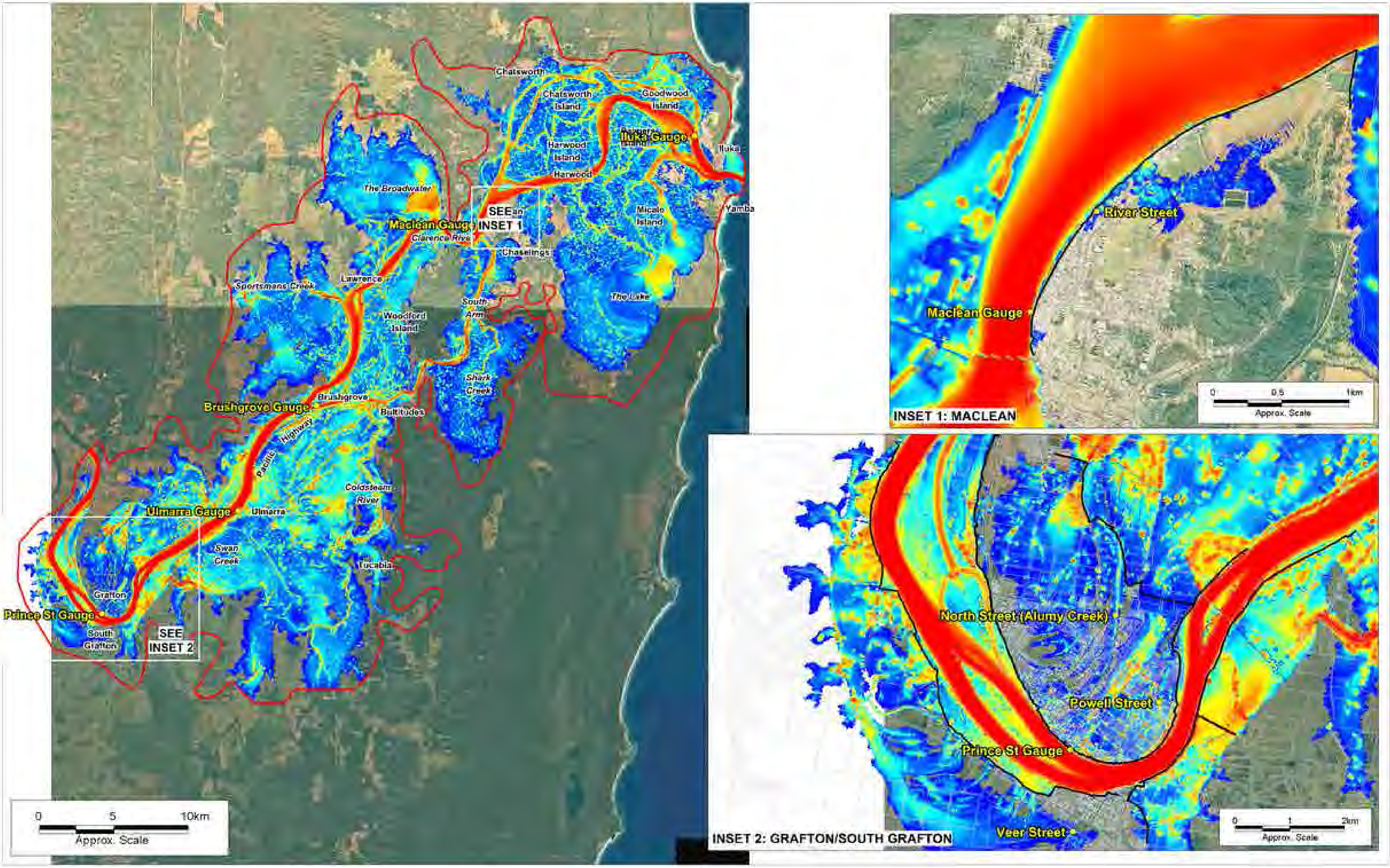

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Velocity (m/s)

- 0.0 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1.0
- 1.0 to 1.2
- 1.2 to 1.4
- 1.4 to 1.6
- 1.6 to 1.8
- 1.8 to 2.0
- Greater than 2.0

Title:

2% AEP Design Event: Peak Flood Velocity

Figure: 4-17

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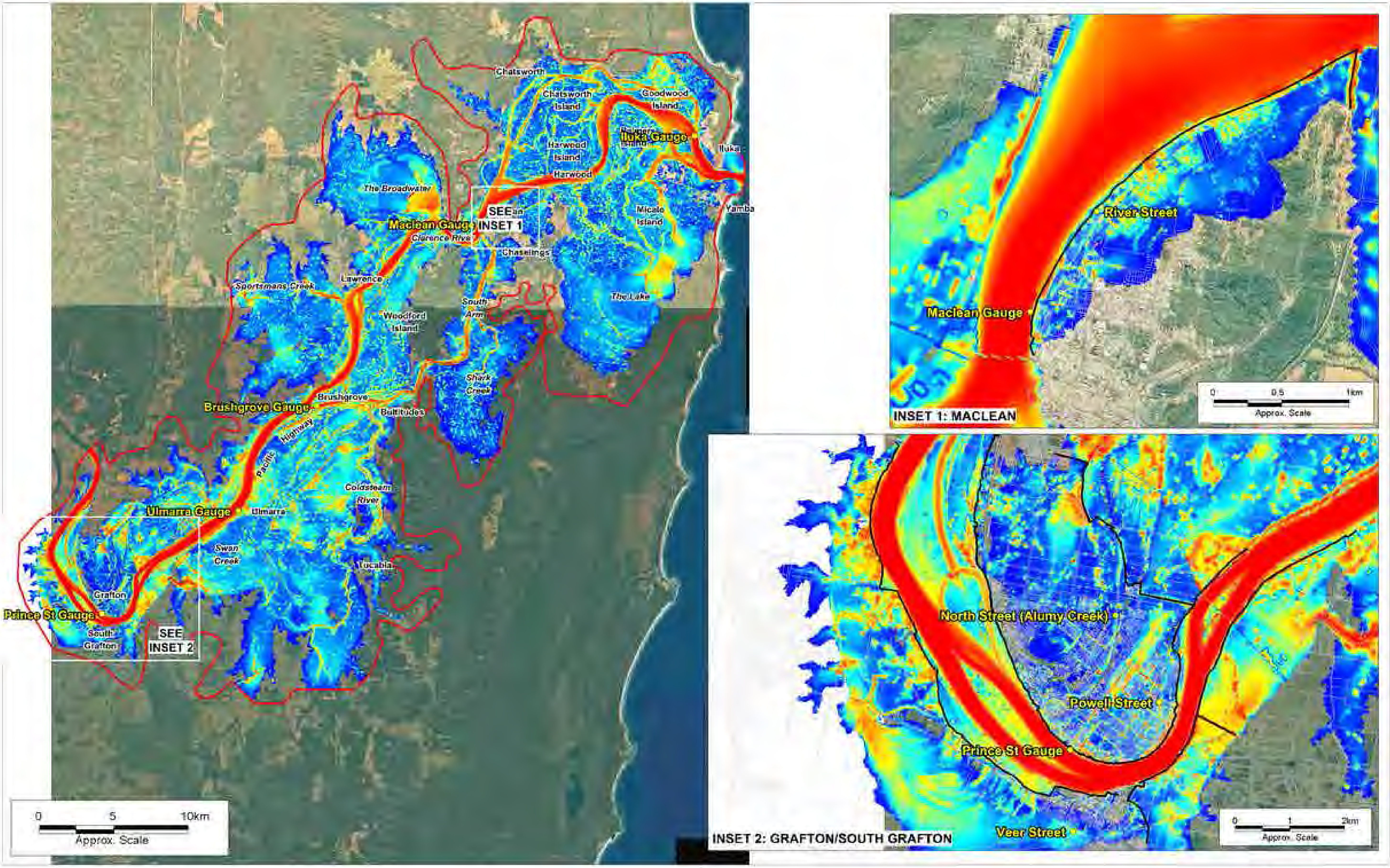

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Velocity (m/s)

- 0.0 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1.0
- 1.0 to 1.2
- 1.2 to 1.4
- 1.4 to 1.6
- 1.6 to 1.8
- 1.8 to 2.0
- Greater than 2.0

Title:

1% AEP Design Event: Peak Flood Velocity

Figure: 4-18

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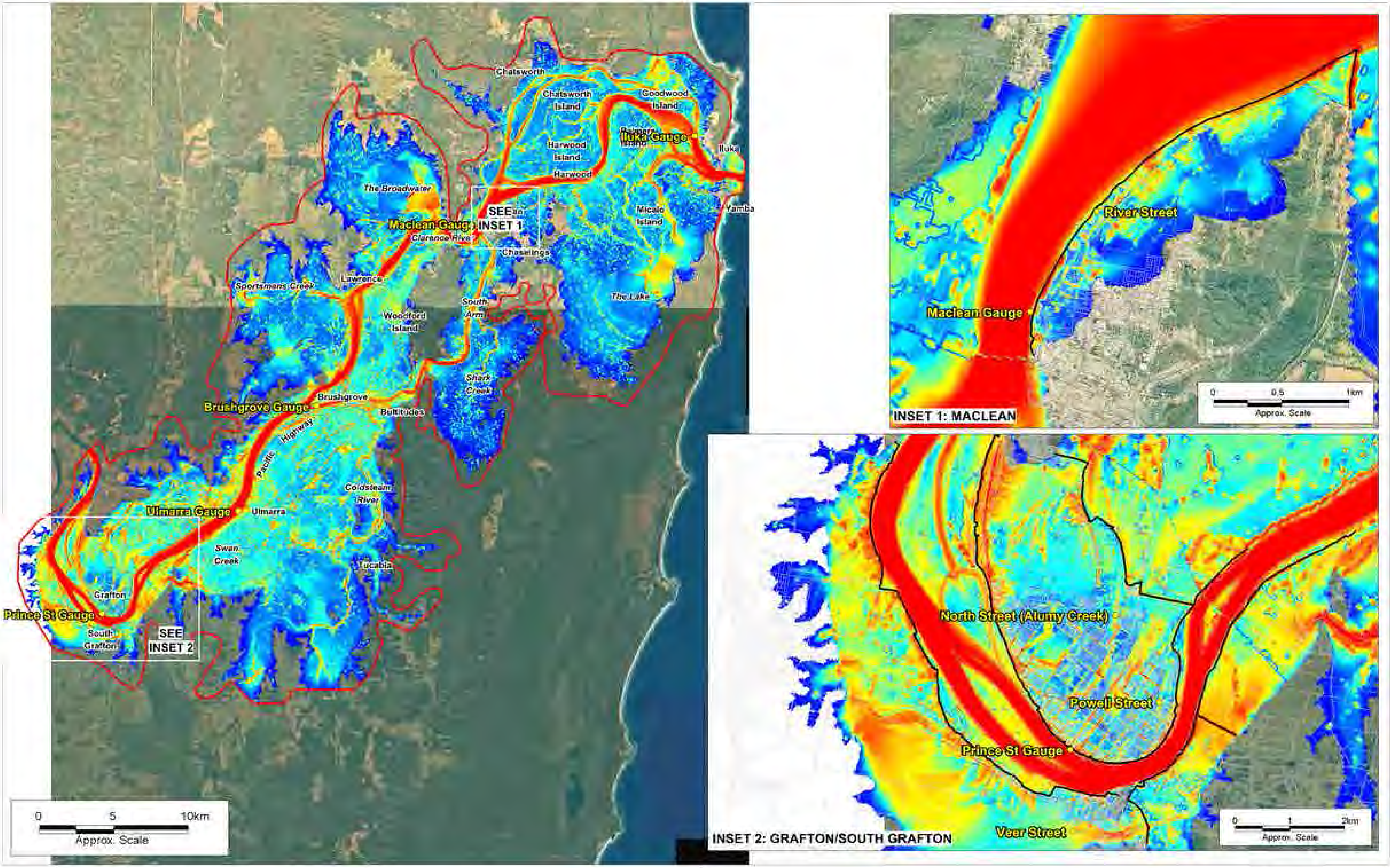

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Velocity (m/s)

- 0.0 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1.0
- 1.0 to 1.2
- 1.2 to 1.4
- 1.4 to 1.6
- 1.6 to 1.8
- 1.8 to 2.0
- Greater than 2.0

Title:

Extreme Event: Peak Flood Velocity

Figure: 4-19

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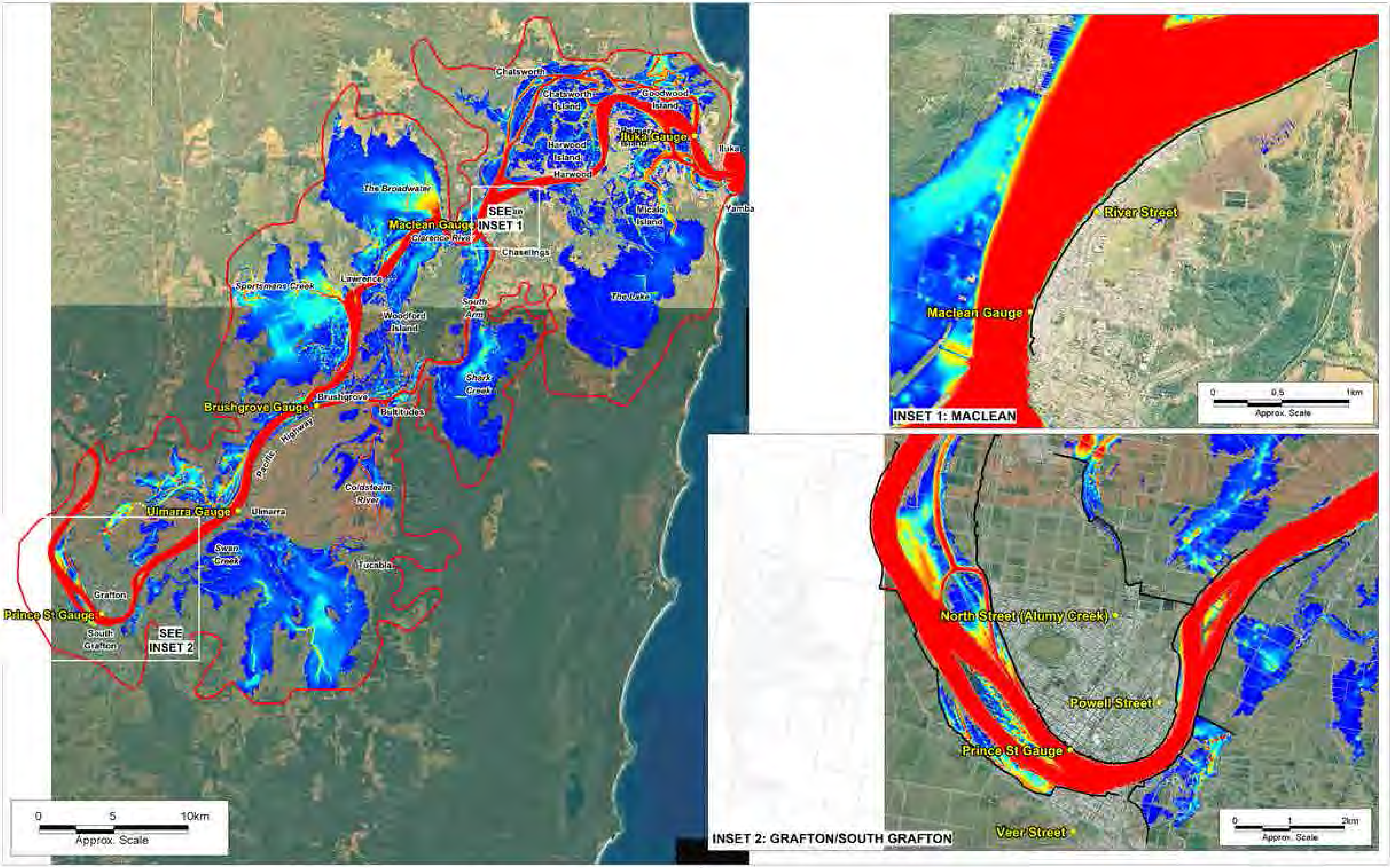

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Velocity Depth Product (m^2/s)

- 0.0 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1.0
- 1.0 to 1.2
- 1.2 to 1.4
- 1.4 to 1.6
- 1.6 to 1.8
- 1.8 to 2.0
- Greater than 2.0

Title:

20% AEP Design Event: Peak Flood Velocity Depth Product

Figure: 4-20

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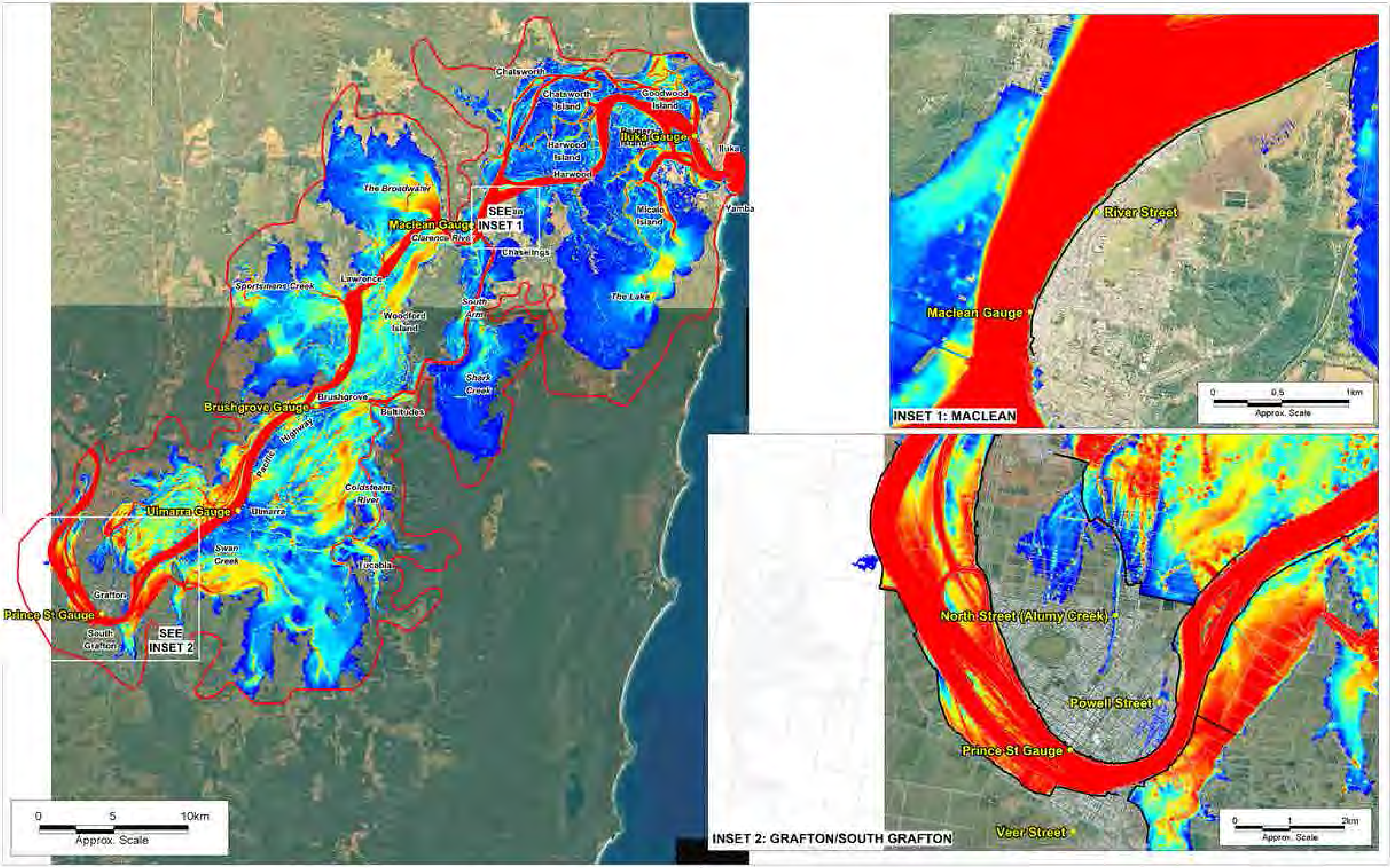

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Velocity Depth Product (m^2/s)

- 0.0 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1.0
- 1.0 to 1.2
- 1.2 to 1.4
- 1.4 to 1.6
- 1.6 to 1.8
- 1.8 to 2.0
- Greater than 2.0

Title:

5% AEP Design Event: Peak Flood Velocity Depth Product

N

Figure: 4-21

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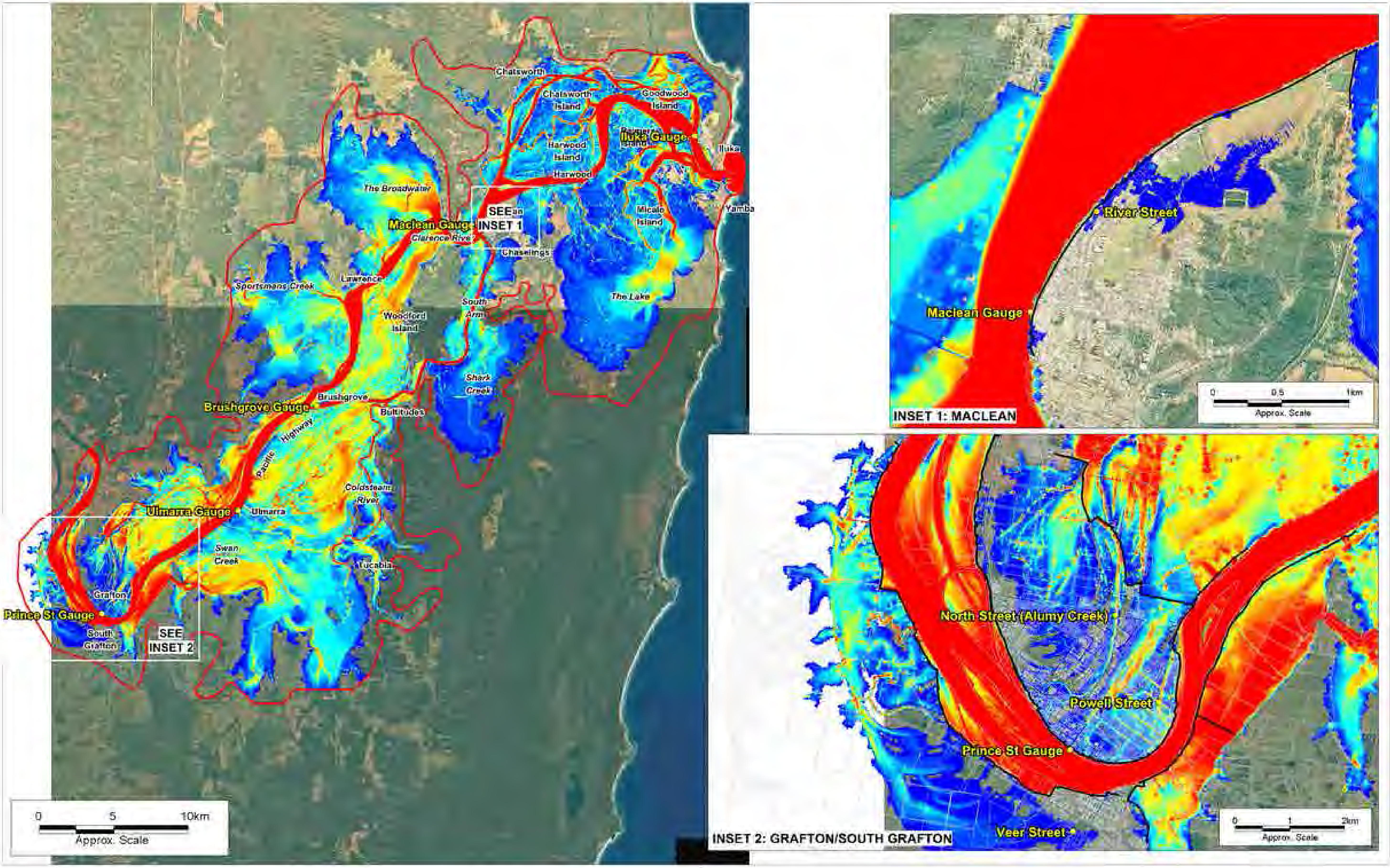

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Velocity Depth Product (m^2/s)

- 0.0 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1.0
- 1.0 to 1.2
- 1.2 to 1.4
- 1.4 to 1.6
- 1.6 to 1.8
- 1.8 to 2.0
- Greater than 2.0

Title:

**2% AEP Design Event:
Peak Flood Velocity Depth Product**

Figure: 4-22

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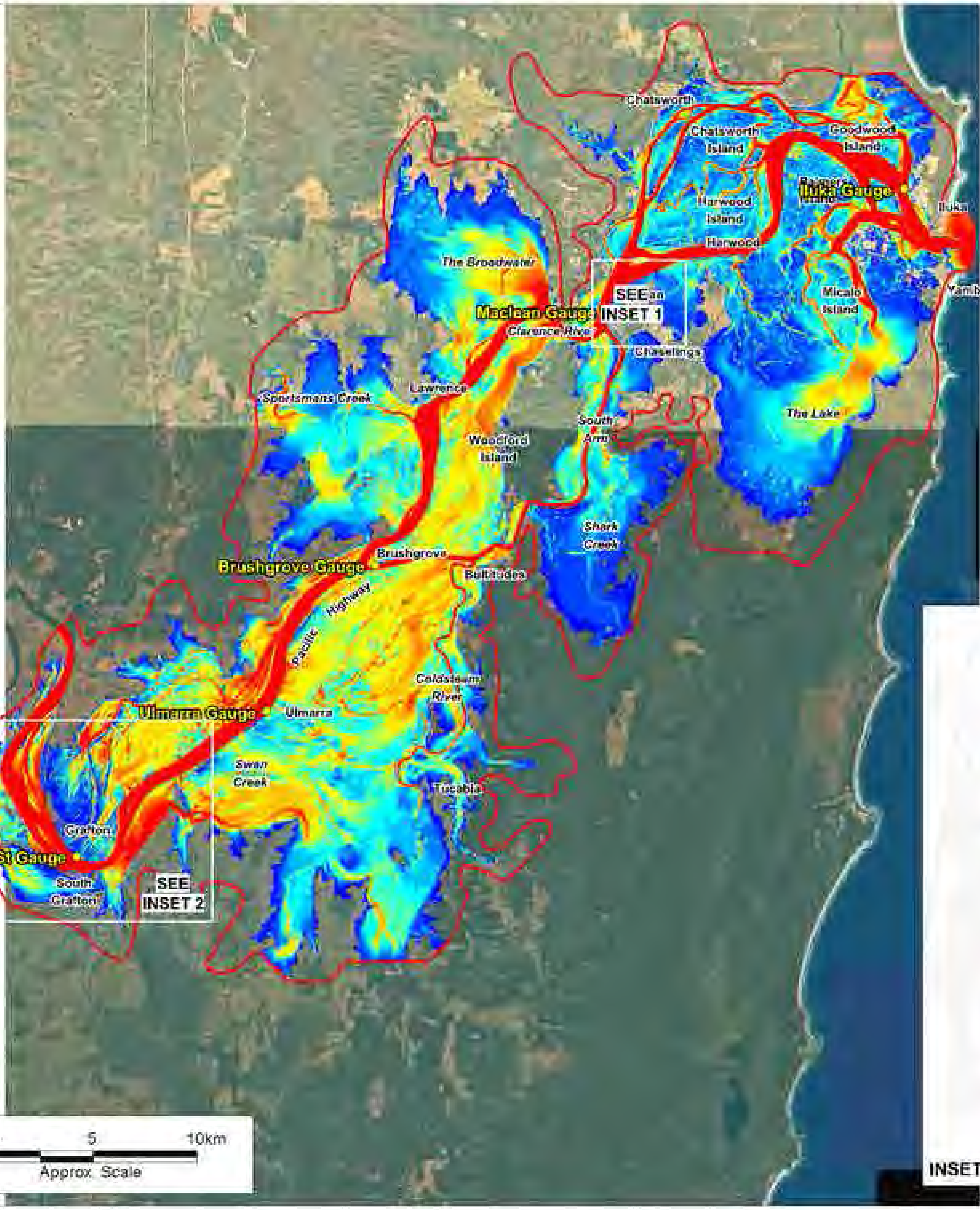

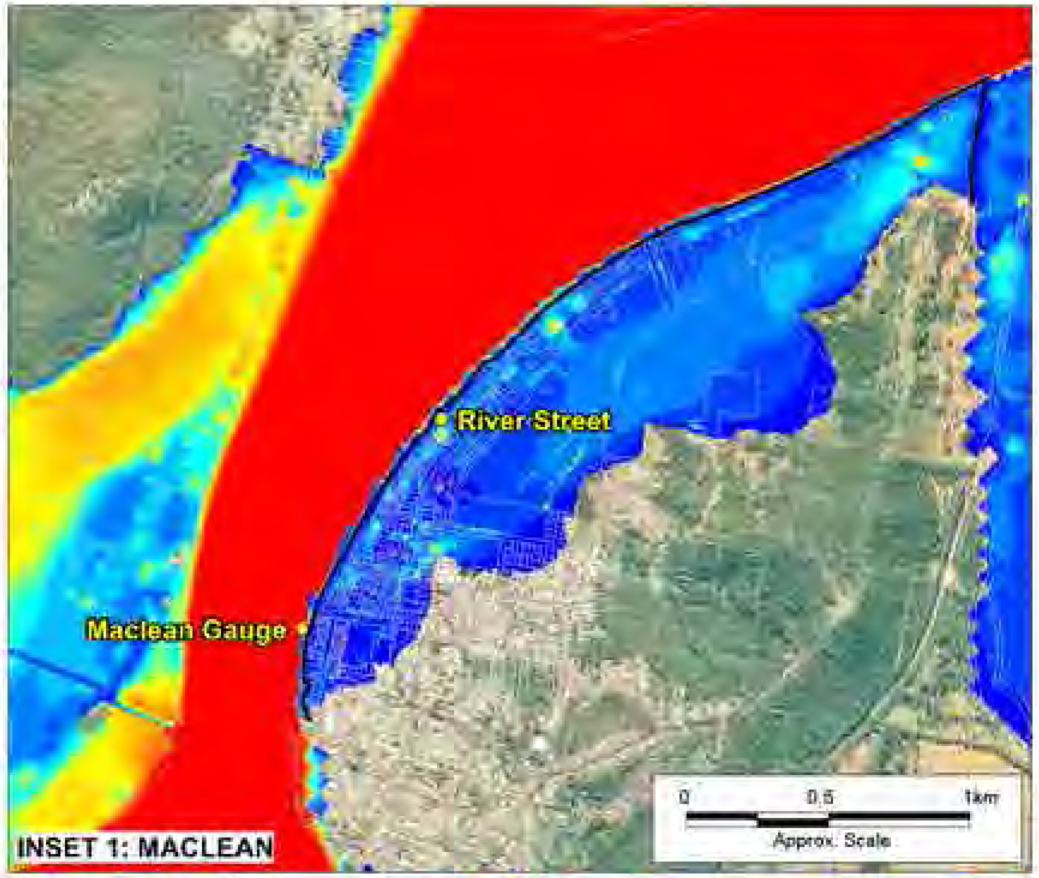

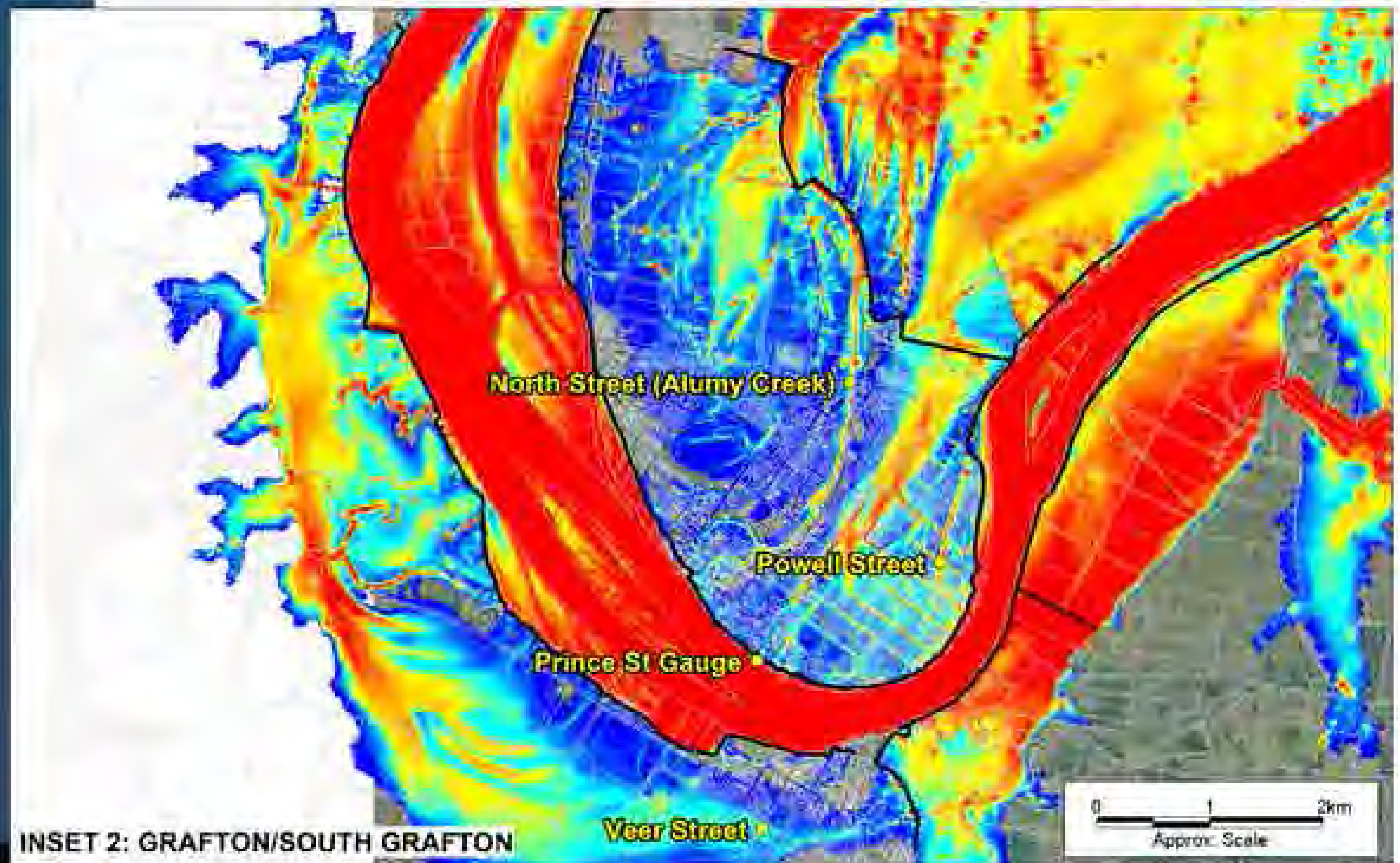

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Velocity Depth Product (m^2/s)

- 0.0 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1.0
- 1.0 to 1.2
- 1.2 to 1.4
- 1.4 to 1.6
- 1.6 to 1.8
- 1.8 to 2.0
- Greater than 2.0

Title:

1% AEP Design Event: Peak Flood Velocity Depth Product

N

Figure: 4-23

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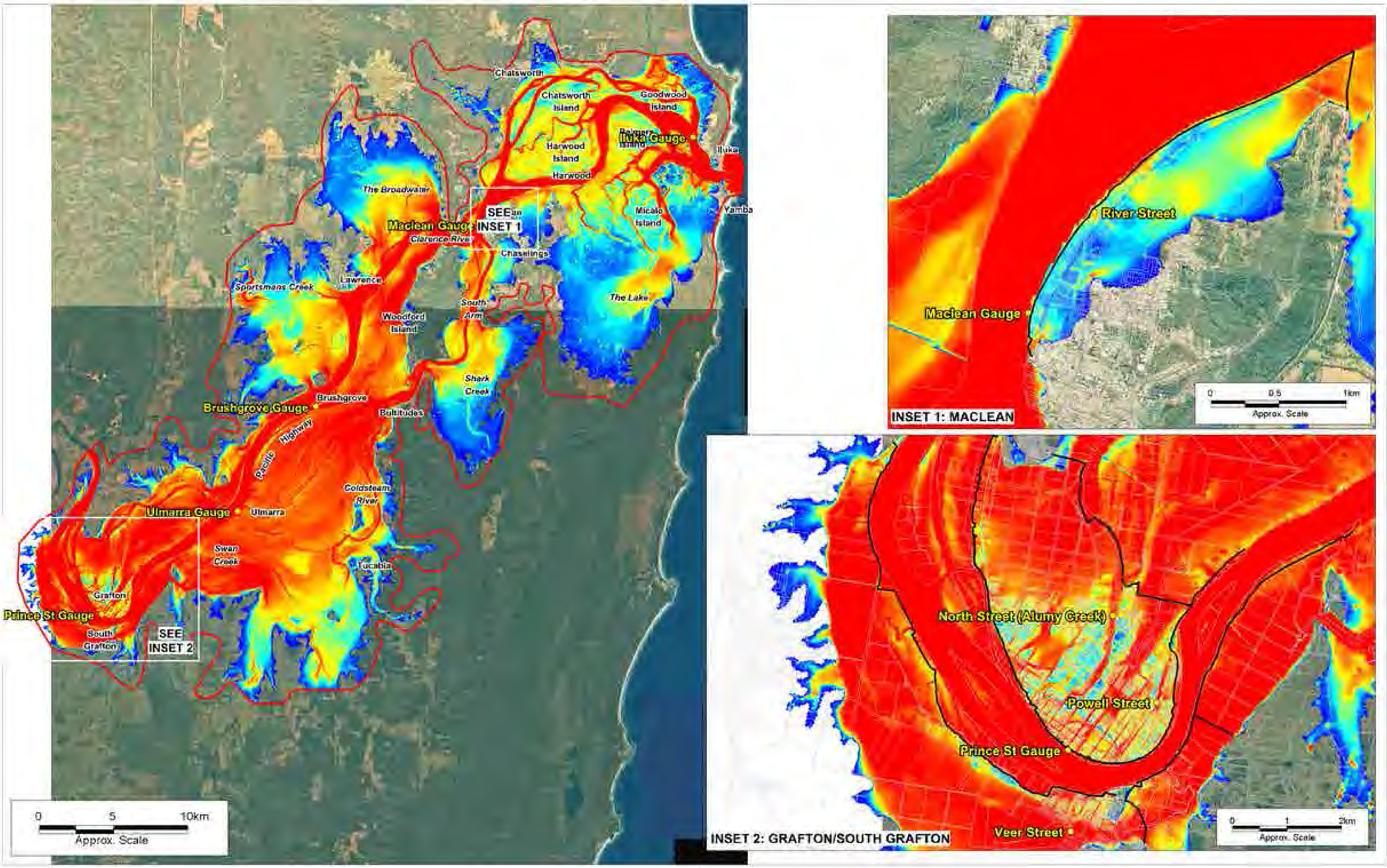

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Velocity Depth Product (m²/s)

- 0.0 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1.0
- 1.0 to 1.2
- 1.2 to 1.4
- 1.4 to 1.6
- 1.6 to 1.8
- 1.8 to 2.0
- Greater than 2.0

Title:

Extreme Event: Peak Flood Velocity Depth Product

Figure: 4-24

Rev: A

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5 CLIMATE CHANGE ASSESSMENT

An assessment of the potential impacts of climate change on the 1% AEP flood behaviour has been undertaken. Three separate climate change scenarios were considered during the assessment. Listed below and summarised in Table 5-1, these scenarios have been derived based on 2050 and 2100 future planning horizon state government guideline values for the Northern Rivers (DECCW, 2007):

1 Base Case - No climate change allowances;

2 Climate Change Scenario 1 (Rainfall intensity sensitivity testing) - 1% AEP event: 10% rainfall intensity increase + no sea level rise;

3 Climate Change Scenario 2 (2050 planning horizon) - 1% AEP event: 10% rainfall intensity increase + 0.4m sea level rise; and

4 Climate Change Scenario 3 (2100 planning horizon) - 1% AEP event: 10% rainfall intensity increase + 0.9m sea level rise.

Table 5-1 Lower Clarence Flood Model Climate Change Scenarios

Climate Change Scenario	*Rainfall Intensity Increase*	*Sea Level Rise*	*Description*	*1% AEP Event Flood Model Inflows (m^3/s)*								*1% AEP Event Ocean Boundary Peak Level (mAHD)*
				Clarence River	*Glenugie Creek*	*Coldstream River*	*Shark Creek*	*Sportsmans Creek*	*Great Estuary Creek*	*Cowley Creek*	*Esk River*	
Base Case	0%	0.0m	Current climate	19,060	445	957	127	884	367	401	1,462	2.6
1	10%	0.0m	Rainfall intensity sensitivity testing	20,970	496	1065	141	989	409	446	1626	2.6
2	10%	0.4m	2050 planning horizon projection	20,970	496	1065	141	989	409	446	1626	3.0
3	10%	0.9m	2100 planning horizon projection	20,970	496	1065	141	989	409	446	1626	3.5

5.1 Climate Change Assessment Results

The changes in flood behaviour associated with the above climate change scenarios have been assessed relative to the 'Base Case' scenario. The results for the climate change assessment are presented in Table 5-2 to Table 5-3 and Figure 5-2 to Figure 5-4.

The results show the following change in flood level trends:

1 Climate Change Scenario 1 - 1% AEP event increases in peak flood level:

   a. 0.0m to 0.3m between Yamba and Maclean;

   b. Up to 0.4m in regional areas upstream of Maclean;

   c. Up to 0.2m within the Maclean Levees;

   d. Up to 0.4m within the Grafton Levees; and

   e. Up to 2.8m within the South Grafton levees.

2 Climate Change Scenario 2 (2050 planning horizon) - 1% AEP event increases in peak flood level:

   a. 0.3m to 0.5m between Yamba and Ulmarra;

   b. Up to 0.3m within the Maclean Levees;

   c. Up to 0.4m within the Grafton Levees; and

   d. Up to 2.8m within the South Grafton levees.

3 Climate Change Scenario 3 (2100 planning horizon) - 1% AEP event increases in peak flood level:

   a. 0.4m to 0.9m between Yamba and Maclean;

   b. Up to 0.4m in regional areas upstream of Maclean;

   c. Up to 0.4m within the Maclean Levees;

   d. Up to 0.5m within the Grafton Levees; and

   e. Up to 2.9m within the South Grafton levees.

For all of the above climate change scenarios, areas within the South Grafton levee experience significant increases in peak flood level (2.8 to 2.9m). Due to the extensive length of the South Grafton levee (approximately 10km), flood levels within South Grafton are sensitive to changes in:

1 Flood level within the main river channel; and

2 Duration of overtopping.

Increasing the rainfall intensity by 10% increases the river levels adjacent to the South Grafton levee by up to approximately 0.2m and also prolongs the period of overtopping, shown in Figure 5-1. This increase, combined with the length of the South Grafton levee, is causing the significant increases in flood levels within South Grafton.

Grafton in contrast does not experience the same magnitude of climate change impact (though still 0.4 to 0.5m). Inundation within Grafton occurs as a result of levee overtopping which predominantly occurs downstream of the Grafton Bridge. River levels adjacent to the North Grafton levee only increase by up to approximately 0.1m. This means there is less impact of climate change on flood levels in Grafton than South Grafton.

Flood levels in areas outside the Grafton, South Grafton and Maclean levees are less sensitive to flood levels within the main river channel and the duration of flooding. Therefore flood level increases due to climate change in these areas are less significant than areas within the urban levee systems.

Table 5-2 Climate Change Assessment Results: Regional Reporting Locations

Results	Climate Change Scenario	1% AEP Event				
		Prince St Gauge (Grafton)	Ulmarra Gauge (Ulmarra)	Brushgrove Gauge (Brushgrove)	Maclean Gauge (Maclean)	Iluka Gauge (Iluka)
Peak Flood Level (mAHD)	Base Case	8.3	6.4	5.8	3.6	2.5
	1	8.4	6.6	6.2	3.8	2.5
	2	8.4	6.6	6.2	3.9	2.8
	3	8.4	6.7	6.3	4.0	3.2
Peak Flood Level Increase (m)	1	0.1	0.3	0.3	0.2	0.0
	2	0.1	0.3	0.4	0.3	0.3
	3	0.1	0.4	0.5	0.4	0.7

Table 5-3 Climate Change Assessment Results: Urban Reporting Locations

Results	Climate Change Scenario	1% AEP Event			
		North St (Alumy Creek) Grafton	Powell Street Grafton	Veer St South Grafton	River Street Maclean
Peak Flood Level (mAHD)	Base Case	6.5	7.1	5.9	3.7
	1	6.8	7.4	8.6	3.9
	2	6.9	7.4	8.6	4.0
	3	6.9	7.4	8.6	4.1
Peak Flood Level Increase (m)	1	0.4	0.3	2.8	0.2
	2	0.4	0.3	2.8	0.3
	3	0.5	0.3	2.8	0.4

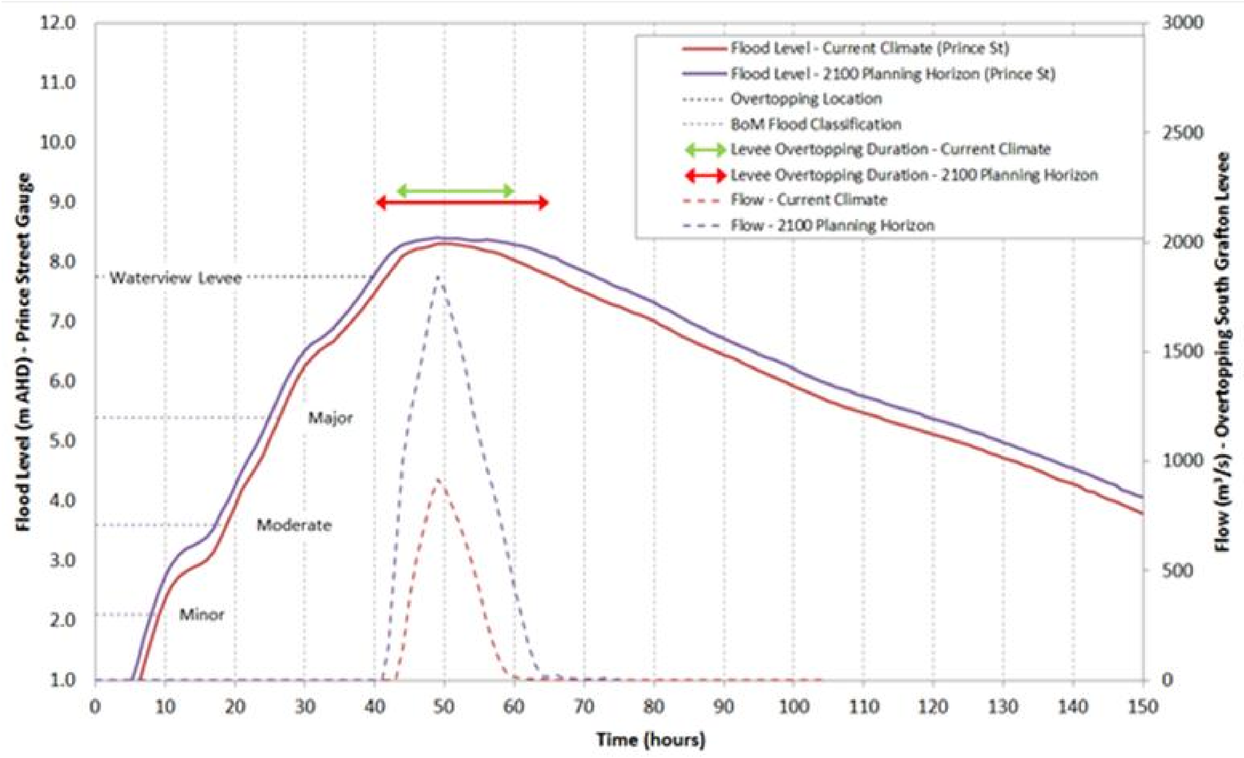
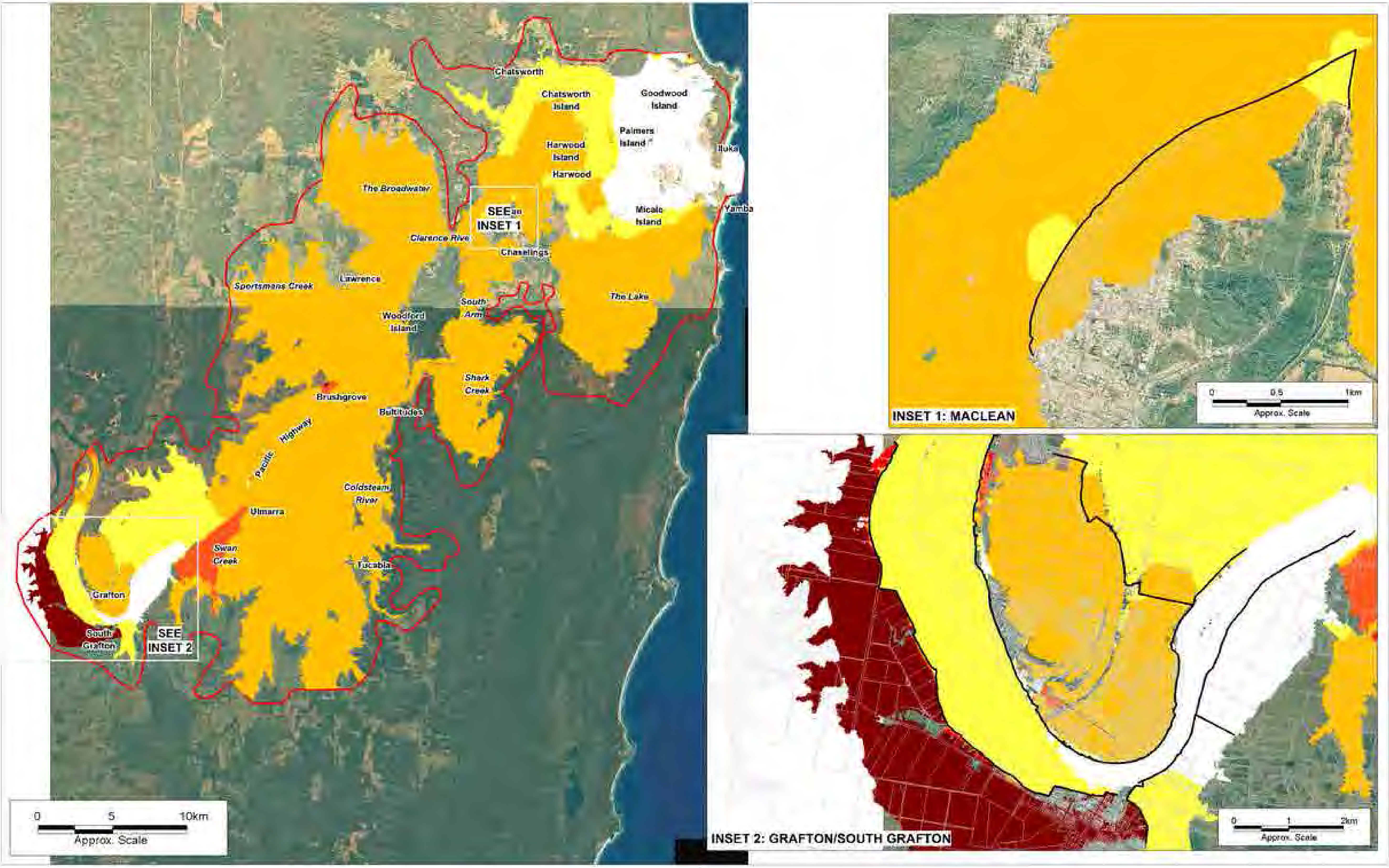


Figure 5-1 Climate Change: Increase in Duration of Levee Overtopping (South Grafton)



LEGEND

- Flood Model Extent
- Levees

Peak Flood Difference (m)

(Climate Change Scenario minus Base Case)

- Less than -0.90
- -0.90 to -0.60
- -0.60 to -0.40
- -0.40 to -0.20
- -0.20 to -0.10
- -0.10 to 0.10
- 0.10 to 0.20
- 0.20 to 0.40
- 0.40 to 0.60
- 0.60 to 0.90
- Greater than 0.90

Title:

Climate Change Scenario 1: 1% AEP Design Event Peak Flood Level Impact

Figure: 5-2

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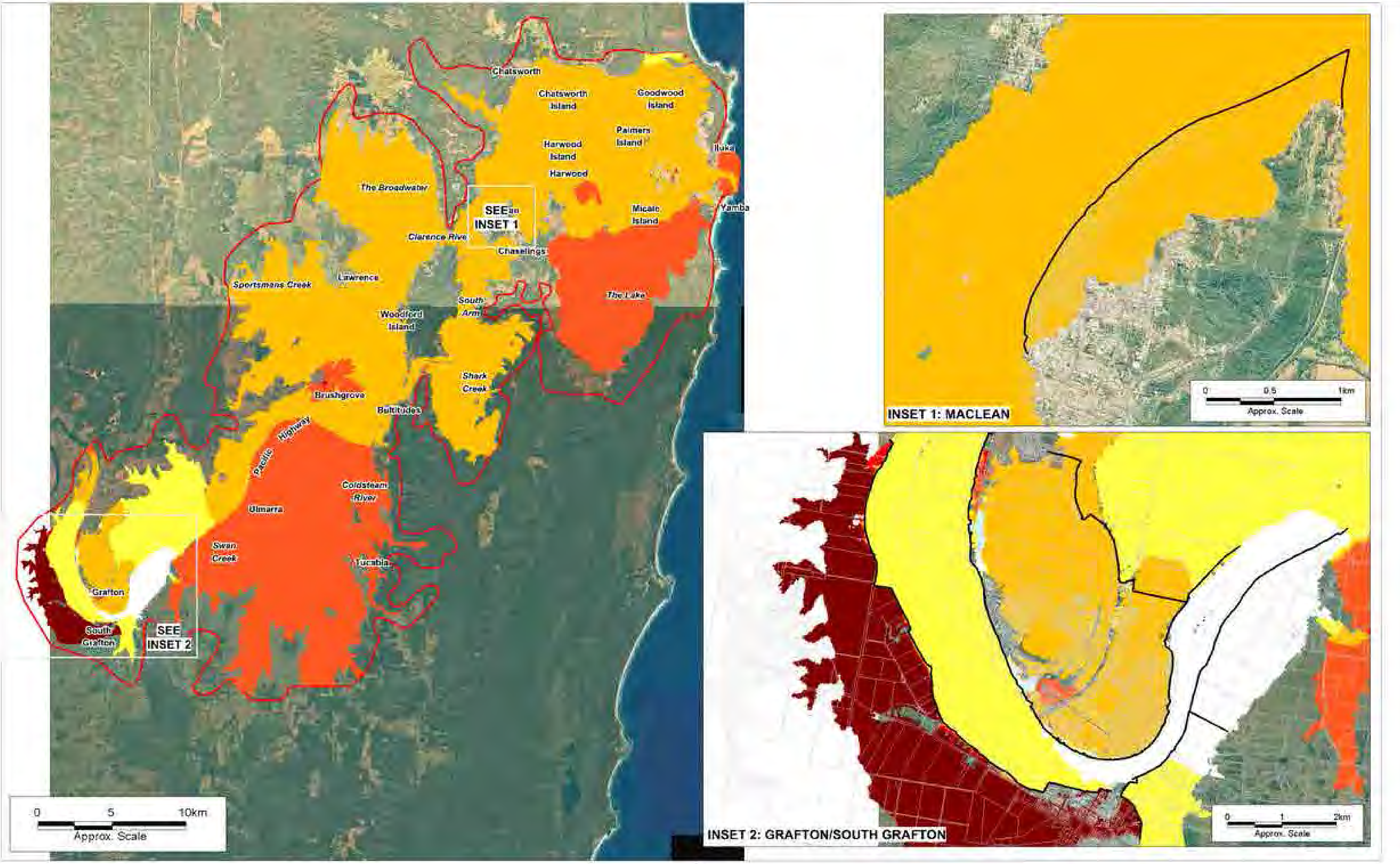

LEGEND

Flood Model Extent

Levees

Peak Flood Difference (m)

(Climate Change Scenario minus Base Case)

Less than -0.90	0.10 to 0.20
-0.90 to -0.60	0.20 to 0.40
-0.60 to -0.40	0.40 to 0.60
-0.40 to -0.20	0.60 to 0.90
-0.20 to -0.10	Greater than 0.90
-0.10 to 0.10	

Title:

Climate Change Scenario 2: 1% AEP Design Event Peak Flood Level Impact

Figure: 5-3

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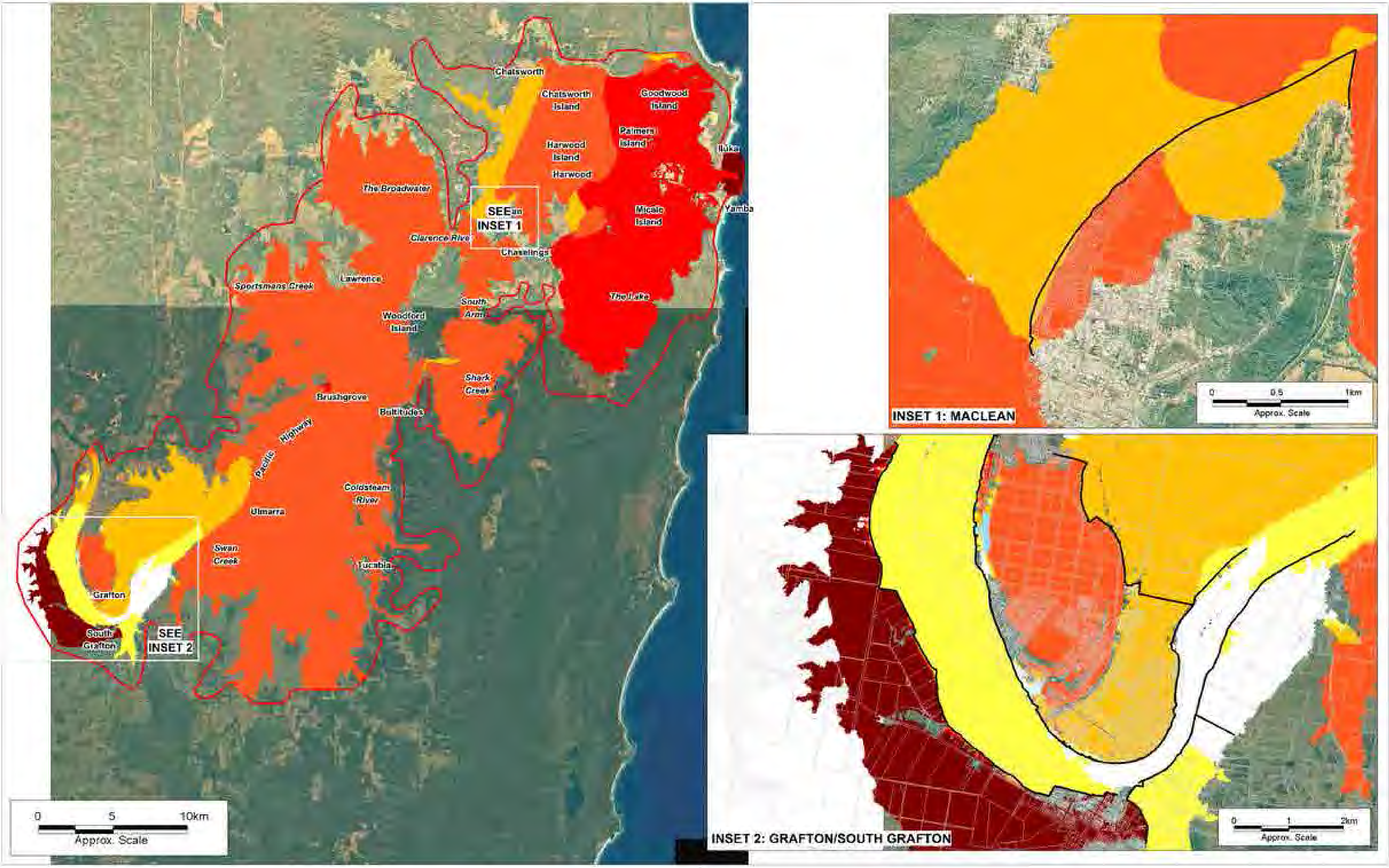

LEGEND

- Flood Model Extent
- Levees

Peak Flood Difference (m)

(Climate Change Scenario minus Base Case)

- Less than -0.90
- -0.90 to -0.60
- -0.60 to -0.40
- -0.40 to -0.20
- -0.20 to -0.10
- -0.10 to 0.10
- 0.10 to 0.20
- 0.20 to 0.40
- 0.40 to 0.60
- 0.60 to 0.90
- Greater than 0.90

Title:

Climate Change Scenario 3:
1% AEP Design Event Peak Flood Level Impact

Figure: 5-4

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6 NORTH GRAFTON INTERNAL DRAINAGE

The modelling to date, summarised in the preceding sections, has largely focused regional flood behaviour in the Lower Clarence River catchment.

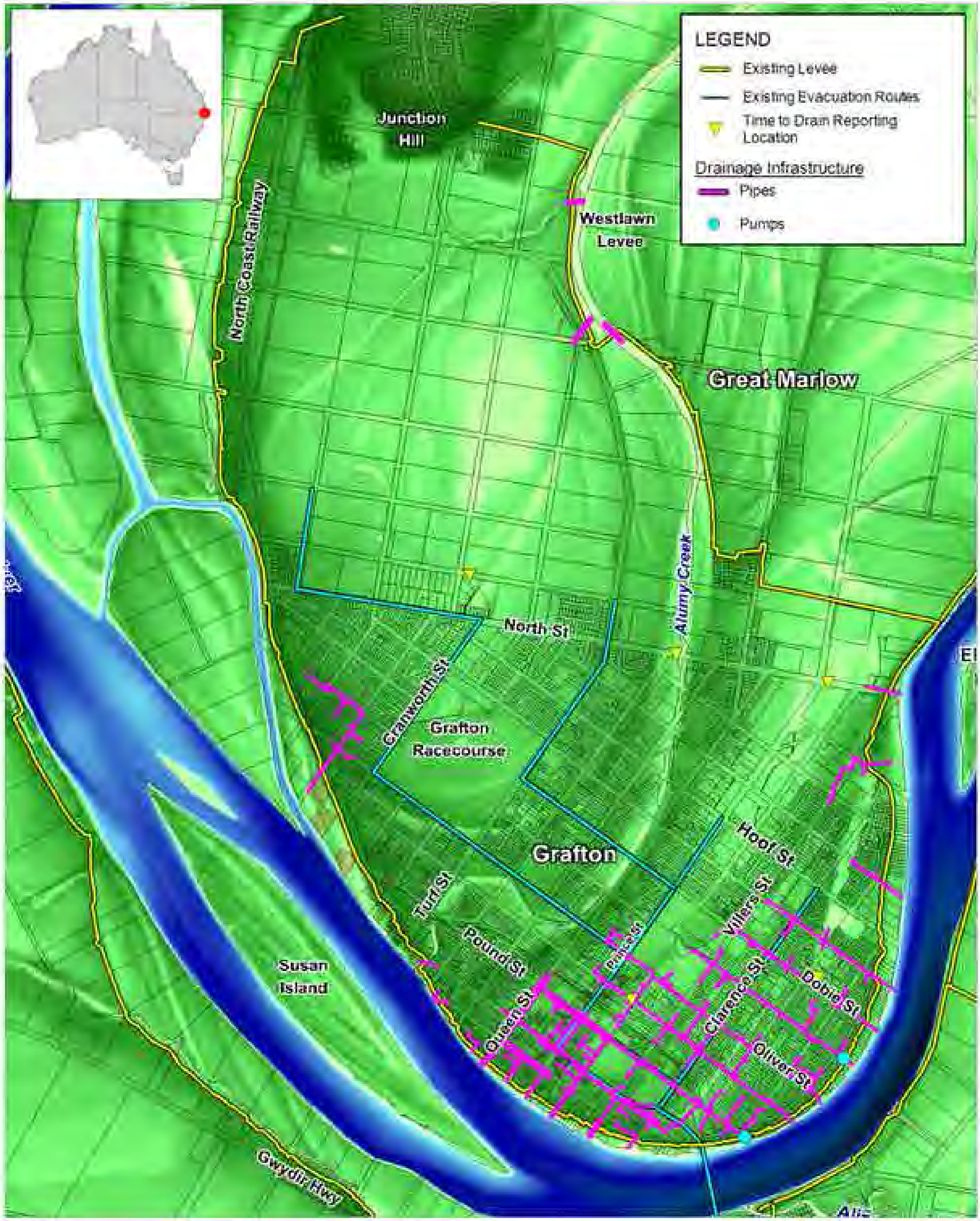
Presently, it is unknown how long it takes for the ponded floodwater within Grafton to drain via the stormwater network following a major overtopping event. Knowledge of the approximate time required for Grafton to drain following an event will assist CVC to plan and conduct the flood recovery process.

Grafton has an extensive stormwater network, including numerous pump stations and over 2,000 pits and underground pipes. The major elements of this system have been represented within the Lower Clarence flood model. The drainage elements which have been included within the flood model are shown in Figure 6-1.

Two event scenarios have been considered using the updated model.

1 Drainage of floodwaters from Grafton following overtopping of the levee system, assuming ponded water associated with preceding rainfall within Grafton has drained prior to the levee overtopping.

2 Drainage of floodwater from Grafton following overtopping of the levee system, assuming coincident rainfall over Grafton does occur. The 72 hour design storm event has been selected for this scenario. The use of this rainfall is consistent with existing regional rainfall inflows within the flood model.



Title:
Grafton Internal Drainage Features

Figure: 6-1

Rev: A

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Approx. Scale

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6.1 Internal Drainage Assessment Results

The two drainage event scenarios have been assessed for the 5%, 2%, 1% AEP events. Flood levels within Grafton drain at different rates within each of its local internal drainage catchments. Five unique internal drainage catchments have been identified within Grafton, including:

- Baker's Swamp;
- North Meadow;
- Dovedale;
- Alumy Creek; and
- Grafton Central Business District.

The internal drainage assessment results for these local catchments are summarised in Table 6-1 and Figure 6-2 to Figure 6-7.

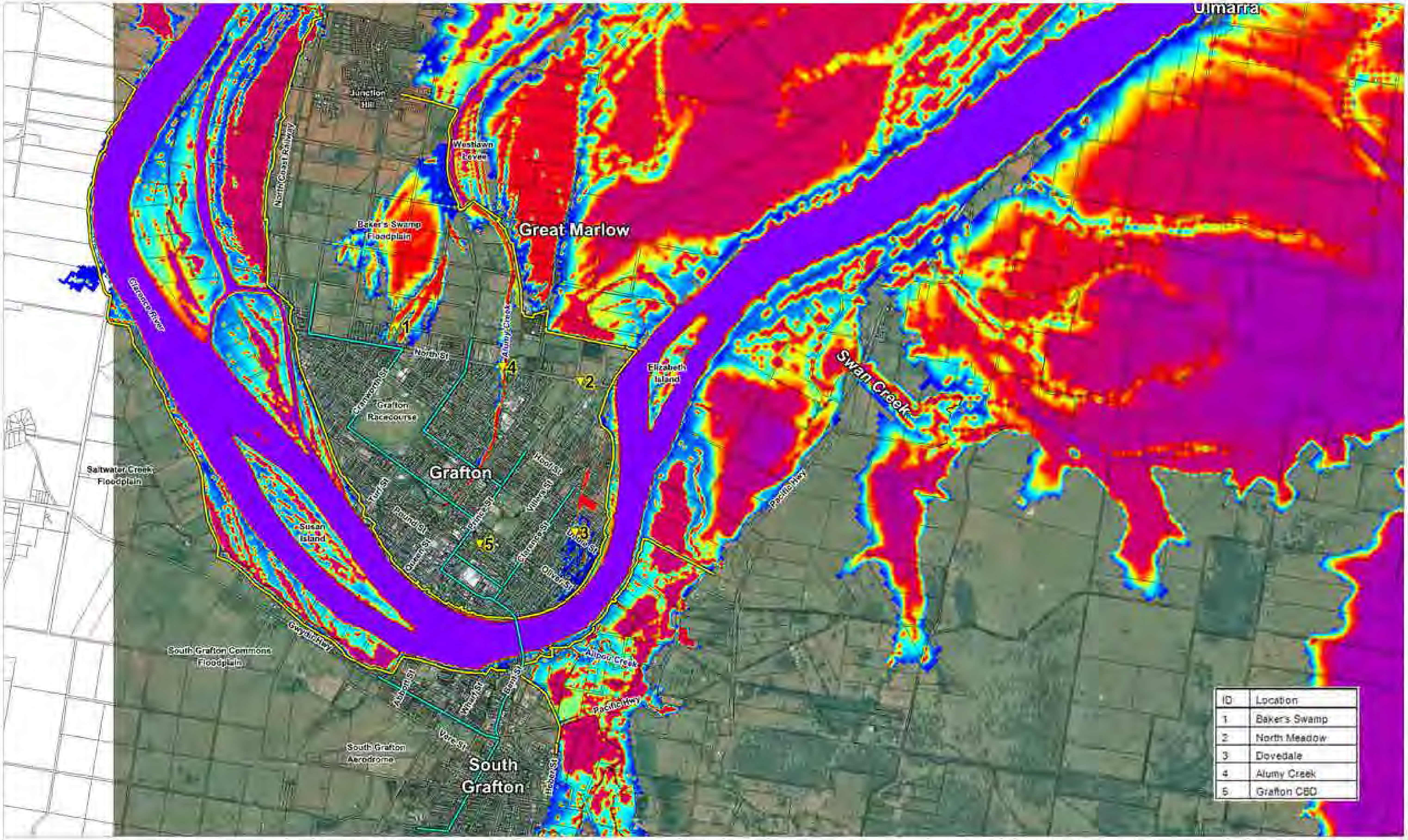
The results highlight the following:

- The volume of floodwater entering Grafton following levee overtopping is significantly greater than the local catchment rainfall volume, as demonstrated by the limited difference between Scenario 1 and Scenario 2 results.
- Drainage times following a 100 year overtopping event typically exceed 7 days:
    - o Rural areas of North Meadows and Bakers Swamp can take in excess of 10 days to drain.
    - o Pumped areas including Dovedale and Grafton CBD typically drain more rapidly, draining after 7 days.

The internal drainage assessment results for these local catchments are summarised in Table 6-1 and Figure 6-2 to Figure 6-7.

Table 6-1 Grafton Assessment – Result Summary

ID	***Location***	***Time to Drain (days)***					
		Scenario 1 (Levee Overtopping Only)			***Scenario 2 (Coincident Levee Overtopping/Local Rainfall)***		
		5% AEP	***2% AEP***	***1% AEP***	***5% AEP***	***2% AEP***	***1% AEP***
1	Baker's Swamp	4.9	6.9	7.4	5.1	7.0	7.4
2	North Meadow	Dry	10.4	10.5	9.9	10.4	10.5
3	Dovedale	0.4	6.5	7.0	3.6	6.7	7.0
4	Alumy Creek	5.1	6.1	6.6	5.1	6.2	6.6
5	Grafton CBD	Dry	6.8	7.3	3.3	7.0	7.4



LEGEND

- Existing Levee
- Existing Evacuation Routes
- Time to Drain Reporting Location

Time of Inundation (hours)
(inundation over 0.1m)

0.0 to 24.0	168.0 to 192.0
24.0 to 48.0	192.0 to 216.0
48.0 to 72.0	216.0 to 240.0
72.0 to 96.0	240.0 to 264.0
96.0 to 120.0	264.0 to 288.0
120.0 to 144.0	288.0 to 312.0
144.0 to 168.0	

Title:
Grafton Drainage Scenario 1:
5% AEP Design Event Flood Drainage Time

Figure: **6-2**

Rev: **A**

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0 1 2km
Approx. Scale

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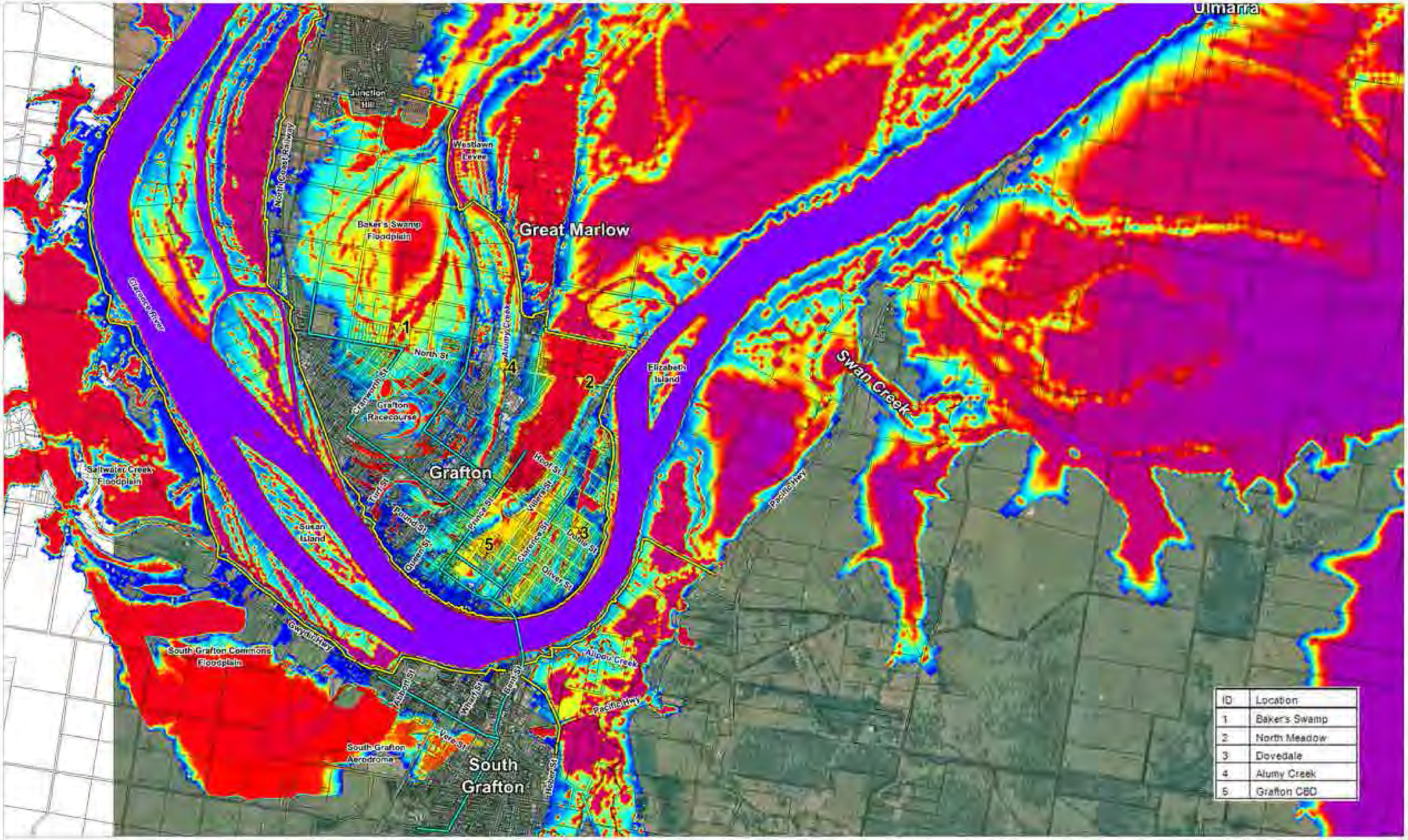

ID	Location
1	Baker's Swamp
2	North Meadow
3	Dovedale
4	Alumy Creek
5	Grafton CBD

LEGEND

- Existing Levee
- Existing Evacuation Routes
- Time to Drain Reporting Location

Time of Inundation (hours)
(inundation over 0.1m)

- 0.0 to 24.0
- 24.0 to 48.0
- 48.0 to 72.0
- 72.0 to 96.0
- 96.0 to 120.0
- 120.0 to 144.0
- 144.0 to 168.0
- 168.0 to 192.0
- 192.0 to 216.0
- 216.0 to 240.0
- 240.0 to 264.0
- 264.0 to 288.0
- 288.0 to 312.0

Title:
Grafton Drainage Scenario 1:
2% AEP Design Event Flood Drainage Time

Figure: 6-3

Rev: A

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Approx. Scale

BMT WBM
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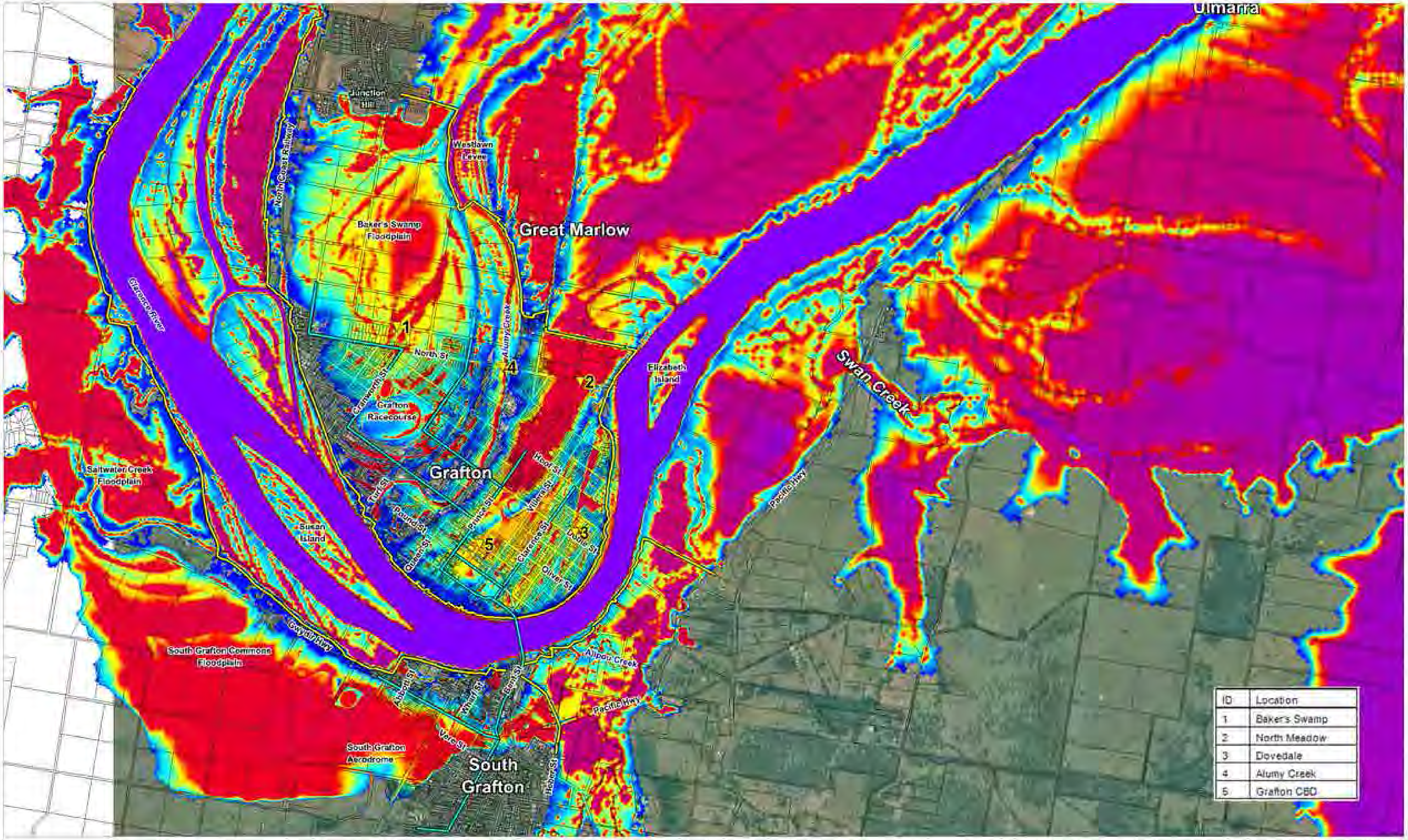
Filepath : I:\B18054\DRG\Draft\FLD_069_130529_50yr_DrainNG01_times.WOR



ID	Location
1	Baker's Swamp
2	North Meadow
3	Dovedale
4	Alumy Creek
5	Grafton CBD

LEGEND

- Existing Levee
- Existing Evacuation Routes
- Time to Drain Reporting Location

Time of Inundation (hours)
(inundation over 0.1m)

- 0.0 to 24.0
- 24.0 to 48.0
- 48.0 to 72.0
- 72.0 to 96.0
- 96.0 to 120.0
- 120.0 to 144.0
- 144.0 to 168.0
- 168.0 to 192.0
- 192.0 to 216.0
- 216.0 to 240.0
- 240.0 to 264.0
- 264.0 to 288.0
- 288.0 to 312.0

Title:

Grafton Drainage Scenario 1:
1% AEP Design Event Flood Drainage Time

Figure: **6-4**

Rev: **A**

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Approx. Scale

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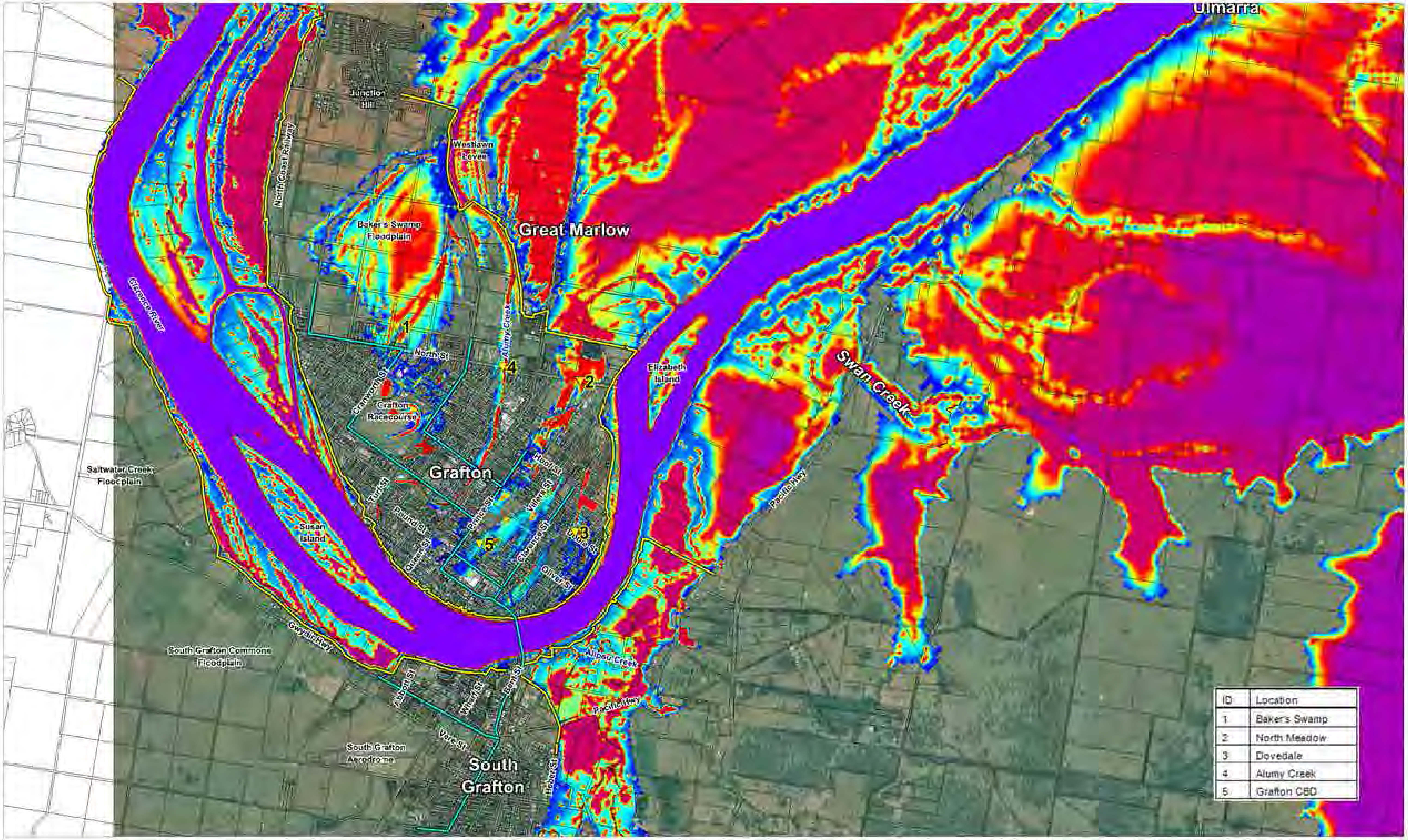

LEGEND

- Existing Levee
- Existing Evacuation Routes
- Time to Drain Reporting Location

Time of Inundation (hours)
(inundation over 0.1m)

0.0 to 24.0	168.0 to 192.0
24.0 to 48.0	192.0 to 216.0
48.0 to 72.0	216.0 to 240.0
72.0 to 96.0	240.0 to 264.0
96.0 to 120.0	264.0 to 288.0
120.0 to 144.0	288.0 to 312.0
144.0 to 168.0	

Title:
Grafton Drainage Scenario 2:
5% AEP Design Event Flood Drainage Time

Figure: **6-5**

Rev: **A**

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Approx. Scale

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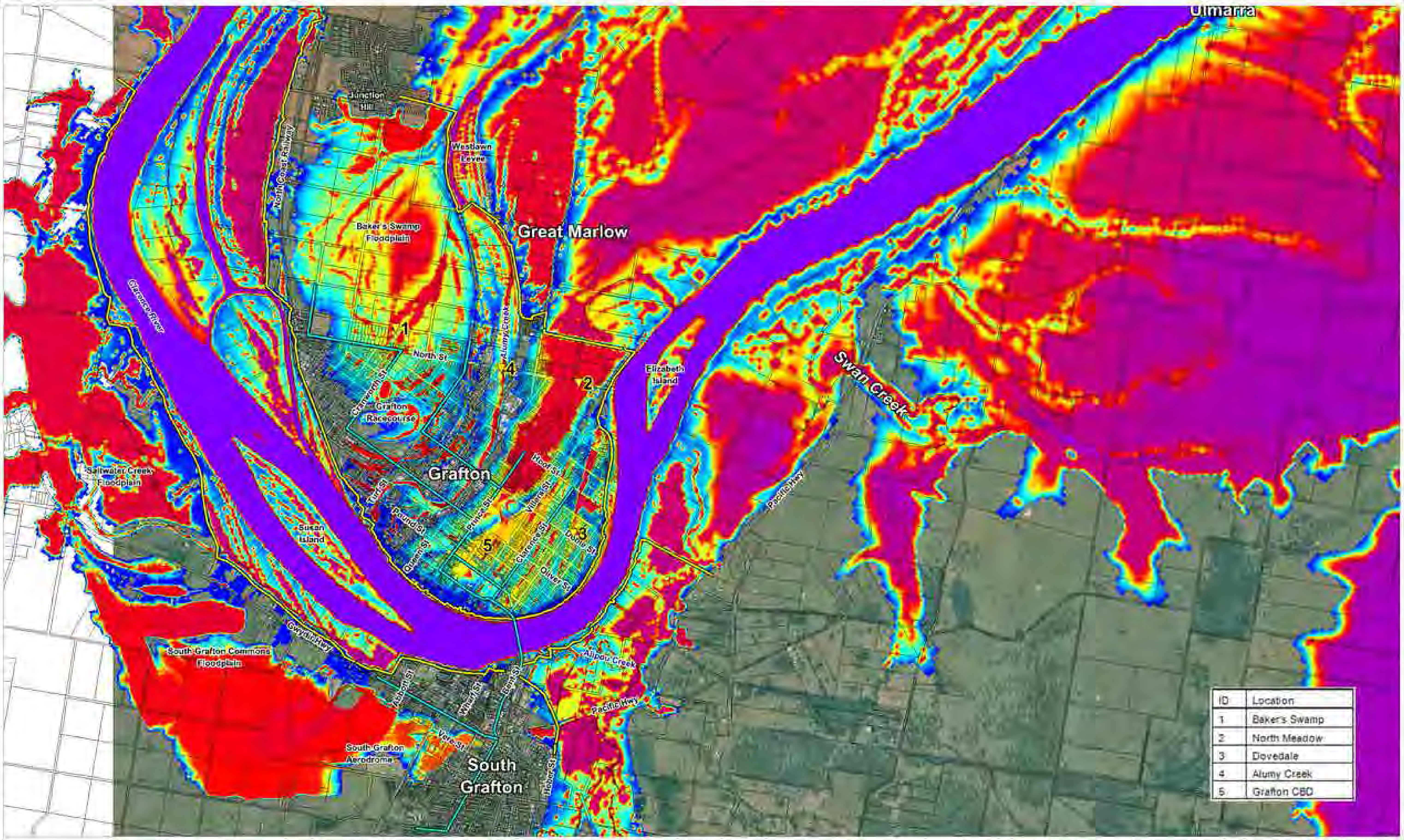
Filepath : I:\B18054\DRG\Draft\FLD_070_130529_20yr_DrainNG02_times.WOR



ID	Location
1	Baker's Swamp
2	North Meadow
3	Dovedale
4	Alumy Creek
5	Grafton CBD

LEGEND

- Existing Levee
- Existing Evacuation Routes
- Time to Drain Reporting Location

Time of Inundation (hours)
(inundation over 0.1m)

- 0.0 to 24.0
- 24.0 to 48.0
- 48.0 to 72.0
- 72.0 to 96.0
- 96.0 to 120.0
- 120.0 to 144.0
- 144.0 to 168.0
- 168.0 to 192.0
- 192.0 to 216.0
- 216.0 to 240.0
- 240.0 to 264.0
- 264.0 to 288.0
- 288.0 to 312.0

Title:
Grafton Drainage Scenario 2:
2% AEP Design Event Flood Drainage Time

Figure: **6-6**

Rev: **A**

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0 1 2km
Approx. Scale

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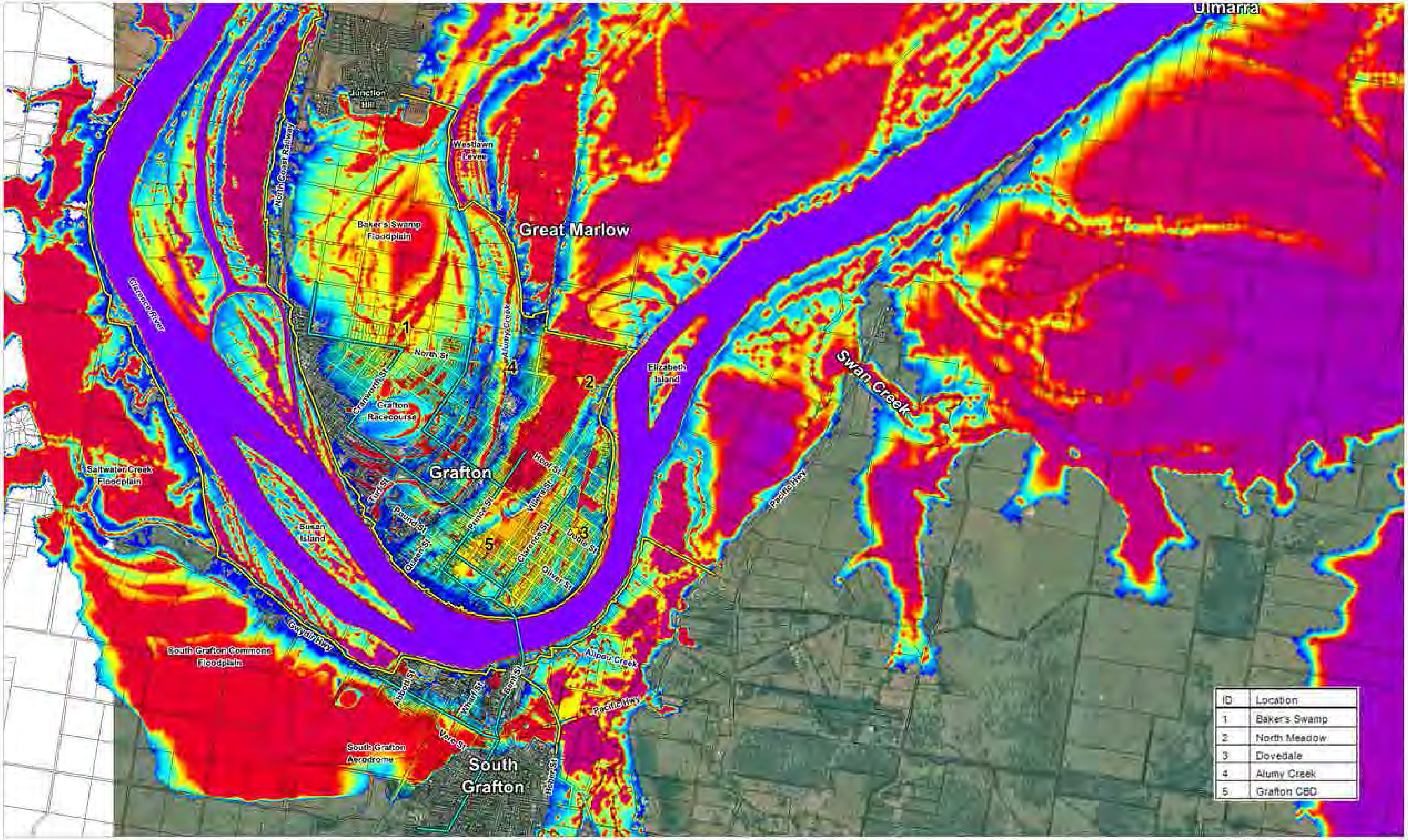

LEGEND

- Existing Levee
- Existing Evacuation Routes
- Time to Drain Reporting Location

Time of Inundation (hours)
(inundation over 0.1m)

0.0 to 24.0	168.0 to 192.0
24.0 to 48.0	192.0 to 216.0
48.0 to 72.0	216.0 to 240.0
72.0 to 96.0	240.0 to 264.0
96.0 to 120.0	264.0 to 288.0
120.0 to 144.0	288.0 to 312.0
144.0 to 168.0	

Title:

Grafton Drainage Scenario 2:
1% AEP Design Event Flood Drainage Time

Figure: 6-7

Rev: A

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Approx. Scale

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7 GRAFTON FLOOD PLANNING LEVELS

Flood planning levels represent an important development control tool used to manage future flood risk within a floodplain.

7.1 Factors for Consideration

A number of factors should be considered when setting development control flood planning levels. These factors may dictate the magnitude of the event upon which the flood planning level is based and the freeboard chosen. A summary of these factors is provided in the following sections.

7.1.1 Risk to Life

The risk to life must be considered for the full range of flood events, including the PMF. A flood larger than that used to derive the flood planning level will result in increased risk to life and property as:

- Water enters buildings or overtops levees built at the flood planning level and may result in the need for evacuation.
- High hazard or flow conditions may develop in areas where floodwaters simply pond in the flood event used to derive the flood planning level.
- Significant access problems may develop. This is not a serious issue in a floodplain with continuously rising roads leading out of it. However, any flood which cuts access and isolates parts of a community can cause serious additional danger to personal safety. This is a particular problem where there is a large flood range between the flood used to derive the FPL and the PMF.

As a consequence of the requirement for critical infrastructure to be functional during extreme flood events, adoption of a flood planning level for these specific landuse types should be considered with knowledge of the PMF peak flood level.

7.1.2 Social Issues

7.1.2.1 Land Availability and Needs

When setting flood levels it is beneficial to have an understanding of the availability of land for development and the likelihood that this land will be needed for development within a reasonable planning horizon.

Knowing where development is likely to occur is important when setting flood planning levels because:

- It allows for consideration of the impact on flood behaviour caused by potential development (for example, new development set at the 2% AEP level would cause different flood impacts to one set at the 1% flood level); and
- It creates planning levels that are sensitive to the need and likelihood of future development within the catchment

7.1.2.2 Existing Level of Development

New development and relatively undeveloped areas provide more flexibility in decision making than developed areas (NSWG, 2005). Areas that have some level of existing development generally have a significant amount of public and private infrastructure. This investment should be considered when setting planning levels.

7.1.2.3 Current Flood Planning Levels for Planning Purposes

Review of current flood planning levels should be considered.

7.1.2.4 Land Values and Social Equity

While higher floor levels for new development results in a higher level of flood protection for people and property, higher floor levels can have the following disadvantages:

- Social inequity can arise when new commercial or industrial buildings must have a higher floor level than existing buildings. This results in inequity when new businesses cannot compete with existing businesses because of the changes to floor level. For example, a new mechanic's garage that cannot achieve the necessary vehicle access due to the required floor level, or a clothes shop that must be built at such a height off the street level that customers do not bother to enter.
- Aesthetic problems may arise when adjacent buildings have substantially different floor levels, particularly when buildings are closely spaced.

7.1.2.5 Duration of Flooding

In some areas, the duration of flooding can result in buildings/townships being completely isolated for a significant period of time (sometimes weeks). To overcome this, some areas may adopt higher flood planning levels to enable the community to function with some normality during times of flood. This is not generally the case throughout Grafton, South Grafton and Maclean, as the duration of flooding is considered too short for a higher flood planning level to be necessary.

7.1.3 Economic Factors

7.1.3.1 Future Development

A key consideration for new development is the ability of people to financially recover from severe flood events. It is this consideration that has led to standard residential development in NSW having a flood planning level based on a risk exposure relating to the 100 year ARI event (thus, typically the flood planning level equals 100 year ARI flood level plus a freeboard of 0.5m). This practice is expected to continue (NSWG, 2005).

A reduction in the flood planning level means that more people are at risk of greater damage. These damages will be borne by future residents whilst any cost savings related to lower fill and/or floor levels are made by the developers of the land.

7.1.3.2 Mitigation Works

The flood planning level of any protective mitigation works relates to the benefit of the works in reducing flood damage to private property and community infrastructure relative to the life cycle cost of the mitigation works. Flood planning level for mitigation works is particularly applicable when considering levee design.

7.1.4 Environmental Issues

In some areas, environmental issues are an important consideration when setting development controls. This may include setting development limits that effectively protect areas with high conservation value.

7.1.5 Cultural Issues

Flood planning levels are unlikely to result in significant impacts upon cultural issues (NSWG, 2005).

7.2 Freeboard

Freeboard is part of the flood planning level (flood planning level = flood level + freeboard). Freeboard provides reasonable certainty that the risk exposure accepted is actually provided. For example, if the 100 year ARI flood event is chosen as the designated flood planning level event, then the risk exposure is that inundation of property may occur in events greater than the 100 year ARI event. Freeboard provides a factor of safety to ensure that property is not inundated in smaller events or the 100 year ARI event itself. For the Lower Clarence Valley catchment, the development control freeboard may allow for:

- Uncertainties in the estimates of flood levels;
- Further increases in sea level rise and rainfall associated with climate change, over and above the current allowances; and
- Wave action induced by vehicles or boats moving through the flooded areas.

7.3 Duty of Care

"As with other planning decisions, councils have a duty of care in advising property owners, occupiers and developers on the extent and level of flooding and in making decisions with regard to an appropriate flood planning level. Because of the importance of such decisions, councils should document and carefully explain the basis of selecting an flood planning level." (NSWG, 2005)

7.4 Flood Planning Level Recommendations

It is recommended that CVC review the issues discussed in within the above sections when considering the revision of the Lower Clarence Valley flood planning levels. The flood modelling results that are recommended for consideration for this purpose is shown in Table 7-1 to Table 7-2 and Figure 7-1 to Figure 7-3.These model results cover the 5%, 2% and 1% AEP events and represent the flood behaviour across the catchment under the following conditions:

- Regional flood flows from the upstream catchment (upstream of Mountain View);
- Local rainfall across the lower catchment and within the leveed regions;

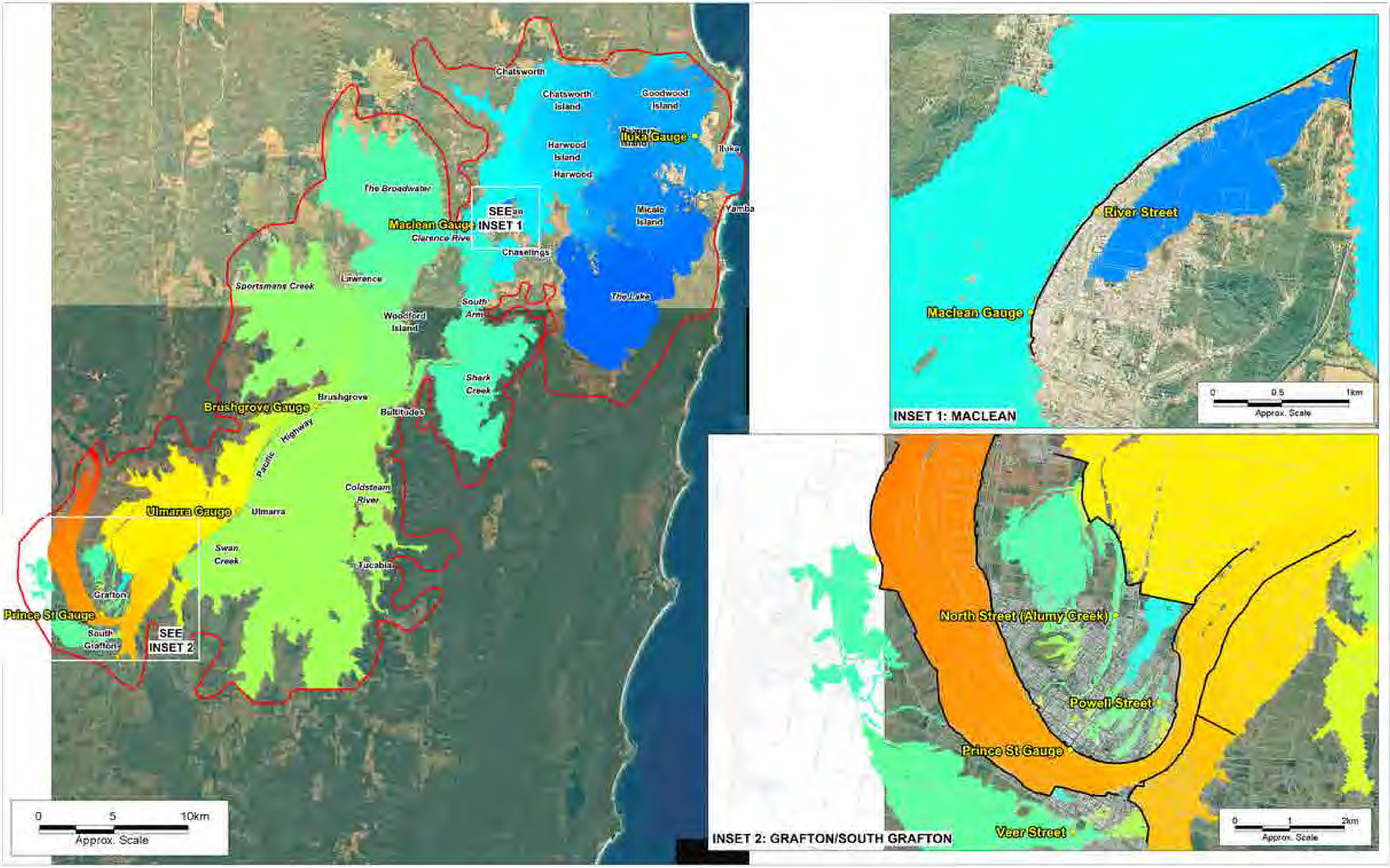
- Inclusion of the stormwater pipe and pit network within the levee system in Grafton; and
- There has been no allowance for the pumping of stormwater within the levee system. This is a conservative assumption made to allow for the possible failure of the pumping network during a flood event.

Table 7-1 Flood Planning Level Modelling Results: Regional Reporting Locations

Design Flood Event	***Peak Flood Level (mAHD) (no freeboard allowance included)***				
	Prince St Gauge (Grafton)	***Ulmarra Gauge (Ulmarra)***	***Brushgrove Gauge (Brushgrove)***	***Maclean Gauge (Maclean)***	***Iluka Gauge (Iluka)***
5% AEP	7.9	6.1	5.1	3.1	2.0
2% AEP	8.2	6.2	5.5	3.4	2.2
1% AEP	8.3	6.4	5.8	3.6	2.5
Extreme Event	9.7	8.4	8.0	5.1	3.5

Table 7-2 Flood Planning Level Modelling Results: Urban Reporting Locations

Design Flood Event	***North St (Alumy Creek) Grafton***	***Powell Street Grafton***	***Veer St South Grafton***	***River Street Maclean***
5% AEP	4.2	4.1	4.1	flood free
2% AEP	6.1	6.6	5.5	3.1
1% AEP	6.5	7.1	6.8	3.7
Extreme Event	8.9	9.0	10.0	5.1



LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Level (m AHD)

- 0.0 to 1.0
- 1.0 to 2.0
- 2.0 to 3.0
- 3.0 to 4.0
- 4.0 to 5.0
- 5.0 to 6.0
- 6.0 to 7.0
- 7.0 to 8.0
- 8.0 to 9.0
- 9.0 to 10.0
- 10.0 to 11.0
- 11.0 to 12.0
- 12.0 to 13.0
- Greater than 13.0

Title:

5% AEP Design Event: Peak Flood Level (Flood Planning Level Review)

Figure: 7-1

Rev: A

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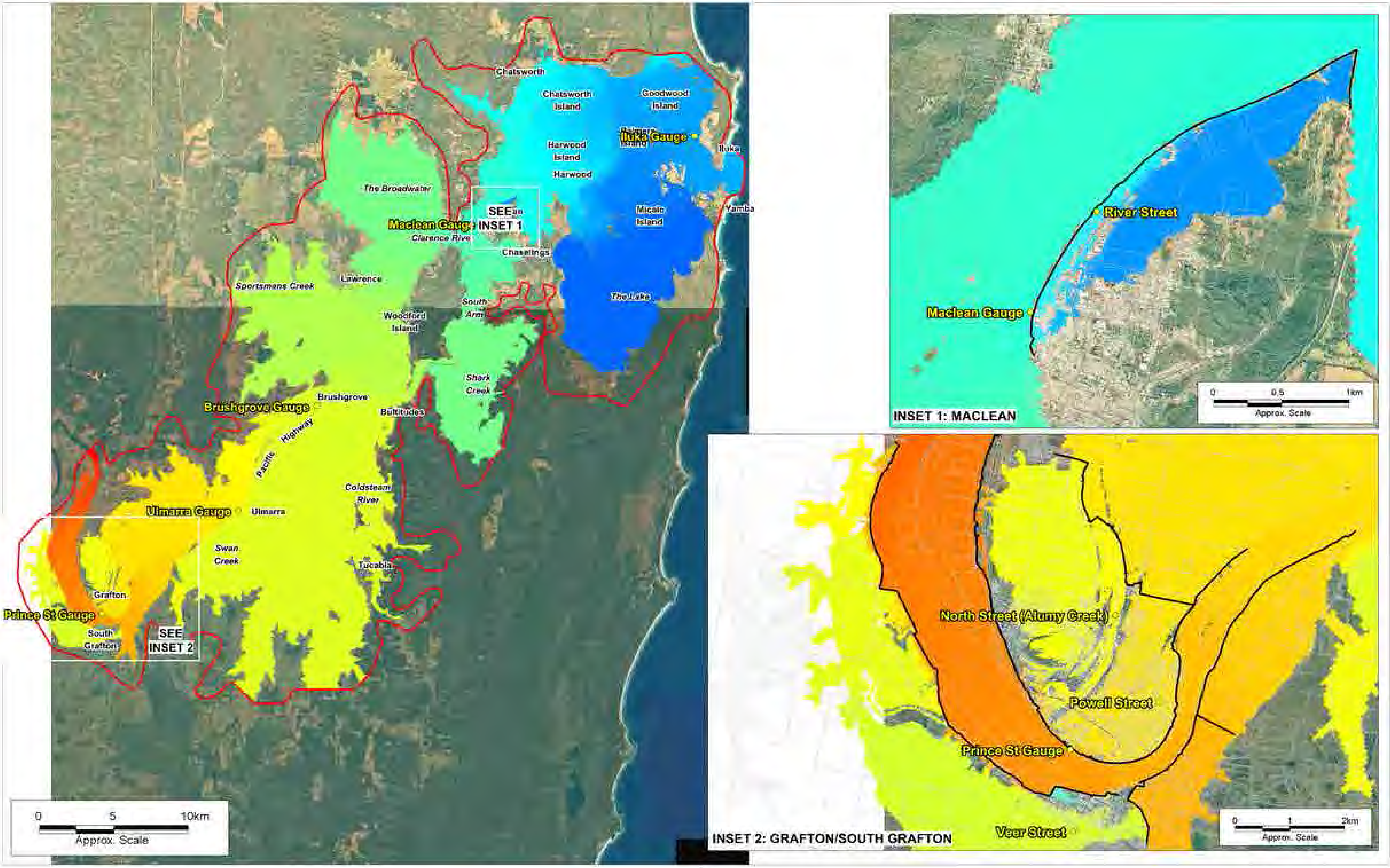

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Level (m AHD)

- 0.0 to 1.0
- 1.0 to 2.0
- 2.0 to 3.0
- 3.0 to 4.0
- 4.0 to 5.0
- 5.0 to 6.0
- 6.0 to 7.0
- 7.0 to 8.0
- 8.0 to 9.0
- 9.0 to 10.0
- 10.0 to 11.0
- 11.0 to 12.0
- 12.0 to 13.0
- Greater than 13.0

Title:

2% AEP Design Event:
Peak Flood Level (Flood Planning Level Review)

Figure: 7-2

Rev: A

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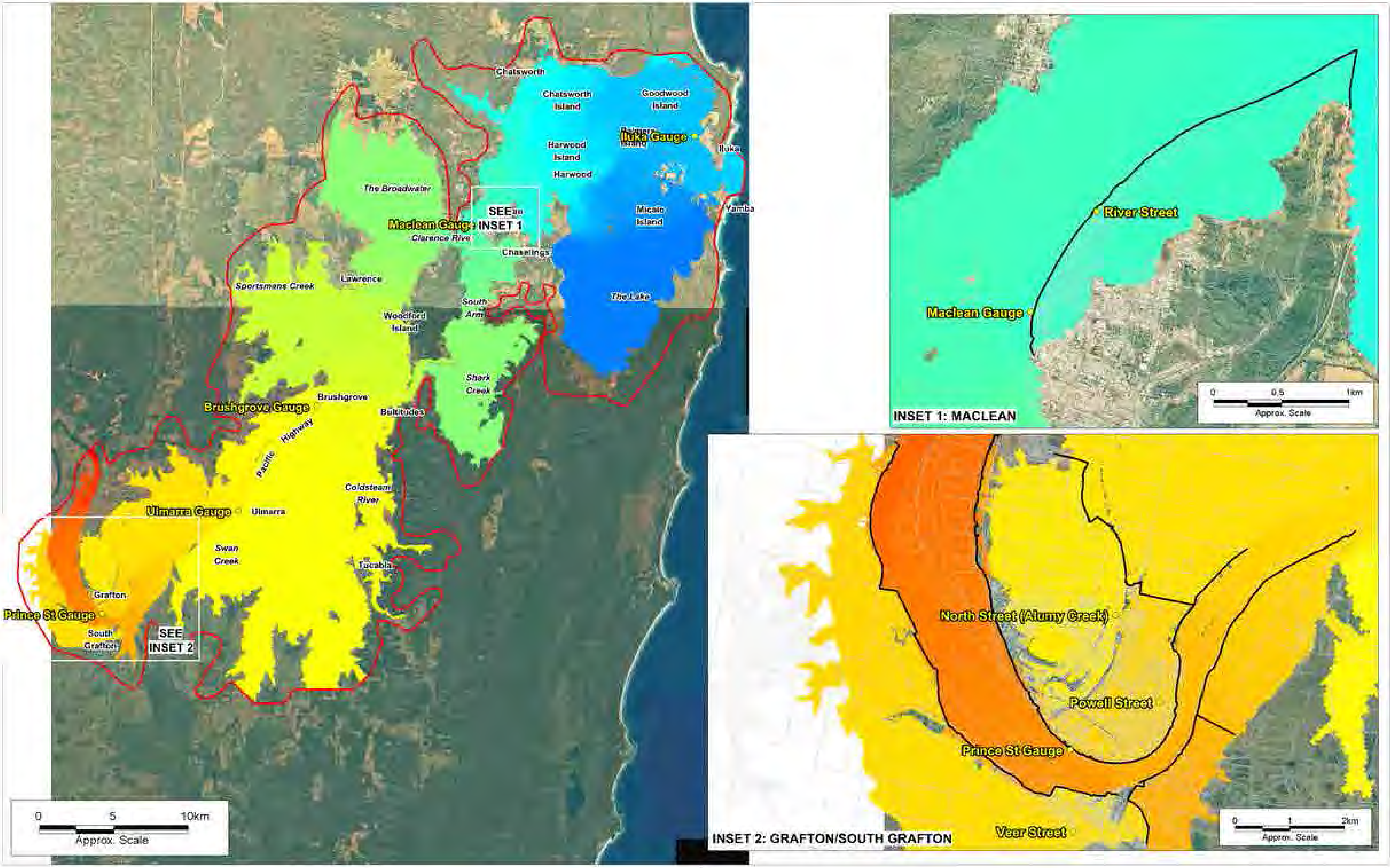

LEGEND

- Flood Model Extent
- Levees
- Reporting Locations

Peak Flood Level (m AHD)

- 0.0 to 1.0
- 1.0 to 2.0
- 2.0 to 3.0
- 3.0 to 4.0
- 4.0 to 5.0
- 5.0 to 6.0
- 6.0 to 7.0
- 7.0 to 8.0
- 8.0 to 9.0
- 9.0 to 10.0
- 10.0 to 11.0
- 11.0 to 12.0
- 12.0 to 13.0
- Greater than 13.0

Title:

1% AEP Design Event: Peak Flood Level (Flood Planning Level Review)

Figure: 7-3

Rev: A

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8 CONCLUSIONS AND RECOMMENDATIONS

This study represents an update to the Lower Clarence Flood Study Review (WBM, 2004) and Grafton and Maclean Flood Levee Overtopping: Hydraulic Assessment (BMT WBM, 2011). The study has:

- Redefined the regional flood behaviour within the Lower Clarence Valley (peak flood level, depth, velocities and velocity depth product);
- Assessed the potential impacts of climate change on peak flood levels;
- Assessed the drainage behaviour within the Grafton levee system; and
- Reviewed the flood planning levels in Grafton, South Grafton and Maclean.

9 REFERENCES

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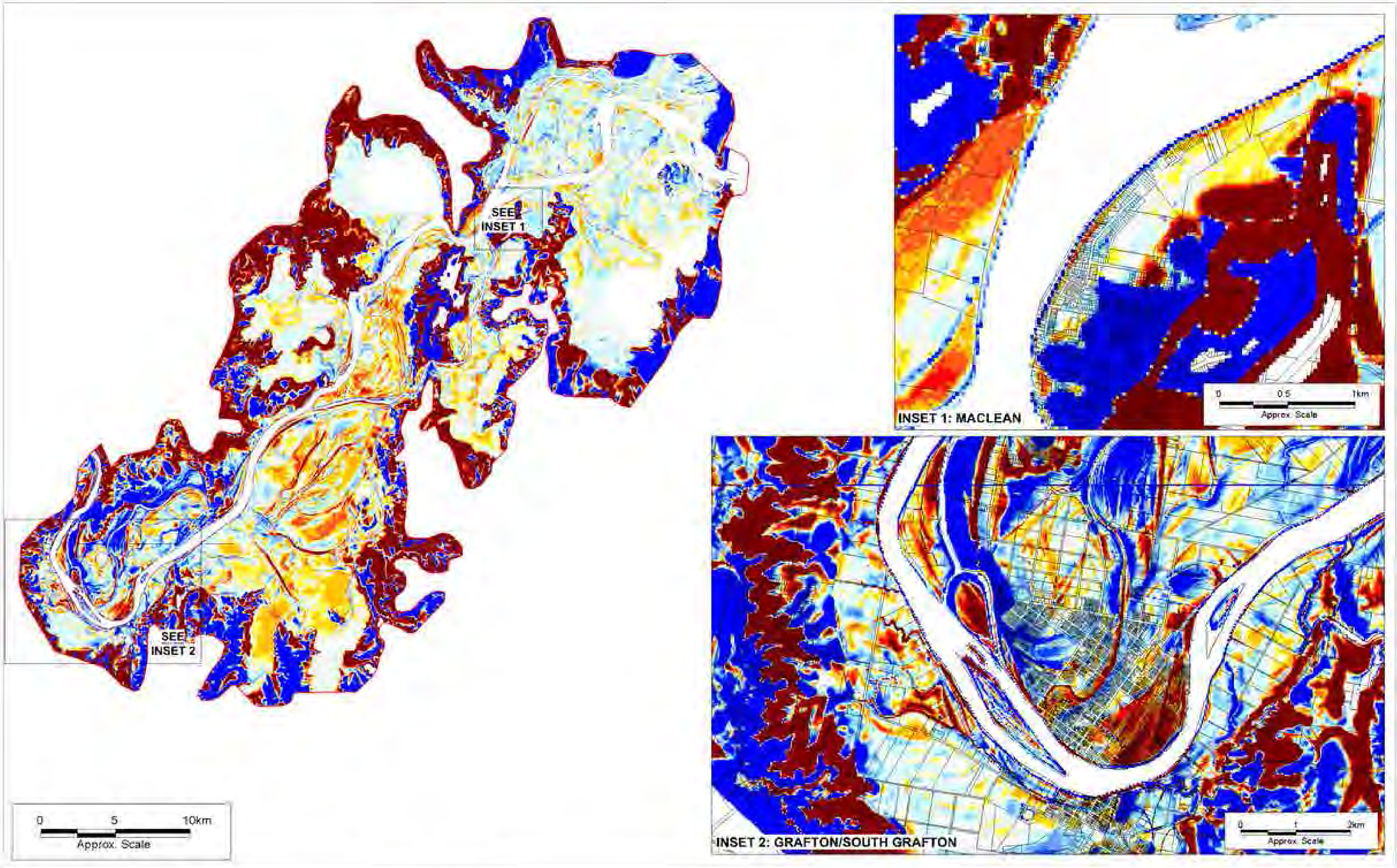
PWD (1988) "Lower Clarence River Flood Study", PWD No. 88066, December 1988.

Soros-Longworth & McKensie and Cameron McNamara (1980) "New South Wales Coastal Rivers Flood Plain Management Studies, Clarence River", Prepared for the NSW Sate Government December 1980

WBM (2004) "Lower Clarence River Flood Study Review", Prepared for Clarence Valley Council March 2004.

APPENDIX A: LOWER CLARENCE RIVER FLOOD STUDY (2004) COMPARISON



LEGEND

Flood Model Extent

Elevation Difference
(2012 ALS minus WBM (2004)

<-1.5	0.2 to 0.5
-1.0 to -1.5	0.5 to 1.0
-0.5 to -1.0	1.0 to 1.5
-0.2 to -0.5	1.5 to 2.0
-0.2 to 0.2	>2.0

Title:
Lower Clarence River DEM Comparison

Figure:
A-1

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A

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BMT WBM
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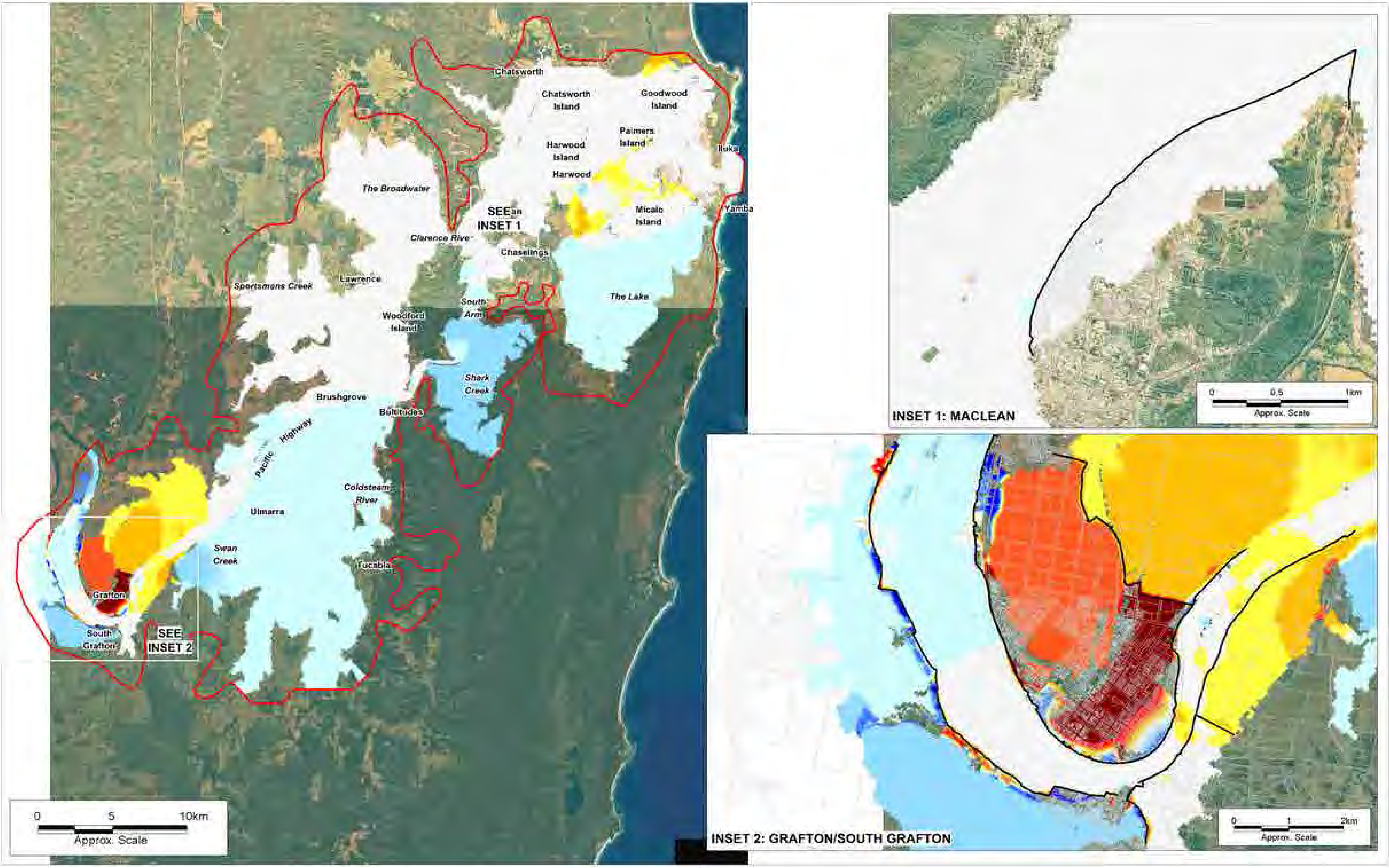

LEGEND

Flood Model Extent

Levees

Peak Flood Difference (m)

(Current Study minus WBM 2004)

- Less than -0.90
- -0.90 to -0.60
- -0.60 to -0.40
- -0.40 to -0.20
- -0.20 to -0.10
- -0.10 to 0.10
- 0.10 to 0.20
- 0.20 to 0.40
- 0.40 to 0.60
- 0.60 to 0.90
- Greater than 0.90

Title:

Lower Clarence River Flood Level Comparison: 1% AEP Event

Figure: **A-2**

Rev: **A**

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Table A- 1 Lower Clarence River Flood Level Comparison: 1% AEP Event - Reporting Locations

Reporting Locations		2004 Model Result (m)	2013 Model Result (m)	Difference (m)
Regional	Maclean Gauge	3.8	3.6	-0.12
	Brushgrove Gauge	5.9	5.8	-0.06
	Ulmarra Gauge	6.4	6.3	-0.07
	Prince St Gauge	8.2	8.3	0.04
	Iluka Gauge	2.4	2.5	0.07
Urban	North Street (Alumy Creek)	6.0	6.5	0.47
	Powell Street	6.4	7.1	0.61
	Veer Street	6.2	5.9	-0.31
	River Street	3.8	3.7	-0.06

APPENDIX B: LOWER CLARENCE FLOOD MODEL CALIBRATION

Table B- 1 Grafton Flood Mitigation Measure List

Structure	Construction Date	Structure Represented in Calibration Flood Model						
		Jun-67	Jan-68	May-80	Apr-88	May-96	Mar-01	May-09
Great Marlow Wall	1894	•	•	•	•	•	•	•
Ulster Lodge Embankment	1894	•	•	•	•	•	•	•
Alumy Creek Embankment	1895	•	•	•	•	•	•	•
Carrs Creek Embankment	1896	•	•	•	•	•	•	•
North Coast Railway Embankment	1902	•	•	•	•	•	•	•
Ulster Lodge Embankment (extended)	1962	•	•	•	•	•	•	•
Seelands Drain and Floodgate	1964	•	•	•	•	•	•	•
Waterview Drain and Floodgate	1964	•	•	•	•	•	•	•
Waterview Levee	1964	•	•	•	•	•	•	•
Saltwater Creek Floodgate	1964	•	•	•	•	•	•	•
Cowan Creek Floodgate	1964	•	•	•	•	•	•	•
Ardent St Floodgate	1964	•	•	•	•	•	•	•
Ardent St Levee	1964	•	•	•	•	•	•	•
Christopher Creek Floodgate	1964	•	•	•	•	•	•	•
Great Marlow Wall raised	1964	•	•	•	•	•	•	•
Clarenza Drain and Floodgate	1964	•	•	•	•	•	•	•
Clarenza Creek Blockage (??)	1964	•	•	•	•	•	•	•
Westlawn Levee	1969			•	•	•	•	•
Westlawn Levee southern end	1969			•	•	•	•	•
Swan Creek Levee	1969			•	•	•	•	•
Carrs Creek Levee	1970			•	•	•	•	•
Cowan Creek Levee at River	1970			•	•	•	•	•
Cowan Creek Levee at Drain	1970			•	•	•	•	•
Cowan Creek Levee at Hwy	1970			•	•	•	•	•
Ardent St Drain Levee	1970			•	•	•	•	•

Structure	Construction Date	Structure Represented in Calibration Flood Model						
		Jun-67	Jan-68	May-80	Apr-88	May-96	Mar-01	May-09
Ardent St Levee at Hwy	1970			•	•	•	•	•
South Grafton Town Levee	1970			•	•	•	•	•
Alipou Creek Blocked	1970			•	•	•	•	•
Alipou Clarenza Levee	1970			•	•	•	•	•
Clarenza Control Levee	1970			•	•	•	•	•
Alice St Levee	1970			•	•	•	•	•
Ulster Lodge Levee	1970			•	•	•	•	•
North St Levee	1970			•	•	•	•	•
Carrs Creek Levee	1970			•	•	•	•	•
Alumy Creek Block	1973			•	•	•	•	•
Ulmarra Levee	1973			•	•	•	•	•
Bunyip Creek Floodgate	1973			•	•	•	•	•
Bunyip Creek Block	1973			•	•	•	•	•
Fabridam	1973			•	•	•	•	•
Waterview Levee	1976			•	•	•	•	•
Waterview Levee	1997						•	•
Rural Levee	1997						•	•
Urban Levee	1997						•	•
Heber St Levee	1997						•	•

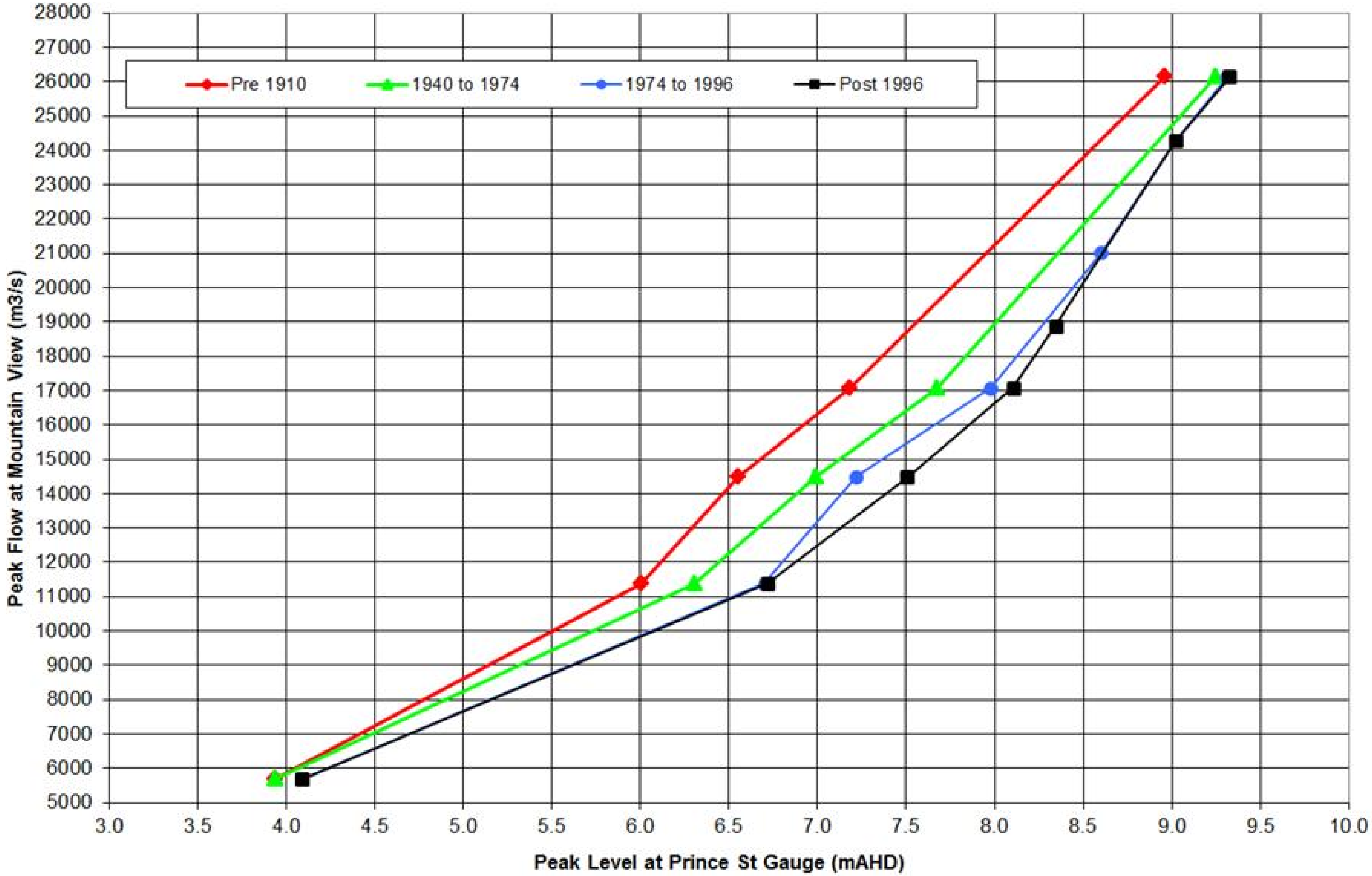

Figure B- 1 Clarence River Historical Rating Curve

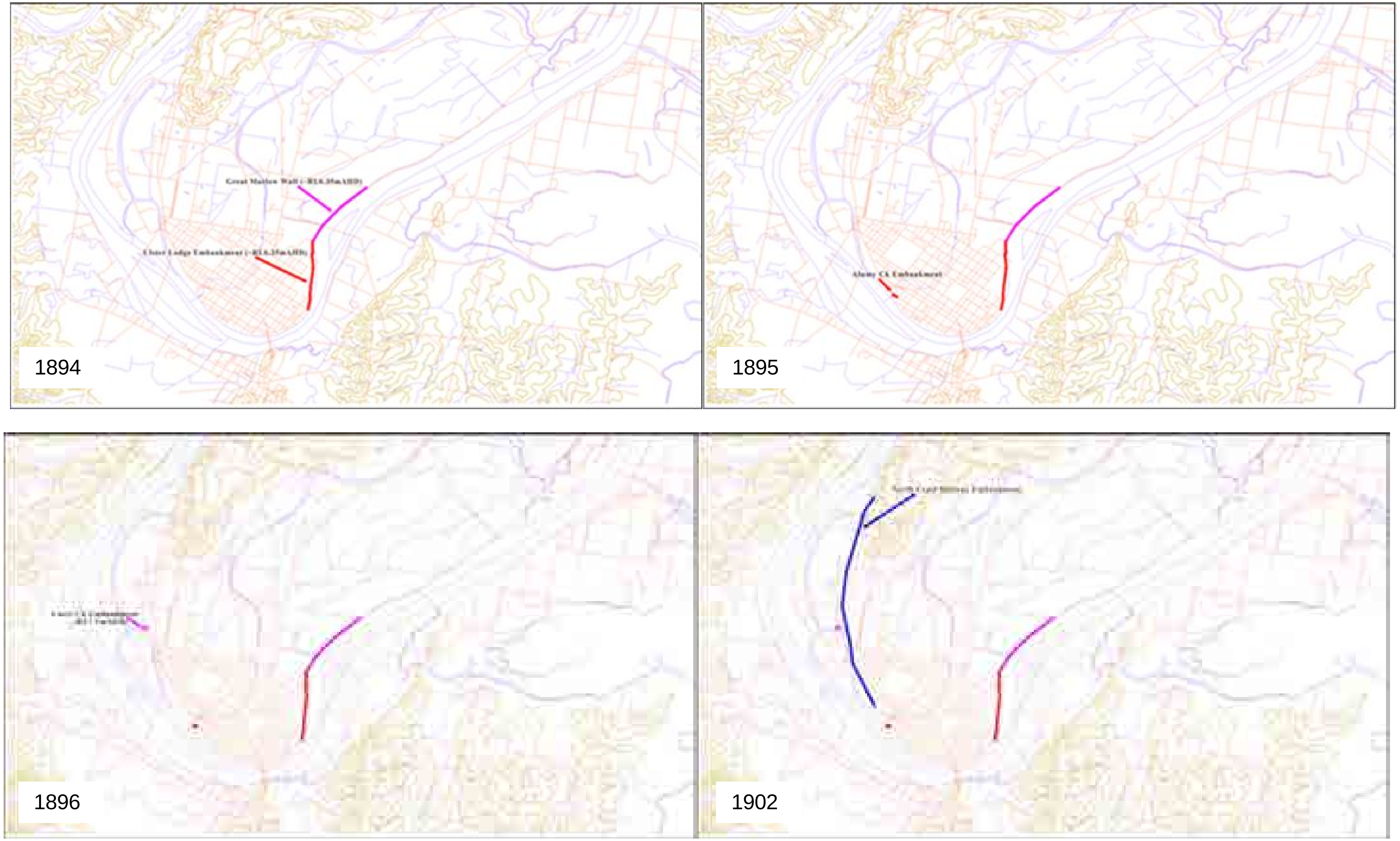

Figure B- 2 Flood Mitigation Structures: Mountain View to Ulmarra 1894 to 1902

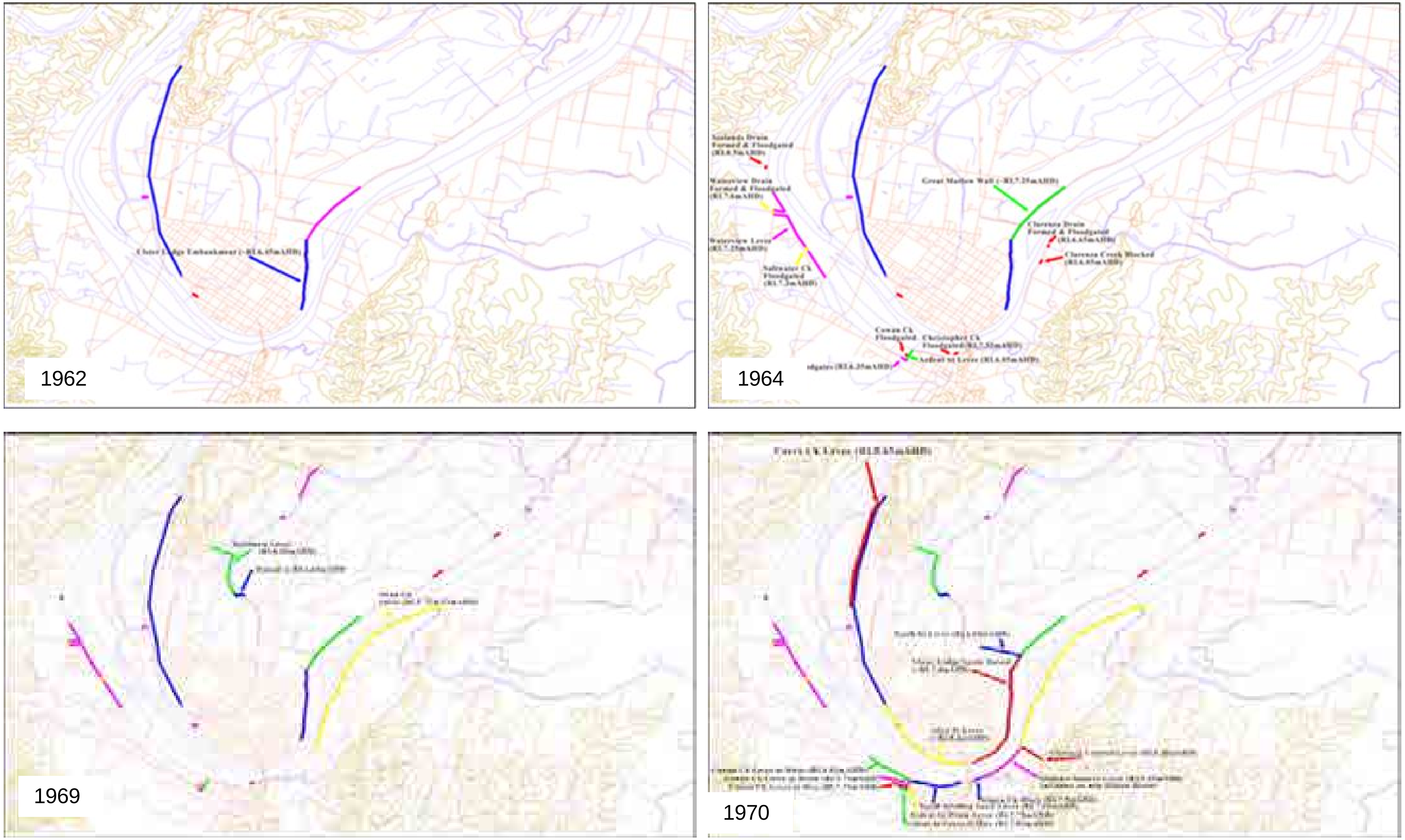

Figure B- 3 Flood Mitigation Structures: Mountain View to Ulmarra 1902 to 1970

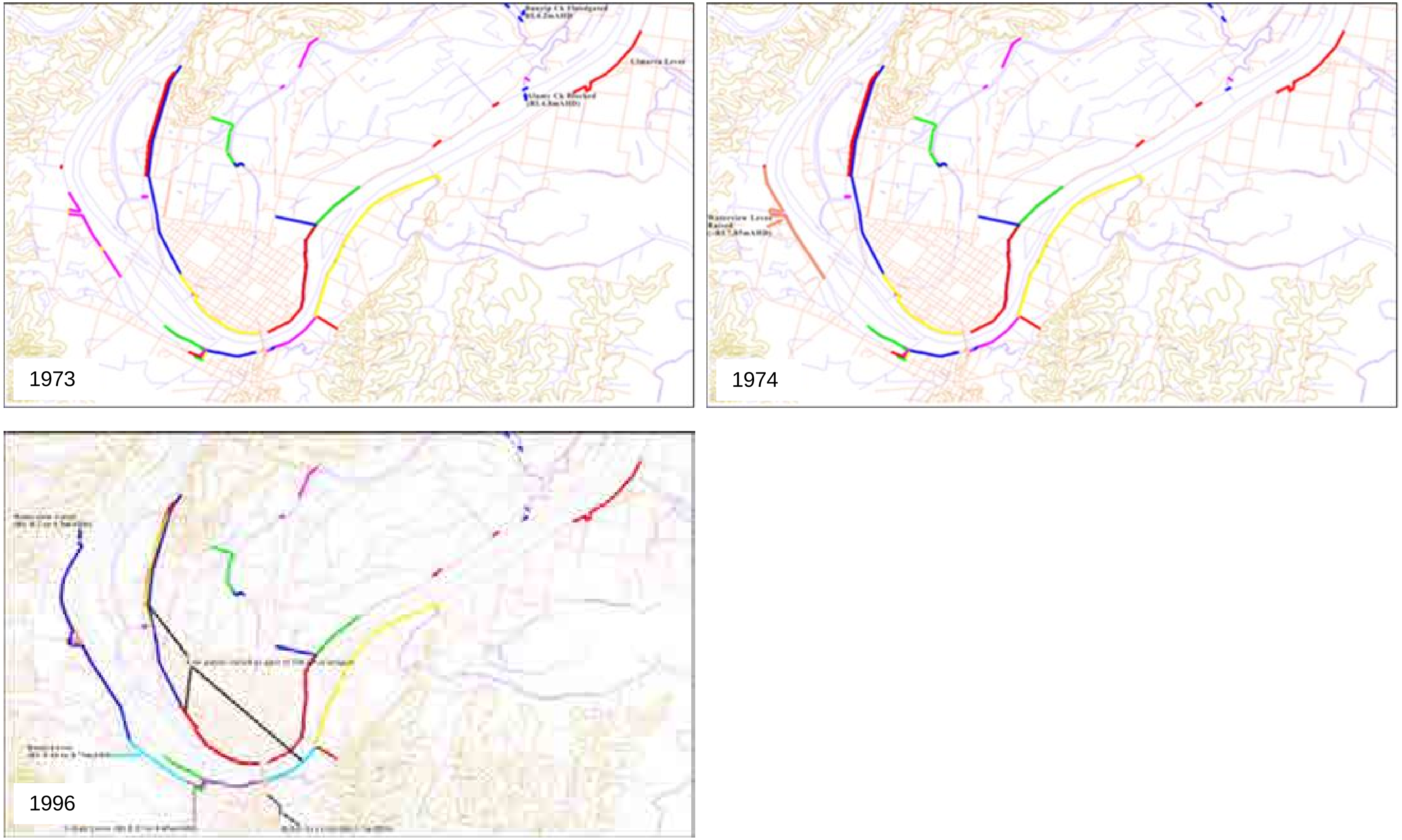

Figure B- 4 Flood Mitigation Structures: Mountain View to Ulmarra 1970 to 1996

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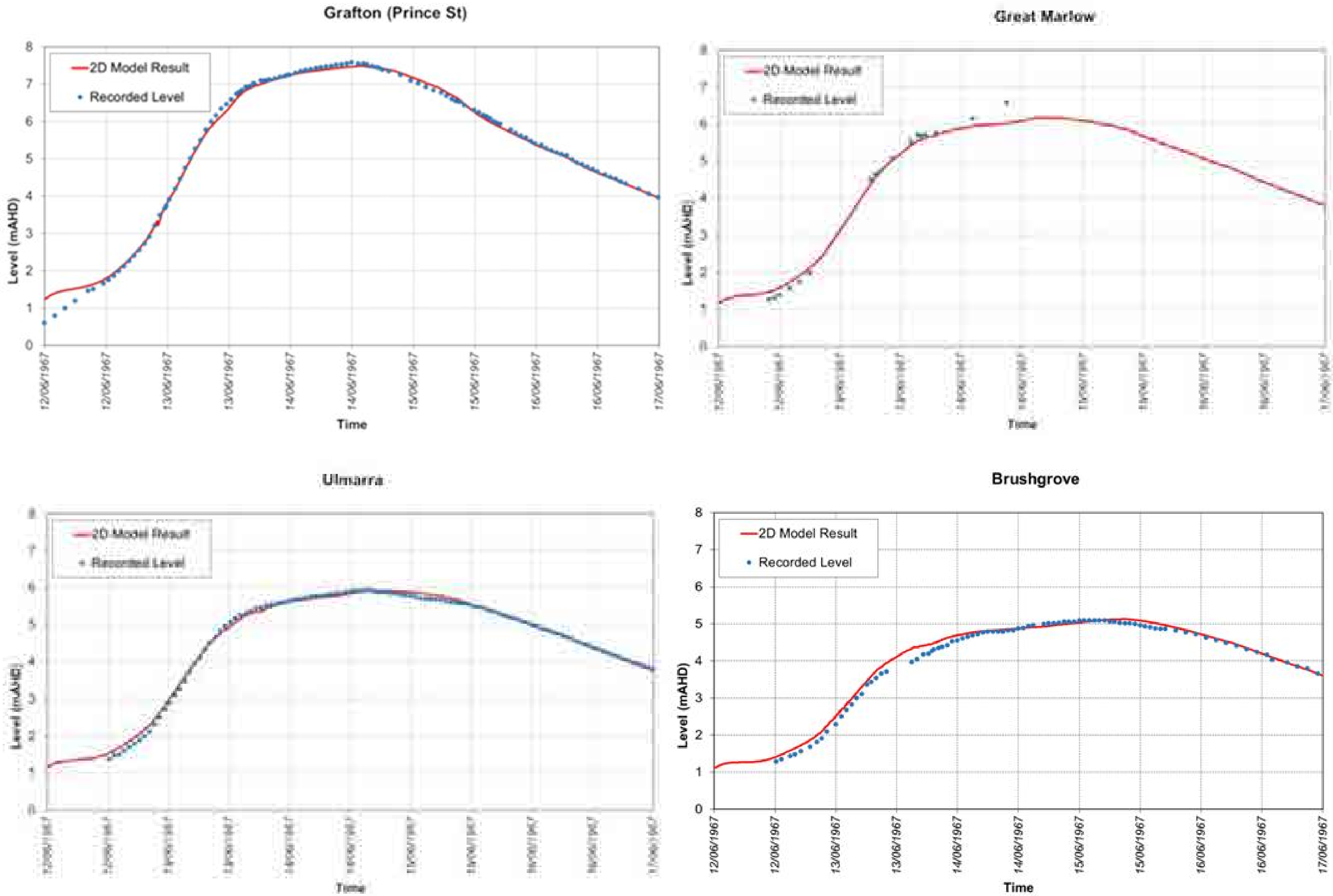


Figure B- 5 June 1967 Calibration Results: Flood Level Timeseries (Set 1)

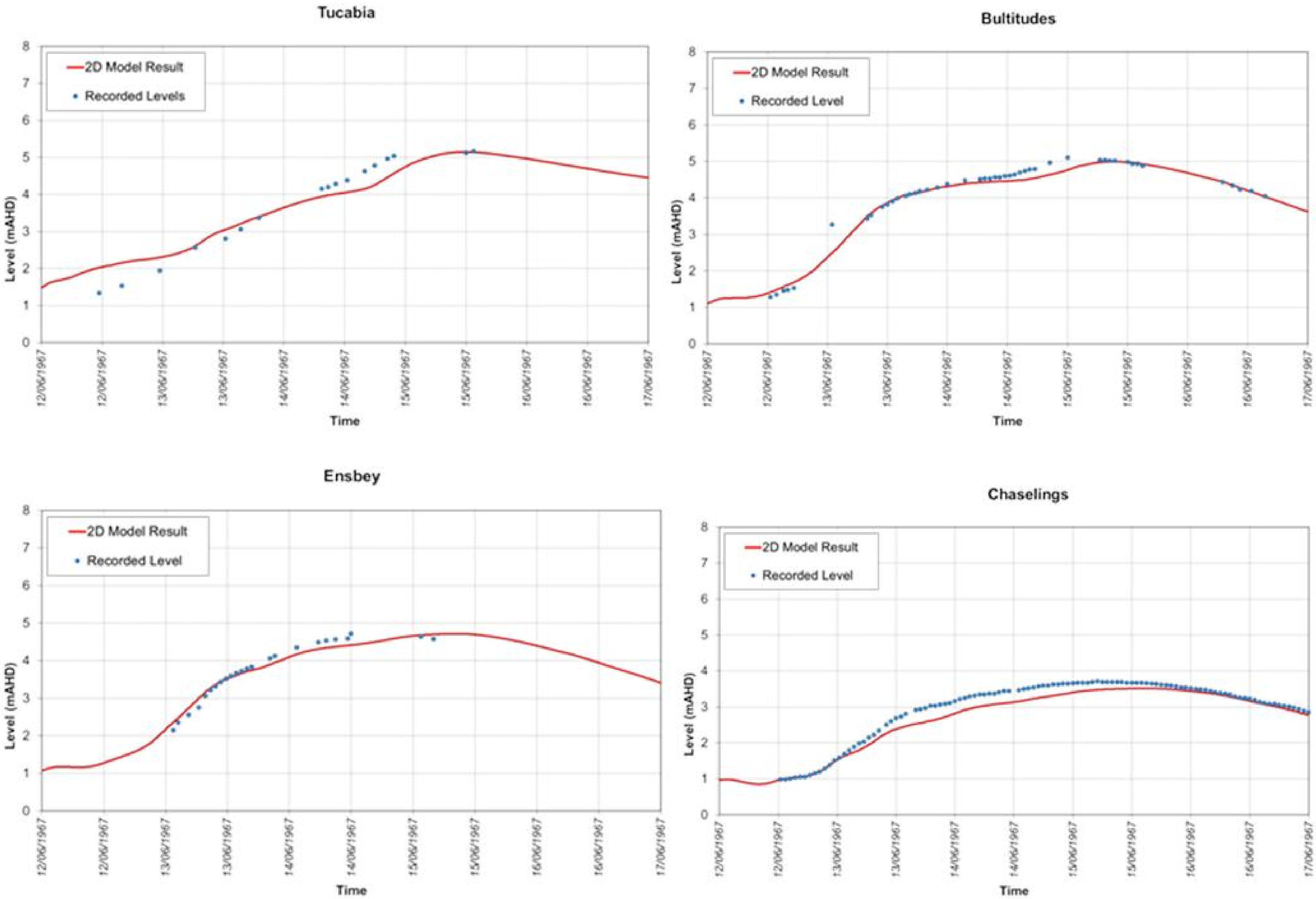


Figure B- 6 June 1967 Calibration Results: Flood Level Timeseries (Set 2)

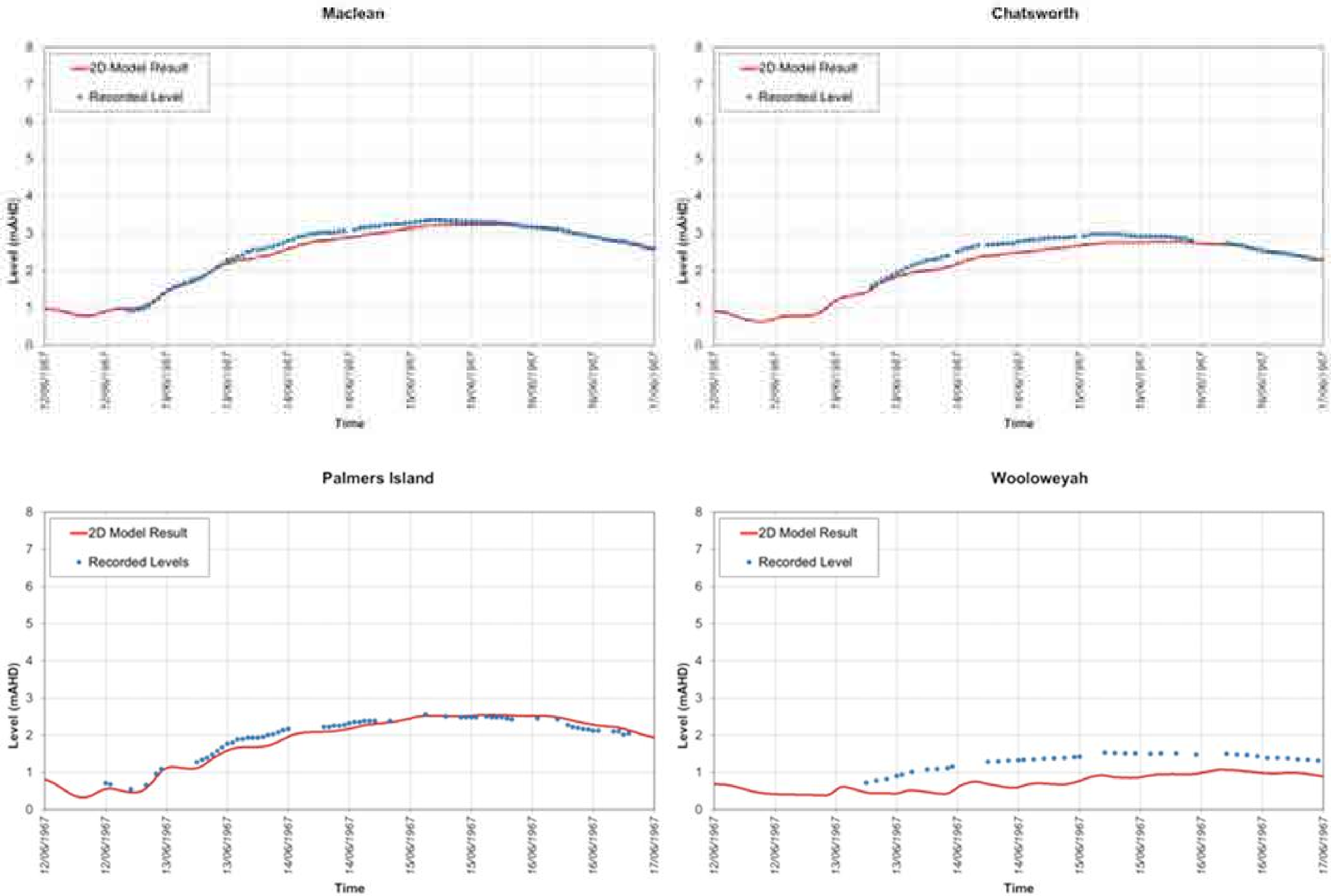


Figure B- 7 June 1967 Calibration Results: Flood Level Timeseries (Set 3)

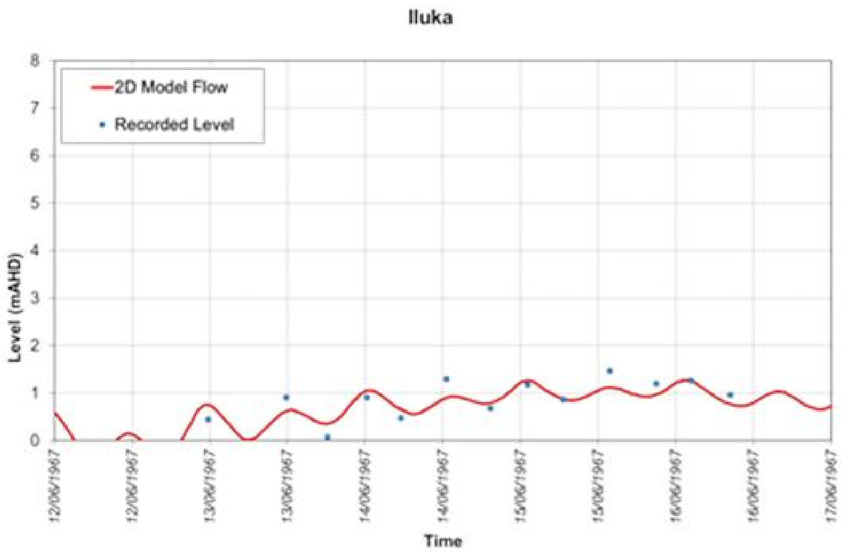


Figure B- 8 June 1967 Calibration Results: Flood Level Timeseries (Set 3)

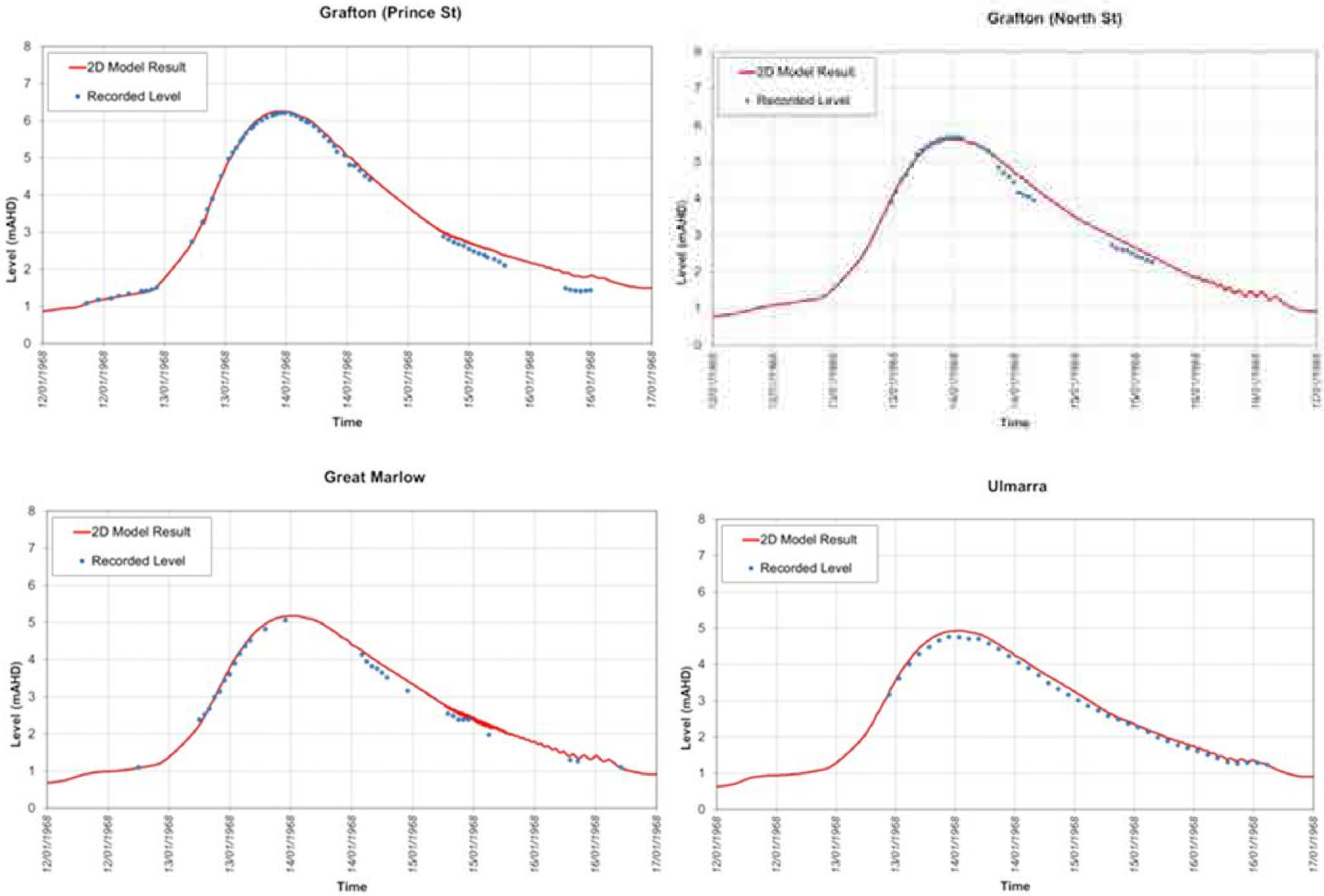


Figure B- 9 January 1968 Calibration Results: Flood Level Timeseries (Set 1)

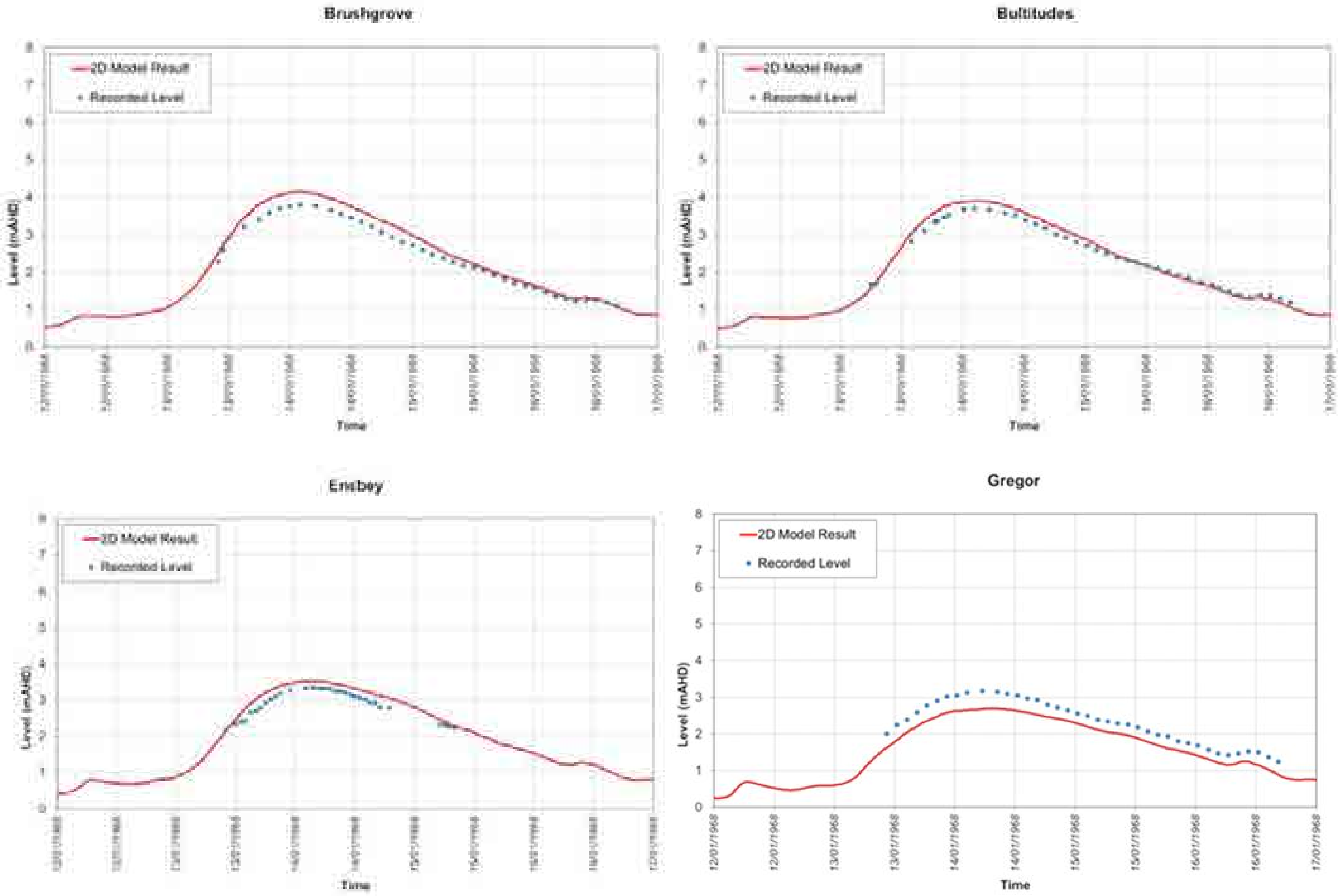


Figure B- 10 January 1968 Calibration Results: Flood Level Timeseries (Set 2)

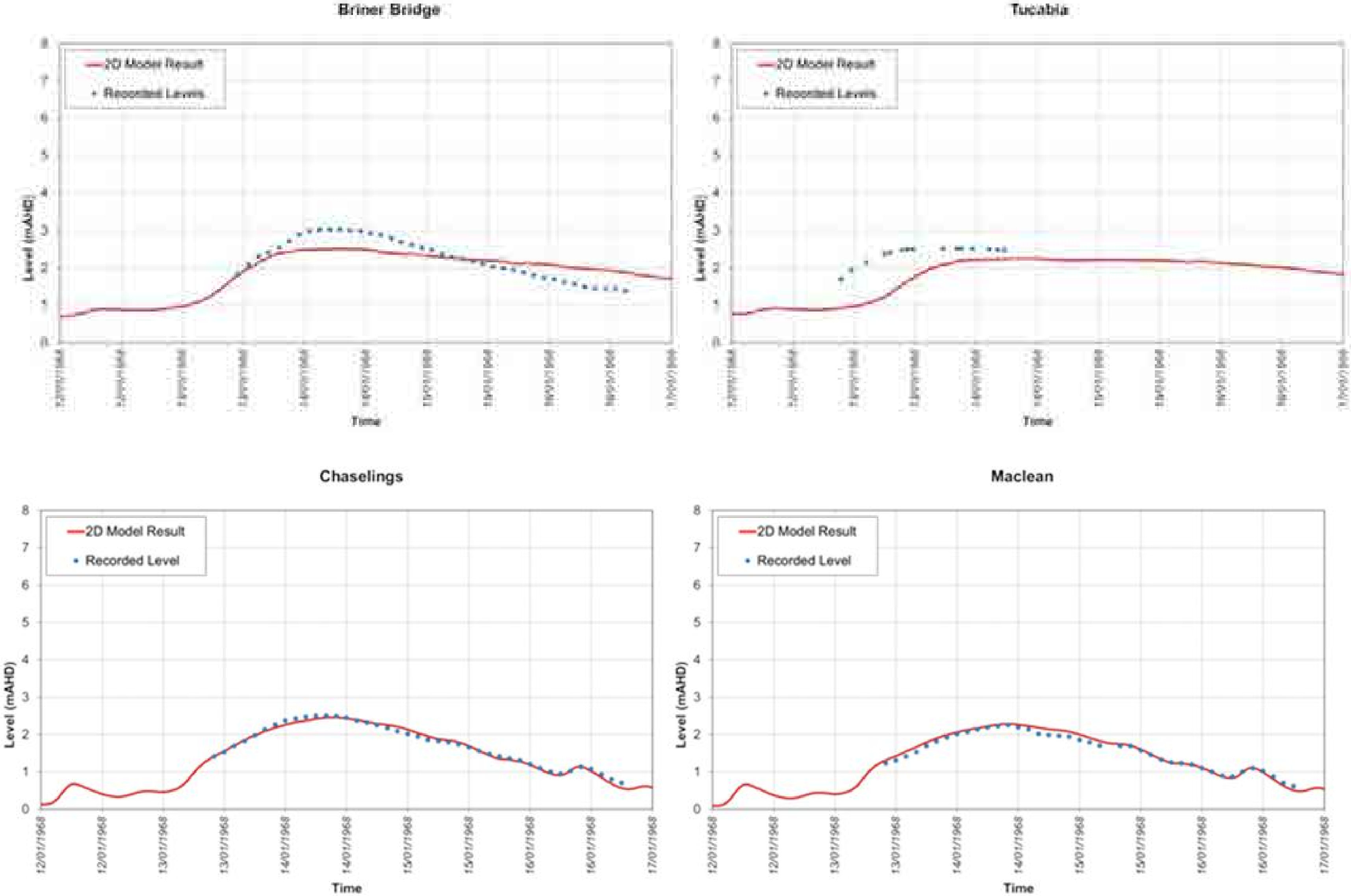


Figure B- 11 January 1968 Calibration Results: Flood Level Timeseries (Set 3)

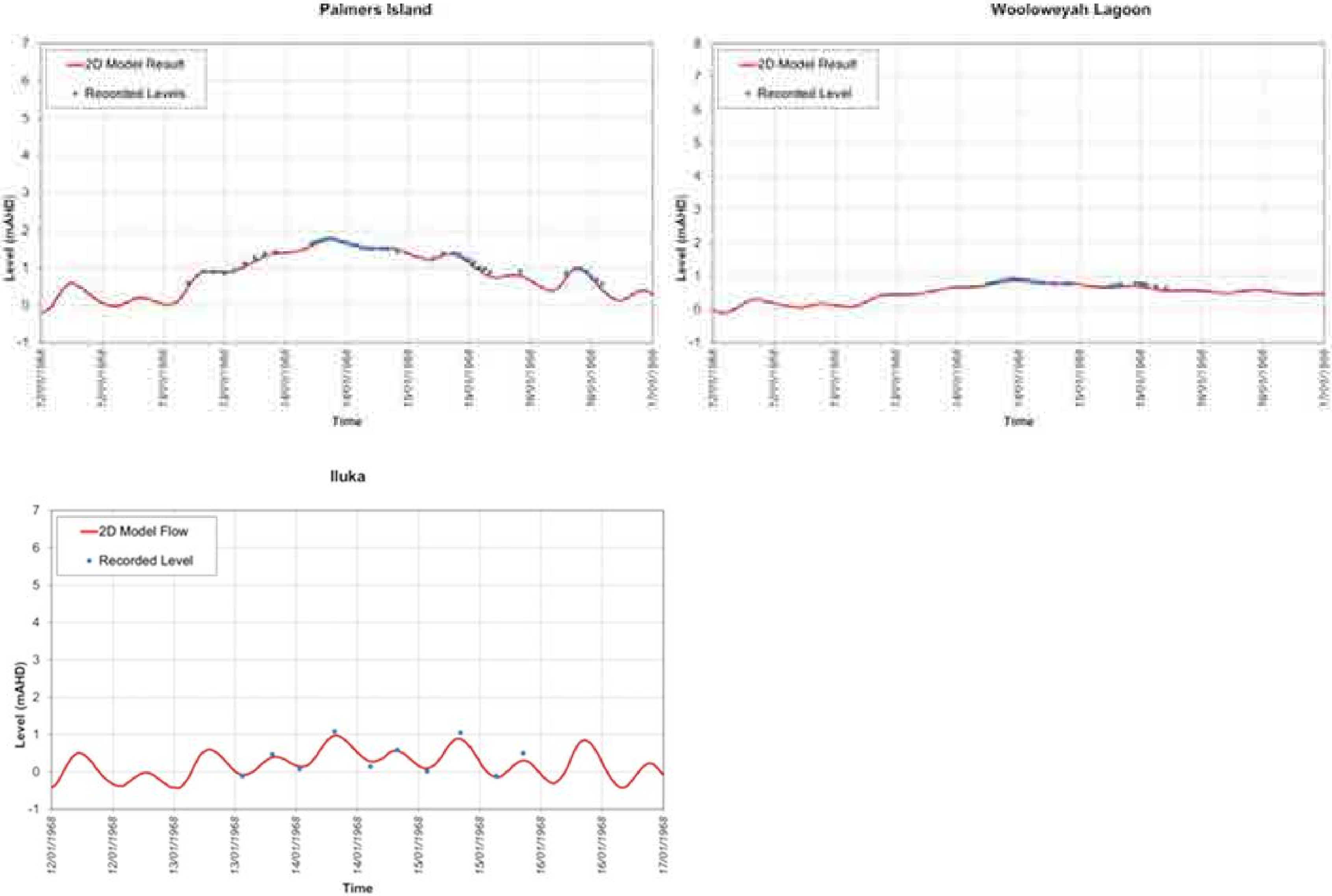


Figure B- 12 January 1968 Calibration Results: Flood Level Timeseries (Set 4)

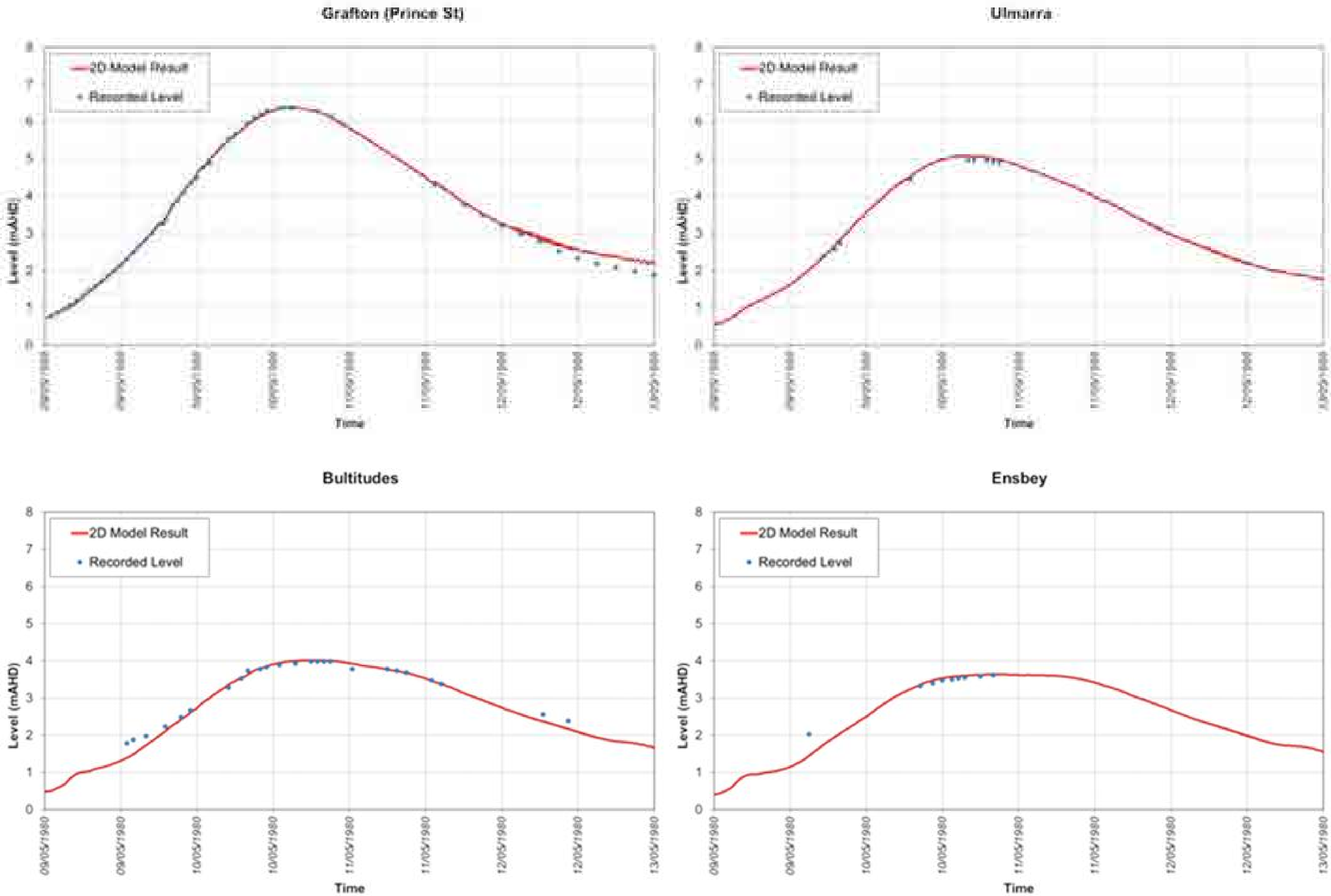


Figure B- 13 May 1980 Calibration Results: Flood Level Timeseries (Set 1)

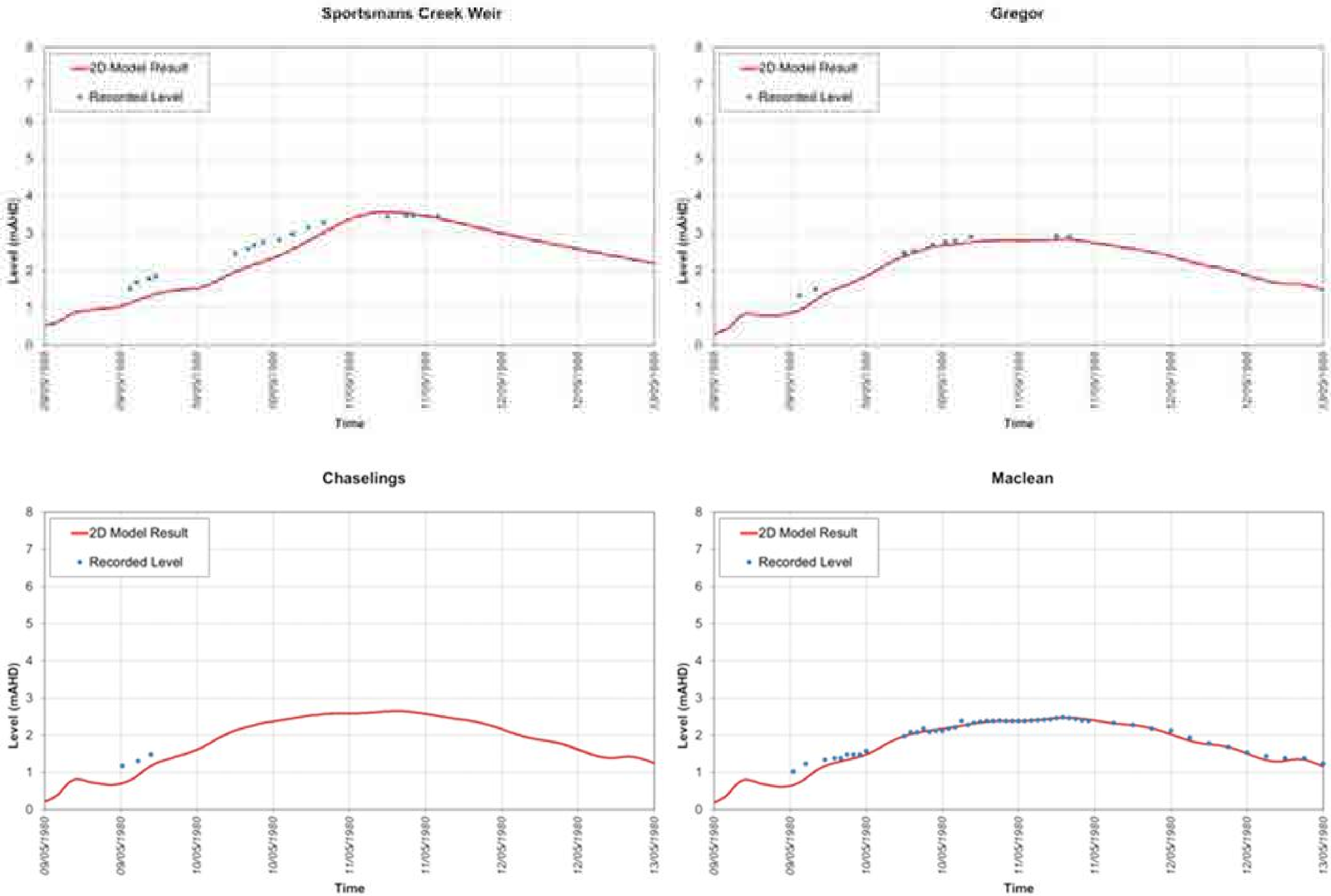


Figure B- 14 May 1980 Calibration Results: Flood Level Timeseries (Set 2)

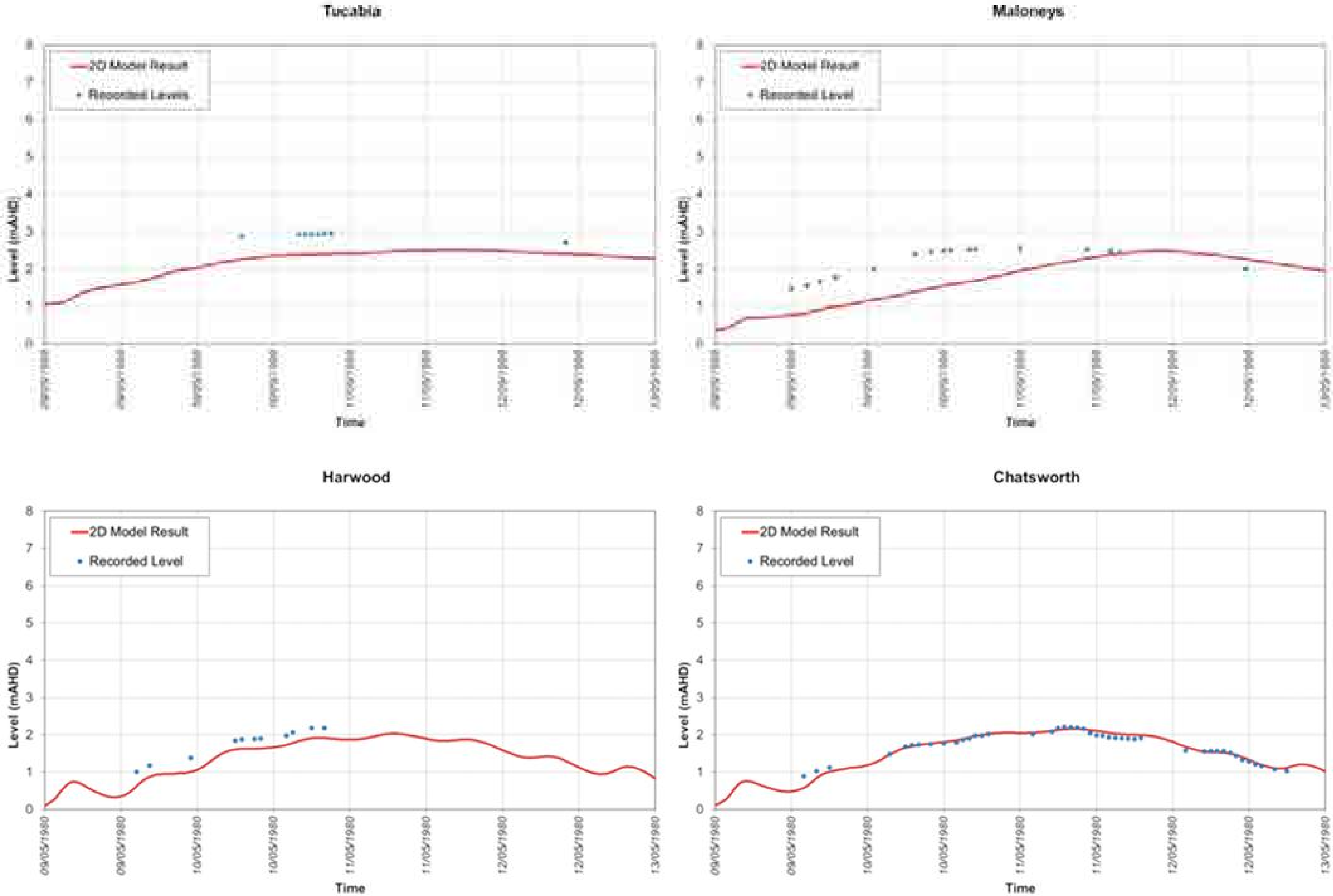
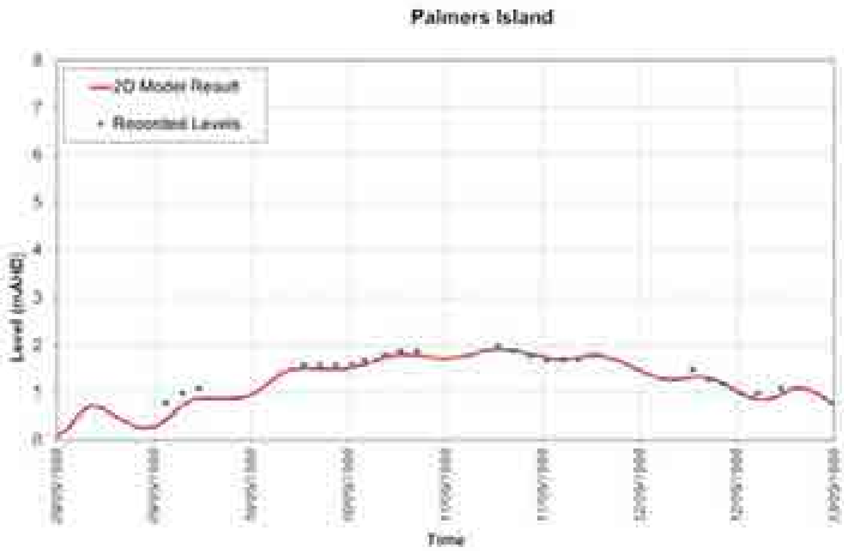
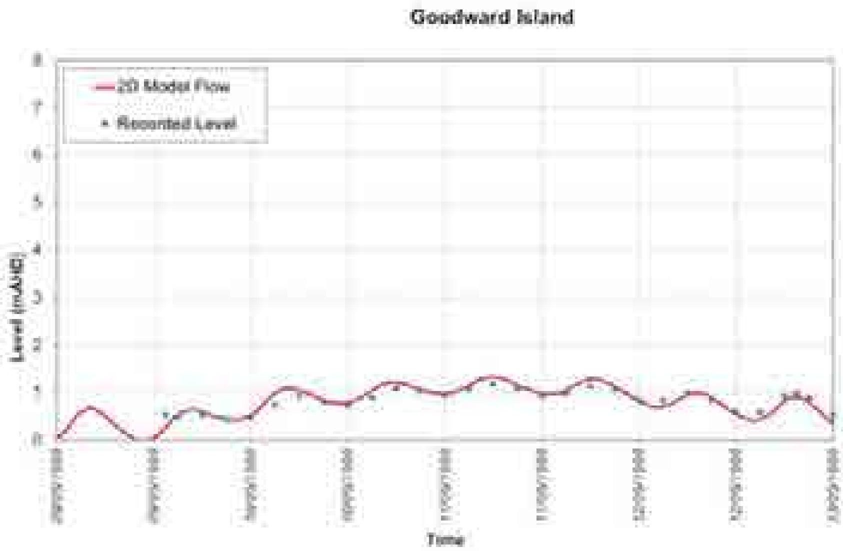


Figure B- 15 May 1980 Calibration Results: Flood Level Timeseries (Set 3)





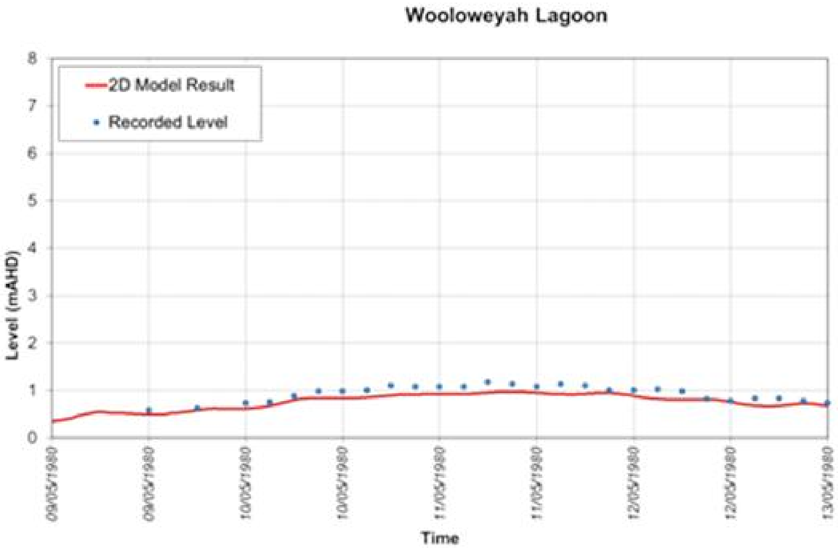


Figure B- 16 May 1980 Calibration Results: Flood Level Timeseries (Set 4)

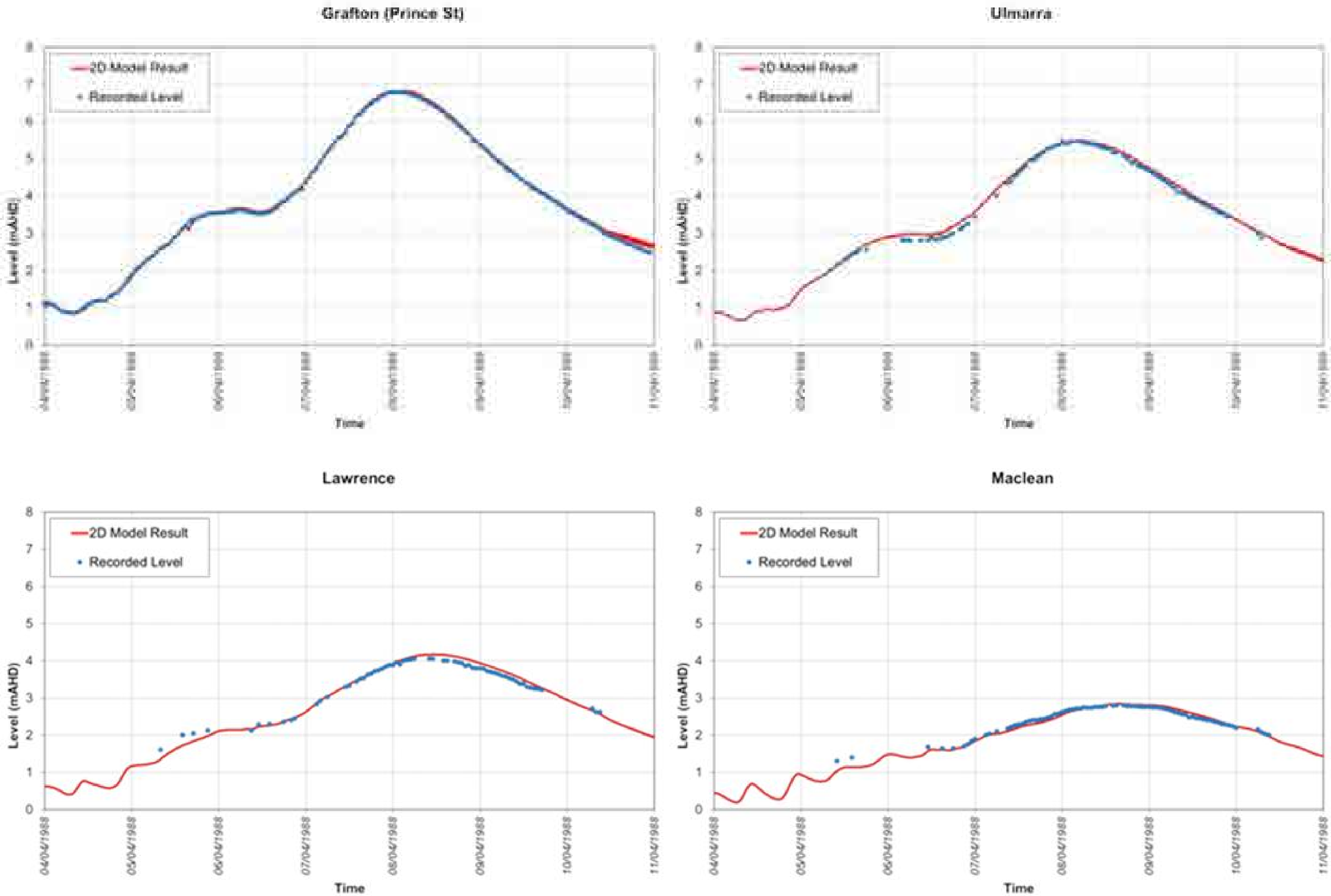


Figure B- 17 April 1988 Calibration Results: Flood Level Timeseries (Set 1)

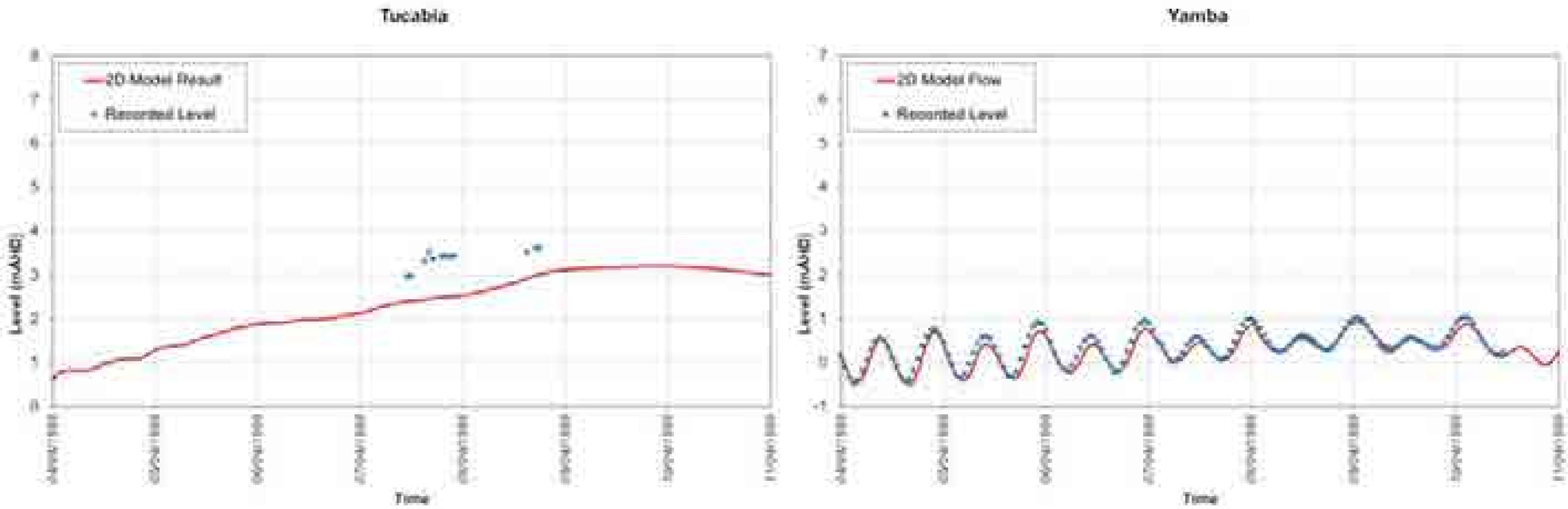


Figure B- 18 April 1988 Calibration Results: Flood Level Timeseries (Set 2)

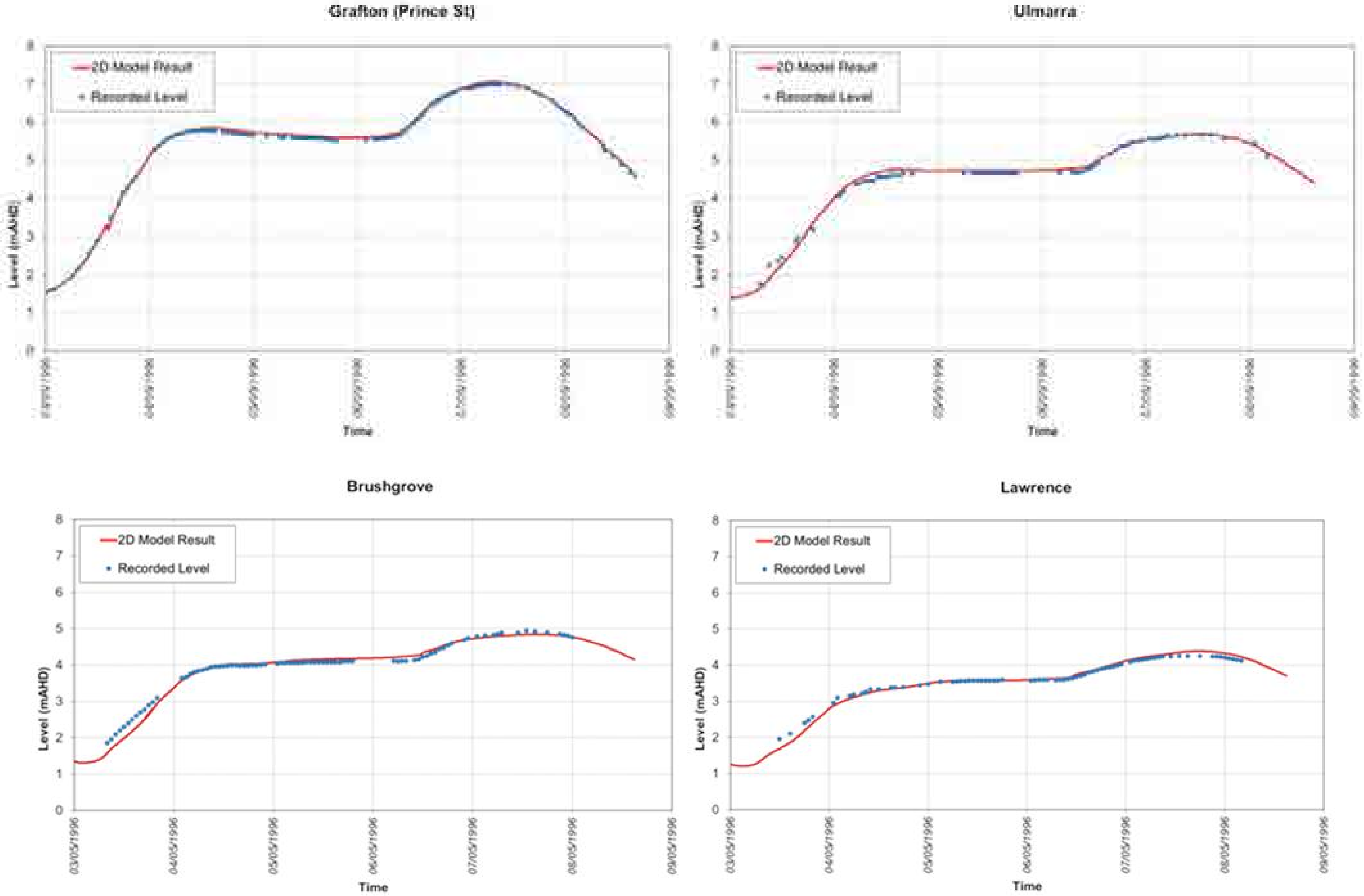


Figure B- 19 May 1996 Calibration Results: Flood Level Timeseries (Set 1)

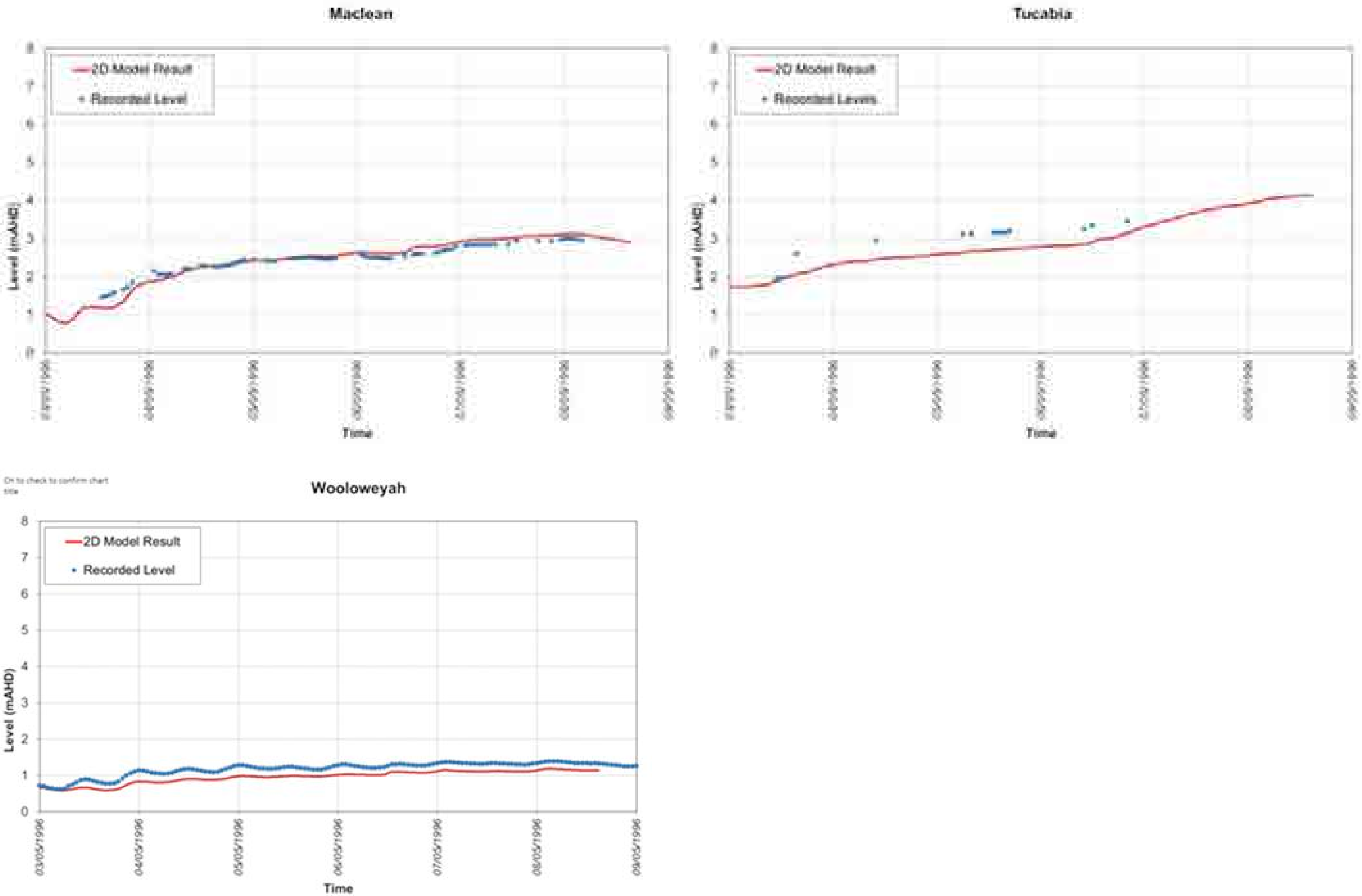


Figure B- 20 May 1996 Calibration Results: Flood Level Timeseries (Set 2)

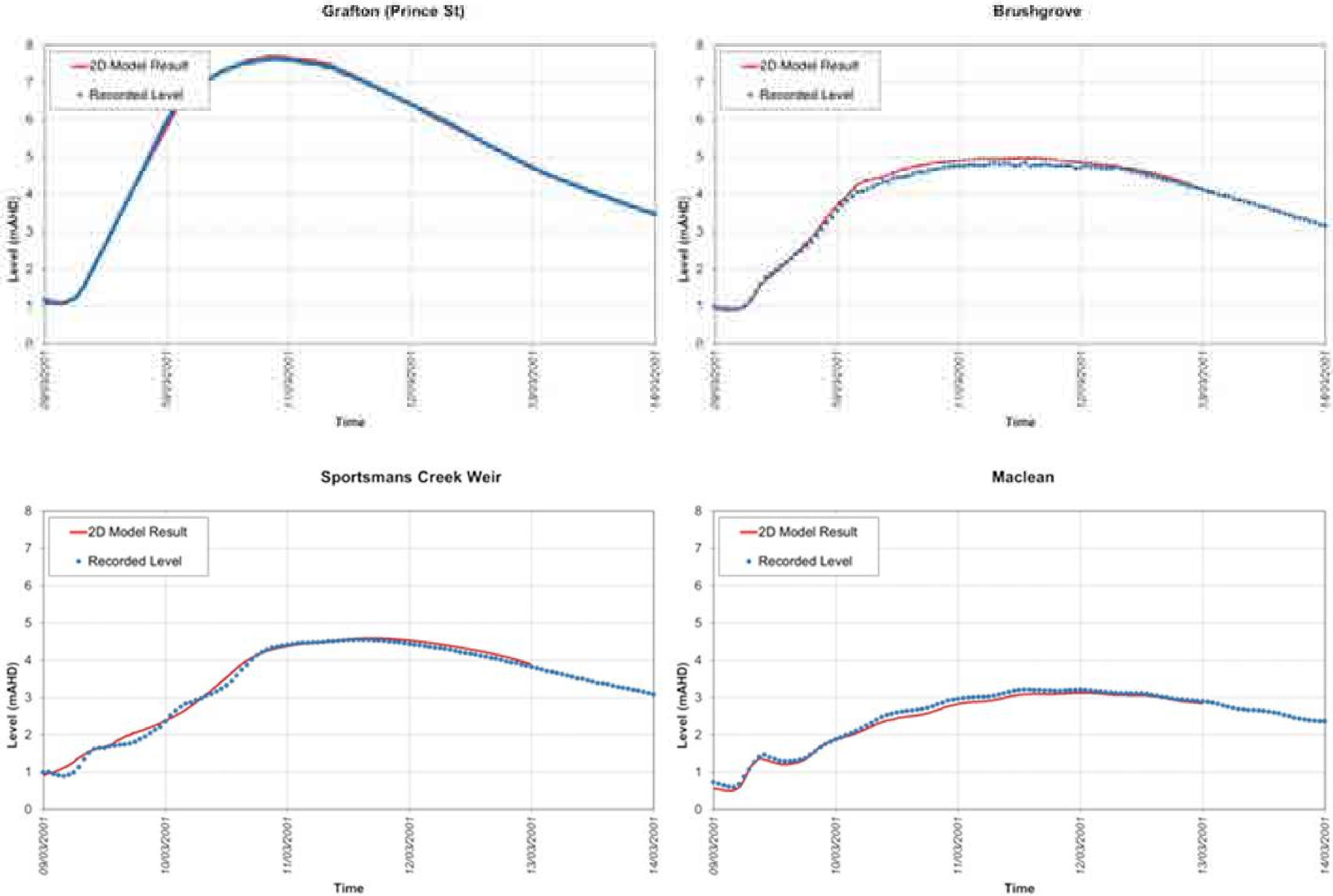


Figure B- 21 March 2001 Calibration Results: Flood Level Timeseries (Set 1)

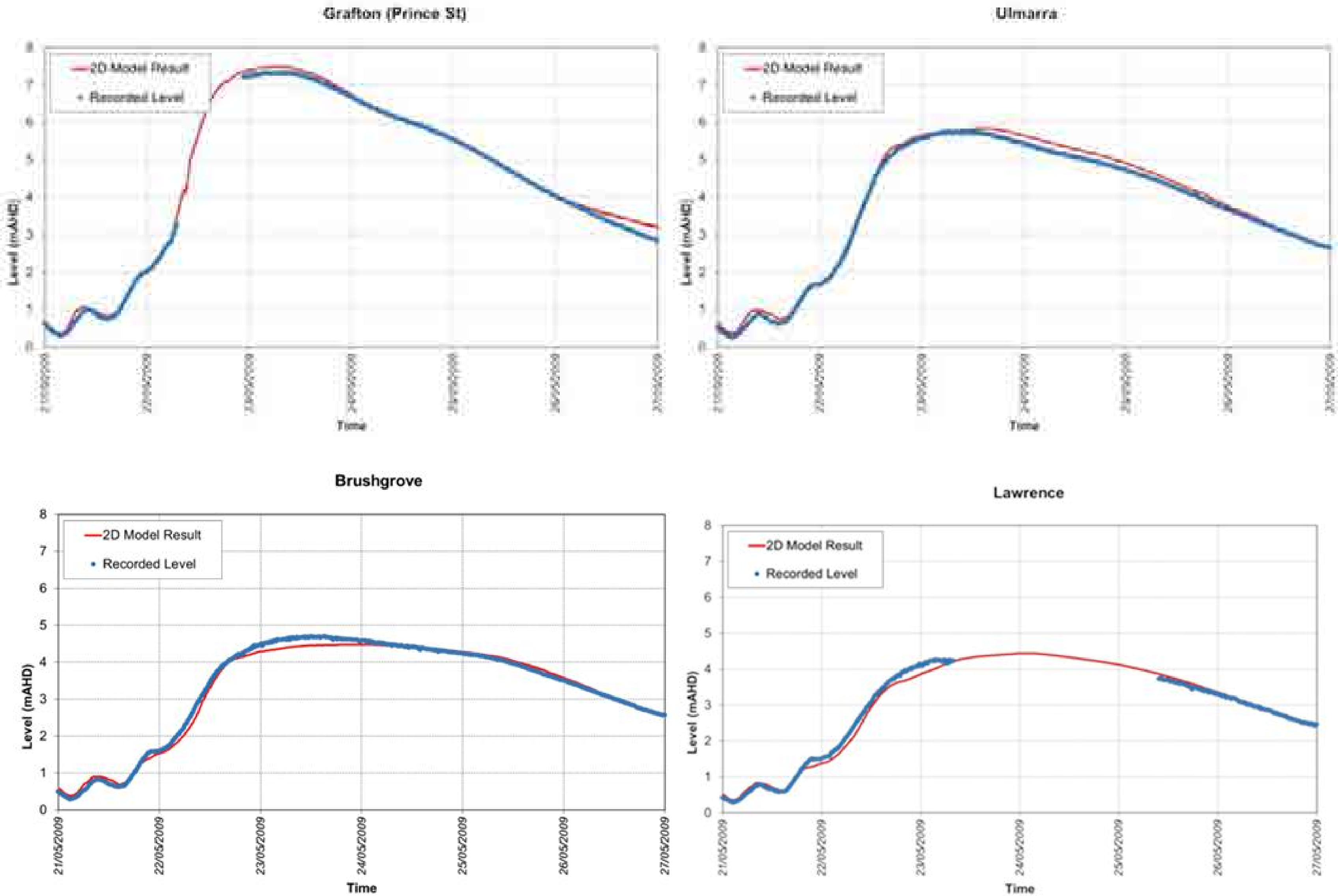
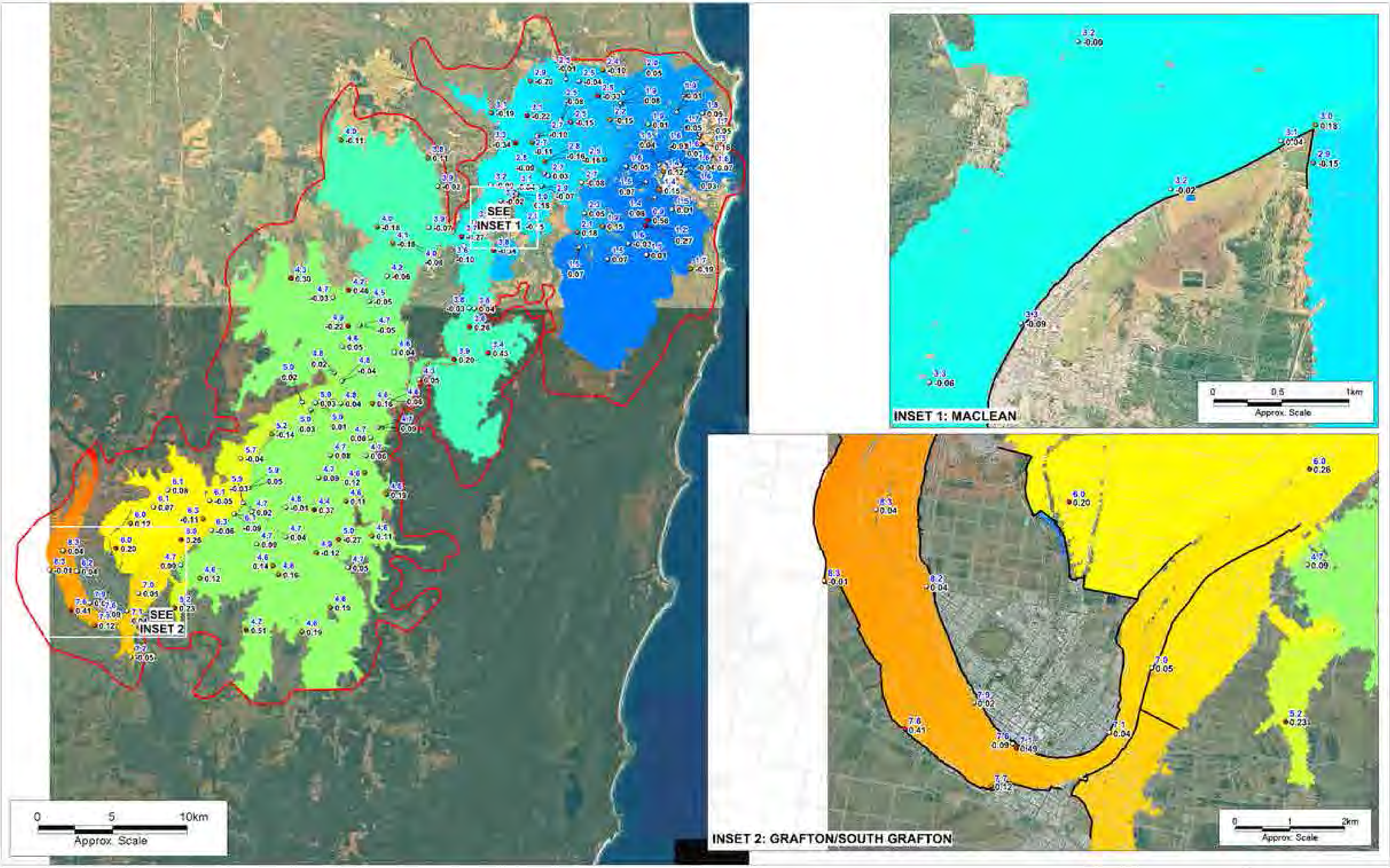


Figure B- 22 May 2009 Calibration Results: Flood Level Timeseries (Set 1)



LEGEND

- Flood Model Extent
- Levees
- 2.0 Recorded Flood Level (mAHD)
- 0.1 Flood Model Difference (m) (Model Result - Recorded Level)

Flood Model Difference (m)

- < 0.1
- 0.1 - 0.2
- >0.2

Modelled Peak Flood Level (mAHD)

0.0 to 1.0	7.0 to 8.0
1.0 to 2.0	8.0 to 9.0
2.0 to 3.0	9.0 to 10.0
3.0 to 4.0	10.0 to 11.0
4.0 to 5.0	11.0 to 12.0
5.0 to 6.0	12.0 to 13.0
6.0 to 7.0	Greater than 13.0

Title:

March 2001 Calibration Results: Peak Flood Level

Figure: **B-23**

Rev: **A**

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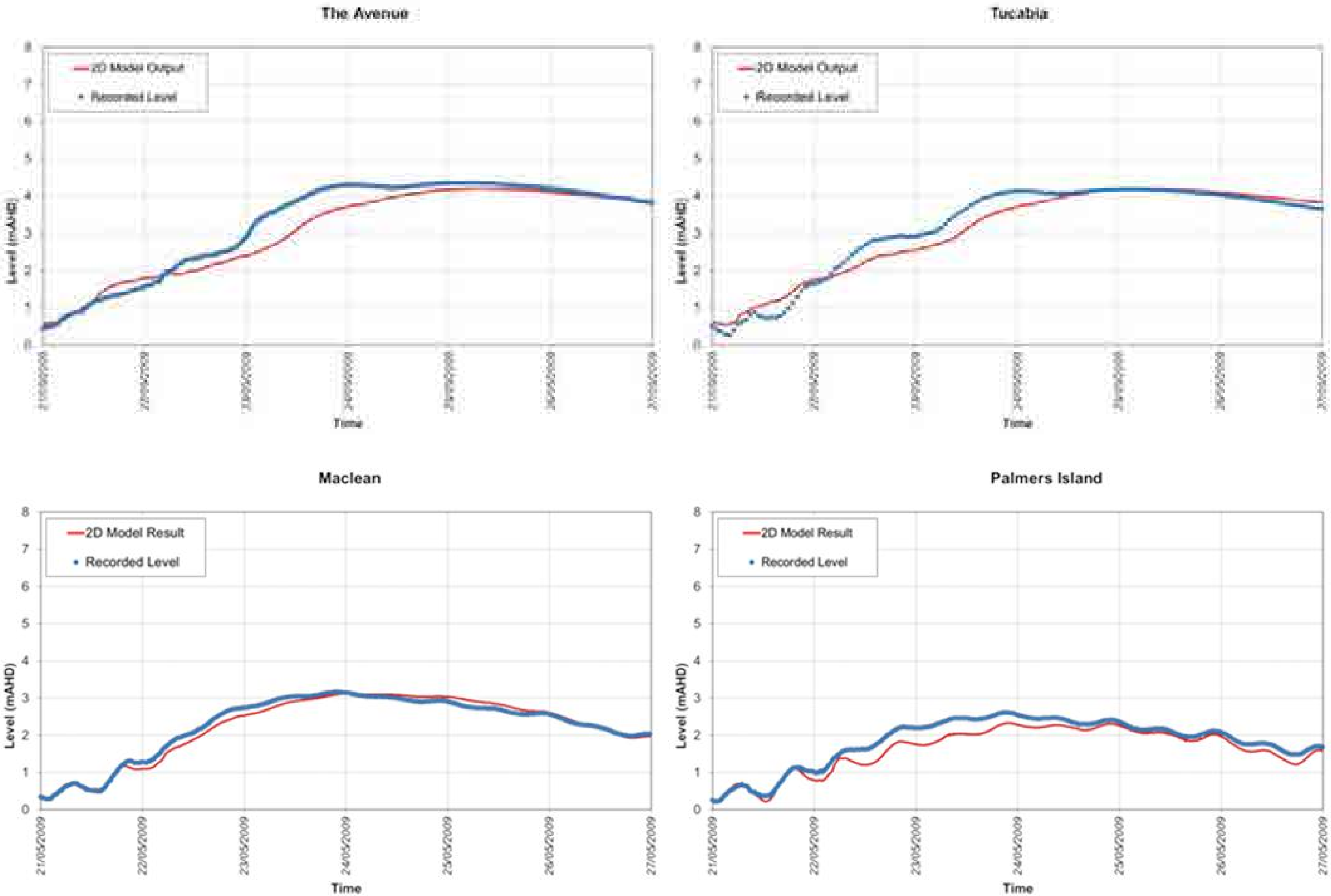
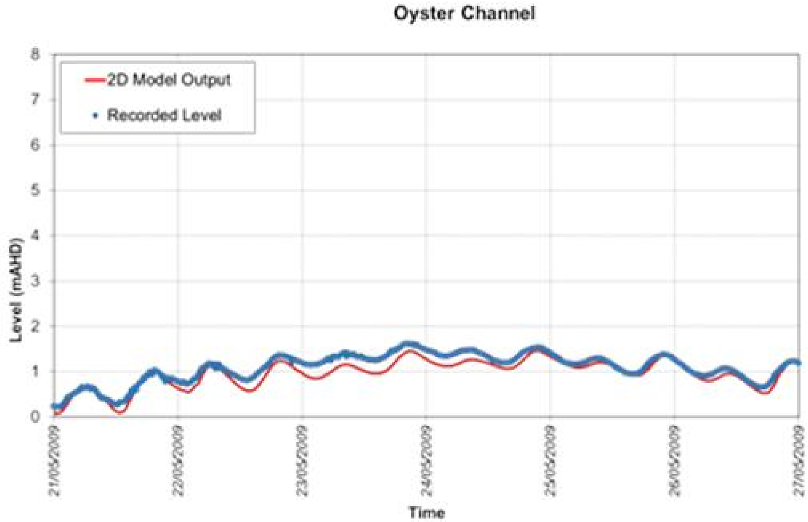
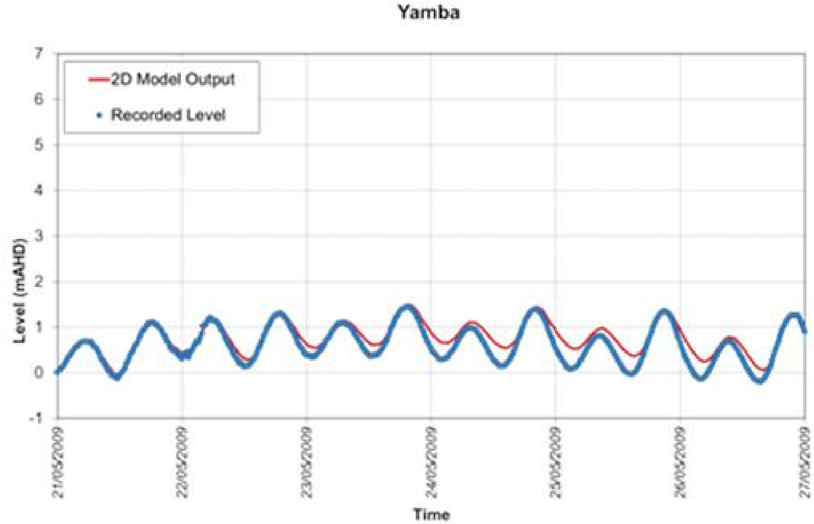


Figure B- 24 May 2009 Calibration Results: Flood Level Timeseries (Set 2)





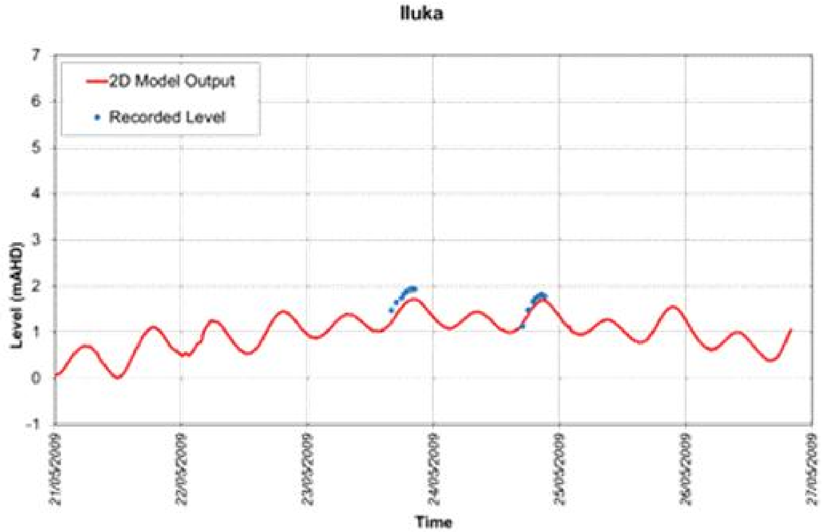
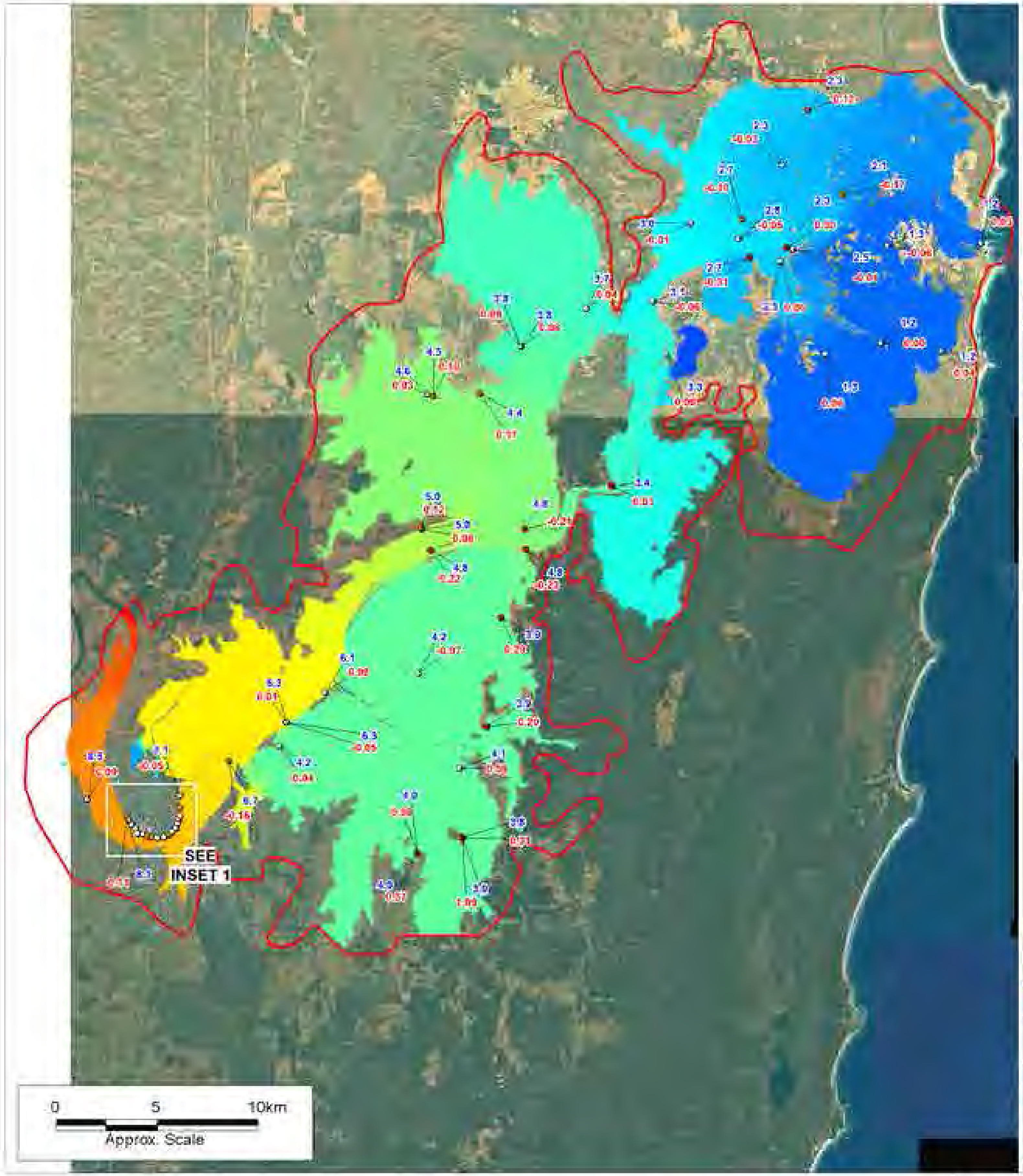
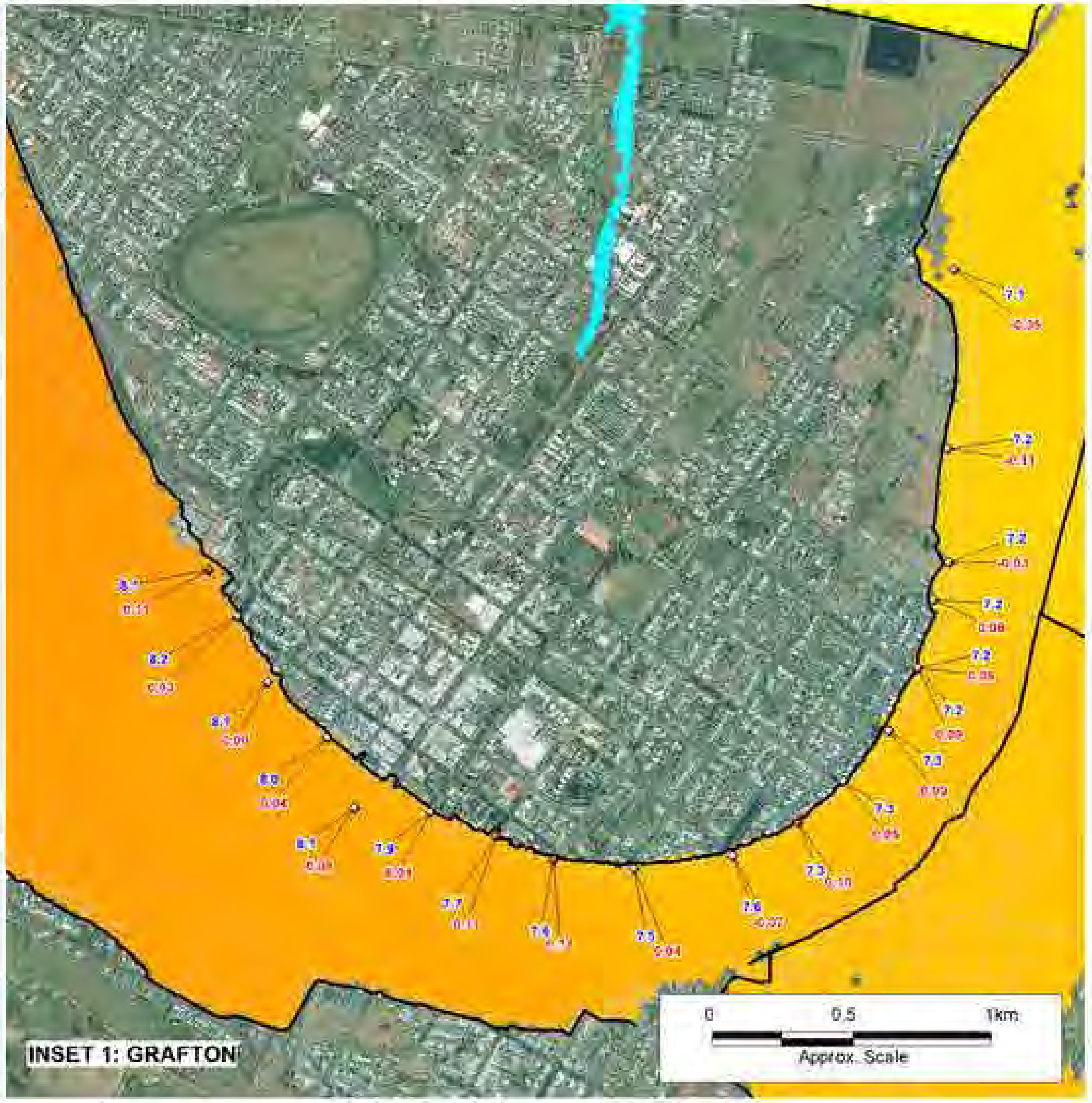


Figure B- 25 May 2009 Calibration Results: Flood Level Timeseries (Set 3)

APPENDIX C: JANUARY 2013 FLOOD EVENT MODEL CALIBRATION





LEGEND

- Flood Model Extent
- Levees
- 2.0 Recorded Flood Level (mAHD)
- 0.1 Flood Model Difference (m) (Model Result - Recorded Level)

Flood Model Difference (m)

- < 0.1
- 0.1 - 0.2
- >0.2

Modelled Peak Flood Level (mAHD)

0.0 to 1.0	7.0 to 8.0
1.0 to 2.0	8.0 to 9.0
2.0 to 3.0	9.0 to 10.0
3.0 to 4.0	10.0 to 11.0
4.0 to 5.0	11.0 to 12.0
5.0 to 6.0	12.0 to 13.0
6.0 to 7.0	Greater than 13.0

Title:

January 2013 Calibration Results: Peak Flood Level

Figure: C-1

Rev: A

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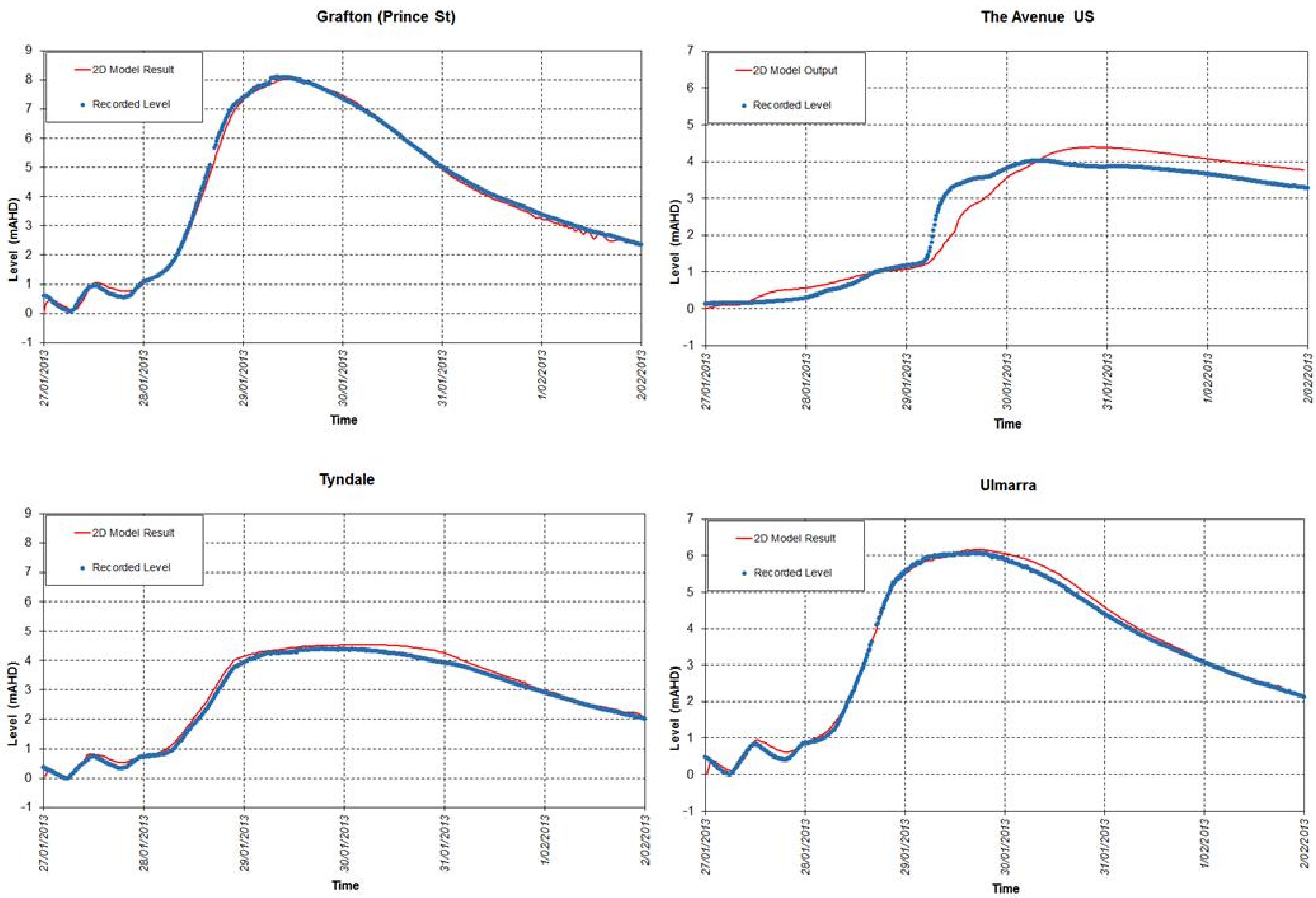


Figure C- 2 January 2013 Calibration Results: Flood Level Timeseries (Set 1)

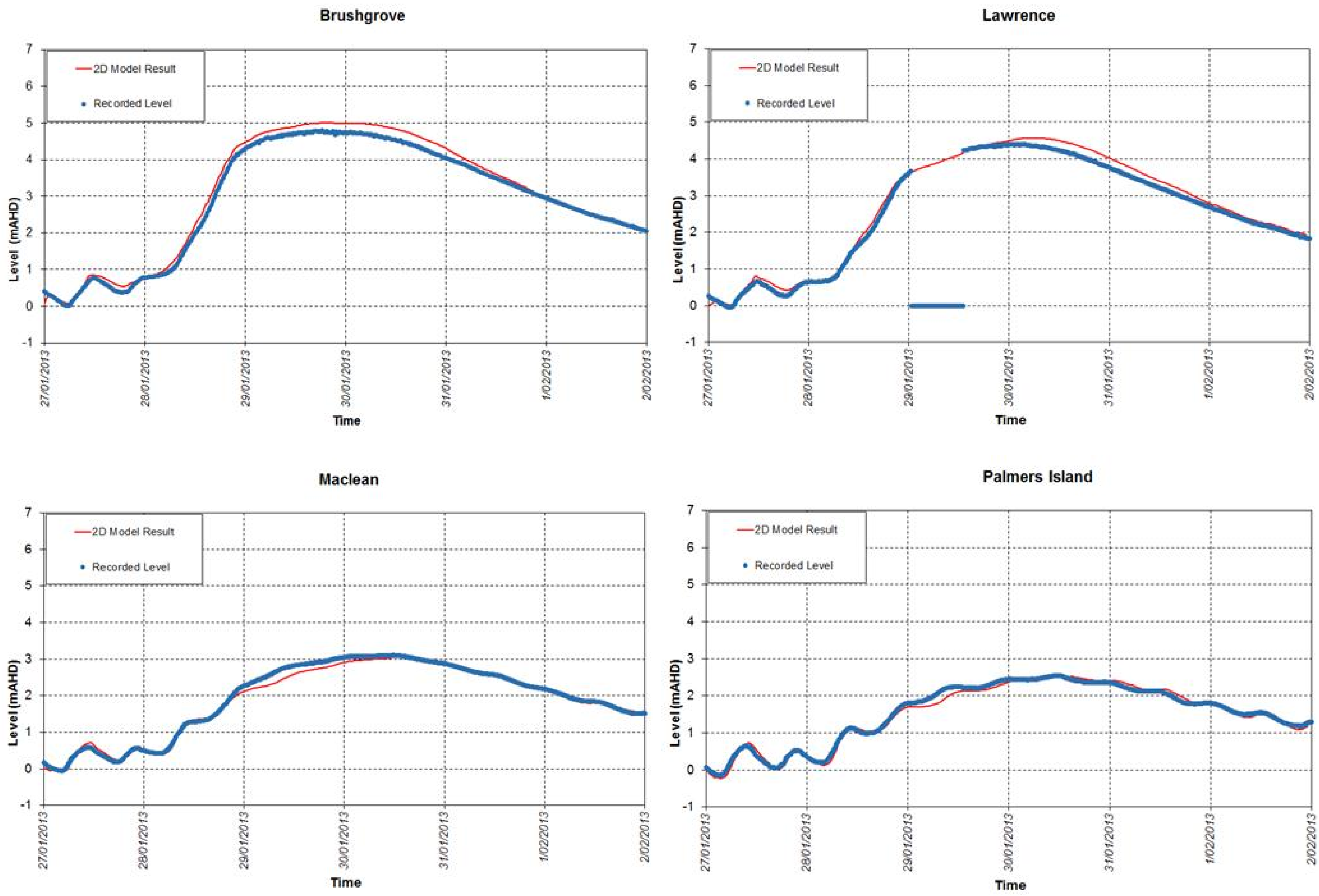


Figure C- 3 January 2013 Calibration Results: Flood Level Timeseries (Set 1)

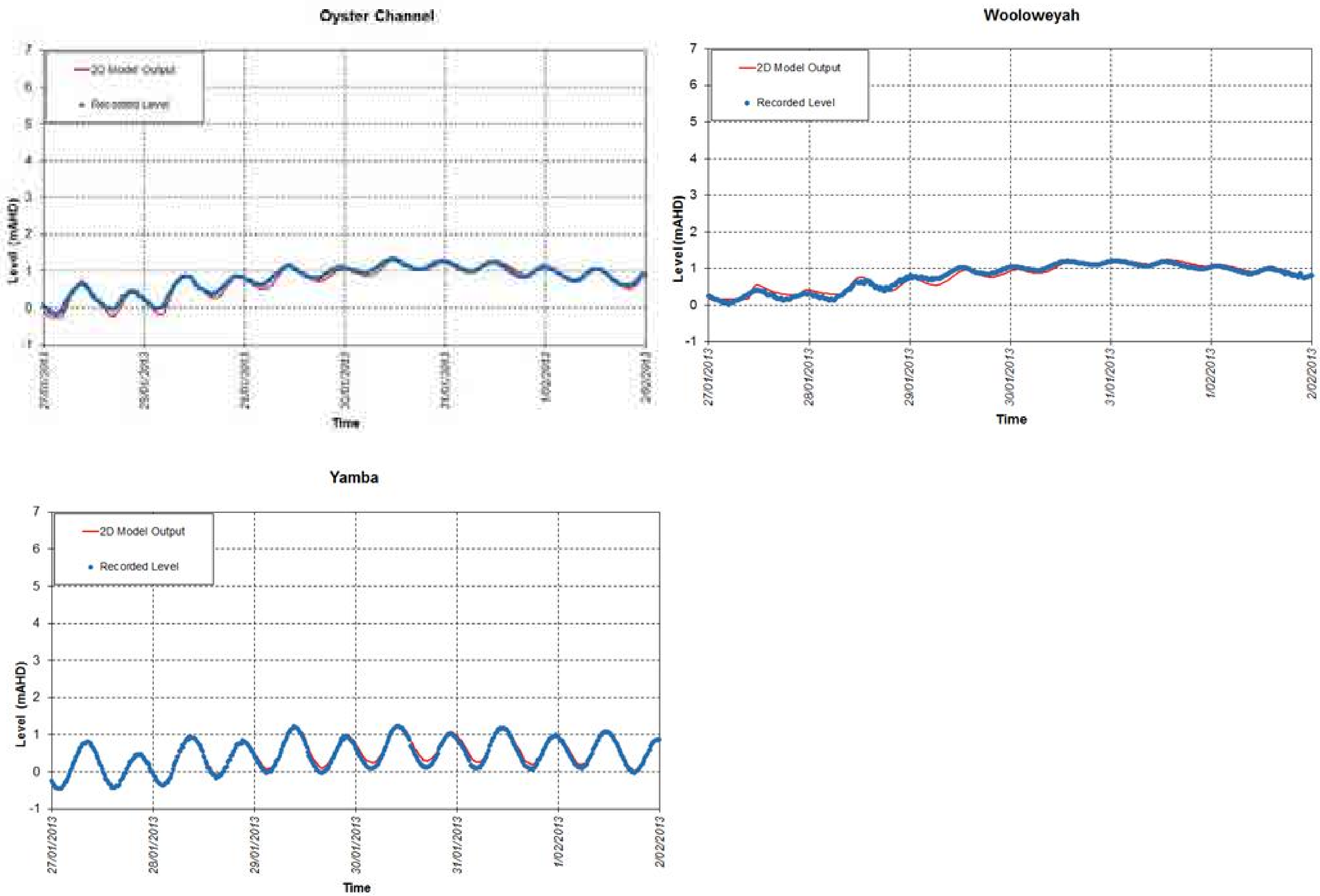
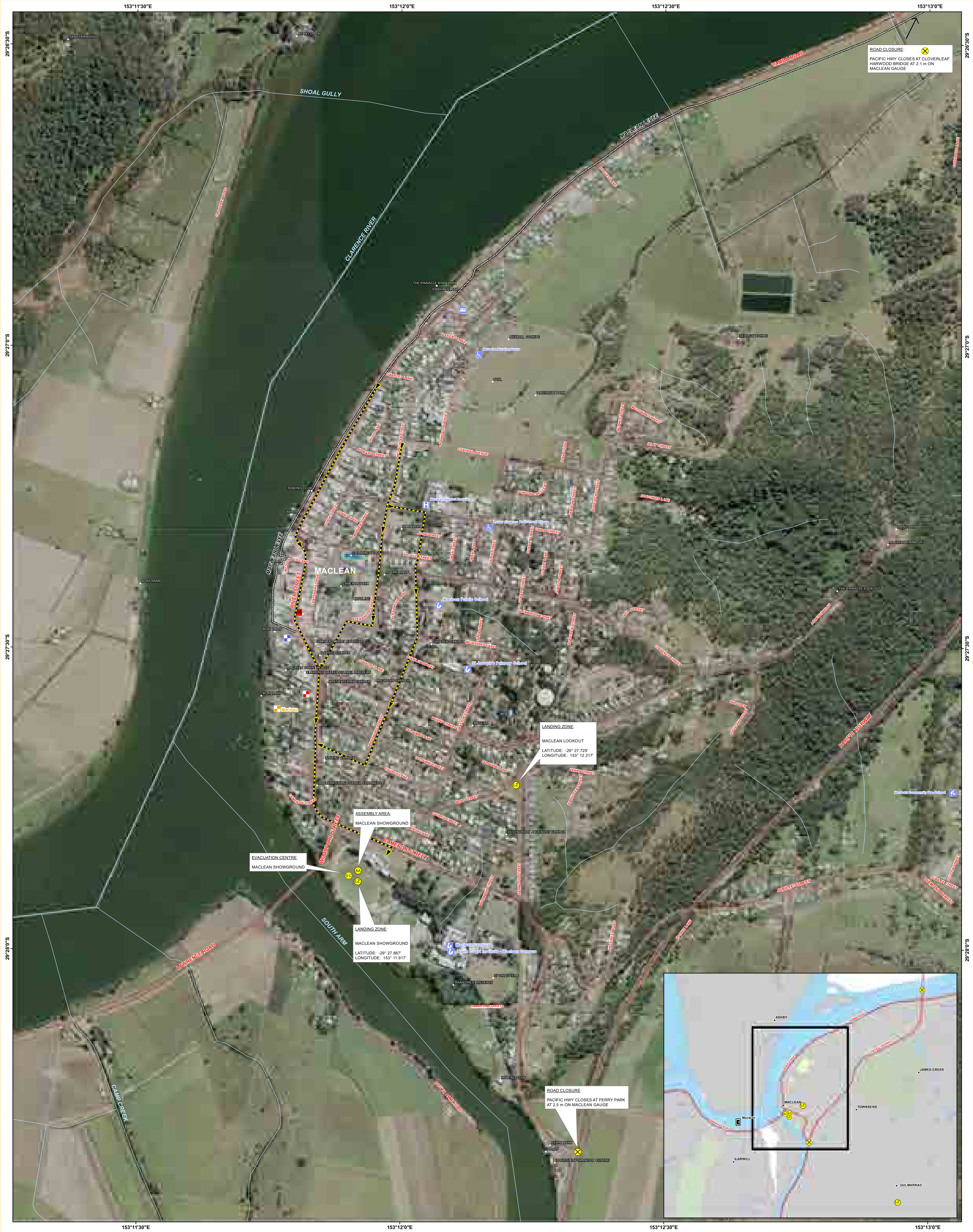


Figure C- 4 January 2013 Calibration Results: Flood Level Timeseries (Set 1)

APPENDIX D: SES EVACUATION SECTOR/ROUTE MAPS



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Production Date: 28 Feb 2012

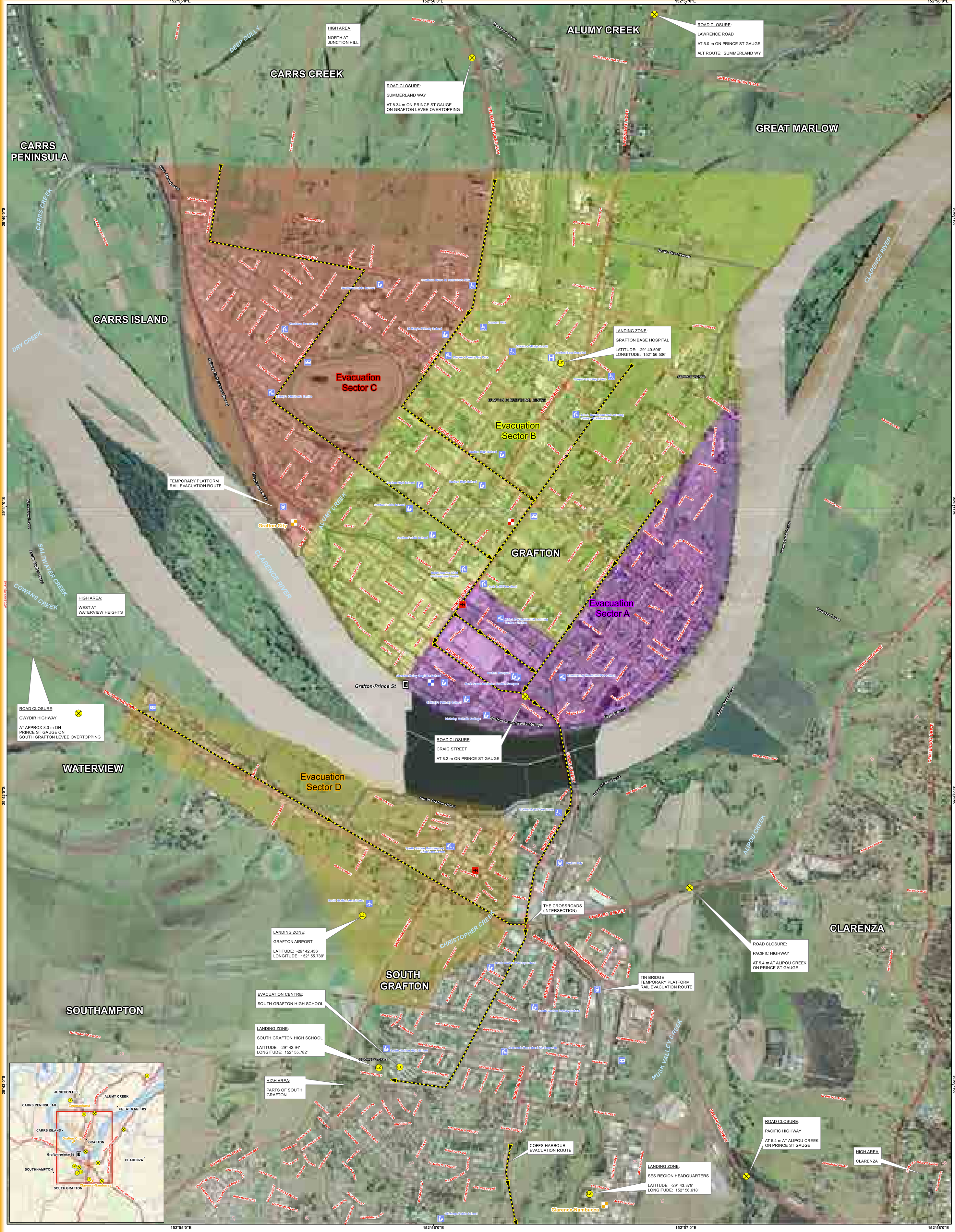
CLARENCE VALLEY LOCAL FLOOD PLAN

ANNEX J - MACLEAN SECTOR RESPONSE

CLARENCE NAMBUCCA REGION

- Assembly Area
- Evacuation Centre
- Landing Zone
- Road Closure
- Evac Route
- SES Headquarters
- Police Stations
- Ambulance Facilities
- RFS Stations
- FRNSW Stations
- Aged Care Facilities
- Caravan Park / Camping
- Child Care Facilities
- Educational Facilities
- Hospitals
- Airports
- Railway Stations
- Flood Gauge
- Levee Alignments
- Railway Lines
- Major Rivers
- All Rivers / Creeks
- Major Roads
- Secondary Roads
- Minor Roads
- Track-Vehicular
- Path

0 0.1 0.2 0.3 0.4
Kilometres(Approx.)



CLARENCE VALLEY LOCAL FLOOD PLAN
ANNEX J - GRAFTON SECTOR RESPONSE
CLARENCE NAMBUCCA REGION

Assembly Area
Evacuation Centre
Landing Zone
Road Closure
Evacuation Routes
SES Headquarters
Police Stations
Ambulance Facilities
FRNSW Stations
RFS Stations
Aged Care Facilities
Caravan Park / Camping
Child Care Facilities
Educational Facilities
Hospitals
Airports
Railway Stations
Flood Gauge
Levee Alignments
Railway Lines
Major Rivers
All Rivers / Creeks
Major Roads
Secondary Roads
Minor Roads
Track-Vehicular
Path

0 0.2 0.4 0.6 0.8 1
Kilometres(Approx.)

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