ADDITIONAL CROSSING OF THE CLARENCE RIVER AT GRAFTON

Appendix E – Technical Paper: Flooding and hydrology assessment

AUGUST 2014

Executive summary

BMT WBM Pty Ltd was commissioned by Arup to undertake the flood risk hydrologic and hydraulic components of the Environmental Assessment phase of the Grafton Bridge project. This assessment has been undertaken on route ‘Option C’ which was confirmed as the preferred option in April 2013.

The study area for this assessment encompasses the portion of the Clarence River floodplain adjacent to Grafton/South Grafton. Grafton and South Grafton have a long history of flooding, and are currently protected by a series of levees that, in addition to natural high ground along with the elevated railway and Pacific Highway embankment, surround the town.

A baseline assessment of existing flood risk was hydraulically modelled focusing on design flood events ranging from the 20 year average recurrence interval (ARI) event to the Probable Maximum Flood. The assessment showed that during major flood events, in excess of the 20 year ARI, significant and extensive overtopping of the levee system occurs. The 100 year ARI flood depths are of the order of 2.5m and 2.7m for Grafton and South Grafton respectively.

The four mitigation options assessed consisted of raising lengths of the existing levee and raising a section of the Gwydir Highway. Following hydraulic modelling, two of the mitigation options were identified as successfully reducing the impacts from the proposed project in Grafton and South Grafton:

- Mitigation Option 2: Raising 3.7km of levee on the north bank and 7km of levee on the south bank of the Clarence River by 0.2m.
- Mitigation Option 4: Raising 3.7km of levee on the north bank, 4.7km of levee on the south bank, and raising a 550m length of the Gwydir Highway to an elevation of 7mAHD (current existing elevations are between 5 and 6.5mAHD).

With mitigation the proposed project would have residual impact in terms of increased water levels remaining for up to 58 rural properties outside of the zone of protection afforded by the levees. Typically these increases are less than 0.1m in the 100 year ARI event. It is recommended that further investigations to quantify this risk and identify additional mitigation measures (if possible) be completed during detailed design. This would include a habitable floor level survey and comparison to existing and predicted flood levels, followed by consideration of additional mitigation options for these properties.

The proposed mitigation measures also include a detention basin and pumping arrangement to provide a flood free approach road to Grafton during a 20 year ARI event.

The communities of Grafton and South Grafton are vulnerable to the potential impacts of a changing future climate. The proposed scheme would not significantly alter this increase in future risk. It is recommended that future stages of this project ensure consistency with any future climate adaptation strategies adopted by Clarence Valley Council. Existing flood evacuation arrangements within Grafton will generally benefit from the proposed project which will improve access to higher ground in South Grafton, subject to the existing constraints of traffic congestion within the business district of Grafton.

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1 Introduction

The Grafton Bridge project is being undertaken by Roads and Maritime Services (Roads and Maritime). Roads and Maritime commissioned Arup to undertake the conceptual development for the study. Part of this conceptual development involves producing an environmental impact statement.

BMT WBM Pty Ltd was commissioned by Arup to undertake the flood risk hydrologic and hydraulic components of the project. This report outlines the flooding assessment results for the Environmental Assessment phase of the project.

1.1 Project description

A description of the project is provided in Chapter 5 and Chapter 6 of the environmental impact statement. This section provides a summary of the project.

The main components of the Grafton Bridge project are:

- Construction of a new bridge over the Clarence River about 70 metres downstream (east) of the existing road and rail bridge, comprising two traffic lanes;
- Construction of a new road to link the new bridge with Iolanthe Street in South Grafton;
- Construction of a new road to link the new bridge with Pound Street in Grafton;
- An approach viaduct, about 58 metres long, on the South Grafton side of the Clarence River and 29 metres long on the Grafton side;
- Upgrades to the road network in South Grafton to connect the new bridge to the existing road network, including:
  - Widening Iolanthe Street to four lanes;
  - Widening the Gwydir Highway to four lanes between Bent Street and the Pacific Highway;
  - Realigning the existing Pacific Highway to join Iolanthe Street near Through Street;
  - Providing a new roundabout at the intersection of the Pacific Highway and Gwydir Highway;
  - Providing a new roundabout at the intersection of Through Street and Iolanthe Street;
  - Limiting Spring Street and the Old Pacific Highway to left in and left out only where they meet Iolanthe Street; and
  - Realigning Butters Lane.
- Upgrades to the road network in Grafton to connect the new bridge to the existing road network, including:
  - Widening Pound Street to four lanes between Villiers Street and the approach to the new bridge;
  - Providing traffic signals at the intersection at Pound Street and Clarence Street;
  - Closing Kent Street where it is crossed by the bridge approach road;

  - Realigning and lowering Greaves Street beneath the new bridge;
  - Realigning Bridge Street to join directly to the southern part of Pound Street (east of the new bridge approach). There would be no direct connection between Pound Street south and the new bridge approach;
  - Widening Clarence Street to provide formal car park spaces; and
  - Minor modifications to the existing Dobie Street and Villiers Street roundabout.
- Replacement of the existing three span concrete arch rail viaduct which crosses Pound Street in Grafton with a single span steel truss bridge;
- Construction of a pedestrian and cycle path to provide connectivity between Grafton, South Grafton and the new bridge;
- Provision of two signalised pedestrian crossings in South Grafton to improve safety for pedestrians crossing Iolanthe Street and Gwydir Highway;
- Construction of new pedestrian links to connect the new bridge with the existing bridge;
- Provision of designated car park spaces in Pound Street and Clarence Street, including some off street parking, to maintain a similar number of existing car park spaces currently available in those two street;
- Flood mitigation works, which include raising the height of sections of the existing levee upstream from the new bridge in Grafton and South Grafton;
- Construction of a stormwater detention basin and pump station in Grafton to manage local flooding;
- Public utilities adjustment; and
- Ancillary facilities required for the construction of the project, including some or all of the following: site compounds, concrete batching plant, pre-cast facilities, and stockpile areas for materials and temporary storage of spoil and mulch.

The main elements of the project are shown in Figure 1-1, including the construction footprint of the project.

1.2 Report purpose

This report documents the flood impact assessment undertaken to support the environmental impact assessment phase of the design. The aims of this flooding assessment are as follows:

(1) Establish the existing flood risk ‘the baseline’ from the Clarence River in the Grafton area.

(2) Identify the potential for hydraulic impacts resulting from the additional crossing on peak flood levels, depths, velocities and durations across a full range of design flood magnitudes.

(3) If hydraulic impacts are identified then the assessment identifies mitigation solutions designed to offset impacts identified in (2).

(4) Quantify any residual impacts that may remain after mitigation.

The results of this flooding assessment contribute towards the environmental impact assessment. Further investigations will be undertaken as part of the design refinement process during the detailed design phase.

1.3 Assessment tool

Definition of the existing flood behaviour in the Grafton region is required to define the baseline for the flooding component of the Environmental Assessment. For this purpose, the Environmental Assessment has been completed using the lower Clarence River flood model, originally developed and calibrated as part of the Lower Clarence River Flood Study Review (WBM, 2004) and subsequently updated for Clarence Valley Council by BMT WBM in 2013 (BMT WBM, 2013).

The updated flood model incorporates a number of changes from that used in the *Route Options Development Report* (Roads and Maritime, 2012) in order to provide a more detailed assessment of the potential flooding impacts of the project. Updates to the lower Clarence River flood model included:

- A more detailed model grid was used to define the existing topography in the flood plain. A combination of a 30 metre grid on the flood plain and a 10 metre grid in the vicinity of Grafton was used. This results in a more detailed representation of flooding in the Clarence River and less averaging of flood depths when compared with the flood model used during the route selection stage of the project (which used a 60 metre grid to define the existing topography).
- More accurate survey data for the flood plain including updated LiDAR[1] data and ground survey of the existing levee system was incorporated into the flood model.
- The model uses the latest version of the TUFLOW modelling software.

These updates were made to improve the resolution of the flood model and to provide a more detailed assessment of flood impacts as a result of the project. As a result of the more detailed flood model and survey data, there are some minor differences in the flood extents and changes in peak flood levels (an additional two centimetres at the existing bridge in a 1 in 20 year flood event) as a result of the project, when compared with the flood model used during the route selection stage of the project

The updated model is considered to represent the latest model and terrain data. The model has been used in consultation and with the approval of Clarence Valley Council. A summary of the lower Clarence River flood model inputs is provided in Appendix A.

The updated lower Clarence River flood model is considered appropriate for use in the Environmental Assessment.

[1] LiDAR is a detection system which works on the principle of radar but uses light from a lasar.

Title:
Route Alignment

Figure: 1-1

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

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2 Existing flood risk

2.1 Background

The Clarence River is a major coastal river in New South Wales with lower floodplain areas subject to frequent and extensive flood inundation. The catchment of the Clarence River covers approximately 20,000km^2 upstream of Grafton and at times of major flooding a floodplain of some 500km^2 downstream of Grafton may become inundated.

Although minor tributaries within the lower floodplain of the Clarence River do have the potential to cause flooding issues, the flooding behaviour of the lower Clarence is dominated by runoff generated in the large catchment area upstream of Grafton. The catchment upstream from Grafton/Mountain View typically contributes 80% to 90% of the total volume of floodwater that enters the lower floodplains during main river flood events. Clarence River floods typically occur from low rainfall intensity events that last several days or even weeks.

The study area for this assessment encompasses the portion of the Clarence River floodplain adjacent to Grafton/South Grafton. Grafton and South Grafton have a long history of flooding, and are currently protected by a series of levees that, in addition to natural high ground along with the elevated railway and Pacific Highway embankment, surround the town.

Overtopping of the current Grafton and South Grafton levees commences when flood levels are at, or close to 8.0m on the Prince Street gauge (See Figure 2-1 for gauge location). Based on flood modelling results defined using the lower Clarence River flood model, there is approximately a 5% annual exceedance probability (AEP) that overtopping of the current levees may occur in a given year. This AEP translates to approximately a 20 year average recurrence interval (ARI) flood event.

Significant overtopping of the Grafton and South Grafton levees occurs during events greater than the 20 year ARI event. Following overtopping, large areas of Grafton and South Grafton are inundated by floodwater. No overtopping is predicted to occur for events with a magnitude less than the 20 year ARI event. For this reason the 20 year ARI event is the lowest magnitude event considered in this assessment.

The existing flooding behaviour of the Grafton area has been defined using the lower Clarence River flood model, originally developed and calibrated as part of the Lower Clarence River Flood Study Review (WBM, 2004) and subsequently updated for Clarence Valley Council (BMT WBM, 2013). A summary of the lower Clarence River flood model inputs and historic event calibration results is provided in Appendix A.

2.2 Existing studies

2.2.1 Flood studies

Lower Clarence Flood Study (1988)

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

Lower Clarence Flood Study Review (2004)

The 1D model created for the lower Clarence Flood Study was updated to a two-dimensional (2D) dynamic flood model with a 60m 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 and an extreme flood event.

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

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 10m 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 30m 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.

Lower Clarence Flood Model Update (2013)

The flood model update was undertaken by BMT WBM and refined the model developed for the overtopping assessment with updated topography data. This data principally consisted of 2010 topographic LiDAR data and 2012 ground level survey of the levees.

Re-calibration of the updated model was undertaken for eight historical events, including the January 2013 event. The model was demonstrated to perform well, offering an improved calibration over previous models. This model is therefore the best and latest model available and has been used to prepare this assessment.

2.2.2 Floodplain management plans

A Grafton and Lower Clarence Floodplain Risk Management Plan was issued by Clarence Valley Council in June 2007 (Bewsher Consulting, 2007). The plan recognises the existing flood risk to Grafton and South Grafton and identifies mitigation works for these communities which are generally focussed on the maintenance and augmentation of levees. The plan notes that any works to increase the levee height have the potential to increase the inundation to areas not protected by the levees.

2.3 Existing conditions

Figure 2-1 to Figure 2-12 present maps showing peak design flood levels, depths and velocities for the 20, 50, 100 year ARI and Probable Maximum Flood (PMF)[2] events under existing conditions.

Peak flood levels for the Prince Street gauge, existing Grafton Bridge, Grafton and South Grafton are provided in Table 2-1. Table 2-2 presents peak flood depth at locations in Grafton and South Grafton. Reporting locations are shown on Figure 2-1.

Table 2-1 Existing design peak flood levels

Design Flood Event	Peak Flood Level (mAHD)			
	Prince St Gauge	Existing Grafton Bridge	Grafton[1]	South Grafton[2]
20 year	7.95	7.60	No Flooding	No Flooding
50 year	8.27	7.90	6.40	3.83
100 year	8.35	7.96	7.05	5.86
PMF	9.78	9.29	9.27	10.01

1 Intersection of Pound Street and Prince Street

2 Intersection of Abbott Street and Vere Street

Table 2-2 Existing design peak flood depths

	Grafton[1]	South Grafton[2]
20 year	No Flooding	No Flooding
50 year	1.00	0.56
100 year	1.65	2.59
PMF	3.87	6.74

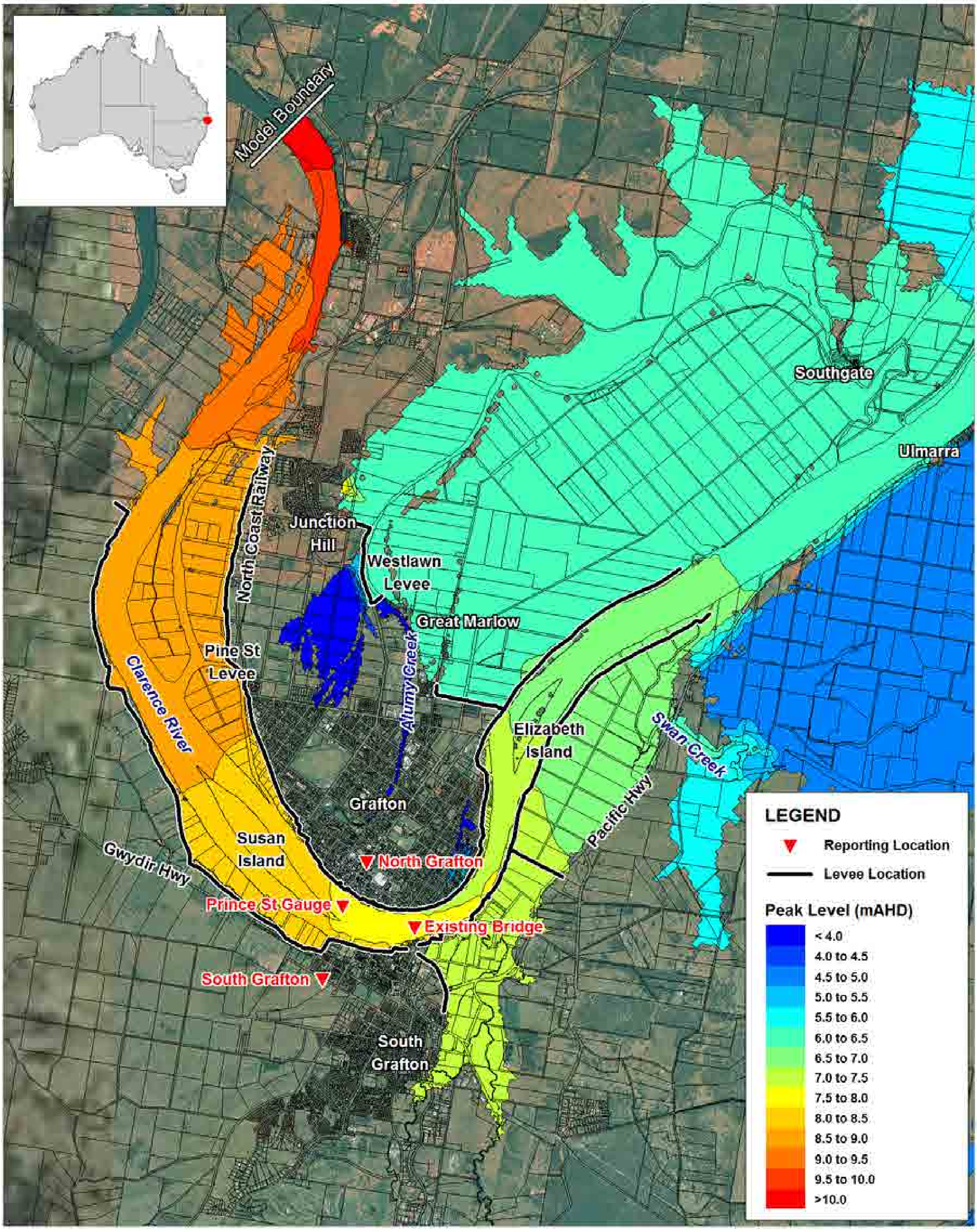
1 Intersection of Pound Street and Prince Street

2 Intersection of Abbott Street and Vere Street

It can be seen from Figure 2-1 to Figure 2-12 and Table 2-1 and Table 2-2 that during major flood events, in excess of the 20 year ARI, significant overtopping of the existing levee system occurs[3].

[2] The PMF event applied for the Clarence River in Councils adopted model is a scaled up version of the 100 year ARI event.
[3] Minor overtopping of levees occurs in the 20 year ARI event affecting small extents within Grafton.

The impact associated with flood inundation for the areas inside levees can be significant. Inundation of individual properties would potentially result in damage to houses and belongings, as well as the physical and mental health impacts associated with flood inundation (e.g. injury during and after floods, sickness, emotional losses, fear of future flooding). Furthermore, local businesses would suffer hardship during and after flood events due to a loss of trade and income. To some extent, these impacts are compounded in communities with levees, as flood inundation and its associated impacts become less frequent and less expected.



Title:
Existing Case Peak Flood Level 20 Year ARI Event

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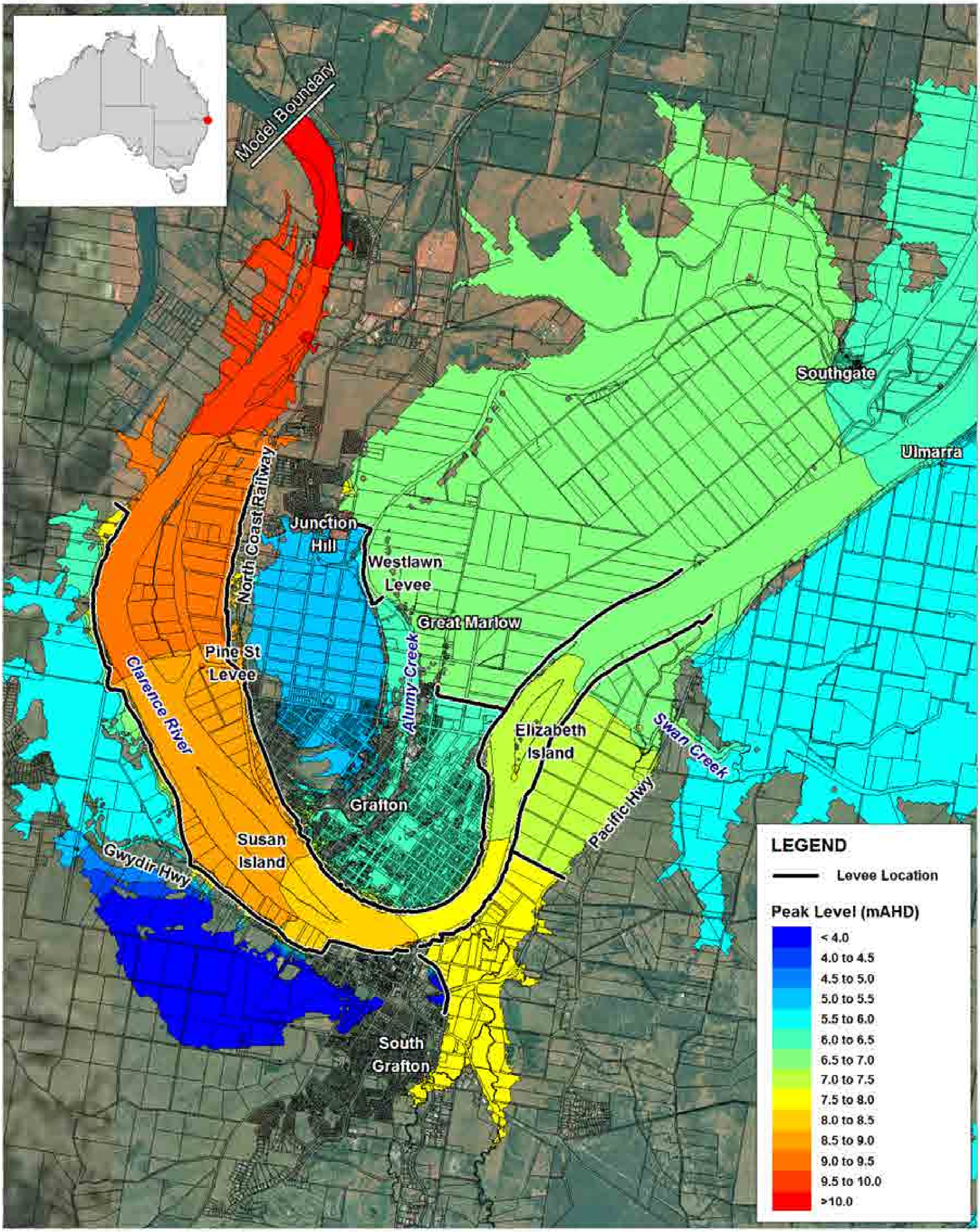

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Existing Case Peak Flood Level 50 Year ARI Event

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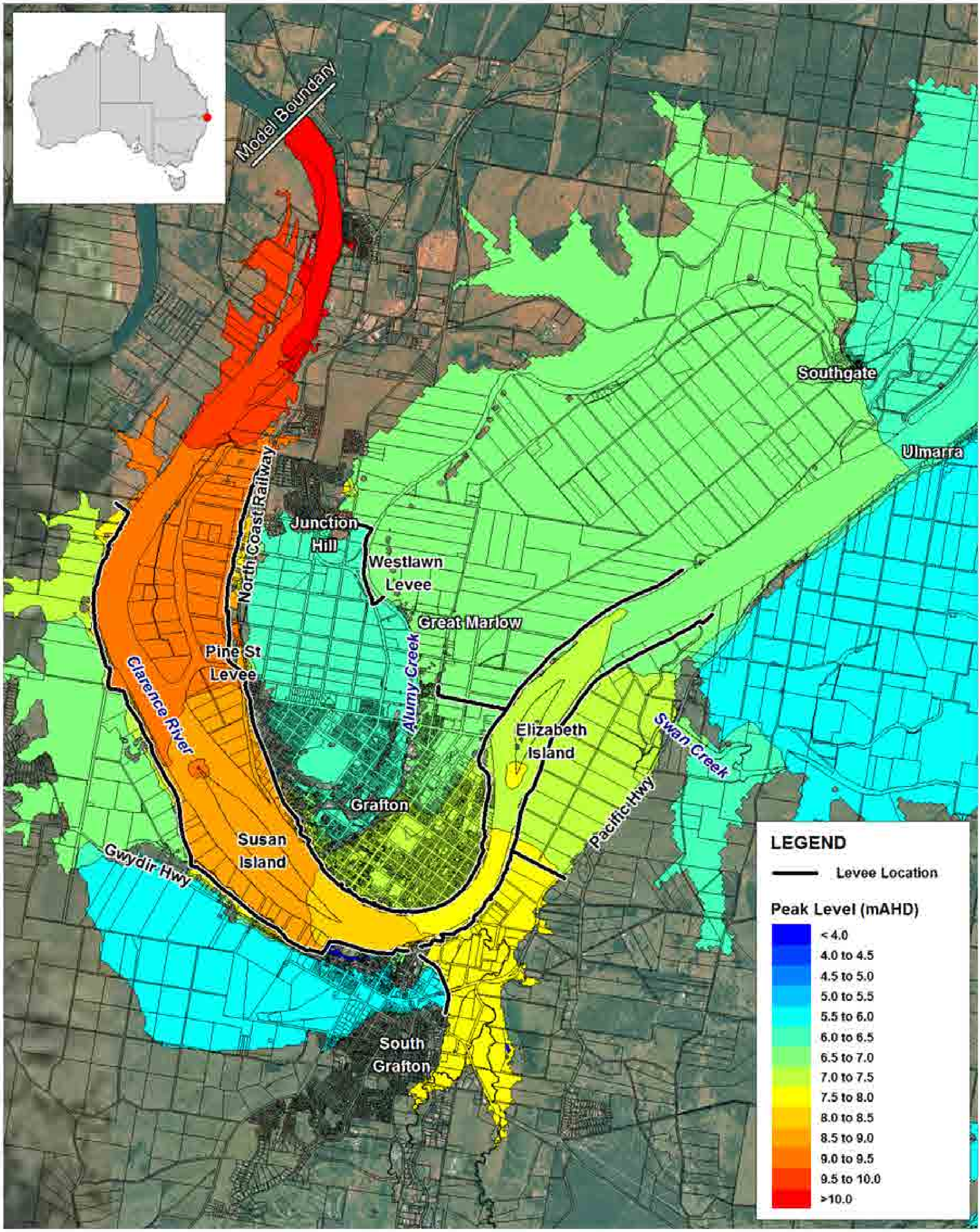

Title: **Existing Case Peak Flood Level 100 Year ARI Event**	Figure: **2-3**	Rev: **A**

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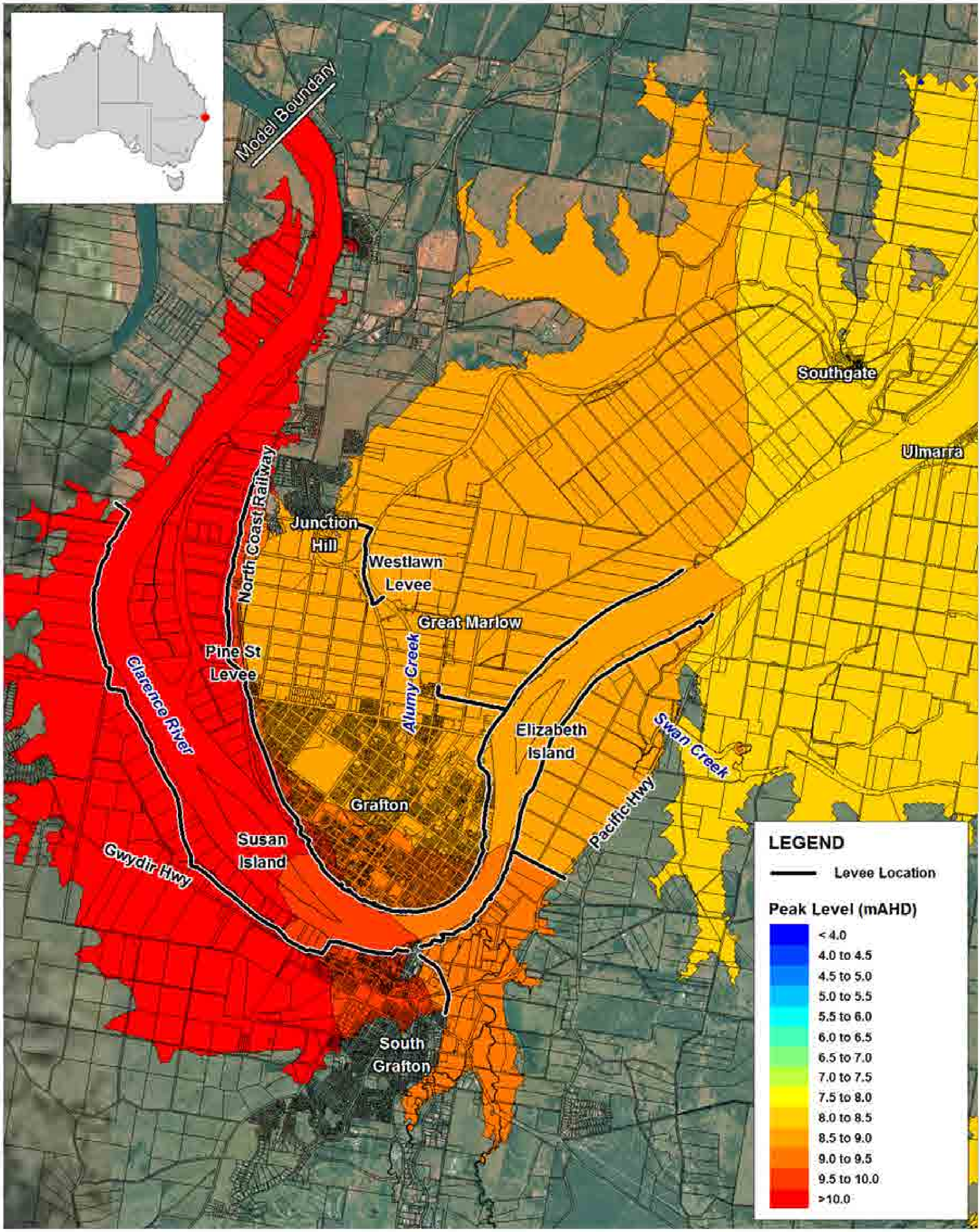

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Existing Case Peak Flood Level PMF Event	**2-4**	**A**

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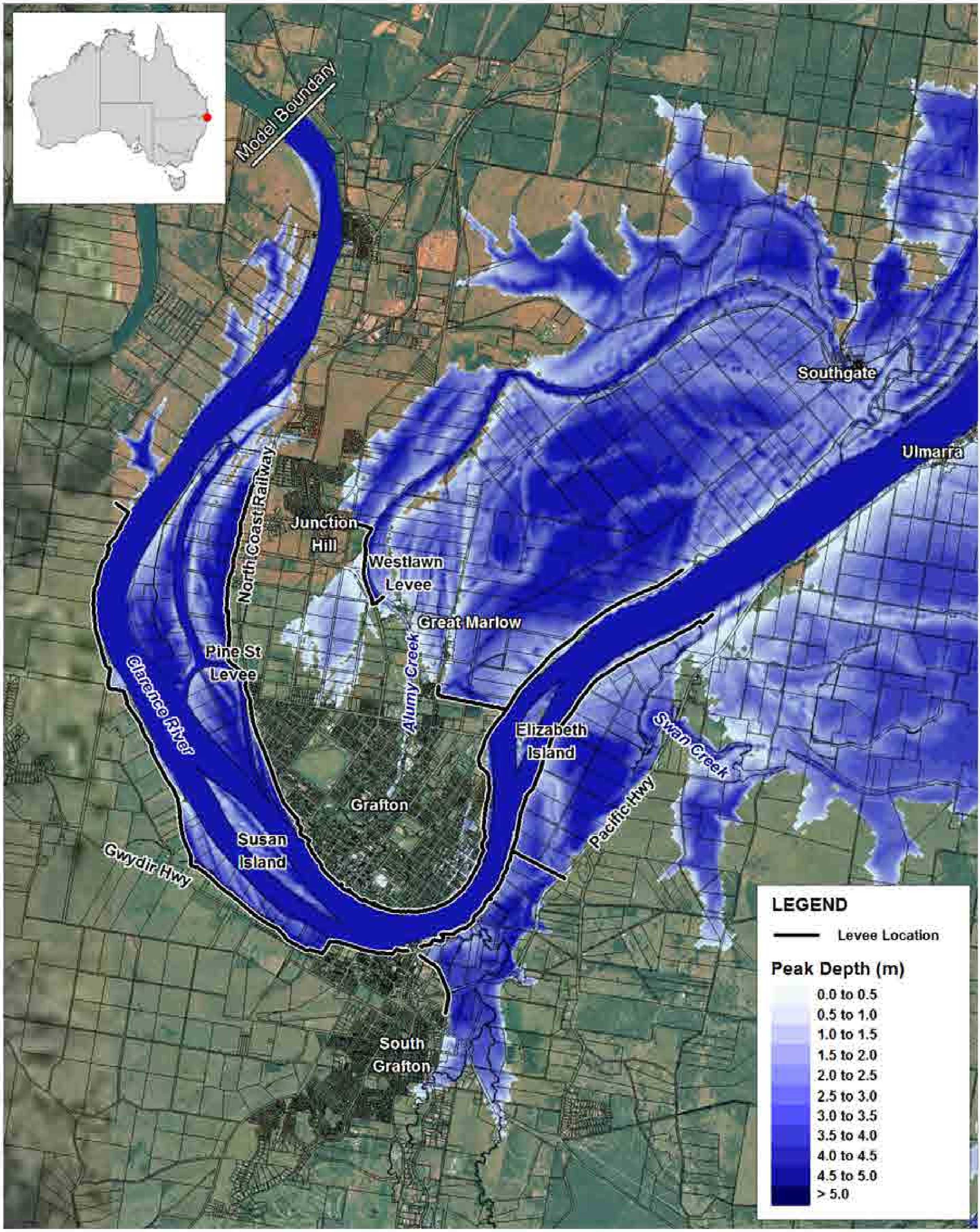

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Existing Case Peak Flood Depth 20 Year ARI Event

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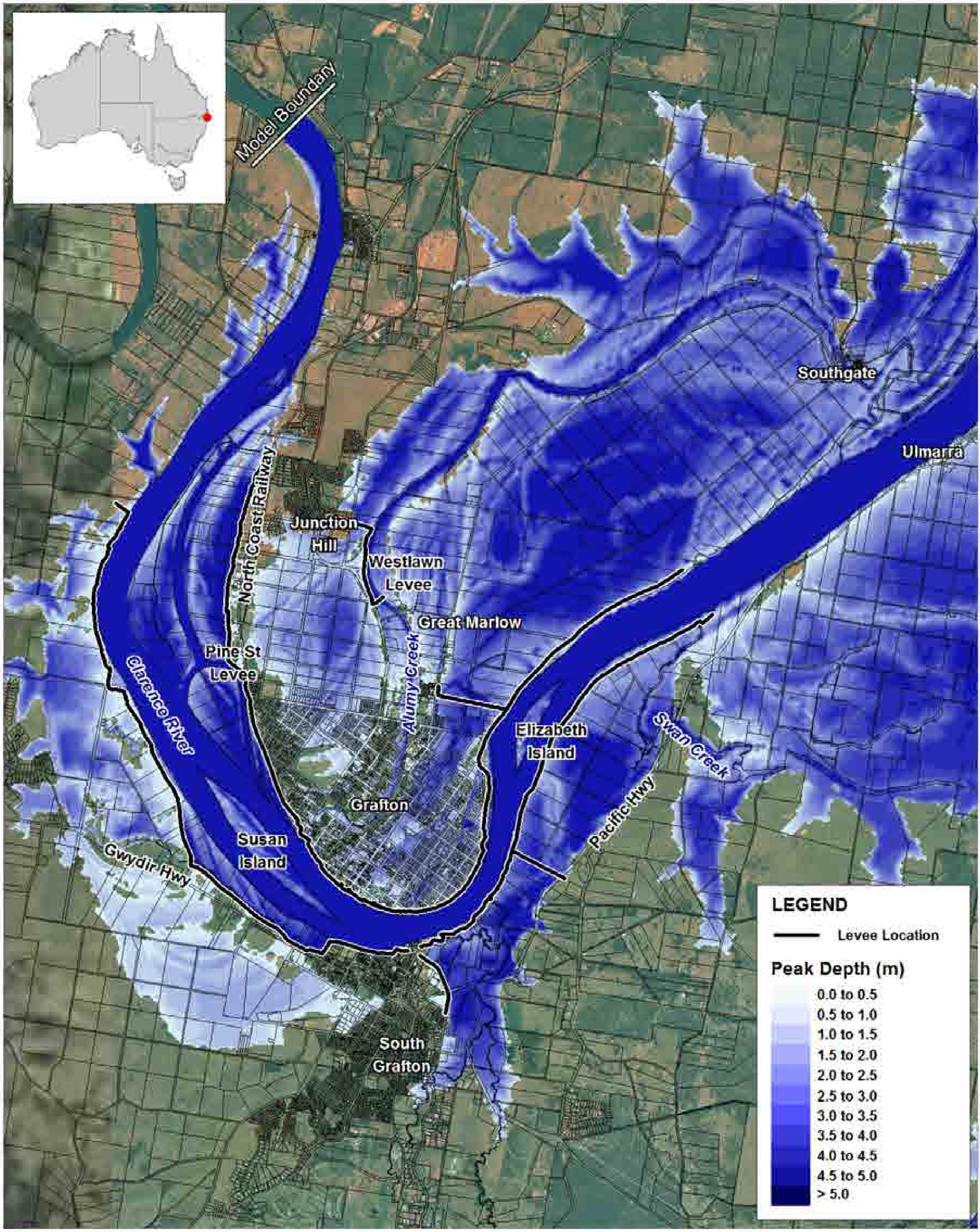

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Existing Case Peak Flood Depth 50 Year ARI Event

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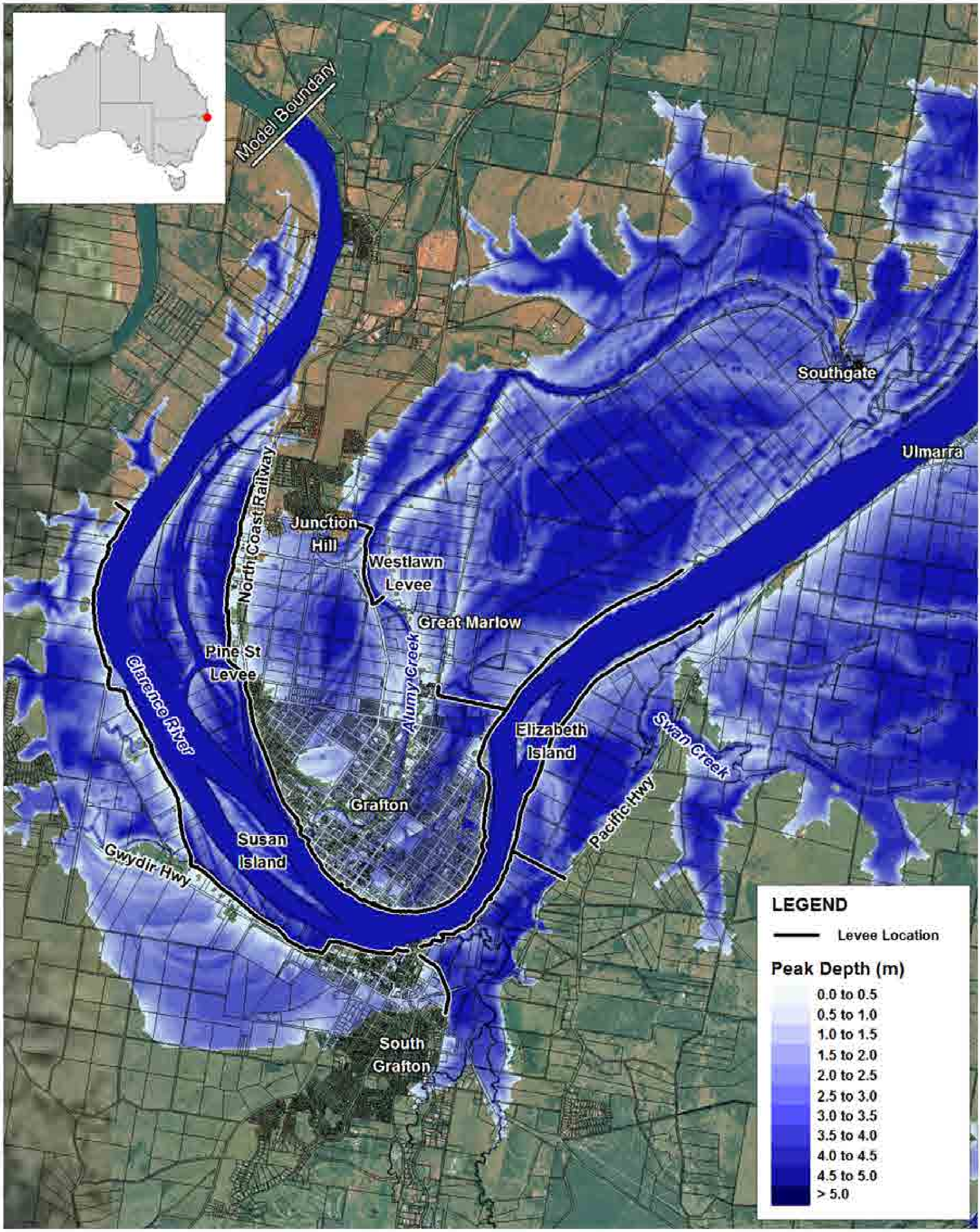

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Existing Case Peak Flood Depth 100 Year ARI Event

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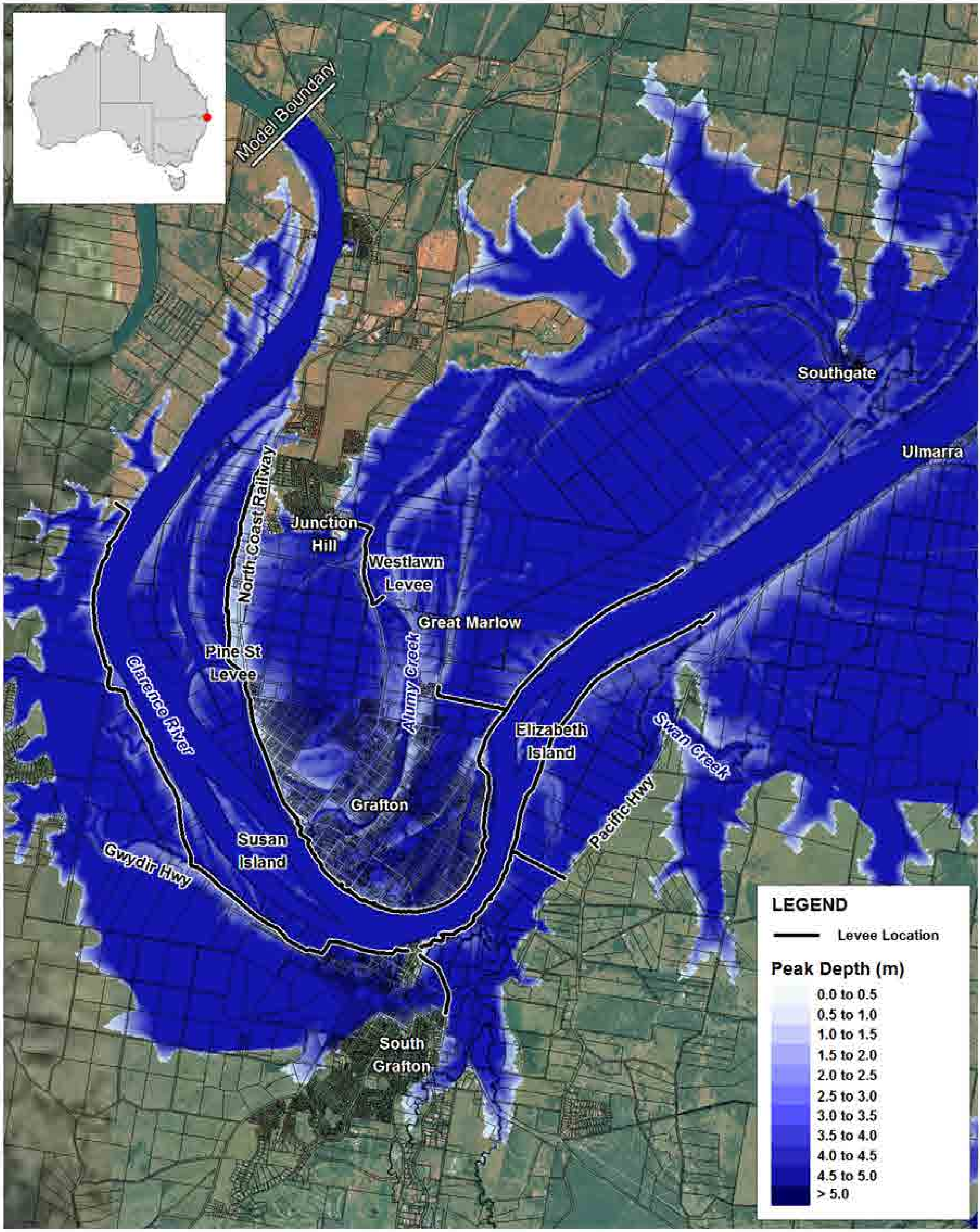

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Existing Case Peak Flood Depth PMF Event

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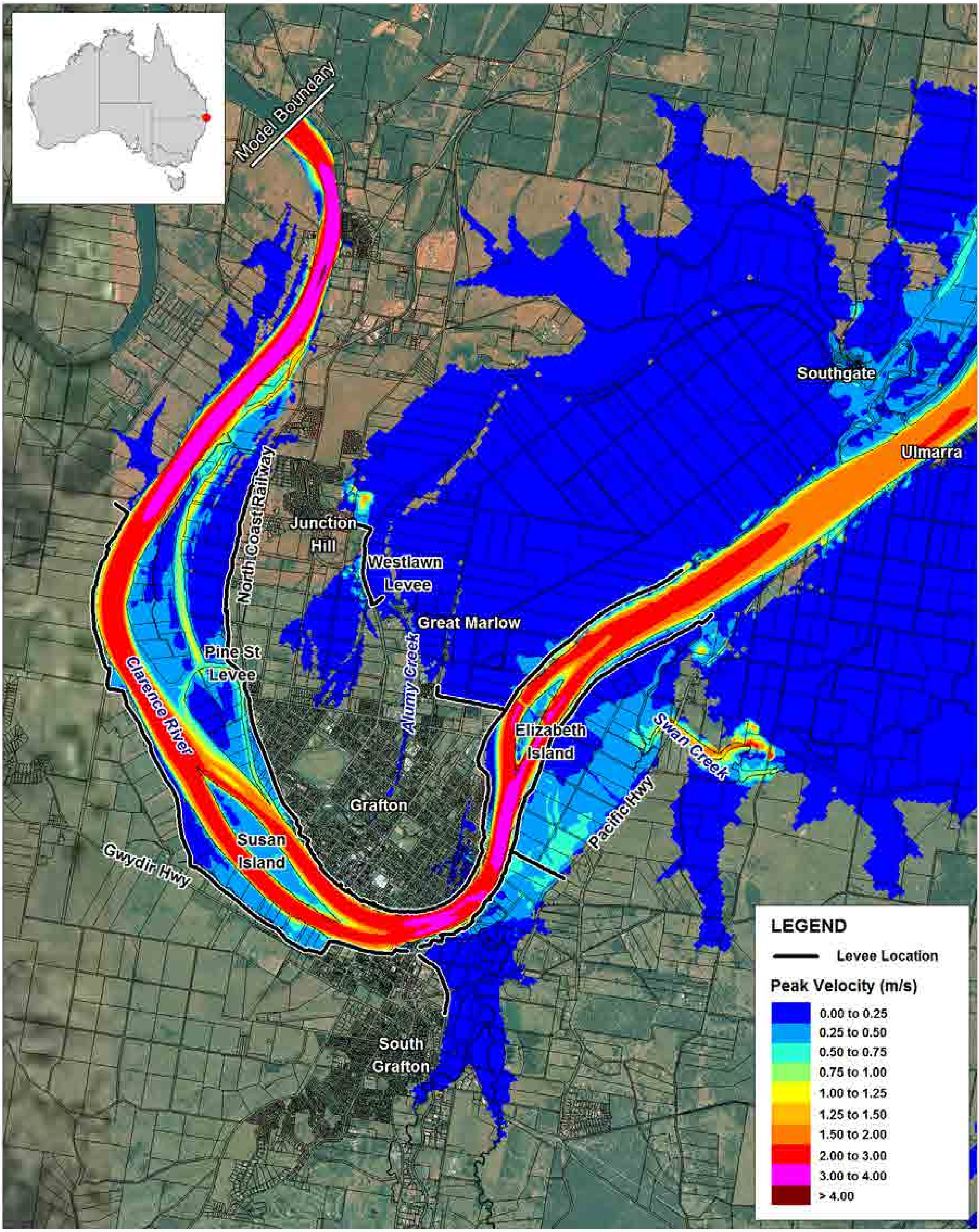

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Existing Case Peak Flood Velocity 20 Year ARI Event

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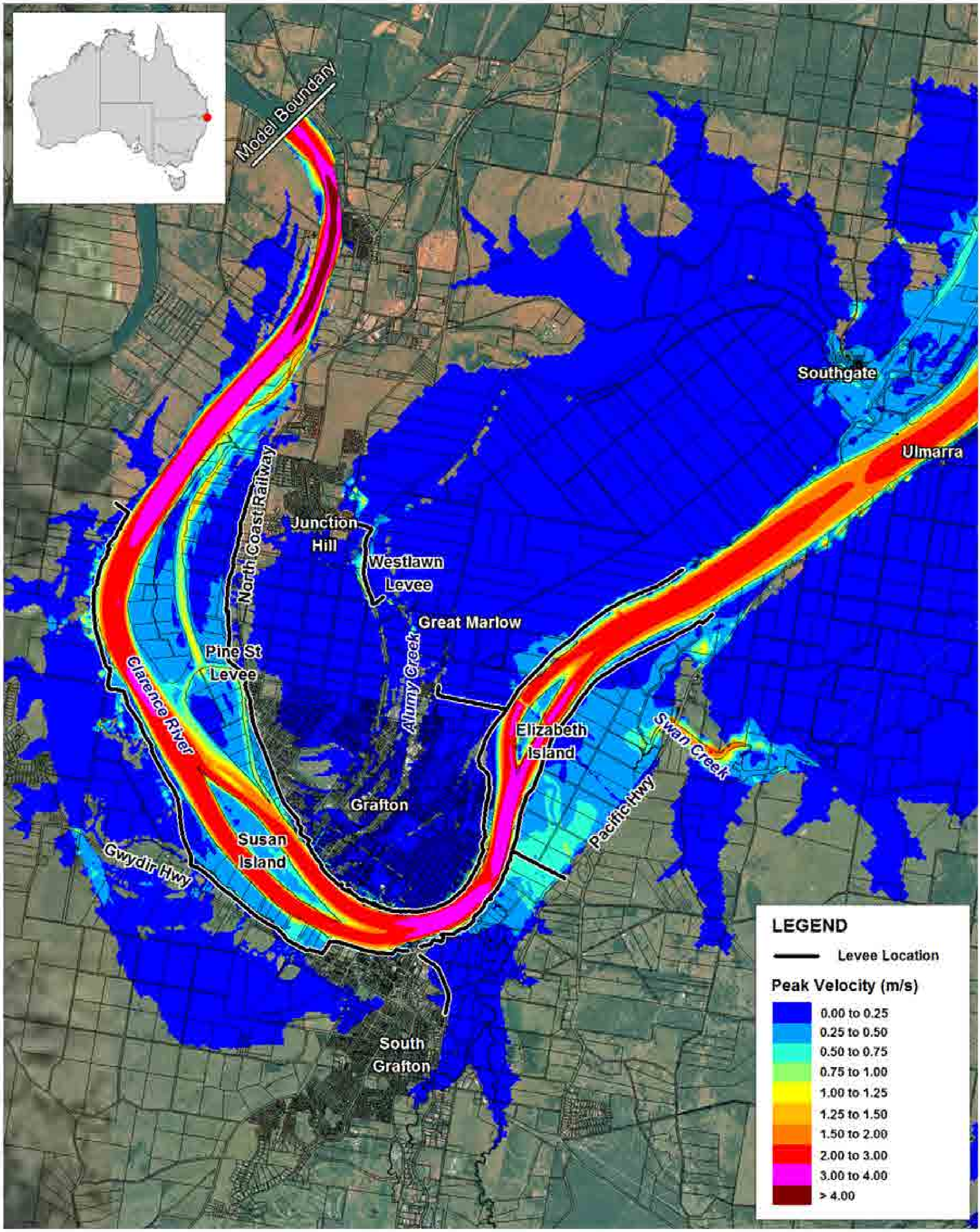

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Existing Case Peak Flood Velocity 50 Year ARI Event

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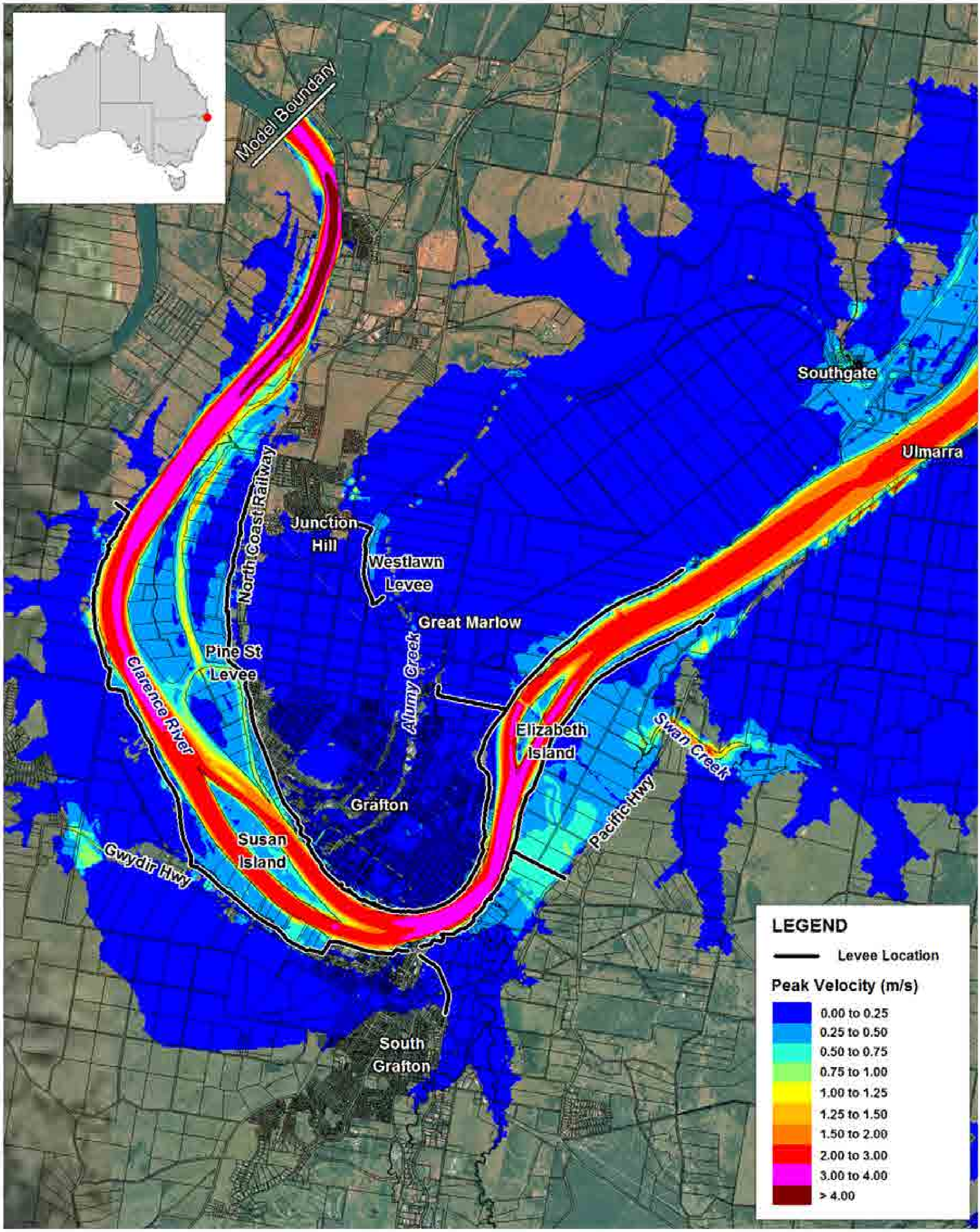

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Existing Case Peak Flood Velocity 100 Year ARI Event

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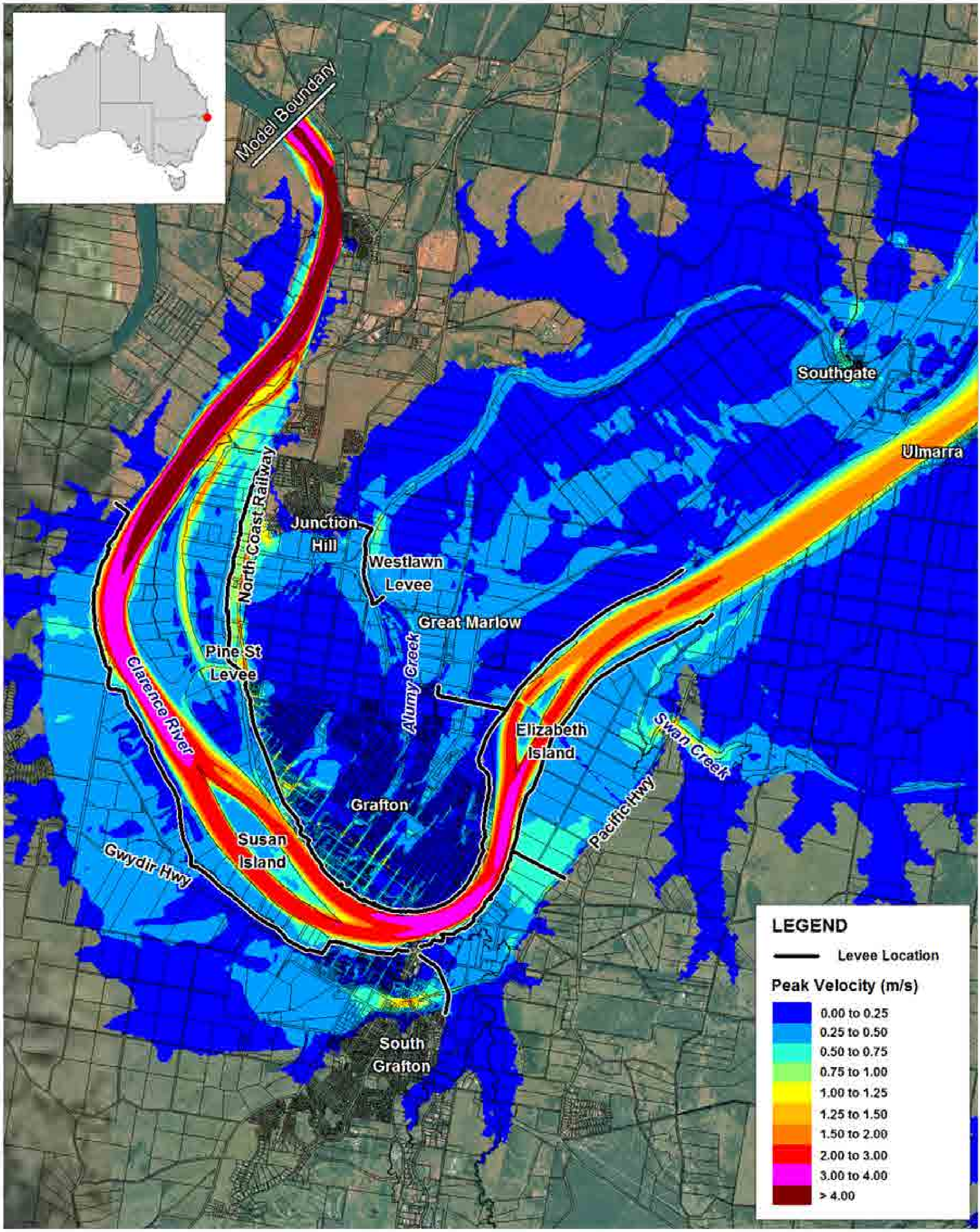

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Existing Case Peak Flood Velocity PMF Event

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3 Bridge design and impact assessment criteria

3.1 Proposed design

The proposed crossing would be located approximately 70m downstream of the existing Grafton Bridge and would connect Grafton to South Grafton via Pound Street and Iolanthe Street (See Figure 1-1). The bridge includes 10 piers, 5 of which are partially submerged by the mean low water surface. There is a maximum span of 74m between the piers and each pier is approximately 3m wide in the direction perpendicular to the main flow. The minimum soffit elevation is 9.1mAHD to comply with navigation requirements. This is significantly above the 100 year ARI peak flood level at the location of the proposed crossing of 8.0mAHD.

In total, the modelled bridge and viaducts representing the proposed project span a total length of 580m.

Refer to the *Additional crossing of the Clarence River at Grafton Environmental Impact Statement: Main Report* for additional details of the proposed project.

3.2 Bridge design criteria

A number of engineering design criteria have been developed to guide the design of the bridge during previous stages of the project. The criteria that relate to flooding include:

- Waterway structures outside of the Grafton levee banks, including the main bridge and viaducts, must be of sufficient height to maintain a freeboard during a 100 year average recurrence interval (ARI) design flood event.
- Bridges within the Grafton levees (Alumy Creek and minor drainage) must be flood immune during a 20 year ARI design flood event.
- The main approach roads to the new bridge must be flood immune during a 20 year ARI design flood event.

As well as design standards, a number of minimum requirements have been proposed to minimise any impacts of the additional bridge crossing on the environment and local community.

The criteria that relate to flooding include:

- Proposed options should not adversely impact the flood immunity in Grafton and South Grafton. Where impacts are identified, design mitigation measures must be implemented to maintain the current level of flood immunity; and
- No adverse impacts on flood evacuation of Grafton.

3.3 Impact assessment criteria

In addition to the bridge design criteria set out in Section 3.2, a number of organisations were consulted as part of the EIS process. Their responses were compiled to form the Director Generals Requirements (DGRs). With regard to hydrology (flood risk) the DG assessment requirements are for an assessment to be in accordance with the Floodplain Development Manual (Department of Natural Resources 2005) and to address the items listed in Table 3-1.

Table 3-1 DGR requirements – Hydrology (flood risk)

DGR assessment requirement	Report section where addressed
Changes to existing flood regimes (including riverine, overland and internal levee ponding) in Grafton and South Grafton, with reference to modelling for a range of flood events (including the 1, 2 and 5 % AEP events[4] and the Probable Maximum Flood (PMF) and across a range of flood characteristics (including changes in depth, velocity, direction, hazard, frequency or duration of inundation).	4,5
Consistency with relevant floodplain risk management plans.	5
Impacts to existing receivers and infrastructure, the future development potential of affected land (including areas outside of the existing levee system) and planned infrastructure (including the project).	4,5,6
Identifying the potential impacts on flow velocities and directions, and impacts on the bed and bank stability, as a result of construction of a new bridge.	4,5
Details of any proposed mitigation measures, including, where required, upgrade of the Grafton, South Grafton and other rural levee systems, evacuation routes, riverbank protection assets and drainage assets.	5,8
An assessment of the effects of sea level rise as a result of climate change on the project.	7

[4] Advice from the Department of Planning and Environment states that reference to the 1, 2 and 5 year ARI in the DGRs is actually the 1%, 2% and 5% AEP events which corresponds to the 100, 50 and 20 year ARI events respectively.

4 Flood impact assessment

4.1 Introduction

The flood impact assessment identifies the potential for hydraulic impacts resulting from the proposed project to existing and potential future receivers. The bridge and approaches have been represented in the hydraulic model of the Clarence River and the model has been simulated for the 20, 50 and 100 year average recurrence interval (ARI) and probable maximum flood (PMF) events. Peak results for flood level, velocity and duration were then compared to the baseline (existing) scenario. The resulting differences between the two scenarios have been mapped to produce impact maps.

Due to the extensive length of the Grafton and South Grafton levees, small 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. Increases in the overtopping volume can potentially result in significant variations in ponded flood levels behind the levee systems as seen by the range of depths in Table 2-2. The remainder of Section 4 details the impacts of the project on Grafton and South Grafton without mitigation.

To reduce the potential adverse flood impacts on adjacent urban areas resulting from the construction of an additional bridge across the Clarence River at Grafton, mitigation measures aimed at maintaining the current level of flood immunity within Grafton and South Grafton have been assessed. The identified mitigation measures are outlined in Section 5 of this report.

4.2 Existing and future receivers

For the purposes of this assessment, existing receivers is taken as being existing property and infrastructure. Future receivers are significant planned infrastructure. Existing and significant planned infrastructure is summarised in Table 4-1.

Table 4-1 Existing and significant planned infrastructure

Infrastructure description	Status
Pacific Highway Upgrade – Woolgoolga to Ballina Highway upgrade which will bypass South Grafton	NSW Planning approval received
Pacific Highway Upgrade – Iluka Road to Woodburn (Devils Pulpit Section)	Recently opened to traffic
Proposed Service Station, fast food restaurant and café – intersection of Spring Street and Iolanthe Street, South Grafton	Application being determined by Clarence Valley Council
Proposed Homemaker Centre at intersection of Through Street and Iolanthe Street, South Grafton	Approval has lapsed and development may change in the future

4.3 Unmitigated flood impacts

Unmitigated flood impacts are presented as follows:

- Table 4-2 summarises the peak (unmitigated) flood level impacts.
- Table 4-3 and Table 4-4 summarise the total volume of water overtopping the levees along with the associated change in overtopping volume from the baseline.
- Figure 4-1 and Figure 4-2 present graphically the expected increases in flood depth from the additional crossing with no mitigation for Grafton and South Grafton respectively.
- Figure 4-3 to Figure 4-6 show hydrographs of the flow entering Grafton and South Grafton during the 50 and 100 year ARI events via overtopping of the levees for the baseline and unmitigated scenarios. Due to only minor localised overtopping in the 20 year ARI event this event has not been included.
- Figure 4-7 to Figure 4-10 map the unmitigated flood level (afflux) impacts for the 20, 50 and 100 year ARI and PMF events. These are the changes in flood depth predicted to occur if the crossing was constructed and no further mitigation works, such as raising the levee, were undertaken.
- Figure 4-11 shows the unmitigated flood velocity impacts for the 100 year ARI event.

Table 4-2 Peak unmitigated flood level impacts summary

Design flood event	Change in peak flood level (m)			
	Prince St Gauge	Existing Grafton Bridge	Grafton[1]	South Grafton[2]
20 year	0.07	0.07	0.00	0.00
50 year	0.04	0.06	0.08	0.67
100 year	0.04	0.06	0.01	0.43
PMF	0.05	0.08	0.04	0.04

1 Intersection of Pound Street and Prince Street

2 Intersection of Abbott Street and Vere Street

Table 4-3 Unmitigated overtopping volumes – North Grafton

Design flood event	Overtopping volume (Megalitres)			
	Baseline	Unmitigated	Change	% Change
50 year	8,304	9,053	749	9%
100 year	17,951	18,941	990	6%

Table 4-4 Unmitigated overtopping volumes – South Grafton

Design flood event	Overtopping volume (Megalitres)			
	Baseline	Unmitigated	Change	% Change
50 year	12,215	16,074	3,858	32%
100 year	30,148	36,015	5,867	19%

Areas highlighted on Figure 4-7 to Figure 4-10 as ‘was wet now dry’ of ‘was dry now wet’ show changes in flood extent. It can be seen that there are no significant changes in extent and inspection of the results shows no predicted changes in flow direction following construction of the additional crossing. Changes in direction are limited to minor increases in flood extent around the periphery of areas subject to existing flooding.

It can be seen from Figure 4-11 that no impacts in terms of increased or decreased flow velocity is predicted to occur as a result of the additional crossing. This finding is the same for all modelled events.

The following observations are summarised for the unmitigated flood impacts:

- The additional bridge crossing results in increased levels within the Clarence River upstream of the crossing for all modelled events. No impacts are predicted downstream of the crossing.
- No impacts to flood velocity or notable changes in flow direction are predicted.
- Increases within the Clarence River range from 0.06m to 0.08m near the proposed crossing and from 0.04m to 0.07m at the Prince Street gauge.
- The increased river water levels result in increases in volume overtopping the levee in Grafton and significant increases in volume overtopping the levee in South Grafton for the 50 and 100 year ARI and PMF events. The South Grafton increase is more pronounced for the 50 year ARI event.
- South Grafton is subject to the greatest increase in flood risk with peak levels increased by up to 0.7m in the 50 year ARI event. However the extent of this increase is generally limited to areas near the periphery of the town and beyond. Significant increases in the order of 0.4m affect South Grafton in the 100 year ARI event. This has a notable impact on the flood extent, more so than for the 50 year ARI event, affecting a greater number of properties within the town.
- Grafton, which experiences significant depths of inundation for events greater than the 20 year ARI, is impacted by the additional bridge crossing with peak flood levels increasing by up to 0.08m.
- The PMF event results in extreme depths of inundation within Grafton and South Grafton. Minor increases in this peak depth are expected to occur due to the additional bridge crossing.
- The planned Pacific Highway Upgrade is not impacted by the additional crossing in any assessed event.

- Other planned infrastructure listed in Table 4-1 and located in South Grafton is predicted to be unaffected by flooding for events up to an including the 50 year ARI event. In the 100 year ARI event the two sites are negatively impacted with peak water level increases of approximately 0.4m.

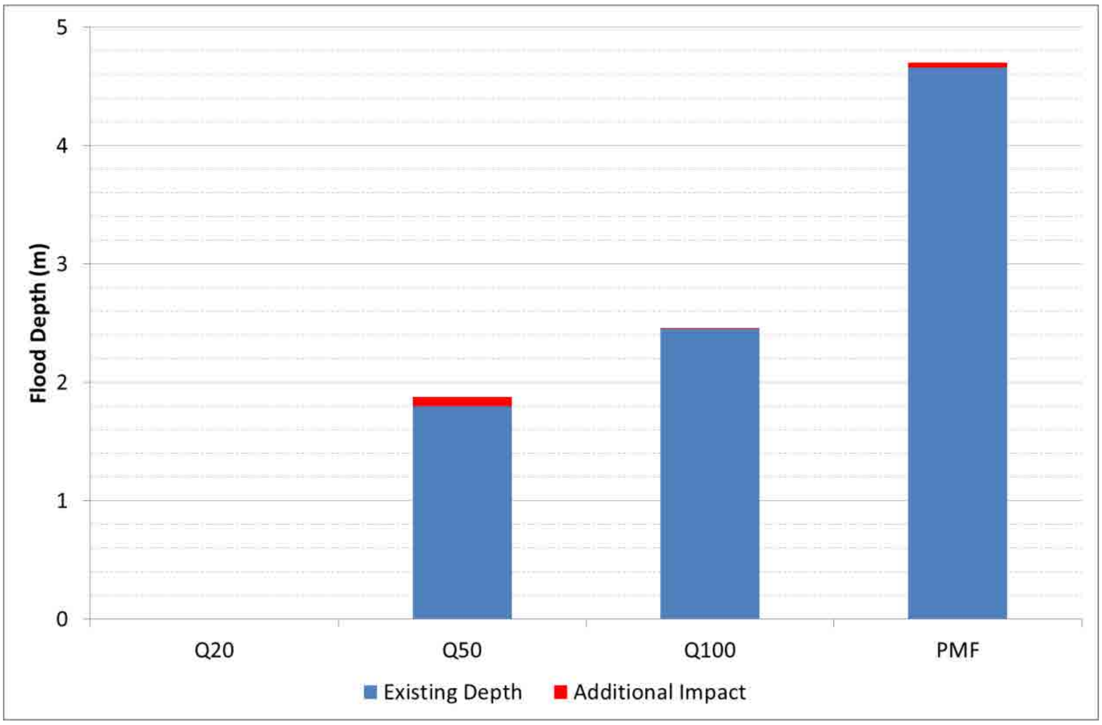


Figure 4-1 Peak flood depth – Grafton (Intersection of Pound Street and Prince Street)

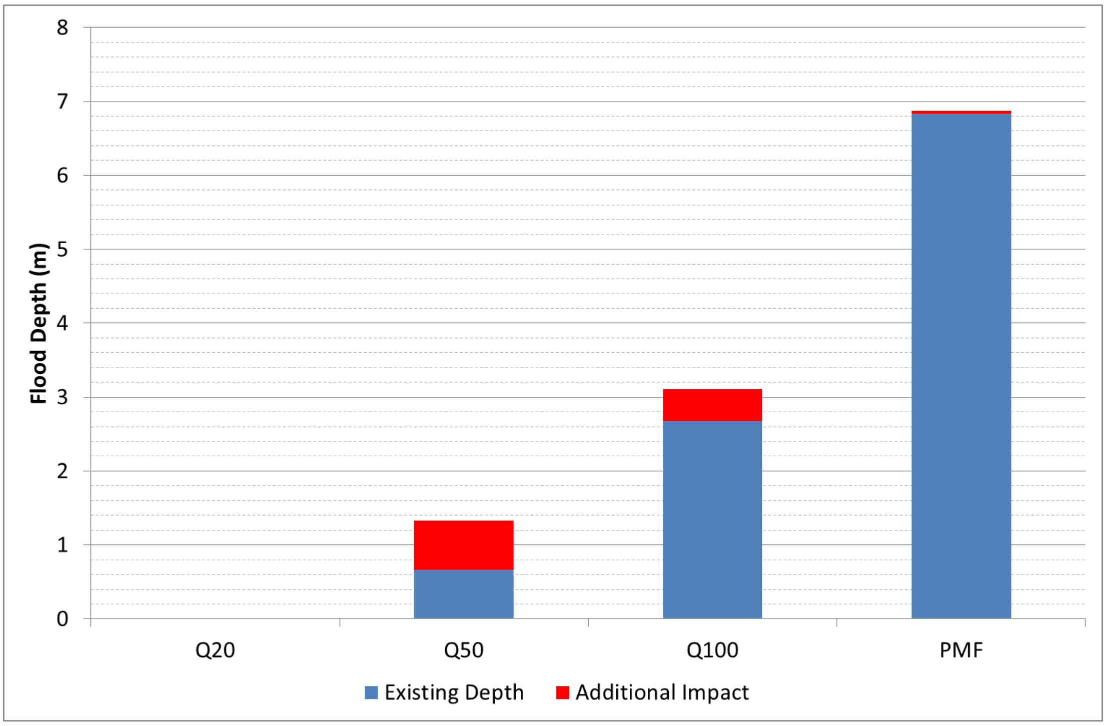


Figure 4-2 Peak flood depth – South Grafton (Intersection of Abbott and Vere Streets)

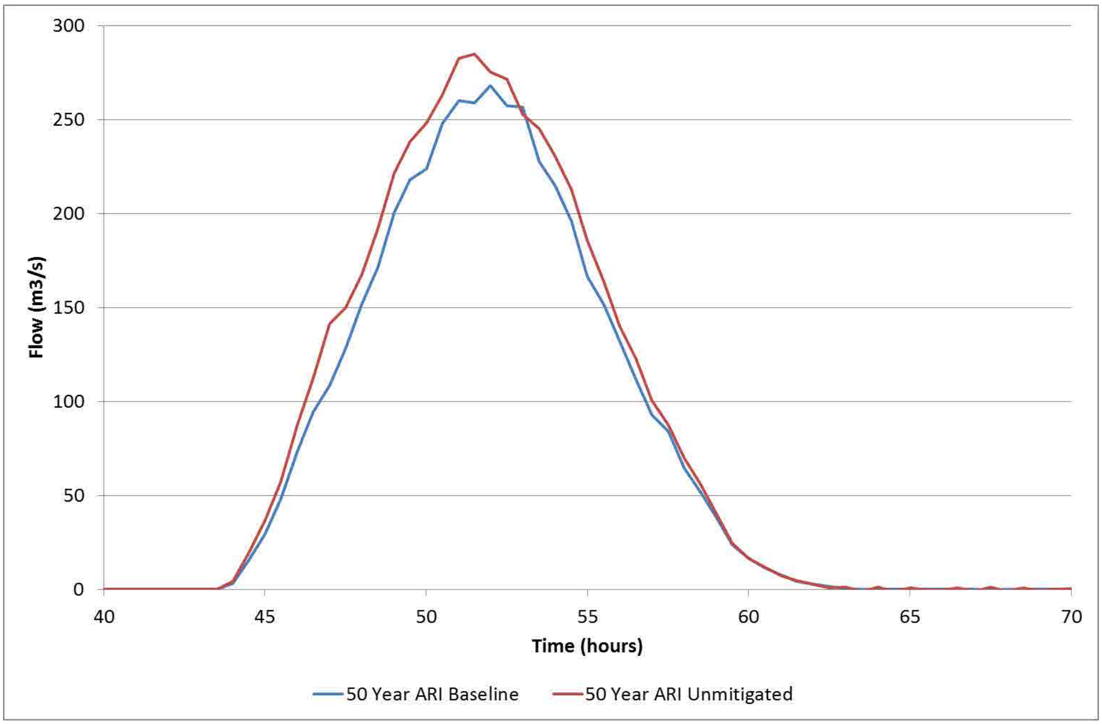


Figure 4-3 North Grafton levee overtopping flow, unmitigated case (50 year ARI)

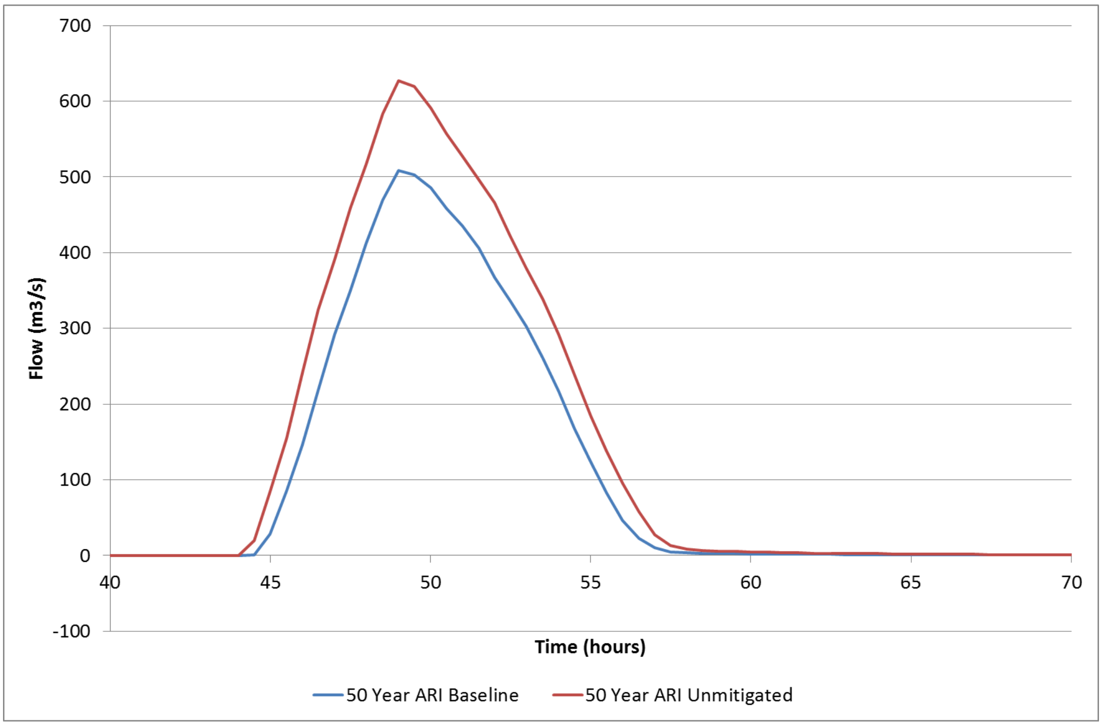


Figure 4-4 South Grafton levee overtopping flow, unmitigated case (50 year ARI)[5]

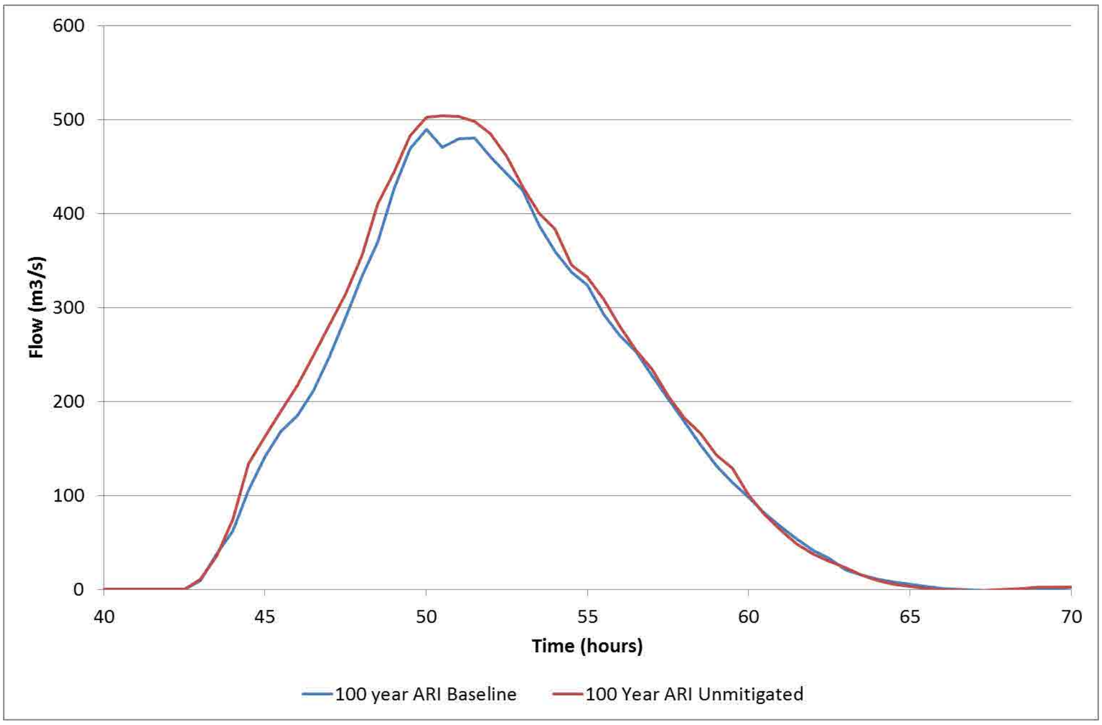


Figure 4-5 North Grafton levee overtopping flow, unmitigated case (100 year ARI)

[5] The south Grafton flows are the combined flows of floodwater spilling over the south Grafton levee adjacent to the town and flow entering from the north across the Gwydir Highway. It is this latter component that dominates in terms of its contribution to the overall inflow volume.

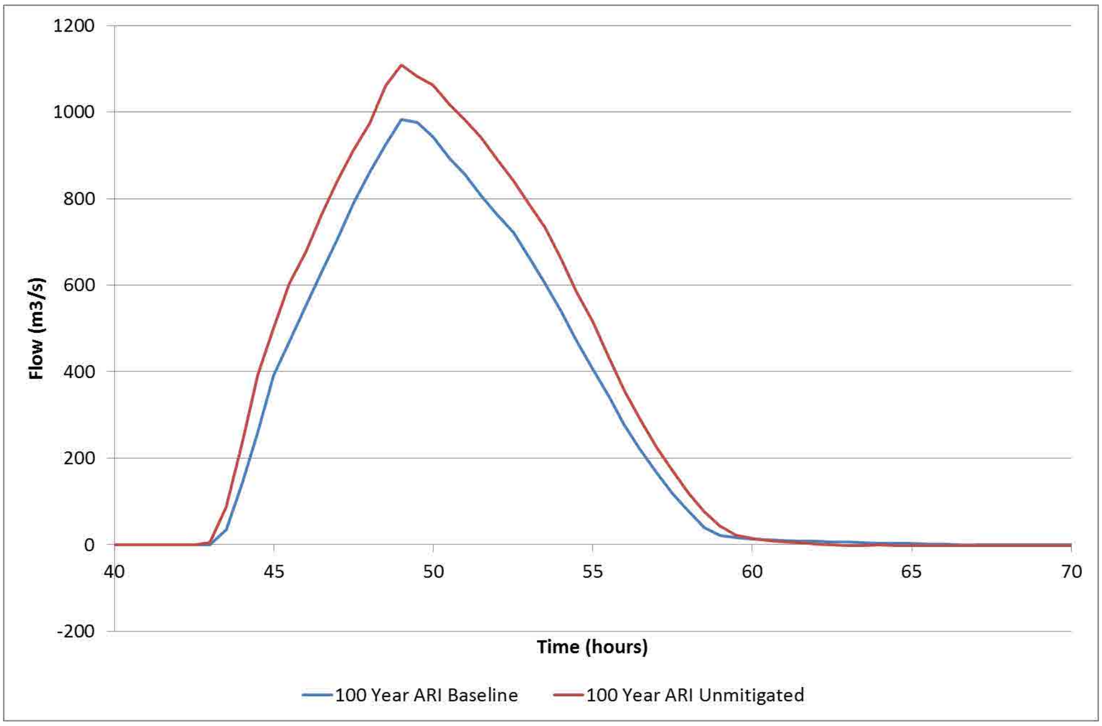
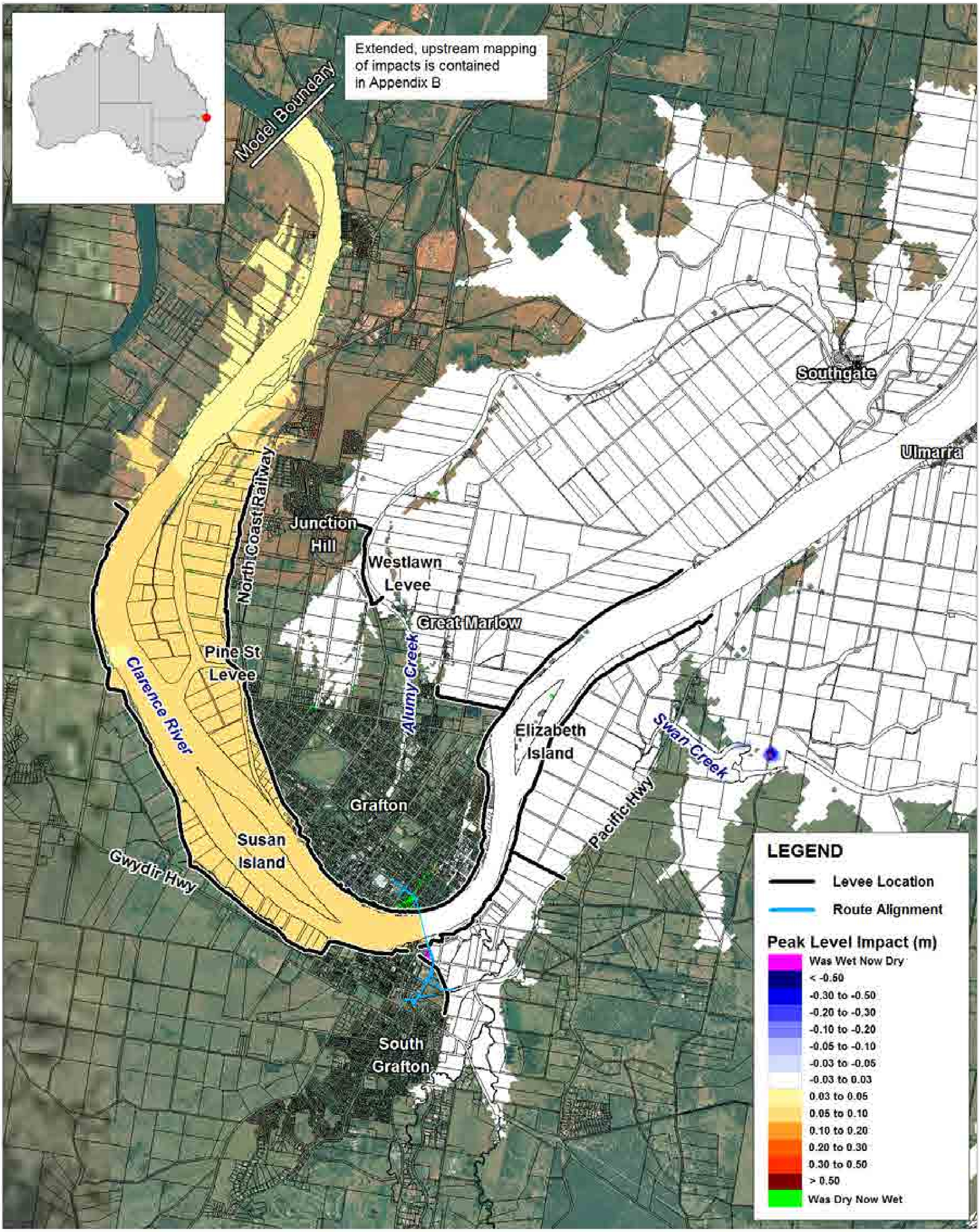


Figure 4-6 South Grafton levee overtopping flow, unmitigated case (100 year ARI)



Title:

Peak Flood Level Impacts (Unmitigated)
20 Year ARI Event

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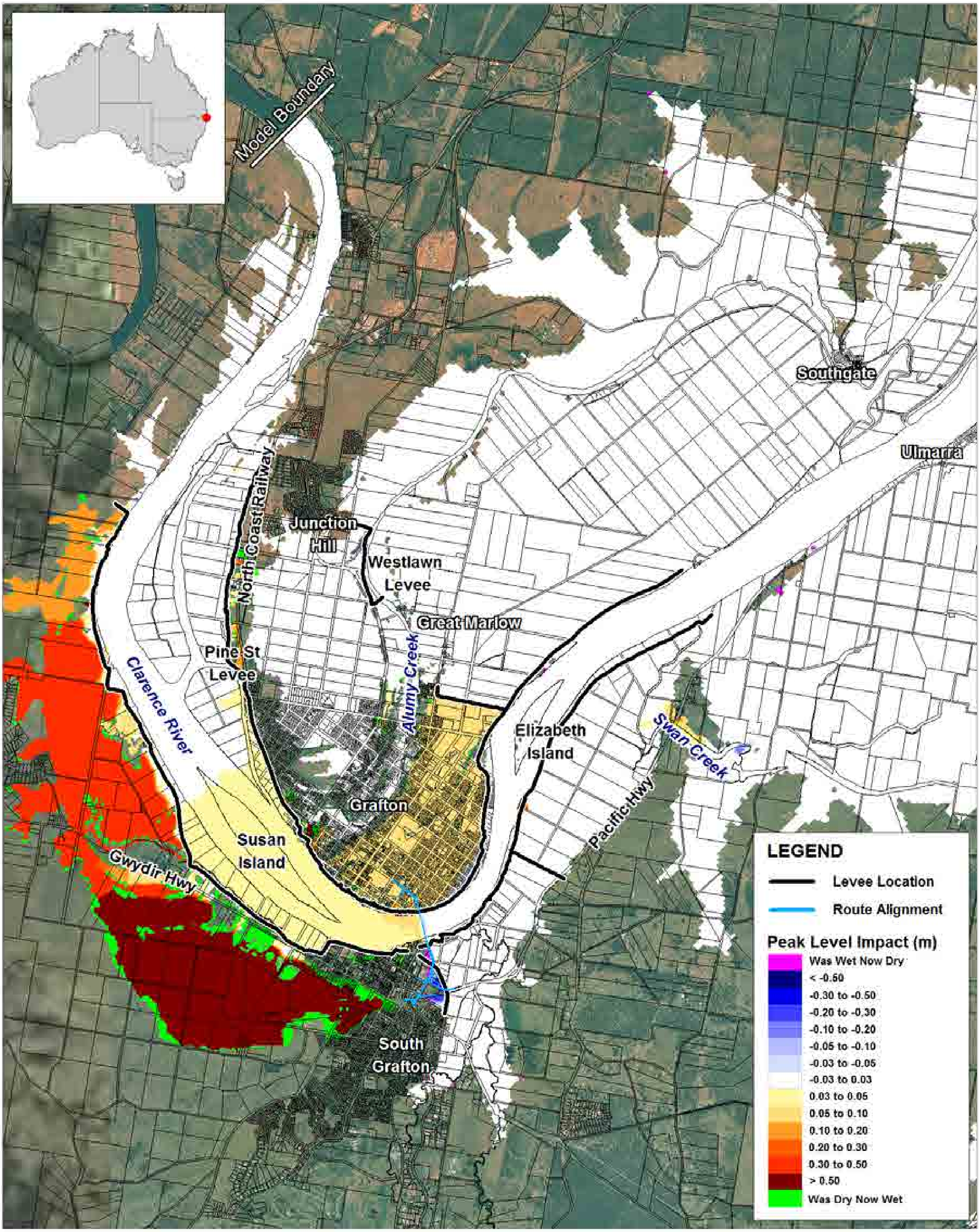

Title:

Peak Flood Level Impacts (Unmitigated)
50 Year ARI Event

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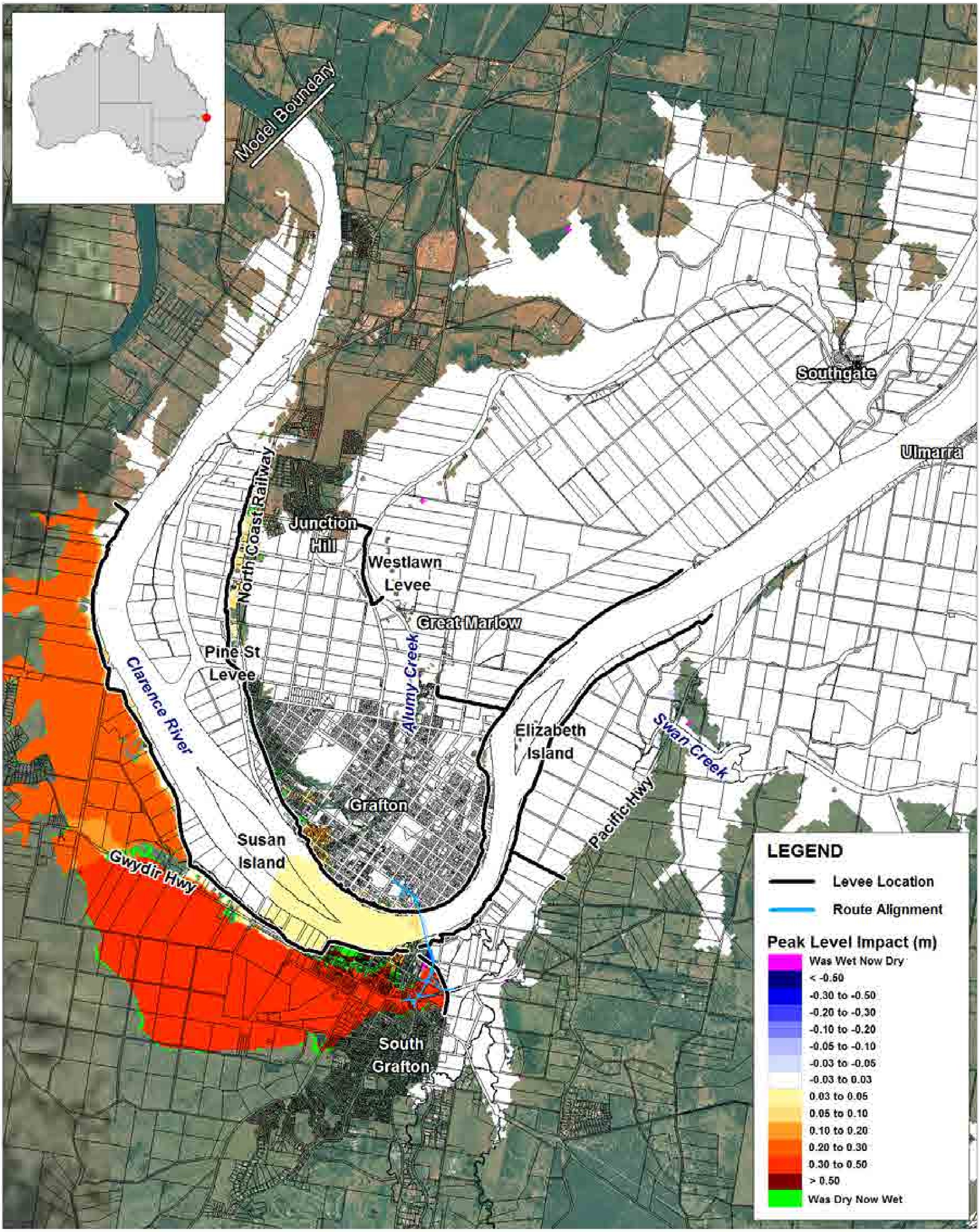

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Peak Flood Level Impacts (Unmitigated)
100 Year ARI Event

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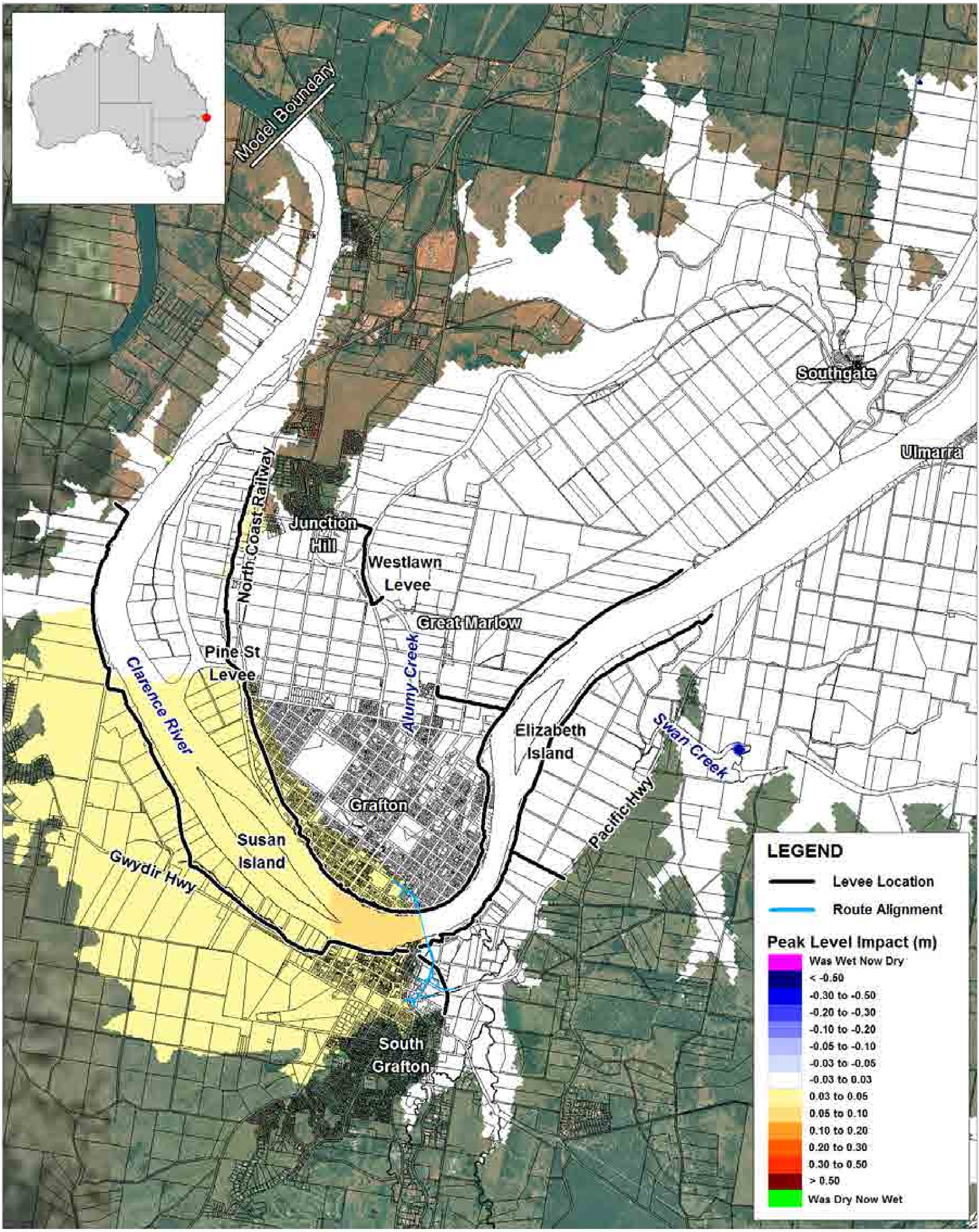

Title:

Peak Flood Level Impacts (Unmitigated) PMF Event

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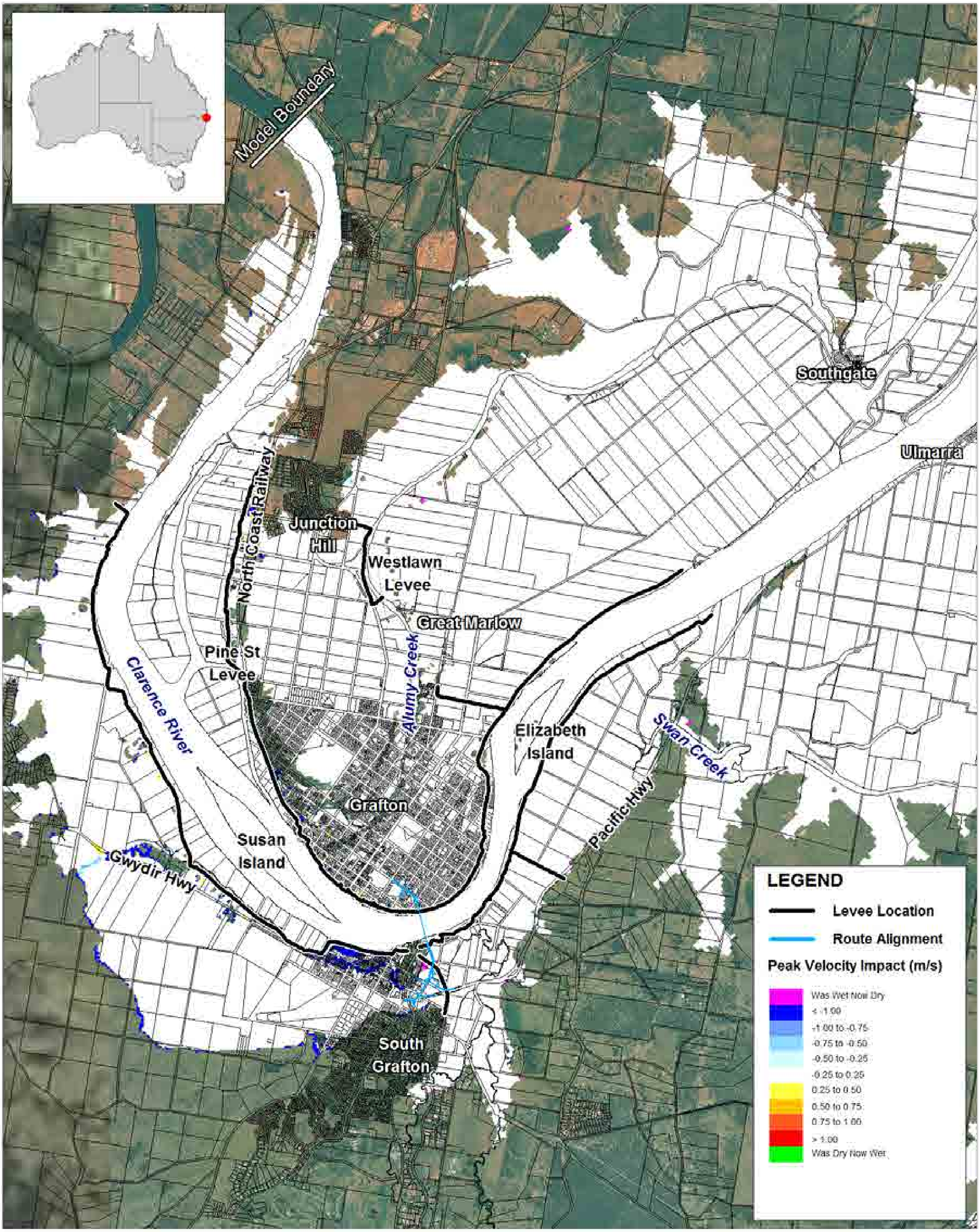

Title:

Peak Flood Velocity Impacts (Unmitigated)
100 Year ARI Event

Figure: 4-11

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5 Mitigation options assessment

5.1 Introduction

The flood impact assessment predicted that without mitigation the additional bridge crossing will result in increases in peak flood level upstream of the crossing during significant flood events. These predicted impacts are particularly significant in South Grafton.

Mitigation of impacts provides an opportunity to not only reduce the impacts but to provide a net reduction (an improvement) in flood risk for the communities of Grafton and South Grafton.

Flood mitigation measures can be classified into three general categories:

- Flood modification – measures to modify the behaviour of floodwater by either reducing flood depths and/or velocities or by excluding floodwater from certain areas. Examples include levees and floodways;
- Response modification – changing or improving a community's response to flooding such as through flood warning or education; and
- Property modification - increasing the resilience of existing property to flooding and implementing appropriate planning controls ensure new property is compatible with the level of flood risk.

Flood risk management typically consists of a suite of measures drawn from all three general categories listed above. For the mitigation of impacts from a development, typically the measures will consist of either flood modification measures to 'offset' or mitigate against the flood modification caused by that development or property modification measures to reduce the consequences of the impacts. Combinations of these measures may also be used.

5.2 Potential mitigation measures for Grafton / South Grafton

Within Grafton and South Grafton the predicted flood impacts resulting from the additional crossing are triggered by relatively minor increases of water level in the Clarence River.

Potential flood modification measures for mitigating such impacts include:

- Dredging the river with the aim of lowering flood levels;
- Implementing a floodway with associated inlet and outlet control structures to reduce downstream flood levels;
- Containing flood level increases through the use of levees; or
- Creating or enhancing zones of storage within the floodplain to temporarily detain or slow the floodwater and reduce the peak levels.

These potential options and their applicability to Grafton and South Grafton are summarised below.

5.2.1 Potential flood modification measures

Dredging

Dredging would involve increasing the depth and conveyance capability of the Clarence River channel through the removal of silt from the river bed. It is not a sustainable solution as dredging operations would need to be repeated within a few years as the river naturally replaces the silt which was previously removed. Dredging itself can also lead to impacts with uncertain outcomes such as increasing the erosive potential of the river which may in turn impact on existing structures crossing the river or the stability of river banks. For these reasons dredging is not considered a viable option for the project.

Floodway

To mitigate the impacts of the additional crossing a floodway would need to be located upstream of the bridge. Existing levees protecting Grafton and South Grafton are located in areas of dense urban development and so there are no feasible locations for a floodway. An opportunity for a floodway bypass exists further upstream in the area to the north of Grafton and to the south of Junction Hill. It would convey a controlled volume of floodwater from the eastern Clarence River floodplain out into the western Clarence floodplain bypassing Grafton.

A floodway would extend for approximately 2km and would require inlet and outlet structures to the Clarence River. Existing viaducts under the North Coast Railway line will require widening to accommodate a floodway. An embankment along the southern side of the floodway may also be required to prevent flow passing south into Grafton.

The likely costs of this measure are likely to be prohibitive when compared to alternative measures and it is therefore not considered further in this assessment.

Construction/Augmentation of Levees

Levees are currently used to manage flood risk in Grafton and South Grafton. Mitigating the increased flood levels from the additional crossing would involve increasing the heights of the existing levees and potentially extending the levees upstream. The Grafton and Lower Clarence Floodplain Risk Management Plan identifies mitigation works for Grafton and South Grafton which are generally focussed on the maintenance and augmentation of levees.

By containing or partially containing floodwater within the channel, levees will raise in-bank flood levels and this in turn will impact on areas outside of the levee’s zone of protection. These areas potentially include Carrs Island and Carrs Peninsula, isolated properties within Grafton and South Grafton and areas of upstream floodplain. This residual risk will need to be established and quantified. Further residual risk remains through the risk of levee failure (breach of overtopping) and evacuation plans should account for this risk.

Levees are considered as a potential option for mitigating the impacts of flooding from the additional crossing. They have been assessed further within sections 5.3 to 5.6.

Floodplain Storage

The creation of dams within the upper Clarence River catchment to detain floodwater and reduce the peak river levels will entail prohibitive costs and would require many further investigations to assess the feasibility and impacts of such measures. The scale of the flood flows (17,700m^3/s in the 100 year ARI event) means that local flood storage measures around Grafton will be of very limited effect against such significant flows.

Floodplain storage options do have the potential when considered alongside other measures such as levees. One potential flood storage measure for South Grafton is to raise the Gywdir Highway to prevent or reduce floodplain flows entering South Grafton from the north. This measure has been considered further in Section 5.5 and 5.6.

5.2.2 Potential property modification measures

Property modification measures can potentially be used with flood modification measures or as standalone measures to mitigate the impacts from the additional crossing.

For Grafton and South Grafton, property modification measures would need to offset the impacts of increased flood levels. The most appropriate measure to achieve this is house raising with the aim of raising dwellings by a height which is greater than the height increases to the flood.

For this project this measure will typically be applied for dwellings located outside of areas mitigated by flood modification measures. Property modification measures are considered further in Section 6.

5.2.3 Summary of potential mitigation measures

Table 5-1 presents a summary of potential mitigation measures highlighting the ones which have been taken forward for further consideration.

Table 5-1 Summary of potential mitigation measures

Measure	Type of measure	Assessed further?	Reason/s for no further assessment
Dredging of Clarence River	Flood Modification	No	Not sustainable Uncertain impacts
Floodway	Flood Modification	No	Prohibitive costs
Levee Options	Flood Modification	Yes	
Floodplain Storage	Flood Modification	Yes	
House Raising	Property Modification	Yes	

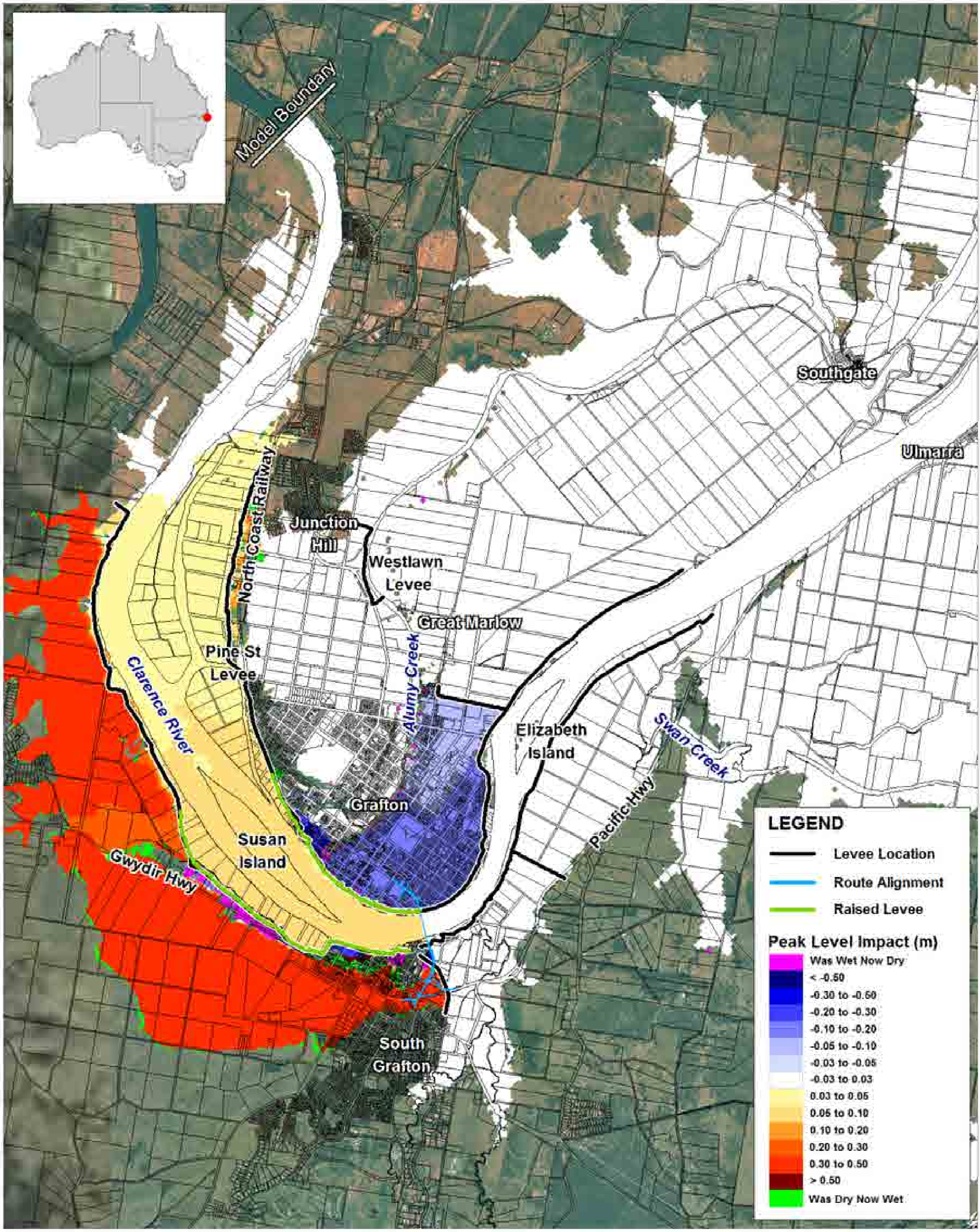
Mitigation measures are further considered in the remainder of this Section 5 with house raising considered in Section 6.

5.3 Mitigation Option 1

Option 1 consists of raising 3.7km of levee on the northern side of the Clarence River by 0.2m and a further 4.7km of levee on the southern side by 0.2m.

Option 1, along with the 100 year average recurrence interval (ARI) modelled impacts are shown in Figure 5-1. Peak levels in Grafton are reduced by 0.13m but an impact of 0.42m remains in South Grafton. Whilst the volume of water overtopping the raised levee into South Grafton is reduced, there remains significant overtopping into the floodplain to the north which then flows into South

Grafton. Option 1 was therefore not considered further in this assessment and no events other than the 100 year ARI were modelled.



Title:

Peak Flood Level Impact 100 Year ARI Event Additional Crossing (Mitigation Option 1)

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5.4 Mitigation Option 2

Option 2 raises the same length of levee on the northern side of the Clarence River as Option 1 (3.7km) but extends the length of levee raised on the southern side to 7km. Both levees are raised by 0.2m.

Figure 5-2 to Figure 5-5 show hydrographs of the flow entering Grafton and South Grafton during the 50 and 100 year ARI events via overtopping of the levees for the baseline and Mitigation Option 2 scenarios. Due to only minor localised overtopping in the 20 year ARI event this event has not been included.

Figure 5-6 to Figure 5-9 plot design flood levels over time at urban locations in Grafton and South Grafton. Much of the urban area of South Grafton remains flood free during the 50 year ARI event. As such only the 100 year levels were plotted.

Figure 5-10 to Figure 5-13 show mitigation Option 2 along with the predicted flood level impacts for the 20, 50 and 100 year ARI and the PMF events. Figure 5-14 show Option 2 with the predicted flood velocity impacts for the 100 year ARI event.

Table 5-2 summarises the changes in peak flood level for locations in Grafton and South Grafton. Table 5-3 and Table 5-4 summarise the levee overtopping volumes.

Table 5-2 Peak flood level impact (Mitigation Option 2)

	Prince St Gauge	Existing Grafton Bridge	Grafton[1]	South Grafton[2]
20 year	0.06	0.07	0.00	0.00
50 year	0.08	0.08	-0.27	0.05
100 year	0.09	0.09	-0.07	-0.11
PMF	0.05	0.07	0.02	0.05

1 Intersection of Pound Street and Prince Street

2 Intersection of Abbott Street and Vere Street

Table 5-3 Option 2 overtopping volumes – North Grafton

Design flood event	Overtopping volume (Megalitres)			
	Baseline	Unmitigated	Change	% Change
50 year	8,304	7,193	-1,111	-13%
100 year	17,951	16,539	-1,412	-8%

Table 5-4 Option 2 overtopping volumes – South Grafton

Design flood event	Overtopping volume (Megalitres)			
	Baseline	Unmitigated	Change	% Change
50 year	12,215	12,617	402	3%
100 year	30,148	28,979	-1,169	-4%

Option 2 significantly reduces the impact resulting from the additional bridge crossing but a minor predicted increase of 0.05m remains in South Grafton for the 50 year ARI event. Whilst the peak levee overtopping flow has reduced (see Figure 5-3), the overall overtopping volume has marginally increased by around 3%. Much of the existing urban extent of South Grafton remains flood free during the 50 year ARI event and the resulting increase in flood level is therefore limited to the periphery of South Grafton. It does impact on the South Grafton Airport and three residential properties on Skinner Street. The reduction in flood levels in South Grafton in the 100 year ARI event benefits existing property.

A predicted net reduction in peak flood levels in Grafton occurs for the 50 and 100 year ARI events along with a very slight reduction in flood duration due to a delayed onset of flooding.

Very minor increases in flood level are predicted for a PMF event. It is not considered necessary to offset this minor impact for an event of such rarity, especially when the baseline flood depths are such that they would most likely result in properties being so badly damaged that they would need to be replaced.

Properties that lie outside of the levee banks such as those on Carrs Island would be affected by increased levels in the Clarence River from both the additional crossing and the Option 2 levee augmentation. The increases in flood levels at Carrs Island are typically between 0.05m and 0.10m for all modelled events. Under Option 2 it may be necessary to compensate or raise any houses that fall within this zone of residual impacts. This is covered further in Section 6.

No notable impacts were observed for changes in peak flood velocity under Option 2. Minor increases in flood hazard will result where the depth has increased but as discussed above the impacts are of limited spatial extent. There are no predicted increases in duration or frequency of flooding and Grafton will experience a slight reduction in the predicted frequency of levee overtopping.

No impacts have been identified on planned infrastructure listed in Table 4-2. The proposed Pacific Highway upgrade is a significant distance downstream from the crossing and no downstream impacts have been predicted for any assessed event. The two planned developments in South Grafton are located outside the extent of the 50 year ARI flood but are potentially affected in the 100 year ARI event. However, the assessment has shown that the mitigation measures included in Option 2 result in lower flood levels at the locations of these developments for this event.

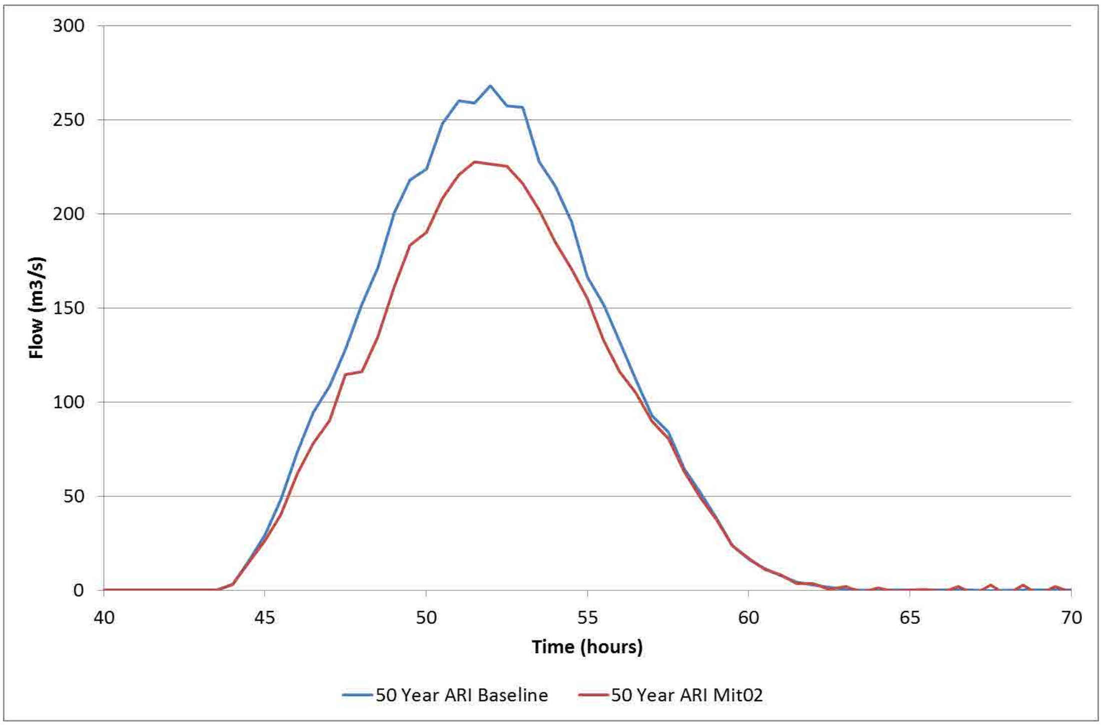


Figure 5-2 North Grafton levee overtopping flow, Option 2 (50 year ARI)

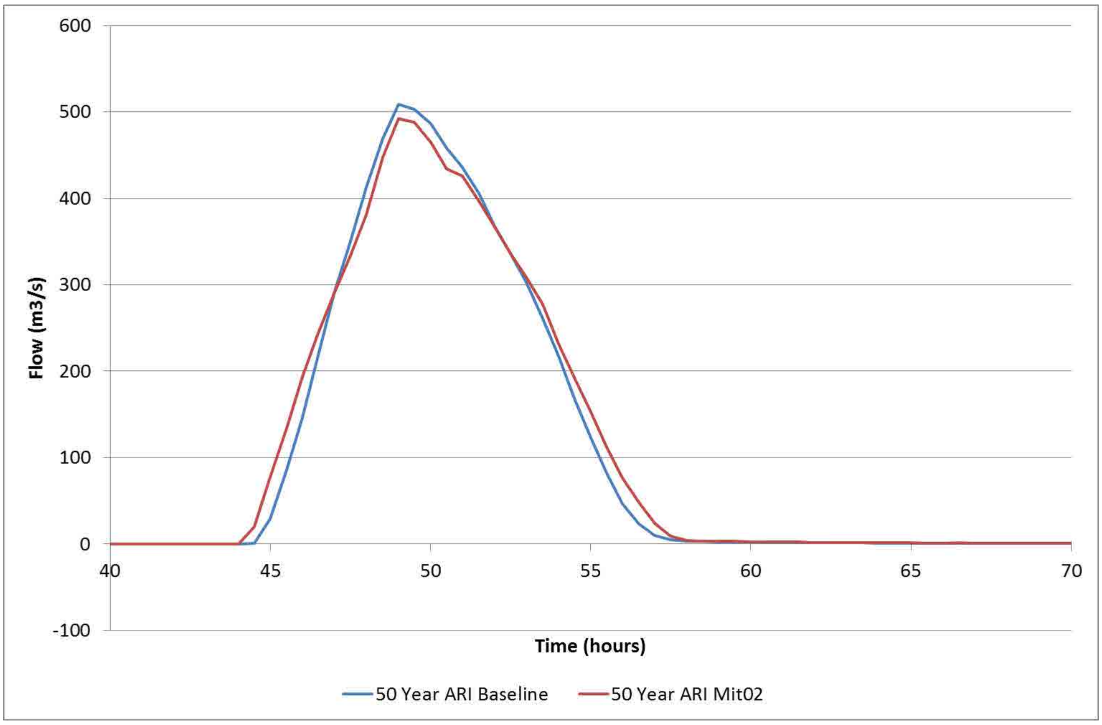


Figure 5-3 South Grafton levee overtopping flow, Option 2 (50 year ARI)

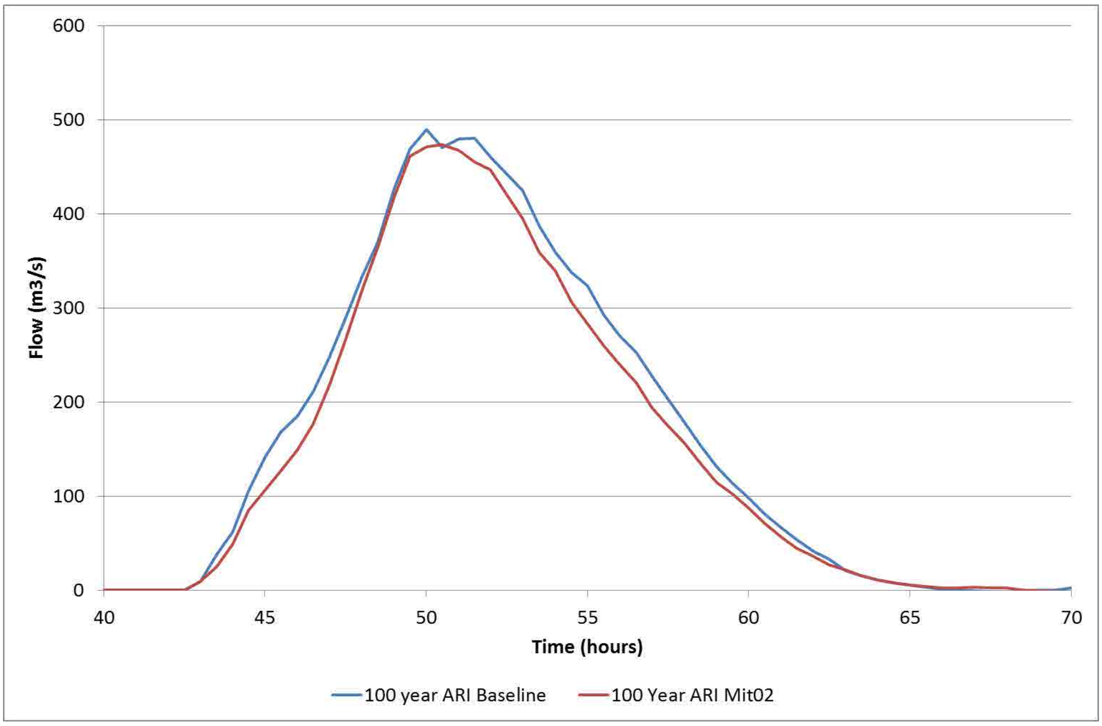


Figure 5-4 North Grafton levee overtopping flow, Option 2 (100 year ARI)

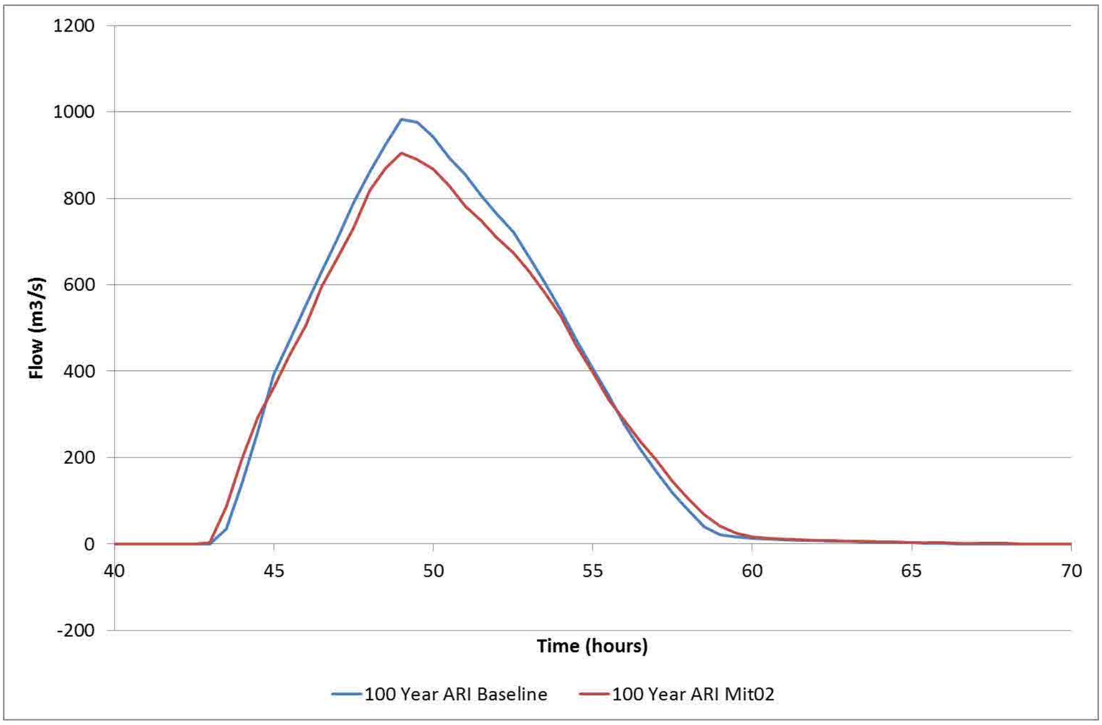


Figure 5-5 South Grafton levee overtopping flow, Option 2 (100 year ARI)

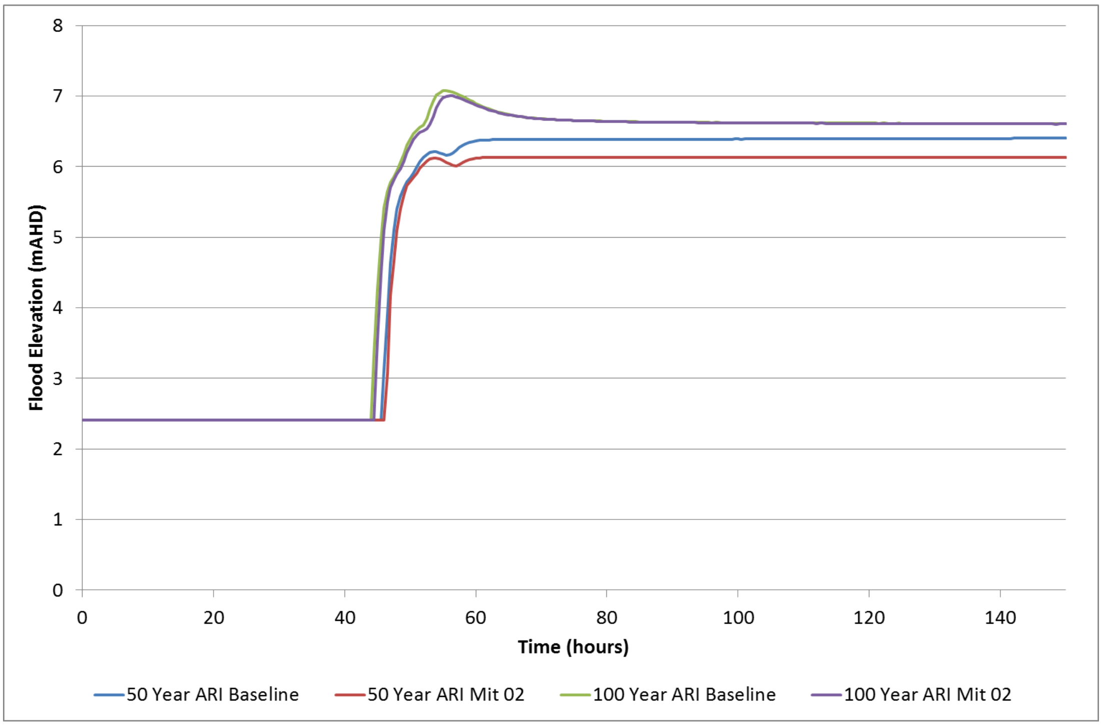


Figure 5-6 Pound Street, North Grafton, design flood elevations, Option 2

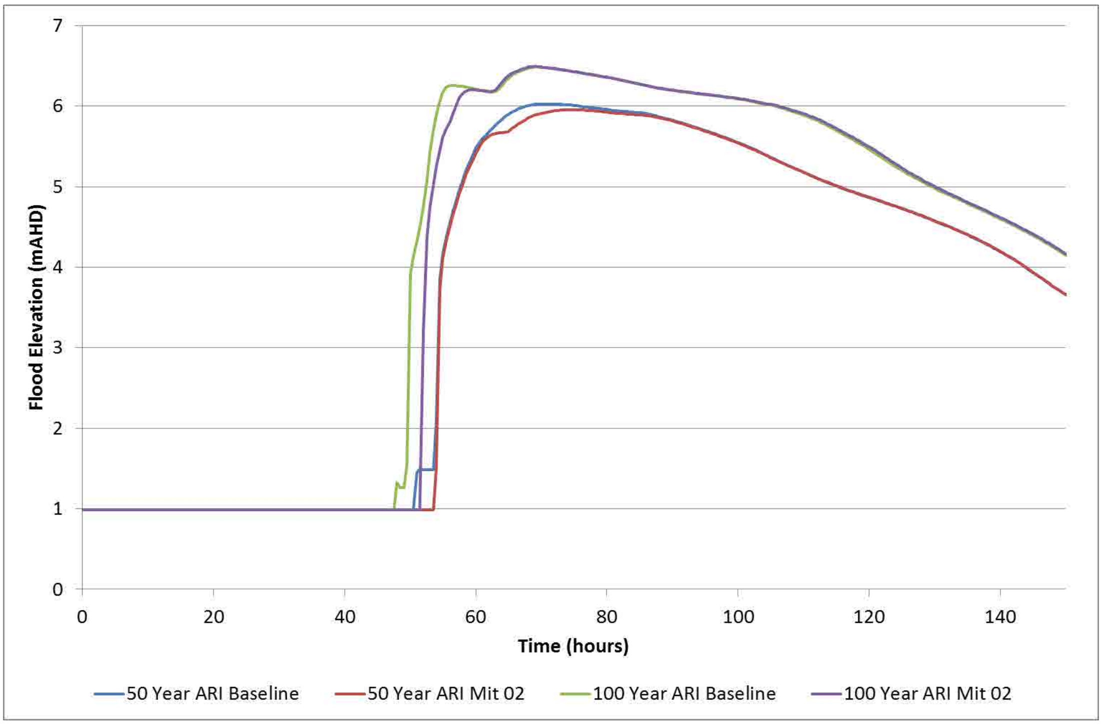


Figure 5-7 Alumy Creek (Fry St), North Grafton, design flood elevations, Option 2

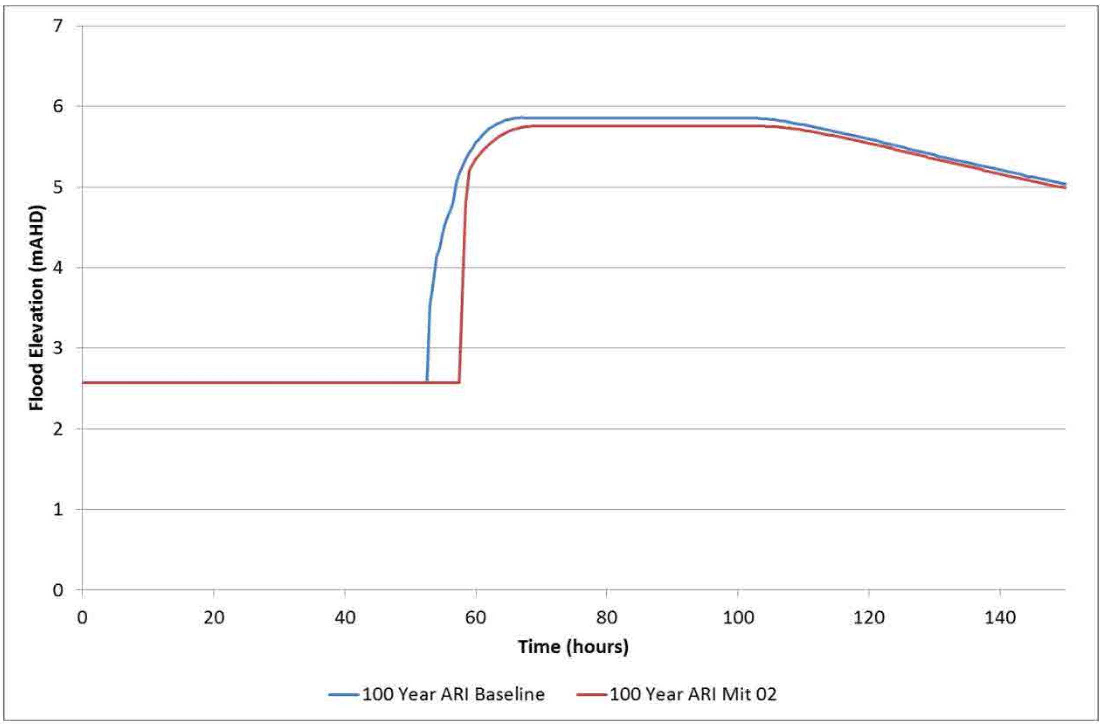


Figure 5-8 Near Wharf St, South Grafton, design flood elevations, Option 2[6]

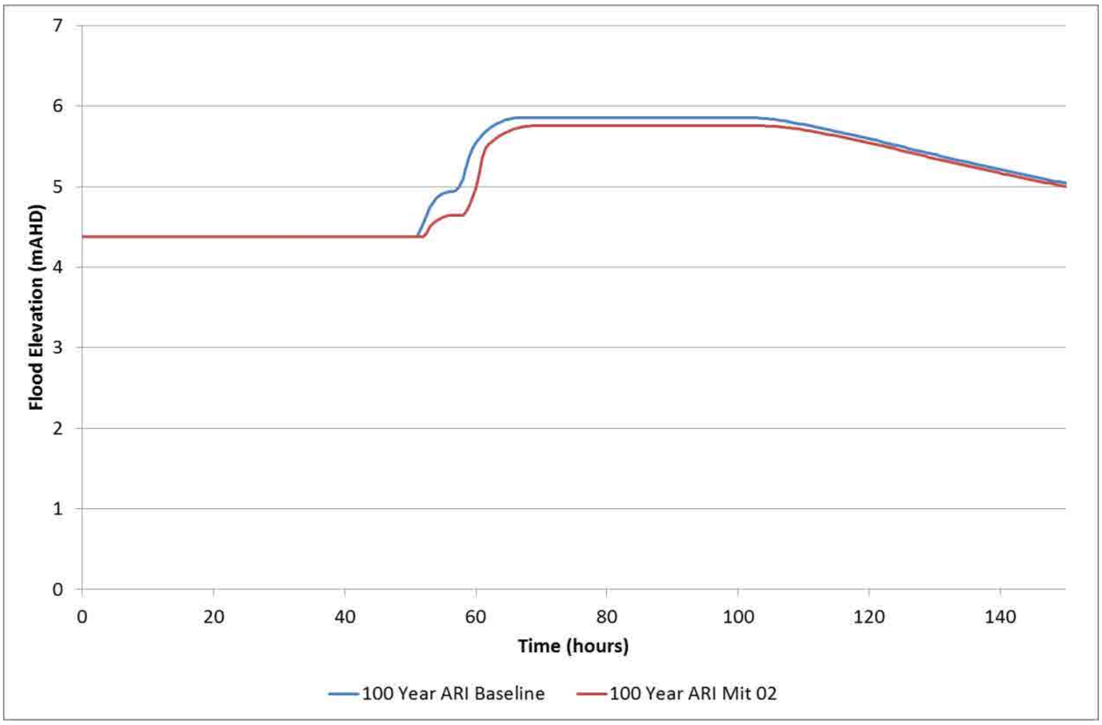
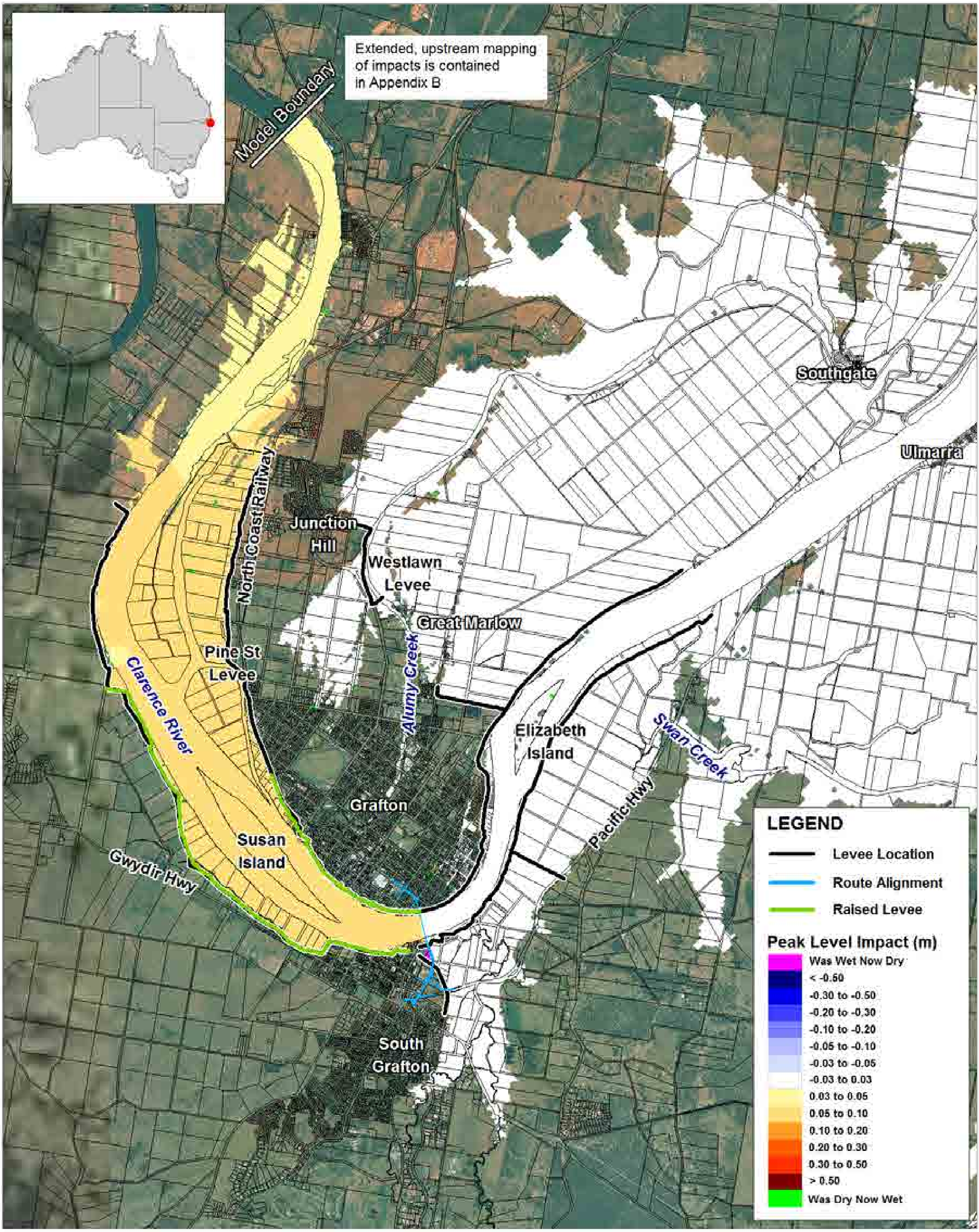


Figure 5-9 Iolanthe St, South Grafton, design flood elevations, Option 2[5]

[6] No flooding at this location in the 50 year ARI event



Title:

Peak Flood Level Impact 20 Year ARI Event
Additional Crossing (Mitigation Option 2)

Figure: 5-10

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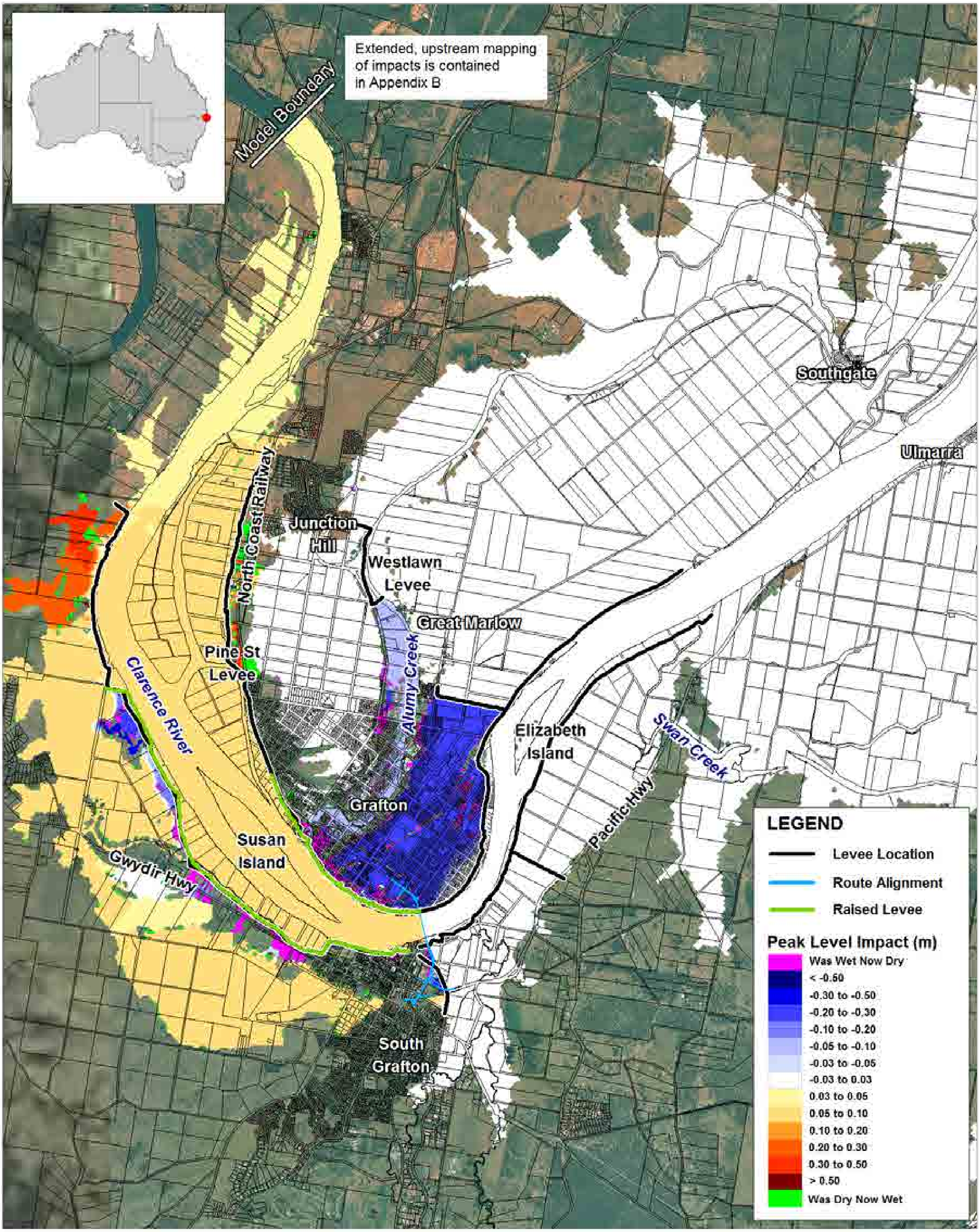

Title:

Peak Flood Level Impact 50 Year ARI Event Additional Crossing (Mitigation Option 2)

Figure: 5-11

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Approx. Scale

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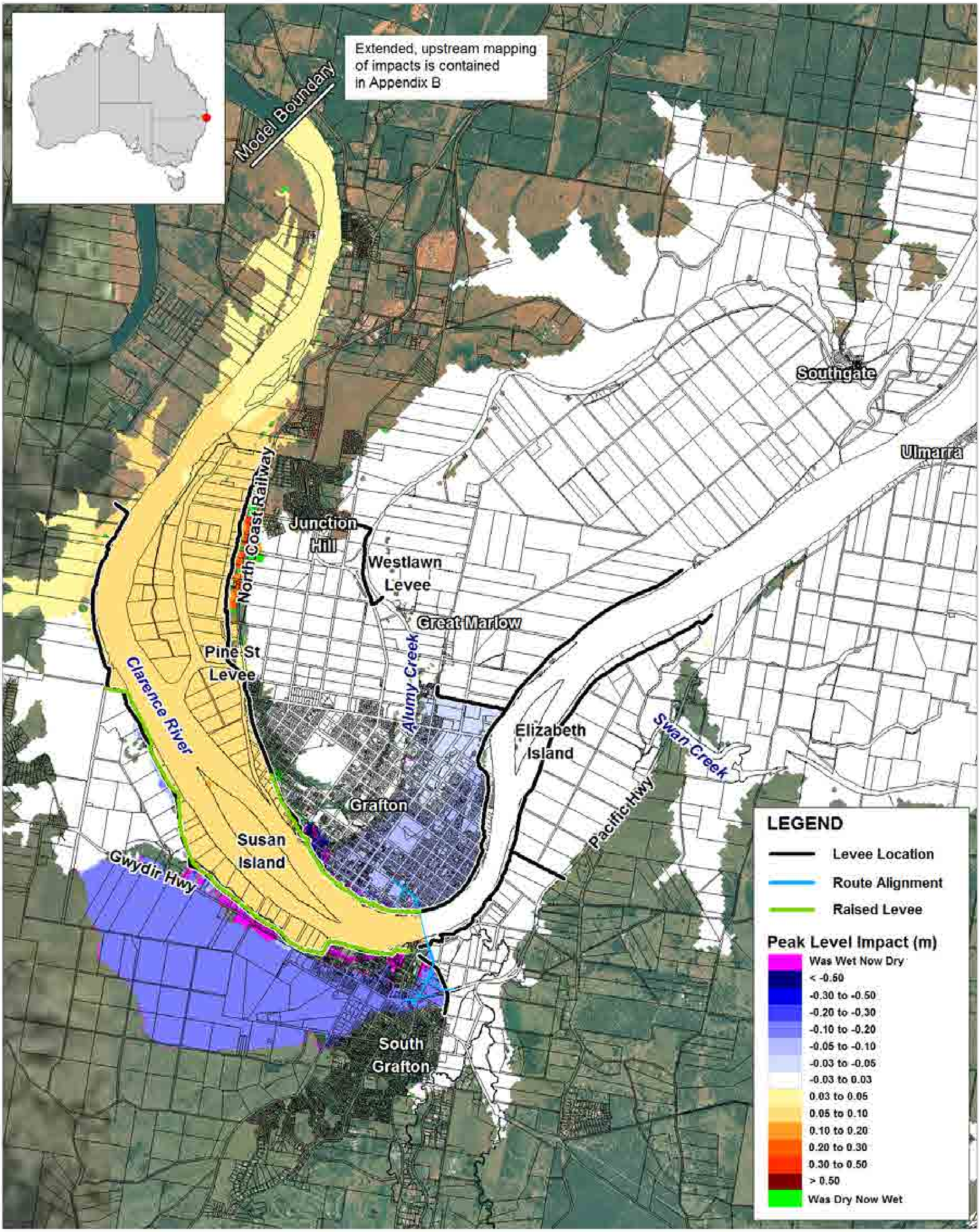

Title:

Peak Flood Level Impact 100 Year ARI Event Additional Crossing (Mitigation Option 2)

Figure: 5-12

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Approx. Scale

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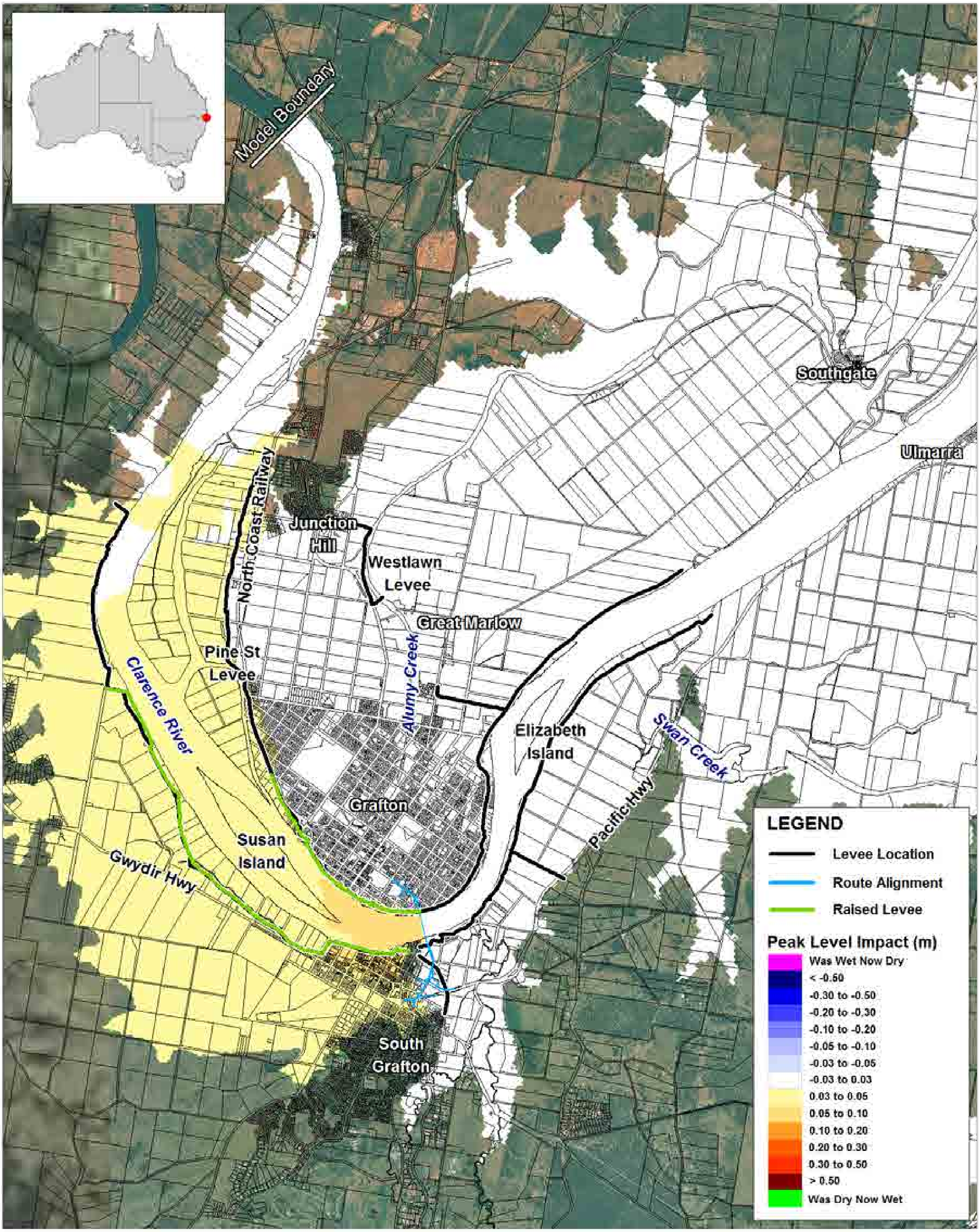

Title:

Peak Flood Level Impact PMF Event Additional Crossing (Mitigation Option 2)

Figure: 5-13

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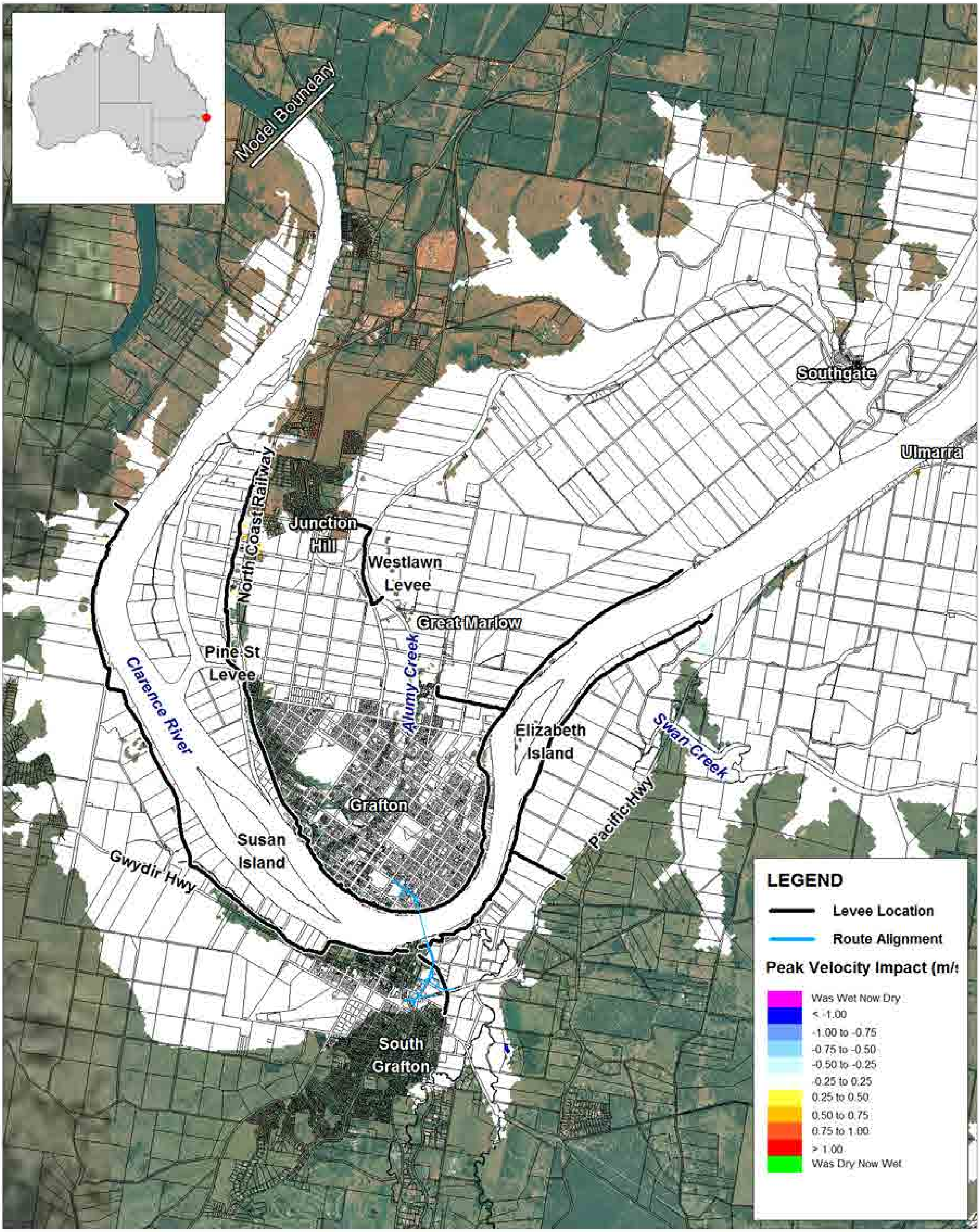

Title:

Peak Flood Velocity Impact 100 Year ARI Event Additional Crossing (Mitigation Option 2)

Figure: 5-14

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Approx. Scale

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5.5 Mitigation Option 3

Option 3 reduces the length of levee raising required compared to Option 2 by utilising and modifying a natural constriction in the floodplain terrain near South Grafton. The aim is to reduce the floodplain flow which is conveyed behind the levee bank into South Grafton.

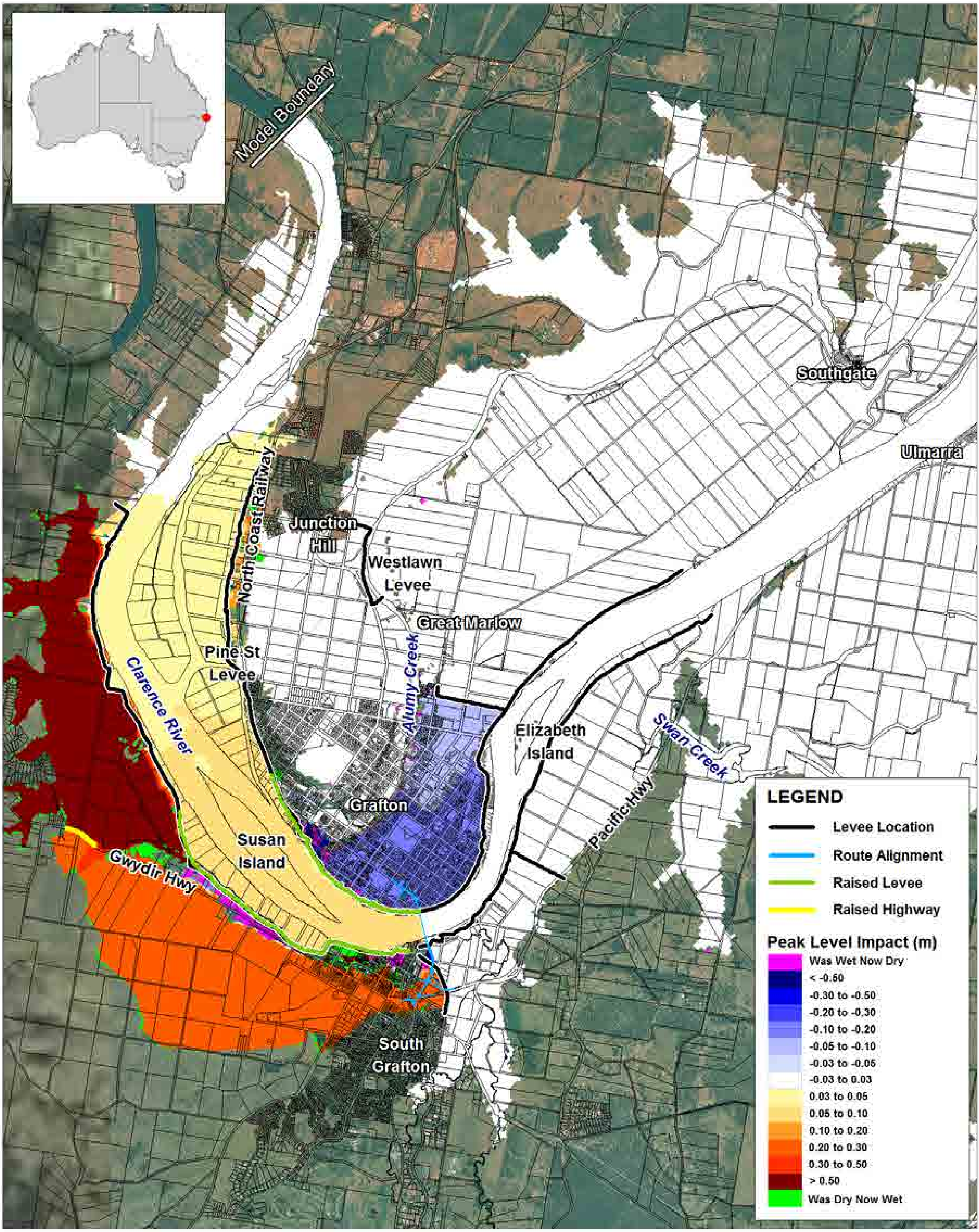
The proposed levee raising extents are the same as Option 1 with 3.7km and 4.7km of levee raised by 0.2m on the northern and southern sides of the Clarence River respectively.

The constriction in the South Grafton floodplain is located along the Gwydir Highway near its intersection with Friars Lane. Mitigation Option 3 would require raising the minimum road elevation of the Gwydir Highway to 6.5mAHD. This represents a total length of 425m of the highway. Current road elevations along this length of highway range between 5mAHD and 6.5mAHD resulting in a maximum raising height of 1.5m. An existing small watercourse, Saltwater Creek, drains the South Grafton Commons floodplain in this area and passes under the Gwydir Highway in a northerly direction. Floodgates would need to be installed under the highway to allow local runoff to drain when the Clarence River is not in flood, which can close and prevent backflow when floodwater flows towards South Grafton from the north.

Figure 5-15 shows the scheme along with the predicted 100 year ARI peak level impacts.

Under Option 3 the peak 100 year ARI flood level in Grafton is reduced by 0.13m. Peak 100 year ARI flood levels in South Grafton are reduced from the unmitigated case but remain 0.24m higher than the baseline peak flood level (before the additional bridge crossing is constructed). This increase affects existing property and is considered unacceptable and therefore no events other than the 100 year ARI were modelled.

Option 3 has not been taken forward for further assessment.



Title:

Peak Flood Level Impact 100 Year ARI Event Additional Crossing (Mitigation Option 3)

Figure: 5-15

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5.6 Mitigation Option 4

Option 4 is similar to Option 3 but with the Gwydir Highway raised to a minimum elevation of 7.0mAHD (0.5m higher than for Option 3). This requires the raising of approximately 550m of road by a maximum height of 2m. As for Option 3, flood gates would be required under the highway to allow Saltwater Creek to drain to the north.

Figure 5-16 to Figure 5-19 show hydrographs of the flow entering Grafton and South Grafton during the 50 and 100 year ARI events via overtopping of the levees for the baseline and Mitigation Option 2 scenarios. Due to only minor localised overtopping in the 20 year ARI event this event has not been included

Figure 5-20 to Figure 5-23 plot design flood levels over time at urban locations in Grafton and South Grafton. Much of the urban area of South Grafton remains flood free during the 50 year ARI event. As such only the 100 year levels were plotted.

Figure 5-24 to Figure 5-27 show mitigation Option 4 along with the predicted impacts for the 20, 50 and 100 year ARI and the PMF events. Figure 5-28 shows the predicted impacts for the 100 year ARI peak flood velocity.

Table 5-5 summarises the changes in peak flood level for two locations in Grafton and South Grafton. Table 5-6 and Table 5-7 summarise the levee overtopping volumes.

Table 5-5 Peak flood level impact (Mitigation Option 4)

	Prince St Gauge	Existing Grafton Bridge	Grafton[1]	South Grafton[2]
20 year	0.06	0.07	0.00	0.00
50 year	0.06	0.06	-0.41	-0.56
100 year	0.07	0.07	-0.13	-0.07
PMF	0.05	0.07	0.02	0.05

1 Intersection of Pound Street and Prince Street

2 Intersection of Abbott Street and Vere Street

Table 5-6 Option 4 overtopping volumes – North Grafton

Design Flood Event	Overtopping Volume (Megalitres)			
	Baseline	Unmitigated	Change	% Change
50 year	8,304	6,537	-1,767	-21%
100 year	17,951	14,009	-3,942	-22%

Table 5-7 Option 4 overtopping volumes – South Grafton

Design Flood Event	Overtopping Volume (Megalitres)			
	Baseline	Unmitigated	Change	% Change
50 year	12,215	16,034	3,819	31%
100 year	30,148	36,106	5,958	20%

Raising the Gwydir Highway creates additional storage in the floodplain upstream of South Grafton. Therefore, whilst levee overtopping volumes have notably increased, the peak flood levels in South Grafton have reduced. The reduced length of levee raising, in comparison with Option 2, means that peak river levels are lower than for Option 2. At Carrs Island there is still a residual impact in the form of increased flood levels with the largest increases predicted at 0.06m in the 20 year ARI event and increases of 0.05m in the 100 year ARI event.

Mitigation Option 4 offers significant benefits to Grafton and South Grafton, over and above the mitigation of the impacts from the additional bridge crossing.

Peak levels are reduced in Grafton in the 50 year ARI by up to 0.41m. In South Grafton the raised levee and highway prevent floodwater inundating the town in the 50 year ARI. This compares to flood depths of up to 0.56m in the baseline (existing) conditions.

Ponding to the north of the raised highway increases the 50 and 100 year ARI peak water levels in the floodplain near Waterview Heights by 0.93m and 0.76m respectively with corresponding peak flood elevations of 6.6mAHD and 7.7mAHD. Development in Waterview Heights is typically above an elevation of 10mAHD and so is not predicted to be affected by the increase in flood level. Highly localised increases in velocity are predicted as water overtops the raised road. Energy dissipation measures such as riprap should be considered as part of the road raising to manage the increases in velocity.

For both Grafton and South Grafton minor increases in flood level are predicted for a PMF event. Minor increases of less than 0.05m are predicted near Waterview Heights in the PMF event. It is not considered necessary to offset this minor impact for an event of such rarity, especially when the baseline flood depths would most likely result in properties being so badly damaged that they would need to be replaced.

Minor increases in flood hazard will result where the depth has increased, particularly for the area to the north of the raised highway. No increases in flood hazard are predicted for the urban areas of Grafton and South Grafton. In both Grafton and South Grafton, the duration of flooding is marginally reduced following the implementation of Option 4 and the frequency of flooding will similarly be marginally reduced.

No impacts have been identified on planned infrastructure listed in Table 4-2. The proposed Pacific Highway upgrade is a significant distance downstream from the crossing and no downstream impacts have been predicted for any assessed event. The two planned developments in South Grafton are located outside the extent of the 50 year ARI flood but are potentially affected in the

100 year ARI event. However, the assessment has shown that the mitigation measures included in Option 4 result in lower flood levels at the locations of these developments for this event.

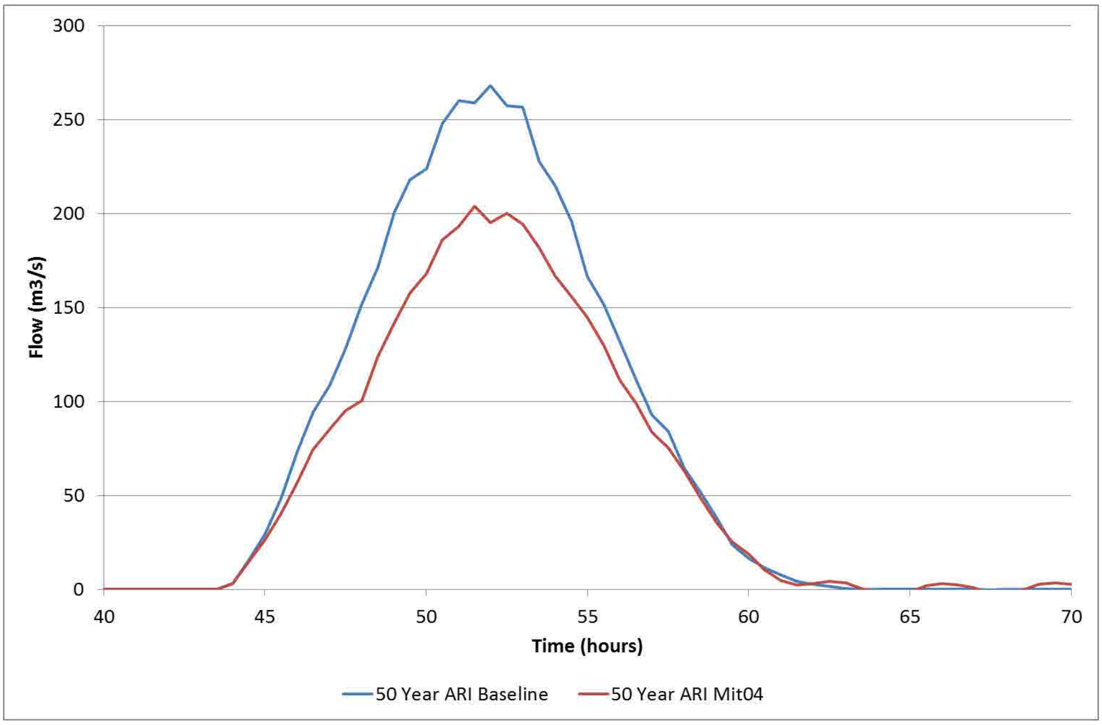


Figure 5-16 North Grafton levee overtopping flow (50 year ARI)

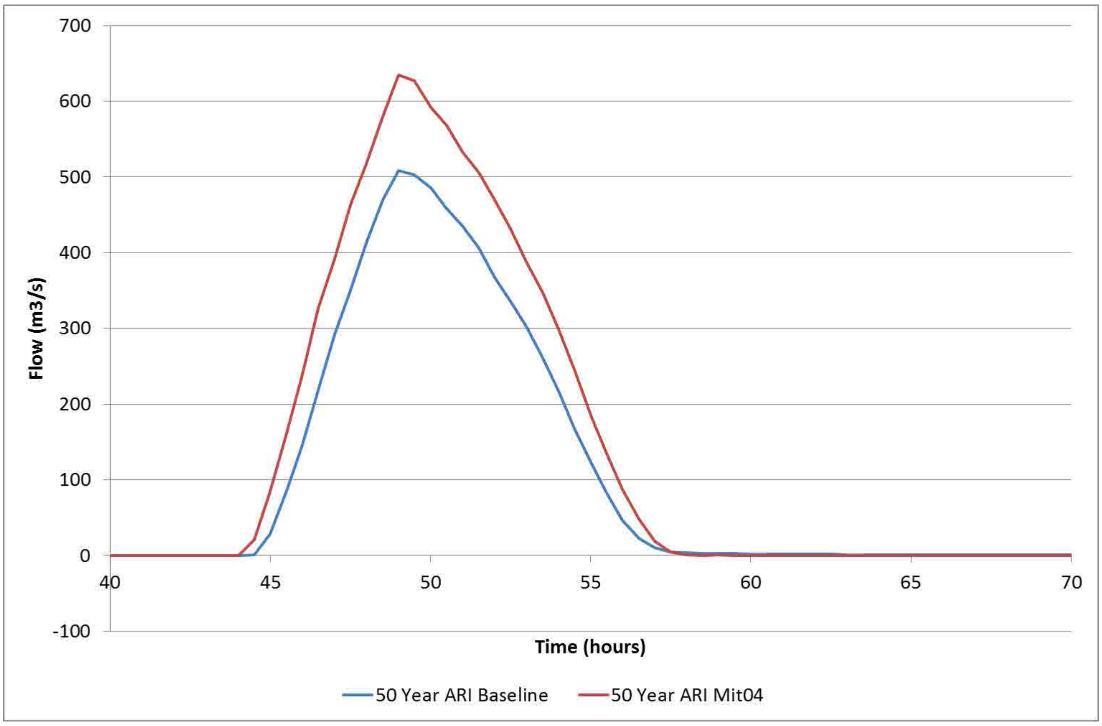


Figure 5-17 South Grafton levee overtopping flow (50 year ARI)

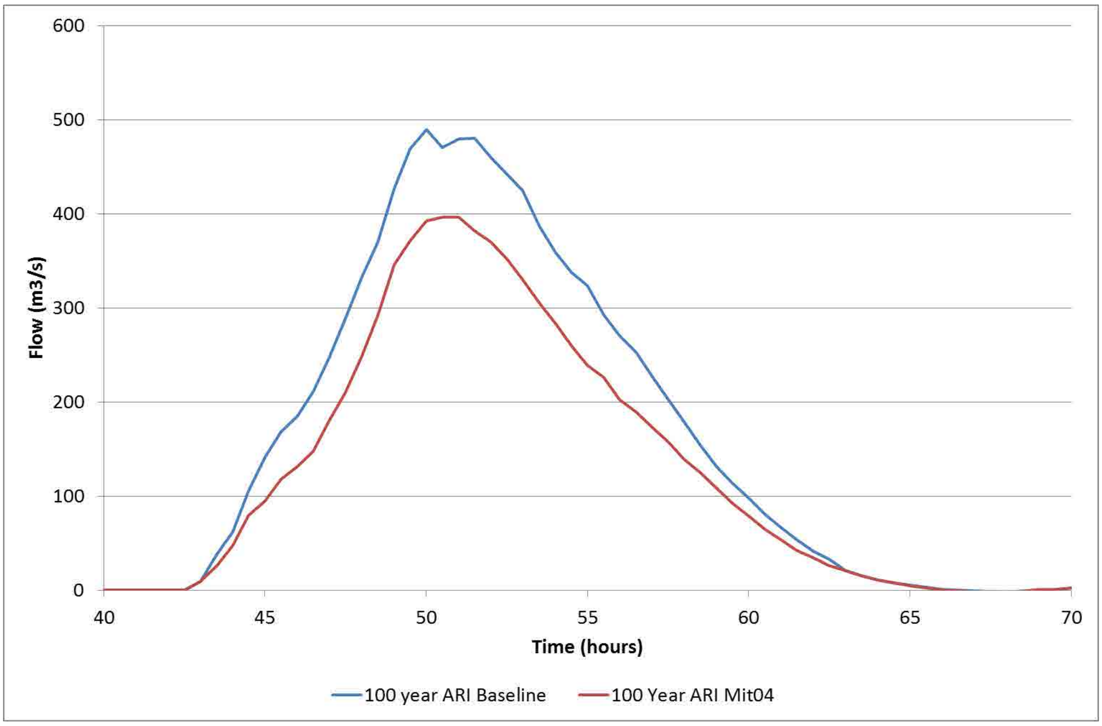


Figure 5-18 North Grafton levee overtopping flow (100 year ARI)

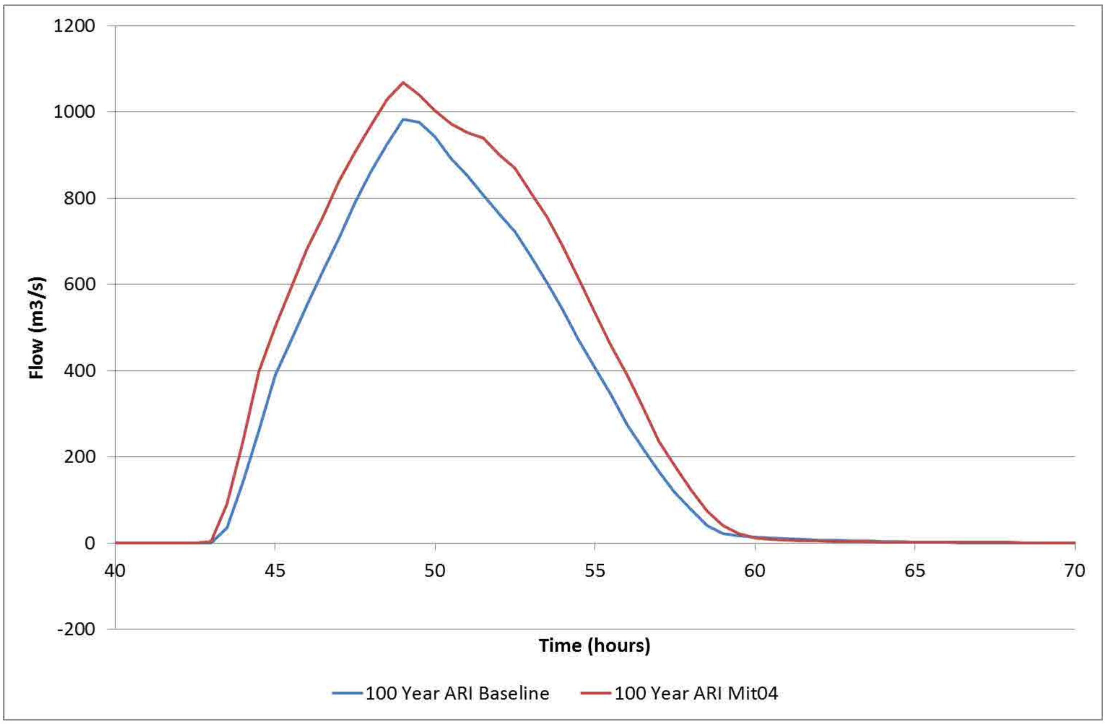


Figure 5-19 South Grafton levee overtopping flow (100 year ARI)

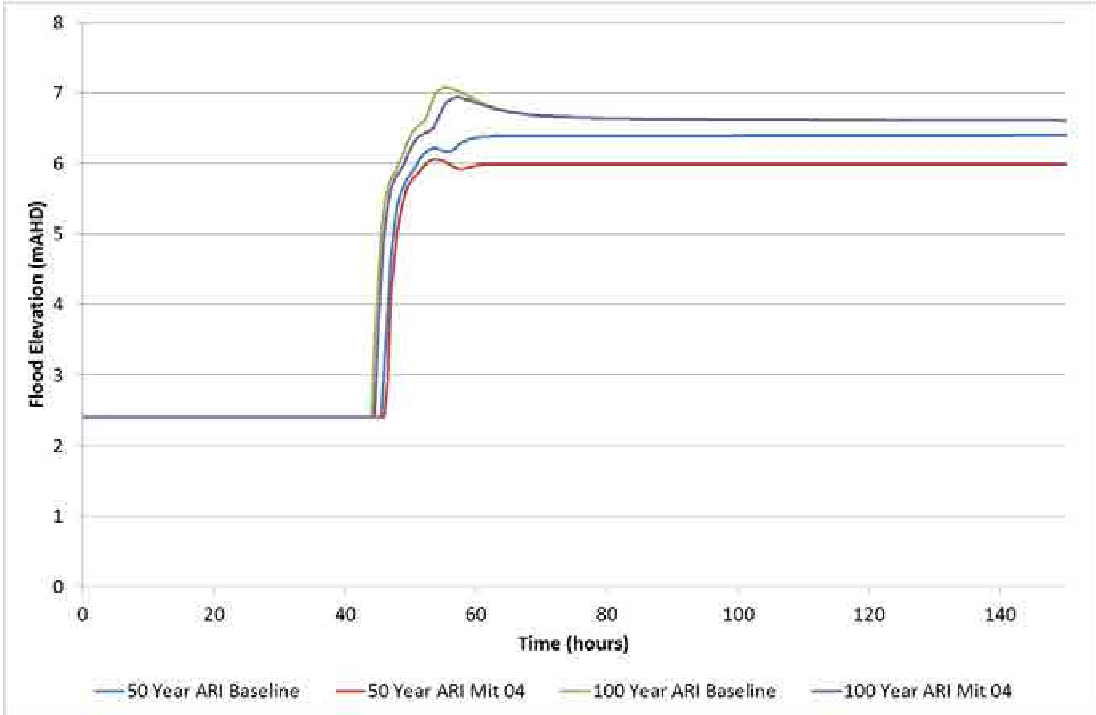


Figure 5-20 Pound Street, North Grafton, design flood elevations, Option 4

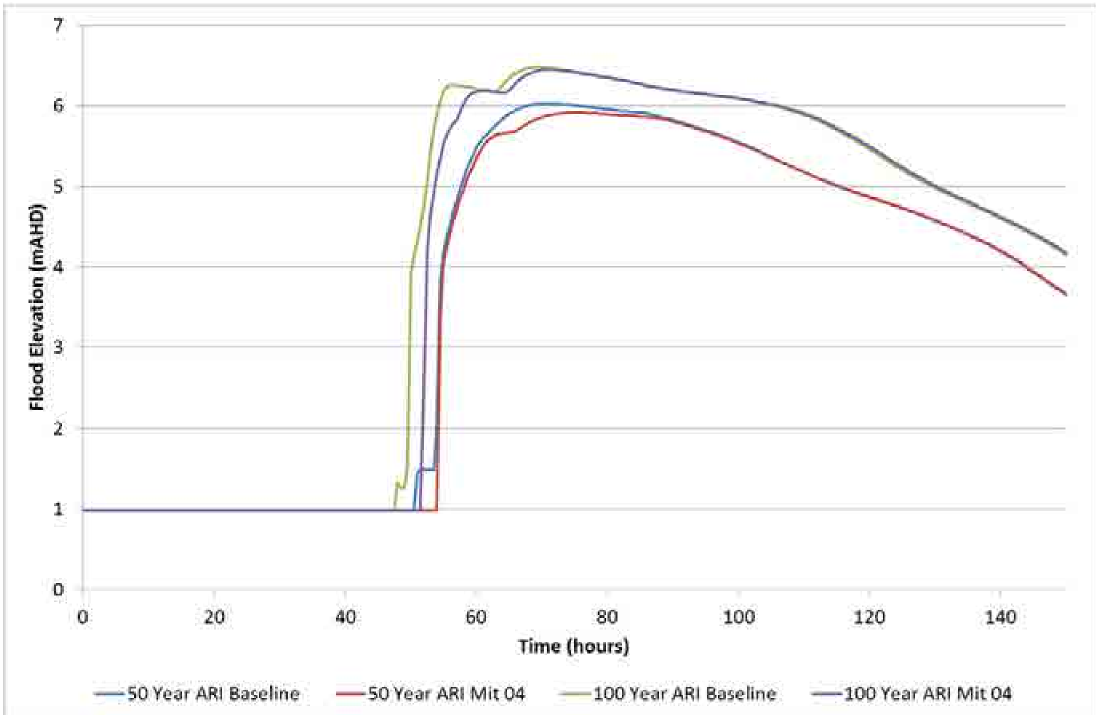


Figure 5-21 Alumy Creek (Fry St), North Grafton, design flood elevations, Option 4

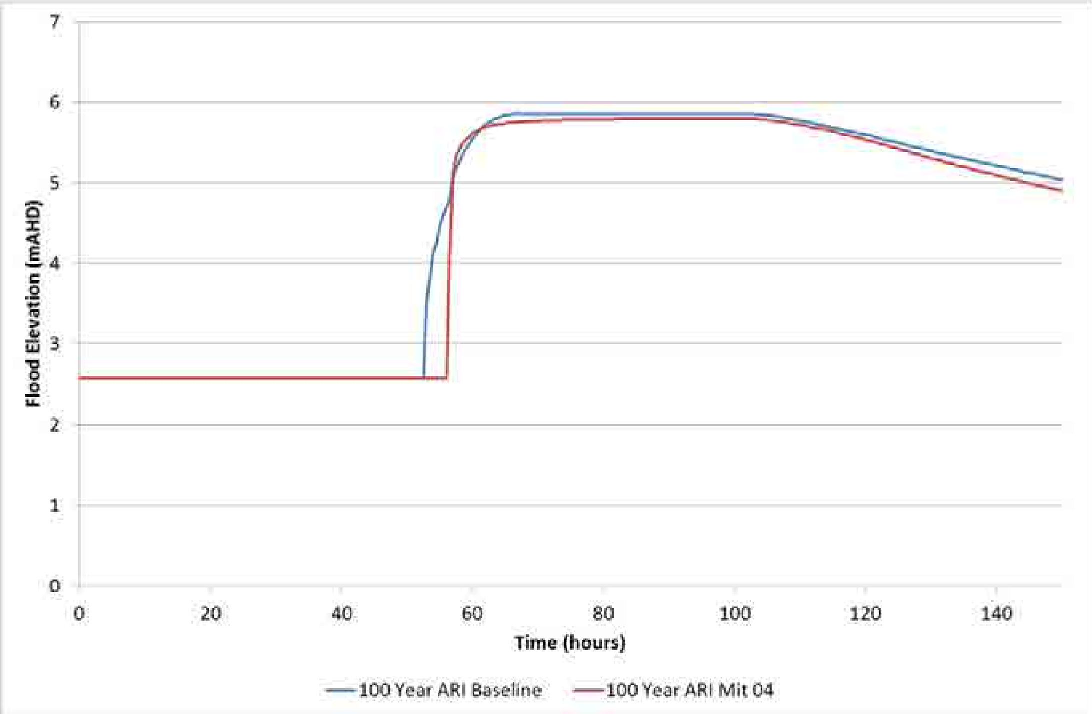


Figure 5-22 Near Wharf St, South Grafton, design flood elevations, Option 4[7]

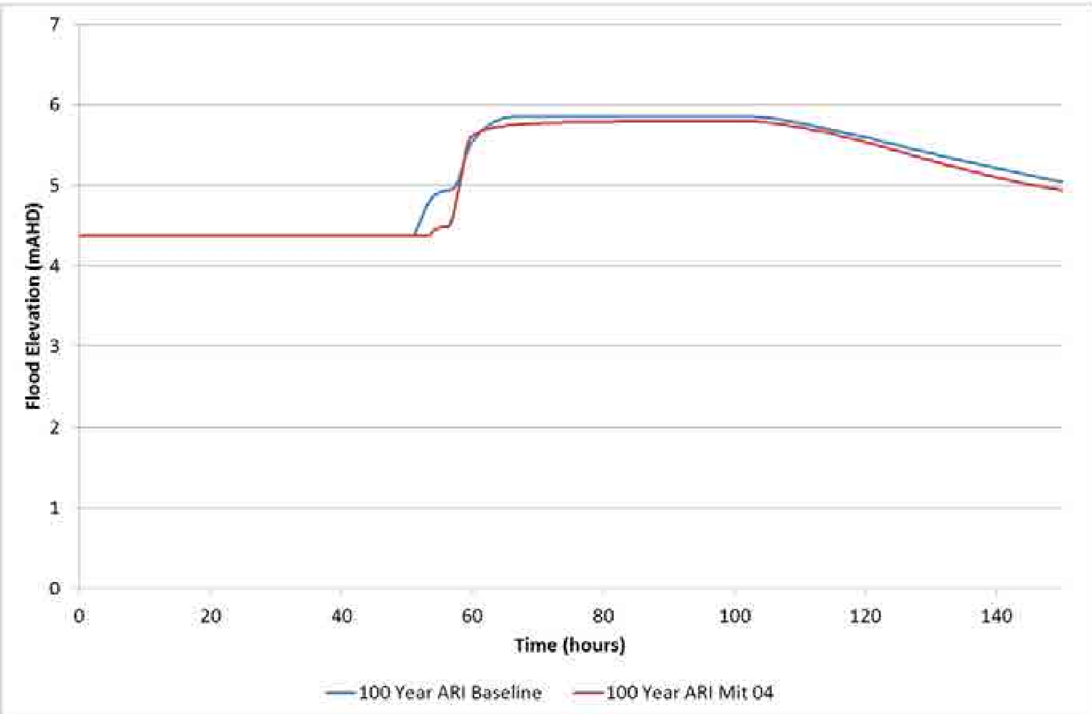
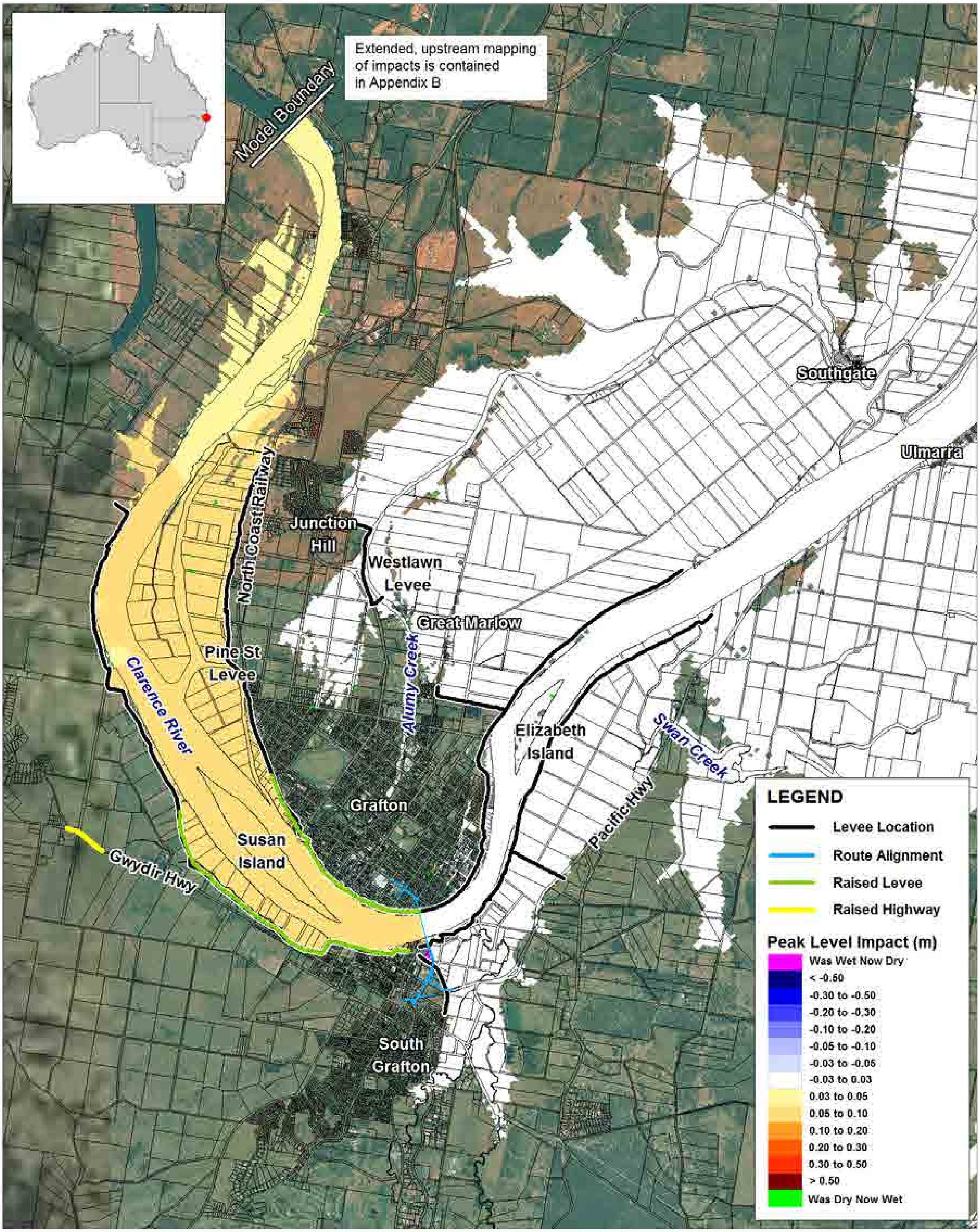


Figure 5-23 Iolanthe St, South Grafton, design flood elevations, Option 4[6]

[7] No flooding at this location in the 50 year ARI event



Title:

Peak Flood Level Impact 20 Year ARI Event Additional Crossing (Mitigation Option 4)

Figure: 5-24

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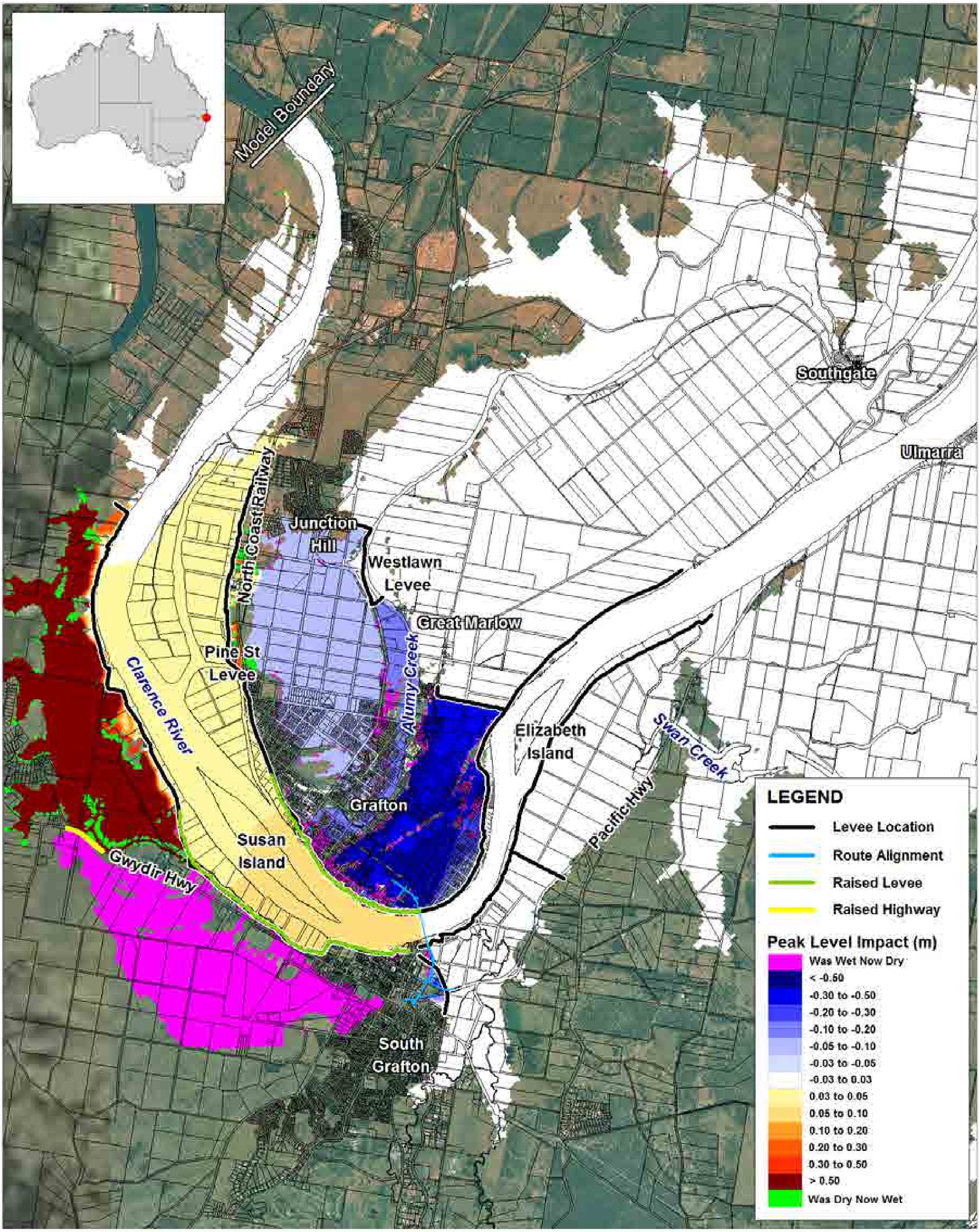

Title:

Peak Flood Level Impact 50 Year ARI Event Additional Crossing (Mitigation Option 4)

Figure: 5-25

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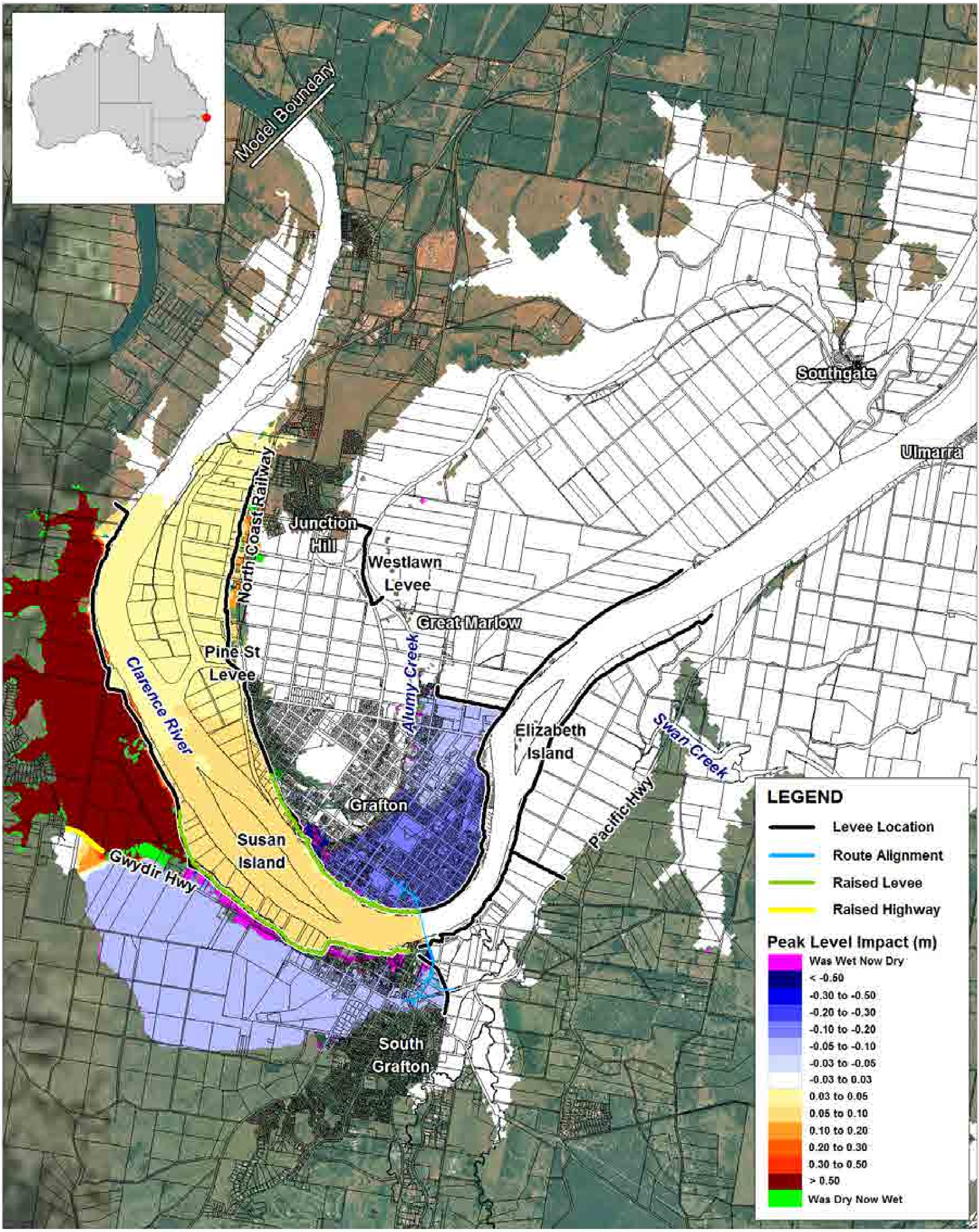

Title:

Peak Flood Level Impact 100 Year ARI Event Additional Crossing (Mitigation Option 4)

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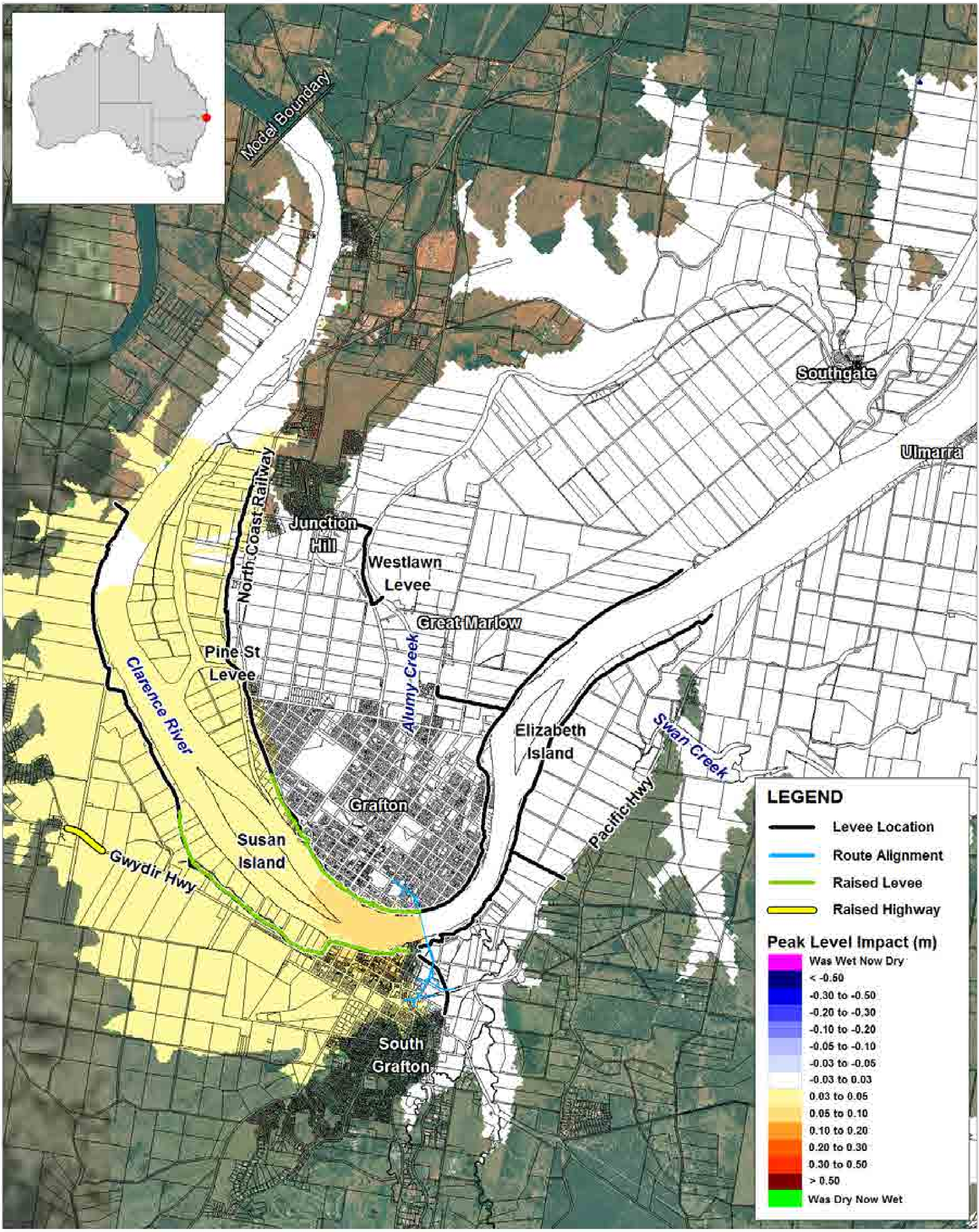

Title:

Peak Flood Level Impact PMF Event
Additional Crossing (Mitigation Option 4)

Figure: 5-27

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Approx. Scale

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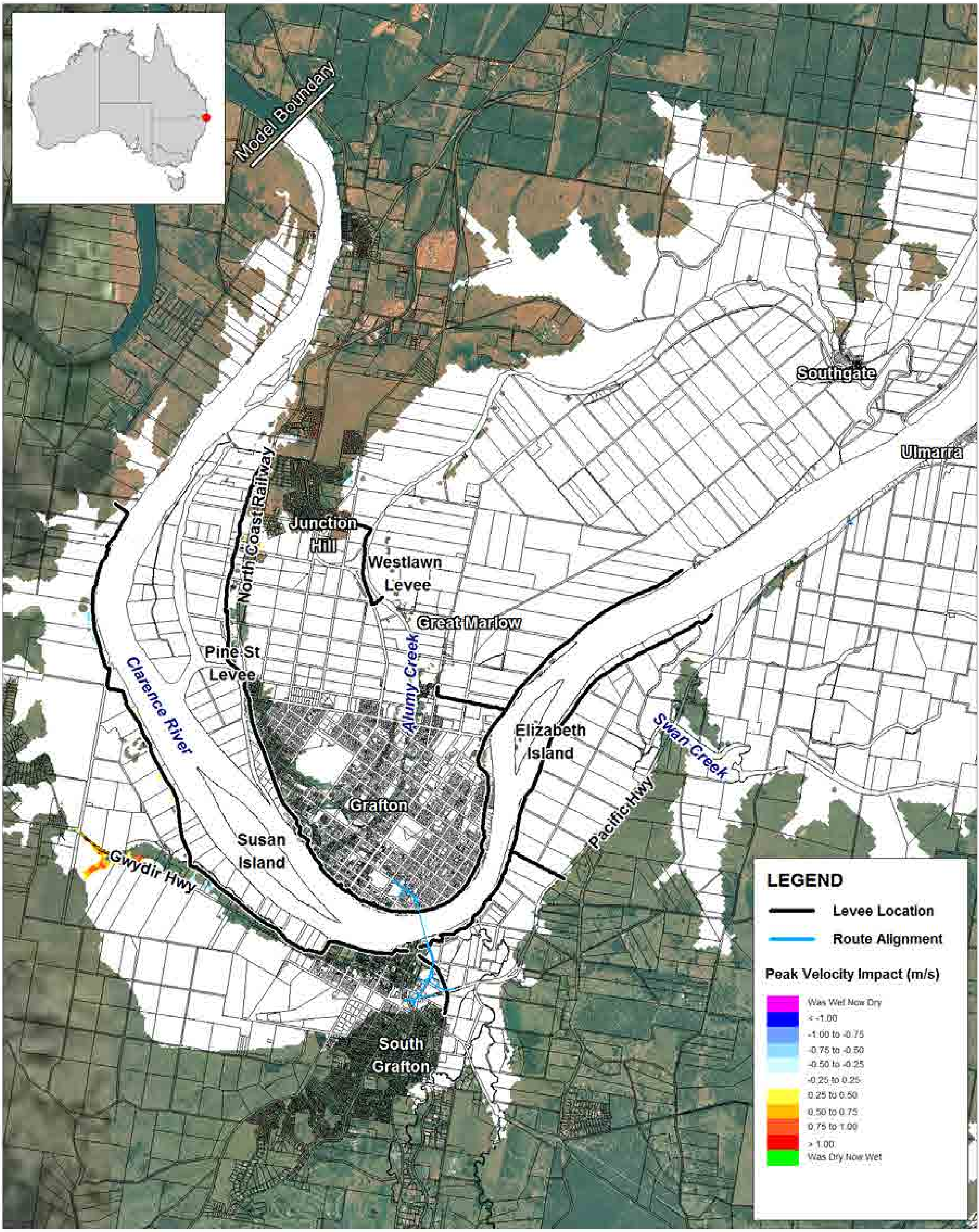

Title:

Peak Flood Velocity Impact 100 Year ARI Event Additional Crossing (Mitigation Option 4)

Figure: 5-28

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5.7 Flood impact assessment conclusions

Two mitigation options, Option 2 and Option 4, were shown to mitigate the majority of the flood impact resulting from the additional crossing to Grafton and South Grafton. In both options residual impacts remain to properties located outside the zone of protection afforded by the levees. The majority of these properties are located on Carrs Island.

Section 6 further considers the risk and additional mitigation measures for properties in locations of remaining residual risk.

6 Residual flood risk

6.1 Introduction

Residual flood risk is considered to be the remaining flood risk after a scheme or measure has been put in place. This may consist of risk to properties outside of the schemes influence, risk of an event occurring larger than that for which the scheme was designed, or flood risk as a result of scheme infrastructure failing.

Mitigation measures considered in this report are designed to offset any predicted flood impacts associated with the additional crossing, rather than any whole scale mitigation scheme to improve the flood risk to Grafton and South Grafton. An assessment of the structural failure of the levee is therefore beyond the scope of this assessment. The (residual) risk of the levee overtopping has been assessed in Section 5.

The remainder of this section assesses the increase in residual flood risk to properties located outside of the zone influence of the respective mitigation option as a result of the additional crossing.

6.2 Additional mitigation

For the majority of flood events Mitigation Options 2 and 4 both decrease the overall level of flood risk in Grafton and South Grafton. However residual impacts remain to properties located in areas outside of the levees and for events in excess of the 20 year ARI event. Estimated numbers of affected properties are summarised in Table 6-1.

Table 6-1 Number of properties potentially affected by residual impacts in events up to the 100 year ARI

Mitigation Option	Number of Properties with Remaining Impacts	Comments
2	45	Majority located on Carrs Island/Peninsula Four properties within the levee potentially affected in the 50 year ARI
4	58	Majority located on Carrs Island/Peninsula Thirteen properties potentially affected on land north of raised Gwydir Highway

Figure 6-1 shows the locations of properties potentially affected by residual impacts (i.e. those impacts which remain after the main mitigation measures are implemented).

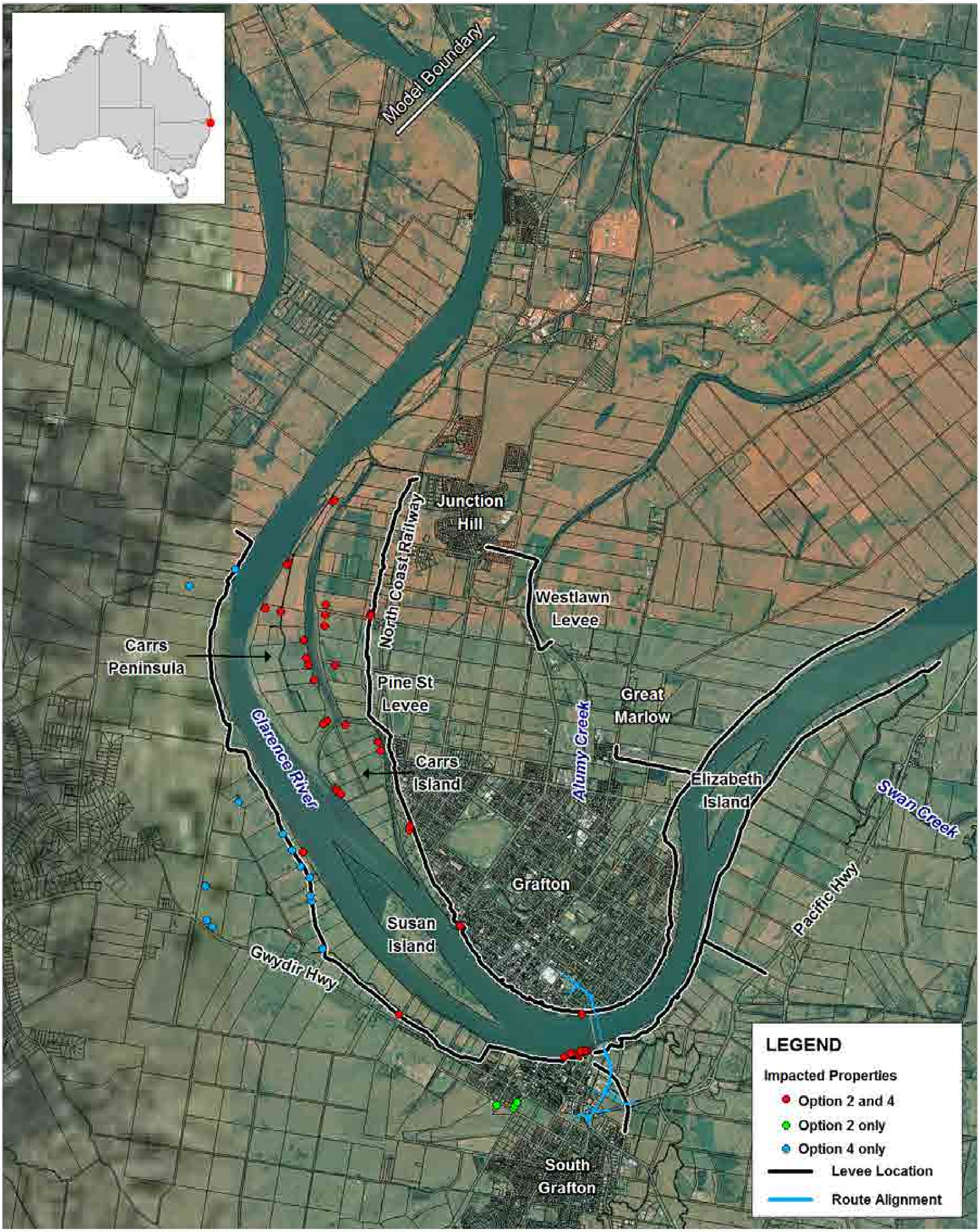
It can be seen from Figure 6-1 that the majority of properties potentially subject to residual impacts are located on Carrs Island/Peninsula. The properties identified are expected to incur increases in flood levels following the construction of the additional bridge crossing (and Mitigation Option 2 or 4). From the impact maps contained in Section 5 it can be seen that the predicted impacts (increases in flood levels) at Carrs Island / Peninsula typically range between 0.03m and 0.10m for all modelled events.

It is recommended that a floor level survey is undertaken of the identified properties shown in Figure 6-1 to establish the relative impact to each property. This will allow the property specific risk to be better understood and can form the basis of any discussion regarding further mitigation options for the property with the property owner.

6.2.1 Summary of additional mitigation

Mitigation Option 2 which involves augmenting and extending the lengths of levees within Grafton and South Grafton would also require consultation with an estimated 45 property owners to determine further mitigation options for residual impacts from the increased flood levels.

Mitigation Option 4 which involves augmenting and extending the lengths of levees within Grafton and South Grafton along with raising the Gwydir Highway would require consultation with an estimated 58 property owners to determine further mitigation options for residual impacts from the increased flood levels.



Title:

Properties potentially affected by residual impacts Mitigation Options 2 and 4

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7 Climate change considerations

7.1 Introduction

Future climate change can potentially affect flood behaviour through:

- Increased sea levels; and
- Increased severity of storms and other weather systems.

The NSW Government announced its Stage One Coastal Management Reforms on 8 September 2012. As part of these reforms the NSW Government no longer recommends state-wide sea level rise benchmarks for use by local councils. Previously the NSW sea level rise planning benchmarks were an increase above 1990 mean sea levels of 40cm by 2050 and 90cm by 2100. The reforms allow councils to have the flexibility to consider local conditions when determining local future hazards. Due to the levees, Grafton and South Grafton are particularly sensitive to any factors which may result in changes to the baseline water levels within the Clarence River. Future sea level rise is one such factor which has the potential to increase the rate and frequency of inundation within the towns. Sea level rise has therefore been modelled as a sensitivity check on predicted flood levels. Both the 2050 and 2100 scenarios have been assessed (ocean boundary increases of 0.4m and 0.9m respectively).

Climate change also has the potential to impact on rainfall. Evidence to date suggests that whilst mean annual rainfall over Australia is likely to reduce, the intensity of extreme daily rainfall could increase. The CSIRO predicts the effects of climate change to result in increases in rainfall of up to 12% by 2070 (CSIRO, February 2007).

As part of this study, a sensitivity assessment was also undertaken on the potential impact of 10% and 20% increases in rainfall intensity combined with the sea level rise, as suggested in a letter from the Office of Environment and Heritage responding to the DGRs. In summary two future climate scenarios have been modelled:

- 2050 Climate: 0.4m rise in sea level and 10% increase in rainfall intensity; and
- 2100 Climate: 0.9m rise in sea level and 20% increase in rainfall intensity.

The 20 and 100 year average recurrence interval (ARI) events were used as the basis of the sensitivity assessment with levels compared for a future baseline and developed case (with mitigation) scenarios.

7.2 Results

7.2.1 Change to baseline conditions

Under a 2050 climate scenario, baseline peak water levels in the Clarence River at Grafton for a 20 year ARI event increase by between 0.2m and 0.3m compared with an existing climate scenario. During a 100 year ARI event the change is less pronounced, but the 100 year ARI peak levels still increase by between 0.1m and 0.15m. The increases result in a significant additional overtopping of the levees into Grafton and South Grafton leading to increased flooding within the towns. In Grafton, this is most notable for the 20 year ARI event, in which floodwaters under an existing climate are largely excluded from urban areas by the levees but which are overtopped under a future climate.

Peak river levels at Grafton increase further still under a 2100 future climate with increases typically between 0.4m and 0.5m for both the 20 and 100 year ARI events.

Figure 7-1 and Figure 7-2 map the differences in peak flood levels between an existing climate scenario and the 2050 and 2100 climate scenarios respectively for a 20 year ARI event. Figure 7-3 and Figure 7-4 present the differences in peak flood levels for the 100 year ARI event. The differences are obtained by deriving the increase in peak level from an existing, present climate. Summary tables of the impacts are presented in Table 7-2 and Table 7-2 for the 20 and 100 year ARI events respectively. It should be noted that these impacts are all derived from a baseline (pre-development) stage.

Table 7-1 Change in 20 Year peak flood levels due to climate change (existing case)

ARI / Climate Scenario	Change in peak flood level (m) Future climate (Baseline Case) minus existing climate (Baseline Case)			
	Prince St Gauge	Existing Grafton Bridge	Grafton[1]	South Grafton[2]
20 Year ARI 2050 Climate	0.27	0.25	0.45	0.00
20 Year ARI 2100 Climate	0.42	0.38	1.68	2.95

1 Intersection of Pound Street and Prince Street. No flooding in baseline therefore increase in level is from ground level (5.40mAHD)

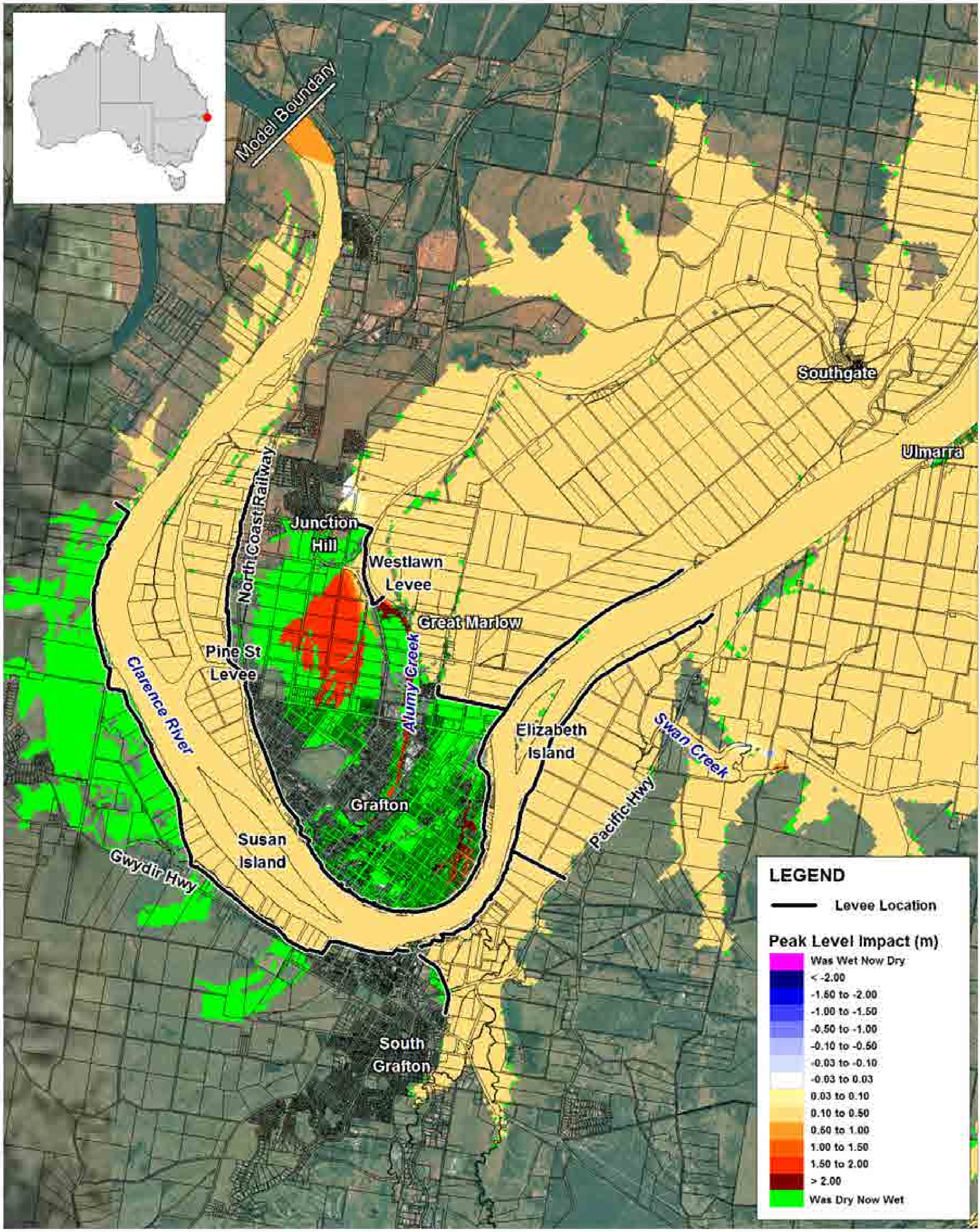
2 Intersection of Abbott Street and Vere Street. No flooding in baseline therefore increase in level is from ground level (3.27mAHD)

Table 7-2 Change in 100 year peak flood levels due to climate change (existing case)

ARI / Climate Scenario	Change in peak flood level (m) Future climate (Baseline Case) minus existing climate (Baseline Case)			
	Prince St Gauge	Existing Grafton Bridge	Grafton[1]	South Grafton[2]
100 Year ARI 2050 Climate	0.10	0.13	0.36	2.79
100 Year ARI 2100 Climate	0.47	0.49	0.98	3.30

1 Intersection of Pound Street and Prince Street

2 Intersection of Abbott Street and Vere Street



Title:

Change in Peak Baseline Levels
20 Year ARI Event (Future Climate 2050)

Figure: **7-1**

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Approx. Scale

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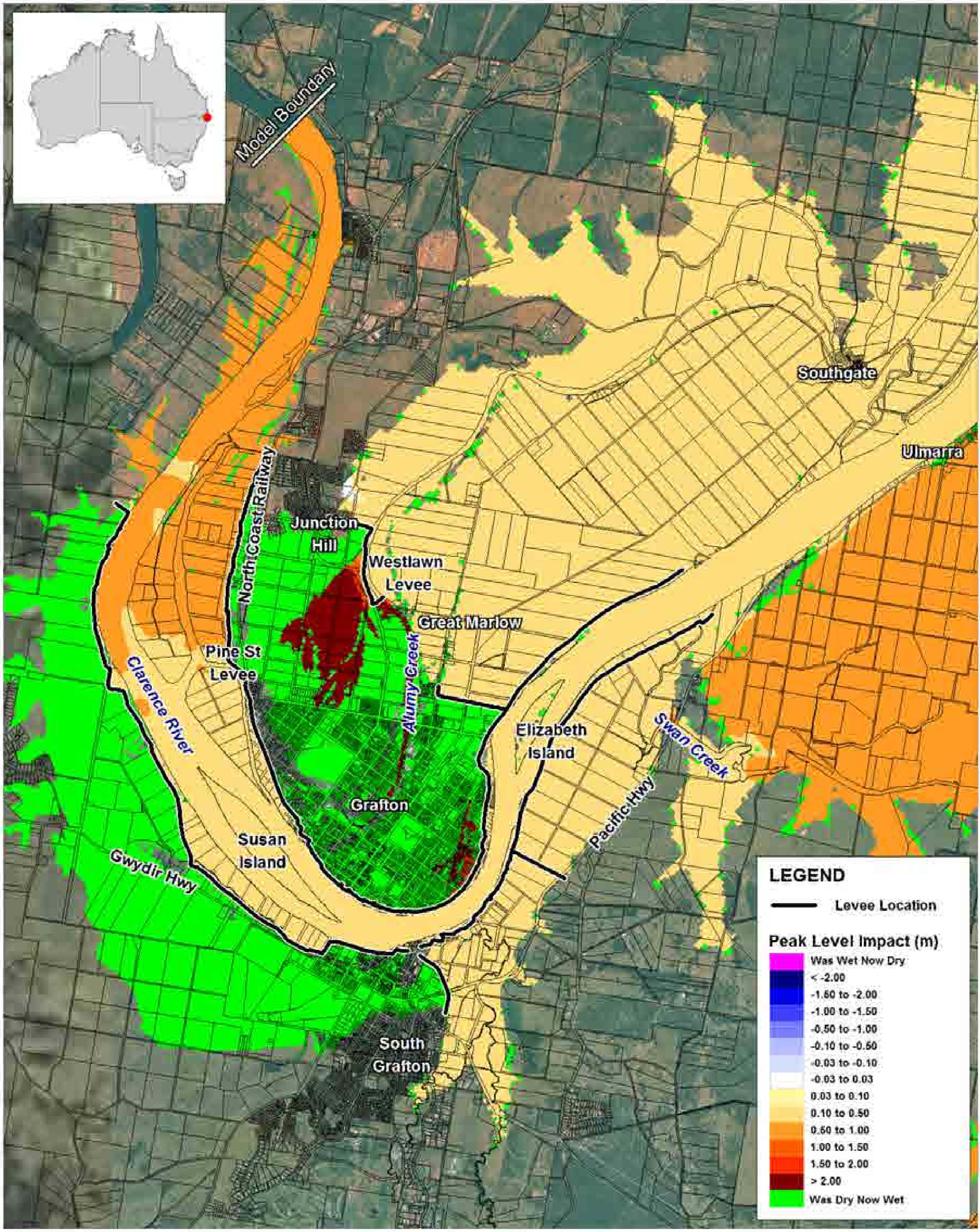

Title:
Change in Peak Baseline Levels
20 Year ARI Event (Future Climate 2100)

Figure: 7-2

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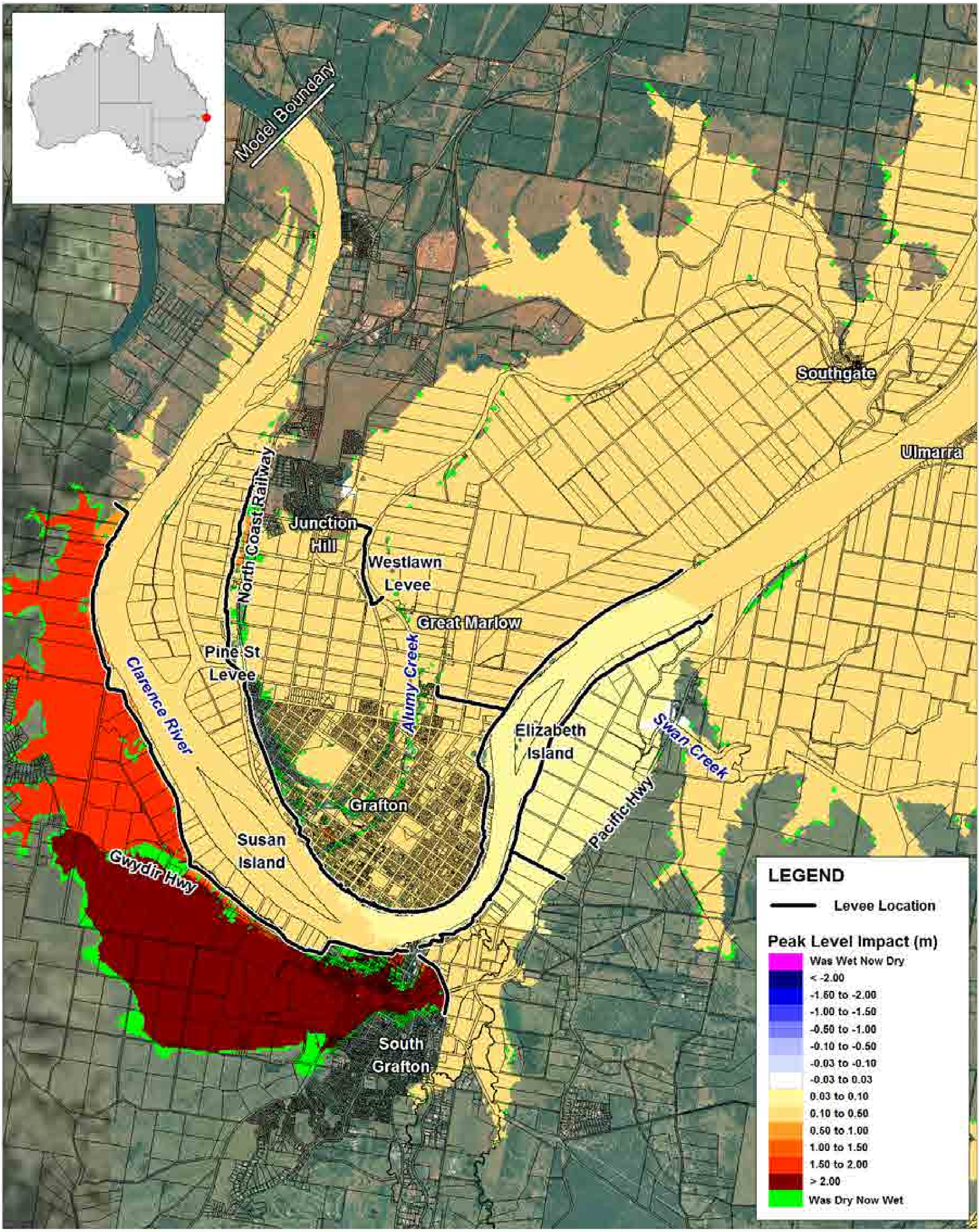

Title:

Change in Peak Baseline Levels
100 Year ARI Event (Future Climate 2050)

Figure: 7-3

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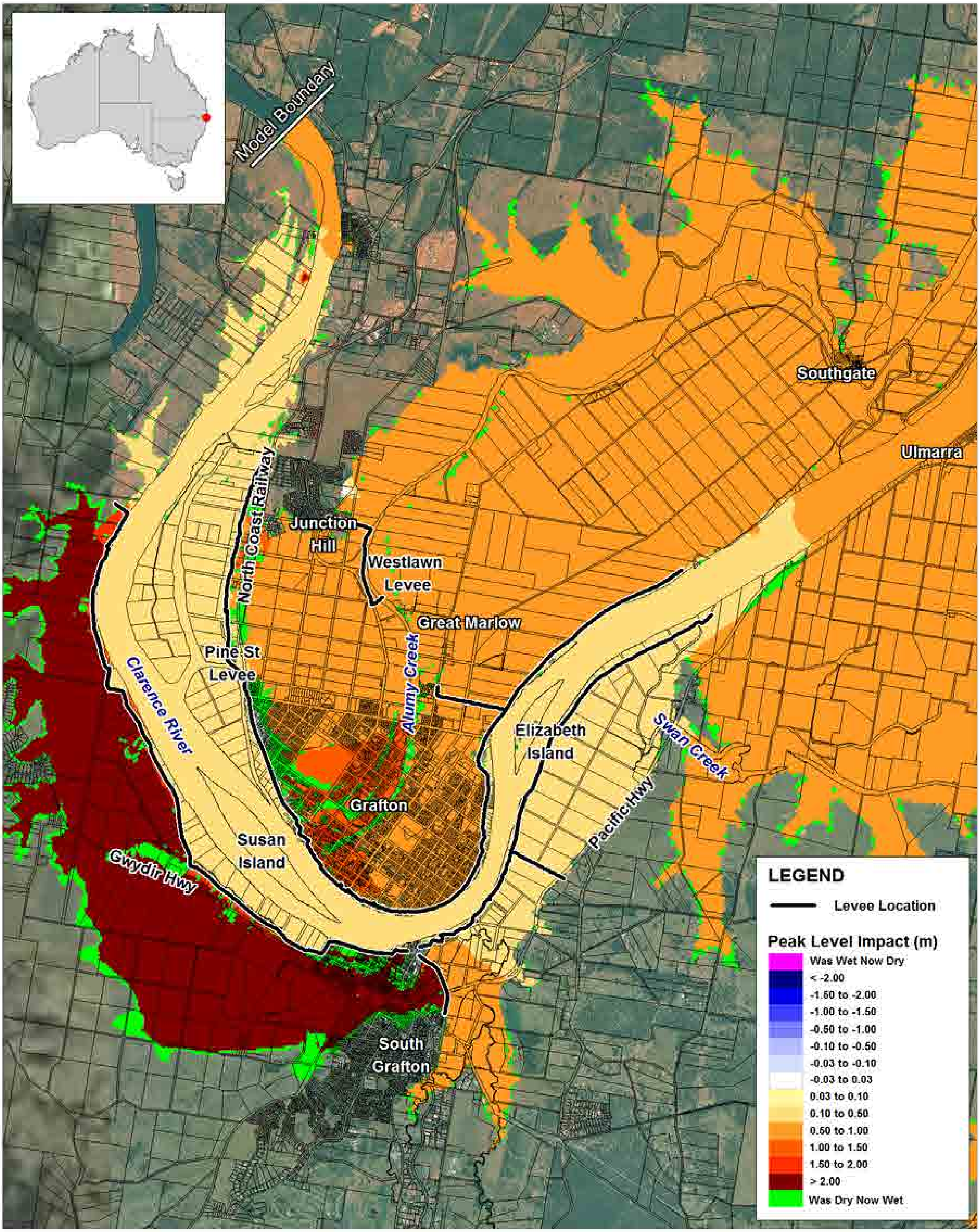

Title:

Change in Peak Baseline Levels
100 Year ARI Event (Future Climate 2100)

Figure: 7-4

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7.2.2 Impacts of the proposed project under a future climate

The potential changes in flood impacts due to climate change were measured by comparing the change in peak flood levels for the proposed project (with mitigation) under the existing climate with the forecast change in peak flood levels for the proposed project (with mitigation) under the 2050 and 2100 climate scenario. Changes in peak flood levels for each climate scenario are summarised in Table 7-3 to Table 7-10 at the specific reporting locations shown in Figure 2-1. Changes in peak flood levels were determined for both the 20 year and 100 year ARI flood events.

Figure 7-5 to Figure 7-12 present the resulting impact maps for mitigation options 2 and 4 under a 2050 and 2100 climate.

Table 7-3 Change in 20 year peak flood levels due to development (Mitigation Option 2) under a future 2050 climate

Climate scenario	Change in peak flood level (m) Developed Case (future climate) minus Baseline Case (future climate)			
	Prince St Gauge	Existing Grafton Bridge	Grafton	South Grafton
Development Impacts for existing climate	0.06	0.07	0.00	0.00
Development Impacts for 2050 climate	0.07	0.08	-0.09	0.00

Table 7-4 Change in 20 Year peak flood levels due to development (Mitigation Option 2) under a future 2100 climate

Climate scenario	Change in peak flood level (m) Developed Case (future climate) minus Baseline Case (future climate)			
	Prince St Gauge	Existing Grafton Bridge	Grafton	South Grafton
Development Impacts for existing climate	0.06	0.07	0.00	0.00
Development Impacts for 2100 climate	0.09	0.09	-0.07	-0.14

Table 7-5 Change in 100 year peak flood levels due to development (Mitigation Option 2) under a future 2050 climate

Climate scenario	Change in peak flood level (m) Developed Case (future climate) minus Baseline Case (future climate)			
	Prince St Gauge	Existing Grafton Bridge	Grafton	South Grafton
Development Impacts for existing climate	0.09	0.09	-0.07	-0.11
Development Impacts for 2050 climate	0.10	0.09	-0.04	-0.15

Table 7-6 Change in 100 year peak flood levels due to development (Mitigation Option 2) under a future 2100 climate

Climate scenario	Change in peak flood level (m) Developed Case (future climate) minus Baseline Case (future climate)			
	Prince St Gauge	Existing Grafton Bridge	Grafton	South Grafton
Development Impacts for existing climate	0.09	0.09	-0.07	-0.11
Development Impacts for 2100 climate	0.05	0.06	-0.07	0.06

Table 7-7 Change in 20 year peak flood levels due to development (Mitigation Option 4) under a future 2050 climate

Climate scenario	Change in peak flood level (m) Developed Case (future climate) minus Baseline Case (future climate)			
	Prince St Gauge	Existing Grafton Bridge	Grafton	South Grafton
Impacts for existing climate	0.06	0.07	0.00	0.00
Impacts for 2050 climate	0.06	0.06	-0.14	0.00

Table 7-8 Change in 20 year peak flood levels due to development (Mitigation Option 4) under a future 2100 climate

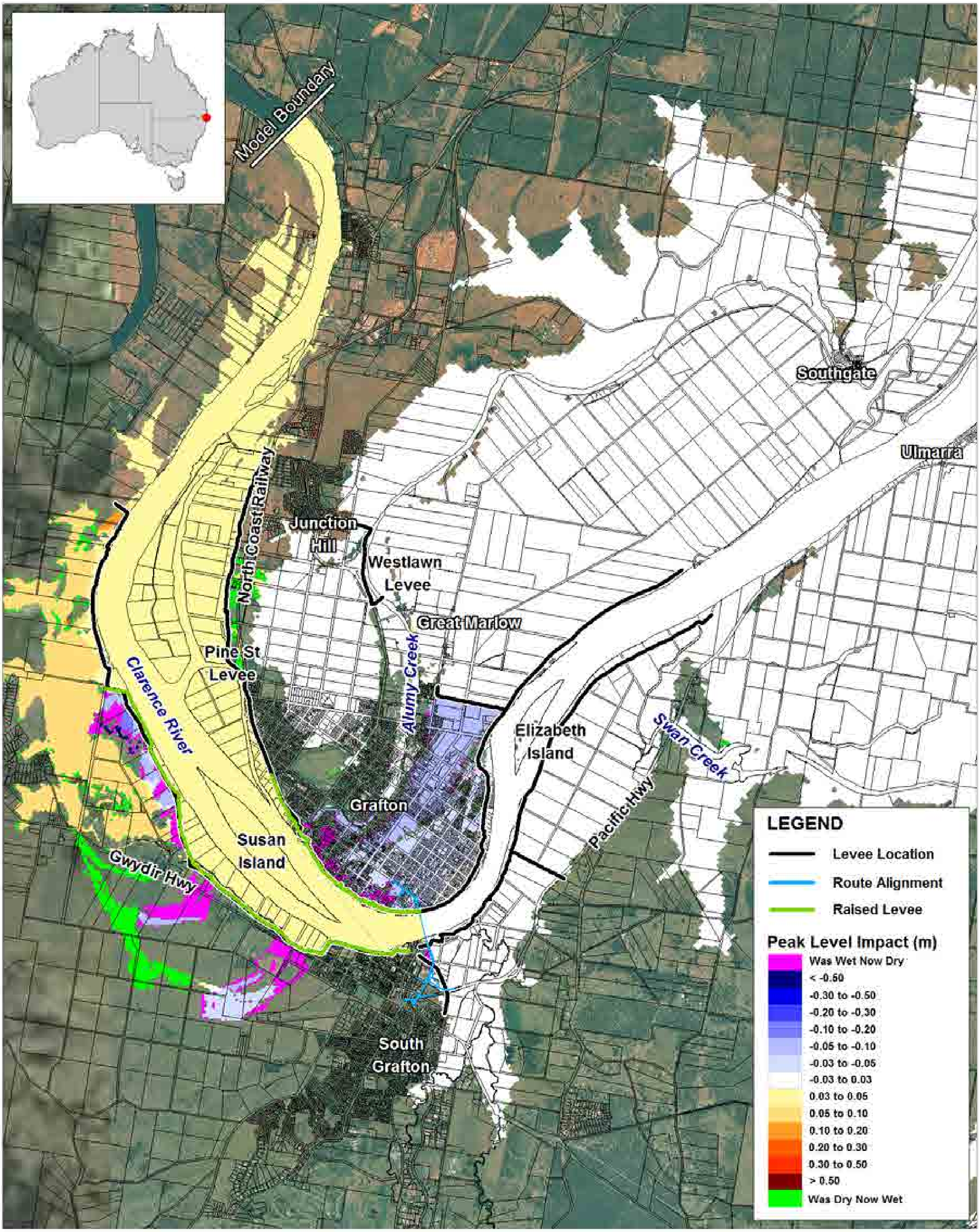
Climate scenario	Change in peak flood level (m) Developed Case (future climate) minus Baseline Case (future climate)			
	Prince St Gauge	Existing Grafton Bridge	Grafton	South Grafton
Impacts for existing climate	0.06	0.07	0.00	0.00
Impacts for 2100 climate	0.07	0.08	-0.14	0.14

Table 7-9 Change in 100 year peak flood levels due to development (Mitigation Option 4) under a future 2050 climate

Climate scenario	Change in peak flood level (m) Developed Case (future climate) minus Baseline Case (future climate)			
	Prince St Gauge	Existing Grafton Bridge	Grafton	South Grafton
Impacts for existing climate	0.07	0.07	-0.13	-0.07
Impacts for 2050 climate	0.08	0.09	-0.09	0.16

Table 7-10 Change in 100 Year peak flood levels due to development (Mitigation Option 4) under a future 2100 climate

Climate scenario	Change in peak flood level (m) Developed Case (future climate) minus Baseline Case (future climate)			
	Prince St Gauge	Existing Grafton Bridge	Grafton	South Grafton
Impacts for existing climate	0.07	0.07	-0.13	-0.07
Impacts for 2100 climate	0.07	0.08	-0.04	0.08



Title:

Peak Flood Level Impact 20 Year ARI Event Mitigation Option 2; Future Climate 2050

Figure: 7-5

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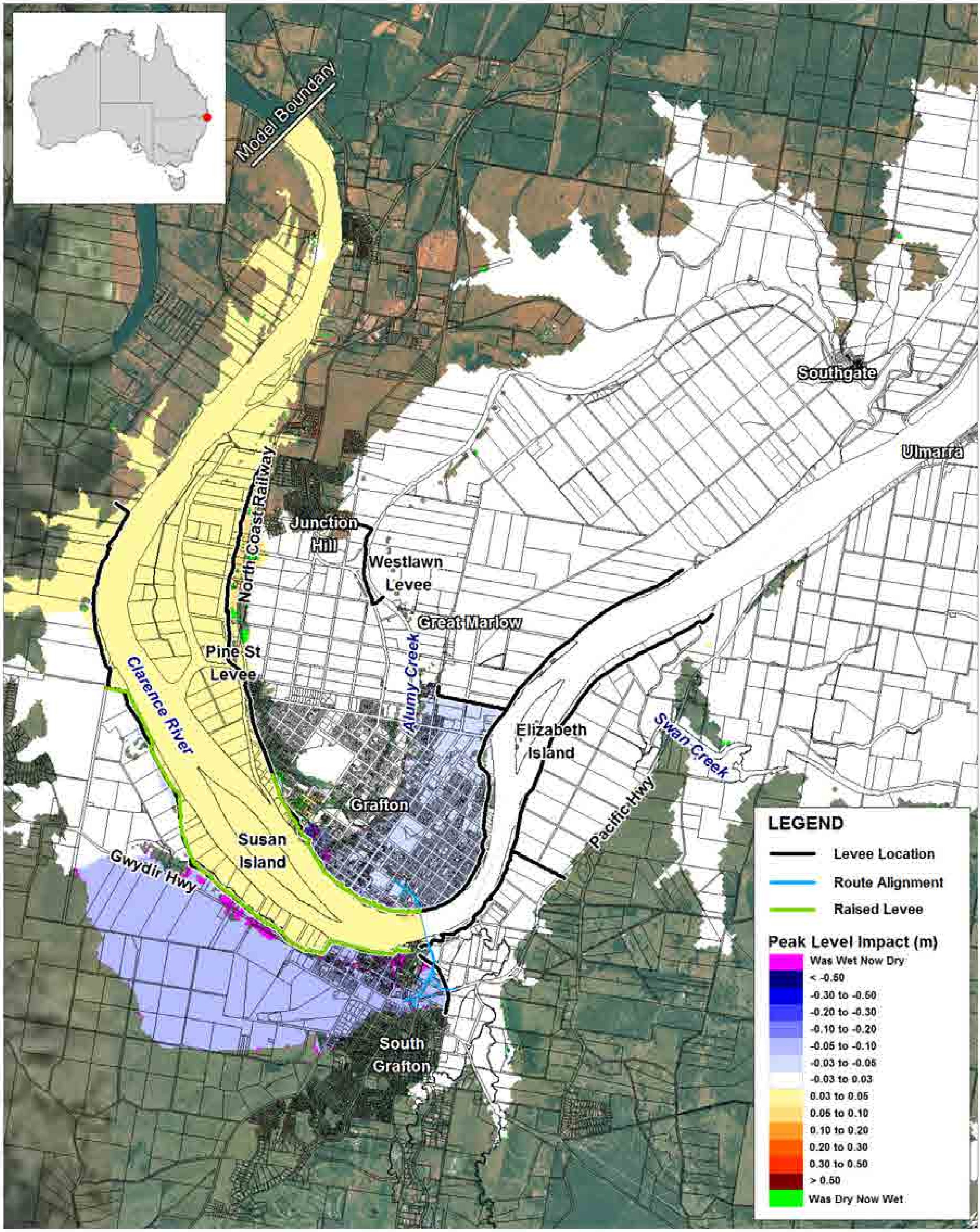

Title:
Peak Flood Level Impact 20 Year ARI Event Mitigation Option 2; Future Climate 2100

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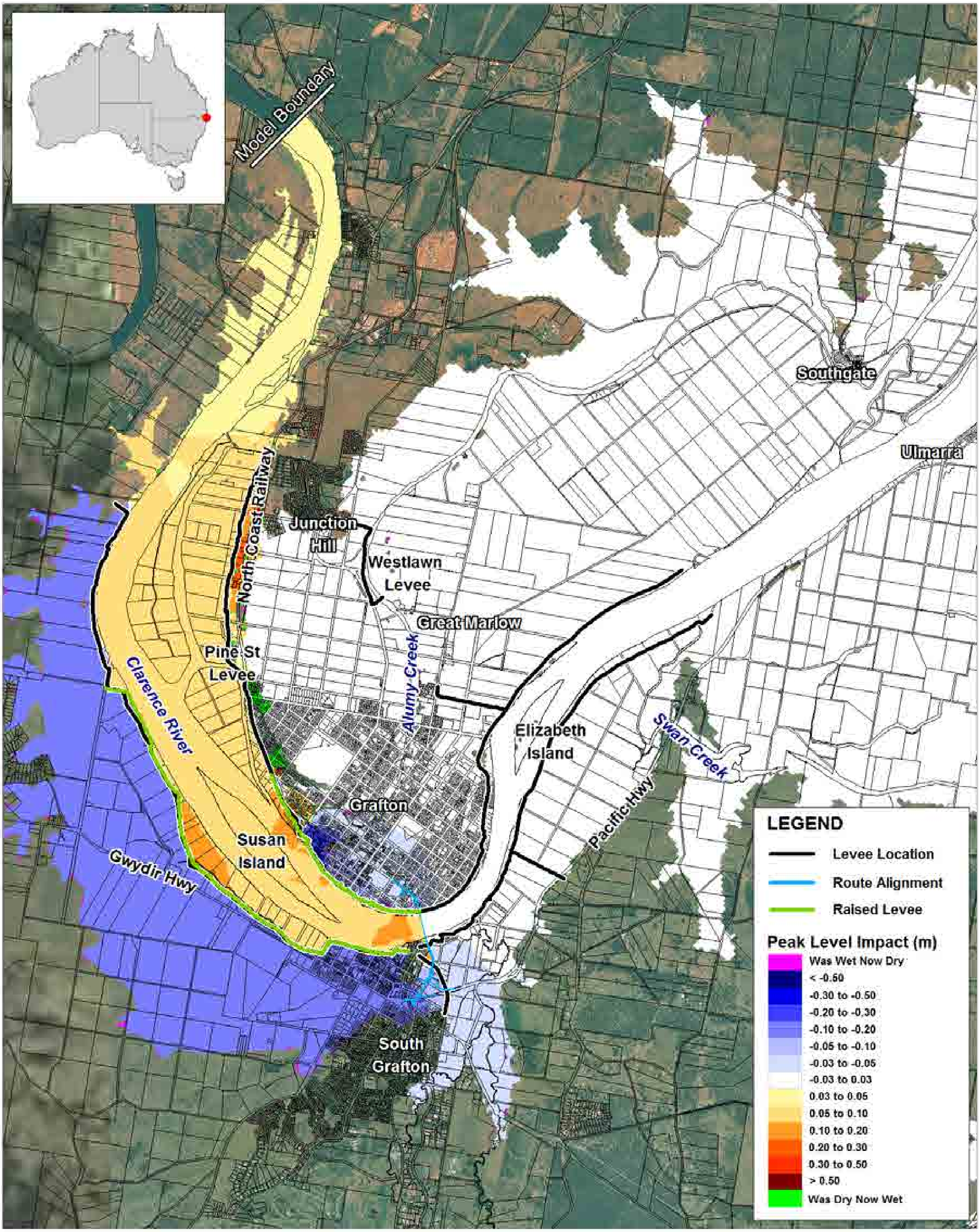

Title:

Peak Flood Level Impact 100 Year ARI Event Mitigation Option 2; Future Climate 2050

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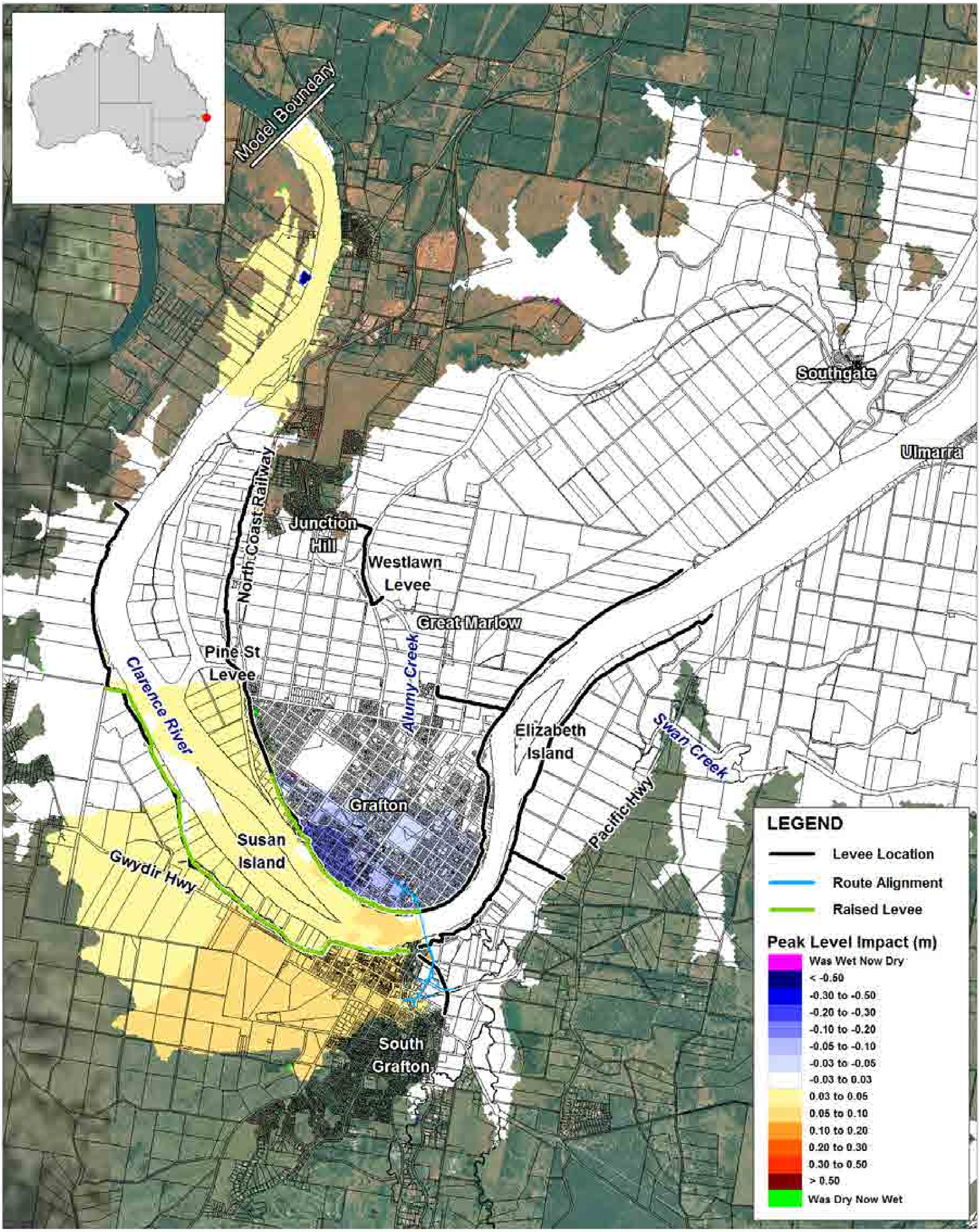

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Peak Flood Level Impact 100 Year ARI Event Mitigation Option 2; Future Climate 2100

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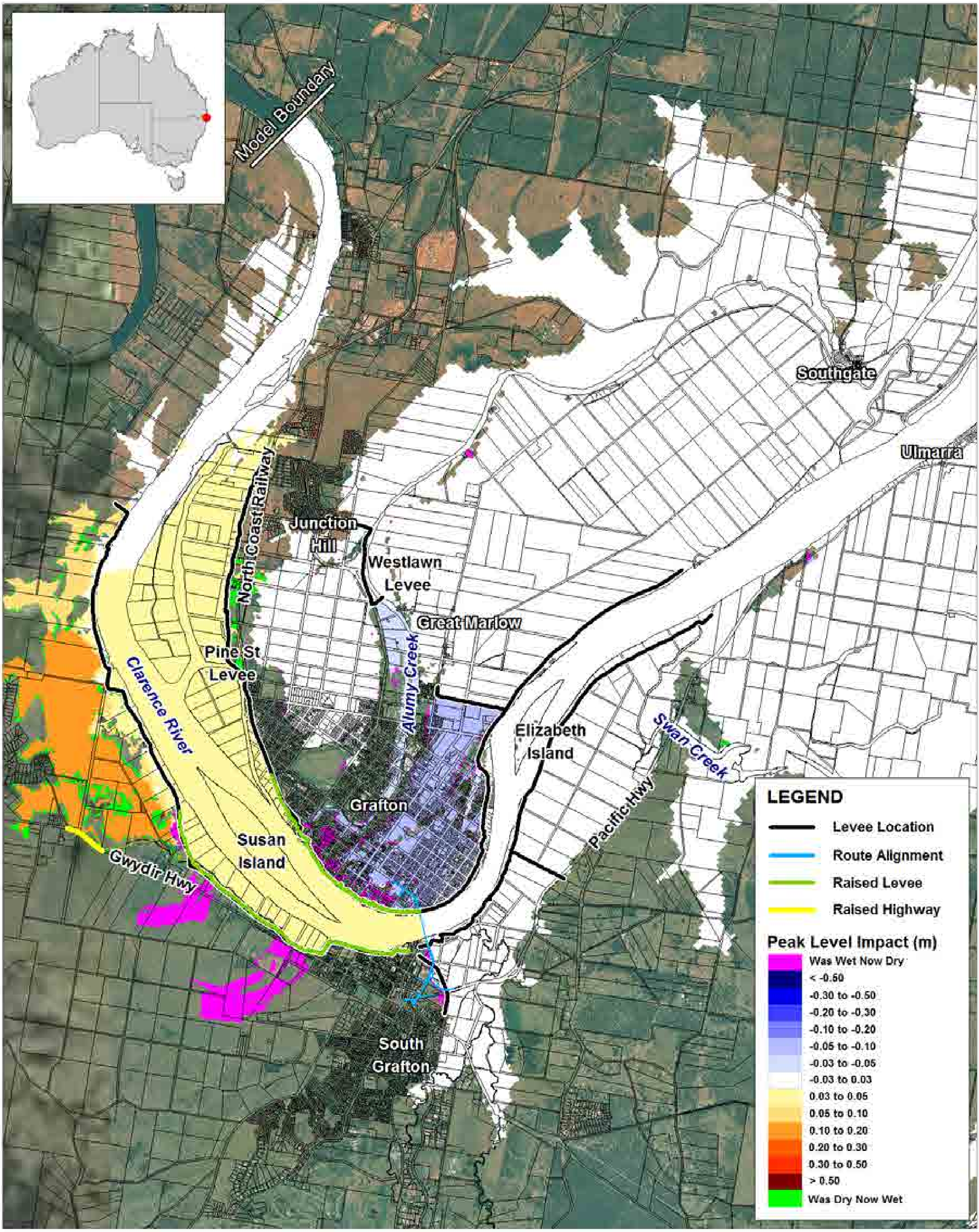

Title:

Peak Flood Level Impact 20 Year ARI Event Mitigation Option 4; Future Climate 2050

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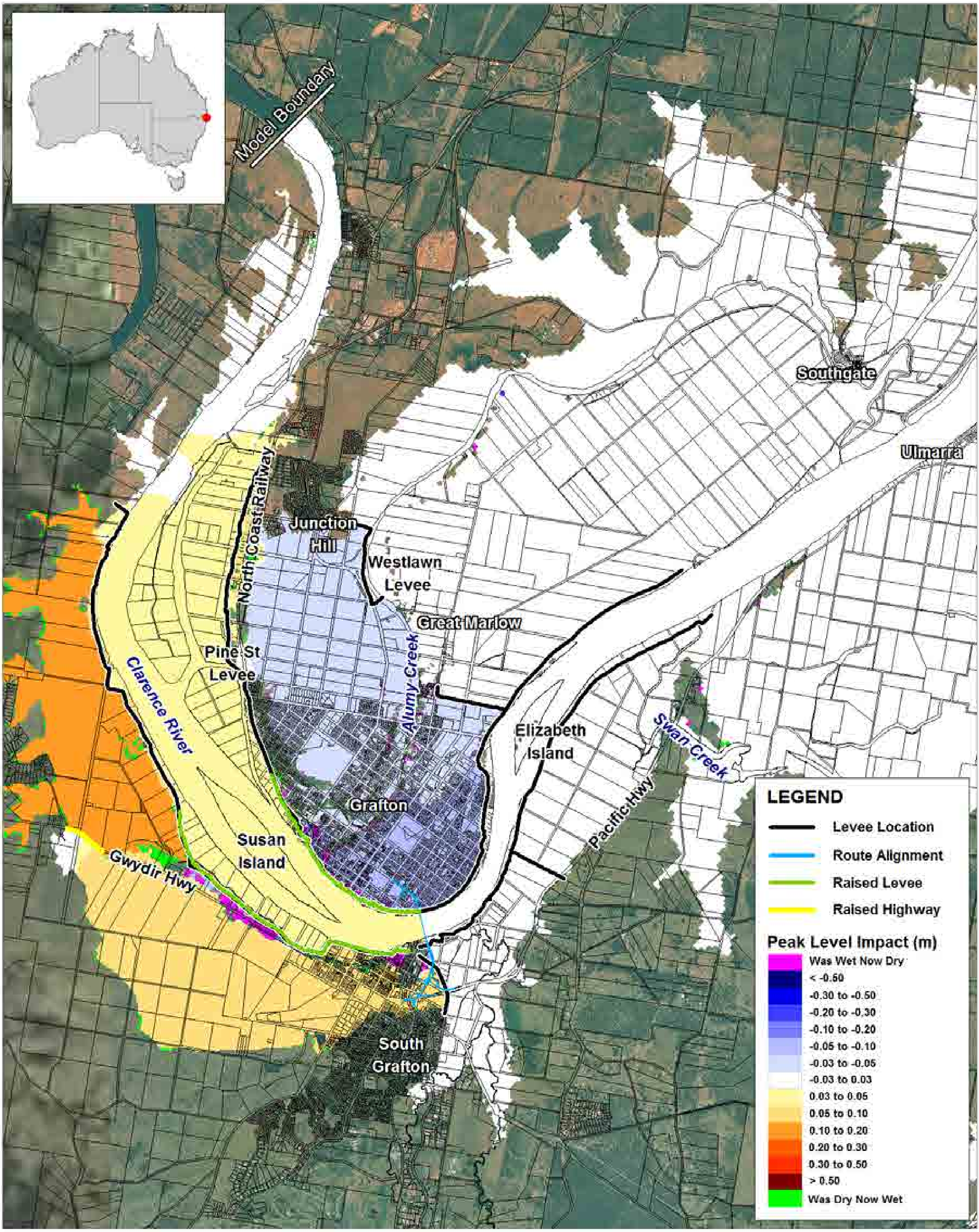

Title:

Peak Flood Level Impact 20 Year ARI Event Mitigation Option 4; Future Climate 2100

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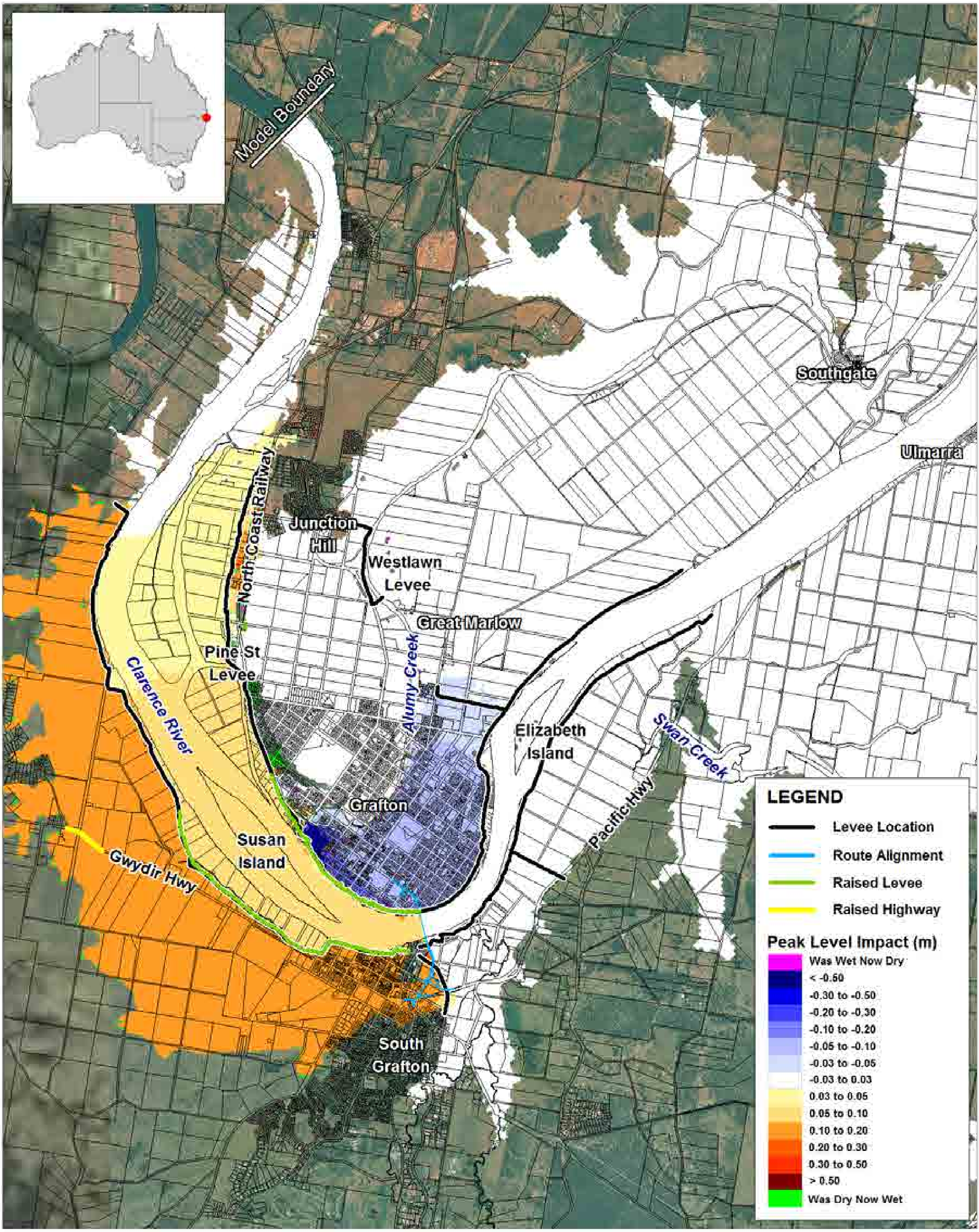

Title:

Peak Flood Level Impact 100 Year ARI Event Mitigation Option 4; Future Climate 2050

Figure: **7-11**

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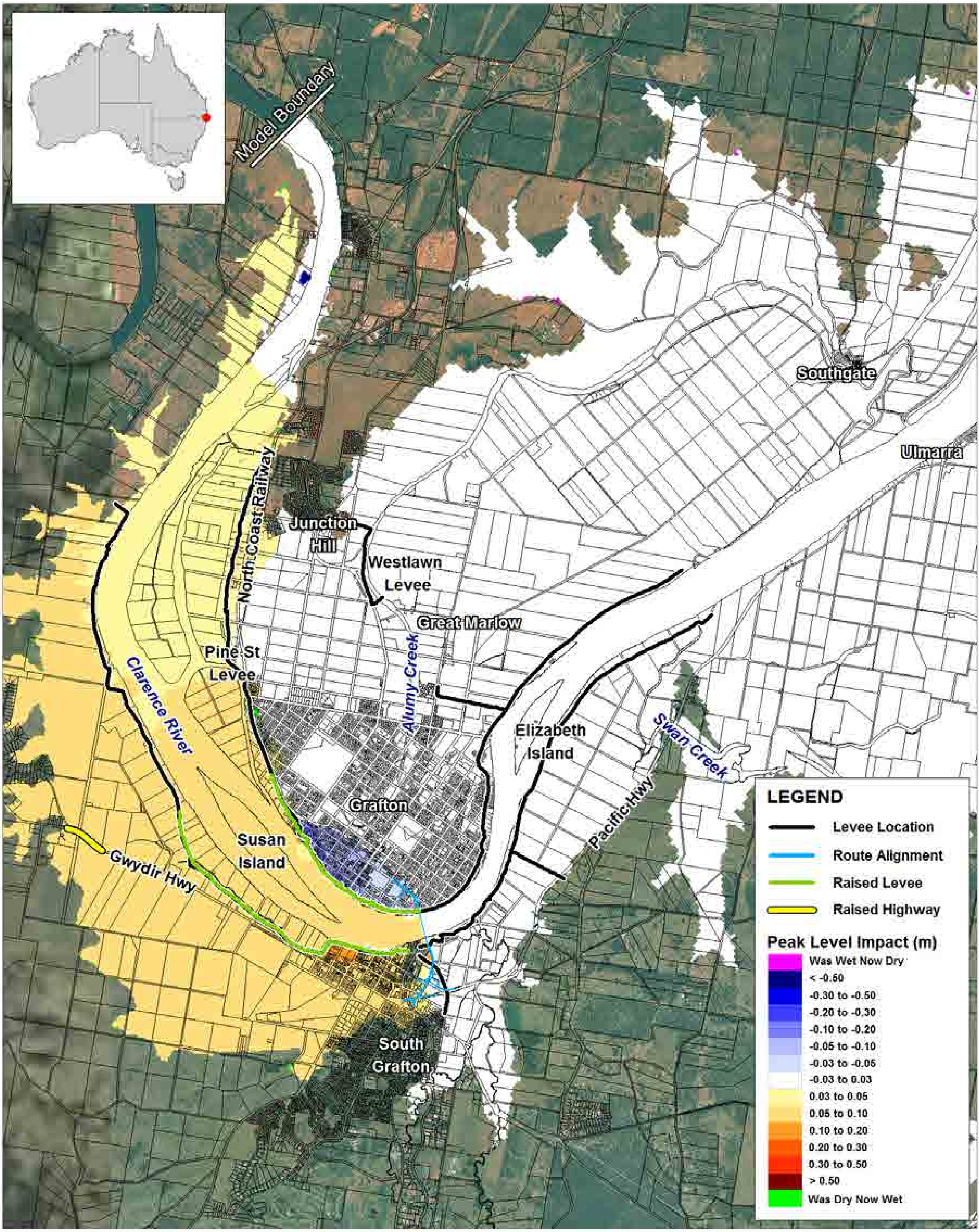

Title:

Peak Flood Level Impact 100 Year ARI Event Mitigation Option 4; Future Climate 2100

Figure: 7-12

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7.3 Climate change results summary

Under a future climate change scenario there will be potential flood impacts in Grafton and South Grafton. These potential impacts would include increases in peak water levels, which result in additional overtopping of the levees and inundation to greater depths than under the current climate.

With mitigation, the impacts of the proposed bridge would be broadly similar to those predicted under an existing climate scenario. Key points from the climate change assessment are summarised below by mitigation option.

7.3.1 Effect of climate change scenario with Mitigation Option 2

20 year ARI event:

- Peak flood level impacts within the river increase by less than 0.01m in the 2050 climate and by up to 0.03m in the 2100 climate.
- Impacts within Grafton and South Graton both decrease under the 2050 and 2100 climates but there are localised increases in impacts by typically 0.3m on largely rural land to the north west of South Grafton. This is due to under an existing climate there being no overtopping in a 20 year ARI event but under a climate change event the raised levee does overtop.

100 Year ARI Event:

- Peak river level impacts generally remain the same under a 2050 climate as for an existing climate. For the 2100 climate the impacts within the river decrease by up to 0.04m.
- Under a 2050 climate minor increases in impact within Graton are predicted within the range of 0.03m to 0.04m. Impacts in South Graton decrease typically by 0.04m. Under a 2100 climate there are no notable changes to impacts within Grafton and increases in impact of up to 0.17m in South Grafton.

7.3.2 Additional bridge with Mitigation Option 4

20 Year ARI Event:

- Peak river level impacts show minimal changes between the existing, 2050 and 2100 climates with any changes being less than 0.01m.
- Impacts are predicted to decrease for Grafton under both 2050 and 2100 climates from an existing climate.
- South Grafton has no change in predicted impacts for the 2050 climate but within the 2100 climate the Gwydir highway overtops to a greater degree resulting in increases in impacts within the town of up to 0.14m.
- In both the 2050 and 2100 climates there is increased ponding behind (north) of the raised Gwydir Highway and this is shown as increased impacts when compared to the existing climate.

100 Year ARI Event:

- Peak river level impacts show minor increases for the 2050 and 2100 climates when compared to an existing climate. These increases are up to 0.02m and 0.01m respectively.
- In Grafton increases in impact of 0.04m and 0.09m occur for the 2050 and 2100 climates respectively. It should be noted that in absolute terms the flood levels have decreased from baseline conditions. The decrease is just not as pronounced under the 2050 and 2100 climates as it is under the existing climate.
- In South Grafton the predicted increases in impact are 0.23m and 0.15m under the 2050 and 2100 climates respectively. Typically, predicted decreases in water level following the additional crossing and mitigation under an existing climate become increases in water level under the future climate scenarios.

7.4 Climate change assessment conclusions

Both mitigation options 2 and 4 mitigate the predicted flooding impacts from the proposed bridge on the area of Grafton located behind the levees. Residual impacts will remain to properties located outside of the levees. These residual impacts would be marginally increased under a future climate scenario (by an estimated 0.03m). Development of any proposed additional mitigation measures for these properties (identified in Section 6) should also take into account the predicted bridge impacts under a future climate.

Typically the impacts to the river levels remain consistent for all modelled climate scenarios. For Grafton, the predicted decreases in flood levels as a result of the proposed bridge and mitigation are less pronounced under future climates and this is shown as an increase in impact (albeit still a net benefit in terms of reduced flood levels from the baseline).

In South Grafton the maximum change in impact under a climate scenario is 0.23m for the 2050 climate scenario. In this case a decrease in peak level of 0.07m under an existing climate becomes an increase in peak level of 0.16m (difference is 0.23m).

It is beyond the scope of this project to mitigate for the impacts of climate change. It is however recommended that future stages of this project ensure consistency with any future climate adaption strategies adopted by Clarence Valley Council and the NSW Government.

8 Other considerations

8.1 Local drainage

A requirement of the design criteria is that the main approach roads to the proposed bridge must be flood immune during a 20 year average recurrence interval (ARI) design flood event (See Section 3). Within Grafton the proposed approach alignment runs under the North Coast Railway viaduct at Pound Street. This is an area known to experience existing local drainage issues.

A preliminary assessment of the local drainage flood behaviour was undertaken which included development of a local scale hydraulic model. This was produced to estimate the baseline 20 year ARI flood levels and to determine if any mitigation measures were required to achieve a 20 year ARI flood immunity for the approach road under the viaduct.

Under the proposed design, the arch forming the railway viaduct over Pound Street will be modified to obtain the required clearance for heavy goods vehicles.

When the Clarence River is not in flood, local runoff can drain to the river via gravity drainage. However, when the river is in flood, the raised water levels prevent gravity drainage to the river and runoff needs to be temporarily stored or pumped until the river levels lower.

Under existing conditions a peak 20 year ARI flood level of 4.35mAHD occurs when the water cannot drain to the river. This compares to a proposed road elevation of 3.70mAHD at its lowest point. Therefore mitigation is required to meet the design criteria.

A proposed mitigation option consisting of the following components has been assessed to achieve the design criteria:

- A detention basin with a volume of approximately 1,500m^3 located on the southern side of Pound Street;
- A new drainage outlet to the river from the detention basin;
- Pump/s with a combined capacity of up to 2m^3/s;
- A series of culverts under Pound Street and the proposed approach road to convey runoff into the detention basin; and
- Diversions of the local piped drainage network into the detention basin.

Following mitigation the peak 20 year ARI flood level is reduced to an elevation of approximately 2.9mAHD. This is approximately 0.5m below the existing road level and 0.8m below the proposed approach road level. As well as meeting the design criteria, the above arrangement reduces the overall flood risk from local flooding in the vicinity of Pound Street compared to the existing situation offering a net benefit to the community.

The volume of water to be pumped into the river is insignificant in the context of the volume of water being conveyed by the river and will have negligible influence on river levels.

Full details of the local drainage assessment including flood impact figures are contained in Appendix C.

8.2 Emergency response and evacuation

Grafton is protected by a ring levee system which has an approximate 20 year ARI immunity (i.e. there is a 5% chance that the levee may be overtopped in any given year). In a worst case scenario the entire township of Grafton will be inundated by flooding, as indicated by flood modelling of the Probable Maximum Flood event (see Figure 2-4). Due to these factors, flooding poses a significant risk to the residents in Grafton.

In response to these risks, the State Emergency Services (SES) has developed a flood evacuation plan for Grafton, documented in the Clarence Valley Council Local Flood Plan (SES, 2012).

The Flood Plan defines the following information:

- Evacuation sectors;
- Evacuation trigger levels, defining sector specific evacuation actions relating to a range of flood levels at the Prince Street gauge;
- Vulnerable community groups requiring special consideration/assistance during an evacuation;
- Evacuation routes; and
- Evacuation centres.

Evacuation routes for Grafton and South Grafton are defined by the SES in the Clarence Valley Local Flood Plan (SES, 2012) and are shown in Figure 8-1. The plan defines three main evacuation routes out of Grafton. Two routes north, to Junction Hill, and one route across the existing Grafton Bridge to South Grafton. Overtopping of the Grafton levees during a large flood event results in ponding within the floodplain between Grafton and Junction Hill and cuts the evacuation routes to the north. When this occurs, the only flood free route available for evacuation is via the existing Grafton Bridge to South Grafton. As such, the efficiency of flood evacuation within Grafton is largely constrained by traffic movement across the bridge.

An additional crossing of the Clarence River in the vicinity of the existing bridge may potentially benefit flood evacuation within Grafton. Key factors which influence how the additional crossing will impact evacuation operations include:

- Evacuation Route Contingency – As shown in Figure 8-1, evacuation routes currently converge within the business district of Grafton.
- Evacuation Route Flood Immunity – An evacuation route is compromised if it is inundated by flood water. It is best practice for evacuation routes to be flood free up to and including the Probable Maximum Flood. This criterion is impractical for Grafton, which is affected by flooding in design flood events greater than the 20 year ARI event. Due to this local flood behaviour, where possible, road elevations of flood evacuation routes should be greater than surrounding land and avoid traversing drainage depressions which many prematurely compromise the evacuation route.
- Provision of Services – Flooding within the Lower Clarence Valley can last for prolonged periods (several days to weeks). Due to this flood behaviour, it is important that evacuated residents

have access to services and shelter following evacuation from Grafton. South Grafton represents the primary location of sufficient size to provide these needs.

- Vulnerable Community Groups – SES resourcing needs to accommodate for vulnerable community groups which may require special consideration/assistance during an evacuation.

The proposed bridge will maintain current evacuation routes but will improve the overall efficiency of evacuation.

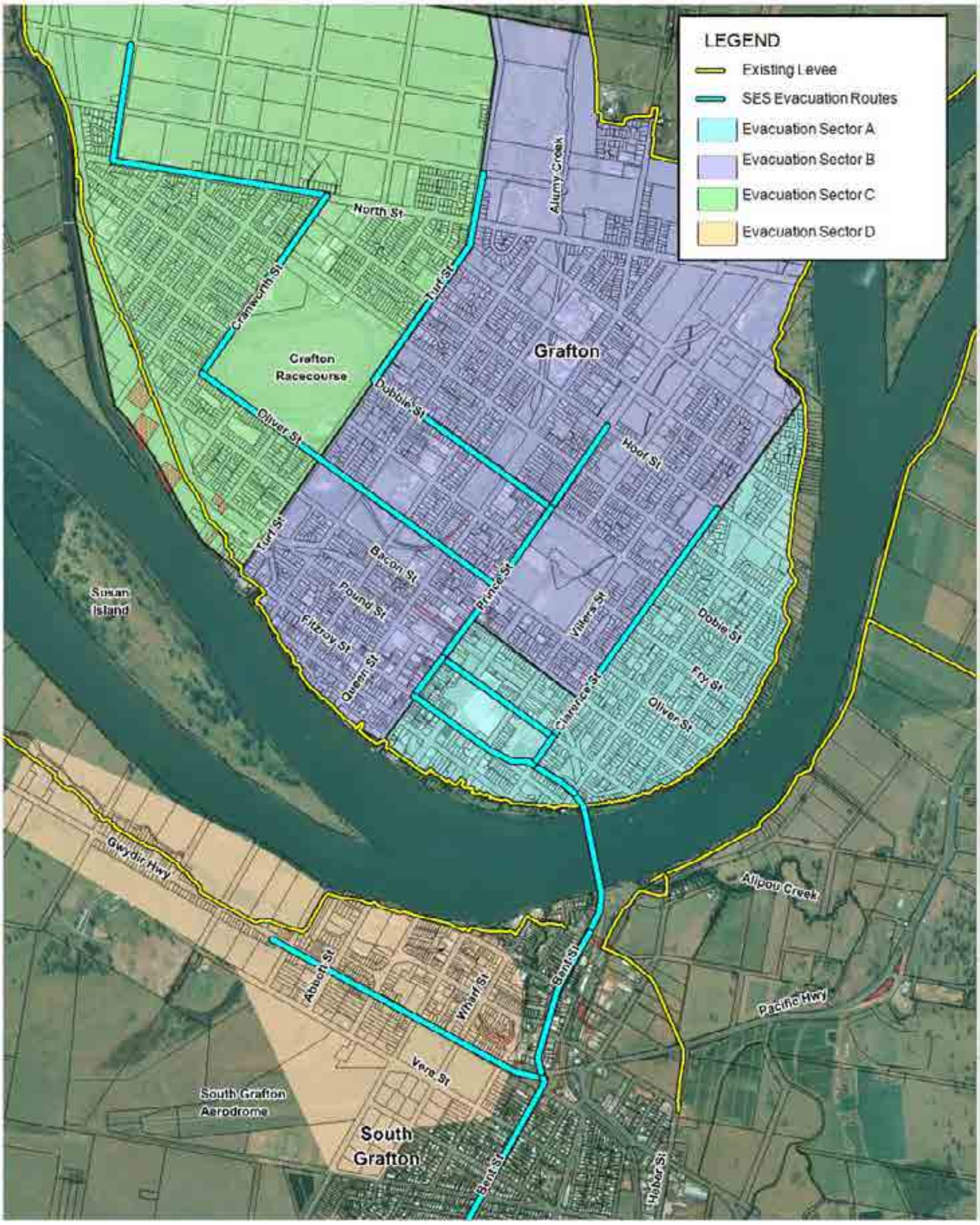

Figure 8-1 Grafton evacuation strategy (SES, 2012)

9 Conclusions

The flooding component of the Environmental Assessment for the proposed project has found the following:

- In the baseline assessment (existing condition), properties in Grafton are particularly affected during flood events of a 50 year average recurrence interval (ARI) or greater. During a 100 year ARI event the extents and depths of flooding are significant for both Grafton and South Grafton.
- Unmitigated, the additional crossing results in an afflux within the Clarence River of less than 0.1m. Due to the significant length of levees and the duration of overtopping, this afflux in the river results in an increase in the volume of floodwater overtopping the levees for events of a 50 year ARI and greater. Unmitigated this would increase flood levels in Grafton and South Grafton.
- To mitigate this increase, four mitigation options were developed and assessed in a hydraulic model. Of these options, two were found to result in an overall reduction in flood risk to both Grafton and South Grafton:
  - Mitigation Option 2: Raising 3.7km of levee on the north bank and 7km of levee on the south bank of the Clarence River by 0.2m; and
  - Mitigation Option 4: Raising 3.7km of levee on the north bank, 4.7km of levee on the south bank, and raising a 550m length of the Gwydir Highway to an elevation of 7mAHD (current existing elevations are between 5 and 6.5mAHD).
- Both Mitigation Options 2 and 4 generally result in reduced peak flood levels and flood hazard for areas protected by existing levees. Changes to peak velocities and durations of flooding were insignificant except for Mitigation Option 4 where part of the proposed mitigation is to detain floodwater to the north of the Gwydir Highway. As there are no predicted changes to peak velocity then it is reasoned that there will be no predicted hydraulic impacts on bed and bank stability. The mitigation options will generally result in minor decreases in flooding frequency to Grafton and South Grafton.
- The proposed mitigation options are generally consistent with the existing floodplain management plan.
- Under a PMF event minor increases in peak level are predicted following the additional crossing. However the significance of these impacts in the context of the severe flooding during a PMF event is considered minimal.
- After the main mitigation, up to 58 properties, generally located outside of the zone of protection afforded by the levees, will be subject to a residual, typically minor, increase in flood level as a result of the proposed project. House raising is proposed as an additional mitigation measure for these affected properties. The estimated number of properties is indicative and should be further investigated commencing with flood level survey and comparison to existing and predicted flood levels.

- The communities of Grafton and South Grafton are vulnerable to the potential impacts of a changing future climate. This assessment has shown that the changes to sea level rise and increased rainfall intensity will not significantly alter the predicted impacts from the additional crossing under a future climate. It is recommended that future stages of this project ensure consistency with any future climate adaptation strategies adopted by Clarence Valley Council.
- Local drainage issues within Grafton will require flood mitigation works to maintain a flood free approach road during a 20 year ARI event. These mitigation works will consist of a detention basin and pump to temporarily store and discharge local runoff when the Clarence River level is in flood.
- Existing flood evacuation arrangements within Grafton will generally benefit from the additional crossing which will improve access to higher ground in South Grafton, subject to the existing constraints of traffic congestion within the business district of Grafton.

10 References

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