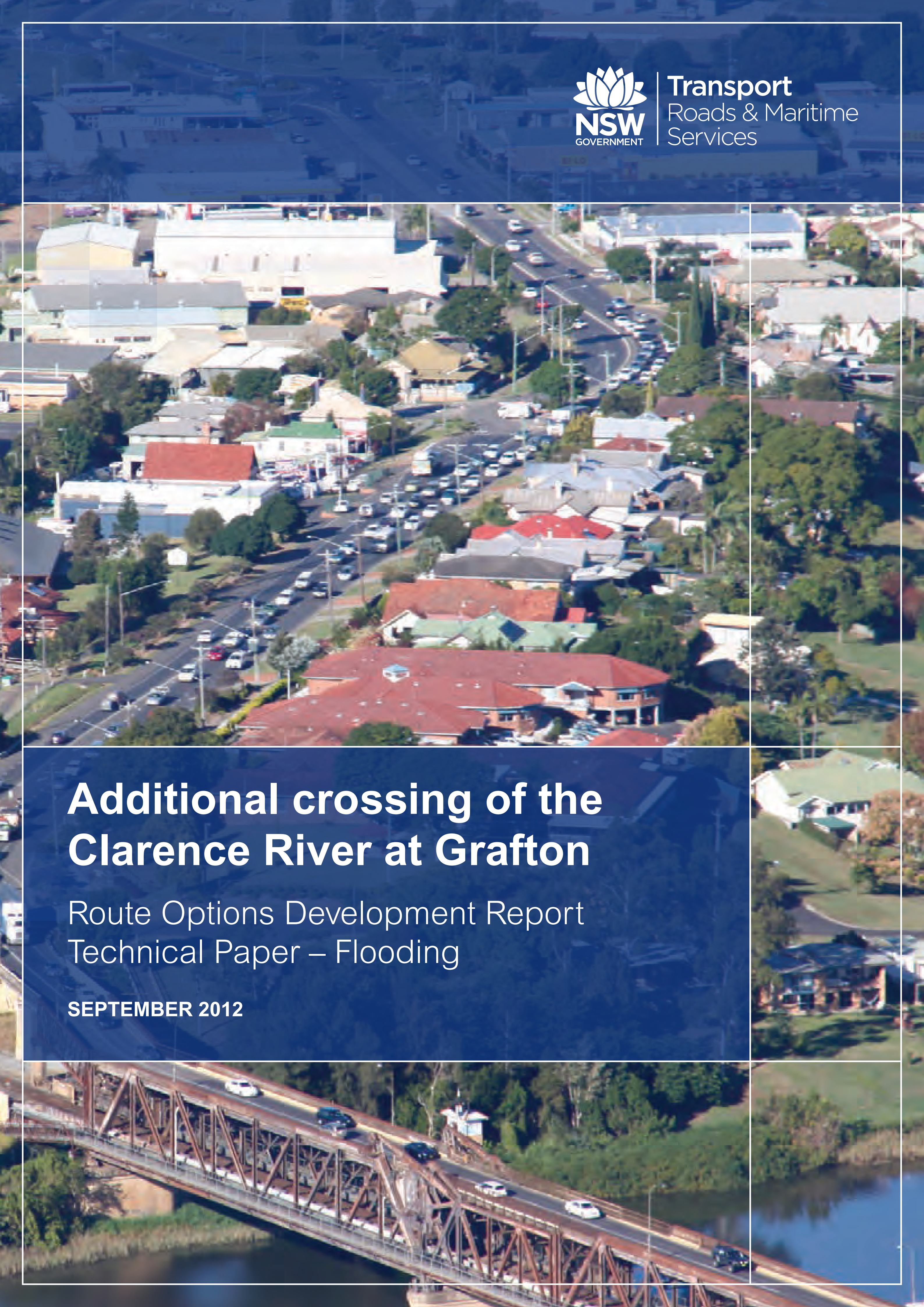

NSW GOVERNMENT | Transport Roads & Maritime Services

Additional crossing of the Clarence River at Grafton

Route Options Development Report
Technical Paper – Flooding

SEPTEMBER 2012

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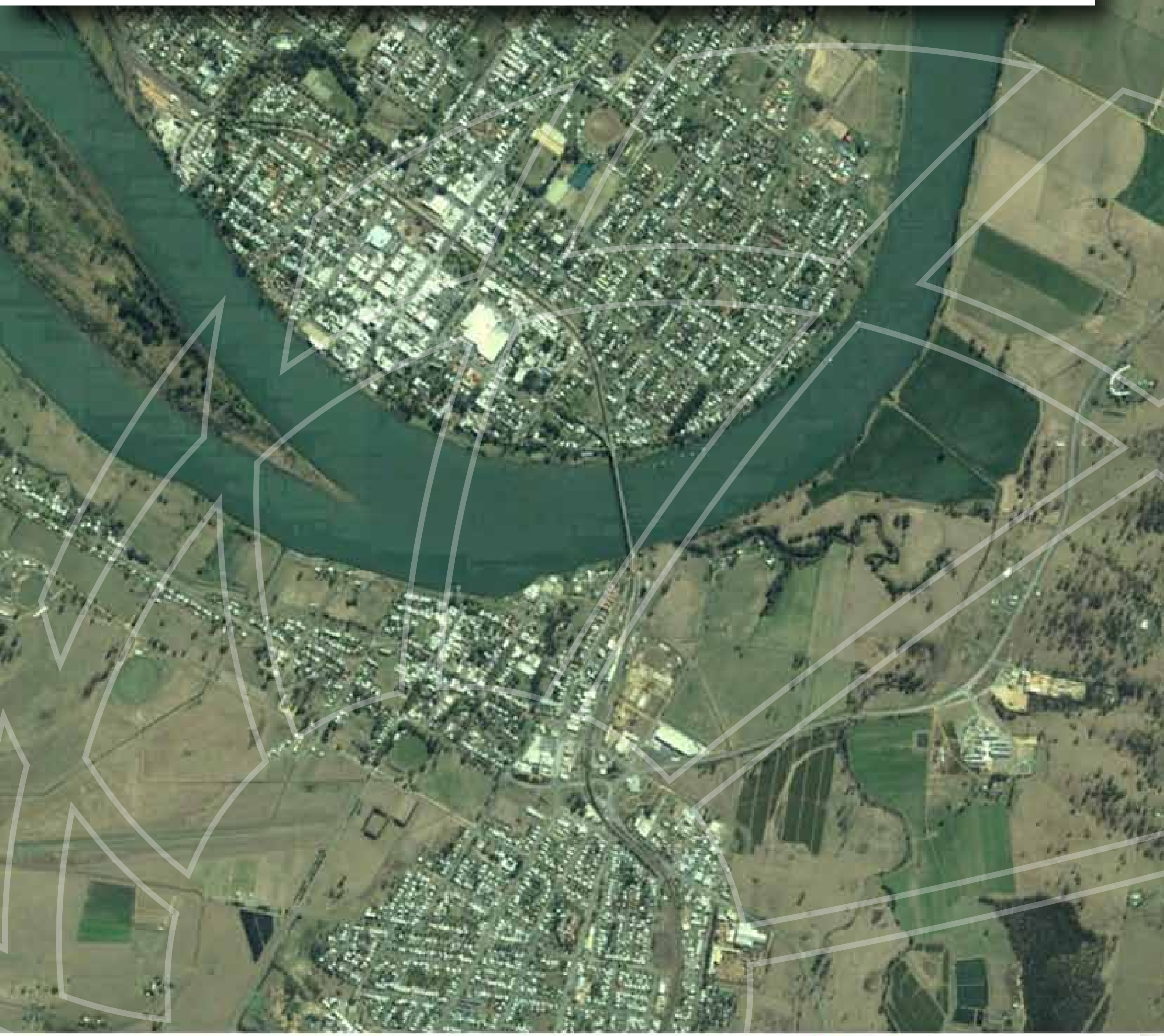
Main Road 83 Summerland Way Additional Crossing of the Clarence River at Grafton

Route Options Development Report Technical Paper – Flooding August 2012



Transport Roads & Maritime Services

NSW GOVERNMENT

Main Road 83
Summerland Way
Additional Crossing of the Clarence River at Grafton

Route Options Development Report
Technical Paper - Flooding

Prepared For:	Roads and Maritime Services, Northern Regional Office
Prepared By:	BMT WBM Pty Ltd (Member of the BMT group of companies)

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GLOSSARY

Annual Exceedance Probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (i.e. a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year (see also average recurrence interval).
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrence of a flood as big as (or larger than) the selected event. For example, floods with a discharge as great as (or greater than) the 20yr ARI design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event (see also annual exceedance probability).
BoM	Australian Bureau of Meterology.
Catchment	The catchment at a particular point is the area of land that drains to that point.
CRCC	Clarence River County Council.
CVC	Clarence Valley Council.
design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100yr ARI or 1% AEP flood).
developed case scenerio	The flood modelling scenario representing the catchment state including the proposed development design.
existing case scenario	The flood modelling scenario representing current catchment state within the study area.
flood	Relatively high river or creek flows, which overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
flood damage	The financial and social costs of flooding.
flood behaviour	The pattern / characteristics / nature of a flood.
flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as "stage".
floodplain	Land adjacent to a river or creek that is periodically inundated due to floods. The floodplain includes all land that is susceptible to inundation by the probable maximum flood (PMF) event.
floodplain management	The co-ordinated management of activities that occur on the floodplain.

flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
floodway	A flow path (sometimes artificial) that carries significant volumes of floodwaters during a flood.
freeboard	The distance between a water level and the design level of a structure.
historical flood	A flood that has actually occurred.
hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrograph	A graph showing how a river or creek's discharge changes with time.
hydrology	The term given to the study of the rainfall-runoff process in catchments.
MHL	Manly Hydraulic Laboratory.
peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
Probable Maximum Flood (PMF)	An extreme flood deemed to be the maximum flood likely to occur.
Probability	A statistical measure of the likely frequency or occurrence of flooding.
PROR	Preliminary Route Option Report.
RODR	Route Option Development Report.
runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
stage	See flood level.
stage hydrograph	A graph of water level over time.
velocity	The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, i.e. the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.
water level	See flood level.

1 INTRODUCTION

The *Additional Crossing of the Clarence River at Grafton* project is being undertaken by the NSW Roads and Maritime Services (RMS, formerly Roads and Traffic Authority). RMS commissioned Arup to undertake the conceptual development for the study. BMT WBM Pty Ltd have subsequently been commissioned by Arup to undertake the flood risk hydrologic and hydraulic component of the project. This report outlines the flooding assessment results for the route options development assessment phase of the project. The results of this quantitative assessment will be used as input during the selection of a preferred route option from the six (6) route options currently identified for consideration.

1.1 Background

RMS is currently undertaking investigations to identify and preserve a route for an additional crossing of the Clarence River at Grafton.

Roads and Maritime Services (RMS) is currently undertaking investigations to identify an additional crossing of the Clarence River at Grafton to address short-term and long-term transport needs. Arup (on behalf of RMS) has engaged BMT WBM to undertake investigations.

Since the early 1970s there have been various discussions and studies into an additional crossing of the Clarence River near Grafton. A number of these studies have been carried out during the past ten years and provide the background to the current investigation.

In December 2010, RMS commenced a revised process to work more closely with the community to determine the preferred location for an additional crossing. As part of this revised process, a series of public surveys, community forums and meetings with residents and community groups have been held and various studies and project documents released for public viewing and comment.

In June 2011, RMS released the *Feasibility Assessment Report*, which describes the assessment undertaken by RMS on the 41 route suggestions identified by the community following the announcement of the revised process in December 2010. The report identifies 25 preliminary options within five strategic corridors to go forward for further engineering and environmental investigation.

Between June 2011 and January 2012, RMS carried out investigations in the Grafton area and surrounds to identify constraints relevant to an additional crossing of the Clarence River. The outcomes of these investigations, community comment and a community and stakeholder evaluation workshop provided the inputs to the selection of the short-list of options.

In January 2012, six route options to be investigated further as part of the process to identify a location for the crossing were announced (as shown in Figure 1-1). The short-listed options were identified in the *Preliminary Route Options Report – Final (*January 2012) which also provided details of the technical investigations undertaken on the 25 preliminary options and the process to select the short-listed options.

This technical paper is an attachment to the Route Options Development Report and will be used to define the flooding assessment for these six short-listed route options. The findings of these investigations will be used as part of the selection of a recommended preferred option.

1.2 Report Purpose

This report documents the flood impact assessment undertaken for the six route options. The flooding assessment aims to:

1 Estimate the flood impacts associated with the concept designs for the six (6) route option designs;

2 Identify necessary mitigation measures required to maintain the current level of flood immunity within Grafton and South Grafton following the construction of the options; and

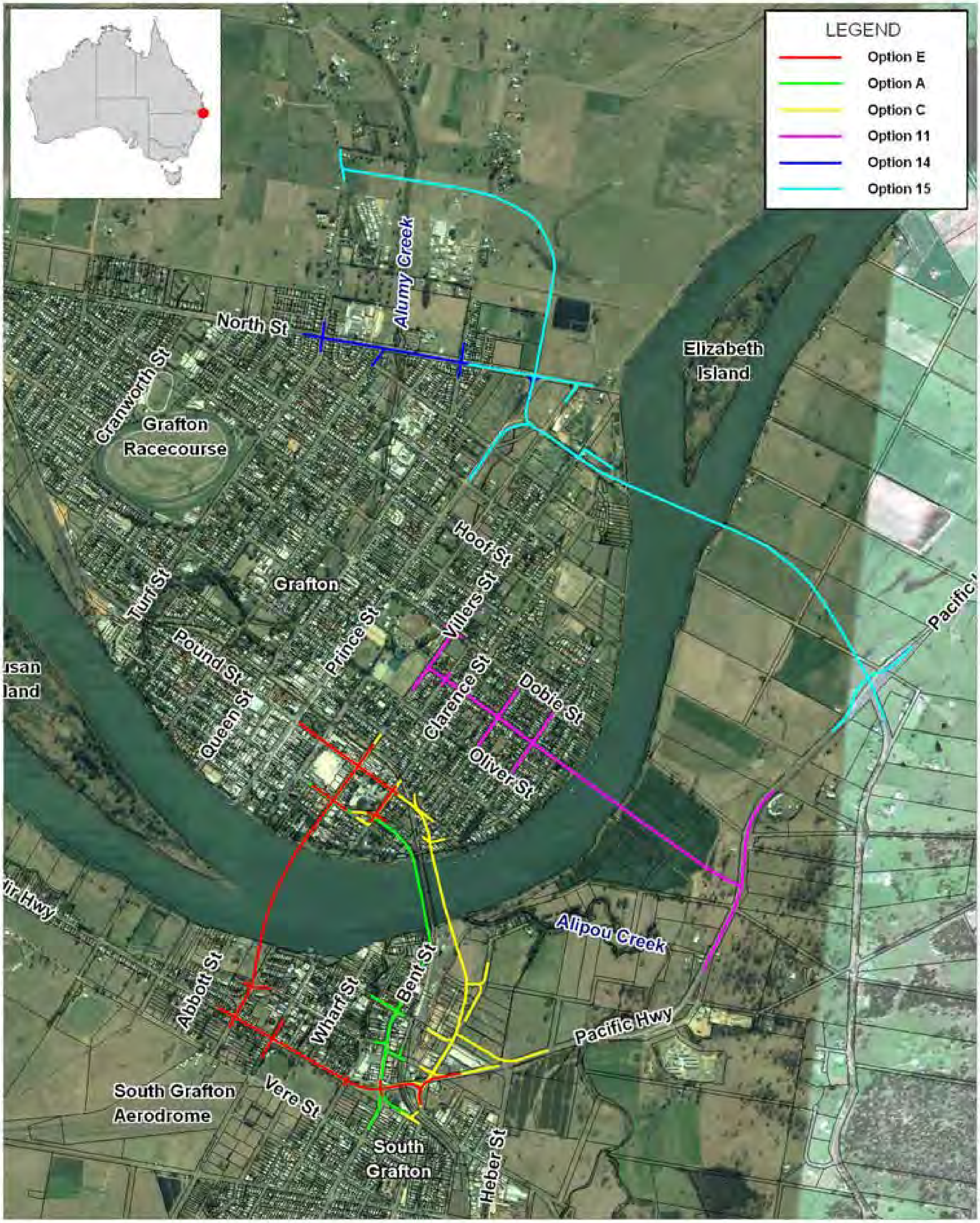
3 Identify qualitatively the effects of the short listed options and designs on (Grafton) flood evacuation.

The results of this flooding assessment will contribute to the selection of a preferred option for the additional crossing of the Clarence River in Grafton. Further flood studies will be undertaken as part of the design refinement process of the concept design during the Environmental Assessment phase and the detailed design phase.

1.3 Assumptions and Limitations

Definition of the existing flood behavior in the Grafton region is required to define the baseline for the flooding assessment. For this purpose, the route options development 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). The 2004 Lower Clarence River Flood model is the latest publicly available flood model of the lower Clarence River catchment; defining the regional flood behaviour between Mountain View, upstream of Grafton, and the Clarence River entrance at Yamba/Iluka. This 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.

For the purpose of comparing and assessing the likely flood impacts and required mitigation measures associated with the six (6) route options, the current state of the lower Clarence River flood model is considered appropriate for the current *Route Options Development Report*.



Grafton and South Grafton Area - Route Option Locations

Figure: 1-1 | A

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Approx. Scale

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2 SHORT LIST OF ROUTE OPTIONS

2.1 Description of Route Options

In January 2012 RMS identified six (6) route options for further analysis, shown in Figure 1-1. Plans and longitudinal cross-sections of the route options are provided in the main *Route Options Development Report*. The six route options are briefly described in Table 2-1 below.

Table 2-1 Description of Route Options

Option	*Description*
Option E	Option E is located upstream of the existing Grafton Bridge and connects Grafton to South Grafton via Villiers Street and Cowan Street.
Option A	Option A is located immediately upstream of the existing Grafton Bridge and connects Grafton to South Grafton via Fitzroy Street and Bent Street.
Option C	Option C is located downstream of the existing Grafton Bridge and connects Grafton to South Grafton via Pound Street and Iolanthe Street.
Option 11	Option 11 is located downstream of the existing Grafton Bridge and connects Grafton to South Grafton via Fry Street and the Pacific Highway.
Option 14	Option 14 is located downstream of the existing Grafton Bridge and connects Grafton to South Grafton via Kirchner Street and the Pacific Highway. Option 14 connects to the Summerland Way via North Street.
Option 15	Option 15 shares a common alignment with Option 14 downstream of the existing Grafton Bridge and connects Grafton to South Grafton via Kirchner Street and the Pacific Highway. Option 15 deviates further to the north than Option 14, through previously undeveloped land.

2.2 Key Bridge Design Features

Key design features for each of the option bridges are also summarised in Table 2-2.

Table 2-2 Route Option Bridge Design Features

Option	*Option*	*Bridge Type*	*Total Bridge Length (m)*	*Span Length (m)*	*Pier Width (m)*	*Minimum Soffit Elevation (mAHD)*
E	Clarence River Bridge	Incrementally Launched	690	49	3.0	9.5
A	Clarence River Bridge	Balanced Cantilever	620	74.5	3.0	9.5
	Floodplain Viaduct	Super T		29	Tapered 2.0 - 3.0	9.5
C	Clarence River Bridge	Balanced Cantilever	580	74	3.0	9.5
	Grafton Floodplain Viaduct	Super T		29	Tapered 2.0 - 3.0	9.5
	South Grafton Floodplain Viaduct			32		
11	Clarence River Bridge	Incrementally Launched	840	48.4	3.0	17.5*
	Floodplain Viaduct	Super T		34	Tapered 2.0 - 3.0	17.5*
14	Clarence River Bridge	Incrementally Launched	1,540	53	3.0	17.5*
	Floodplain Viaduct	Super T		34	Tapered 2.0 - 3.0	17.5*
	Alumy Creek	Super T	50	30	Tapered 2.0 - 3.0	4.0
	Minor Drainage	-	15	-	-	-
15	Clarence River Bridge	Incrementally Launched	1,540	53	3.0	17.5
	Floodplain Viaduct	Super T		34	Tapered 2.0 - 3.0	17.5
	Alumy Creek	Super T	95	30	Tapered 2.0 - 3.0	4.0
	Minor Drainage	-	15	-	-	-

Refer to main report for route option plans and longitudinal cross-sections

*To provide required navigation clearance

2.3 Design Criteria

The flooding design criteria for the route options include the following:

1. Option Design:

   a. Waterway structures outside of the Grafton levee banks, including the main ridge and viaducts, must be of sufficient height to maintain a freeboard during a 100 year Average Recurrence Interval (ARI) design flood event.

   b. Bridges within the Grafton levees (Alumy Creek and minor drainage) must be flood immune during a 20 year ARI design flood event.

   c. The main approach roads to the new bridge must be flood immune during a 20 year ARI design flood event.

2. Flood Impacts:

   a. Proposed options should not adversely impact the flood immunity in Grafton and South Grafton. Where impacts are identified, design mitigation measures would be implemented to maintain the current level of flood immunity.

   b. No adverse impacts on flood evacuation of Grafton.

3 ASSESSMENT METHODOLOGY

In order to measure the extent to which the flood impact assessment aligns with the project objectives, a set of specific indicators have been developed by the project team and BMT WBM Pty Ltd. These indicators have been used to enable a comparison to be made between the different route options, and are listed in Table 3-1.

Table 3-1 Flooding Indicators

Indicator	*Description*
Maximum Clarence River afflux upstream of option in a 20-year ARI flood event with levee upgrades in place (m)	This indicator compares the maximum expected change in the peak flood level in the Clarence River immediately upstream of the new (or proposed) bridge as a result of the route option, as measured in the project flood model. This is the peak flood level assuming that the levees have been upgraded. The level reported is for the 20-year average recurrence interval (ARI) design flood event. The 20-year ARI design flood event is the flood that can be expected to occur, based on long-term averages, once every 20 years.
Length of levees upstream that would need to be upgraded for a 20-year ARI flood event (km)	This indicator compares the length of existing levees that must be upgraded to maintain the current level of flood immunity in a 20-year ARI design flood event (see point above for definition).
Flooding emergency response considerations	This indicator provides a qualitative comparison of the route options which considers the following key factors of evacuation operations: • Availability of alternative evacuation routes – Existing evacuation routes are defined in the Grafton Evacuation Strategy (SES 2008) and currently converge within the business district of Grafton. Options which are not located adjacent to the existing bridge provide some contingency for an evacuation scenario in which roads within the business district of Grafton are compromised (inundated by flooding or impacted by a serious traffic crash). Furthermore, options which are distanced away from the existing Grafton Bridge will require new evacuation routes in addition to the existing ones. The additional evacuation routes will reduce traffic congestion within the Grafton business district. • The flood immunity of the evacuation routes – 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. However, this criterion is impractical for Grafton, which is affected by flooding in design flood events greater than a 20-year ARI flood event. • Access to evacuation services and shelter – 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. • Impact on evacuation of vulnerable community groups – State of Emergency Services resourcing needs to accommodate for vulnerable community groups which may require special consideration/assistance during an evacuation.

The flooding investigations completed for the route options development assessment aim to:

1. Estimate the flood impacts associated with the six (6) route option designs;
2. Identify necessary mitigation measures required to maintain the current level of flood immunity within Grafton and South Grafton following the construction of the route option designs; and
3. Identify qualitatively the effects of the route options and designs on (Grafton) flood evacuation.

Definition of the existing flood behaviour in the Grafton region is required to define the baseline for the flooding assessment. For this purpose, the route options development 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). The 2004 Lower Clarence River Flood model is the latest publicly available flood model of the lower Clarence River catchment; defining the regional flood behaviour between Mountain View, upstream of Grafton, and the Clarence River entrance at Yamba/Iluka. A summary of the lower Clarence River flood model inputs is provided in Appendix A.

The flood modelling results documented in the Lower Clarence River Flood Study Review report (WBM, 2004), also shown in Figure 4-1 to Figure 4-6 have been used to define the baseline for this flooding assessment. These results represent the existing flood behaviour within the study area.

The potential changes to the existing flood behaviour, resulting from each of the route options, have been identified following update of the lower Clarence River flood model. The model update was required to represent the following option design features within the flood model:

1. Bridge losses accounting for bridge type, soffit level, span width, pier width, pier configuration and pile cap allowances;
2. Road upgrades and embankments associated with the bridge approaches; and
3. Inclusion of mitigations measures, required to maintain the existing level of flood immunity within Grafton and South Grafton following the construction of the route option designs.

Assessment of flood impacts for the purposes of this study have been estimated by comparing the peak flood level results associated with the developed case scenario[1] and the existing case scenario[2].

For the purpose of comparing the six (6) route options, this flood impact assessment only considers the 20 and 100 year ARI design flood events. These design events were selected for the assessment following scoping meetings attended by representatives from RMS, Arup, Paterson Consulting and BMT WBM. These two design flood events were identified for assessment due to their respective flood levels relative to the Grafton and South Grafton levees, as discussed in Section 4.

For these defined flood events, the flood impacts associated with proposed options, including associated mitigation measures, are summarised in Section 5. For comparison, flood impact assessment results from design scenarios not including associated mitigation measures are provided in Appendix C.

[1] Developed case scenario = local topography including the design details associated with the proposed route options.
[2] Existing case scenario = current catchment condition.

Assessment of the qualitatively the effects of the route options and designs on (Grafton) flood evacuation is summarised in Section 5.6. The evacuation assessment has been based on:

1. The catchment flood behaviour relative to the option location and design, defined using the lower Clarence River flood model; and

2. Local emergency response experience (pers. comm. Clarence Valley Council and local State Emergency Service, 30/3/2012).

4 EXISTING CONDITIONS AND CONSTRAINTS

4.1 Existing Conditions

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 20,000 km2 upstream of Grafton and at times of major flooding some 500 km2 downstream of Grafton may become inundated.

Due to the size of the Clarence River catchment upstream of Grafton, relative to its various downstream tributary catchments, the flooding behaviour of the Lower Clarence River floodplain is dominated by the flow originating from upstream of Grafton/Mountain View in terms of both peak flood levels and duration of inundation. The flow typically contributes 80% to 90% of the total volume of floodwaters that enters the lower floodplains 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 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, 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. 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.

During events greater than the 20 year ARI event, overtopping of the Grafton and South Grafton levees occurs. Following overtopping, significant areas of Grafton and South Grafton are inundated by floodwater. Due to this flood behaviour, and as noted in Section 3, the following Clarence River flood events have been used for the assessment being carried out as part of the Route Option Development Report.

1. The 20 year ARI event representing a catchment flood event approximately equivalent to the level of flood immunity provided by the Grafton and South Grafton levees; and
2. The 100 year ARI event representing a major levee overtopping event. At the peak of the 100 year ARI event approximately 60% of the Grafton and 75% of the South Grafton levee length is overtopped by floodwaters.

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). A summary of the lower Clarence River flood model inputs and historic event calibration results is provided in Appendix A

As defined in the Lower Clarence River Flood Study Review (WBM, 2004), Table 4-1 summarises the peak flood levels, velocities and flows for the 5, 20 and 100 year ARI and the probable maximum flood (PMF) events. Design flood modelling results are also shown for the 20 and 100 year ARI events in Figure 4-1 to Figure 4-6.

Table 4-1 Existing Case Flood Behaviour

Design Flood Event	Peak Flood Level (mAHD)				Peak Flood Velocity (m/s)	Peak Flood Flow (m^3/s)
	Prince St Gauge	Existing Grafton Bridge	Grafton[1]	South Grafton[2]	Existing Grafton Bridge	Mountain View[3]
5 year ARI event	6.1	6.0	No levee overtopping		2.2	9,360
20 year ARI event	8.0	7.7	2.1	No levee overtopping	3.4	16,280
100 year ARI event	8.4	8.1	6.0	6.2	3.7	19,060
PMF event	9.8	9.4	9.0	10.2	4.2	29,160

[1] Result extraction location = Alumy Creek adjacent to North Street.

[2] Result extraction location = Intersection of Abbott Street and Vere Street.

[3] Flow results extracted from river cross-section upstream of Grafton. Refer to Figure A-2.

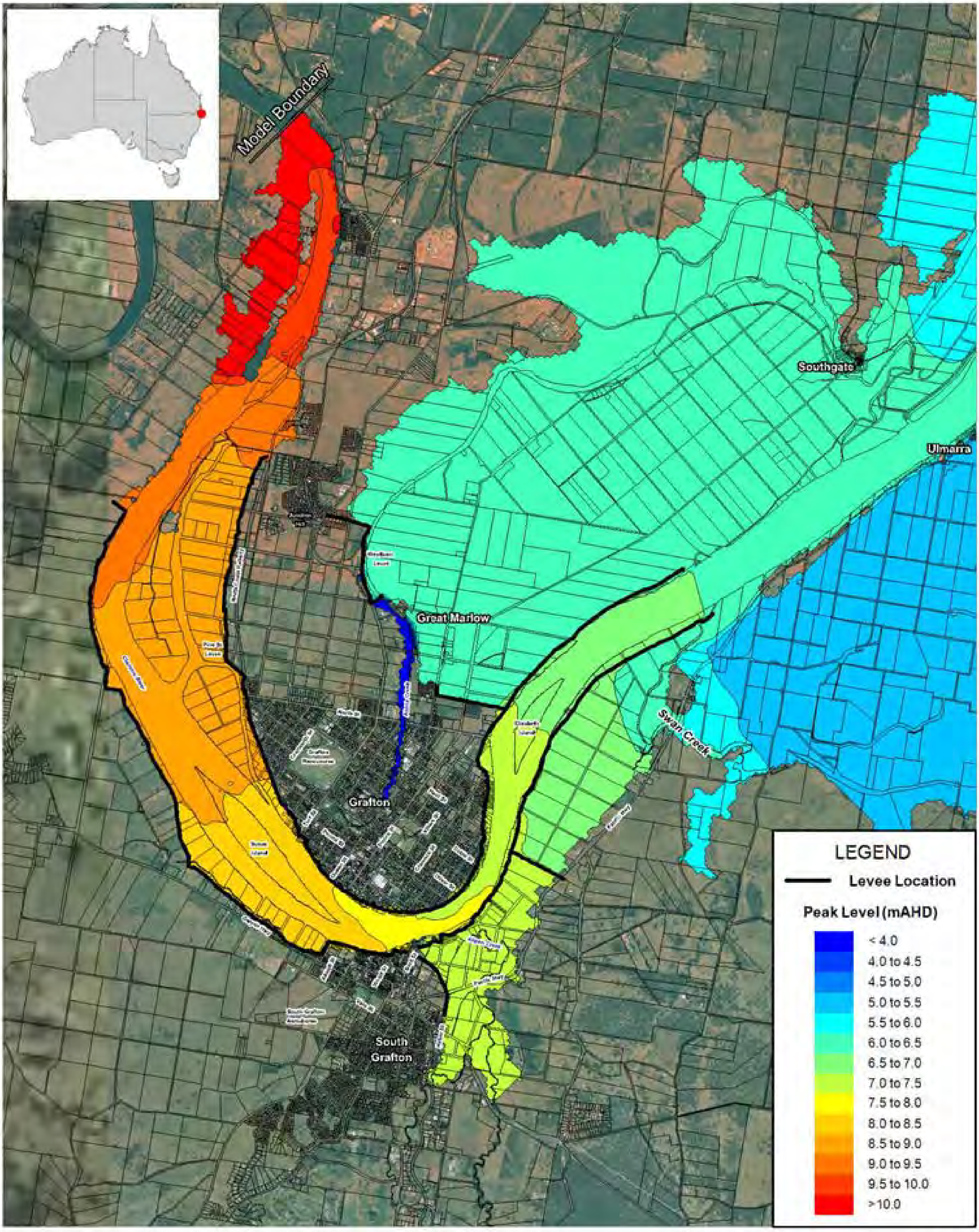
4.2 Flooding Constraints

Grafton and South Grafton have a long history of flooding, and are currently protected by a series of levees. These levees at present provide Grafton and South Grafton with a level of flood immunity approximately equivalent to the 20 year ARI flood event. This equates to a 5% annual exceedance probability (AEP) that overtopping of the current Grafton and South Grafton levees may occur in a given year.

During major flood events, greater than the 20 year ARI event, flood levels within Grafton and South Grafton are strongly regulated by the water volume overtopping the respective levee systems. Due to the extensive length of the Grafton and South Grafton levees, slight changes in flood level within the main Clarence River (even as little as 0.01m) have the potential to significantly alter the volume of water overtopping the levee. Increases in the overtopping volume can potentially result in significant variations in ponding flood levels behind the levee systems. An additional crossing of the Clarence River at Grafton may create an increase in river flooding levels due to the impact of bridge piers and embankments. Without additional levee wall improvements, this may effectively reduce the flood immunity of Grafton and South Grafton. These impacts are highlighted in the unmitigated development scenario results provided in Appendix C.

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.

Therefore, 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 investigated. The identified mitigation measures are outlined in Section 5.



Title:
Existing Case Peak Flood Level 20 Year ARI Event

Figure: 4-1

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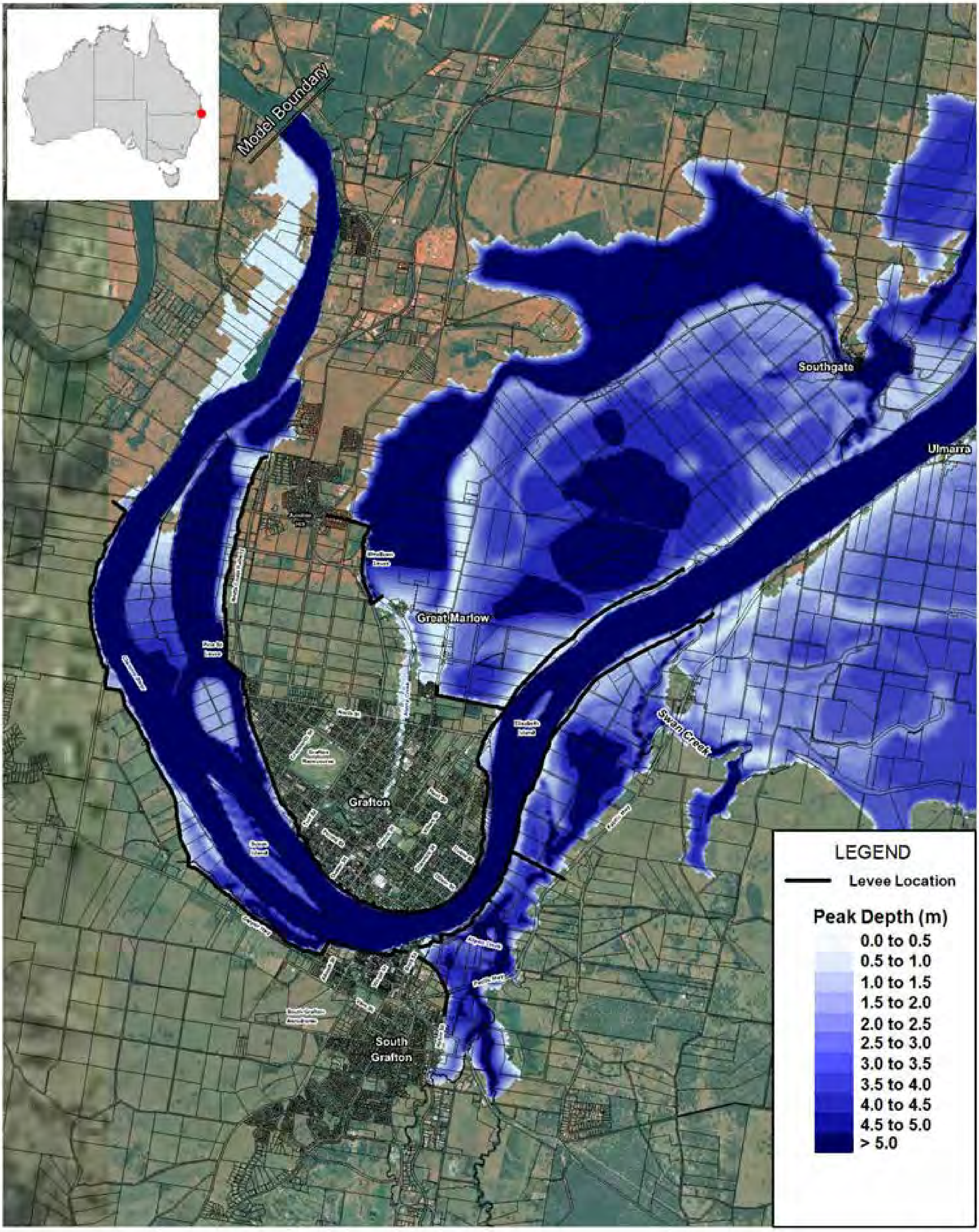

Title:

Existing Case Peak Flood Depth 20 Year ARI Event

Figure: 4-2

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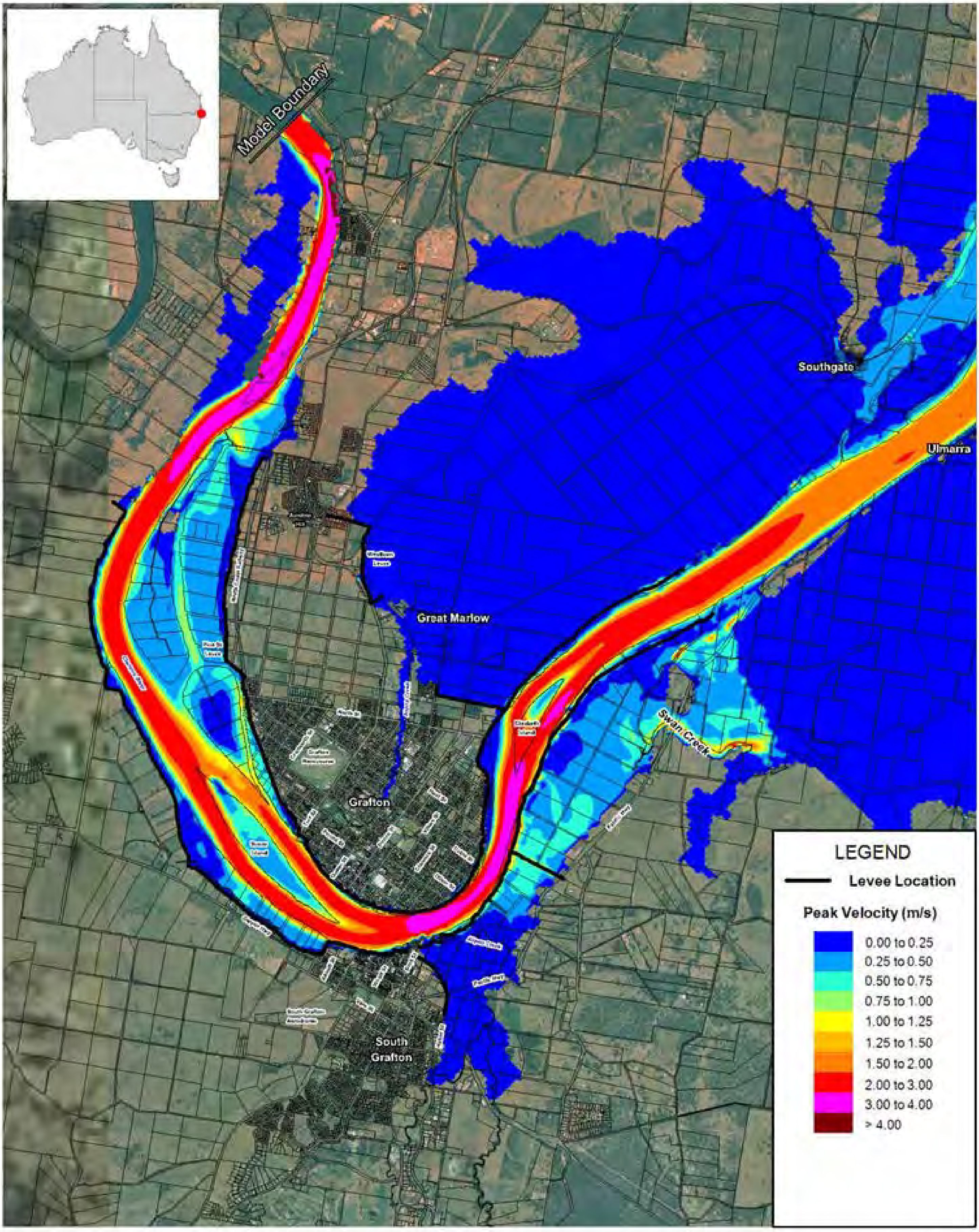

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Existing Case Peak Flood Velocity 20 Year ARI Event

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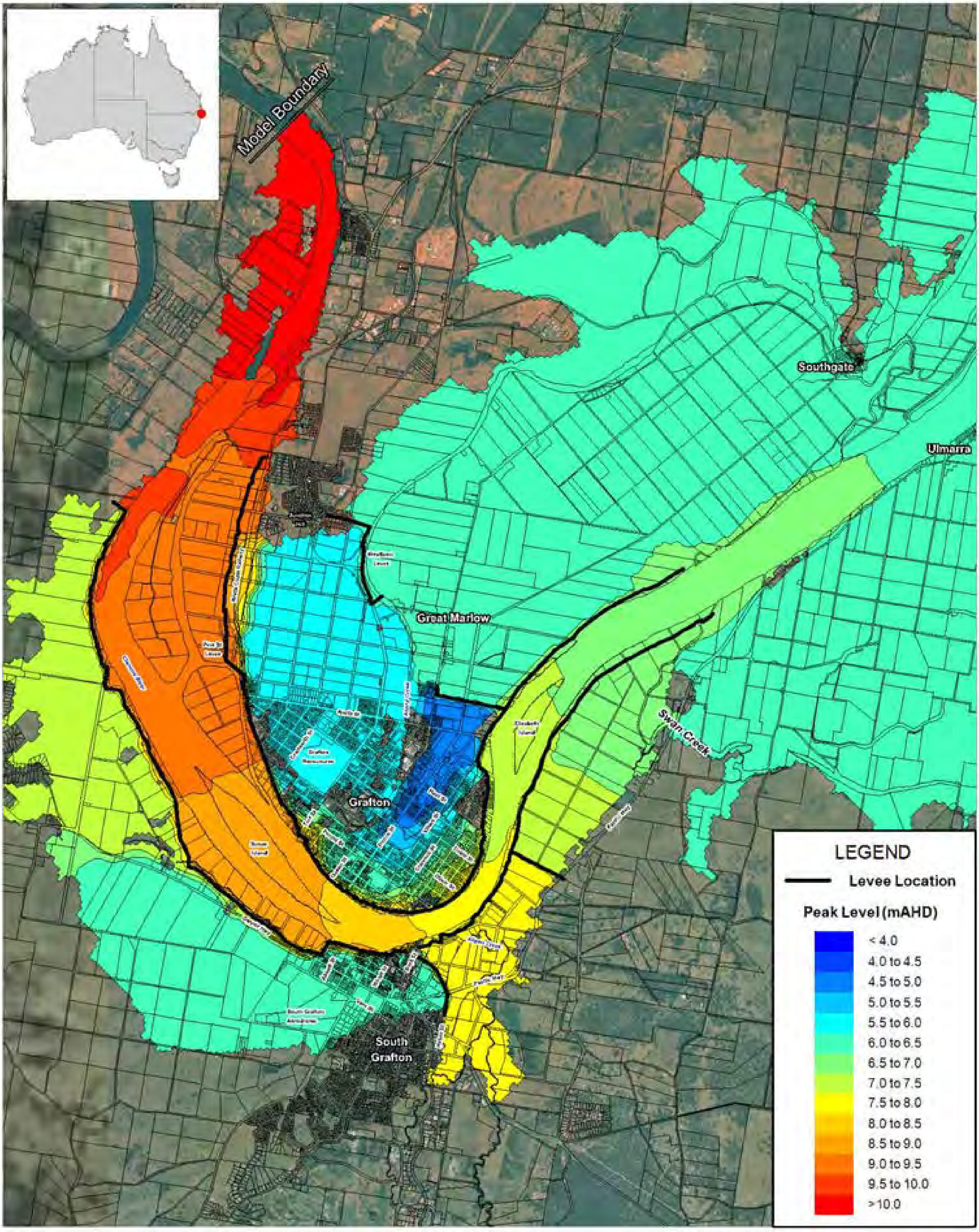

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Existing Case Peak Flood Level 100 Year ARI Event

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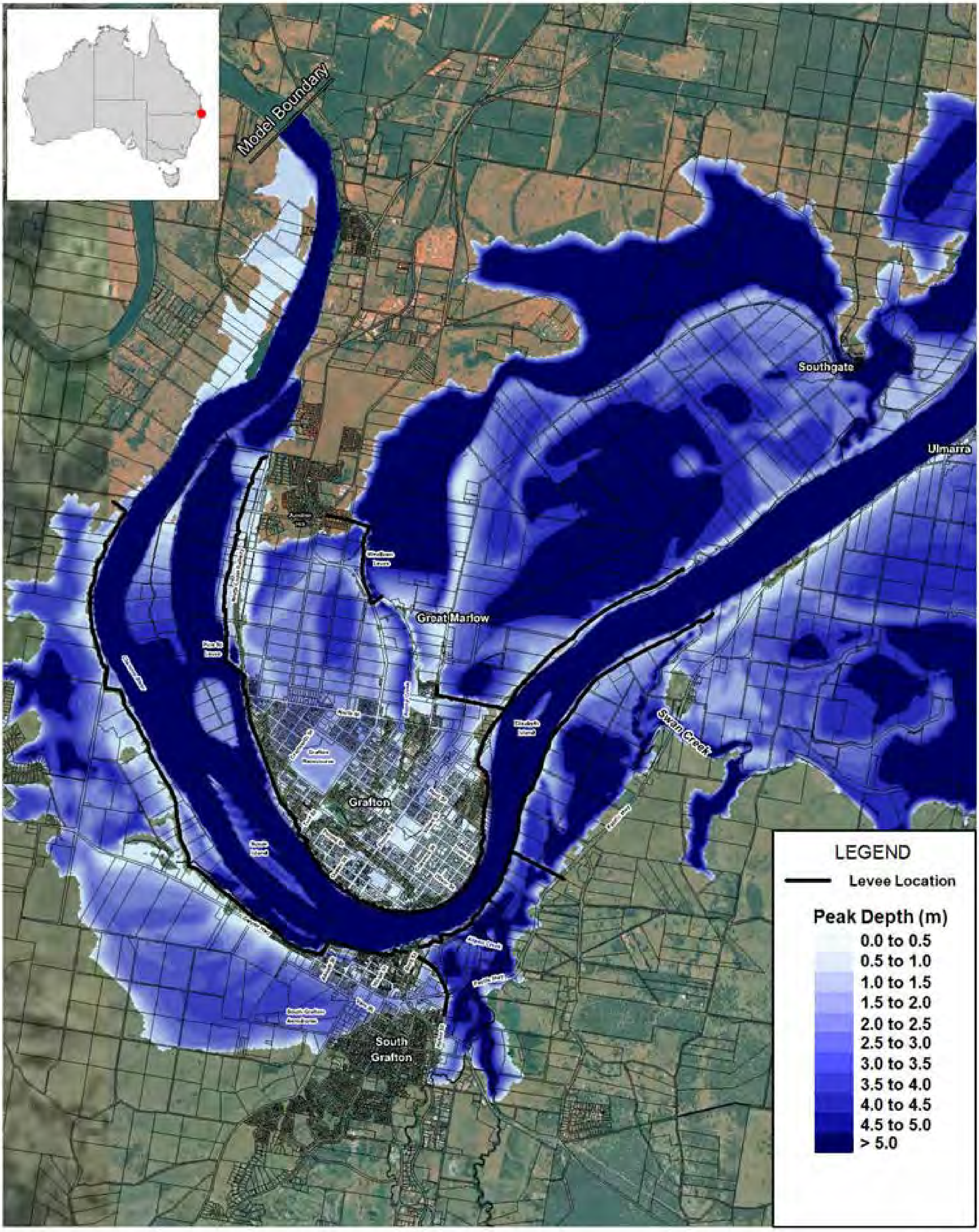

Title:

Existing Case Peak Flood Depth 100 Year ARI Event

Figure: 4-5

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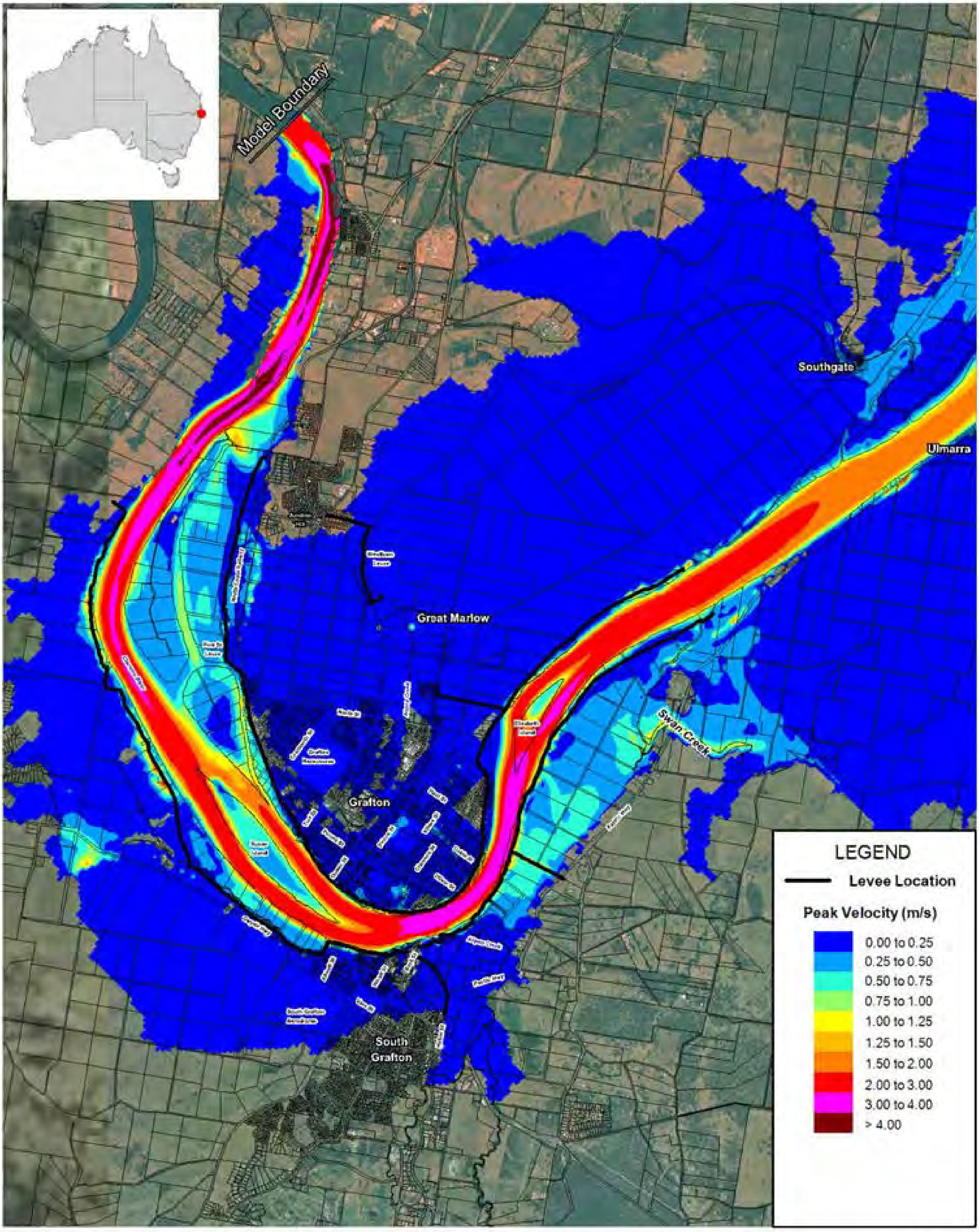

Title:

Existing Case Peak Flood Velocity 100 Year ARI Event

Figure: 4-6

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5 ASSESSMENT OF ROUTE OPTIONS

The flooding assessment completed for the six (6) route options aims to:

1. Estimate the flood impacts associated with the six (6) route option designs; and
2. Identify necessary mitigation measures required to maintain the current level of flood immunity within Grafton and South Grafton following the construction of the proposed route option designs.

Common for all options, construction of an additional bridge crossing will result in flood level increases within the Clarence River. Without mitigation, the flood level increases within the main river channel would result in significant adverse flood impacts in both Grafton and South Grafton. Flood mitigation measures have been developed for all option designs to manage these flood impacts. The primary mitigation measure is to raise sections of the existing levees. The flooding assessment results for the design scenarios which do not include these mitigation measures are provided in Appendix C and also listed in the result summary tables in the following 'option' specific sections.

In addition to the levee upgrade requirement, where current option designs do not meet the design criteria listed in Section 4-1, mitigation measures required to achieve the identified design objectives have been investigated. Such measures have been identified for Option C where the route passes through an area in Grafton with an existing local drainage issue.

Downstream from Grafton, the potential flood impacts of the six (6) route option designs has been considered at Swan Creek, Ulmarra, Great Marlow and Southgate. The assessment has found that all options do not significantly impact flood levels or arrival times at these locations.

Figure 5-1 and Table 5-1 summarise the mitigation measures which have been identified for the six (6) route options.

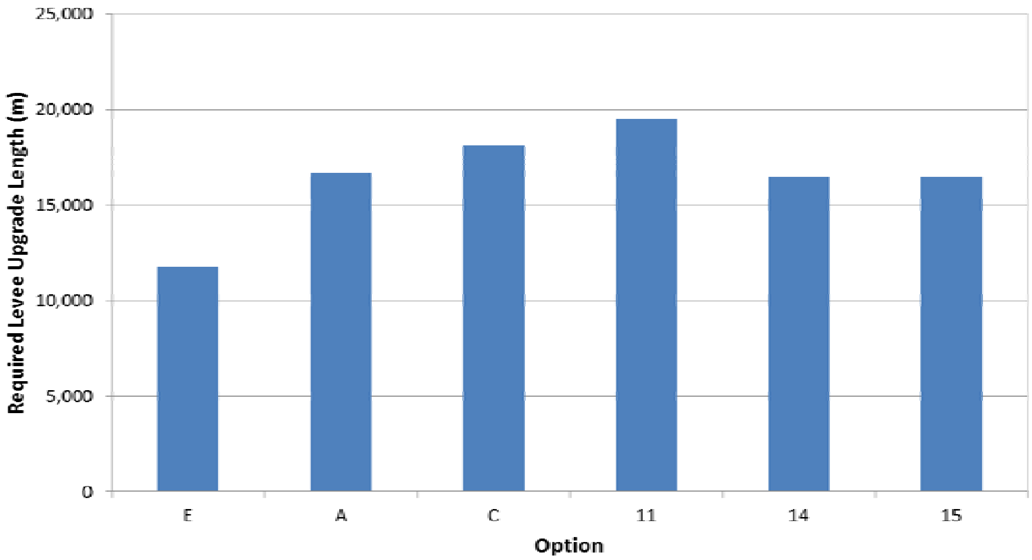


Figure 5-1 Option Levee Raising Flood Mitigation Measure Summary

Table 5-1 Flood Mitigation Measure Summary

Option	Change in Peak Flood Level: 20 Year ARI Event (m)	Levee Length Requiring Raising by 0.05m (m) [1]			Levee Length Requiring Raising by 0.10m (m) [1]			Additional Mitigation
		Grafton	South Grafton	Heber Street	Grafton	South Grafton	Heber Street	
E	0.03	5,450	6,300	0	0	0	0	No additional mitigation measures required.
A	0.04	8400	8300	0	0	0	0	Minor flood level increases of up to 0.10m are shown within Grafton in the mitigated scenario assessment results. Additional slight raising of levee crest levels adjacent to Prince St can mitigate these flood level changes. If selected, mitigation of these impacts can be assessed as part of a preferred option assessment. This additional mitigation will not alter the levee raising lengths reported in the adjacent columns.
C	0.05	3000	4100	0	5400	5600	0	Pump station and detention basin required to manage local drainage issues where Option C passes under the north coast railway viaduct (refer to Appendix B).
11	0.10	1900	1700	0	7700	7100	1100	No additional mitigation measures required.
14	0.04	8900	6500	1100	0	0	0	No additional mitigation measures required.
15	0.04	8900	6500	1100	0	0	0	No additional mitigation measures required.

[1] Refer Figure 5-2 to Figure 5-13 for recommended location and extent of levee raising.

5.1 Option E

The total required bridge length for Option E is approximately 690m.

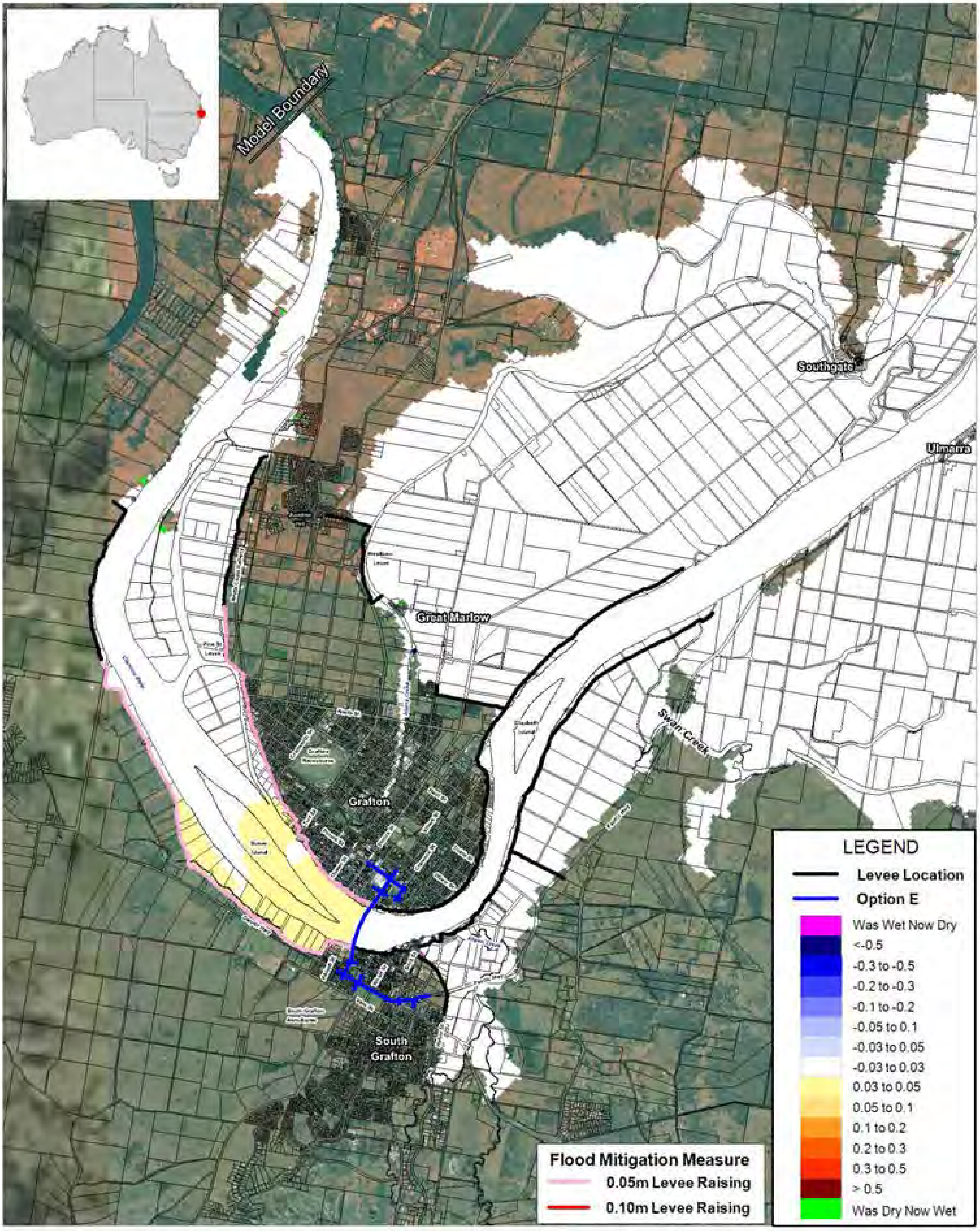
The Grafton/South Grafton levees require raising upstream by 0.05m for an approximate length of 5,450m and 6,300m respectively. The extent of these levee upgrades is highlighted in Figure 5-2 and Figure 5-3.

The flood impacts resulting from the proposed Option E design incorporating these flood mitigation measures are summarised in Table 5-2, Figure 5-2 and Figure 5-3 for the 20 and 100 year ARI flood event respectively. Additionally, Appendix D includes a summary table of site specific flood impacts for buildings near to the option which are not protected by the Grafton and South Grafton urban levees.

Table 5-2 Option E Flood Impact Assessment Results

Location	*Existing Case Peak Flood Level (mAHD)*		*Option E: Change in Peak Flood Level (m)*		
			Mitigated Case (Including Levee Raising)		*Unmitigated Case[1,8]*
	20 Year ARI Event	*100 Year ARI Event*	*20 Year ARI Event*	*100 Year ARI Event*	*100 Year ARI Event*
North Meadows[2]	No flooding	4.8	No change	-0.05	**0.05**
Grafton Business District[3]	No flooding	6.0	No change	-0.06	**0.12**
Junction Hill Floodplain[4]	No flooding	6.0	No change	0.02	-0.01
South Grafton Floodplain[5]	No flooding	6.2	No change	-0.02	**0.20**
Clarence River[6]	8.1	8.5	0.03	0.04	0.02
Swan Creek[7]	6.3	6.6	0.00	0.00	-0.01
Ulmarra[7]	6.1	6.4	0.00	0.00	0.00
Great Marlow[7]	6.1	6.5	0.00	0.00	-0.01
Southgate[7]	6.1	6.4	0.00	0.00	0.00

[1] Unmitigated case result figures provided in Appendix C.
[2] Result extraction location = Intersection of Prince Street and North Street.
[3] Result extraction location = Intersection of Prince Street and Pound Street.
[4] Result extraction location = Intersection of Cranworth Street and North Street.
[5] Result extraction location = Intersection of Abbott Street and Vere Street.
[6] Result extraction location = Upstream of Option.
[7] Result extraction location corresponds to label location in following flood impact figures.
[8] Red highlights significant adverse impact.



Title:

Option E (Mitigated Case)
Peak Flood Level Impact 20 Year ARI Event

Figure: 5-2

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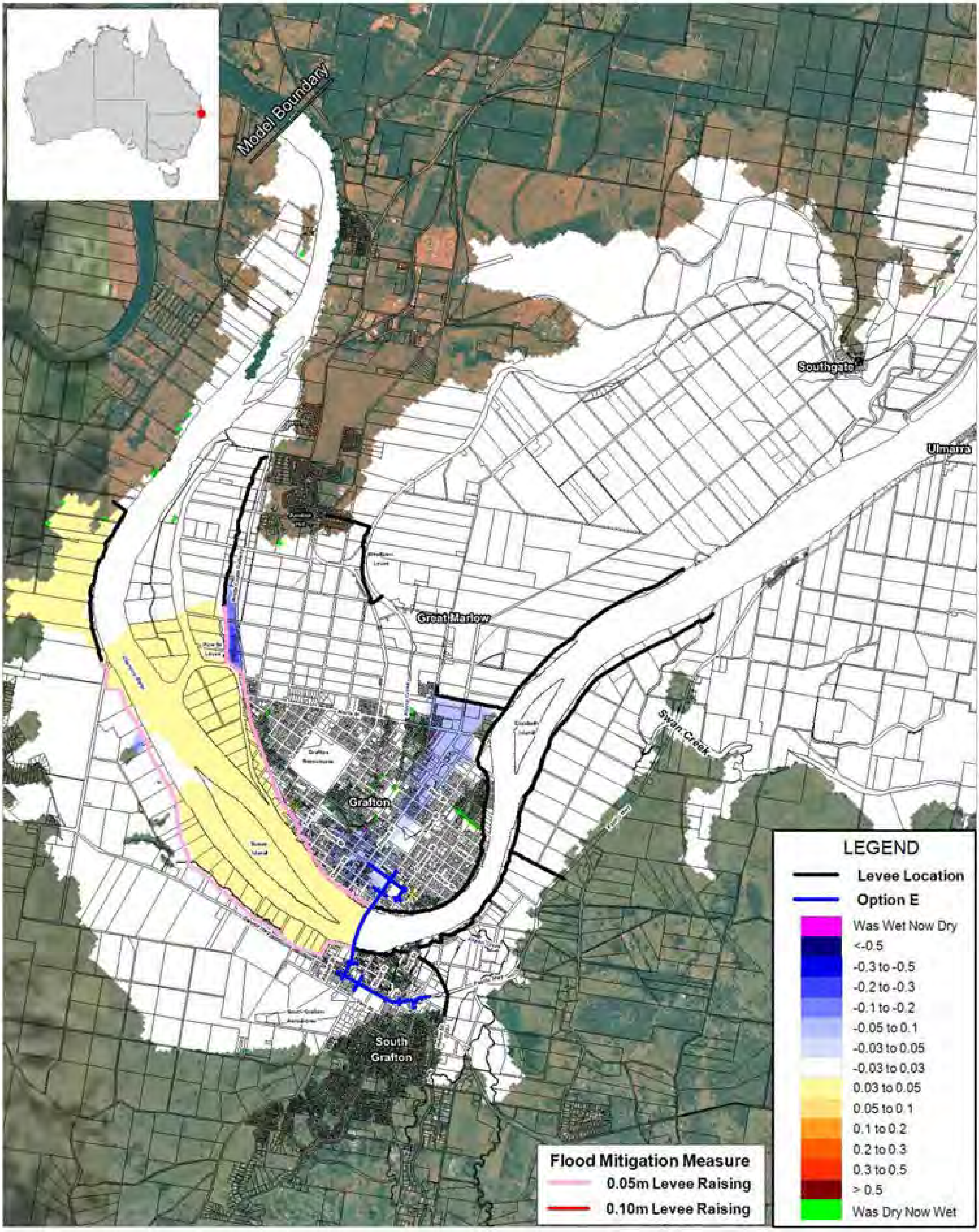

Title:

Option E (Mitigated Case)
Peak Flood Level Impact 100 Year ARI Event

Figure: 5-3

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5.2 Option A

The total required combined bridge/viaduct length for Option A is approximately 620m.

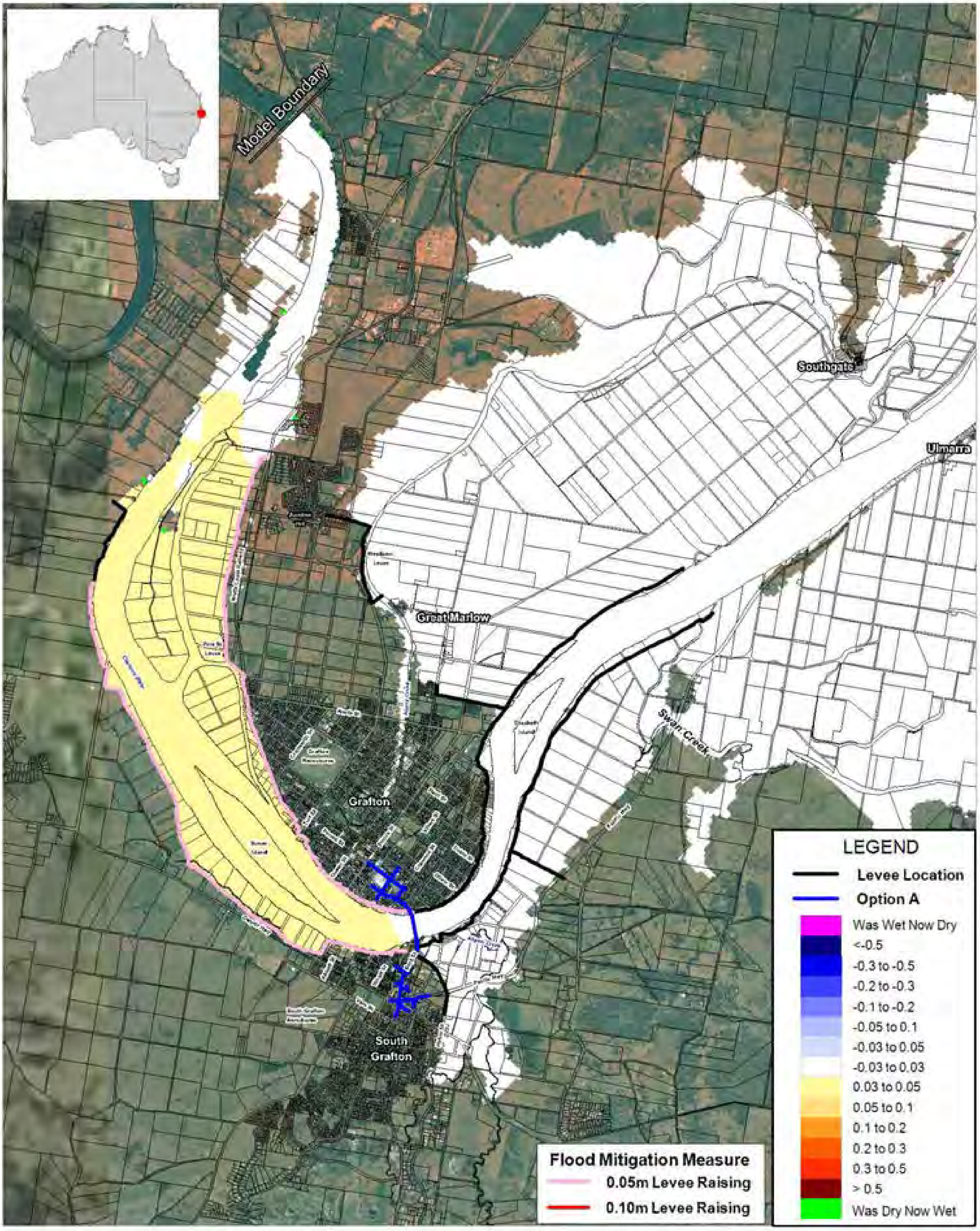
The Grafton/South Grafton levees require raising upstream by 0.05m for an approximate length of 8,400m and 8,300m respectively. The extent of these levee upgrades is highlighted in Figure 5-4 and Figure 5-5.

The flood impacts resulting from the proposed Option A design (including these flood mitigation measures) are summarised in Table 5-3, Figure 5-4 and Figure 5-5 for the 20 and 100 year ARI flood event respectively. Additionally, Appendix D includes a summary table of site specific flood impacts for buildings near to the option which are not protected by the Grafton and South Grafton urban levees.

Table 5-3 Option A Flood Impact Assessment Results

Location	*Existing Case Peak Flood Level (mAHD)*		*Option A: Change in Peak Flood Level (m)*		
			Mitigated Case (Including Levee Raising)		*Unmitigated Case*[1,8]
	20 Year ARI Event	*100 Year ARI Event*	*20 Year ARI Event*	*100 Year ARI Event*	*100 Year ARI Event*
North Meadows[2]	No flooding	4.8	No change	-0.03	**0.24**
Grafton Business District[3]	No flooding	6.0	No change	0.02	**0.21**
Junction Hill Floodplain[4]	No flooding	6.0	No change	-0.01	-0.02
South Grafton Floodplain[5]	No flooding	6.2	No change	-0.02	**0.26**
Clarence River[6]	7.7	8.2	0.04	0.06	0.03
Swan Creek[7]	6.3	6.6	0.00	0.00	-0.01
Ulmarra[7]	6.1	6.4	0.00	0.00	0.00
Great Marlow[7]	6.1	6.5	0.00	0.00	-0.01
Southgate[7]	6.1	6.4	0.00	0.00	0.00

[1] Unmitigated case result figures provided in Appendix C.
[2] Result extraction location = Intersection of Prince Street and North Street.
[3] Result extraction location = Intersection of Prince Street and Pound Street.
[4] Result extraction location = Intersection of Cranworth Street and North Street.
[5] Result extraction location = Intersection of Abbott Street and Vere Street.
[6] Result extraction location = Upstream of Option.
[7] Result extraction location corresponds to label location in following flood impact figures.
[8] Red highlights significant adverse impact.



Title:

Option A (Mitigated Case)
Peak Flood Level Impact 20 Year ARI Event

Figure: **5-4**

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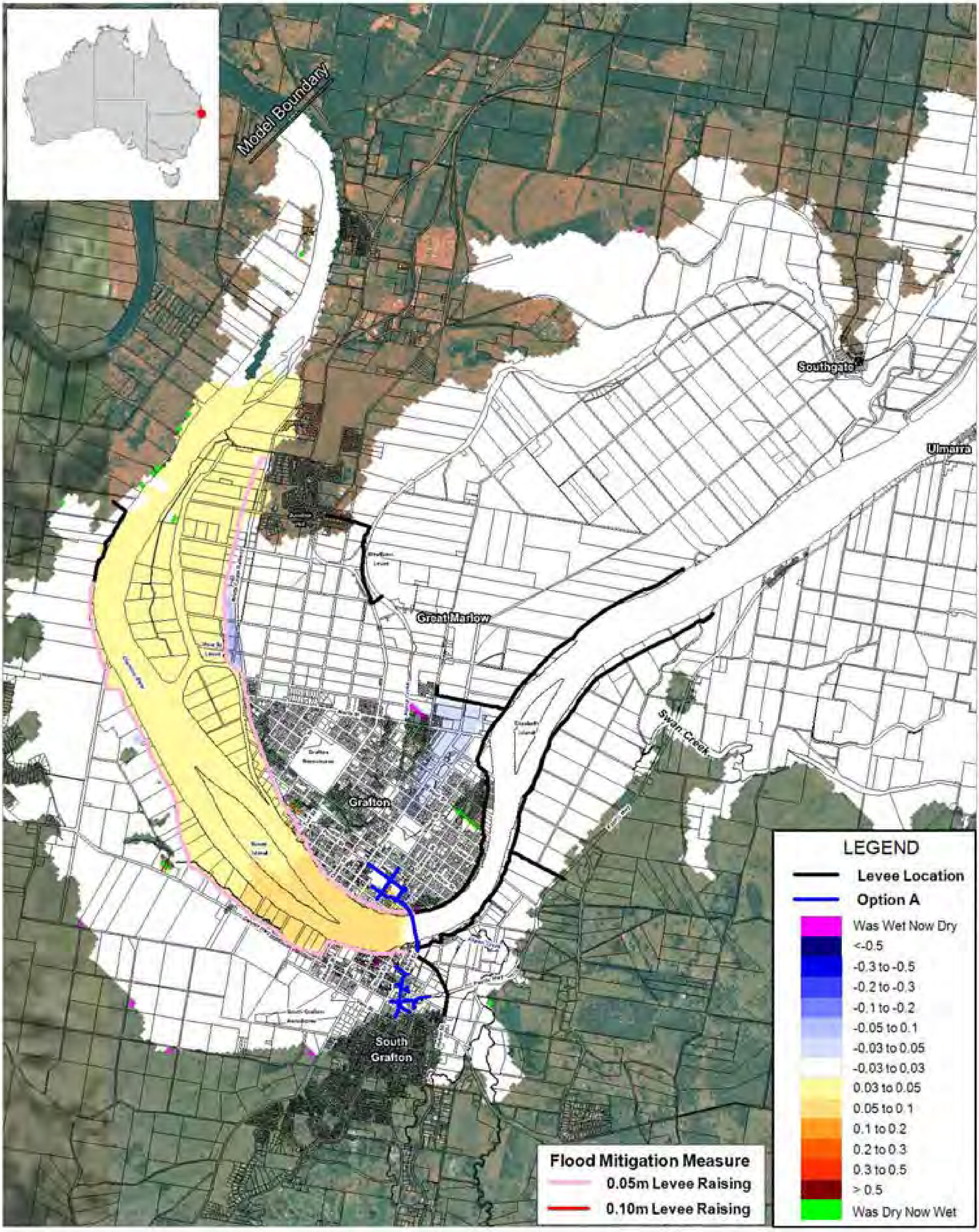

Title:

Option A (Mitigated Case)
Peak Flood Level Impact 100 Year ARI Event

Figure: 5-5

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5.3 Option C

The total required combined bridge/viaduct length for Option C is approximately 580m.

The Grafton/South Grafton levees require raising upstream for an approximate length of 8,400m and 9,700m respectively. The required height of levee raising along these lengths range from 0.05m to 0.10m. The extent of these levee upgrades is highlighted in Figure 5-6 and Figure 5-7.

The flood impacts resulting from the proposed Option C design including these flood mitigation measures are summarised in Table 5-4, Figure 5-6 and Figure 5-7 for the 20 and 100 year ARI flood event respectively. A summary table of site specific flood impacts for buildings near to the option which are not protected by the Grafton and South Grafton urban levees has also been included in Appendix D.

In addition to the levee raising, Option C requires additional flood mitigation measures where the route passes under the North Coast Railway viaduct. As part of this option, ground lowering is necessary to provide sufficient clearance for heavy vehicles under the viaduct. This is in an area known to experience existing local drainage issues.

A preliminary assessment of the local drainage flood behaviour has been undertaken including development of a local drainage model. To achieve immunity during the 20 year ARI event, flood levels adjacent to the viaduct need to be less than 1.9mAHD. One conceptual drainage strategy for achieving this includes the following features:

- A catch drain north of Option C;
- A detention basin south of Option C with a 560m3 capacity (2.8m x 20m x 10m) and a design bed level of 0.7mAHD;
- A 2m3/s capacity pump station to extract water from the detention basin; and
- 8 x 0.5m x 1m box culverts under Option C, providing connectivity between the catchment north of Option C and the proposed detention basin.

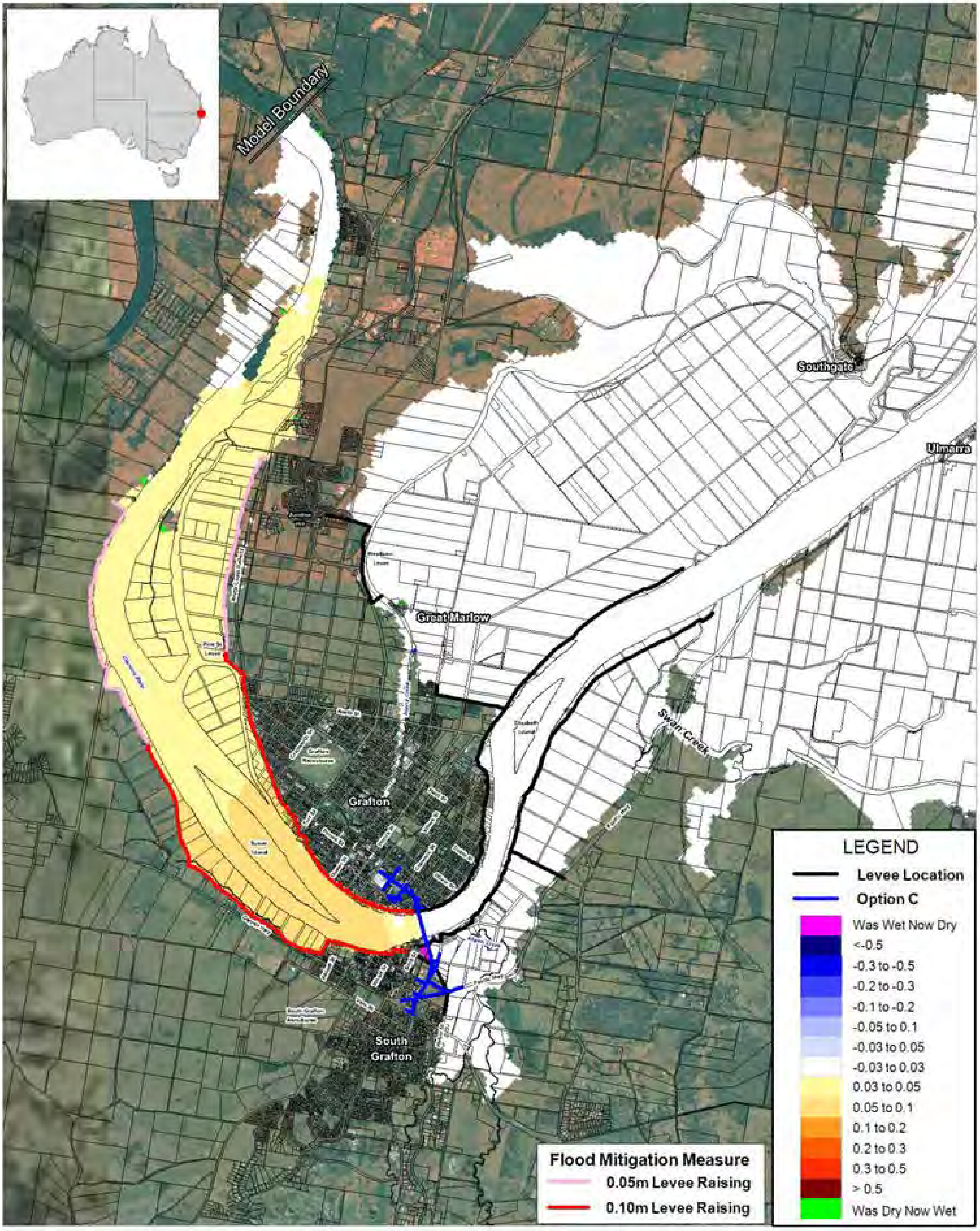
The local drainage assessment, including assessment of this strategy and flood impact result figures, is provided in Appendix B.

This drainage strategy has been identified as one possible option for achieving 20 year ARI flood immunity of the Option C approach road for the purposes of route option comparison. If Option C is selected as the preferred route option, it is recommended that further assessment of this and alternate drainage strategies be investigated.

Table 5-4 Option C Flood Impact Assessment Results

Location	*Existing Case Peak Flood Level (mAHD)*		*Option C: Change in Peak Flood Level (m)*		
			Mitigated Case (Including Levee Raising)		*Unmitigated Case*[1,8]
	20 Year ARI Event	*100 Year ARI Event*	*20 Year ARI Event*	*100 Year ARI Event*	*100 Year ARI Event*
North Meadows[2]	No flooding	4.8	No change	-0.08	**0.38**
Grafton Business District[3]	No flooding	6.0	No change	-0.09	**0.27**
Junction Hill Floodplain[4]	No flooding	6.0	No change	0.02	-0.02
South Grafton Floodplain[5]	No flooding	6.2	No change	0.00	**0.44**
Clarence River[6]	7.6	8.1	0.05	0.10	0.03
Swan Creek[7]	6.3	6.6	0.00	0.00	-0.01
Ulmarra[7]	6.1	6.4	0.00	0.00	0.00
Great Marlow[7]	6.1	6.5	0.00	0.00	-0.01
Southgate[7]	6.1	6.4	0.00	0.00	0.00

[1] Unmitigated case result figures provided in Appendix C.
[2] Result extraction location = Intersection of Prince Street and North Street.
[3] Result extraction location = Intersection of Prince Street and Pound Street.
[4] Result extraction location = Intersection of Cranworth Street and North Street.
[5] Result extraction location = Intersection of Abbott Street and Vere Street.
[6] Result extraction location = Upstream of Option.
[7] Result extraction location corresponds to label location in following flood impact figures.
[8] Red highlights significant adverse impact.



Title:

Option C (Mitigated Case)
Peak Flood Level Impact 20 Year ARI Event

Figure: 5-6

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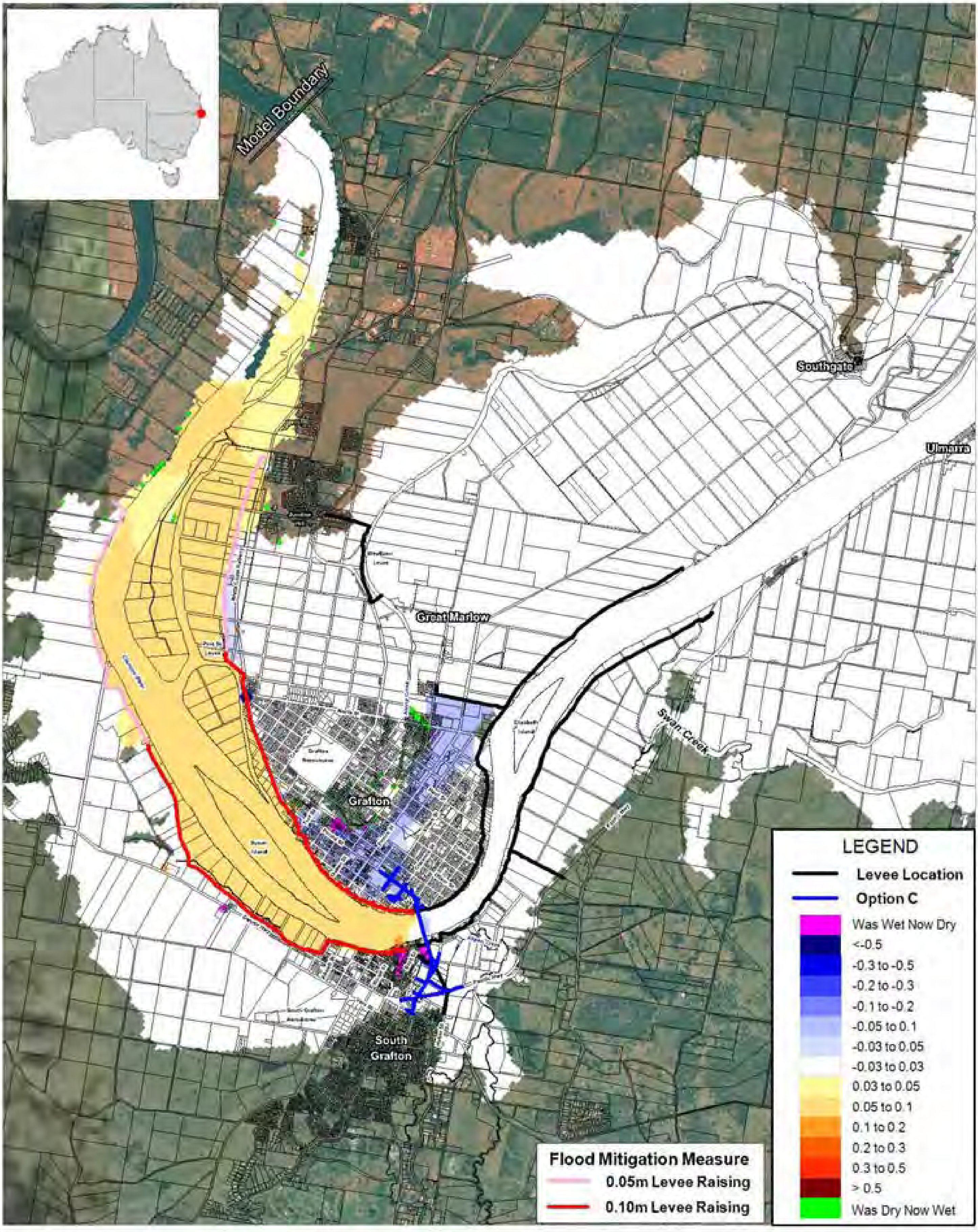

Title:

Option C (Mitigated Case)
Peak Flood Level Impact 100 Year ARI Event

Figure: **5-7**

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5.4 Option 11

The total required combined bridge/viaduct length for Option 11 is approximately 840m.

The Grafton/South Grafton[3] levees require raising upstream by 0.05m to 0.1m for an approximate total length of 9,600m and 9,900m respectively. The extent of these levee upgrades is highlighted in Figure 5-8 and Figure 5-9.

Within the rural areas of South Grafton adjacent to Alipou Creek (between the Clarence River and the Pacific Highway) Option 11 results in changes in flood levels within 0.10m. These flood level changes are considered acceptable, given they are confined to rural, undeveloped areas which do not include any critical infrastructure.

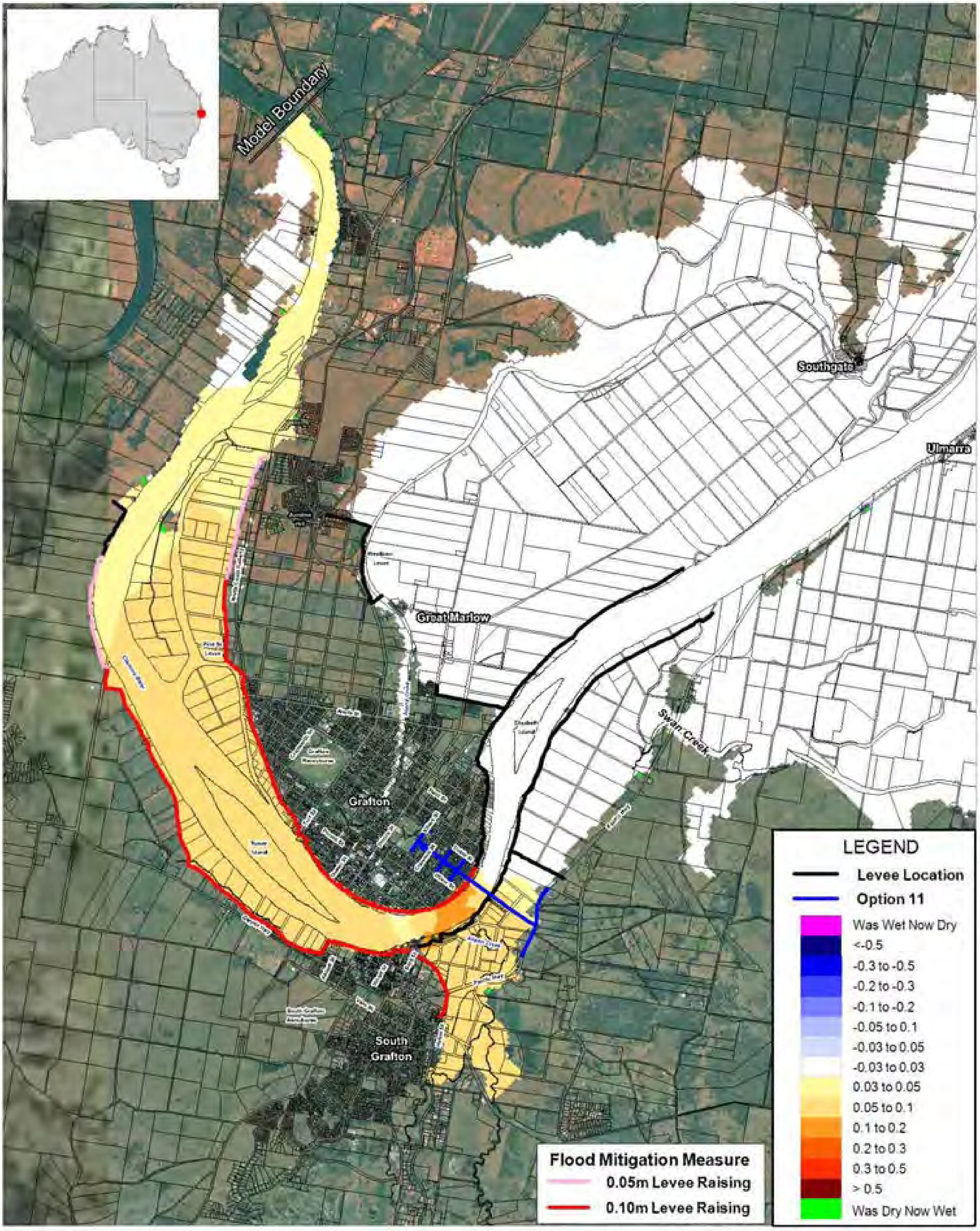
The flood impacts resulting from the proposed Option 11 design including these flood mitigation measures are summarised in Table 5-5, Figure 5-8 and Figure 5-9 for the 20 and 100 year ARI flood event respectively. A summary table of site specific flood impacts for buildings near to the option which are not protected by the Grafton and South Grafton urban levees has also been included in Appendix D.

[3] Including Heber Street levee

Table 5-5 Option 11 Flood Impact Assessment Results

Location	Existing Case Peak Flood Level (mAHD)		Option 11: Change in Peak Flood Level (m)		
			Mitigated Case (Including Levee Raising)		Unmitigated Case[1,8]
	20 Year ARI Event	100 Year ARI Event	20 Year ARI Event	100 Year ARI Event	100 Year ARI Event
North Meadows[2]	No flooding	4.8	No change	-0.03	**0.55**
Grafton Business District[3]	No flooding	6.0	No change	-0.08	**0.28**
Junction Hill Floodplain[4]	No flooding	6.0	No change	0.01	-0.02
South Grafton Floodplain[5]	No flooding	6.2	No change	0.01	**0.54**
Clarence River[6]	7.5	7.8	0.10	0.09	0.05
Swan Creek[7]	6.3	6.6	0.00	0.00	-0.01
Ulmarra[7]	6.1	6.4	0.00	0.00	0.00
Great Marlow[7]	6.1	6.5	0.00	0.00	-0.01
Southgate[7]	6.1	6.4	0.00	0.00	0.00

[1] Unmitigated case result figures provided in Appendix C.
[2] Result extraction location = Intersection of Prince Street and North Street.
[3] Result extraction location = Intersection of Prince Street and Pound Street.
[4] Result extraction location = Intersection of Cranworth Street and North Street.
[5] Result extraction location = Intersection of Abbott Street and Vere Street.
[6] Result extraction location = Upstream of Option.
[7] Result extraction location corresponds to label location in following flood impact figures.
[8] Red highlights significant adverse impact.



Title:

Option 11 (Mitigated Case)
Peak Flood Level Impact 20 Year ARI Event

Figure: 5-8

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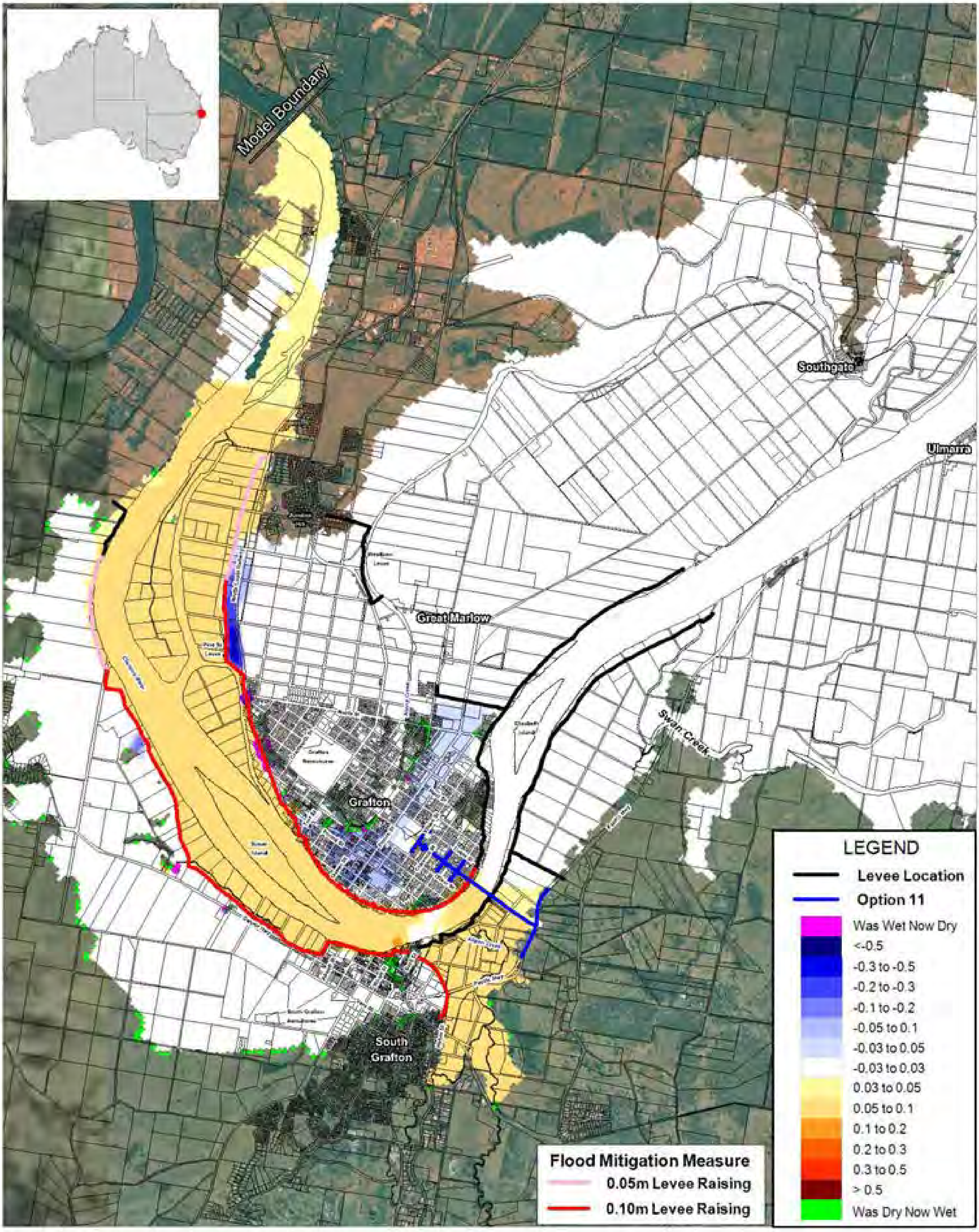

Title:

Option 11 (Mitigated Case)
Peak Flood Level Impact 100 Year ARI Event

Figure: **5-9**

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5.5 Option 14/15

In total, the required combined bridge/viaduct length for Options 14 and 15 is approximately 1,540m.

As the bridge and viaduct portions of these routes are the same the regional flood impacts and required flood mitigation measure for Options 14 and 15 are equivalent. The Grafton/South Grafton levees require raising upstream by 0.05m for an approximate length of 8,900m and 7,600m respectively. The extent of these levee upgrades is highlighted in Figure 5-10 to Figure 5-13.

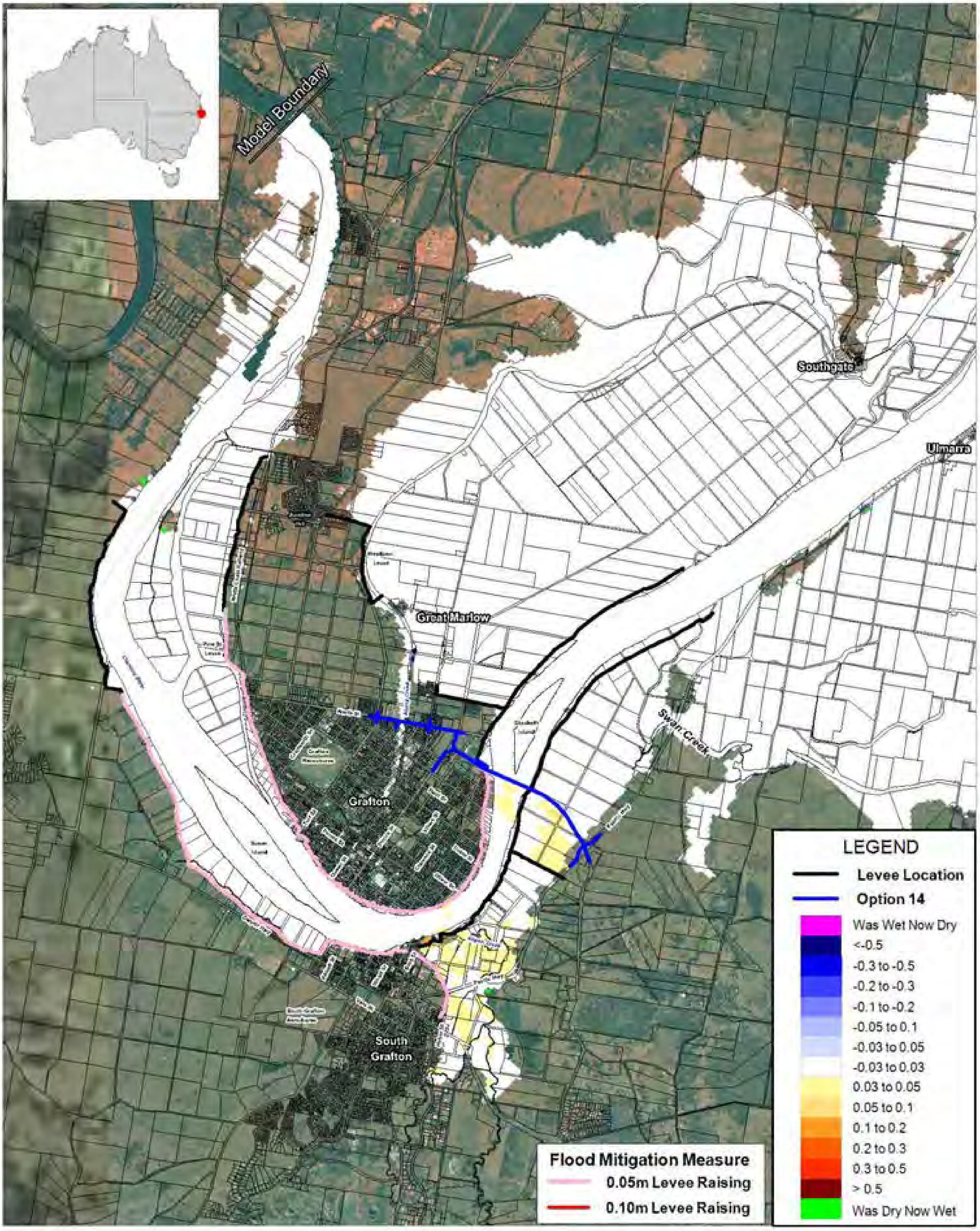
Within the rural areas of South Grafton adjacent to Alipou Creek Options 14 and 15 result in changes in flood levels within 0.05m. These flood level changes are considered acceptable, given they are confined to rural, undeveloped areas which do not include any critical infrastructure.

The flood impacts resulting from the proposed Options 14 and 15 design including these flood mitigation measures are summarised in Table 5-6, Figure 5-10 to Figure 5-13 for the 20 and 100 year ARI flood events. Additionally, Appendix D includes a summary table of site specific flood impacts for buildings near to the option which are not protected by the Grafton and South Grafton urban levees.

Table 5-6 Option 14/15 Flood Impact Assessment Results

Location	Existing Case Peak Flood Level (mAHD)		Option 14/15: Change in Peak Flood Level (m)		
			Mitigated Case (Including Levee Raising)		Unmitigated Case[1,8]
	20 Year ARI Event	100 Year ARI Event	20 Year ARI Event	100 Year ARI Event	100 Year ARI Event
North Meadows[2]	No flooding	4.8	No change	-0.10	**0.24**
Grafton Business District[3]	No flooding	6.0	No change	-0.10	**0.12**
Junction Hill Floodplain[4]	No flooding	6.0	No change	0.01	-0.01
South Grafton Floodplain[5]	No flooding	6.2	No change	0.02	**0.18**
Clarence River[6]	7.2	7.4	0.04	0.04	0.04
Swan Creek[7]	6.3	6.6	0.00	0.00	-0.01
Ulmarra[7]	6.1	6.4	0.00	0.00	0.00
Great Marlow[7]	6.1	6.5	0.00	0.00	-0.01
Southgate[7]	6.1	6.4	0.00	0.00	0.00

[1] Unmitigated case result figures provided in Appendix C.
[2] Result extraction location = Intersection of Prince Street and North Street.
[3] Result extraction location = Intersection of Prince Street and Pound Street.
[4] Result extraction location = Intersection of Cranworth Street and North Street.
[5] Result extraction location = Intersection of Abbott Street and Vere Street.
[6] Result extraction location = Upstream of Option.
[7] Result extraction location corresponds to label location in following flood impact figures.
[8] Red highlights significant adverse impact.



Title:

Option 14 (Mitigated Case)
Peak Flood Level Impact 20 Year ARI Event

Figure: 5-10

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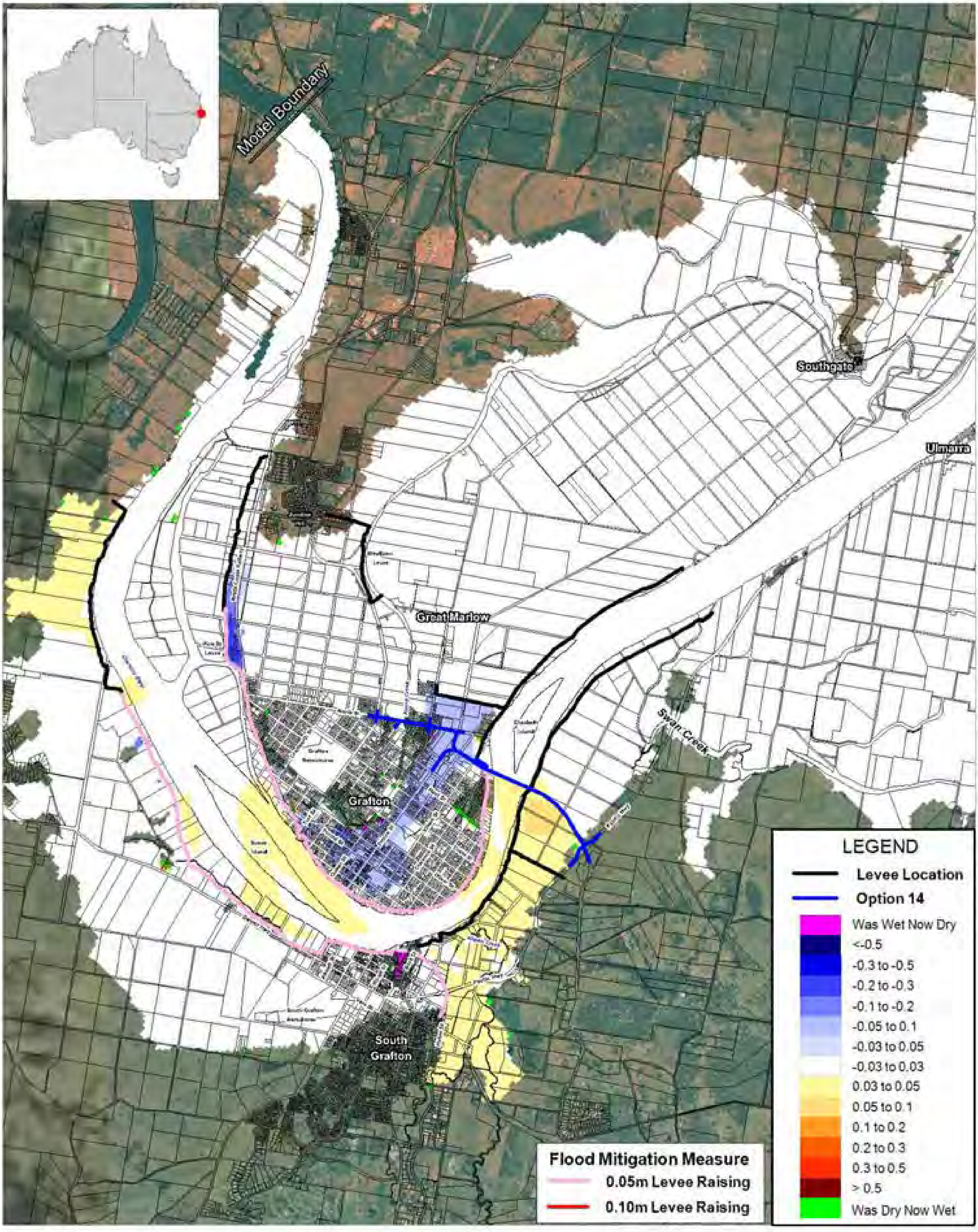

Title:

Option 14 (Mitigated Case)
Peak Flood Level Impact 100 Year ARI Event

Figure: 5-11

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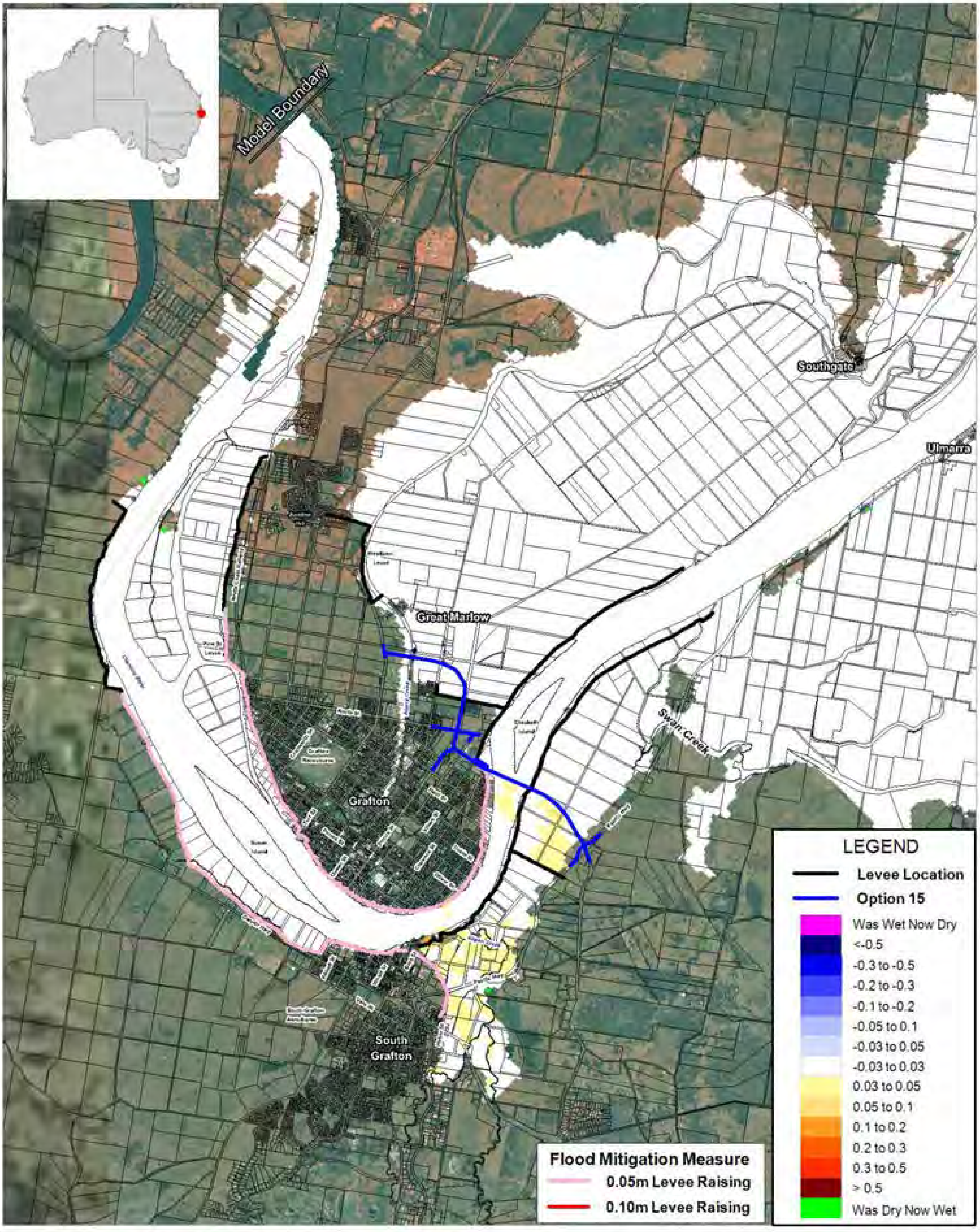

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Option 15 (Mitigated Case)
Peak Flood Level Impact 20 Year ARI Event

Figure: 5-12

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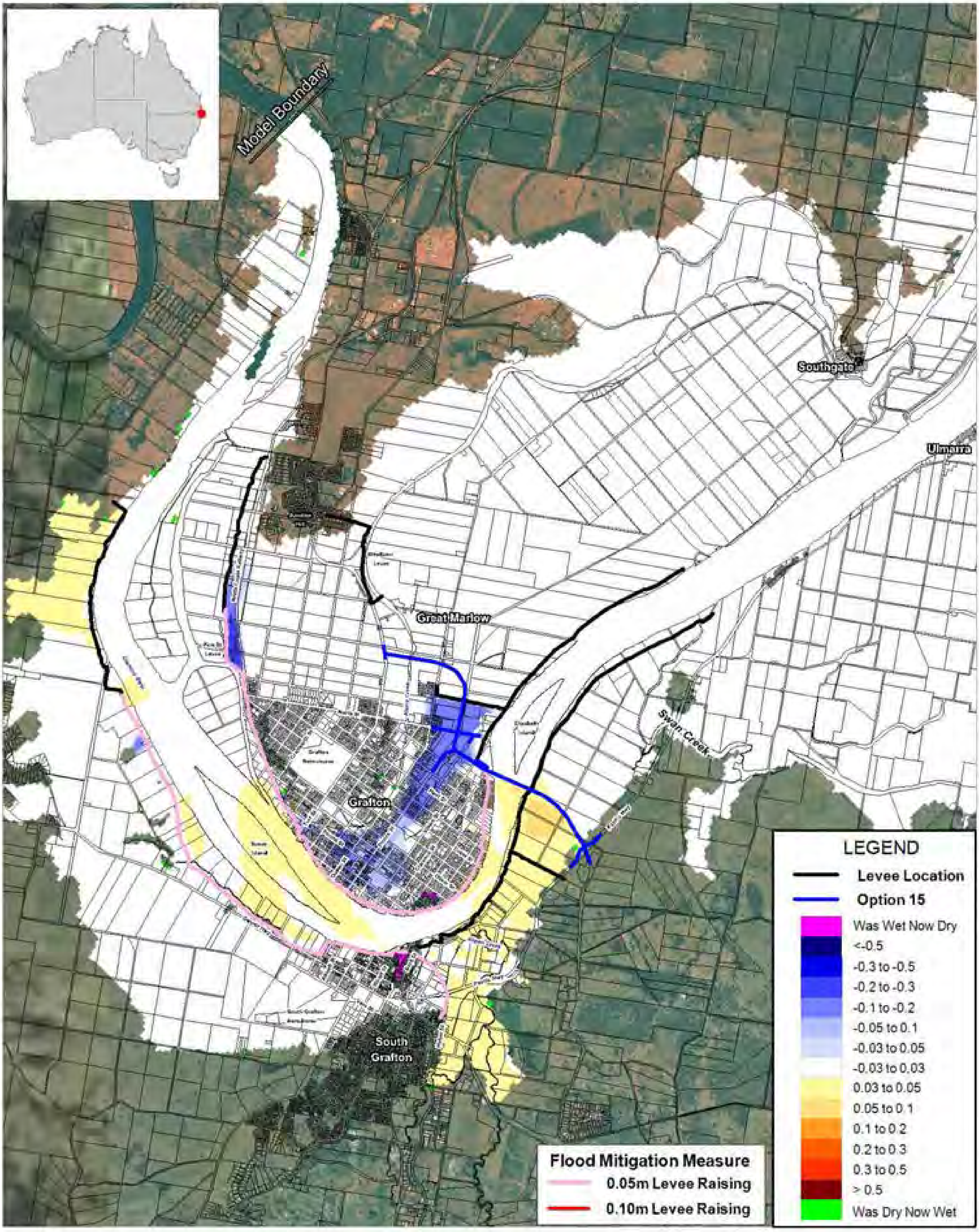

Title:

Option 15 (Mitigated Case)
Peak Flood Level Impact 100 Year ARI Event

Figure: **5-13**

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5.6 Emergency Response - Flood Evacuation

Grafton is protected by a ring levee system which has an approximate 5% Average Exceedance Probability (AEP) 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 (WBM, 2004). Due to these factors, flooding poses a significant risk to the 11,000 residents in Grafton. In response to these risks, the State Emergency Services (SES) have developed a flood evacuation plan for Grafton, documented in the Clarence Valley Council Local Flood Plan (SES, 2008).

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 St gauge;
- Vulnerable community groups requiring special consideration/assistance during an evacuation;
- Evacuation routes; and
- Evacuation centres.

The Grafton Evacuation Strategy (SES, 2008) is provided in Figure 5-14. The strategy 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. During a flood event, following overtopping of the Grafton levees, ponding within the floodplain between Grafton and Junction Hill 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 may potentially benefit flood evacuation within Grafton. Key factors which influence how the additional crossing will impact evacuation operations include:

1. Evacuation Route Contingency – Shown in Figure 5-14, evacuation routes currently converge within the business district of Grafton. Options which are not located adjacent to the existing bridge provide some contingency for an evacuation scenario in which roads within the business district of Grafton are compromised (inundated by flooding or impacted by a serious traffic crash). Furthermore, options which are distanced away from the existing Grafton Bridge will require new evacuation routes in addition to those shown in Figure 5-14 and Figure 5-15. The additional evacuation routes will reduce traffic congestion within the Grafton business district.
2. 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 5% AEP event. Due to this local flood behaviour, were possible, road elevations of flood evacuation routes should be greater than surrounding land and avoid traverse drainage depressions which many prematurely compromise the evacuation route.
3. 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.

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

In all cases, the proposed Options will increase the efficiency of mass evacuation of Grafton during a major flood event. Acknowledging this, the proposed Options have been reviewed against the above listed factors, summarised in Table 5-7 and shown in Figure 5-15. Ranking of a preferred option from an emergency response perspective has not been completed as the relative importance of these factors is complex, along with other aspects of emergency operations not detailed here. If required, such a ranking process should be undertaken in consultation with the local SES and Clarence Valley Council.

Table 5-7 Emergency Response Considerations Summary

<table>
<tr><th>Option</th><th>Evacuation Route Contingency</th><th>Evacuation Route Flood Immunity</th><th>Provision of Services and Shelter</th><th>Vulnerable Community Groups</th></tr>
<tr><td>All</td><td>By providing an additional crossing of the Clarence river, all options would increase the efficiency of the evacuation of Grafton during a major flood event.</td><td>See below for option specific considerations.</td><td>See below for option specific considerations.</td><td>See below for option specific considerations.</td></tr>
<tr><td>E</td><td rowspan="3">Option E, A and C use current Grafton evacuation routes.
1) No contingency if evacuation routes within the business district of Grafton are inundated or impeded.
2) Concentrates evacuation though the business district of Grafton. Evacuation efficiency may be limited by traffic congestion within the Grafton town centre.</td><td>Bridge approach in South Grafton directs traffic to potentially flood prone area adjacent to South Grafton Aerodrome.</td><td rowspan="3">Direct access to flood free evacuation services and shelter at South Grafton.</td><td rowspan="3">No additional benefit.</td></tr>
<tr><td>A</td><td>Similar to current situation. Limited by inundation of approach road in Grafton.</td></tr>
<tr><td>C</td><td>Requires lowering of the bridge approach road to achieve clearance under the railway viaduct. This may compromise the evacuation route earlier than other options within Grafton.
This issue may partially be mitigated via design of an emergency access to the proposed bridge approach via Kent Street. This additional access design however will only benefit properties east of Kent Street. Properties west of Kent Street will not have access to the bridge.</td></tr>
<tr><td>11</td><td rowspan="2">Provides an additional evacuation route out of Grafton which is separate from the current routes that use the existing Grafton bridge and approaches.
1) Provides a contingency if evacuation routes to the existing Grafton bridge are compromised.
2) Will reduce traffic congestion within the Grafton business district, where evacuation routes currently converge.</td><td rowspan="2">Option 11, 14 and 15 Grafton approaches may remain flood free longer (up to approx. 4hrs) than the Option A, E and C approaches.
East of the Clarence River, flooding associated with Alipou Creek inundates the Pacific Highway. Access to South Grafton may be achieved via Centenary Road and Lillypool Road.</td><td rowspan="2">Options provide access to flood free land, though may not provide access to evacuation services and shelter.
Access to South Grafton services and shelter may be achieved via Centenary Drive and Lillypool Road (pending local drainage).</td><td rowspan="2">Well located to assist evacuation of Grafton Base Hospital and surrounding aged care facilities (refer to Figure 5-15).</td></tr>
<tr><td>14/15</td></tr>
<tr><td colspan="5">Information Source: BMT WBM Pty Ltd assessment and flood evacuation meeting attended by representatives from RMS, Clarence Valley Council and local SES (30/3/2012).</td></tr>
</table>

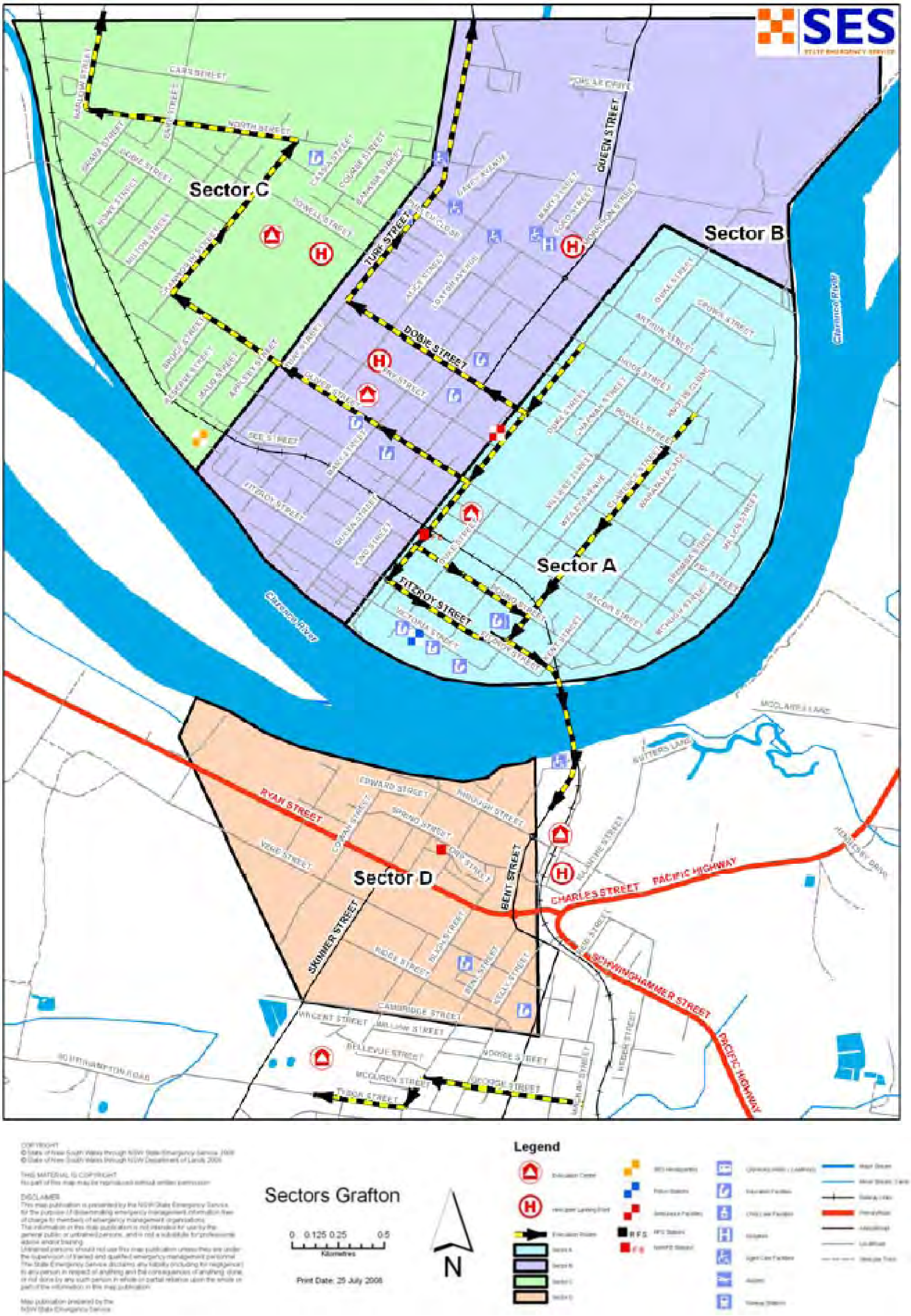
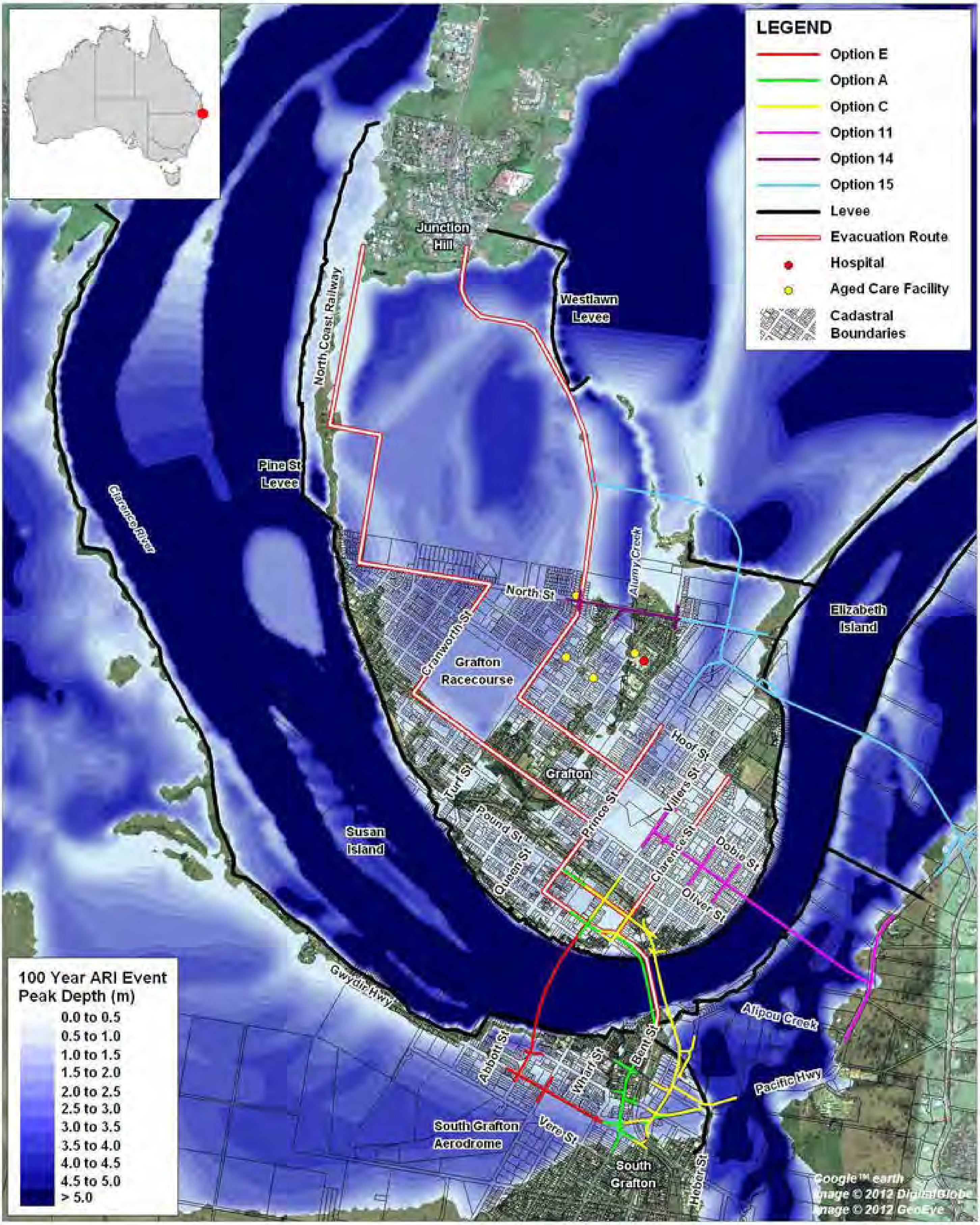


Figure 5-14 Grafton Evacuation Strategy (SES, 2008)



Title:

Grafton Evacuation Strategy - Options Comparison

Figure: 5-15

Rev: A

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6 CONCLUSIONS

The Route Options Development Report documents the flood impact assessment undertaken for the proposed additional crossing of the Clarence River at Grafton. The flooding assessment aimed to:

1. Estimate the flood impacts associated with the six (6) route option designs;
2. Identify necessary mitigation measures required to maintain the current level of flood immunity within Grafton and South Grafton following the construction of the proposed route option designs; and
3. Identify the qualitative flood evacuation considerations affected by the route option locations and designs.

The assessment has been completed using the lower Clarence River flood model, developed as part of the Lower Clarence River Flood Study Review (WBM, 2004). Flood impacts resulting from the proposed options were assessed following update of the flood model to represent the key design features associated with each of the assessed option designs. Where the proposed option designs are likely to adversely impact the flood immunity in Grafton and South Grafton, mitigation measures have been proposed and assessed. Compensatory levee raising is proposed for all options.

Downstream from Grafton, the assessment has found that all options do not impact the flood behaviour at Swan Creek, Ulmarra, Great Marlow or Southgate.

For Option C, additional mitigation is required to achieve target flood immunity levels for the bridge approach road in Grafton due to local drainage issues. A local drainage model was developed and a conceptual drainage strategy proposed and assessed.

Table 6-1 summarises the key design features, flood impacts, flood mitigation measures and emergency response considerations for each of the assessed route options. Provided these flood mitigation measures are implemented, the route options would maintain the existing level of flood immunity within Grafton and South Grafton. The information provided in Table 6-1 will contribute to the preferred option comparison and selection for the additional crossing of the Clarence River in Grafton.

Table 6-1 Options Assessment Summary

Option	*Required Bridge / Viaduct Length (m)*	*20 Year ARI Event Change in Peak Flood Level (m)*[1]	*Mitigation Measure Required (Length of Levee Raising (m)*	*Significant Emergency Response Considerations*	*Additional Commentary*
All	See below	See below	See below	By providing an additional crossing of the Clarence river, all options would increase the efficiency of the evacuation of Grafton during a major flood event.	See below
E	690	+0.03	11,750	Option E, A and C use current Grafton evacuation routes: 1) No contingency if evacuation routes within the business district of Grafton are inundated or impeded. 2) Concentrates evacuation though the business district of Grafton. Evacuation efficiency may be limited by traffic congestion or a crash within the Grafton town centre. Option C Only: Requires lowering of the bridge approach road to achieve clearance under the railway viaduct. This may compromise the evacuation route earlier than other options within Grafton.	NA
A	620	+0.04	16,700		NA
C	580	+0.05	18,100		Additional mitigation measures required to manage local drainage issues.
11	840	+0.10	19,500	Option 11, 14 and 15 provide an additional evacuation route out of Grafton which is separate from the current routes that use the existing Grafton bridge and approaches: 1) Provides a contingency if evacuation routes to the existing Grafton bridge are compromised. 2) Will reduce traffic congestion within the Grafton business district, where evacuation routes currently converge. These options are also well located to assist evacuation of Grafton Base Hospital and surrounding aged care facilities.	NA
14	1,540	+0.04	16,500		
15	1,540	+0.04	16,500		

[1] Result extraction location = Upstream of Option.

7 REFERENCES

BMT WBM (2010) *"Lower Clarence River May 2009 Flood Event: Event Summary and Model Validation",* Prepared by BMT WBM for the NSW Department of Environment, Climate Change and Water.

PWD (1988) *"Lower Clarence River Flood Study",* PWD No 86010, December 1986.

SES (2007) *"Clarence Valley Local Flood Plan",* Prepared by the NSW State Emergency Service.

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

APPENDIX A: LOWER CLARENCE RIVER FLOOD MODEL

The hydraulic model used for this assessment was developed and calibrated as part of the *Lower Clarence Flood Study Review* (WBM, 2004). The extent of the Lower Clarence flood model is shown in Figure A- 2. The following sections outline the model input used by the flood model.

A.1 Model Geometry

Various topographic datasets were used to develop the Lower Clarence flood model, which has subsequently formed the base dataset of the model used for this *Route Options Development Report*.

The topography datasets used to define the catchment topography include:

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

A.2 Hydraulic Roughness

Landuse mapping is used by the hydraulic model to represent the various vegetation types and associated hydraulic roughness within the model. The landuse mapping used for this study is consistent with the data used in the *Lower Clarence Flood Study Review* (WBM, 2004).

In total, 10 areas of different landuse type were used, based on aerial photography and planning data provided by CVC. The Manning's 'n' values adopted for the various defined landuses within the hydraulic model are listed in Table A- 1.

Table A- 1 Lower Clarence Flood Model Landuse Categories

Landuse Type	*Manning's n Coefficient*
River Bank	0.08
River	0.025
Island Vegetation	0.08
Drainage Channel	0.035
Pasture	0.08
Sugar Cane	0.15
Crops	0.10
Forest	0.20
Urban Blocks	0.30
Parks	0.04

A.3 Model Boundaries

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

- Flood inflows for the Clarence River at Mountain View;
- Flood inflows for the Clarence River tributaries downstream of Mountain View;
- Catchment rainfall in rural floodplain areas; and
- Ocean water levels.

The derivation of these inflow conditions for the model validation and design event modelling undertaken for this study are provided below.

A.3.1 Design Event Model Inflows

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

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

Flood Event	*Clarence River Inflow (m^3/s)*	*Tributary Inflows (m^3/s)*						
		Glenugie Creek	*Coldstream River*	*Shark Creek*	*Sportsmans Creek*	*Great Estuary Creek*	*Cowley Creek*	*Esk River*
5 year ARI	9,360	223	486	66	458	192	209	780
10 year ARI	13,717	267	582	79	658	228	248	923
20 year ARI	16,280	326	708	96	658	276	300	1,110
50 year ARI	18,220	407	877	118	813	341	370	1,361
100 year ARI	19,060	445	957	127	884	367	401	1,462
PMF Event	29,162	715	1538	201	1438	587	641	2,330

A.3.2 Clarence River Inflows

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

Four “historical” rating curves were derived to represent four distinct floodplain states. These rating curves were then used to derive revised peak inflows based on the recorded flood levels at Prince Street Gauge over the last 150 years.

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

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

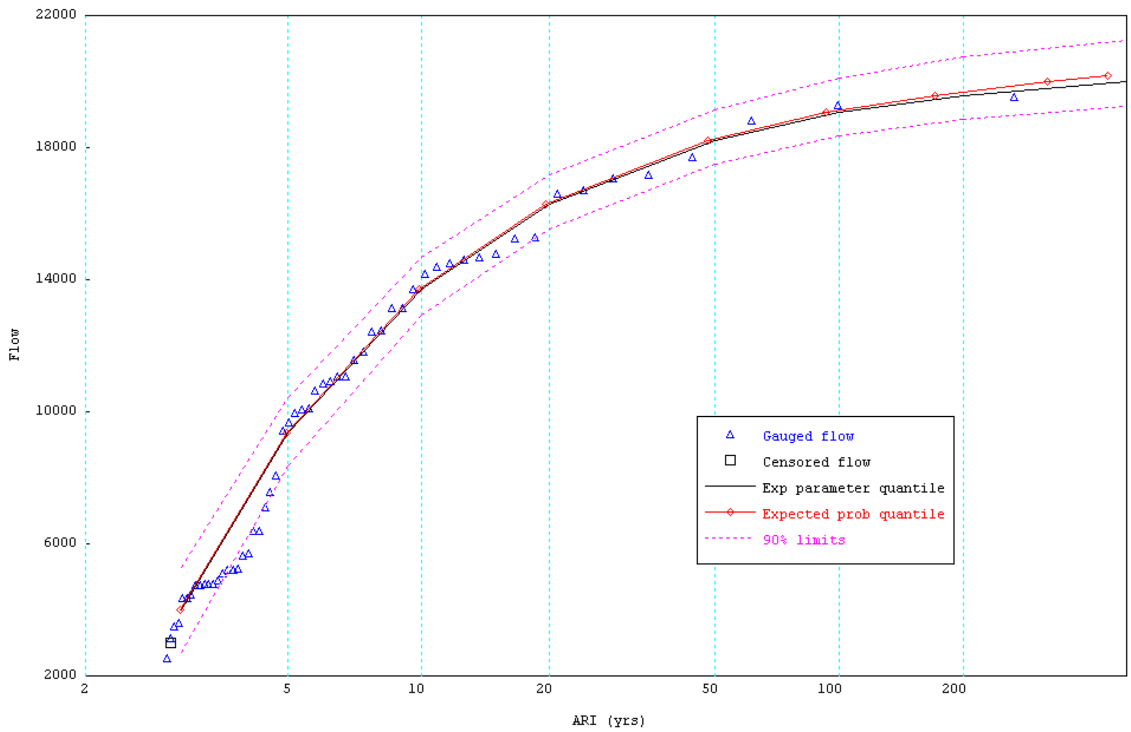

Figure A- 1 Flood Frequency Curve using GEV **(Annual Series of Flows from 1839 to 2000)**

A.3.3 Tributary Inflows

The design rainfall and temporal patterns for the tributary catchments as recommended in Australian Rainfall and Runoff (1987) were used as input to the hydrologic models of these catchments. For the initial and continuing rainfall losses, values of 30mm and 2mm/h were used. These losses are typical of values used for design flood assessments of NSW coastal rivers.

A.3.4 Floodplain Runoff

The rainfall on the floodplain was simulated as runoff to the 2D flood model by simulating ponding of the rainfall immediately on the floodplain without any flood routing.

A.3.5 Ocean Boundary Condition

WBM (2004) adopted design flood ocean levels defined by the *Lower Clarence River Flood Study* (PWD, 1988). These ocean boundaries have subsequently been adopted for this study.

A.4 Model Calibration

During the *Lower Clarence Flood Study Review* (WBM, 2004), calibration of the developed flood model was undertaken for the June 1967, January 1968, May 1980, April 1988, May 1996 and March 2001 flood events. Additional Calibration of the lower Clarence flood model was completed in 2010 as part of the *Lower Clarence River May 2009 Flood Event: Event Summary and Model Validation (BMT WBM, 2010).* A summary of the calibration results is provided below.

LEGEND

Lower Clarence Flood Model Extent

River Gauge Locations

Model Inflows

Model Outflows

Title:

Lower Clarence Flood Model

Figure: A-2

Rev: A

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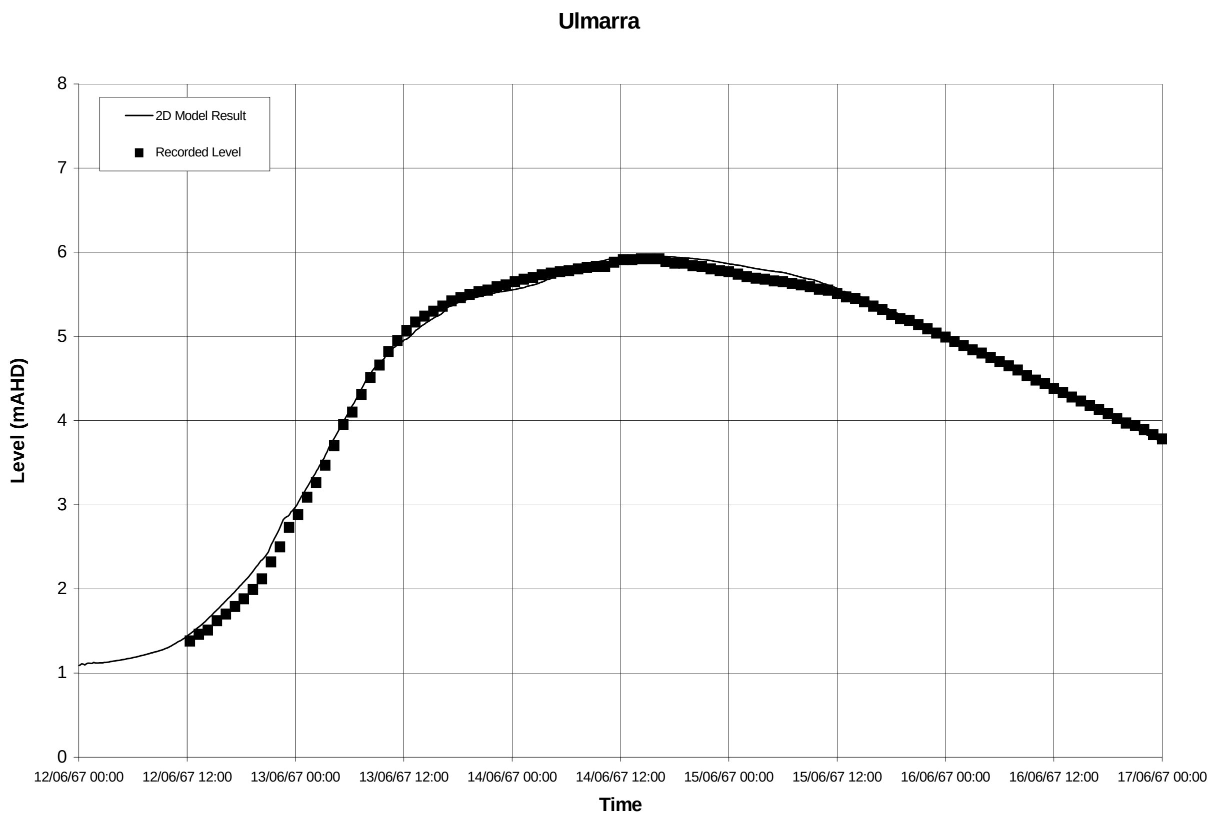
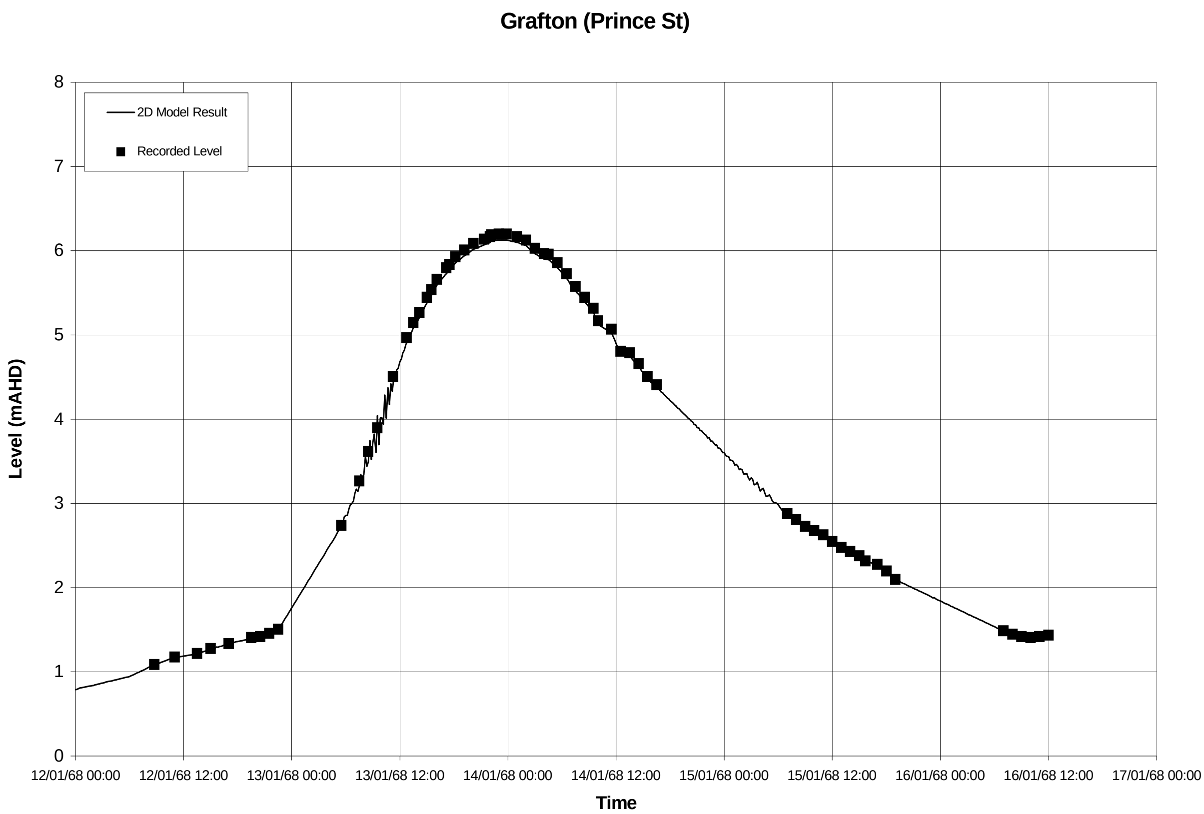


Figure A- 3 June 1967 Flood Model Calibration Results



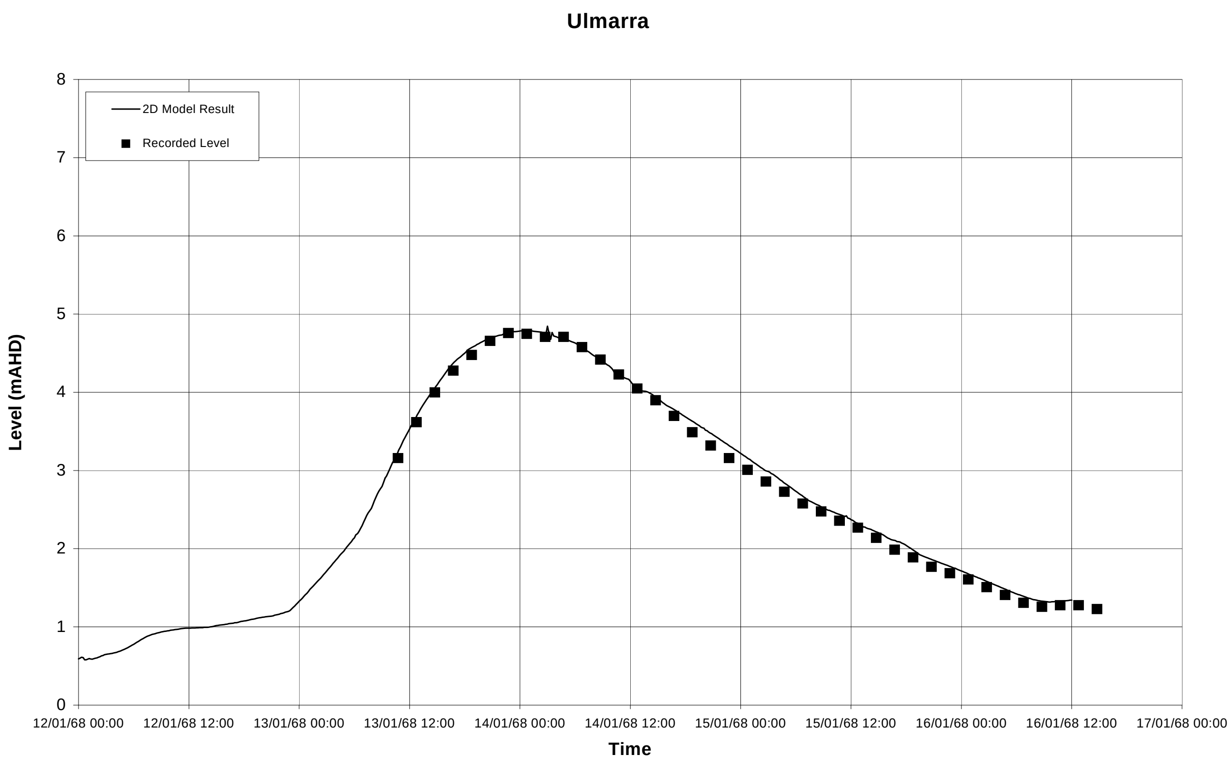
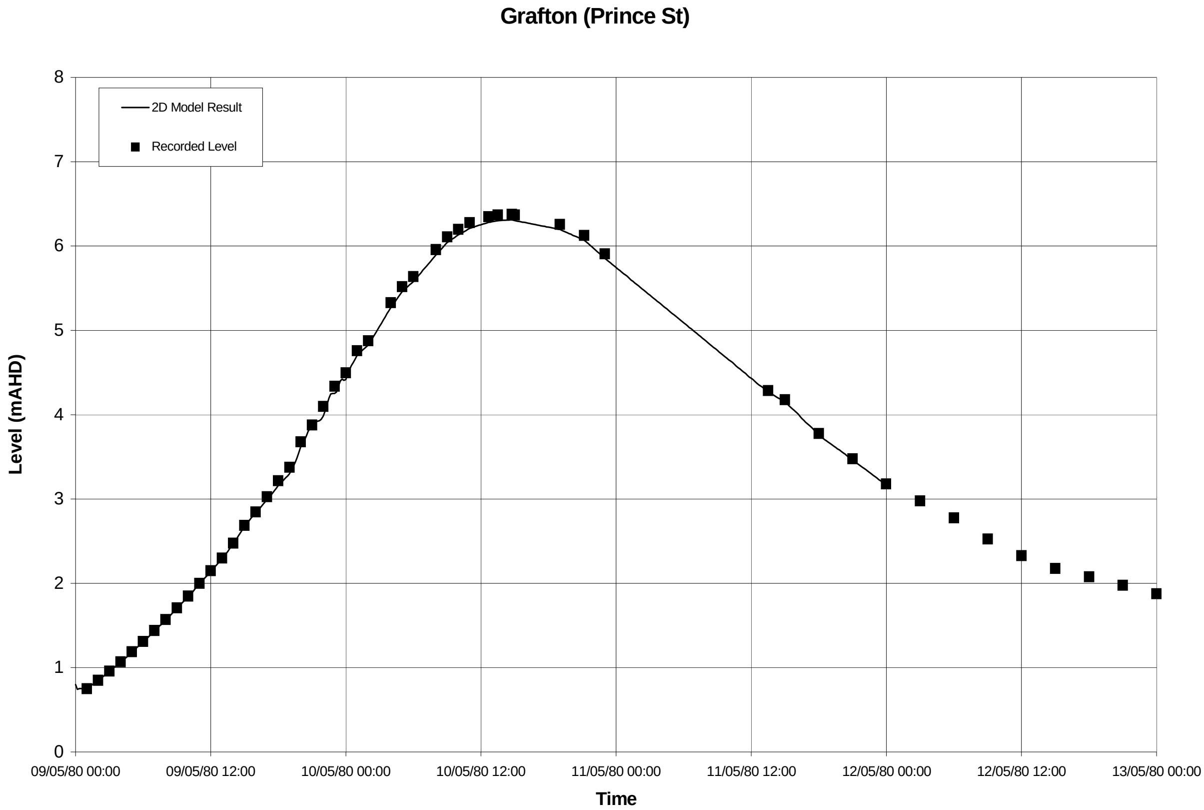


Figure A- 4 January 1968 Flood Model Calibration Results



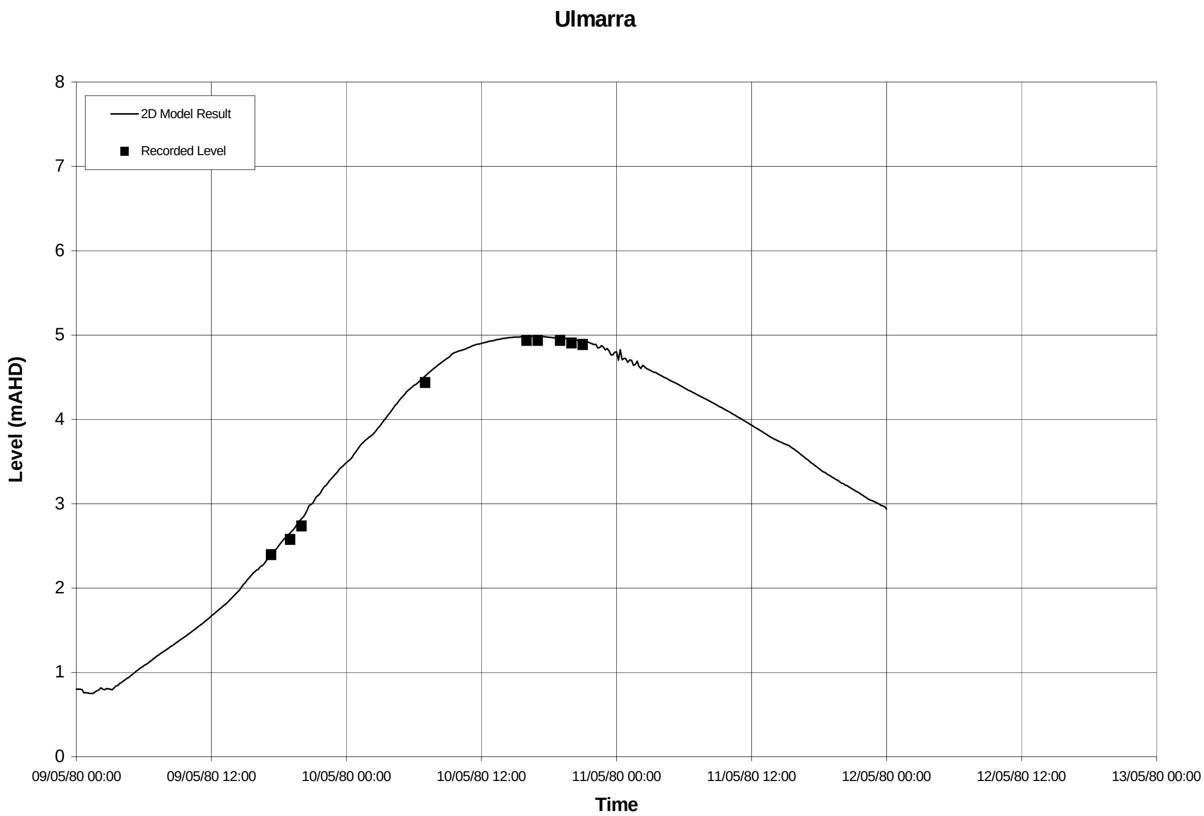
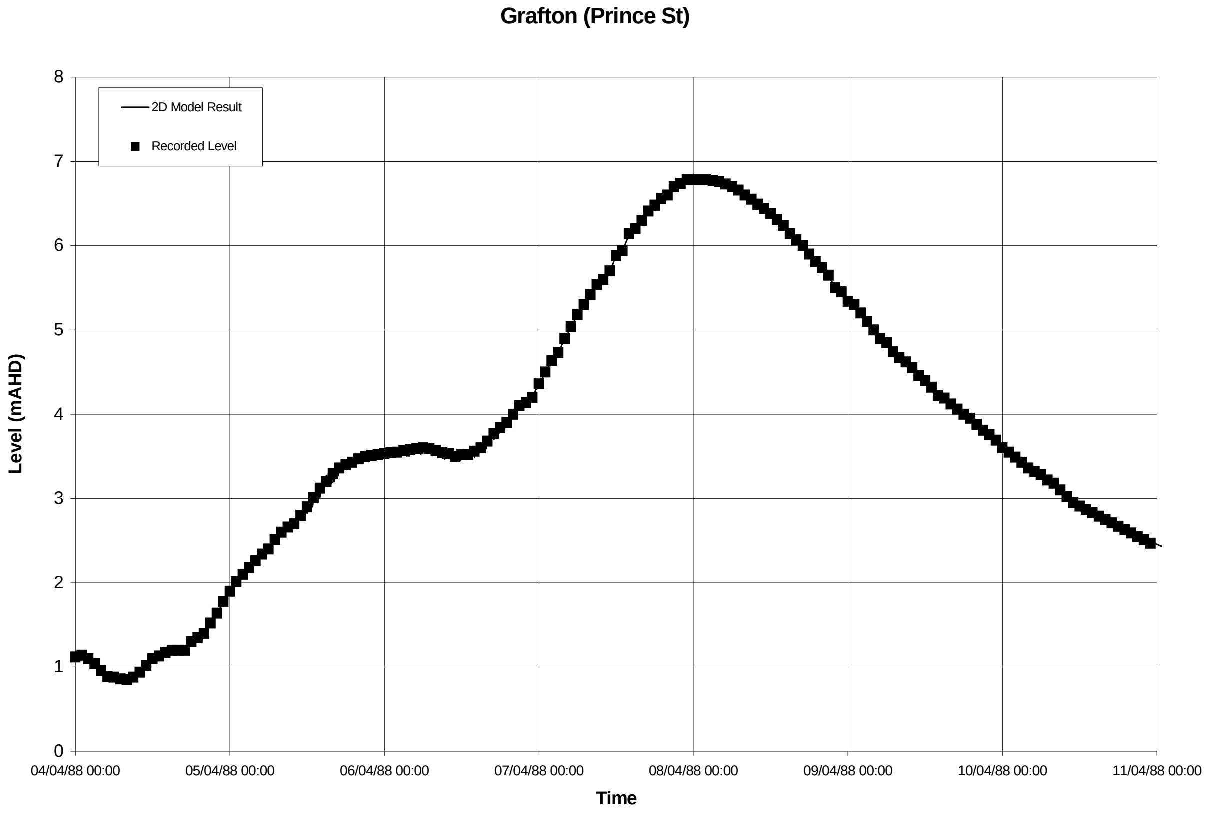


Figure A- 5   May 1980 Flood Model Calibration Results



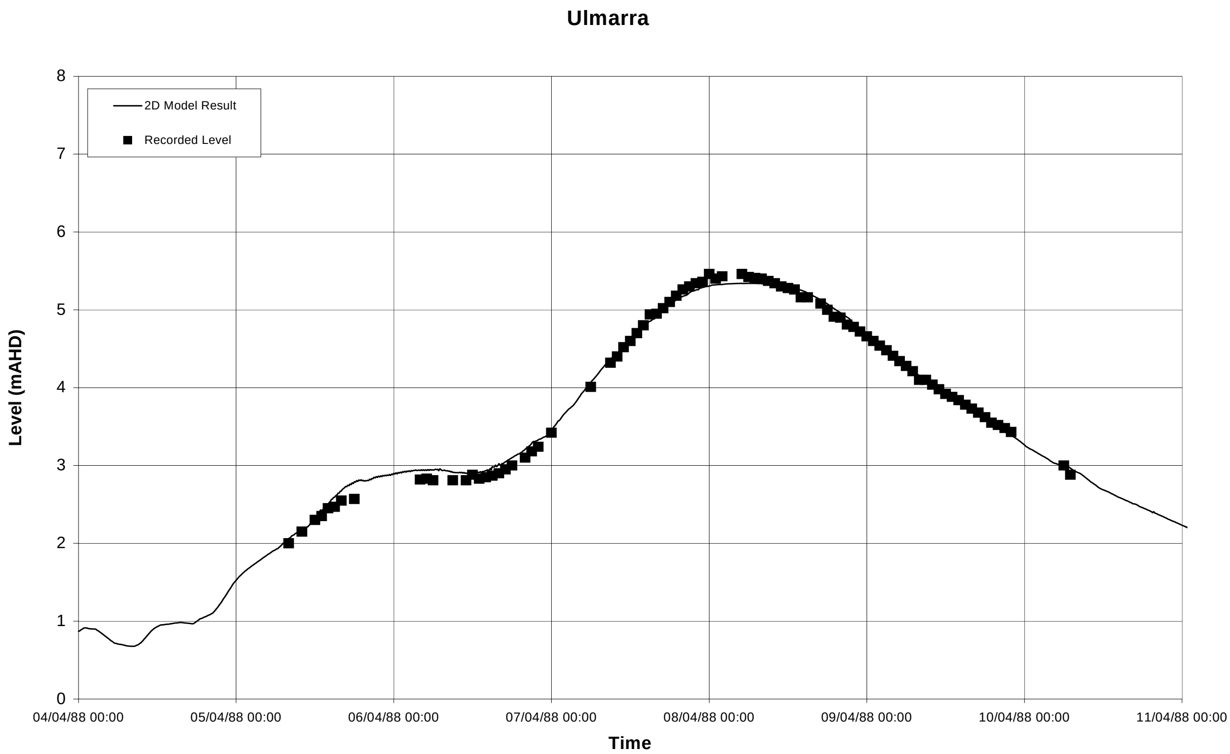
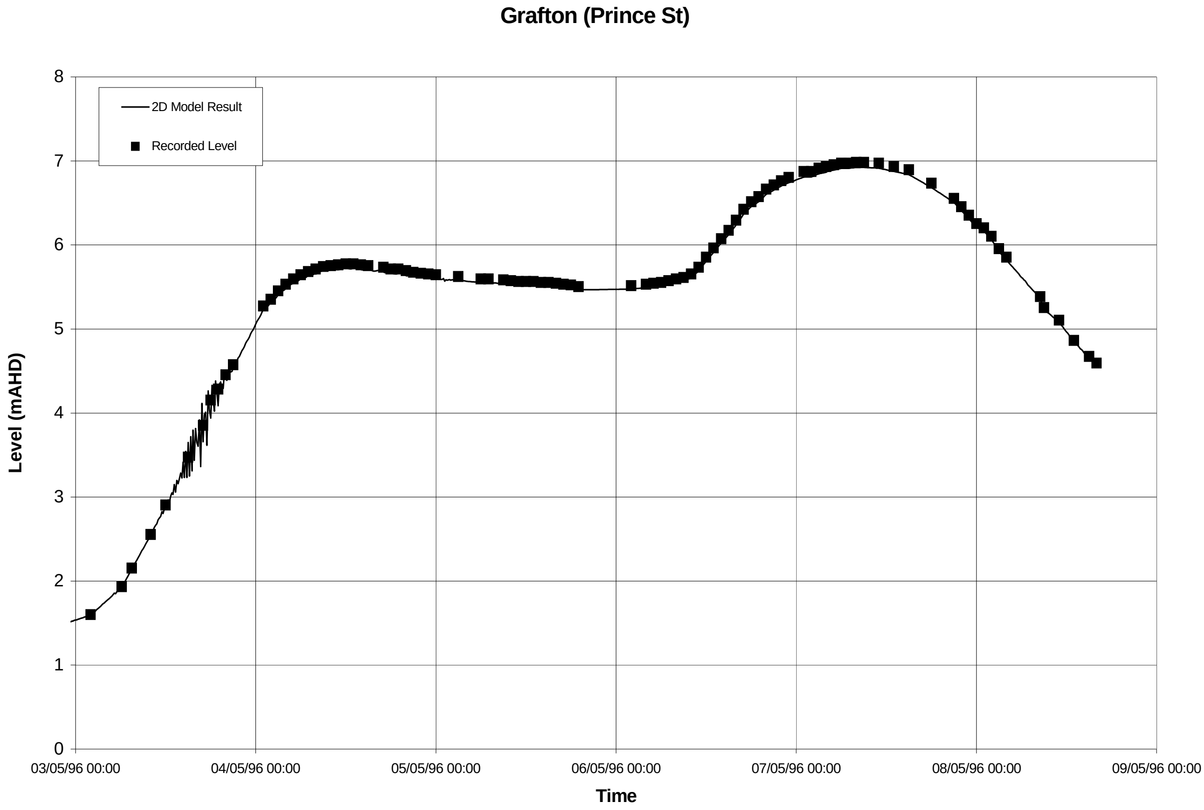


Figure A- 6 April 1988 Flood Model Calibration Results



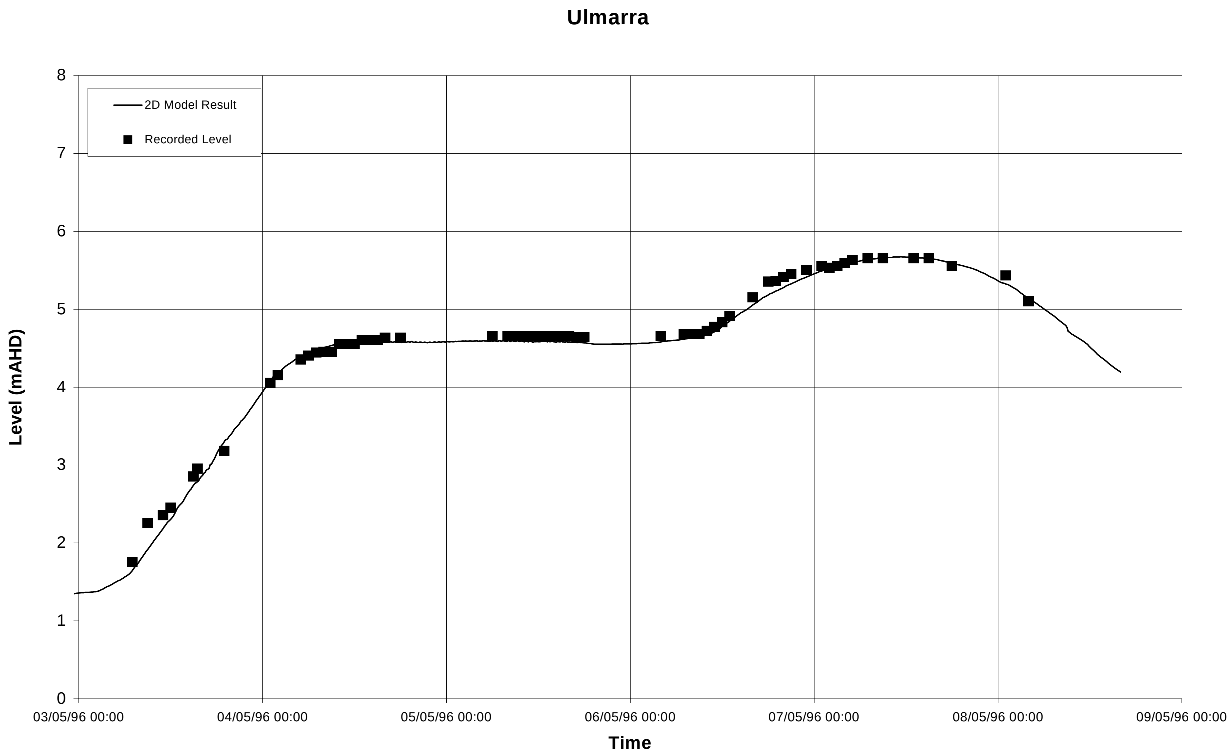
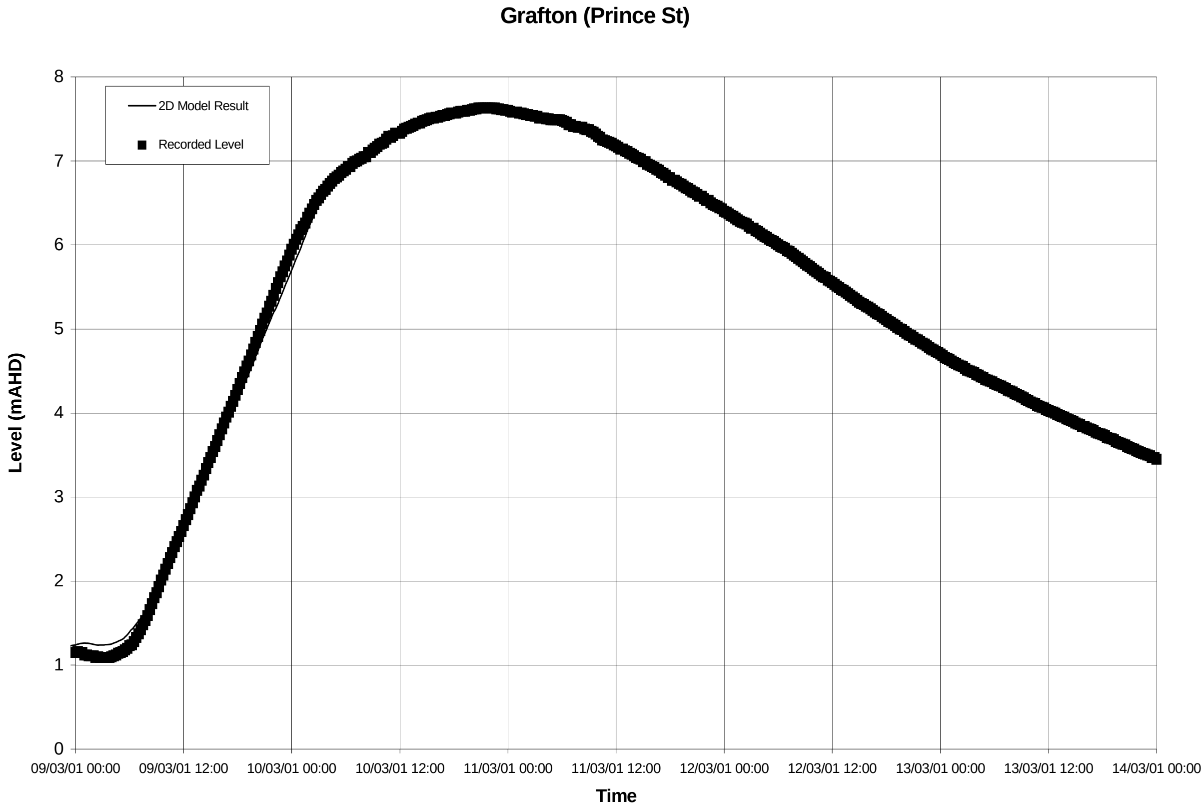


Figure A- 7 April 1996 Flood Model Calibration Results



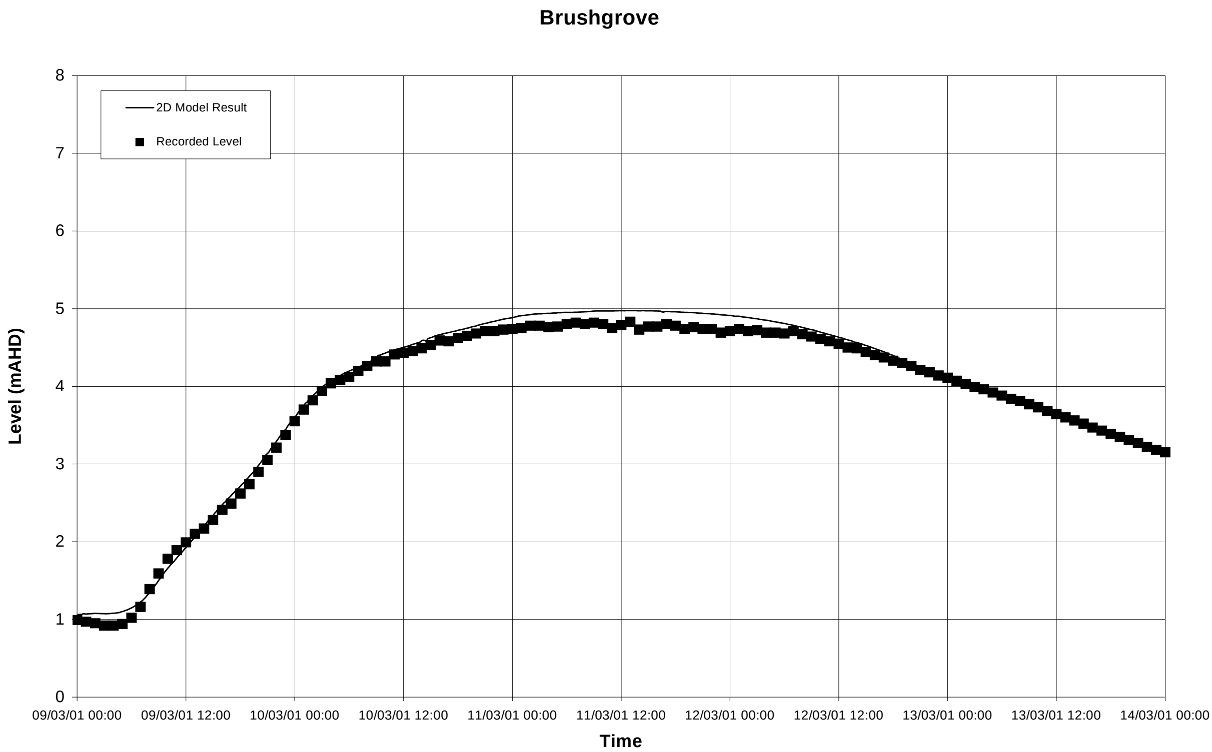
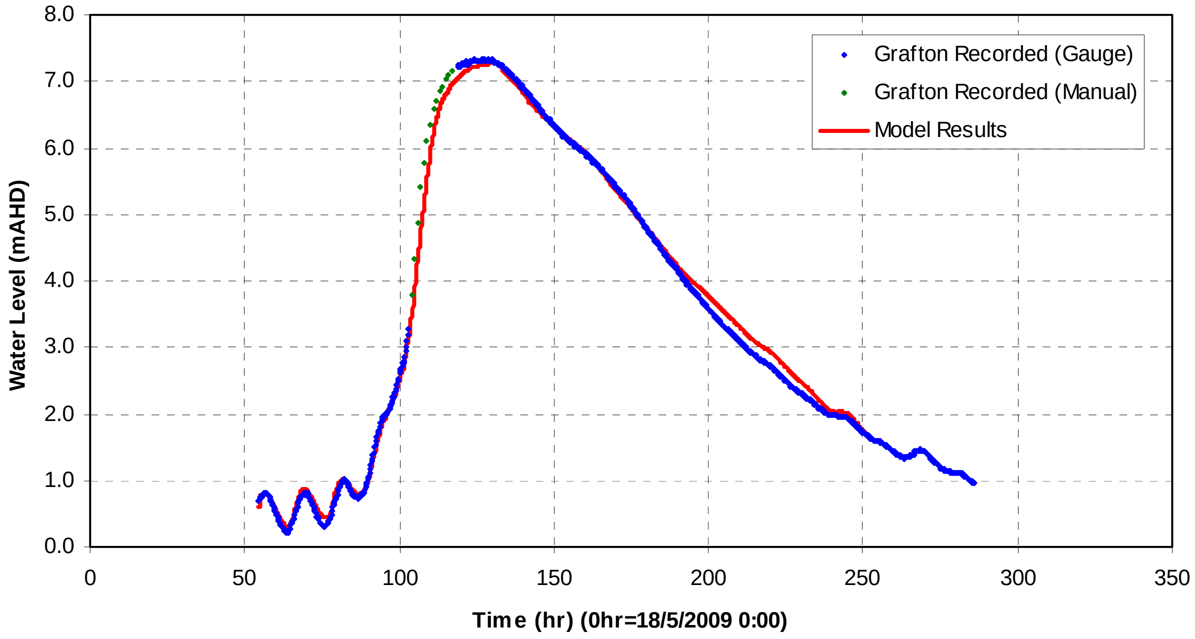


Figure A- 8 March 2001 Flood Model Calibration Results



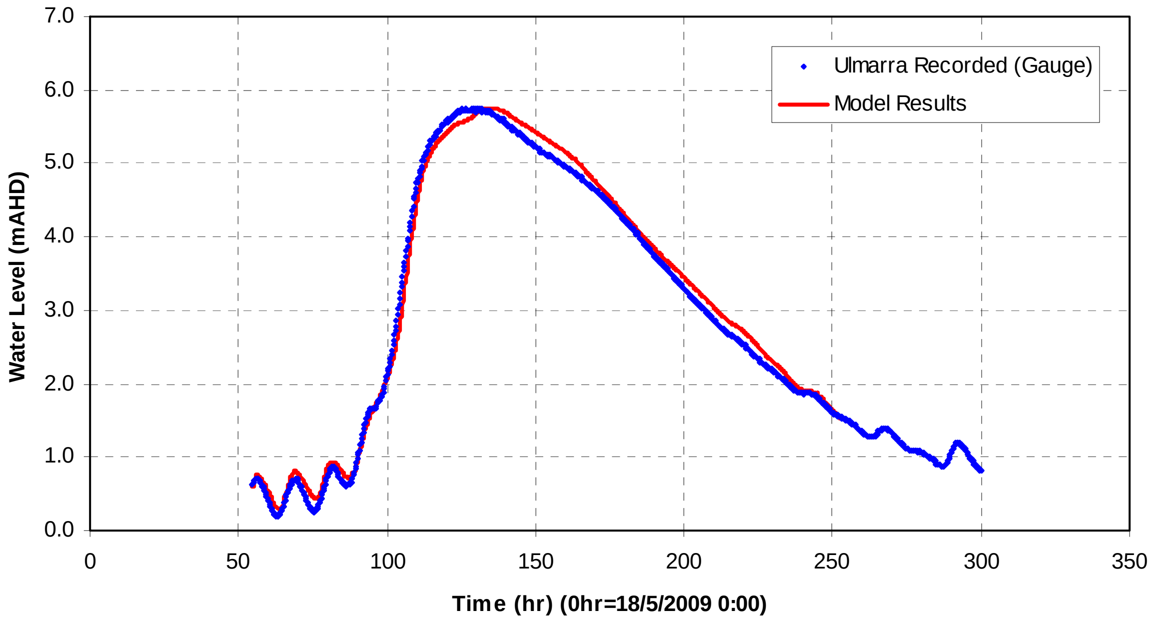


Figure A- 9 2009 Flood Model Calibration Results

APPENDIX B: OPTION C LOCAL DRAINAGE ASSESSMENT

B.1 Background

Option C requires the lowering of ground levels locally in Grafton to provide sufficient heavy vehicle clearance under the railway viaduct. The location where this is required is an area which currently experiences local drainage issues. The drainage issues in this part of Grafton are predominantly caused by:

1. Intense short duration storms, resulting in local drainage catchment runoff exceeding the capacity of the stormwater drainage network; and/or
2. Long duration events resulting in elevated flood levels within the Clarence River, reducing stormwater network outflow.

A preliminary local drainage assessment has been undertaken in order to assess the flood mitigation measures required for Option C to meet the 20 year ARI event immunity design criteria. A TUFLOW flood model of the local catchment has been developed for this purpose.

The local drainage model layout is shown in Figure B- 5. The model extends beyond the local catchment of the Option C/railway viaduct crossing. This increased area of assessment was required due to connectivity between neighbouring local drainage catchments via the Grafton stormwater network. A 2D grid resolution of 5m was applied to the entire area, allowing for a detailed representation of the flows within the catchment. 1D elements were used to represent the stormwater network within the developed model.

General features represented in the model include:

- The Grafton stormwater pipe network (as supplied by Clarence Valley Council);
- Topographic data obtained from Airborne Laser Survey flown in March of 2011 (supplied by Arup); and
- Refined landuse use mapping digitised from aerial photography, applying Manning's roughness values consistent with the greater Lower Clarence flood model (WBM, 2004).

A 'direct rainfall' approach was used for the inflows to the hydraulic model with a mapping cutoff depth of $\geq$ 50mm. Losses applied during the modelling include:

- Initial Rainfall Loss = 0mm;
- Continuing Rainfall Losses – Pervious Areas = 2.5mm/h; and
- Continuing Rainfall Losses – Impervious Areas = 0.0mm/h.

B.2 Boundary Conditions

Four event scenarios have been modelled as part of this assessment.

Table B- 1 Grafton Local Drainage Model Event Scenarios

Event		***Catchment Rainfall Inflow***	***River Downstream Boundary Condition***	***Comment***
ID	***Description***			
1	Historic 2009 Flood Event	Rainfall data sourced from BoM from South Grafton gauge	River water level boundaries sourced from 2009 event Lower Clarence flood model calibration simulation (BMT WBM, 2010)	Model verification event
2	3 hour 20 Year ARI Event Rainfall combined with a Mean High Water Spring Tide (fixed river boundary)	Rainfall data sourced from BoM Intensity Frequency Duration Program (rainfall volume = 95mm)	Mean high water tide level sourced from Manly Hydraulics	3hrs = Critical storm event duration when Clarence River is not in flood
3	72 hour 20 Year ARI Event Rainfall combined with a 20 Year ARI Clarence River Flood Event (dynamic river boundary)	Rainfall data sourced from BoM Intensity Frequency Duration Program (rainfall volume = 312mm)	River water level boundaries sourced from 20 Year ARI event Lower Clarence flood model	72hrs = Critical storm event duration when Clarence River is in flood
4	*Drainage Improvement Sensitivity Test* 3 hour 100 Year ARI Event Rainfall combined with a 20 Year ARI Clarence River Flood Event (dynamic river boundary)	Rainfall data sourced from BoM Intensity Frequency Duration Program (rainfall volume = 124mm)	Mean high water tide level sourced from Manly Hydraulics	Sensitivity testing

Figure B- 1 to Figure B- 3 show the model boundary conditions for the first three event scenarios.

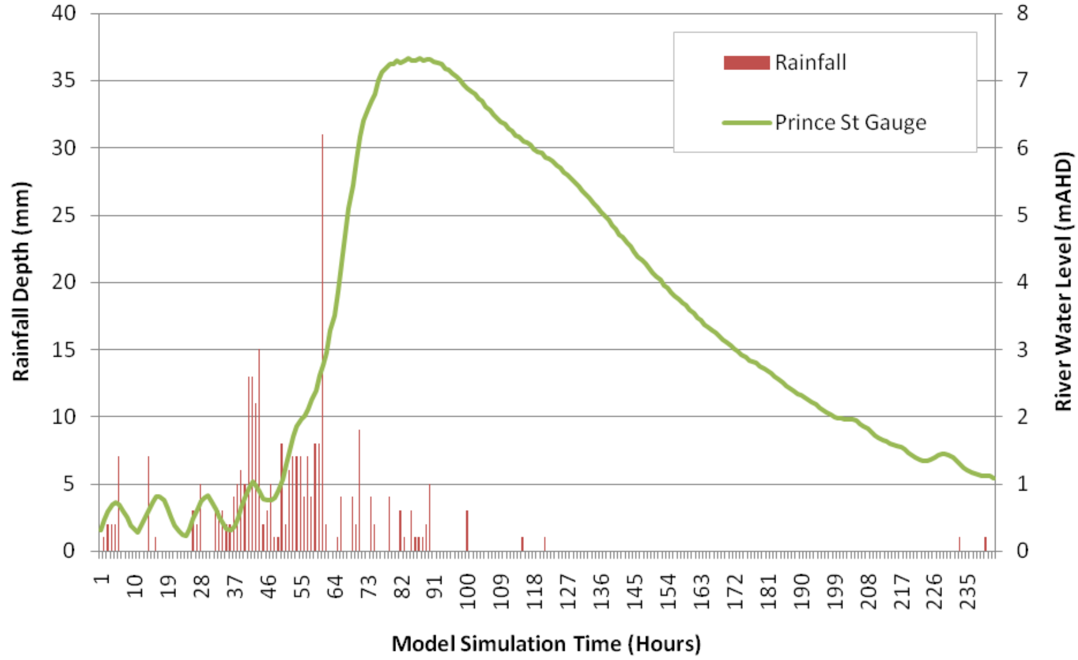


Figure B- 1 Grafton Local Drainage Model – 2009 Event Boundary Conditions

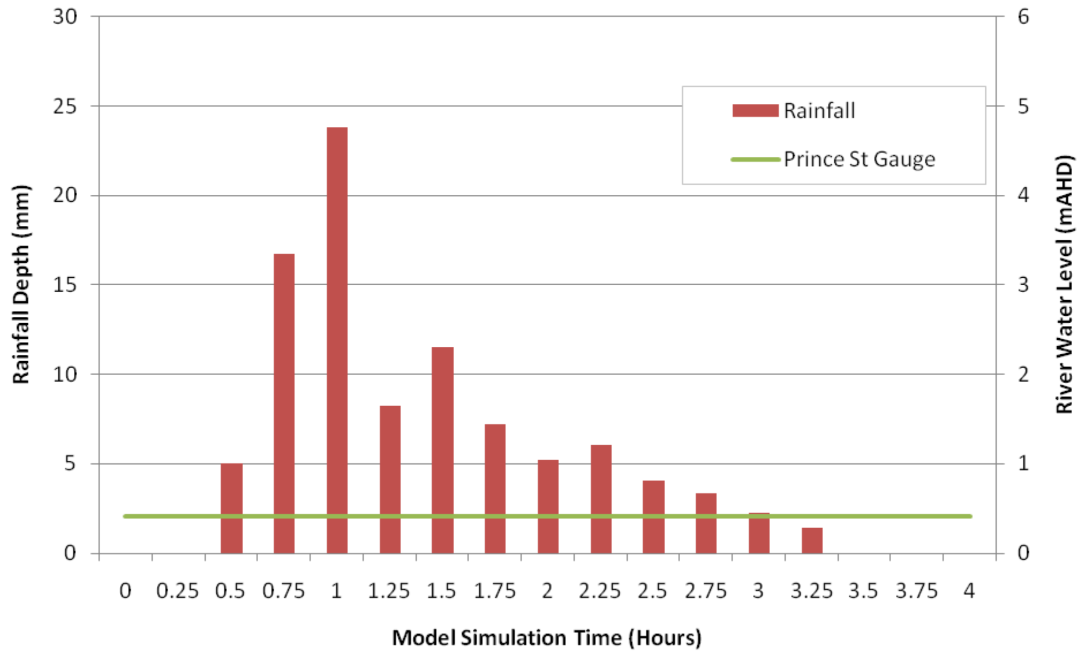


Figure B- 2 Grafton Local Drainage Model – 3 Hour 20 Year ARI Event Boundary Conditions

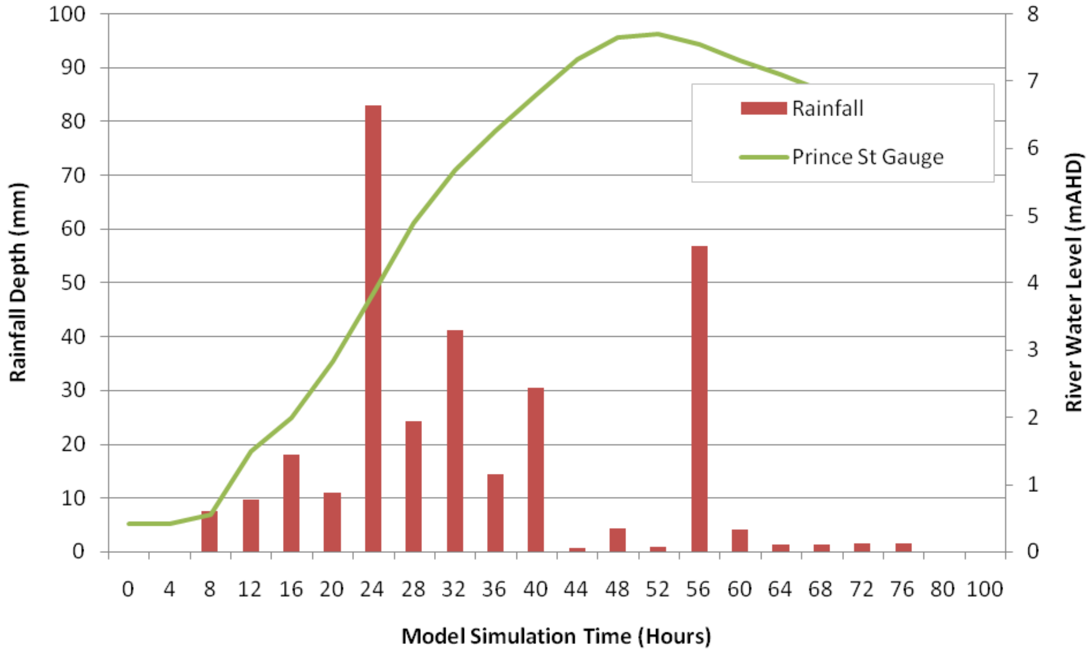


Figure B- 3 Grafton Local Drainage Model – 72 Hour 20 Year ARI Event Boundary Conditions

The 2009 event shown in Figure B- 4 is approximately equivalent to a 10 year ARI event for a scenario where the Clarence River is in flood (when compared against the 72 hour design event rainfall intensity).

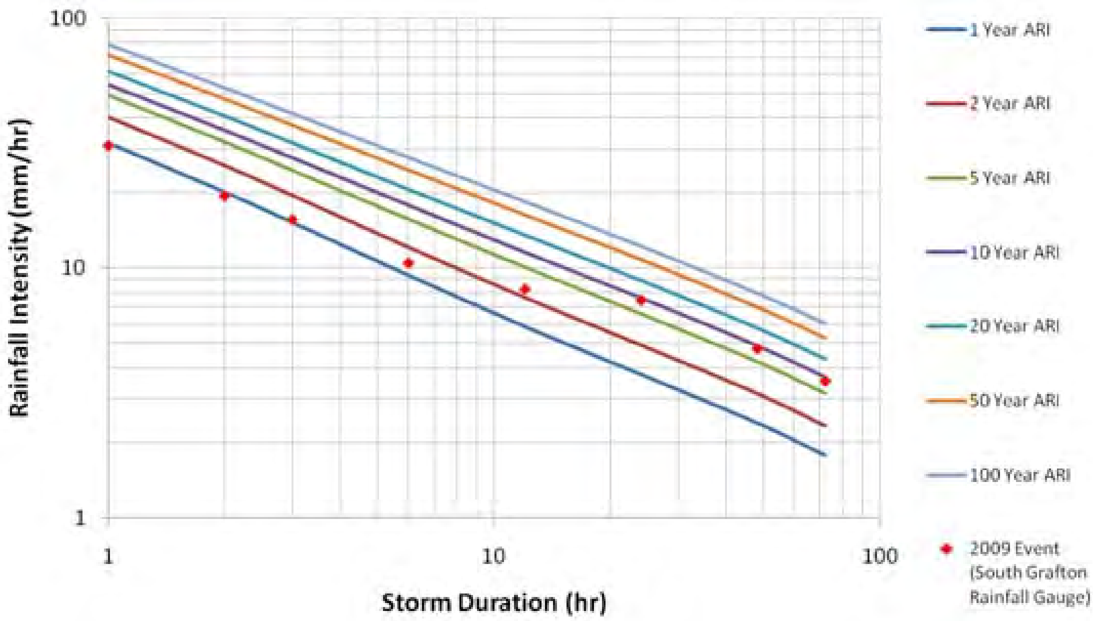


Figure B- 4 2009 Event Rainfall Design Event Analysis

B.3 Assessment Results

B.3.1 Existing Case

The results for the existing catchment state shown in Figure B- 6 to Figure B- 8 (i.e. not including the design features for Option C) show significant inundation in the area of interest, where Option C passes under the railway viaduct.

Flood levels adjacent to the railway viaduct for the assessed event scenarios are summarised below:

1. Historic Flood Event = Recorded = **3.75mAHD**; Modelled **3.81mAHD**;
2. hour 20 Year ARI event combined with a mean high water spring tide): **3.44mAHD**; and
3. 72 hour 20 Year ARI event rainfall combined with a 20 year ARI flood event within the Clarence River) = **4.40mAHD**.

B.3.2 Developed Case

For Option C to meet the 20 year ARI event flood free bridge approach design criteria, flood levels within the local drainage area adjacent to the railway viaduct need to be reduced to be less than 1.9mAHD. The assessment of mitigation measures required to lower the flood levels in this location was undertaken by modelling a range of measures using the TUFLOW local drainage model.

Testing has found that the following conceptual drainage strategy will successfully achieve the flood immunity requirements:

- Increasing of the capacity of the existing gravity drainage system servicing the Pound/Kent Street area. Requiring three additional 1050mm flap gated culverts emptying into the Clarence River;
- A 2m^3/s capacity pump station, extracting water from the Pound/Kent Street area;
- A catch drain north of Option C;
- 8 x 0.5m x 1m box culverts under Option C, providing connectivity between the catchment north of Option C and the proposed detention basin; and
- A detention basin south of Option C with a 560m^3 capacity (2.8m x 20m x 10m) and a design bed level of 0.7mAHD.

The above drainage features have been sized ensuring that the efficiency of the proposed drainage infrastructure is limited by the proposed pump capacity, not the associated detention basin or culverts under Option C

Although this drainage strategy has a primary objective focused on achieving the desired flood immunity requirements for Option C, it should be acknowledged that this measure will have a residual benefit for surrounding property owners. The drainage strategy will successfully reduce the occurrence of local stormwater flooding within an area of problem drainage within Grafton.

The conceptual drainage strategy has been designed to be free draining (not requiring pumping) during local rainfall events which occur when the Clarence River is not in flood. When the Clarence River is in flood, elevated water levels within the Clarence River do not allow for gravity drainage from Grafton, requiring the use of the pumps to drain the Pound/Kent Street area.

Flood Event Scenario 2[4] – Local Catchment Flooding/Low River Level

Upsizing of the existing gravity drainage system has been investigated to mitigate inundation associated with storm events which occur when the Clarence River is not in flood. **This design option does not require the operation of pumps when the Clarence River is not in flood**.

Scenario testing has found that three additional 1050mm flap gated culverts draining the Pound/Kent St area will lower flood levels from 3.4mAHD to 1.7mAHD, below the design road level for Option C, providing the required 1 in 20 year flood immunity for the route.

Flood Event Scenario 3[4] – Local Catchment Flooding/High River Level

During the 20 Year ARI local drainage event which coincides with flooding within the greater Clarence River catchment, elevated water levels within the Clarence River do not allow for gravity drainage from Grafton. Upsizing of the existing gravity drainage system will not be able to mitigate the drainage issues adjacent to Option C during this flood scenario. Due to this constraint, pumping of ponded water adjacent to the Option C is required.

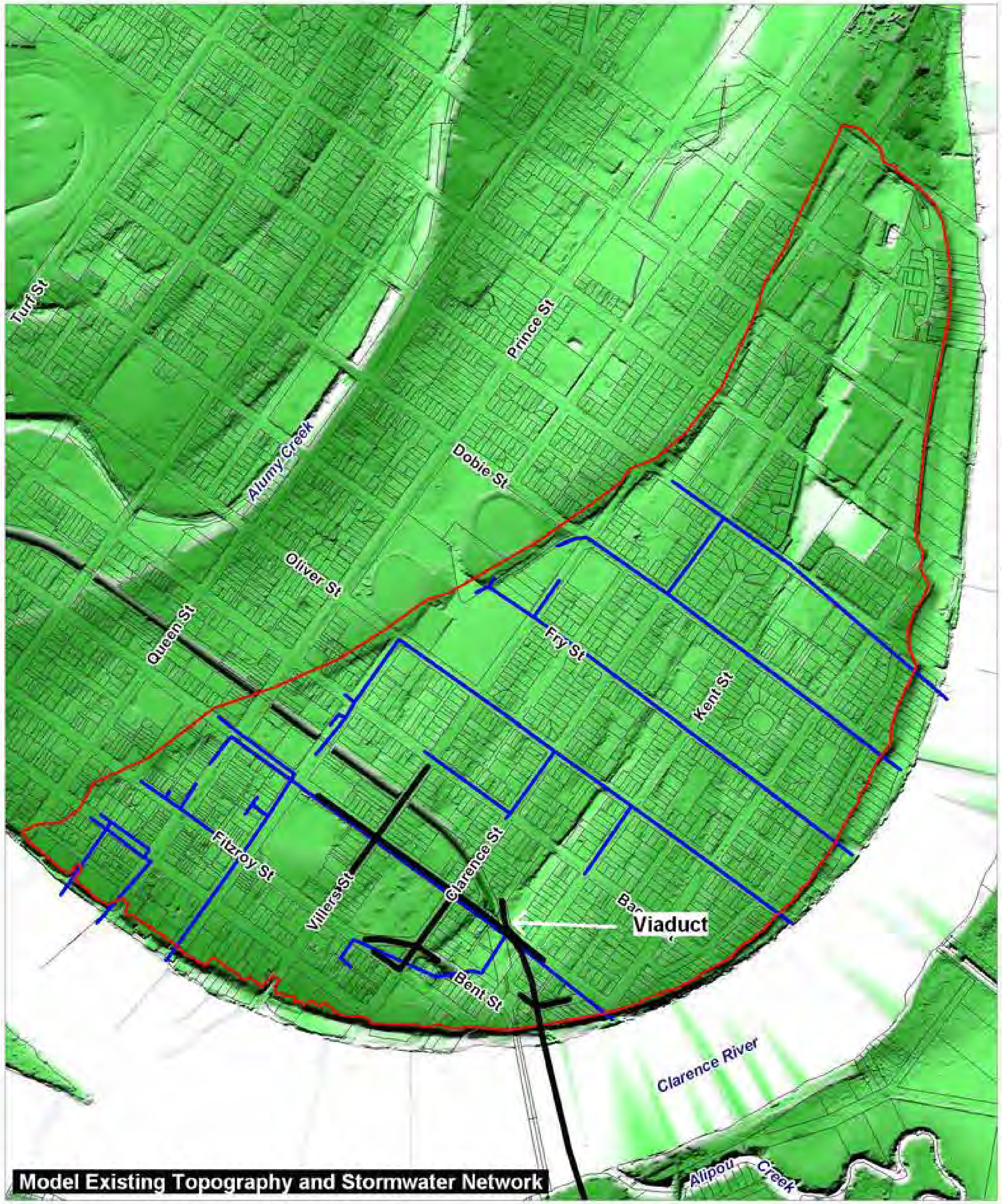
Scenario testing has found that a $2m^3/s$ capacity pump station is required to lower water levels to 1.7mAHD, less than the target level of 1.9mAHD, providing the required 1 in 20 year flood immunity for the route.

Flood Event Scenario 4[4] – Local Catchment Flooding/ Low River Level

Design event sensitivity testing has been completed. The proposed drainage strategy lowers flood levels adjacent to Option C to 2.4mAHD during the 3 hour 100 Year ARI rainfall event. This flood level is 0.5m above the low point in the design road level for Option C.

Results for the developed case scenarios including the Option C drainage improvement mitigation measures are provided in Figure B- 9 and Figure B- 10.

[4] Refer to Table B-1



LEGEND

- Local Drainage Model Extent
- Stormwater Network
- Cadastral Boundaries
- Option C

Landuse

- Urban Blocks
- Roads
- Maintained Grass
- Unmaintained Grass

Title:
Grafton Local Drainage Model Layout

Figure: B-5

Rev: A

N

0m 300 600
Approx. Scale

BMT WBM
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Filepath : I:\B17815_I_Summerland_Way\DRG\RODR_Report\FLD_040_120202_Local_DR_Model.wor

LEGEND

- Railway Line
- Option C
- 3.81 Modelled Flood Level (mAHD)
- 3.75 Recorded Flood Level (mAHD)
- Cadastral Boundaries

Peak Level (mAHD)

- 1.0 to 2.0
- 2.0 to 3.0
- 3.0 to 4.0
- 4.0 to 5.0
- 5.0 to 6.0
- 6.0 to 7.0
- 7.0 to 8.0
- 8.0 to 9.0

Peak Depth (m)

- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- 4.5 to 5.0
- > 5.0

Title:

Grafton Local Drainage Model Validation 2009 Event Results

Figure: B-6

Rev: A

N 0m 100 200 Approx. Scale

BMT WBM
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Filepath : I:\B17815_I_Summerland_Way\DRG\RODR_Report\FLD_041_120202_Local_DR_2009Cal.wor

LEGEND

- Railway Line
- Option C
- Cadastral Boundaries

Peak Level (mAHD)	Peak Depth (m)
1.0 to 2.0	0.0 to 0.5
2.0 to 3.0	0.5 to 1.0
3.0 to 4.0	1.0 to 1.5
4.0 to 5.0	1.5 to 2.0
5.0 to 6.0	2.0 to 2.5
6.0 to 7.0	2.5 to 3.0
7.0 to 8.0	3.0 to 3.5
8.0 to 9.0	3.5 to 4.0
	4.0 to 4.5
	4.5 to 5.0
	> 5.0

Title:

Existing Case Grafton Local Drainage Model
3 Hour 20 Year ARI Event Results (MHWS River Level)

Figure: **B-7**

Rev: **A**

N 0m 100 200 Approx. Scale

BMT WBM www.bmtwbm.com.au

Filepath : I:\B17815_I_Summerland_Way\DRG\RODR_Report\FLD_042_120202_Local_DR_Q20_3hr.wor

LEGEND

- Railway Line
- Option C
- Cadastral Boundaries

Peak Level (mAHD)
1.0 to 2.0
2.0 to 3.0
3.0 to 4.0
4.0 to 5.0
5.0 to 6.0
6.0 to 7.0
7.0 to 8.0
8.0 to 9.0

Peak Depth (m)
0.0 to 0.5
0.5 to 1.0
1.0 to 1.5
1.5 to 2.0
2.0 to 2.5
2.5 to 3.0
3.0 to 3.5
3.5 to 4.0
4.0 to 4.5
4.5 to 5.0
> 5.0

Title:

Existing Case Grafton Local Drainage Model
72 Hour 20 Year ARI Event Results (Combined River Flooding)

Figure: B-8

Rev: A

N

0m 100 200
Approx. Scale

BMT WBM
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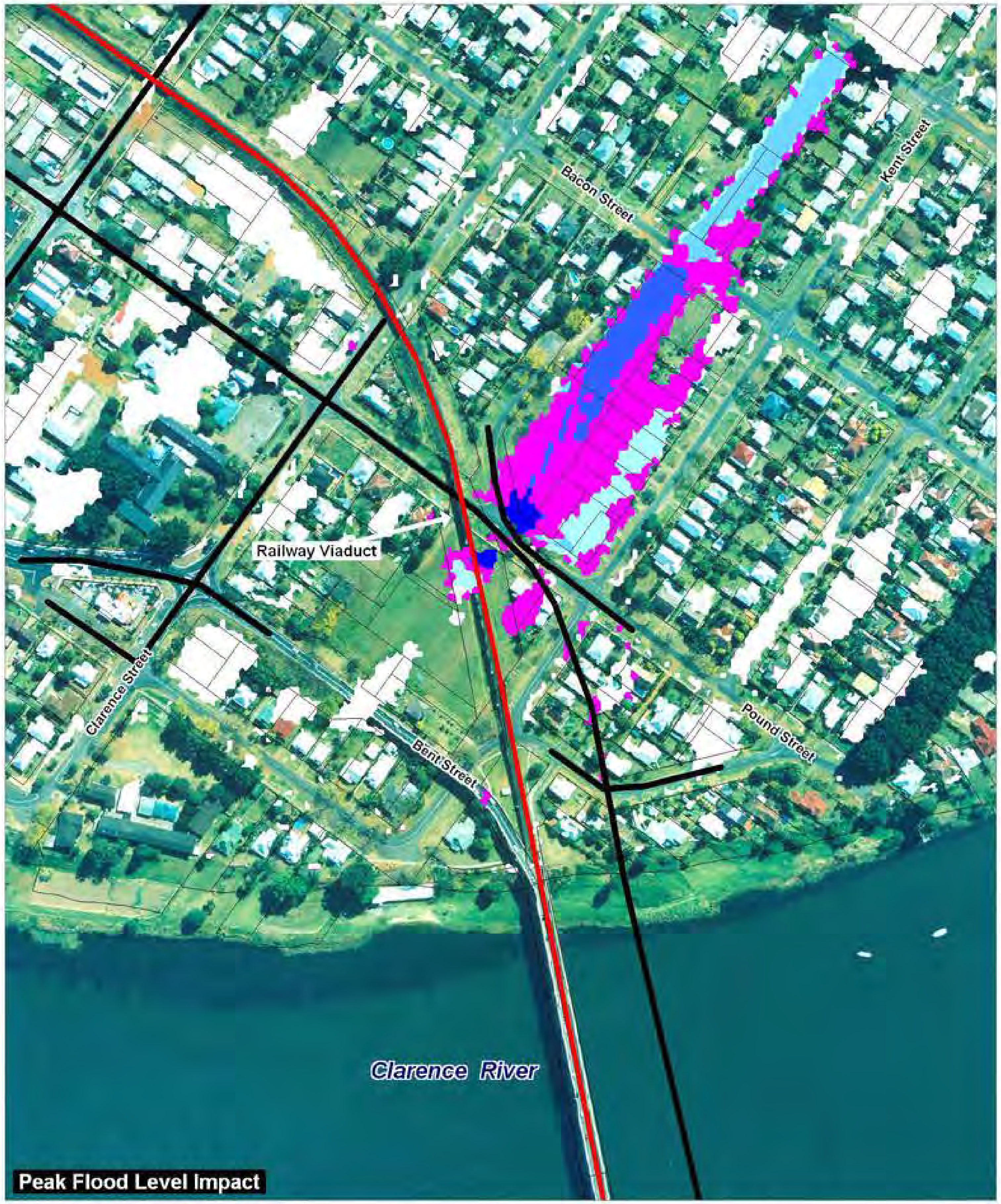
Filepath : I:\B17815_I_Summerland_Way\DRG\RODR_Report\FLD_043_120202_Local_DR_Q20_72hr.wor



LEGEND

- Railway Line
- Option C
- Cadastral Boundaries

Peak Level (mAHD)

- 1.0 to 2.0
- 2.0 to 3.0
- 3.0 to 4.0
- 4.0 to 5.0
- 5.0 to 6.0
- 6.0 to 7.0
- 7.0 to 8.0
- 8.0 to 9.0

Peak Level Impact (m)

- Was Wet Now Dry
- < -1.00
- -1.00 to -0.50
- -0.50 to -0.25
- -0.25 to -0.10
- -0.10 to 0.10
- 0.10 to 0.25
- 0.25 to 0.50
- 0.50 to 1.00
- > 1.00
- Was Dry Now Wet

Title:

Option C Grafton Local Drainage Model
3 Hour 20 Year ARI Event Results (MHWS River Level)

Figure: B-9

Rev: A

N

0m 100 200
Approx. Scale

BMT WBM
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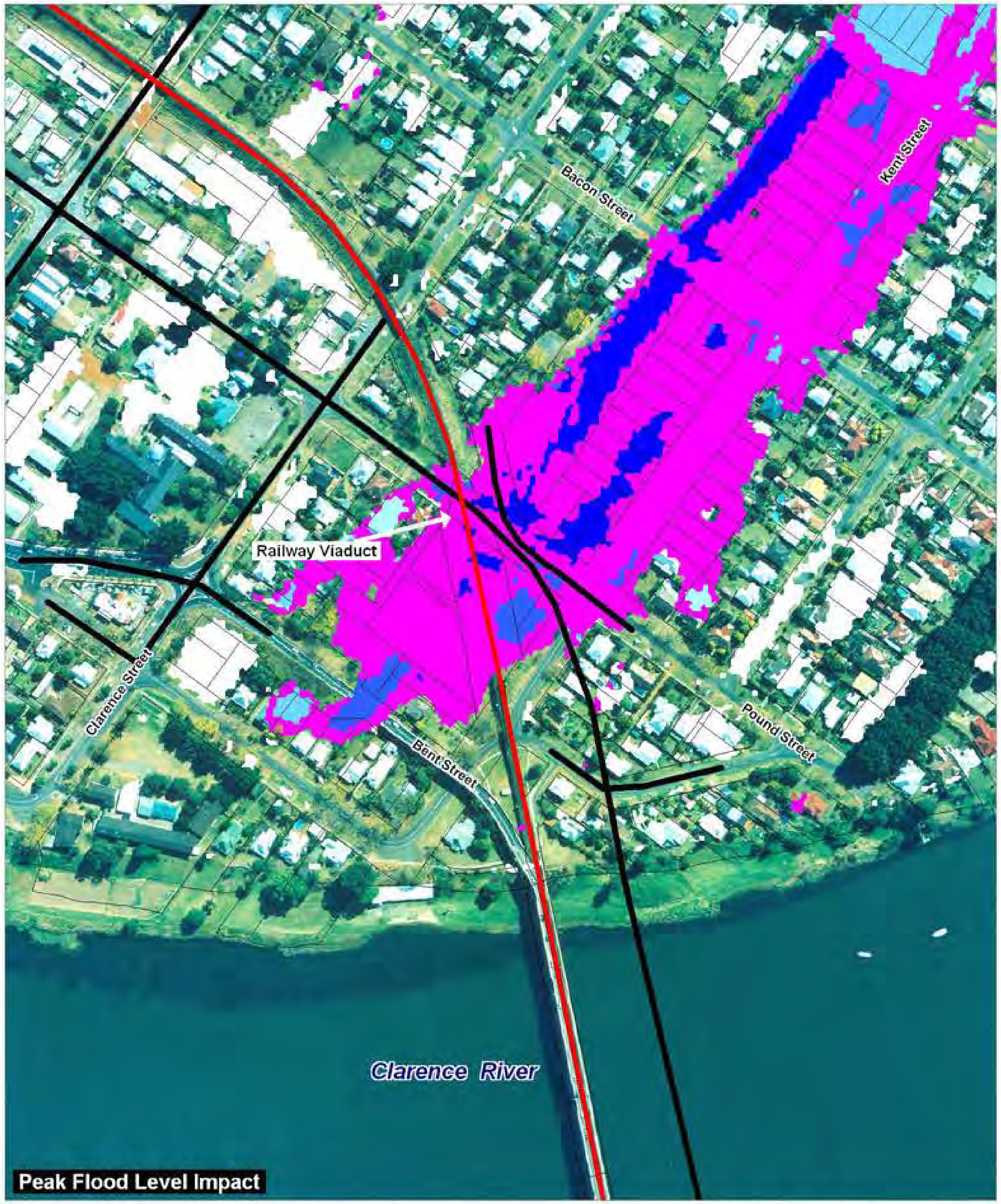
Filepath : I:\B17815_I_Summerland_Way\DRG\RODR_Report\FLD_044_120202_Local_DR_Q20_3hr_Impact.wor



LEGEND

- Railway Line
- Option C
- Cadastral Boundaries

Peak Level (mAHD)
1.0 to 2.0
2.0 to 3.0
3.0 to 4.0
4.0 to 5.0
5.0 to 6.0
6.0 to 7.0
7.0 to 8.0
8.0 to 9.0

Peak Level Impact (m)
Was Wet Now Dry
< -1.00
-1.00 to -0.50
-0.50 to -0.25
-0.25 to -0.10
-0.10 to 0.10
0.10 to 0.25
0.25 to 0.50
0.50 to 1.00
> 1.00
Was Dry Now Wet

Title:

Option C Grafton Local Drainage Model
72 Hour 20 Year ARI Event Results (Combined River Flooding)

Figure: B-10

Rev: A

N 0m 100 200 Approx. Scale

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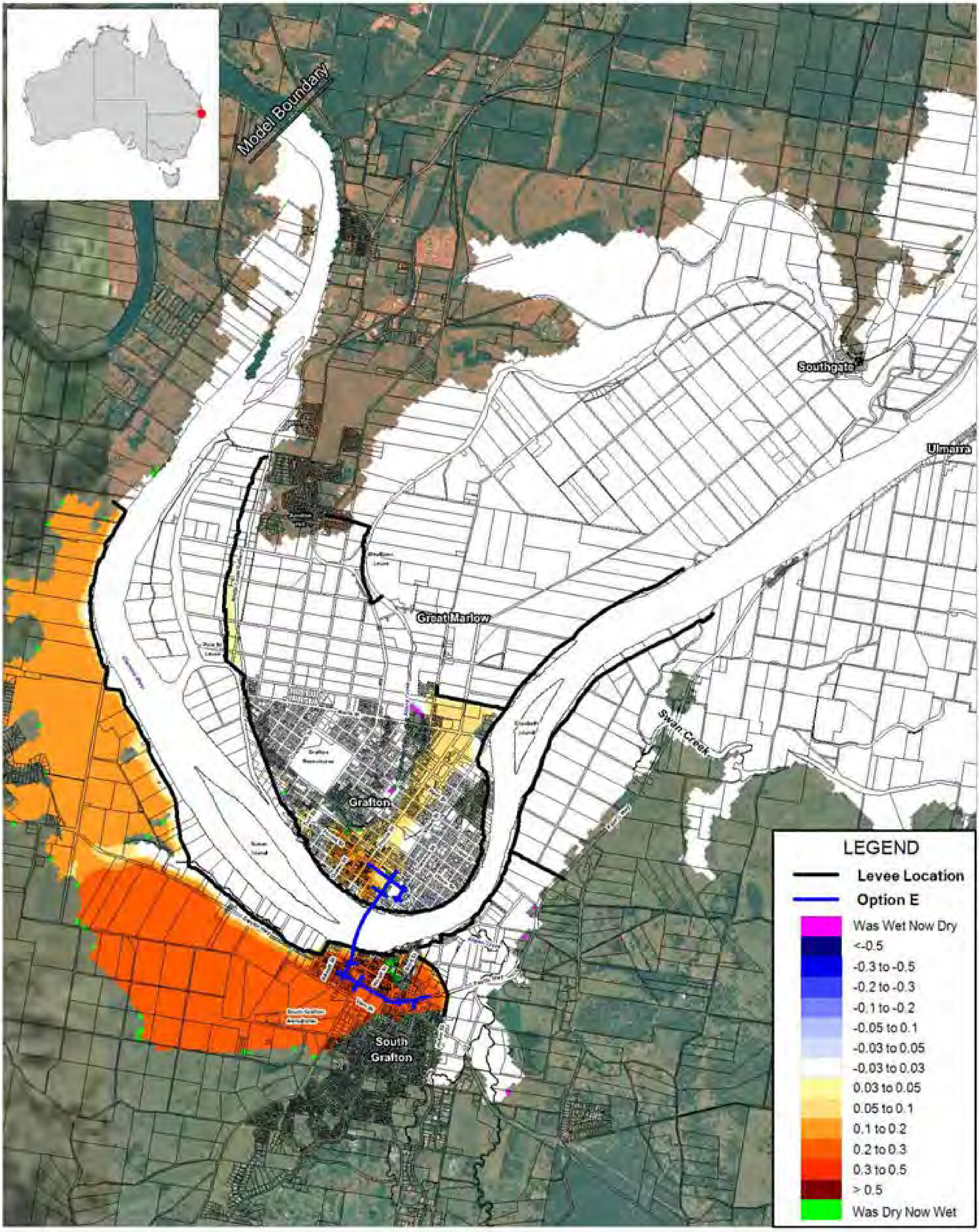
Filepath : I:\B17815_I_Summerland_Way\DRG\RODR_Report\FLD_045_120202_Local_DR_Q20_72hr_Impact.wor

APPENDIX C: OPTION IMPACTS - UNMITIGATED SCENARIO



Title:

Option E (Unmitigated Case)
Peak Flood Level Impact 100 Year ARI Event

Figure: C-1

Rev: A

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N

0 1 2km
Approx. Scale

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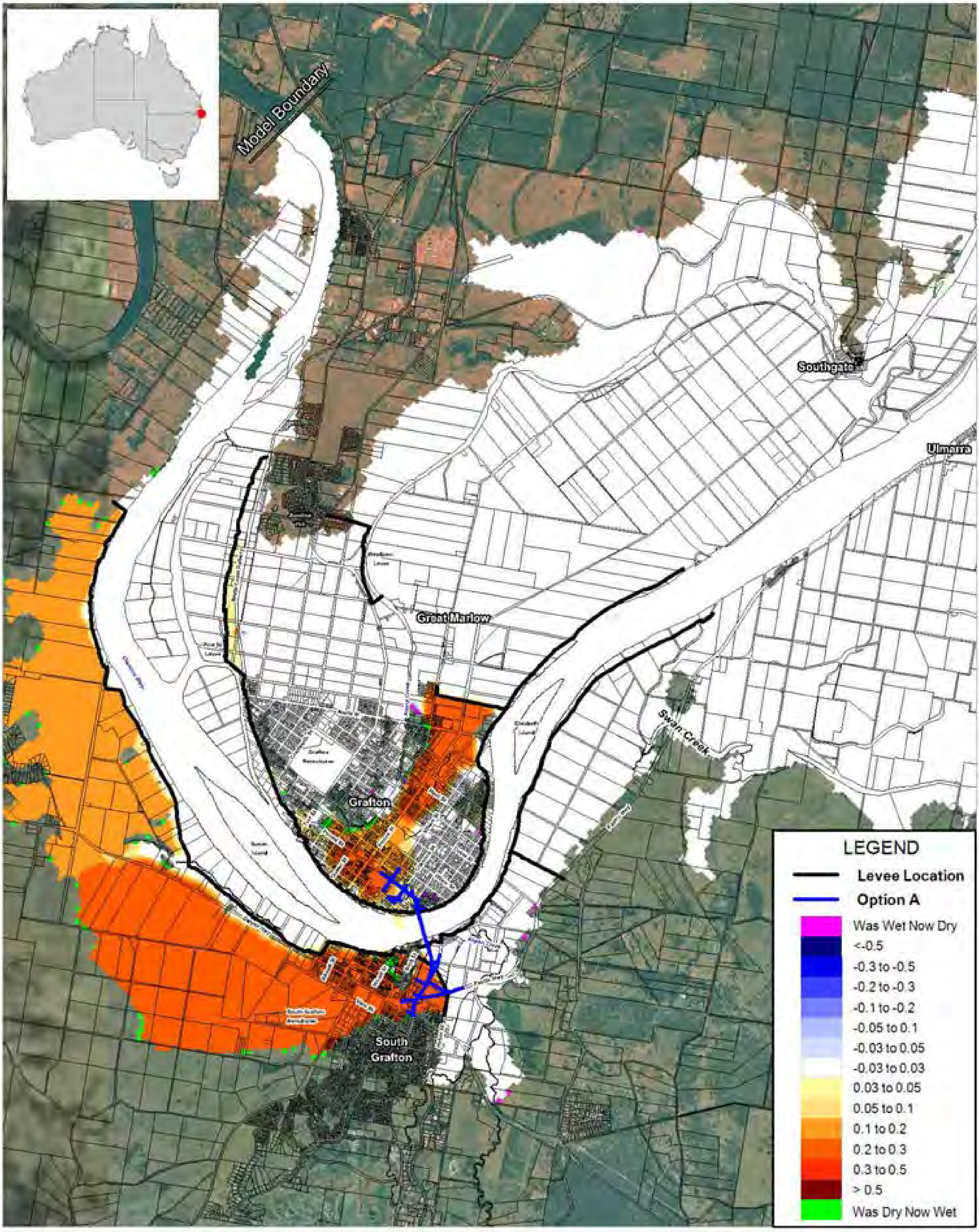
Filepath : I:\B17815_I_Summerland_Way\DRG\RODR_Report_Final\FLD_031_120122_Q100_OptE_NoMit_Hdiff.wor



Title:

Option A (Unmitigated Case)
Peak Flood Level Impact 100 Year ARI Event

Figure: **C-2**

Rev: **A**

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N

0 1 2km
Approx. Scale

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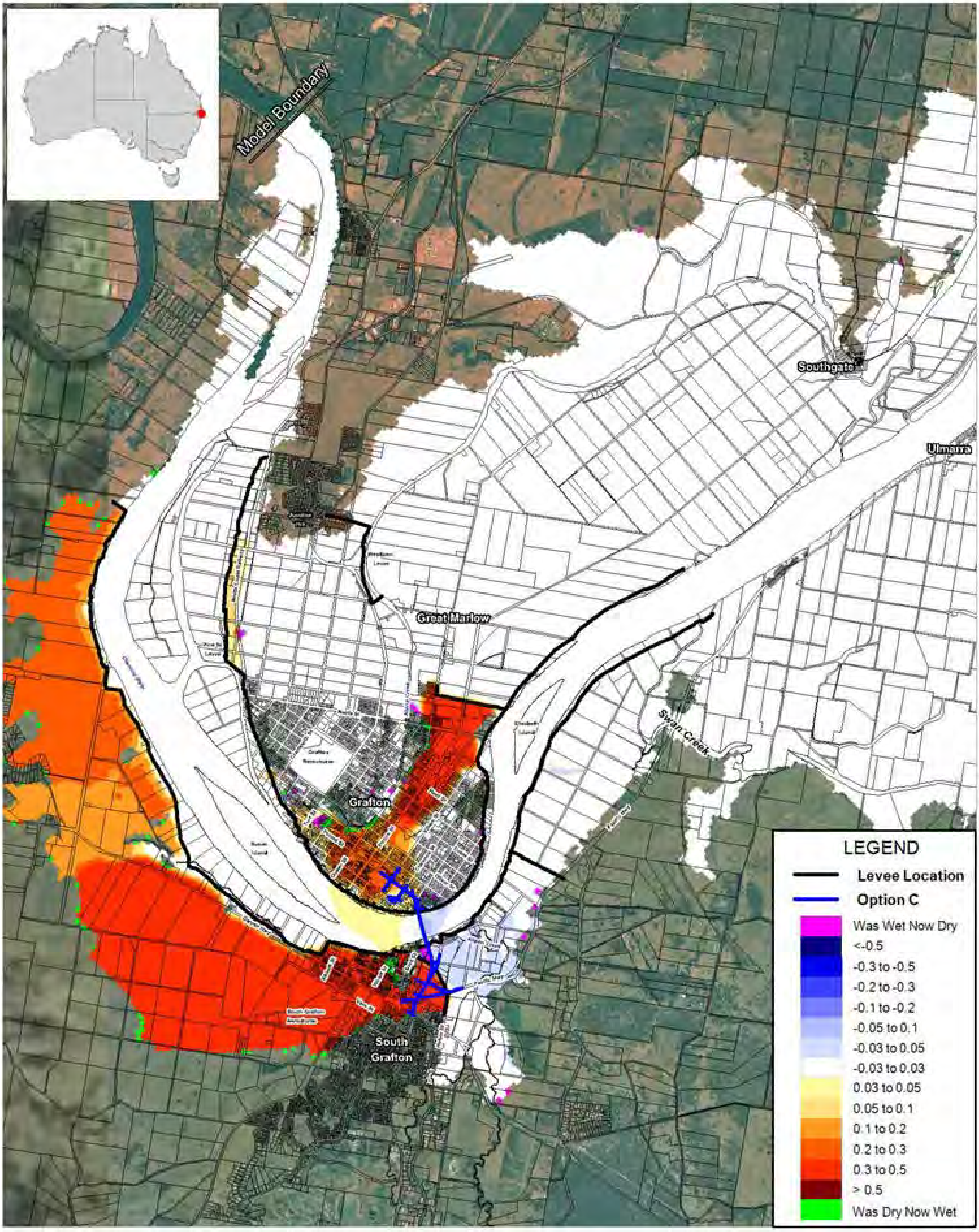
Filepath : I:\B17815_I_Summerland_Way\DRG\RODR_Report_Final\FLD_032_120122_Q100_OptA_NoMit_Hdiff.wor



Title:

Option C (Unmitigated Case)
Peak Flood Level Impact 100 Year ARI Event

Figure: **C-3**

Rev: **A**

N

0 1 2km
Approx. Scale

BMT WBM
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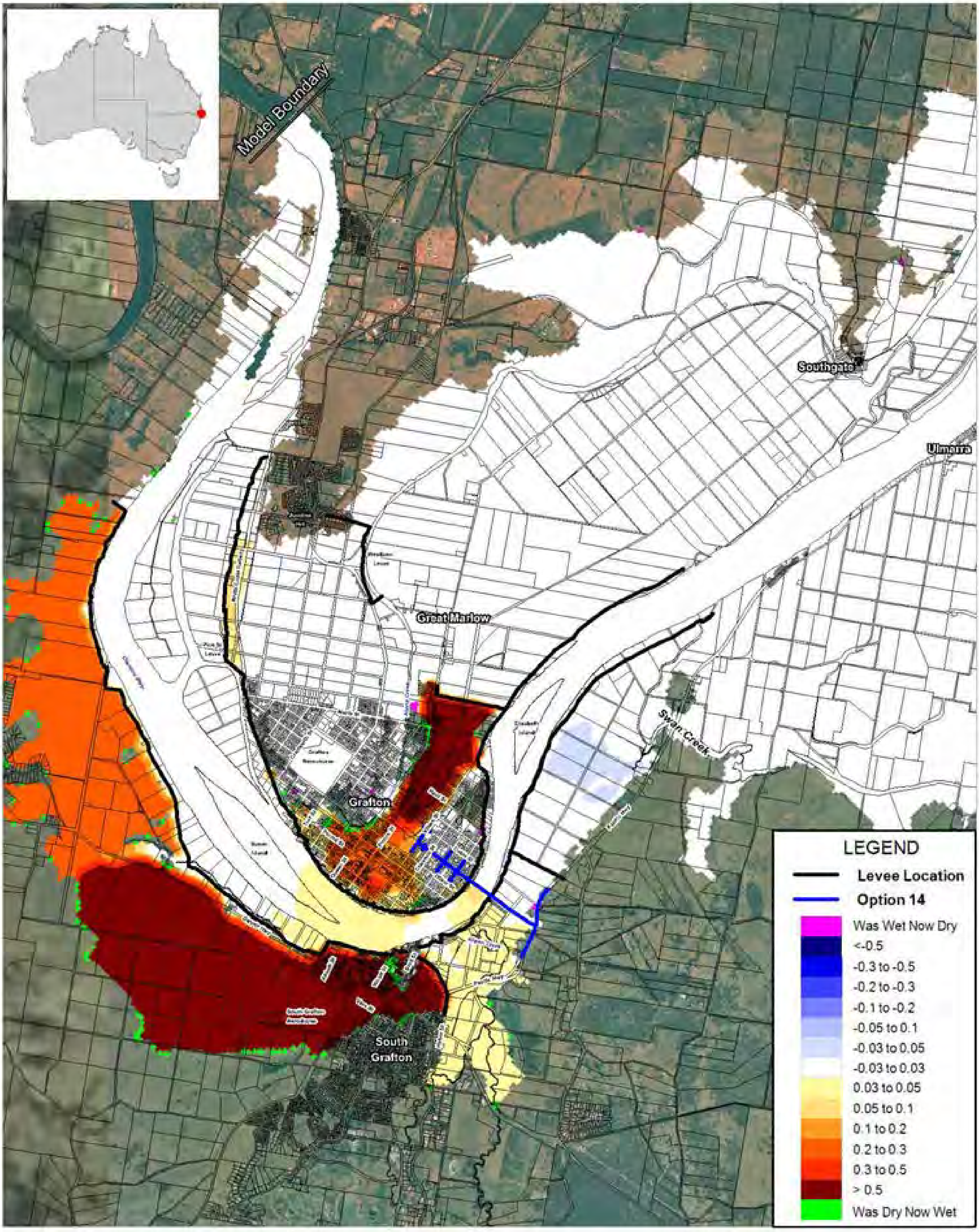
Filepath : I:\B17815_I_Summerland_Way\DRG\RODR_Report_Final\FLD_033_120122_Q100_OptC_NoMit_Hdiff.wor



Title:

Option 11 (Unmitigated Case)
Peak Flood Level Impact 100 Year ARI Event

Figure: **C-4**

Rev: **A**

N

0 1 2km
Approx. Scale

BMT WBM
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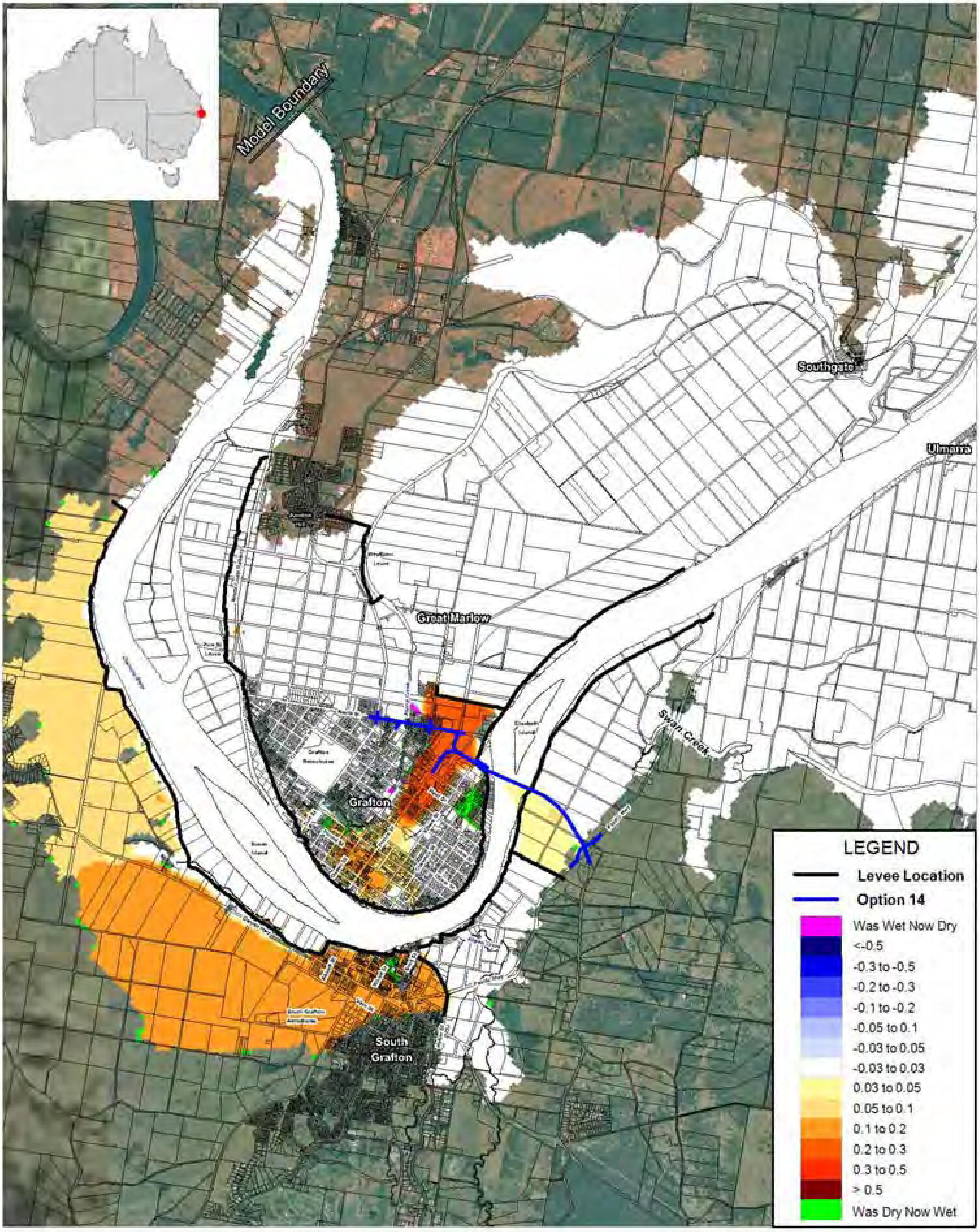
Filepath : I:\B17815_I_Summerland_Way\DRG\RODR_Report_Final\FLD_034_120122_Q100_Opt11_NoMit_Hdiff.wor



Title:

Option 14 (Unmitigated Case) Peak Flood Level Impact 100 Year ARI Event

Figure: C-5

Rev: A

N

0 1 2km
Approx. Scale

BMT WBM
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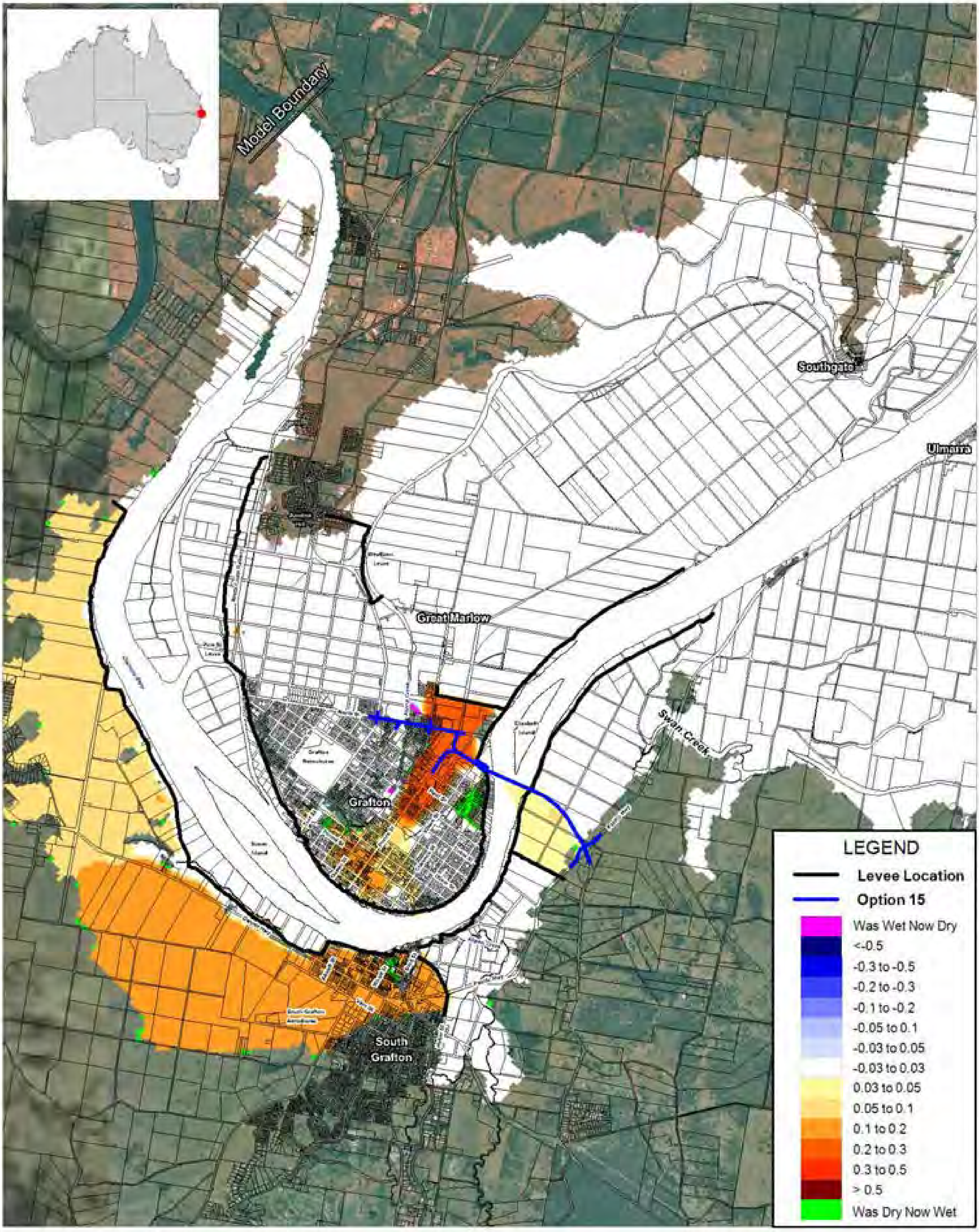
Filepath : I:\B17815_I_Summerland_Way\DRG\RODR_Report_Final\FLD_035_120122_Q100_Opt14_NoMit_Hdiff.wor



Title:

Option 15 (Unmitigated Case)
Peak Flood Level Impact 100 Year ARI Event

Figure: C-6

Rev: A

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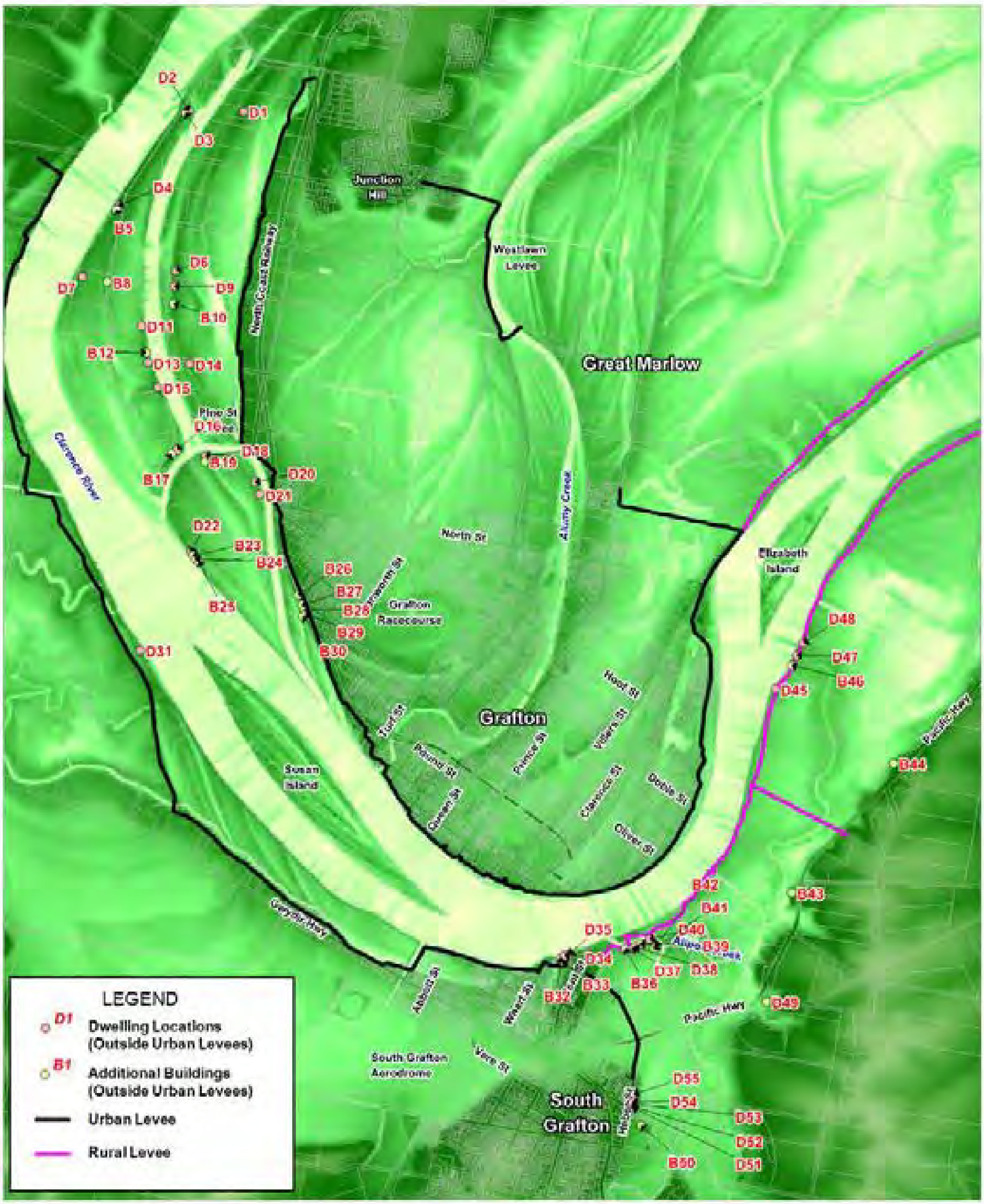
APPENDIX D: Flood Impact Reference Table – Properties Outside the Urban Grafton/South Grafton Levees



Title:
Building Location Reference (Outside the Grafton/South Grafton Urban Levees)

Figure: **D-1** Rev: **A**

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N 0 1 2km
Approx. Scale

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Filepath: I:\B17815_I_Summerland_Way\DRG\RODR_Report Final\FLD_101_120202_Property_Afflux.WOR

Table D- 1 Property Flood Impacts Summary Table - 20 Year ARI Event

Building ID	Existing Peak Flood Level (mAHD)	Option (Mitigated) - Peak Flood Level Impact (m)					
		E	A	C	11	14	15
D1	9.0	0.03	0.03	0.04	0.05	0.02	0.02
D2	9.0	0.02	0.03	0.04	0.05	0.02	0.02
D3	9.0	0.02	0.03	0.04	0.05	0.02	0.02
D4	9.0	0.02	0.03	0.04	0.05	0.01	0.01
B5	9.0	0.02	0.03	0.04	0.05	0.01	0.01
D6	8.9	0.03	0.04	0.05	0.05	0.02	0.02
D7	9.0	0.02	0.03	0.04	0.05	0.02	0.02
B8	8.9	0.03	0.03	0.04	0.05	0.02	0.02
D9	8.9	0.03	0.04	0.05	0.05	0.02	0.02
B10	8.8	0.03	0.04	0.05	0.05	0.02	0.02
D11	8.8	0.03	0.04	0.05	0.05	0.02	0.02
B12	8.8	0.03	0.04	0.05	0.05	0.02	0.02
D13	8.8	0.03	0.04	0.05	0.05	0.02	0.02
D14	8.8	0.03	0.04	0.05	0.05	0.02	0.02
D15	8.8	0.03	0.04	0.05	0.05	0.02	0.02
D16	8.8	0.03	0.04	0.05	0.05	0.02	0.02
B17	8.8	0.03	0.04	0.05	0.05	0.02	0.02
D18	8.8	0.03	0.04	0.05	0.05	0.02	0.02
B19	8.8	0.03	0.04	0.05	0.05	0.02	0.02
D20	8.7	0.03	0.04	0.05	0.05	0.02	0.02
D21	8.7	0.03	0.04	0.05	0.05	0.02	0.02
D22	8.7	0.03	0.04	0.05	0.05	0.02	0.02
B23	8.7	0.03	0.04	0.05	0.05	0.02	0.02
B24	8.7	0.03	0.04	0.05	0.05	0.02	0.02
B25	8.7	0.03	0.04	0.05	0.05	0.02	0.02
B26	8.6	0.03	0.04	0.05	0.05	0.02	0.02
B27	8.6	0.03	0.04	0.05	0.05	0.02	0.02
B28	Dry	Dry	Dry	Dry	Dry	Dry	Dry
B29	Dry	Dry	Dry	Dry	Dry	Dry	Dry
B30	8.6	0.03	0.04	0.05	0.05	0.02	0.02
D31	8.7	0.03	0.04	0.05	0.05	0.02	0.02
B32	7.8	0.00	0.03	0.05	0.06	0.01	0.01
B33	7.8	0.00	0.03	0.05	0.06	0.01	0.01
D34	7.8	0.00	0.03	0.05	0.05	0.01	0.01
D35	7.8	0.00	0.03	0.05	0.05	0.01	0.01
B36	7.5	0.00	0.00	-0.02	0.10	0.04	0.03
D37	7.5	0.00	0.00	-0.01	0.10	0.03	0.03
D38	7.4	0.00	0.00	-0.01	0.08	0.03	0.03
B39	7.4	0.00	0.00	-0.01	0.09	0.03	0.03
D40	7.4	0.00	0.00	-0.01	0.08	0.03	0.03
B41	7.4	0.00	0.00	0.00	0.08	0.03	0.03
B42	7.4	0.00	0.00	0.00	0.08	0.03	0.03
B43	Dry	Dry	Dry	Dry	Dry	Dry	Dry
B44	Dry	Dry	Dry	Dry	Dry	Dry	Dry
D45	7.1	-0.01	-0.01	0.00	0.00	0.02	0.02
B46	7.1	0.00	0.01	0.00	0.00	0.01	0.01
D47	7.1	0.00	0.00	0.00	0.00	0.01	0.00
D48	7.1	0.00	0.00	0.00	0.00	0.00	0.00
D49	Dry	Dry	Dry	Dry	Dry	Dry	Dry
B50	7.4	0.00	0.00	0.00	0.08	0.03	0.03
D51	7.4	0.00	0.00	0.00	0.08	0.03	0.03
D52	7.4	0.00	0.00	0.00	0.08	0.03	0.03
D53	7.4	0.00	0.00	0.00	0.08	0.03	0.03
D54	7.4	0.00	0.00	0.00	0.08	0.03	0.03
D55	7.4	0.00	0.00	0.00	0.08	0.03	0.03

Table D- 2 Property Flood Impacts Summary Table - 100 Year ARI Event

Building ID	*Existing Peak Flood Level (mAHD)*	*Option (Mitigated) - Peak Flood Level Impact (m)*					
		E	*A*	*C*	*11*	*14*	*15*
D1	9.4	0.03	0.04	0.06	0.07	0.02	0.02
D2	9.4	0.03	0.04	0.05	0.07	0.02	0.02
D3	9.4	0.03	0.04	0.05	0.07	0.02	0.02
D4	9.4	0.02	0.03	0.05	0.06	0.02	0.02
B5	9.4	0.02	0.03	0.05	0.06	0.02	0.02
D6	9.3	0.03	0.04	0.06	0.07	0.03	0.03
D7	9.5	0.02	0.04	0.05	0.06	0.02	0.02
B8	9.4	0.03	0.04	0.06	0.07	0.02	0.02
D9	9.3	0.03	0.04	0.06	0.07	0.03	0.03
B10	9.3	0.03	0.04	0.06	0.07	0.03	0.03
D11	9.3	0.03	0.04	0.06	0.07	0.03	0.03
B12	9.3	0.03	0.04	0.06	0.07	0.03	0.03
D13	9.3	0.03	0.04	0.06	0.07	0.03	0.03
D14	9.3	0.03	0.04	0.06	0.08	0.03	0.03
D15	9.2	0.03	0.04	0.06	0.08	0.03	0.03
D16	9.2	0.03	0.04	0.06	0.08	0.03	0.03
B17	9.2	0.03	0.04	0.06	0.08	0.03	0.03
D18	9.2	0.03	0.04	0.06	0.08	0.03	0.03
B19	9.2	0.03	0.04	0.06	0.08	0.03	0.03
D20	9.2	0.03	0.04	0.06	0.08	0.03	0.03
D21	9.1	0.03	0.04	0.06	0.08	0.03	0.03
D22	9.1	0.03	0.04	0.06	0.08	0.03	0.03
B23	9.1	0.03	0.04	0.06	0.08	0.03	0.03
B24	9.1	0.03	0.04	0.06	0.08	0.03	0.03
B25	9.1	0.03	0.04	0.06	0.07	0.03	0.03
B26	9.1	0.03	0.04	0.06	0.07	0.03	0.03
B27	9.0	0.03	0.05	0.06	0.07	0.03	0.03
B28	Dry	Dry	Dry	Dry	Dry	Dry	Dry
B29	Dry	Dry	Dry	Dry	Dry	Dry	Dry
B30	9.0	0.03	0.05	0.06	0.07	0.03	0.03
D31	9.1	0.03	0.04	0.06	0.07	0.03	0.03
B32	8.1	0.00	0.04	0.07	0.08	0.01	0.01
B33	7.9	0.00	0.03	0.07	0.06	0.01	0.01
D34	8.2	0.00	0.04	0.07	0.08	0.01	0.01
D35	8.3	0.00	0.02	0.03	0.03	0.00	0.00
B36	7.9	0.01	0.01	-0.01	0.05	0.02	0.02
D37	7.8	0.00	0.00	0.00	0.06	0.03	0.03
D38	7.8	0.00	0.00	0.00	0.07	0.03	0.03
B39	7.8	0.00	0.00	0.00	0.07	0.03	0.03
D40	7.8	0.00	0.00	0.00	0.07	0.03	0.03
B41	7.8	0.00	0.00	0.00	0.07	0.03	0.03
B42	7.8	0.00	0.00	0.00	0.07	0.03	0.03
B43	Dry	Dry	Dry	Dry	Dry	Dry	Dry
B44	Dry	Dry	Dry	Dry	Dry	Dry	Dry
D45	7.3	0.00	0.00	0.00	0.00	0.05	0.05
B46	7.4	0.00	0.00	0.00	0.00	0.03	0.03
D47	7.4	0.00	0.00	0.00	0.00	0.03	0.03
D48	7.4	0.00	0.00	0.00	0.00	0.01	0.01
D49	7.8	0.00	0.00	0.00	0.07	0.02	0.02
B50	7.8	0.00	0.00	0.00	0.08	0.03	0.03
D51	7.8	0.00	0.00	0.00	0.08	0.03	0.03
D52	7.8	0.00	0.00	0.00	0.08	0.03	0.03
D53	7.8	0.00	0.00	0.00	0.08	0.03	0.03
D54	7.8	0.00	0.00	0.00	0.08	0.03	0.03
D55	7.8	0.00	0.00	0.00	0.08	0.03	0.03

APPENDIX E: DRAFT ROUTE OPTIONS DEVELOPMENT REPORT TECHNICAL PAPER - PEER REVIEW COMMENTS

Roads and Maritime Services (RMS) and BMT WBM (WBM) response to peer review comments by Paterson Consulting (PC) on the "Draft Route Options Development Report Technical Paper – Flooding May 2012"

PC: *I have been through the report "Draft Route Options Development Report Technical Paper – Flooding May 2012" several times.*

PC: *My thoughts on the Report are as follows:-*

PC: *3a. I have not sought to comment on the grammar, spelling or editorial inputs to the report. I did note that:*

- At least one use of words that I view as incorrect.
- Inconsistency regarding if the bridge options cause overtopping of the Grafton levee system "may cause adverse impacts" and or " will cause adverse impacts."

WBM: The technical paper has been reviewed for grammar, spelling and consistency.

PC: *3b. The differences between the levee options are identified on the basis of lengths of levee requiring adjustment.*
WBM: This measurable has been used as it provides a comparable estimate of the upstream extent of flood impacts associated which each of the options.

PC: *Some of the levees are in household backyards while others are in open rural landscape. The cost of up-grade of these two levee systems will be significantly different. Further, in my view, this river model over-estimates flood levels up stream of Grafton thus over-estimates the impact of bridge options upstream of Grafton.*
WBM: BMT WBM believe B.Patersons' comment is overstated. This was discussed during a meeting preceding the development of the draft Route Options Development Report and the flooding technical paper, attended by B.Paterson, RMS, ARUP and BMT WBM. The point of difference was not resolved during the meeting, though, as an outcome of the meeting it was agreed that the Lower Clarence flood model (2004) represented the best tool available to assess the relative flood impacts associated with proposed options. As such, it was agreed that the flood behaviour represented by the Lower Clarence flood model (2004) was suitable for the relative assessment of the proposed options on the local flood behaviour.

PC: *The consequence of these two points is that the costs downstream of the existing bridge options will be understated while the upstream options costs will be overstated. Thus on the comparison of options on cost criteria the downstream will be favoured against the upstream options.*
RMS: The cost allowance for levee raising (which includes 50% contingency) is less than 1% of the estimated cost of each of the options. Any discrepancies in the estimated cost of levee raising for the options is unlikely to significantly alter the estimated cost or the relative value for any of the options.

PC: *3c. There are buildings and dwellings on the floodplain which are not protected by the levee system. The report does not indicate the change in freeboard to these building while this data should be at hand and shown. I am not concerned about farm buildings but residential, commercial or industrial uses should be addressed.*
WBM: This information has been included in the final report.

PC: *3d. I am not convinced that the WBM frequency analysis is correct for a variety of technical reasons. Nonetheless, the levee system is a physical topographic reality and potential overtopping is a real possibility thus the frequency of how often overtopping may occur is a matter of conjecture. This issue could simply be addressed by using Prince Street gauge as reference point for both flood gauge height and levee height and potential overtopping.*
WBM: BMT WBM disagree with B Paterson regarding the flood frequency analysis comment. It was previously agreed by B.Paterson, RMS, ARUP and BMT WBM at the meeting preceding the development of the draft Route Options Development Report and the flooding technical paper that the Lower Clarence Flood model (2004) be used for the bridge duplication assessment. Based on this understanding, the 20 year and 100 year

ARI design flood events have been used for the flooding assessment due to their flood behaviour relative to the levees in Grafton/South Grafton.

(Excerpt from Draft Route Options Development Report Technical Paper – Flooding May 2012)

1 The 20 year ARI event representing a catchment flood event approximately equivalent to the level of flood immunity provided by the Grafton and South Grafton levees; and
2 The 100 year ARI event representing a major levee overtopping event. At the peak of the 100 year ARI event approximately 60% of the Grafton and 75% of the South Grafton levee length is overtopped by floodwaters.

Regardless of its frequency, a flood of the significance of the 20 year ARI design flood in the BMT WBM flood model is the flood event that is at, or close to, the level of the flood levee. A flood of this level and magnitude is the appropriate flood to assess the relative impact of options on flooding in the Grafton area.

The height of the flood on the Prince Street gauge that is at, or close to, the level of the flood levee has been included in the final report

PC: *3e. Changes to the levee system at Grafton and indeed the downstream bridge options will be a significant issue for community downstream of Grafton (in particular in the floodplain near Swan Creek, Ulmara, Great Marlow and Southgate).*
The report needs to address:

- *Increases in flood levels in these areas.*
- *Changes in timing of flood arrival times (whilst noting the "Design Flood" hydrograph is a synthesis of past events and that fatter and sharper flood hydrographs have occurred and can represent quite large deviations from the design flood hydrograph).*

WBM:

- The flood level impacts resulting from the mitigated options in these locations are negligible. Figure extents have been extended further downstream and additional reporting locations corresponding to these downstream locations have been added to the final report result tables.
- The proposed options do not significantly impact the flood arrival times at the above listed locations for the assessed design event. This outcome has been included in the final Route Options Development Report Technical Paper – Flooding. Assessment of a varied flood hydrograph is outside the scope of the current assessment.

PC: *3f. The report refers to a rural levee system on the eastern side of the Clarence River downstream of the existing bridge. My recollection is that there is no significant constructed levee in this location so that the "levee" in the model is simply representing a natural high river bank (a "natural levee"). As part of the 1990 South Grafton levee works topping up of a small section of the river bank was undertaken. This works was not undertaken to protect the adjacent rural lands but to create a small change in flood arrival times for the areas east of Ulmara in response to changes caused by the 1990 South Grafton Works (not withstanding that significant benefits in flood timing were created by the 1974 South Grafton levee program).*
WBM: Whether the Alipou Basin Levee is 'natural' or 'man-made' is irrelevant when considering the aims/objectives of the Route Options Development Report. It is however important that the flood model adequately represents the region of raised ground, which it does.

The figures documented in the draft Route Options Development Report Technical Paper – Flooding are consistent with publicly available levee data from the Clarence Valley Council, which refers to the area in question as the 'Alipou Basin Levee' – refer to:
http://www.clarence.nsw.gov.au/cp_content/resources/Map_of_Grafton_and_South_Grafton_levee_system.pdf

PC: *3g. The option using a pump system to create an inundation free approach to the proposed Option C raises significant concerns. Having investigated the use of pumps to reduce ponding in the Kent Street area on three occasions, I should point out:*

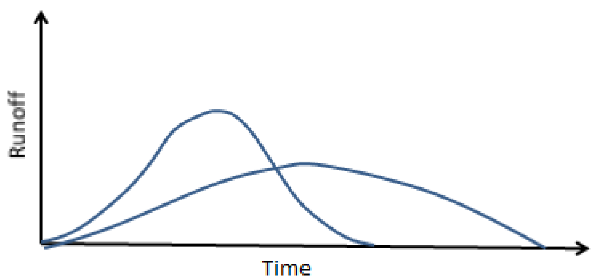
- *Ponding in the Kent Street area has occurred quite regularly when river levels are high enough to prevent drainage to the river.*
- *To my recollection significant ponding has occurred in 1974, 1988, 1989, possibly 1996 and 2009. thus return period is about once in 10 years ARI.*
- *Since 1974, Grafton City Council has required any filling below about RL 4.0 m AHD to be balanced by equal volumes of flood storage. This approach followed the 1974 event where it became apparent that the*

drainage system interconnects through Grafton, east of Queen Street. The subtlety of this approach may well have been lost in the amalgamation of Maclean and Grafton into Clarence Valley Council.

- *The pump arrangement for Option C will reduce the total storage available in Grafton leading to higher ponding levels (or even more pumps).*
  WBM: The conceptual drainage strategy includes a detention basin which provides an additional 560m^3 of storage.
- *The pump capacity set at 2 cu. m/sec appears to be set to match design flow peaks. A pump station of this capacity is not a cheap item by the time pump and discharge line, physical station construction and power supply requirements are considered.*
  RMS: Acknowledged. The strategic cost estimate for Option C includes the cost of the proposed drainage and pumping arrangements.
- *Given there appears to be no storage available for a pumping pool, pump start timing, the need for at least one stand-by pump, and the ability of the existing drainage system to supply the required flow to the pumps will become major issues.*
  WBM: The 560m^3 detention basin, catch drain and culverts under option C have been designed to collect the local runoff before pumping. Should Option C be selected as the preferred option, the provision of a stand-by pump to manage the residual risks associated with pumping would be assessed during the detailed design of the drainage and pumping arrangements.
- *The analysis has adopted the 72 hour storm for design. In reality, drainage from Kent Street can be blocked for significantly longer periods that 72 hours and thus the analysis needs consideration over the length of historical rainfall record.*
  WBM: For clarification: definition of the critical duration event = the duration storm which results in the greatest flood levels for a given location. This in no way implies that the current drainage infrastructure within Grafton can drain the Kent St area within 72 hours.

Historically, the duration of elevated river levels (preventing the gravity drainage of the Grafton storm water network) can vary significantly from one event to another. Due to the uncertainty associated with this flood behaviour, and also for consistency with the regional Route Options Development Report flooding assessments, the local catchment critical storm duration assessment was completed assuming coincident design flood event levels within the Clarence River. This is a reasonable “worst case” scenario for the flooding assessment.

It is true that some historic events have occurred which were longer than the 72 hour event. From a hydraulic perspective, a local catchment event (coinciding with a river flood event) with a longer duration than that of the 72hr storm will result in a greater runoff volume within Grafton. It should however be recognised that the rainfall intensity (mm/h) of the longer duration storm will be less than the 72hr storm (see below figure for concept illustration). Considering this reduced intensity, it is possible/likely that the proposed pump flow rates will successfully mitigate runoff associated with the longer duration storms. Should Option C be selected as the preferred option, additional sensitivity tests which more fully consider duration event coincident river/local runoff events would be undertaken during the detailed design of the drainage and pumping arrangements.



- *In my view, the maintenance and operation of the pump system will create on-going issues for the RMS in maintaining access to the new bridge and I suspect on-going community complaints regarding failure to provide an implied service.*
  WBM: Noted.
- *In my view, the pump system option fails the sustainability test of environmental outcomes.*
  WBM: Pumps are commonly used to manage inundation of areas protected by flood levees. Compared to the current situation, the proposed drainage and pumping arrangements would reduce the frequency and

extent of inundation in the Kent Street area both with and without elevated water levels in the Clarence River. This reduction in inundation level provides and additional benefit to residents in the area.

PC: *3f. I note a number of inconsistencies in the drawings. These are evident on a careful examination but would not be picked up by a casual view. As such, I don't think there are significant in terms if route selection.*
WBM: Noted.

PC: *4. There is an underlying assumption that "the model is correct" not simply a representation of reality. I have consistently asked for a demonstration of the afflux as calculated by the model versus other techniques (such as drag on piers or broader US Highway model tests). I have not been apprised why this cannot be done as a check.*
WBM: Upstream bridge affluxes have been verified against hand calculation estimates using methods prescribed in the Hydraulic of Bridged Waterways (US Army Corps).These calculations have not been included within the Route Options Development Report Technical Paper – Flooding, given they do not provide the reader with any additional information which would otherwise affect the conclusions of the Route Options Development Report. The calculations have been provided to PC.

PC: *5. Section 3.2 "Flooding Constraints", last paragraph. Whilst the concept of maintenance of the current level of flood protection in Grafton is mentioned in the subject paragraph and in Chapter 2, First paragraph, my view is that this concept should be highlighted.*
WBM: We disagree that further emphasis is required. This concept is already consistently discussed throughout the entire report (Section references from R.B17815.007.04.RODR.pdf):

- Section 1.2 'Background' - Bullet Point 3 (listed as one of the main aims of the assessment);
- Section 2 'Assessment Methodology' - Paragraph 1, Bullet Point 2 (listed as one of the main aims of the assessment);
- Section 2 'Assessment Methodology' - Paragraph 4, Bullet Point 3 (listed as one of key design feature required within the assessment methodology);
- Section 3.2 'Flooding Constraints' - Last paragraph;
- Section 4.1 'Design Criteria' - Bullet Point 2a;
- Section 6 'Conclusions' - Bullet Point 2; and
- Appendix C – Unmitigated results included for reference.

PC: *6. Further, that in comparison of various route options, each option provides a similar level of flood protection and hence, for comparative purposes, the differences between each route option reduces to a question of cost.*
WBM: Costs associated with the flood mitigation measures have been considered separately, not as part of the flooding assessment. The cost allowance for levee raising (which includes 50% contingency) is less than 1% of the estimated cost of each of the options.

PC: *7. Section 5.4 – "Option 11", paragraph 3. The subject paragraph refers to the area near Alipou Creek. Reference to the same area also appears in: Section 5.4 "Options 14/15" paragraph 3, Table 5.1 and Table 6.1*
With respect to the levees on the eastern side of the Clarence River, downstream of Alipou Creek, I would note:

- *The levee between the Clarence River and the Pacific Highway is a low levee that was constructed circa 1973, to push water back into South Grafton.*
- *The bulk of the line beside the Clarence River is in fact high river bank and not a constructed levee (as I am aware).*
- *The "Alipou Basin Levee" was in fact a topping up of the river bank over some 1000 m simply using topsoil. The height raised was the order of 200 to 300 millimetres. This work was done to create some minor changes to flood timing (in the design flood) following construction of the current flood protection for South Grafton. The object of the work was not to provide flood protection to the rural areas at Alipou Creek. Given the depth of flooding in the Alipou Creek area, the absence of critical infrastructure and given that an afflux of 0.1 metres would not normally be of major concern for rural areas, I suggest that the references to the potential raising of the natural high river bank downstream of Alipou Creek be removed.*

Raising of the river bank downstream of Alipou Creek has the potential to:

- *Change timing of floods downstream of Grafton; and*
- *Increase flood levels in areas relatively distant from the possible route options.*

WBM: In light of these comments all references which mention potential raising of the Alipou Basin Levee/Riverbank have been removed.
Revised text example: "Within the rural areas of South Grafton adjacent to Alipou Creek (between the Clarence River and the Pacific Highway) Option 11 results in changes in flood levels within 0.10m. These flood level

changes are considered acceptable, given they are confined to rural, undeveloped areas which do not include any critical infrastructure. ~~Mitigation of these flood level changes via compensatory raising of the adjacent rural levee can be considered as part of a preferred option assessment, if the option is selected and these flood level changes are deemed unacceptable~~."

PC: *8. Chapter 2 – "Assessment Methodology" – footnotes. The report footnotes refer to the "catchment state". In my view, the "catchment state" is unchanged from existing to possible bridge construction in Grafton. However, the topography in and around Grafton (for the purposes of assessment of flood impacts) will change. I suggest "catchment state" be changed to "local topography".*
WBM: "catchment state" has been replaced with "local topography".

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