Narrabri Floodplain Risk Management Study and Plan

Volume I: Supplementary Flood Study - Namoi River, Mulgate Creek and Long Gully

Narrabri Shire Council

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Report Title	Narrabri Floodplain Risk Management Study and Plan: Volume I: Supplementary Flood Study - Namoi River, Mulgate Creek and Long Gully
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Acknowledgements and limitations

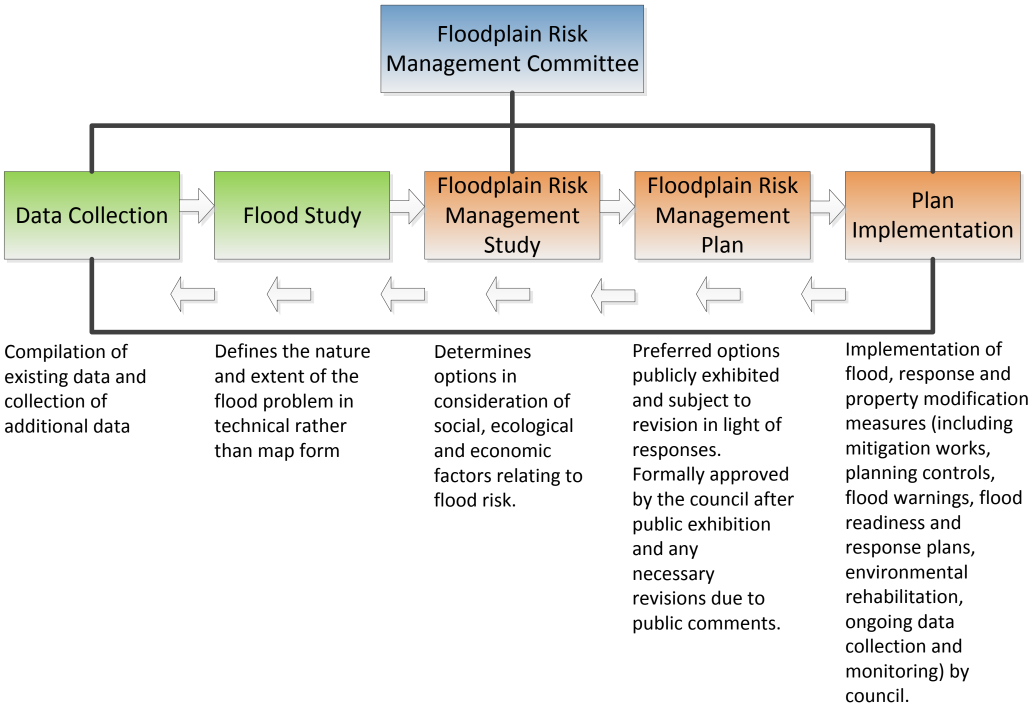
This project was prepared with financial assistance from the NSW Government's Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Office of Environment and Heritage.

While all due effort has been made to ensure the reliability of flood model results, all models have limitations (Ball et al., 2019). The accuracy of any model is a function of the quality of the data used in the model development including topographical data, drainage structure data and calibration data. Modelling is by nature a simplification of very complex systems and results of flood model simulations should be considered as a best estimate only. There is, therefore, an unknown level of uncertainty associated with all model results that should be considered when utilising the outputs from this study.

Foreword

The NSW Government's Flood Prone Land Policy provides a framework for managing development on the floodplain. The primary objective of the policy is to develop sustainable strategies for managing human occupation and use of the floodplain using risk management principles. Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The NSW Government's Floodplain Development Manual (2005) (the Manual) has been prepared to support the NSW Government's Flood Prone Land Policy. The Manual provides council's with a framework for implementing the policy to achieve the policies primary objective. The framework is shown below.



The Narrabri Flood Study constituted the first stage of the Floodplain Risk Management process and assessed the risk of regional flooding from the Namoi River and local flooding from its tributaries, Mulgate Creek and Long Gully. It was prepared by consultants WRM Water & Environment Pty Ltd and the Narrabri Shire Floodplain Risk Management Committee for Narrabri Shire Council.

Modelling conducted for the Narrabri Flood Study was updated as part of the Floodplain Risk Management process, with this report presenting the results of the updated Flood Study modelling. The results presented herein supersede the Narrabri Flood Study and will be used throughout the remainder of the Floodplain Risk Management process.

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1 Introduction

1.1 OVERVIEW

The township of Narrabri is located on the Namoi River floodplain and is drained by a number of smaller tributaries including Mulgate Creek, Horsearm Creek and Long Gully. In the past Narrabri has experienced above floor flooding from each of these sources on a regular basis posing a significant risk to property and life. The location of Narrabri and the drainage characteristics of the area of interest are shown in Figure 1.1.

There have been several studies prepared to define the flood risk from the Namoi River but minimal investigations have been undertaken to define the flood risk from its minor tributaries Mulgate Creek and Long Gully. The most recent of these studies was the Narrabri Flood Study, completed by WRM Water & Environment Pty Ltd (WRM) in December 2016 which addressed flooding from both regional (Namoi River) and local (Mulgate Creek and Long Gully) sources. This report is referred to as the 2016 flood study herein.

WRM have been commissioned by Narrabri Shire Council (NSC), with funding assistance administered by the NSW Office of Environment and Heritage (OEH), to prepare a Floodplain Risk Management Study and Plan (FRMP), which in conjunction with the previously prepared flood study will continue the floodplain risk management process. This Supplementary Flood Study updates the flood modelling conducted during the FRMP process to bring the modelling up to date with the latest revision of Australian Rainfall and Runoff (AR&R) (Ball et al., 2019) while utilising updated versions of modelling software.

1.2 ADOPTED APPROACH

The approach of this Supplementary Flood Study is consistent with the previous 2016 flood study (WRM, 2016), hence only the changes made since the completion of the 2016 flood study are outlined in this report. As such, this report should be read in conjunction with the 2016 flood study. However the results presented in this report supersedes all results presented in the 2016 flood study.

1.3 REPORT STRUCTURE

The report is structured as follows:

- Section 2 describes the configuration of the XP-RAFTS hydrological model;
- Section 3 describes the configuration of the MIKE-FLOOD hydraulic model;
- Section 4 outlines the model calibration against five historical flood events;
- Section 5 presents the design discharge estimates for both local and regional flooding;
- Section 6 presents the results from the design flood modelling and the sensitivity analysis undertaken, as well as a description of the local flooding behaviour;
- Section 7 describes the hydraulic hazard category analysis and provides the provisional hydraulic hazard categories proposed for the study area;
- Section 8 provides a summary of the findings for the study;
- Section 9 is a list of references; and
- Section 10 is a glossary of technical terms used in this report.

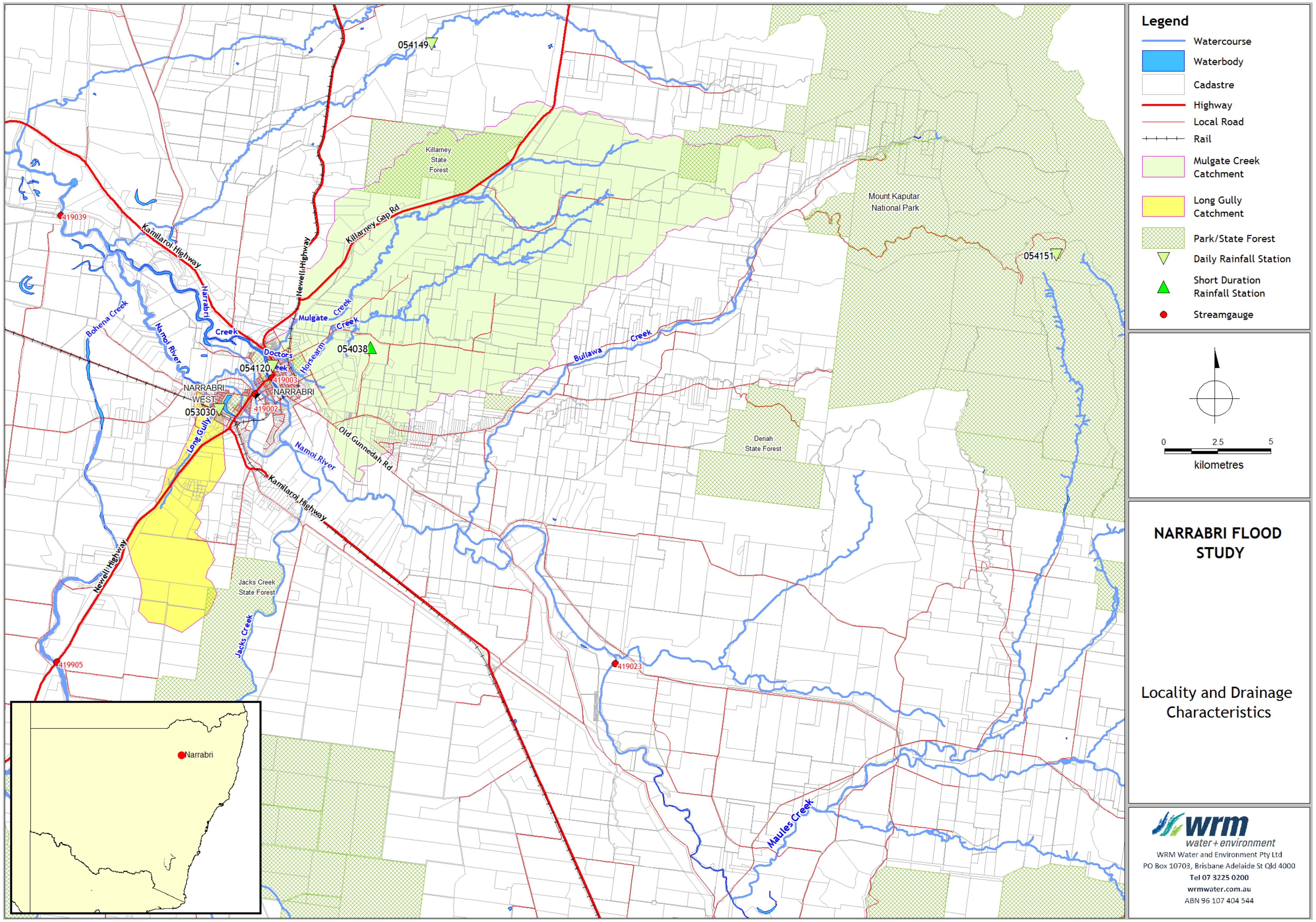

Figure 1.1 - Narrabri locality and drainage characteristics

2 Hydrological modelling (local catchments)

2.1 CHANGES FROM THE 2016 FLOOD STUDY

The XP-RAFTS hydrologic model developed for the 2016 flood study was updated to the latest version of the software and updated to incorporate new design rainfalls and methodology from AR&R (Ball et al., 2019). The model configuration and adopted model parameters have not been changed.

3 Hydraulic model development

3.1 CHANGES FROM THE 2016 FLOOD STUDY

The MIKE-FLOOD hydraulic model developed for the 2016 flood study was updated to a more recent version of the software. Minor changes were also made to the adopted hydraulic resistance parameters and hydraulic structure representation to improve model calibration and improve model stability.

3.2 MODEL CONFIGURATION

3.2.1 MIKE-21FM mesh properties

The MIKE-21 module is the two dimensional component of the hydrodynamic model. Figure 3.1 shows the extent of the Narrabri MIKE-21 model. The flexible mesh version of MIKE-21 (MIKE-21FM) uses triangular and/or trapezoidal elements to create a computational mesh on which the element-centred two-dimensional shallow water equations are solved. An adaptive time step is used by the computational engine to maintain simulation stability.

Any number of regions can be digitised within the model domain. Each distinct region can have a unique set of mesh properties that includes element type, maximum element area, smallest allowable angle and maximum number of nodes. The ability to subdivide the model domain allows greater topographic definition to be implemented in critical study areas, while limiting the computational resources being used in non-critical areas. Mesh orientation can also be controlled by digitising points and lines within the model domain.

For this study, important flow locations, structures, topographical features, watercourses, water bodies, roads, railways and the 1D structure alignments were digitised in a GIS package to define the mesh orientation at these hydraulically significant locations. MIKE-21FM was then used to generate and refine a computational mesh.

Table 3.1 details the six sets of mesh properties that were used to create the flexible mesh. The spatial locations of the six mesh regions are shown in Figure 3.2.

Table 3.1 - Mesh generation inputs

<table>
<tr><th>Region</th><th>Maximum Element Area (m^2)</th><th>Smallest Allowable Angle</th><th>Maximum Number of Nodes</th></tr>
<tr><td>Important flow path</td><td>75</td><td rowspan="6">26°</td><td rowspan="6">6,000,000</td></tr>
<tr><td>Developed area</td><td>100</td></tr>
<tr><td>Secondary flow path</td><td>200</td></tr>
<tr><td>General floodplain / rural land</td><td>400</td></tr>
<tr><td>Intensive cropping</td><td>600</td></tr>
<tr><td>Non floodplain</td><td>1200</td></tr>
</table>

The adopted mesh parameters were aimed at optimising run times while providing sufficient model definition in critical areas flow areas. The following is of note:

- The non-floodplain area is not inundated during flooding events (i.e. the hill slope areas on the fringe of the hydraulic model);
- The intensive cropping regions have been applied to land found behind levee banks and earthen bunds and are likely to be laser levelled. The relatively constant topography requires little model definition to fully capture flow behaviour;

- The general floodplain / rural land regions are modelled at an element size sufficient to simulate the flow distribution while not detracting from model performance and run times;
- The secondary flow path regions have been applied around breakouts from the one-dimensional representation of Narrabri Creek to the Namoi River. The smaller element being applied to these regions have been used to simulate the terrain of flood runners that break out from the main channel;
- The developed areas of Narrabri have been modelled at 100 m^2 element size to capture sufficient detail on the flow obstructions, as well as capture the varying hydraulic resistance; and
- The important flow path regions have been applied to ill-defined channels as well as some of the smaller flow paths to adequately capture channel capacity.

The end result was a flexible mesh of 1,015,397 elements covering an area of 22,820 ha. A single coupled MIKE-FLOOD model was created that covers the combined study areas for both the local and regional flooding investigations, hence large portions of the model remain dry when simulating only local or only regional flooding.

Each mesh node was assigned an elevation using the project DTM. Manual changes to the element elevations were made to match the invert levels of the 1D and 2D domains at the coupling locations. Some manual variation of mesh topography was also undertaken to improve the definition of the crest levels of levees and bunds. Survey of the levees and bunds were not available for the study. It was also assumed that the levees/bunds do not fail during flood events.

A single hydraulic model mesh based on the project DTM (derived from LiDAR data captured in 2014) was used for all calibration and design simulations. A review of model calibration showed that historical topographical changes over the past 70 years have been minor and would not significantly change the overall distribution of flow across the floodplain. Any impacts on flooding of recent developments would occur in the local area only.

3.2.2 Hydraulic resistance

The model uses Manning's 'n' values to represent hydraulic resistance (notionally channel or floodplain roughness). Discrete regions of continuous vegetation types and land uses were mapped, and appropriate roughness values assigned to each region. Vegetation and land use mapping were based on ortho-photograph imagery obtained from SixMaps online mapping tool provided by NSW Land and Property Information as well as the project DTM. The Manning's 'n' values were selected during model calibration and were applied to all model scenarios. Table 3.2 shows the adopted Manning's 'n' values used in the model and Figure 3.3 shows the locations of the Manning's 'n' regions.

Table 3.2 - **Manning's** roughness parameters

Region	Manning's 'n' Value
Floodplain	0.080
Flood channel	0.045
Open water/airport	0.034
Buildings	0.300
Road/rail	0.025

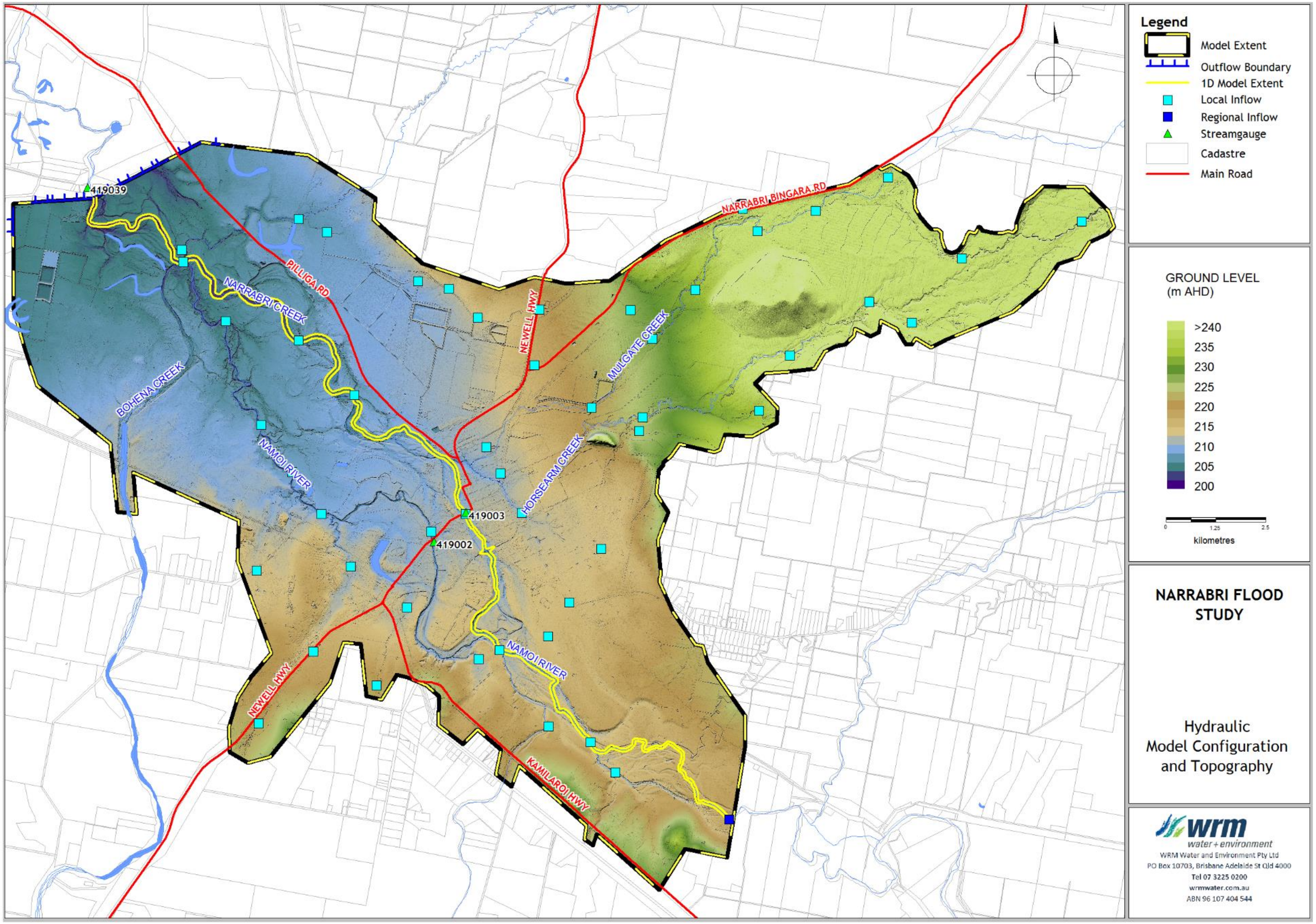

Figure 3.1 - MIKE-FLOOD model configuration and topography

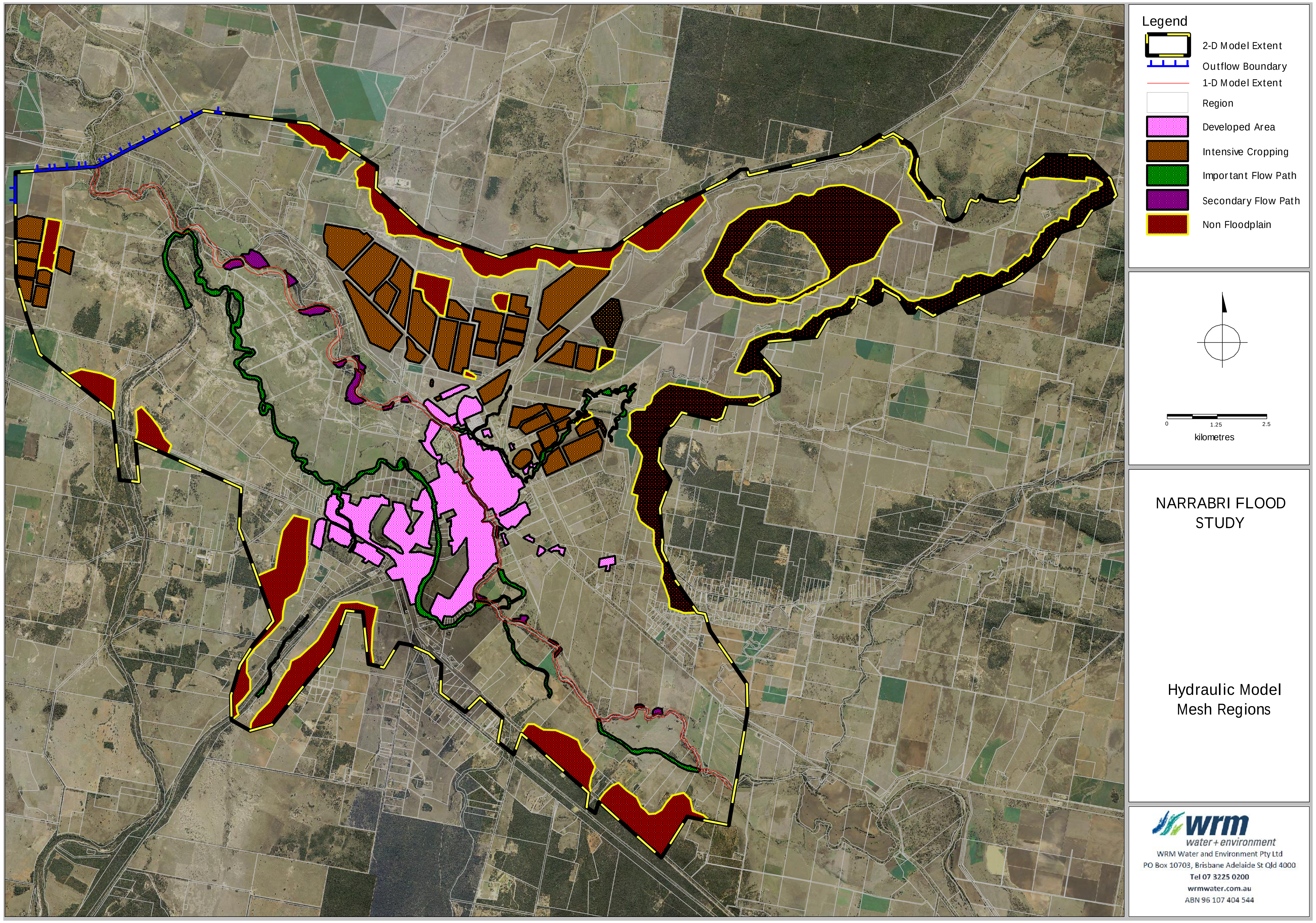

Figure 3.2 - MIKE-21FM mesh regions

3.2.3 Model boundaries

Figure 3.1 shows the locations of the inflow and outflow boundaries of the hydraulic model. A single upstream inflow was used to represent the flows from the Namoi River for regional modelling. All other inflows were associated with local catchment modelling of Mulgate Creek and Long Gully.

A total of 15 outflow boundaries were used at the downstream end of the model. The 14 outflow boundaries in the 2D domain were specified as Q-H rating curves derived using separate HEC-RAS models. The 1D outflow boundary was also specified as a Q-H rating curve calculated by MIKE-11. The outflow boundary Q-H rating curve was verified against the Namoi River at Mollee stream gauge (GS419039) rating curve, which is located approximately 300 m downstream of the boundary. Gauging records show that the DPI Water rating curve for this gauge is a good representation of flows up to around 1,500 m^3/s. Further discussion of the rating curve of this gauge is given in the WRM Flood Study (2016).

3.2.4 Model parameters

A number of model parameters were varied from default values to aid simulation stability and keep run times manageable. Parameters that were varied are shown in Table 3.3.

Table 3.3 - Adopted MIKE modelling parameters

Model Parameter	Adopted Value
MIKE Software Version	2017 Service Pack 2
MIKE-FLOOD	
Momentum conservation through couples	Yes
Standard link smoothing factor	0.28 - 0.30
MIKE-21FM	
Courant-Friedrichs-Levy (CFL) number	0.8
Maximum Timestep	2.0 s
Computation	Hydrodynamic - inland flooding
Time and Space Discretisation	Higher order
Flooding and Drying	Advanced flood and dry (floodplain)
Drying depth	0.005 m
Flooding depth	0.025 m
Wetting depth	0.05 m
Eddy viscosity formulation	Smagorinsky
Smagorinsky coefficient	0.28 (constant)
Computing approach	Single Precision GPU
MIKE-11	
Solution Engine	MIKE-11
FroudeMax	1
FroudeExp	2
Delta	0.85
MaxIterSteady	120

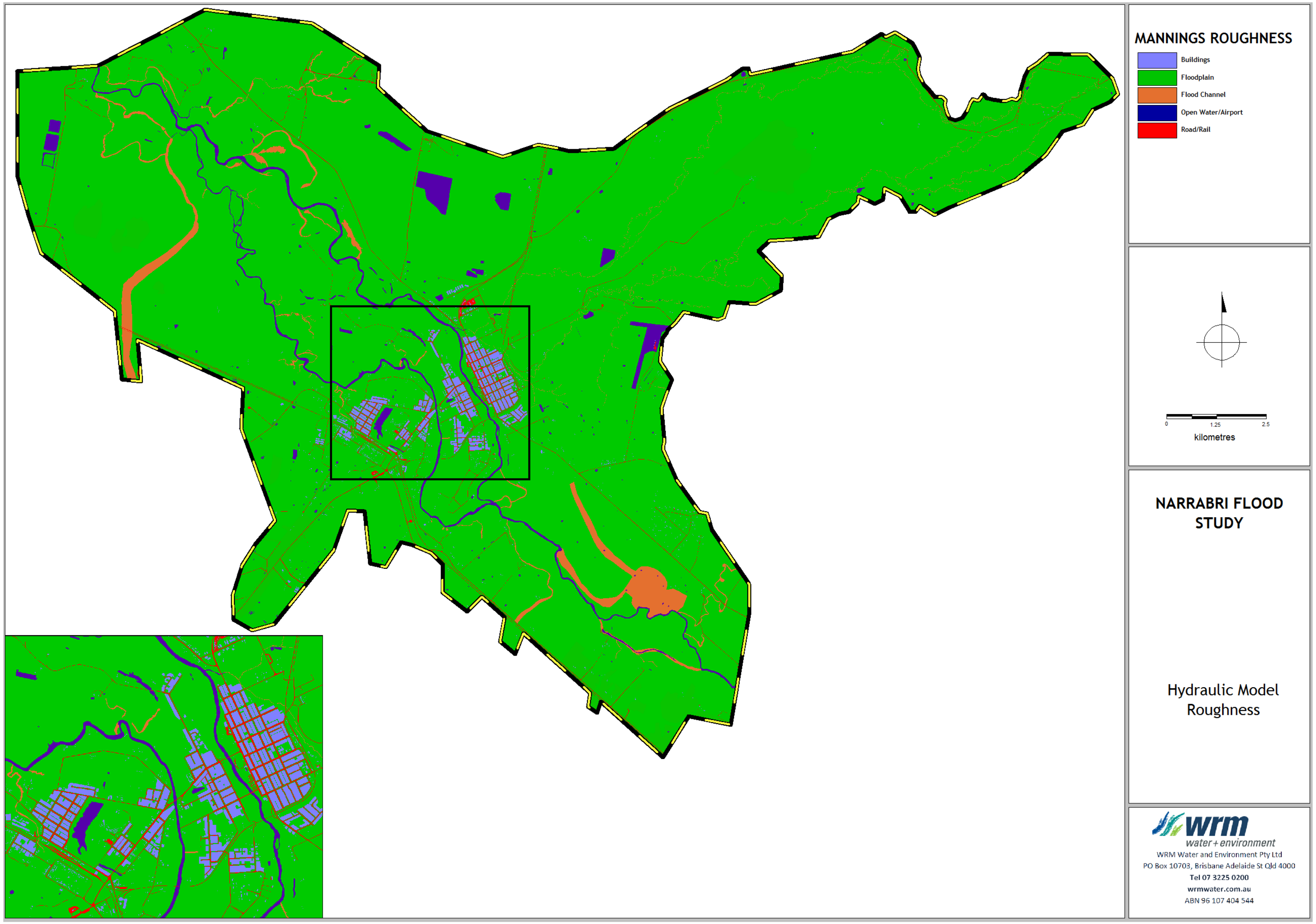

Figure 3.3 - **Manning's roughness distri**bution

3.2.5 Bridge, culvert and levee structures

The bridge and culvert structures were modelled within the 1D (MIKE-11) and 2D (MIKE-21FM) numerical schemes. Details of the bridge and culvert structures included in the study area are given in Table 3.4. The remaining hydraulic structures within the study area were deemed to be too small to affect flood levels or the distribution of flow. Those structures that weren't explicitly modelled in MIKE-11 or MIKE-21FM were handled in the two-dimensional mesh by lowering element topography (effectively leaving a gap to maintain the flow path).

A number of earthen levees and bunds were defined within the 2D domain using MIKE-21FMs dike regime. The dike regime creates a string of nodes along the crest of the levee/bund so that its hydraulic properties can be properly represented. In addition to the earthen structures, the road and rail embankments were also modelled as dikes to improve the definition of the crest levels of these structures. The concrete wall weir at the northern end of Narrabri Lake was also modelled as a dike in the 2D domain.

Table 3.4 - Culvert and bridge details

MIKE Name	Road/Rail Crossing	Dimension[a]	U/S Invert (mAHD)	D/S invert (mAHD)	Length (m)	Source	Representation
K Hwy 01	Kamilaroi Hwy	1 RCP 0.525	210.05	210.04	13.50	WRM Inspection	MIKE-21FM culvert
K Hwy 05	Kamilaroi Hwy	4 box 0.9x1.8	209.09	209.08	9.60	RMS Structure Plan	MIKE-11 culvert
K Hwy 25	Kamilaroi Hwy	4 box 1.2x2.4	213.52	213.51	9.60	RMS Structure Plan	MIKE-21FM culvert
Misc 03	Stoney Creek Rd	3 box 1.8x2.75	220.10	220.09	9.60	NSC Spreadsheet	MIKE-21FM culvert
Misc 14	Old Cemetery Rd	3 span	208.23	209.31	5.20	Detailed Survey	MIKE-21FM culvert
Misc 19	Namoi St	3 box 1.8x2.44	207.45	207.44	7.00	NSC Spreadsheet	MIKE-21FM culvert
Misc 22	Saleyards Ln	2 box 0.6x0.4	211.60	211.59	10.00	WRM Inspection	MIKE-11 culvert
Misc 36	Old Turrawan Rd	3 box 1.3x0.9	212.20	212.19	10.00	WRM Inspection	MIKE-21FM culvert
Misc 40	Violet St	4 span	200.80	200.70	11.00	NSC Structure Plan	MIKE-11 bridge
Misc 45	Ugoa St	3 box 1.8x0.9	209.85	209.84	10.00	WRM Inspection	MIKE-21FM culvert
Misc 53	Yarrie Lake Rd	2 box 2.1x2.1	208.58	208.51	7.96	Detailed Survey	MIKE-11 culvert
Misc 54	Mooloobar St	2 span	210.49	210.27	14.20	Detailed Survey	MIKE-21FM culvert
Misc 80	Gould Street	4 box 1.2x0.75	211.21	211.20	10.00	WRM Inspection	MIKE-11 culvert
Misc 86	Ugoa Street	3 box 1.8x0.9	209.9	209.89	10.00	WRM Inspection	MIKE-21FM culvert
N Hwy 01	Newell Hwy	4 box 2.4x1.2 2 box 2.4x1.35	217.55	217.54	16.00	WRM Inspection	MIKE-11 culvert
N Hwy 03	Newell Hwy	1 span	215.58	215.57	10.20	RMS Structure Plan	MIKE-21FM culvert
N Hwy 06	Newell Hwy	1 RCP 1.05	211.05	211.04	25.00	WRM Inspection	MIKE-11 culvert
N Hwy 07	Newell Hwy	2 box 2.1x2.1	210.00	209.99	28.50	-	MIKE-11 culvert
N Hwy 08	Newell Hwy	5 span	206.00	206.00	9.4	RMS Structure Plan	MIKE-11 culvert
N Hwy 09	Newell Hwy	2 box 2.1x2.1	210.20	210.19	19.00	-	MIKE-21FM culvert
N Hwy 10	Newell Hwy	7 span	201.54	201.89	13.2	RMS Structure Plan	MIKE-11 bridge
N Hwy 12	Newell Hwy	5 span	205.428	205.428	13.2	RMS Structure Plan	MIKE-11 culvert
N Hwy 13	Newell Hwy	9 span	210.88	210.88	18.00	RMS Structure Plan	MIKE-21FM culvert
N Hwy 14	Newell Hwy	4 span	210.13	210.13	13.85	RMS Structure Plan	MIKE-21FM culvert
N Hwy 29	Newell Hwy	2 box 1.2x0.6	218.90	218.89	17.00	WRM Inspection	MIKE-21FM culvert
N Hwy 30	Newell Hwy	4 box 3.2x1.8	218.45	218.44	17.50	WRM Inspection	MIKE-21FM culvert
Rail 01	Werris Creek Mungindi Railway	30 CMP 0.6	217.57	217.56	10.00	WRM Inspection	MIKE-11 culvert
Rail 02	Werris Creek Mungindi Railway	1 CMP 1.2	217.55	217.54	7.50	WRM Inspection	MIKE-11 culvert
Rail 05	Werris Creek Mungindi Railway	23 box 0.9x3.8	214.62	214.61	5.00	URS Model	MIKE-11 culvert
Rail 06	Werris Creek Mungindi Railway	9 span	208.53	208.69	2.60	Detailed Survey	MIKE-21FM culvert
Rail 07	Werris Creek Mungindi Railway	12 span	202.03	202.07	4.50	NSC Structure Plan	MIKE-11 bridge
Rail 08	Werris Creek Mungindi Railway	15 box 2.74x4.98	212.31	212.32	8.00	Detailed Survey	MIKE-21FM culvert
Rail 10	Werris Creek Mungindi Railway	28 span	205.64	205.64	5.50	NSC Structure Plan	MIKE-11 bridge
Rail 12	Werris Creek Mungindi Railway	4 box 2.56x4.8	210.90	210.88	4.42	Detailed Survey	MIKE-21FM culvert
Rail 15	Narrabri West Walgett Railway	5 CMP 2.1	210.88	210.87	7.20	WRM Inspection	MIKE-21FM culvert
Rail 24	Werris Creek Mungindi Railway	2 box 1.95x2.95	212.47	212.23	6.70	Detailed Survey	MIKE-21FM culvert
Rail 99	Narrabri West Walgett Railway	1 RCP 1.5	211.56	211.17	26.00	-	MIKE-21FM culvert

[a] - RCP = reinforced concrete pipe, box = box culvert, 3 span = 3 span bridge, CMP = corrugated metal pipe

4 Model calibration

4.1 OVERVIEW

The MIKE-FLOOD model was calibrated to the available data for:

- three regional (Namoi River) flood events:
  - February 1955;
  - February 1971; and
  - July 1998.
- two local (Mulgate Creek/Long Gully) flood events:
  - December 2004; and
  - February 2012.

No major flood events have occurred since 2016, hence the calibration events adopted for the 2016 flood study were re-run.

The purpose of model calibration was to match as close as possible the predicted and recorded flood levels across the floodplain in Narrabri for all the historical events using a single set of hydraulic model parameters. No changes were made to the hydrology model or the regional discharge estimates for the historical events.

4.2 REGIONAL FLOODING

4.2.1 February 1955 event

The February 1955 flood event was calibrated to the peak flood level data obtained from the NSW Department of Environment and Heritage (NSW OEH). The 1955 peak flood level data originated from a survey of floodmarks completed in April 1980.

Figure A.1 in Appendix A shows the predicted 1955 flood depths, levels and extent. Comparisons of the recorded and predicted peak flood levels at the available stream gauges and at the surveyed flood marks are also shown.

The overall calibration of the model to the 1955 flood marks is good with predicted peak flood levels in reasonable agreement with the recorded values. Of the 46 surveyed peak flood level marks available, the median difference is 0.00 m with 80th percentile values between 0.14 m low and 0.10 m high. There are two levels along Eathers Creek near the Newell Highway where the model predictions are 0.62 m and 0.36 m low. There are also two levels immediately downstream of Narrabri Township (along the Kamilaroi Highway and Lagoon Creek) that are 0.30 m and 0.49 m high. It was not possible to calibrate the model to these levels without significantly impacting on the calibration at the other points.

Overall a good calibration has been achieved for the February 1955 flood.

4.2.2 February 1971 event

The February 1971 flood event was calibrated to the surveyed peak flood level data obtained from the NSW OEH. The 1971 peak flood level data also originated from a survey of floodmarks completed in April 1980.

Figure A.2 in Appendix A shows the predicted 1971 flood depths, levels and extent. Comparisons of the recorded and predicted peak flood levels at the available stream gauges and at the surveyed flood marks are also shown.

The overall calibration of the model to the 1971 flood is good. Of the 58 surveyed peak flood level marks available, the median difference is 0.05 m with 80th percentile values between 0.19 m low and 0.07 m high.

4.2.3 July 1998 event

The July 1998 flood event was calibrated to the recorded water levels at the two stream gauges together with the flood extent shown in the aerial imagery of this event obtained from Narrabri Shire Council. There was no metadata supplied with the aerial photograph so it is uncertain whether the photograph captured the peak of the flood event.

Figure A.3 in Appendix A shows the predicted 1998 flood depths, levels and extent and Figure A.4 in Appendix A compares the predicted and actual flood extents given in the aerial imagery. Figure A.3 also shows a comparison of the recorded and predicted peak flood levels at the Narrabri Creek stream gauge is also shown. The recorded and predicted peak flood level at the Narrabri gauge is within 0.01 m for this event.

The flood extent comparison map in Figure A.4 in Appendix A shows that the model accurately predicts the flood extent for this event with the exception of the Francis Street industrial area. The hydrodynamic model underestimates the flood extent in this area. It appears that some filling has occurred between 1998 and the capture of the LiDAR data in 2014, which prevents this area being inundated during this event. Note that predicted flood levels would only have to be about 0.1 m higher to inundate this area as shown in the aerial photograph. Overall a good calibration has been achieved for the July 1998 flood.

4.3 LOCAL FLOODING

4.3.1 December 2004 event

Figure A.5 and Figure A.6 in Appendix A show the predicted December 2004 flood extents for Mulgate Creek and Long Gully derived by the MIKE-FLOOD model. The XP-RAFTS model inflows were used to represent the local catchment flows and the recorded Narrabri Creek at Narrabri (GS419003) discharge hydrograph was factored and input into the upstream end of the model to represent the Namoi River/Narrabri Creek flow that occurred during the event. The peak recorded Namoi River discharge during the December 2004 event was approximately 720 m^3/s, which has an AEP of less than 20%.

Mulgate Creek and Long Gully drain into Narrabri Creek and the Namoi River respectively, downstream of the Narrabri gauges and therefore the recorded Narrabri Creek flows are a good representation of the flows from the Namoi River catchment that potentially impact on peak flood levels at the downstream boundary of Mulgate Creek and Long Gully.

Figure 4.1 shows the recorded and predicted water levels at the Narrabri Creek at Narrabri stream gauge as well as the predicted water levels in Mulgate Creek upstream of the Newell Highway (Newell reporting location - see Figure A.5) and Long Gully upstream of the Narrabri West Walgett Rail (Burt St reporting location - see Figure A.6).

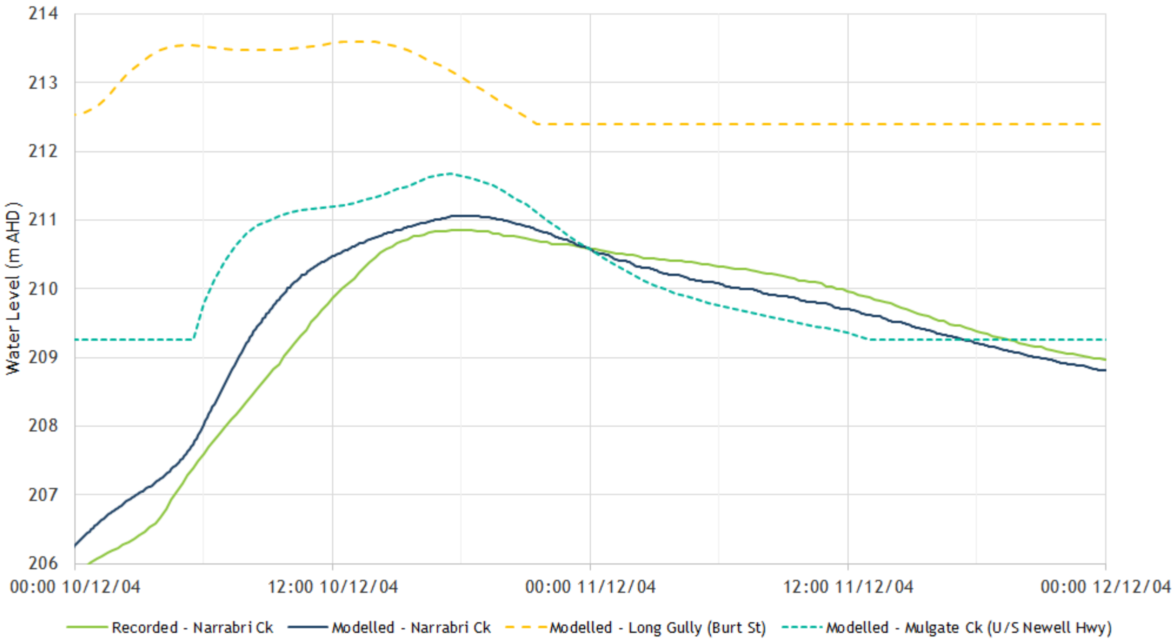

Figure 4.1 - Recorded and predicted water level hydrographs, December 2004 event

The Narrabri Creek water level comparison shows that the MIKE-FLOOD model adequately represents the Narrabri Creek flows for this event at that location. The figure also shows that the Namoi River peaks at a similar time to the Mulgate Creek peak for this event. However, Namoi River flows of this magnitude are generally confined to the Narrabri Creek and Namoi River channels at Narrabri and do not significantly impact on flooding in Mulgate Creek. Long Gully is not impacted by Namoi River flows for this event.

Table 4.1 compares the model results to the anecdotal flooding information provided during the community consultation process. The locations of the anecdotal information are shown in Figure A.5 and Figure A.6 in Appendix A.

Overall, the model provides a reasonably good representation of the 2004 flood along Mulgate Creek. The flood extents are generally consistent with the oblique aerial photography supplied by OEH as shown by Figure 4.2 and Figure 4.3. The model well represents flooding upstream of the rail (see Figure 4.2) and slightly overestimates the flood extent along Mulgate Creek downstream of the rail (see Figure 4.2 and Figure 4.3). The model could not reproduce the flooding at reporting locations 10, 13 and 14.

Overall the model provides a reasonable representation of the 2004 flood along Long Gully. There is anecdotal information on SES call outs in the vicinity of Long Gully, which suggests that the flood extent may have been higher than what has been predicted. However, no information was available as to why the SES were called out to these locations. Given that the URS study (2011) reports much higher anecdotal rainfalls in the upper catchment of Long Gully (higher than what was officially recorded and subsequently used in the hydrologic model), some underestimation of flood extent would be expected.

Table 4.1 - Comparison of anecdotal flood information and modelling results, December 2004 event

ID	Anecdotal information	Modelling results	Comment
2	Office and house inundated	Parts of lot inundated up to 0.65 m depth	Consistent
4	House inundated	Lot inundated up to 2.90 m depth	Consistent
5	Paddocks inundated. Breakout locations and detailed account of flooding provided	Surrounding area inundated. Mulgate Creek breakouts replicated	Consistent
6	Paddocks flooded to many metres depth	Many paddocks inundated, some to great depth	Consistent
7	Yard inundated up to 0.4 m depth	Parts of lot inundated to shallow depth	Consistent
10	Inundated to up 2.5 m depth	No inundation of property (resident may be referring to Namoi River flood earlier in the year)	Inconsistent
11	Flood water present for more than 5 hours	Duration of surrounding inundation greater than 5 hours, no inundation of property	Consistent
13	Yard inundated up to 0.6 m	No inundation of property. Model predicts inundation in street up to 0.40 m depth	Inconsistent
14	Yard inundated up to 0.6 m	Parts of lot inundated up to 0.20 m depth	Inconsistent
16	Water in street	Inundation in street and inundation into lot up to 0.20 m depth	Consistent
17	Yard inundated up to 0.02 m	Inundation in street and inundation into lot up to 0.15 m depth	Consistent
18	Yard inundated up to 0.08 m	Inundation in street and inundation into lot up to 0.25 m depth	Consistent
19	Flood water present for more than 5 hours	Water in street and into lot for more than 5 hours	Consistent
21	Yard inundated up to 0.4 m	Lot inundated up to 0.45 m depth	Consistent
22	Yard inundated up to 0.4 m	Parts of lot inundated up to 0.20 m depth	Consistent
23	Yard inundated up to 0.05 m	Parts of lot inundated up to 0.05 m depth	Consistent
25	Inundation up to 1.0 m	Lot inundated up to 0.75 m depth	Consistent
26	Inundation up to 1.0 m	Lot inundated up to 1.00 m depth	Consistent
27	Inundation up to 0.5 m	Inundation of lot averages around 0.5 m	Consistent
28	Flood water present for more than 5 hours	Lot inundated for more than 5 hours	Consistent
29	Inundated up to 0.6 m	Parts of lot inundated up to 0.55 m depth	Consistent
30	Inundated up to 2.0 m	Lot inundated up to 2.65 m depth	Consistent
32	Inundation in street and surrounds	Inundation in street, lot frontage and surrounds	Consistent
33	Inundation up to 0.1 m	Parts of lot inundated up to 0.20 m depth	Consistent
34	Inundation up to 0.5 m	Lot inundated up to 0.30 m depth	Consistent

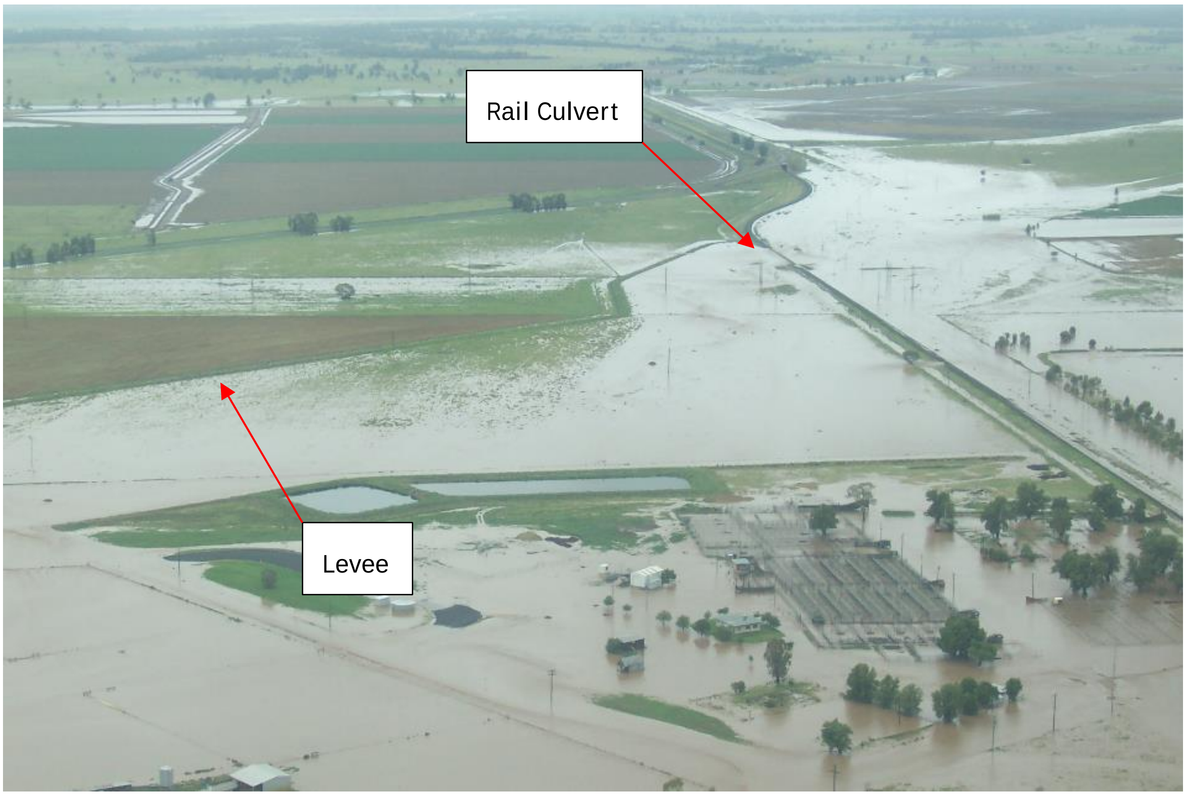

Figure 4.2 - Mulgate Creek flooding, looking north along the Saleyards and rail line, December 2004

Figure 4.3 - Mulgate Creek flooding, looking east at Francis Street Industrial Estate, December 2004

4.3.2 February 2012 event

Figure A.7 and Figure A.8 in Appendix A show the predicted February 2012 flood extents for Mulgate Creek and Long Gully derived by the MIKE-FLOOD model. The XP-RAFTS model inflows were used to represent the local catchment flows and the recorded Narrabri Creek at Narrabri (GS419003) discharge hydrograph was factored and input into the upstream end of the model to represent the Namoi River/Narrabri Creek flow that occurred during the event. The recorded peak Namoi River discharge during the February 2012 event was approximately 1,070 m^3/s, which has an AEP of approximately 20%.

Figure 4.4 shows the recorded and predicted water levels at the Narrabri Creek at Narrabri stream gauge as well as the predicted water levels in Mulgate Creek upstream of the Newell Highway (Newell reporting location - see Figure A.7) and Long Gully upstream of the Narrabri West Walgett Rail (Burt St reporting location - see Figure A.8).

The comparison of Narrabri Creek water levels shows that the MIKE-FLOOD model adequately represents the Narrabri Creek flows at the location of the gauge for this event.

The figure also shows that the Namoi River peaked some 15 hours after the Mulgate Creek peak for this event. A review of the recorded water level data from upstream gauges for this event showed that the Namoi River peak was generated by the catchment downstream of Boggabri. The Namoi River at Boggabri peaked about 48 hours after the peak at Narrabri.

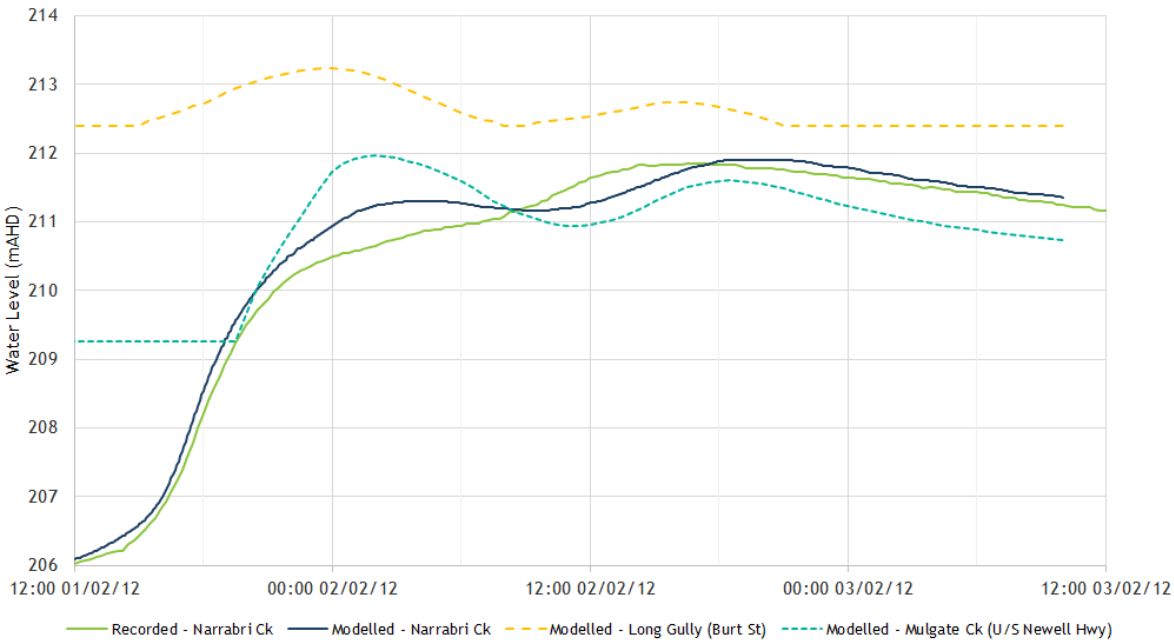

Figure 4.4 - Recorded and predicted water level hydrographs, February 2012 event

Table 4.2 compares the model results to the anecdotal flooding information provided during the community consultation process. The locations of the anecdotal information are shown in Figure A.7 and Figure A.8 in Appendix A. Overall, the model provides a reasonably good representation of the 2012 flood along Mulgate Creek and Long Gully. Predicted peak flood levels are on average marginally lower than the anecdotal data. Given that the rainfall temporal pattern adopted for this event was taken from a site 67 km away and therefore may not be reflective of the rainfall intensities in the catchment, the predicted flood extent appears reasonable.

Table 4.2 - Comparison of anecdotal flood information and modelling results, February 2012 event

ID	Anecdotal information	Modelling results	Comment
1	Not inundated	Lot not inundated	Consistent
2	Office inundated 0.1 m above floor level	Parts of lot inundated up to 0.25 m depth	Inconsistent
3	Inundation up to 0.25 m	Inundation of building to approximately 0.1 m depth	Consistent
4	Inundation up to 0.6 m around shed	Most of lot inundated to around 0.85 m depth	Consistent
6	Paddocks flooded up to many metres depth. Flooding less than 2004	Many paddocks inundated, some to great depth. Flooding to similar level than 2004	Consistent
7	Yard inundated up to 0.3 m depth	Parts of lot inundated to shallow depth	Consistent
8	Water up to 1.0 m above road	Goldman Street inundated up to around 0.5 m depth but depth upstream and downstream exceeds 1.0 m depth	Consistent
9	Surveyed peak level - 214.22 mAHD	Predicted peak level - 214.25 mAHD	Consistent
11	Flood water present for more than 5 hours	Duration of surrounding inundation greater than 5 hours, no inundation of property	Consistent
12	Flood water present for more than 5 hours	Duration of surrounding inundation greater than 5 hours, no inundation of property	Consistent
13	Inundation up to 0.5 m	Parts of lot inundated up to 0.15 m depth	Inconsistent
14	Inundation up to 0.5 m	Parts of lot inundated up to 0.35 m depth	Consistent
15	Inundation to floor level	Inundation within 0.05 m of floor level	Consistent
17	Inundation up to 0.3 m	Lot inundated up to 0.25 m depth	Consistent
18	Inundation up to 0.3 m	Parts of lot inundated up to 0.40 m depth	Consistent
19	Flood water present for more than 5 hours	Water in street and into lot for more than 5 hours	Consistent
20	Inundation up to 0.3 m	Lot inundated up to 0.25 m depth	Consistent
21	Inundation up to 0.3 m	Lot inundated up to 0.55 m depth	Consistent
22	Inundation up to 0.3 m	Lot inundated up to 0.25 m depth	Consistent
23	No property inundation	Parts of lot inundated to shallow depth	Inconsistent
24	Inundation up to 0.3 m	Parts of lot inundated up to 0.20 m depth	Consistent
25	Inundation up to 1.0 m	Lot inundated up to 0.95 m depth	Consistent
26	Inundation up to 1.5 m	Lot inundated up to 1.35 m depth	Consistent
27	Inundation up to 0.5 m	Inundation of lot averages around 0.6 m	Consistent
28	Flood water present for more than 5 hours	Duration of inundation greater than 5 hours	Consistent
29	Inundation up to 0.6 m	Parts of lot inundated up to 0.70 m depth	Consistent
30	Inundation up to 1.5 m	Lot inundated up to 2.85 m depth	Consistent
31	Inundation up to 2.0 m	Parts of lot inundated up to 0.35 m depth	Inconsistent
32	Inundation in street and surrounds	Inundation in street, lot frontage and surrounds	Consistent
33	Inundation up to 0.2 m	Lot inundated up to 0.25 m depth	Consistent
34	Inundation up to 0.3 m	Lot inundated up to 0.40 m depth	Consistent

35	Widespread inundation across site	Almost entire lot inundated	Consistent

4.3.3 Discussion of results

Overall, the model appears to predict peak flood levels moderately lower than the anecdotal data for the December 2004 and February 2012 events. Sensitivity testing of modelling parameters given in Section 6.3.2.1 would suggest that significant increases to Manning's roughness values are required to increase peak levels, therefore other factors may be contributing. It should be noted that all Manning's roughness and other hydraulic model parameters used in the local flooding calibration remained consistent with those values adopted from the regional flooding analysis. That is, the adopted hydraulic parameters are consistent for both regional and local flooding events.

It would appear that the greatest uncertainty surrounding the historical events is the limited information on rainfall depth and intensity, particularly short duration rainfall data. To overcome these potential shortcomings, the design discharges were validated against estimates made using the Regional Flood Frequency Estimation (RFFE) approach given in Ball et al. (2019) (see Section 5.3.2).

5 Estimation of design discharges

5.1 CHANGES FROM THE 2016 FLOOD STUDY

The 2016 flood study estimated regional and local design discharges and flood levels for events up to the 1% AEP and an extreme flood event. For the FRMP, design flood estimates were extended to include the 0.5% and 0.2% AEP events for both regional and local flooding.

The regional flooding design discharge estimates used the flood frequency analysis (FFA) from the 2016 flood study. Since the completion of the 2016 study no flow events of significance have been recorded at Narrabri so the FFA has not been updated.

The estimation of local flooding design discharges used the hydrologic model and the updated design rainfall associated with AR&R (Ball et al., 2019).

5.2 REGIONAL FLOODING

5.2.1 General

Design flood discharges for the Namoi River at Narrabri for events up to the 0.2% AEP event were estimated by annual series flood frequency analysis (FFA). All available flood information for Narrabri dating back to 1890 (126 years from 1890 to 2015) was included in the analysis. Kinhill (1991) also provided anecdotal evidence of flooding dating back to 1865 that was used to extend the data set. The FFA was undertaken to fit a Log-Pearson Type III distribution to an annual series of recorded (and inferred) peak flood discharges at Narrabri using the Bayesian inference methodology recommended in Australian Rainfall and Runoff (Ball et al., 2019) using the TUFLOW FLIKE software.

5.2.2 Extreme event

It is not possible to estimate the Probable Maximum Flood (PMF) using the FFA methodology because the PMF is beyond the credible limit of extrapolation from the 151 years of data used in the FFA. For this catchment, the PMF has a notional AEP of about 1 in 40,000 using the methodology given in AR&R (Ball et al., 2019). Therefore an estimate of a peak discharge for an 'extreme' flood has been made by using three times the 1% AEP discharge estimate.

5.2.3 Comparison with previous estimates

Table 5.1 shows a comparison of the 2016 flood study FFA design discharge estimates and estimates made by Kinhill (1991) and URS (2014). The results show that the WRM FFA is in reasonable agreement with the Kinhill (1991) study, with the 1% AEP event some 3% lower but the smaller events marginally higher. The differences are expected to be due to the additional 26 years of data and the different modifications made to the high flow rating. There are significant differences between the WRM FFA results and the URS (2014) estimates. It is noted that URS (2014) also identified the discrepancy in the Namoi River at Narrabri gauge and therefore adopted the Kinhill (1991) estimates for their design event modelling.

Table 5.1 - Comparison of regional design discharges with previous estimates

Design Event	Peak Discharge (m^3/s)		
	WRM FFA[b] (1865-2015)	Kinhill FFA (1991)	URS FFA (2014)
20% AEP	1,070	-	1,130
10% AEP	1,980	1,470	1,740
5% AEP	2,920	2,260	2,320
2% AEP	4,090	3,680	2,890
1% AEP	4,860	5,090	3,240
0.5% AEP	5,500	-	-
0.2% AEP	6,180	-	-
Extreme event	14,580 [a]	-	-

[a] - Extreme event given by 3 x 1% AEP
[b] - expected parameter quantiles adopted given minimal difference from AEP quantiles

5.3 LOCAL FLOODING

5.3.1 General

The calibrated hydrologic and hydraulic models were used to derive design discharges, flood levels, depths and velocities throughout the study area for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events and the PMF for existing conditions. All model parameters derived via the model calibration remained unchanged for the design event modelling.

5.3.2 Design discharges up to the 0.2% AEP event

5.3.2.1 Methodology

Design discharges for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events were derived using the methodology given in AR&R (Ball et al., 2019) and then verified against estimates made using the Regional Flood Frequency Estimation (RFFE) approach given in Ball et al. (2019).

5.3.2.2 Design rainfall

Rainfall depths for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP design events were taken from the Bureau of Meteorology's (BoM) 2016 Intensity-Frequency-Duration (IFD) database. An IFD located approximately in the centre of Narrabri was adopted. All previous flood studies for Narrabri used IFDs from the BoM 1987 IFD database or earlier simpler methods. As a result of the updated IFDs, the design rainfall depths used in this supplementary flood study are in general slightly lower than the design rainfall depths adopted in the 2016 flood study. Decreases in rainfall depths of up to 16% are present (6 hour and 12 hour 1% AEP rainfalls).

5.3.2.3 Areal variability

Areal reduction factors (ARFs) based on the Mulgate Creek catchment area were applied for design rainfalls up to 0.2% AEP as per the recommendation in AR&R (Ball et al., 2019). No ARF was adopted for PMP rainfalls due to catchment area already being incorporated into the PMP rainfall estimation.

5.3.2.4 Temporal patterns

The Central Slopes temporal patterns from AR&R Data Hub (Geoscience Australia, 2017) were used for all events up to and including the 0.2% AEP event. Areal temporal patterns were used where appropriate.

5.3.2.5 Design losses

The recommended regional loss values for Narrabri from the AR&R Data Hub (Geoscience Australia, 2019) were an initial loss of 34.0 mm (prior to adjustment for preburst rainfall) and a continuing loss of 1.1 mm/h. The recommended regional loss values were adjusted during verification of the design discharges to the RFFE peak discharge estimates. The adopted design losses were as follows:

- An initial rainfall loss of:
  - 55 mm was applied to the 20% AEP event;
  - 45 mm was applied to the 10% AEP event;
  - 35 mm was applied to the 5% AEP event;
  - 10 mm was applied to the 2% AEP event; and
  - 5 mm was applied to the 1%, 0.5% and 0.2% AEP events.
- A continuing loss of 1.1 mm/h was applied to all design events up to and including the 0.2% AEP event.

5.3.2.6 XP-RAFTS results

The ensemble of ten temporal patterns was run for all design events for durations between 2 and 48 hours. The critical duration for Long Gully and Mulgate Creek catchments was consistent across the design events. The adopted ensemble for each design event is shown in Table 5.2. Figure 5.1 and Figure 5.2 show boxplots of the ensemble results for the 1% AEP event.

Table 5.2 - Adopted ensemble for each design event

AEP (%)	Adopted Ensemble
20	36 hour TP10
10	48 hour TP1
5	48 hour TP2
2	12 hour TP10
1	12 hour TP10
0.5	12 hour TP10
0.2	12 hour TP10

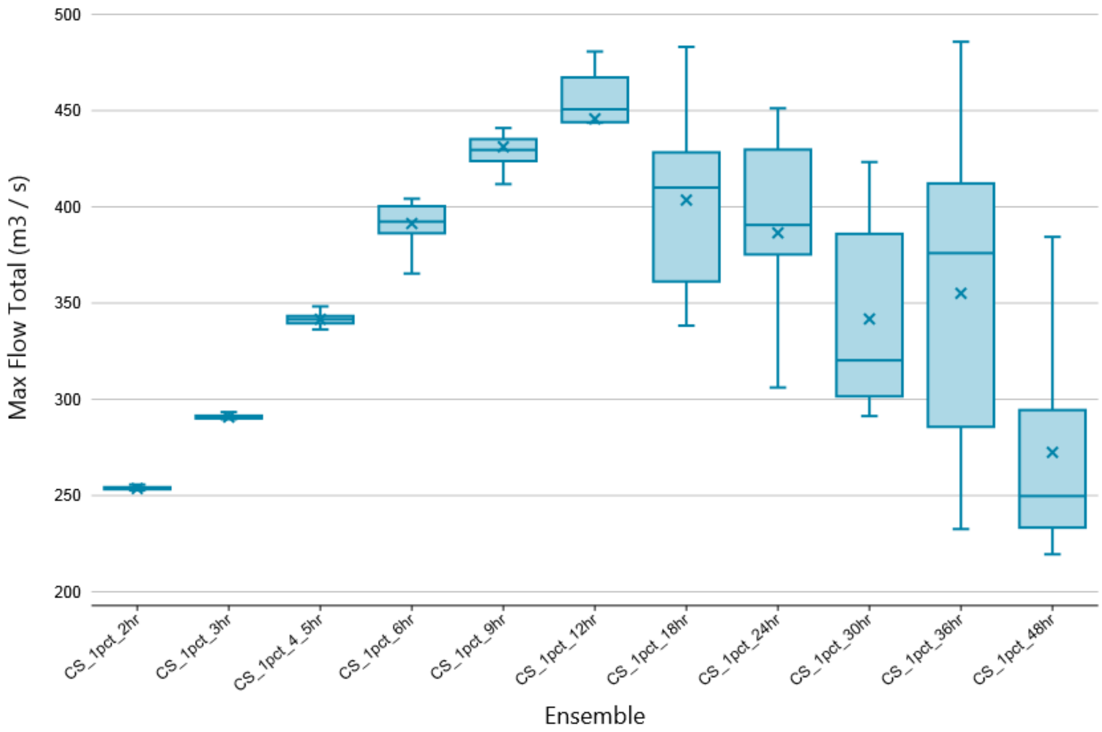

Figure 5.1 - Boxplot of 1% AEP design discharge ensembles, Mulgate Creek

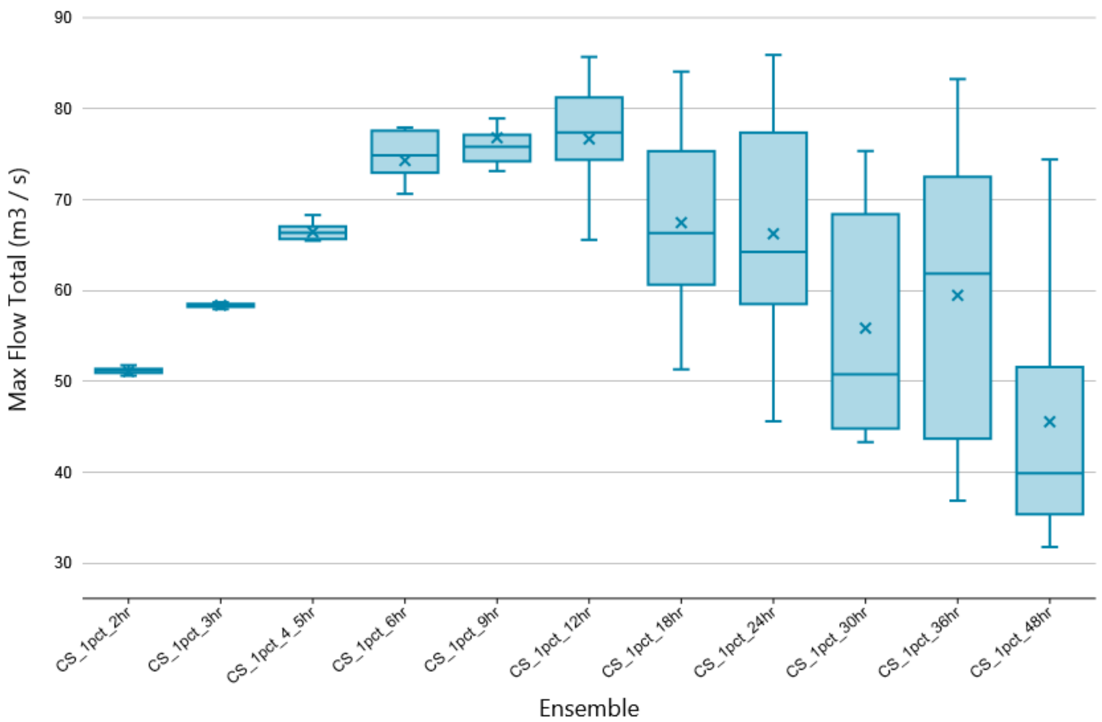

Figure 5.2 - Boxplot of 1% AEP design discharge ensembles, Long Gully

5.3.2.7 Regional Flood Frequency Estimation (RFFE) verification

Table 5.3 and Table 5.4 show the Mulgate Creek (to the Newell Highway) and Long Gully (to the Narrabri West Walgett Railway) design flood discharges estimated using the MIKE-FLOOD model (with XP-RAFTS inflows). The MIKE-FLOOD discharges take into account the flood storage and routing characteristics of the catchment that are not fully represented by the XP-RAFTS model. Given the flat nature of the floodplain, this method of deriving design discharges is more appropriate than using the XP-RAFTS model alone.

Given the limited data available for model calibration, the design discharges were validated against estimates made using the Regional Flood Frequency Estimation (RFFE) approach given in Ball et al. (2019). The RFFE approach is recommended for use when a peak discharge estimate is required on a small to medium sized ungauged catchment (Ball et al., 2019). The RFFE technique was developed by Dr Ataur Rahman and Dr Khaled Haddad from the University of Western Sydney with the assistance of Professor George Kuczera from the University of Newcastle and Mr Erwin Weinmann and is based on data from 853 gauged catchments across Australia. The RFFE method is calculated using a web based application.

The RFFE discharge estimates and the 5% and 95% confidence limits of the estimate for Mulgate Creek are given in Table 5.3. The RFFE used the following parameters:

- 201 km^2 catchment area;
- catchment outlet coordinates (149.777°E, -30.315°S); and
- catchment centroid coordinates (149.907°E, -30.291°S).

The RFFE discharge estimates and the 5% and 95% confidence limits of the estimate for Long Gully are given in Table 5.4. The RFFE used the following parameters:

- 28 km^2 catchment area;
- catchment outlet coordinates (149.747°E, -30.329°S) ; and
- catchment centroid coordinates (149.732°E -30.385°S).

Note that the web based RFFE program suggests that RFFE estimates for Long Gully may have a lower accuracy because of the 'unusual' shape of the catchment. The RFFE method also only produces peak design discharge estimates for design events up to and including the 1% AEP event.

Table 5.3 - XP-RAFTS/MIKE-FLOOD and RFFE design discharge estimates, Mulgate Creek

AEP (%)	XP-RAFTS/MIKE-FLOOD Discharge (m^3/s)	RFFE Discharge (m^3/s)		
		RFFE	Lower Confidence Limit (5%)	Upper Confidence Limit (95%)
20	112	96	40	230
10	207	155	64	375
5	235	232	94	575
2	408	367	143	948
1	486	501	189	1,340
0.5	548	-	-	-
0.2	616	-	-	-

Table 5.4 - XP RAFTS/MIKE-FLOOD and RFFE design discharge estimates, Long Gully

AEP (%)	XP-RAFTS/MIKE-FLOOD Discharge (m^3/s)	RFFE Discharge (m^3/s)		
		RFFE	Lower Confidence Limit (5%)	Upper Confidence Limit (95%)
20	23	16	7	38
10	39	26	11	62
5	48	38	15	95
2	73	61	24	157
1	88	83	31	222
0.5	102	-	-	-
0.2	118	-	-	

Table 5.3 shows that the XP-RAFTS/MIKE-FLOOD peak discharges in Mulgate Creek for the 20%, 10%, 5% and 2% AEP events are higher than the RFFE estimates but is lower for the 1% AEP event. For all design events the XP-RAFTS/MIKE-FLOOD peak design discharge is within the confidence limits of the RFFE estimate.

Table 5.4 shows that all XP-RAFTS/MIKE-FLOOD discharges in Long Gully for all design events are larger than the RFFE peak discharge estimate but always within the confidence limits of the RFFE estimate. On this basis, the XP-RAFTS/MIKE-FLOOD discharges have been adopted for the assessment.

5.3.3 Design discharges for the Probable Maximum Flood (PMF)

Table 5.5 shows PMF discharge estimates for Mulgate Creek (at the Newell Highway) and Long Gully (at the Narrabri West Walgett Railway). Design rainfalls for the PMF were determined in accordance with the Generalised Tropical Storm Method (Revised) (GTSMR) (BoM, 2005) and the Generalised Short Duration Method (GSDM) (BoM, 2003). As per recommendations in AR&R (Ball et al., 2019) rainfall losses of 0 mm initial and 1 mm/h continuing were adopted. As per recommendations in AR&R (Ball et al., 2019) ensemble temporal patterns from Jordan et al. (2005) were adopted for use with GSDM rainfall depths while GTSMR areal ensemble temporal patterns were adopted for use with GTSMR rainfall depths.

The critical duration storm for both catchments was found to be the 6 hour event. The discharges shown in Table 5.5 were derived using the XP-RAFTS model, because MIKE-FLOOD modelling shows significant inter-basin flow both in and out of these catchments for the PMF event.

Table 5.5 - XP-RAFTS PMF discharge estimates, Mulgate Creek and Long Gully

Catchment	XP-RAFTS Mean Peak Discharge (m^3/s)	Adopted Ensemble
Mulgate Creek	3,010	GSDM 6 hour TP5
Long Gully	610	GSDM 6 hour TP5

5.3.4 Coincident Namoi River flooding

The modelling of the December 2004 (see Figure 4.1) and February 2012 events (see Figure 4.4) showed that these two local catchment events coincided with moderate flow events in the Namoi River. Although the purpose of this section of the study is to investigate the flooding of the local Mulgate Creek and Long Gully catchments, it is necessary to define a Namoi River flow that would likely occur concurrently with the local catchment events.

A detailed joint probability analysis between the Namoi River and the local catchment flood events is required to provide a fully informed relationship between the two flood scenarios. However, in this case the peak flood levels at the confluence of the two systems will be wholly dominated by Namoi River flooding. In fact, Namoi River flooding produces higher design flood levels across most of the study area except for the upper reaches of the local creeks. The differences in sizes between the local and Namoi River catchments would also mean that large Namoi River floods would be unlikely to coincide with a local catchment event.

For this study, the coincident Namoi River flows have been determined from a review of the recorded stream gauge water level data along the Namoi River for the December 2004 and February 2012 events.

- For the December 2004 event, the Namoi River peak at the Narrabri gauge (GS419003) that corresponded to the local event was associated with runoff generated by the catchment downstream of the Turrawan gauge (GS419023), that is from the adjacent Bullawa Creek and Jacks Creek catchments (see Figure 1.1). Flood flows generated upstream of Turrawan (from Maules Creek) arrived at Narrabri well after the Mulgate Creek peak occurred and at a lower level. There were little to no flows from the Namoi River catchment upstream of Boggabri.
- For the February 2012 event, which was a longer duration event with more flow volume, the Namoi River flood peak corresponding to the local event was due to flows from the whole catchment downstream of Boggabri (the combined flows from Bullawa, Jacks and Maules creeks and others) and this peak occurred much later than the Mulgate Creek peak. The Namoi River peak from the catchment upstream of Boggabri occurred much later again. On further analysis, the Namoi River water level at the time of the Mulgate Creek peak would appear to have occurred due to runoff downstream of the Turrawan gauge, in a similar manner to 2004.

Given this, a design event generated from the catchment downstream of the Turrawan Gauge (Bullawa and Jacks creeks) has been used as the basis for determining the Namoi River discharge that would coincide with the local catchment event. The RFFE web based method (described in Section 5.3.2.7) has been used to determine the peak discharges from this catchment. To avoid the larger Namoi River events from impacting on local catchment flows, an AEP slightly higher has been used for each design event, as shown in Table 5.6.

Table 5.6 - Coincident Namoi River discharge adopted for each local design event

Mulgate Creek/Long Gully design event	Coincident Downstream Turrawan event	RFFE Derived Namoi River Discharge (m^3/s)
20% AEP	50% AEP	122
10% AEP	20% AEP	301
5% AEP	10% AEP	487
2% AEP	5% AEP	729
1% AEP	2% AEP	1,150
0.5% AEP		
0.2% AEP	1% AEP	1,570
PMF		

6 Design flood events

6.1 OVERVIEW

The calibrated MIKE-FLOOD model described in Section 3 was used to estimate peak depths, levels and extent of flooding for the 20% (5 year ARI), 10% (10 year ARI), 5% (20 year ARI), 2% AEP (50 year ARI), 1% AEP (100 year ARI), 0.5% AEP (200 year ARI) and 0.2% AEP (500 year ARI) design events and an extreme flood event for both local and regional flooding. As discussed in Section 5 the regional extreme event was based on the factoring the 1% AEP event by three, while the local extreme event was a PMF event, derived from probable maximum precipitation in the Mulgate Creek catchment hydrologic model. All model parameters derived via the model calibration remained unchanged for the design event modelling.

6.2 REGIONAL FLOODING

6.2.1 Design flood depth, levels and extents

Predicted flood extent, depths and flood contours for the regional 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and 0.2% AEP and the extreme (3x1% AEP) event are shown in Appendix B. Figure 6.1, Figure 6.2 and Figure 6.3, show longitudinal profiles of peak flood levels for the historical events and design events along Narrabri Creek, Namoi River, and the Eastern Flood Runner of Doctors Creek and Horsearm Creek respectively. The Narrabri Creek and Namoi River longitudinal sections start and finish at their respective upstream and downstream confluences. The Eastern Flood Runner commences at the Doctors Creek and Narrabri Creek confluence and finishes at Old Gunnedah Road.

6.2.2 Peak flood level comparison to previous estimate

Table 6.1 shows the peak flood level estimates from the hydraulic model at the Namoi River at Narrabri (GS419002) and Narrabri Creek at Narrabri (GS419003) stream gauges and compares them to the 2016 flood study estimates. The results are similar to those found in the 2016 flood study with design levels varying minimally at the Namoi River and Narrabri Creek gauges. The inclusion of 0.5% and 0.2% AEP events shows that the nominated regional extreme flood event (3 x 1% AEP event) gives design flood levels over 2.2 m higher than the 1% AEP event and over 1.7 m higher than 0.2% AEP event.

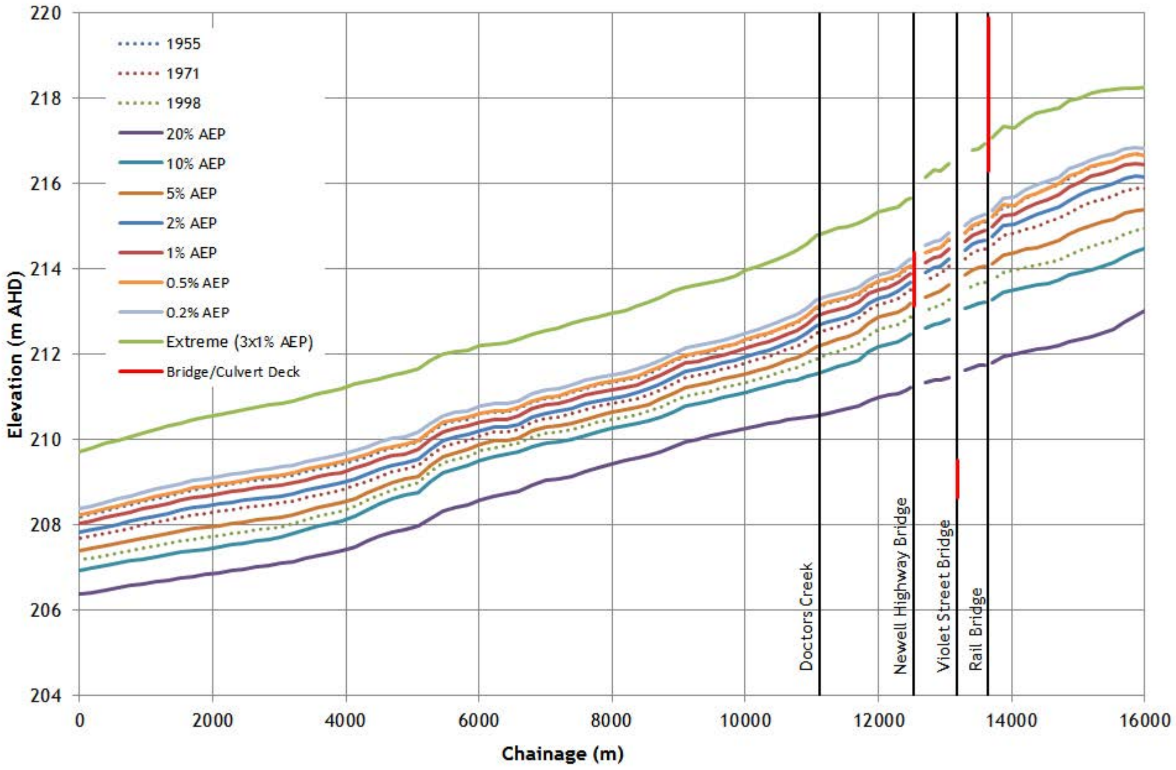

Figure 6.1 - Regional design and historical event longitudinal flood profiles, Narrabri Creek

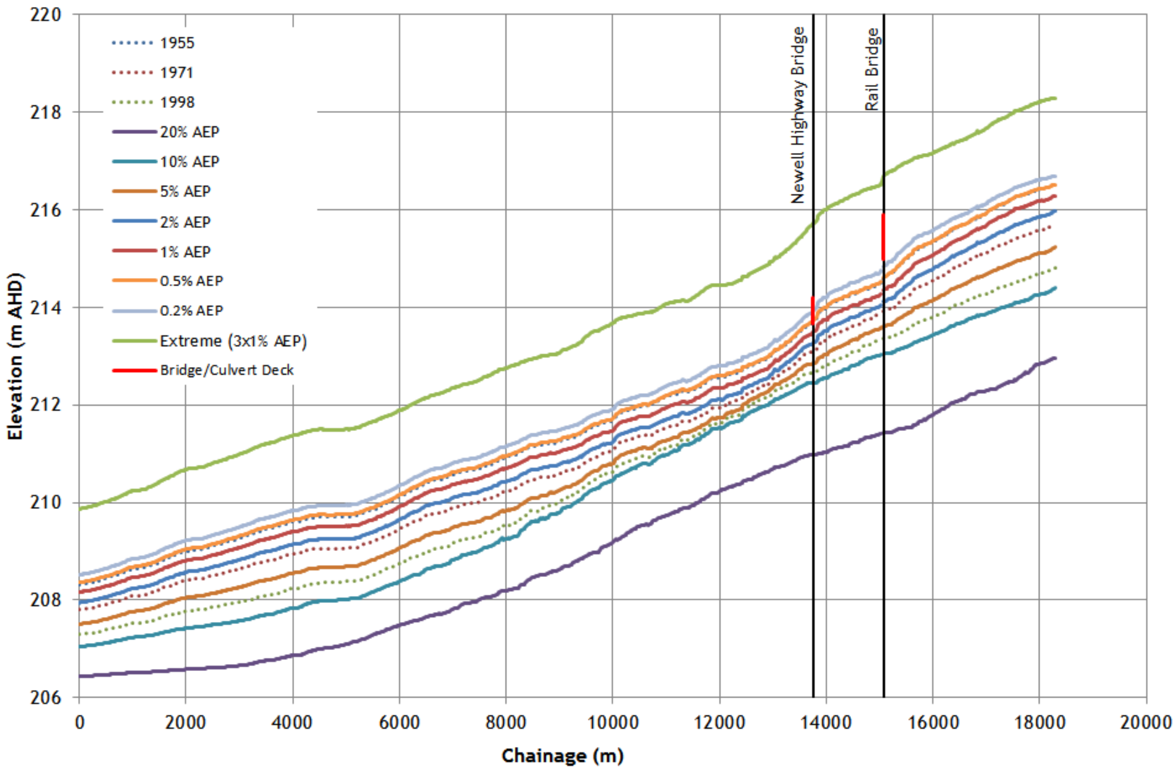

Figure 6.2 - Regional design and historical event longitudinal flood profiles, Namoi River

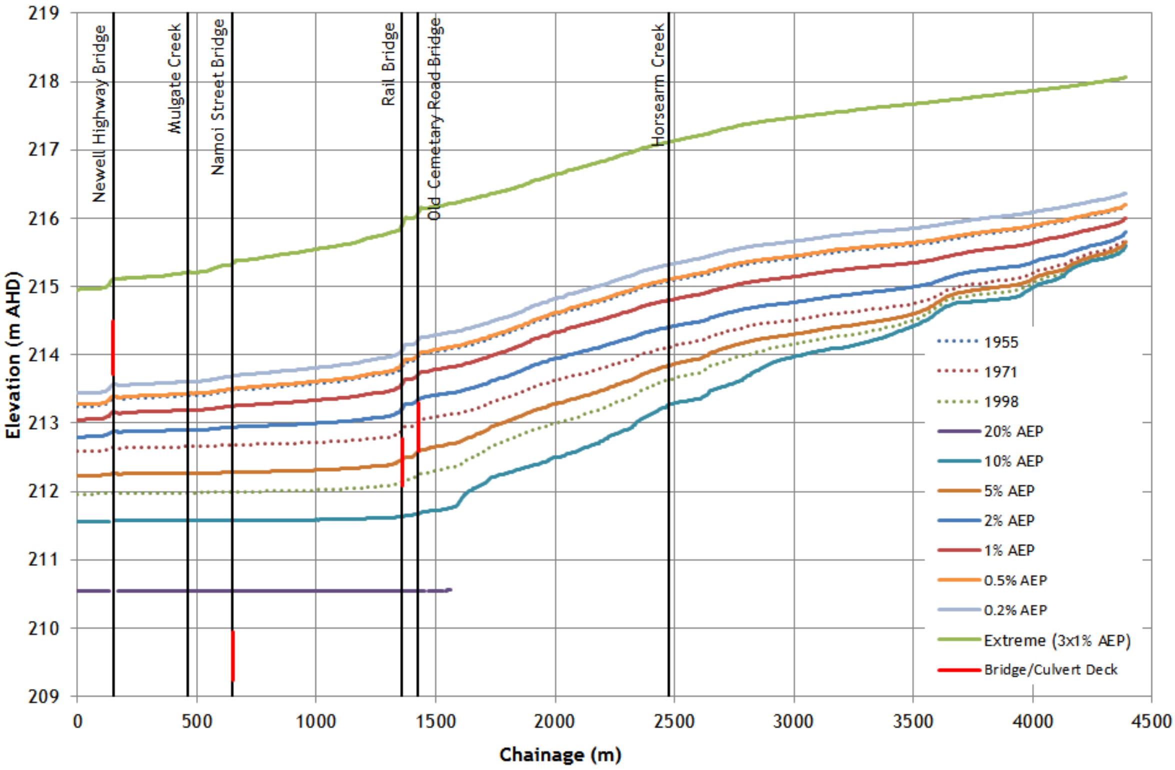

Figure 6.3 - Regional design and historical event longitudinal flood profiles, Eastern Flood Runner / Horsearm Creek / Doctors Creek

Table 6.1 - Comparison of peak regional design flood levels at the Namoi River and Narrabri Creek stream gauges

Design event	WRM (2016)		WRM (2019)	
	Namoi	Narrabri	Namoi	Narrabri
Extreme	10.91	11.51	10.79	11.57
0.2% AEP	-	-	9.02	9.77
0.5% AEP	-	-	8.81	9.58
1% AEP	8.62	9.34	8.56	9.36
2% AEP	8.37	9.08	8.34	9.11
5% AEP	7.97	8.55	7.91	8.53
10% AEP	7.51	7.74	7.51	7.80
20% AEP	6.04	6.56	6.03	6.56

6.3 LOCAL FLOODING

6.3.1 Design flood depth, levels and extents

Predicted flood extents, depths and flood contours for the local 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and 0.2% AEP and the PMF events are shown in Appendix B. Table 6.2 shows the predicted distribution of flow at key reporting locations given in these figures for the various design events. Design event mapping shows that the 2004 event had an AEP of between 5% and 2% in Mulgate Creek and Long Gully and the 2012 event had an

AEP of between 5% and 1% in Mulgate Creek and about 5% AEP in Long Gully. Note that these flow distributions assume that the levees and bunds do not fail during flooding. The flow distributions and flood levels could potentially change if the levees and bunds fail. A description of flooding for the various events in the Mulgate Creek and Long Gully catchments are given below.

Table 6.2 - Floodplain flow distribution

Section ID	Peak discharge (m^3/s)						
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
				Horsearm Creek			
H1	47.6	89.8	96.4	138.6	159.1	181.6	214.4
H2	67.5	109.7	116.8	148.9	160.7	171.7	186.2
H3	1.2	14.4	19.6	41.0	45.4	50.0	56.3
H4	57.9	101.9	111.4	191.7	219.2	242.0	268.2
				Mulgate Creek			
M1	70.4	118.1	123.5	145.2	153.4	159.8	166.2
M2	62.0	103.9	113.4	210.8	257.6	301.1	350.5
K1	4.4	10.4	19.3	82.5	112.4	143.4	183.0
				Doctors Creek			
D1	112.0	206.6	234.8	408.1	486.4	547.8	616.0
				Long Gully			
L1	18.0	33.4	39.1	59.3	70.3	80.6	93.6
L2	23.0	39.2	48.4	73.4	87.7	101.8	118.3
N1	0.9	1.2	1.1	1.2	1.1	1.2	1.3

6.3.1.1 Mulgate Creek

Figure 6.4 shows the longitudinal profiles of peak flood levels for the historical events and design events along Mulgate Creek. The Mulgate Creek longitudinal section starts at the Horsearm Creek confluence and finishes just upstream of the rail culverts. The 1% AEP peak flood level from the regional flood modelling is also shown.

Figure 6.5 shows the longitudinal profiles of peak flood levels for the historical events and design events along Doctors Creek / Horsearm Creek. The Doctors Creek / Horsearm Creek longitudinal section starts at the Narrabri Creek confluence and finishes at Old Gunnedah Road. The 1% AEP peak flood level from the regional flood modelling is also shown.

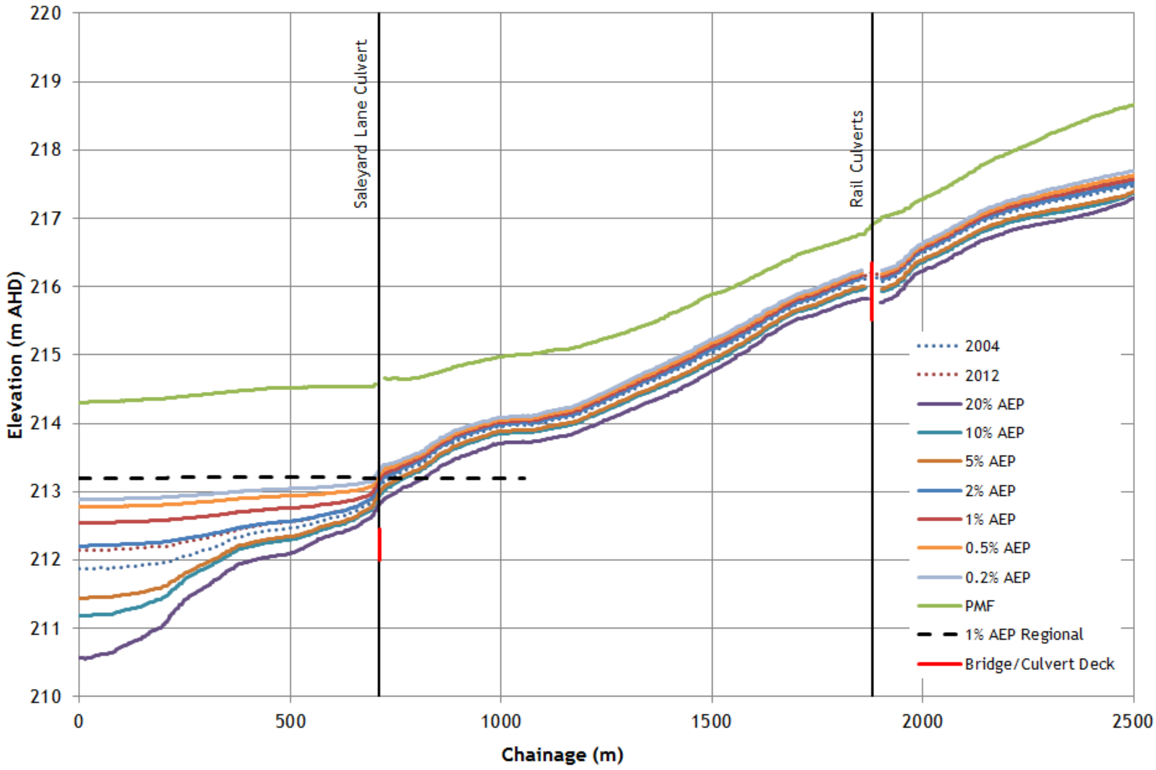

Figure 6.4 - Local design and historical event longitudinal flood profiles, Mulgate Creek

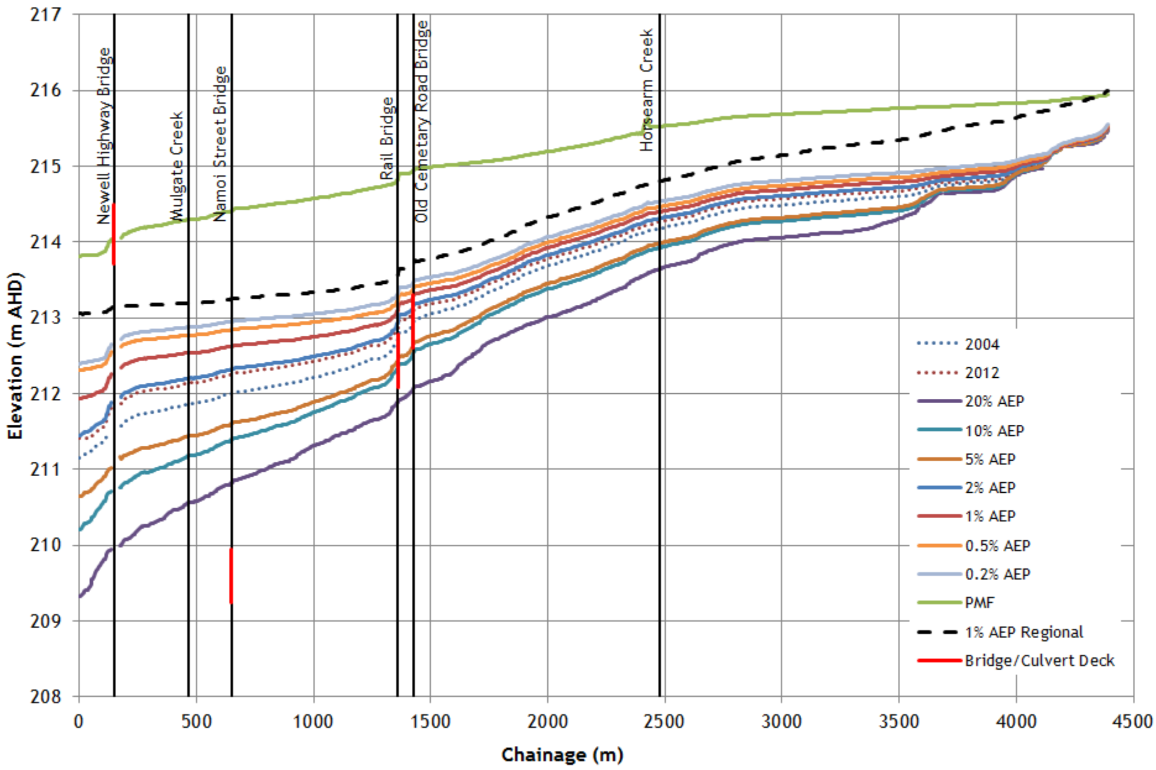

Figure 6.5 - Local design and historical event longitudinal flood profiles, Eastern Flood Runner / Horsearm Creek / Doctors Creek

The following is of note:

- The longitudinal sections show that Namoi River flooding dominates peak flood levels along the lower reaches of Horsearm Creek, Doctors Creek and Mulgate Creek adjacent to the urban areas of Narrabri;
- For the 20% AEP event, flows along Killarney Gap Road (K1) and to the west of the Newell Highway are generated from local catchment runoff (do not include Mulgate Creek overflows);
- Mulgate Creek overflows to Killarney Gap Road for events rarer than or equal to the 10% AEP event. The proportion of flow being conveyed along Killarney Gap Road increases as the magnitude of flow event increases with around 40% (or greater) of the total Mulgate Creek flow being conveyed along Killarney Gap Road for events equal to or greater than 2% AEP. It is likely that all of the Killarney Gap Road flows (K1) would bypass Narrabri if Killarney Gap Road and possibly the Newell Highway and the rail were not there. This could reduce 1% AEP flows in Doctors Creek (which includes flows from both Mulgate Creek and Horsearm Creek) by around 25%;
- Mulgate Creek overflows into Horsearm Creek upstream of the study area along Mulgate Creek Road (about 3.1 km southeast of Killarney Gap Road). The model predicts that less than 10% of the 1% AEP flow in Mulgate Creek overflows to Horsearm Creek at this location;
- Flooding is primarily contained to streets and undeveloped land between the Francis and Newell reporting locations (Francis St industrial area) for the 20% AEP event multiple developed lots inundated for the 10% AEP event;
- Mulgate Creek overflows the rail upstream of the Francis St industrial area for events rarer than or equal to the 5% AEP event;
- Horsearm Creek overflows into the urban areas of Narrabri for the 2% AEP event;
- The Old Cemetery Road and adjacent rail bridge do not appear to be significant constrictions to flow. However even a small afflux could potentially direct floodwater into the urban areas of Narrabri; and
- The 2% AEP event overtops the Newell Highway.

6.3.1.2 Long Gully

Figure 6.6 shows longitudinal profiles of peak flood levels for the historical events and design events along Long Gully. The Long Gully longitudinal section starts at the Namoi River confluence and finishes at end of the urban areas of Narrabri (Kelvin Vickery Avenue). The 1% AEP peak flood level from the regional flood modelling is also shown.

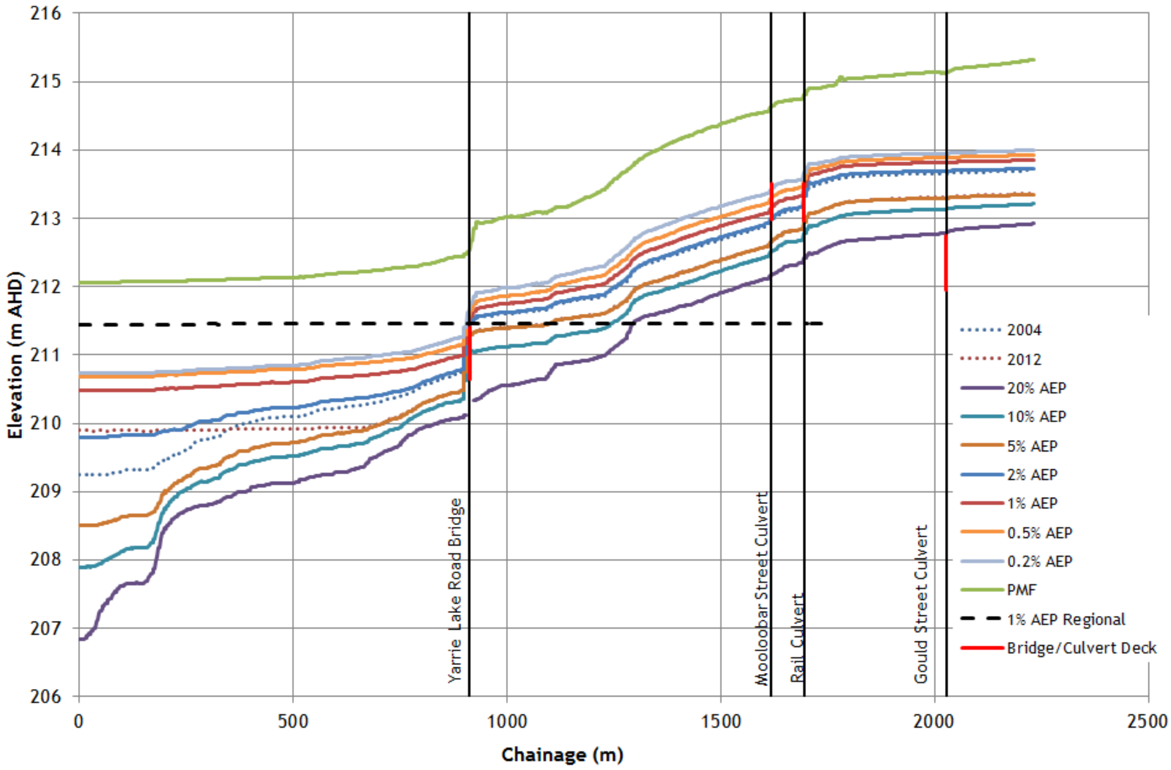

Figure 6.6 - Local design and historical event longitudinal flood profiles, Long Gully

The following is of note:

- The longitudinal sections show that Namoi River flooding dominates the lower sections of Long Gully below Yarrie Lake Road and Long Gully flows dominate flood levels for the remainder of Long Gully;
- The Newell Highway diverts Long Gully flows towards the Kamilaroi Highway for all design events but the diverted flows are small in comparison to the total catchment flows; and

6.3.2 Sensitivity analysis

6.3.2.1 Changes in floodplain roughness

The hydraulic model was used to assess the sensitivity of peak flood levels to changes in floodplain roughness for the 1% AEP event. For the purposes of the assessment the adopted floodplain Manning's 'n' of 0.08 was increased to 0.12 and decreased to 0.04 to test sensitivity. The floodplain roughness covers the majority of the inundated areas and therefore will have the greatest impact on model results. The results of the sensitivity analysis at the six reporting locations (shown in Figure B.10 in Appendix B) are shown in Table 6.3.

The results show that changes in Manning's 'n' values may significantly impact on flood levels at the Long Gully reporting locations, particularly when the roughness is decreased. In Mulgate Creek, the increased roughnesses increase peak flood levels at all reporting locations with the exception of the Newell Highway, where peak flood levels reduce. The higher roughness values appear to increase the available flood storage and change the timing of the flood peaks from the tributaries to reduce flood levels at this reporting location. The lower roughnesses produce significantly lower peak flood levels (except at the Newell Highway).

Table 6.3 - Sensitivity analysis of hydraulic model results to changes in floodplain roughness, 1% AEP event

Reporting Location	1% AEP Peak Level (mAHD)			Peak Level Change (m)	
	Calibrated	Increased Roughness	Decreased Roughness	Increased Roughness	Decreased Roughness
Burt	214.60	214.70	214.47	+0.10	-0.13
Kamilaroi	213.72	213.77	213.62	+0.05	-0.10
Newell	212.41	212.40	212.34	-0.01	-0.07
Francis	213.16	213.25	212.90	+0.09	-0.26
Reid	213.58	213.66	213.32	+0.08	-0.26
Shannon	214.65	214.75	214.43	+0.10	-0.22

6.3.2.2 Climate change

The Floodplain Development Manual (NSW Government, 2005) recognises the need for analysis of the consequences of climate change on flood levels and flood behaviour. For this assessment, sensitivity to climate change was tested by increasing peak rainfall and storm volume by 30% (NSW Government, 2007b) for the 1% AEP flood. This represents the 'worst case' of the three climate change sensitivity analyses recommended by the NSW Government (2007b). The results of this sensitivity analysis at the six reporting locations (shown in Figure B.10 in Appendix B) are shown in Table 6.4. The results show that climate change could increase peak 1% AEP flood levels significantly across the study area with an increase of 0.35 m at the Newell Highway in the Mulgate Creek catchment. The increased rainfall intensities would significantly increase the flood extent and flood levels through the urban areas of Narrabri.

Table 6.4 - Sensitivity analysis of hydraulic model results to climate change, 1% AEP event

Reporting Location	1% AEP Peak Level (mAHD)		Peak Level Change (m)
	Calibrated	Climate Change	
Burt	214.60	214.73	+0.13
Kamilaroi	213.72	213.86	+0.14
Newell	212.41	212.76	+0.35
Francis	213.16	213.31	+0.15
Reid	213.58	213.74	+0.16
Shannon	214.65	214.77	+0.12

7 Provisional hydraulic hazard mapping

7.1 OVERVIEW

The flood modelling results show that regional flooding poses the greatest threat to the developed areas of Narrabri. Significant areas of Narrabri are liable to flooding to varying levels of risk. Any development within floodprone areas would therefore be considered to be in a flood hazard zone as they are prone to damage if mitigation measures are not implemented. Provisional hydraulic hazard mapping has been prepared by combining the hazards from both local and regional flooding.

7.2 PROVISIONAL HYDRAULIC HAZARD

Figure C.1 to Figure C.8 in Appendix C show the provisional hydraulic hazard categories in the study area from a combination of local and regional catchment flooding. Provisional hydraulic hazards have been defined using the depth and velocity of the floodwaters calculated using the flood model and determined in accordance with Figure 7.1 as given in Appendix L of the NSW Floodplain Development (NSW Government, 2005).

The provisional hydraulic hazard mapping presented herein will be revised to represent true hazard categories during the next phase of the FRMP.

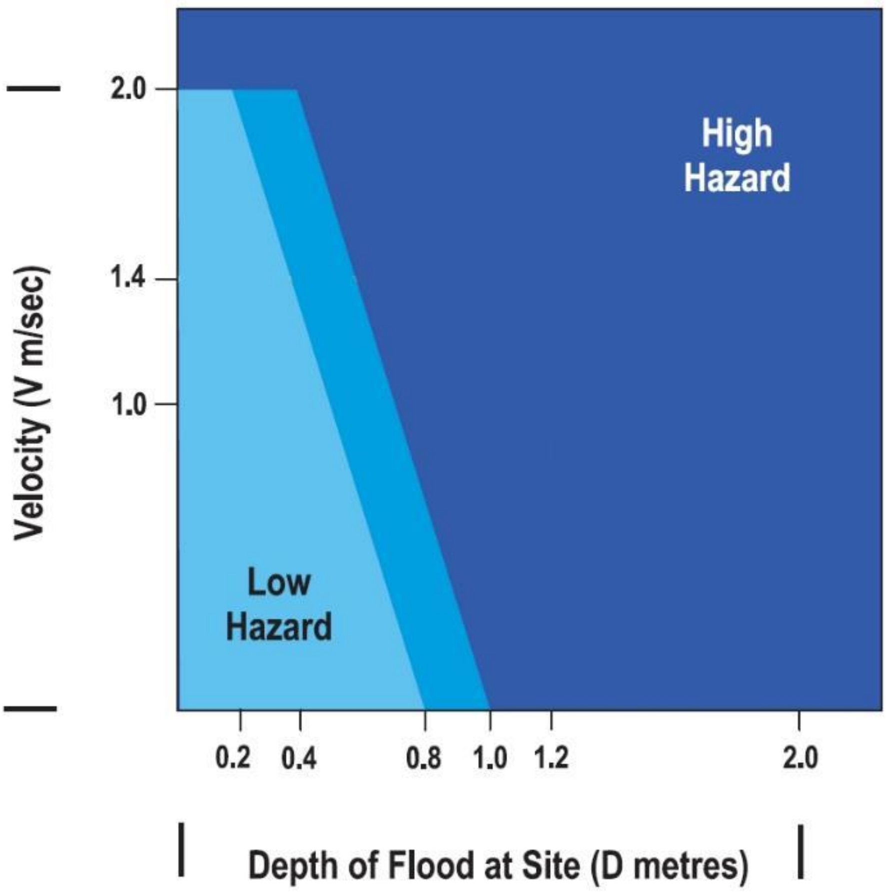

Figure 7.1 - Provisional hydraulic hazard categories (Source: NSW Government, 2005)

8 Conclusions

Narrabri Shire Council engaged WRM Water & Environment Pty Ltd (WRM) to prepare a Floodplain Risk Management Study and Plan (FRMP).This report details updates to the Narrabri Flood Study (WRM, 2016) conducted as part of the FRMP process to bring modelling up to date with the latest revision of AR&R (Ball et al., 2019).

The regional design discharges at Narrabri have been estimated from an annual series flood frequency analysis of the recorded flows at the two stream gauges at Narrabri using the methodology recommended in AR&R (Ball et al, 2019). The 1% AEP discharge at Narrabri was estimated to be 4,860 m^3/s, which is 3% lower than the previously adopted estimate (Kinhill, 1991) and slightly lower than the historical 1955 flood of the Namoi River. The estimated AEP of the 1955 flood is between 1% and 0.5% (i.e. between 100 and 200 year ARI).

The local design discharges were derived using an XP-RAFTS model developed for this study. XP-RAFTS design discharge estimates for the local catchments were validated against estimates from the Regional Flood Frequency Estimate (RFFE) program (Ball et al., 2019).

Hydraulic modelling of the study area has been undertaken to derive design flood levels, depths and extents for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP flood events and an extreme flood. Preliminary hydraulic hazard mapping has also been prepared.

Following approval of this Flood Study, the following actions are recommended:

- Update Flood Planning Levels based on the results of this Flood Study, as well as Local Environmental Plans and Development Control Plans as appropriate;
- Update Council's GIS systems with the flood mapping outputs from this Flood Study;
- Update S149 certificates for properties affected by flooding; and
- Proceed to the preparation of the Floodplain Risk Management Study, to determine options to manage and/or reduce the flood risk taking into consideration social, ecological and economic factors.

On completion of the Floodplain Risk Management Study, preferred options recommended by Council will be presented in a Floodplain Risk Management Plan publicly exhibited for subsequent implementation by Council.

9 References

Ball et al. (2019)	***'Australian Rainfall and Runoff: A Guide to Flood Estimation'***, Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) Commonwealth of Australia (Geoscience Australia), 2019.
BoM (2003)	*'The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method'*, Hydrometeorological Advisory Service, Commonwealth Bureau of Meteorology, June 2003.
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DHI (2017)	*'MIKE FLOOD - 1D-2D Modelling: User Manual'*, Danish Hydraulic Institute, Denmark, 2017.
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Max Winders & Associates (2002)	*'Narrabri Supplementary Floodplain Management Study',* Max Winders & Associates, QLD, February 2002.
NSW Government (2005)	*'Floodplain Development Manual - the management of flood liable land',* New South Wales Government, Department of Infrastructure, Planning and Natural Resources, April 2005.
NSW Government (2007a)	*'Floodplain Risk Management Guideline - Flood Emergency Response Planning Classification Of Communities',* New South Wales Government, Department of Environment and Climate Change, October 2007.
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URS (2014)	*'Narrabri Flood Study Review',* URS Australia Pty Ltd, NSW, February 2014.
WRM (2016)	*'Narrabri Flood Study: Namoi River, Mulgate Creek and Long Gully'*, Report prepared for Narrabri Shire Council by WRM Water & Environment Pty Ltd, QLD, December 2016.

10 Glossary

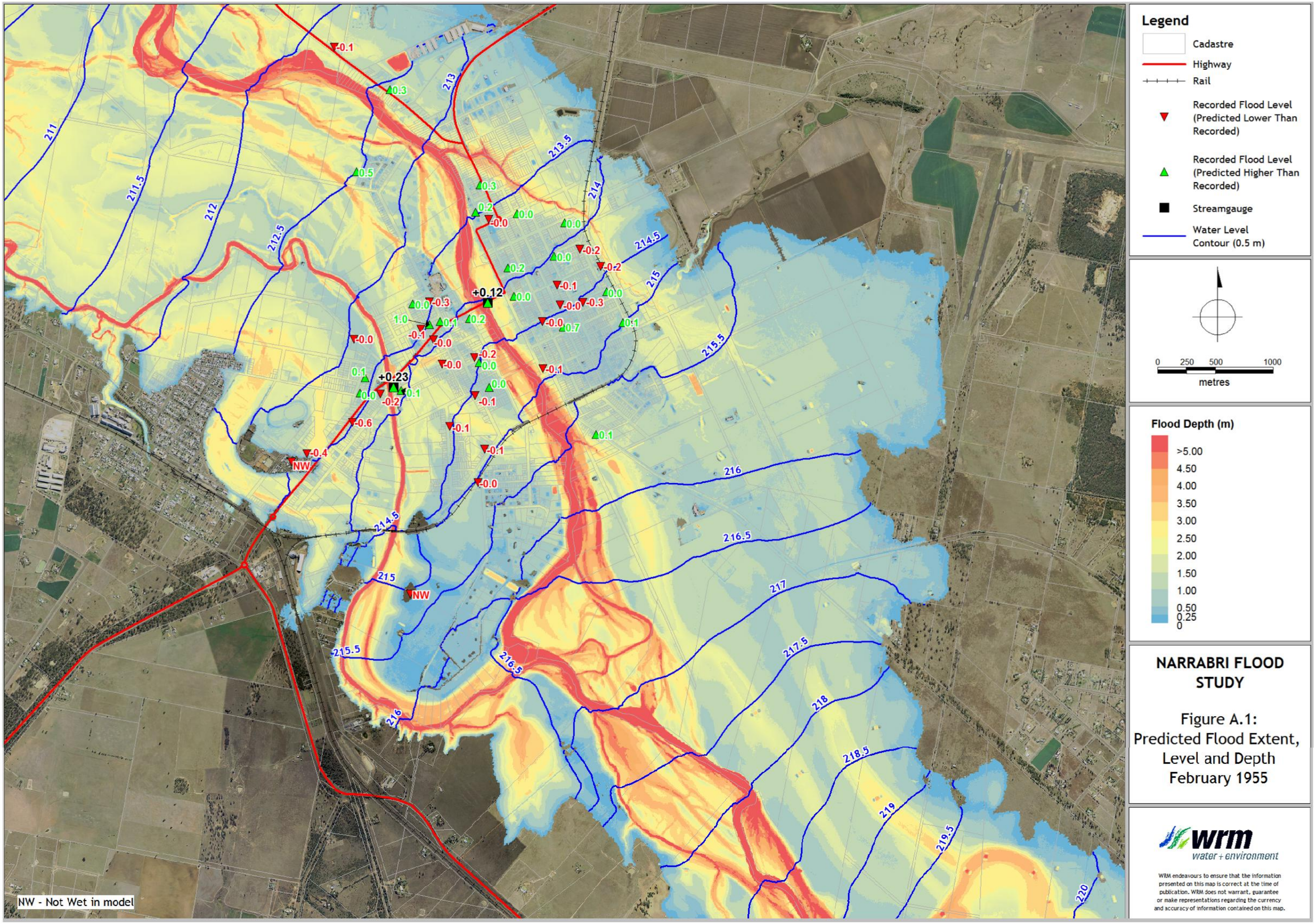
annual exceedance probability (AEP)	the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. (see ARI)
Australian Height Datum (AHD)	a common national surface level datum approximately corresponding to mean sea level.
average recurrence interval (ARI)	the long-term average number of years between the occurrence of a flood as big as or larger than the selected event.
catchment	the land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
discharge	the rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
effective warning time	the time available after receiving advice of an impending flood and before floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	a range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood fringe areas	the remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	is synonymous with flood prone land, i.e., land susceptible to flooding by the PMF event. Note that the term flood liable land covers the whole floodplain, not just that part below the FPL (see flood planning area).
flood mitigation standard	the average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.

floodplain	area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	the measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	a management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	a sub-plan of a disaster plan that deals specifically with flooding. They can exist at state, division and local levels. Local flood plans are prepared under the leadership of the SES.
flood planning area	the area of land below the FPL and thus subject to flood related development controls.
flood planning levels (FPLs)	are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans.
flood proofing	a combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	land susceptible to flooding by the PMF event. Flood prone land is synonymous with flood liable land.
flood readiness	readiness is an ability to react within the effective warning time.
flood risk	potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. existing flood risk: the risk a community is exposed to as a result of its location on the floodplain. future flood risk: the risk a community may be exposed to as a result of new development on the floodplain. continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

flood storage areas	those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
freeboard	provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
hazard	a source of potential harm or a situation with a potential to cause loss. In relation to this study the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in Appendix L of the Floodplain Development Manual (2005).
historical flood	a flood which has actually occurred.
hydraulics	term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	a graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
mathematical / computer models	the mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
peak discharge	the maximum discharge occurring during a flood event.
probable maximum flood (PMF)	the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event.
probable maximum precipitation (PMP)	the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.

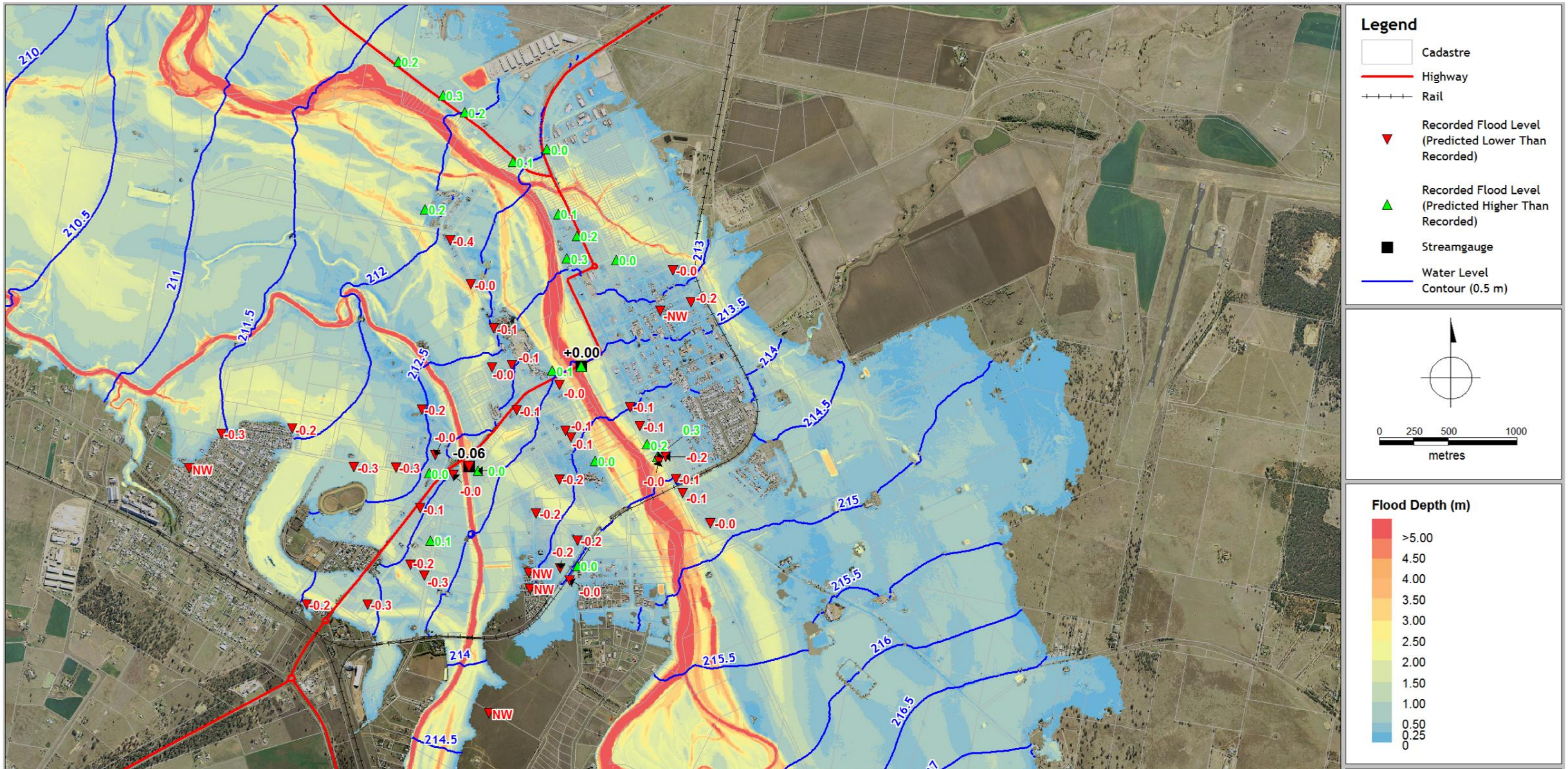
probability	a statistical measure of the expected chance of flooding (see annual exceedance probability).
risk	chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	the amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	equivalent to water level (both measured with reference to a specified datum).
stage hydrograph	a graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
MIKE-FLOOD	a one-dimensional and two-dimensional flood simulation software. It simulates the complex movement of floodwaters across a particular area of interest using mathematical approximations to derive information on floodwater depths, velocities and levels.
velocity	the speed or rate of motion (distance per unit of time, e.g., metres per second) in a specific direction at which the flood waters are moving.
water surface profile	a graph showing the flood stage at any given location along a watercourse at a particular time.

Appendix A - Historical event flood mapping



NARRABRI FLOOD STUDY

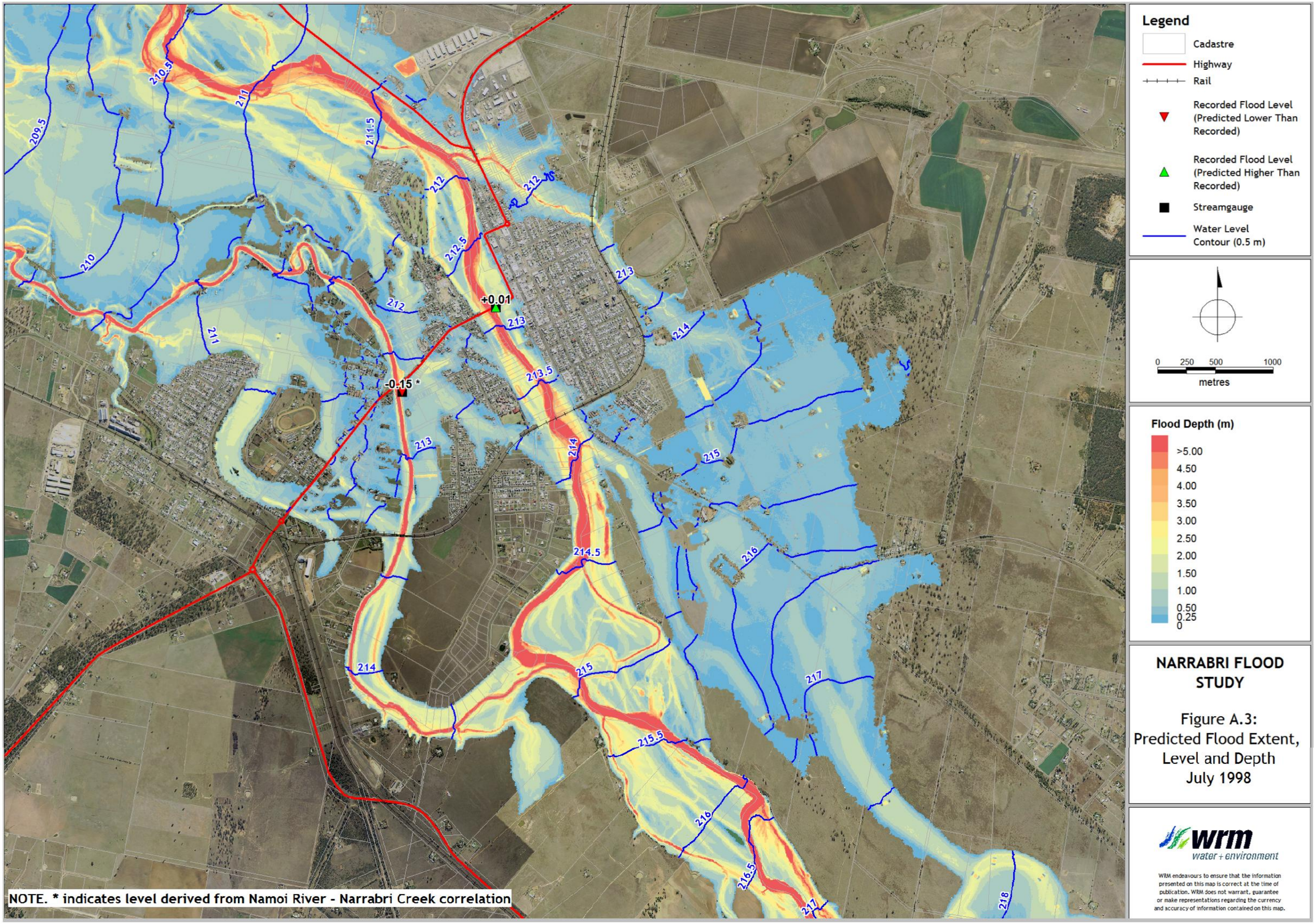
Figure A.1: Predicted Flood Extent, Level and Depth February 1955



NARRABRI FLOOD STUDY

Figure A.2: Predicted Flood Extent, Level and Depth February 1971

wrm water + environment



NARRABRI FLOOD STUDY

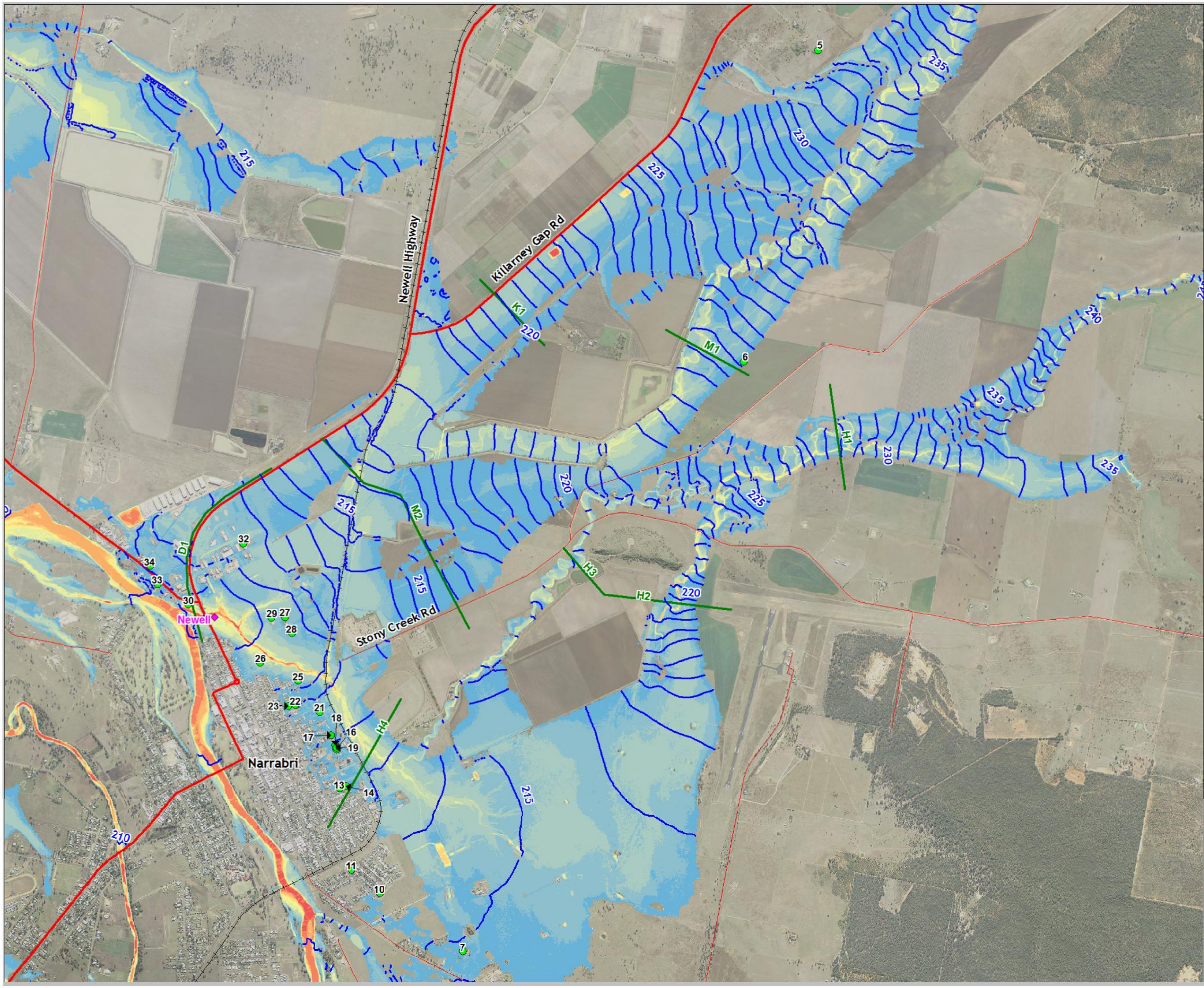
Figure A.3: Predicted Flood Extent, Level and Depth July 1998

wrm water + environment

NARRABRI FLOOD STUDY

Figure A.4: Predicted and Observed Flood Extents July 1998

wrm water + environment



Legend

Highway
Local Road
Rail
Discharge Reporting Location
Water Level Reporting Location
Anecdotal Flood Information

0 250 500 1000
metres

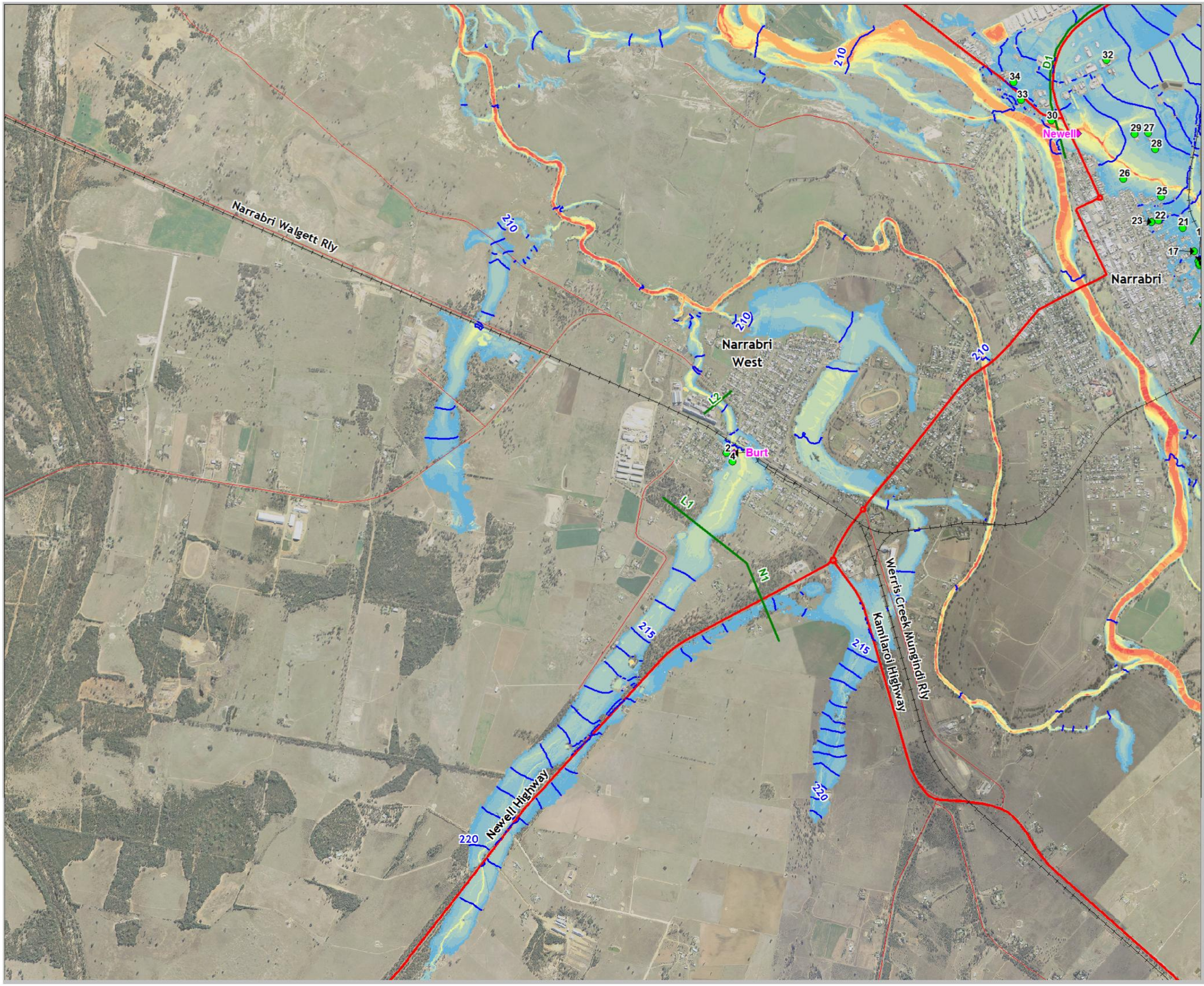
Flood Depth (m)

>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0

NARRABRI FLOOD STUDY

Figure A.5: Predicted Flood Extent, Level and Depth Mulgate Creek December 2004

wrm water + environment



Legend

- Highway
- Local Road
- Rail
- Water Level Contour (0.5 m)
- Discharge Reporting Location
- Water Level Reporting Location
- Anecdotal Flood Information

0 250 500 1000
metres

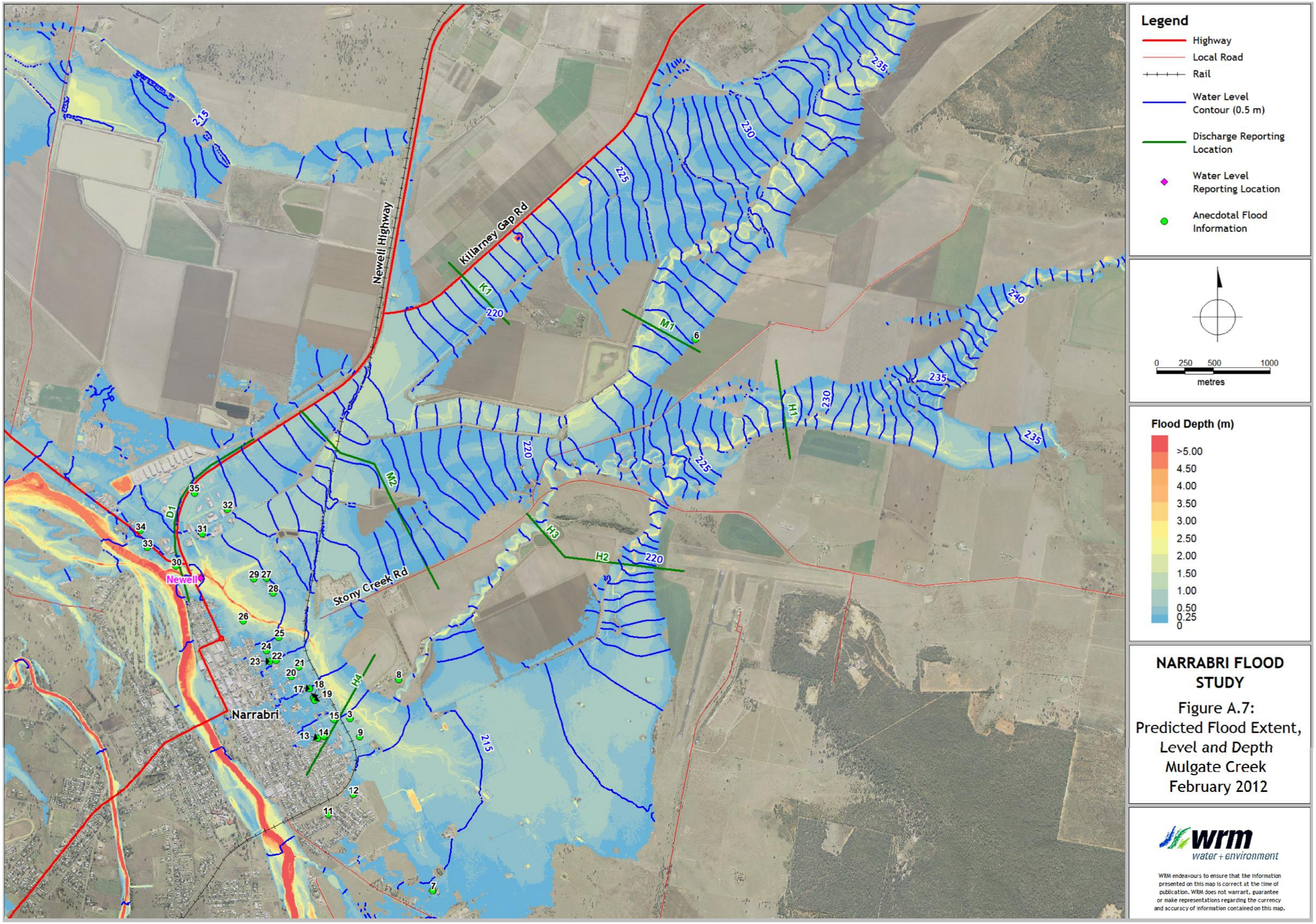
Flood Depth (m)

>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0

NARRABRI FLOOD STUDY

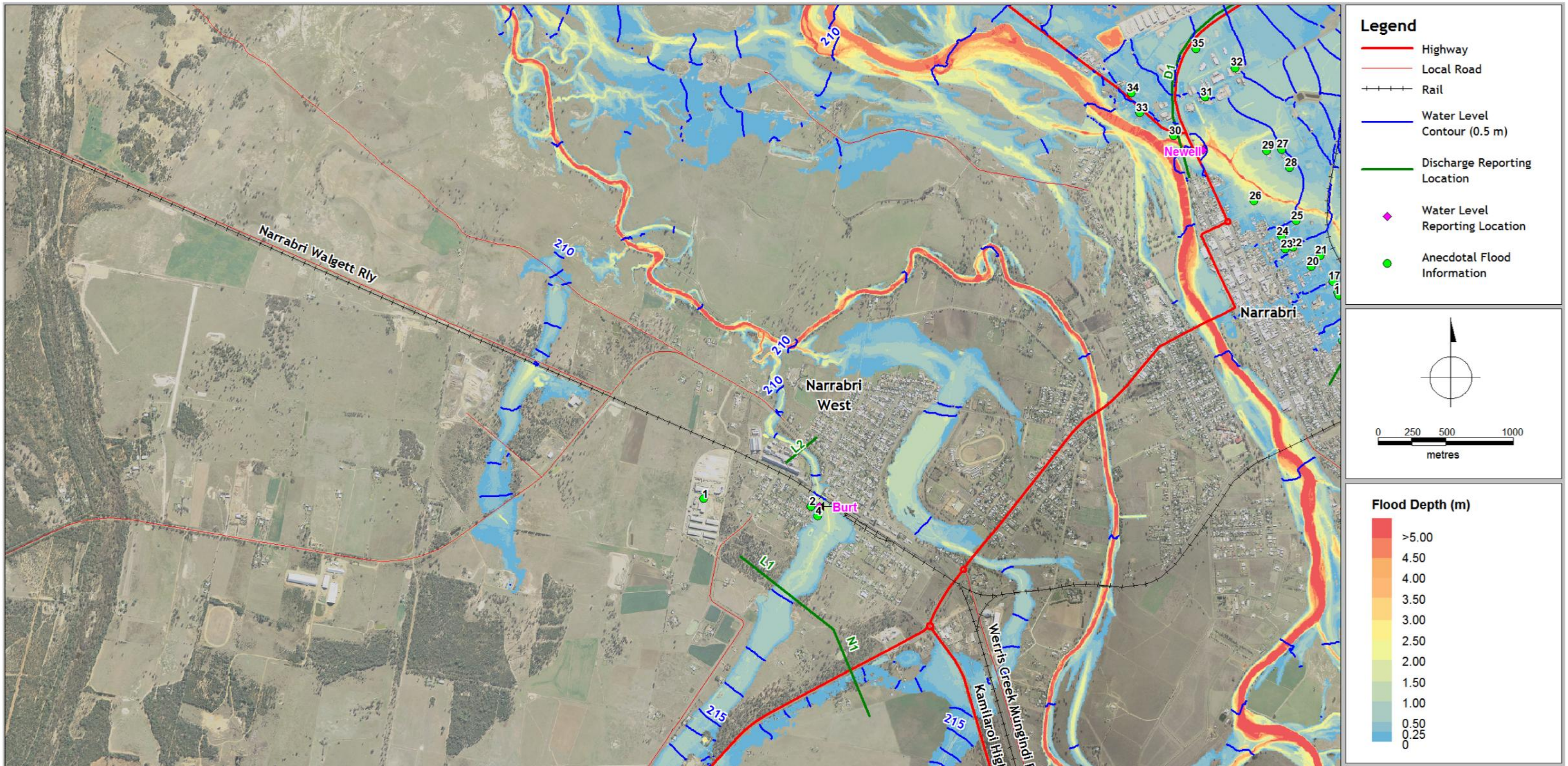
Figure A.6:
Predicted Flood Extent, Level and Depth
Long Gully
December 2004

wrm water + environment



NARRABRI FLOOD STUDY

Figure A.7: Predicted Flood Extent, Level and Depth Mulgate Creek February 2012

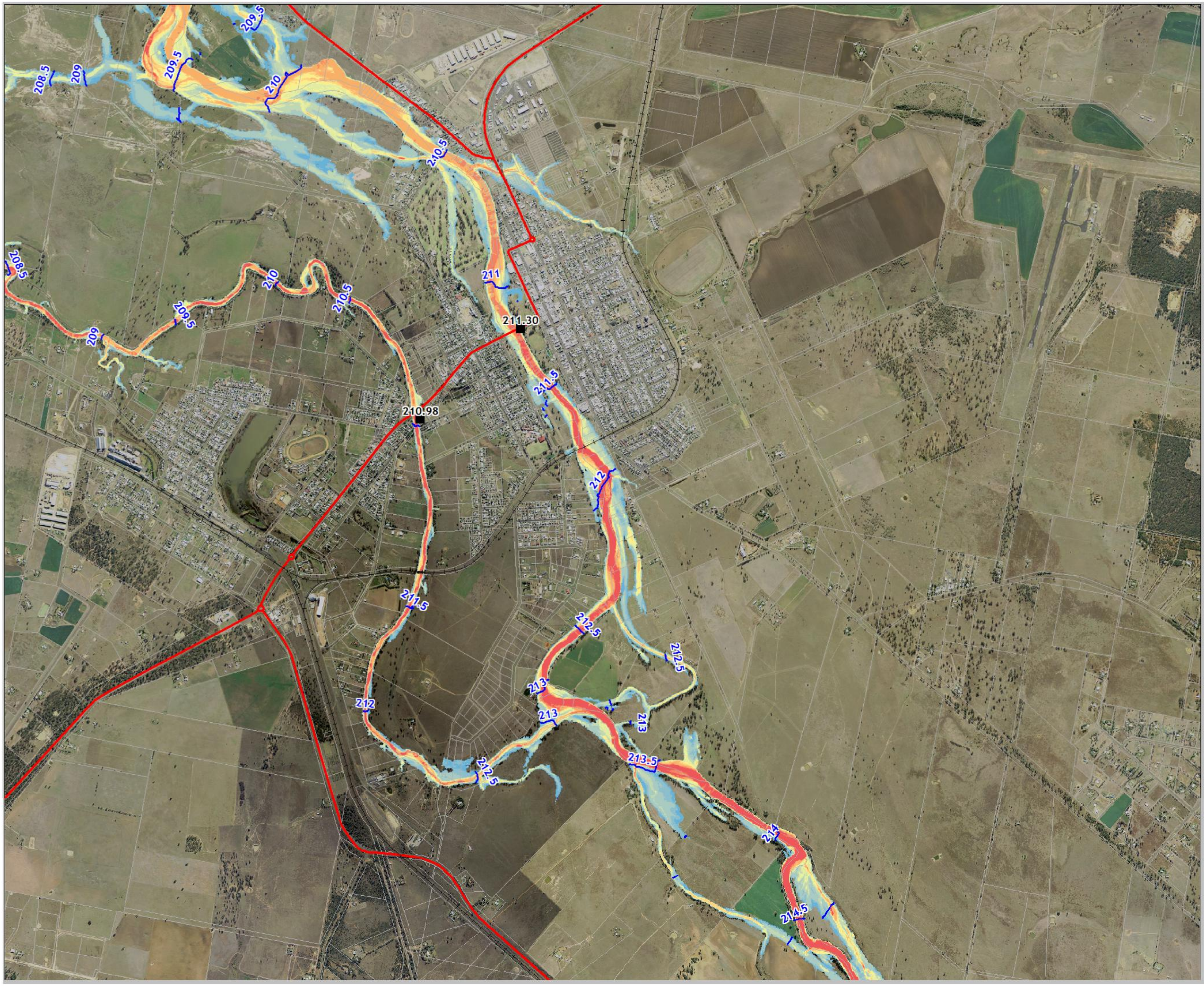


NARRABRI FLOOD STUDY

Figure A.8:
Predicted Flood Extent, Level and Depth
Long Gully
February 2012

wrm water + environment

Appendix B - Design flood mapping



Legend

- Cadastre
- Rail
- Highway
- Streamgauge
- Water Level Contour (0.5 m)

0 250 500 1000
metres

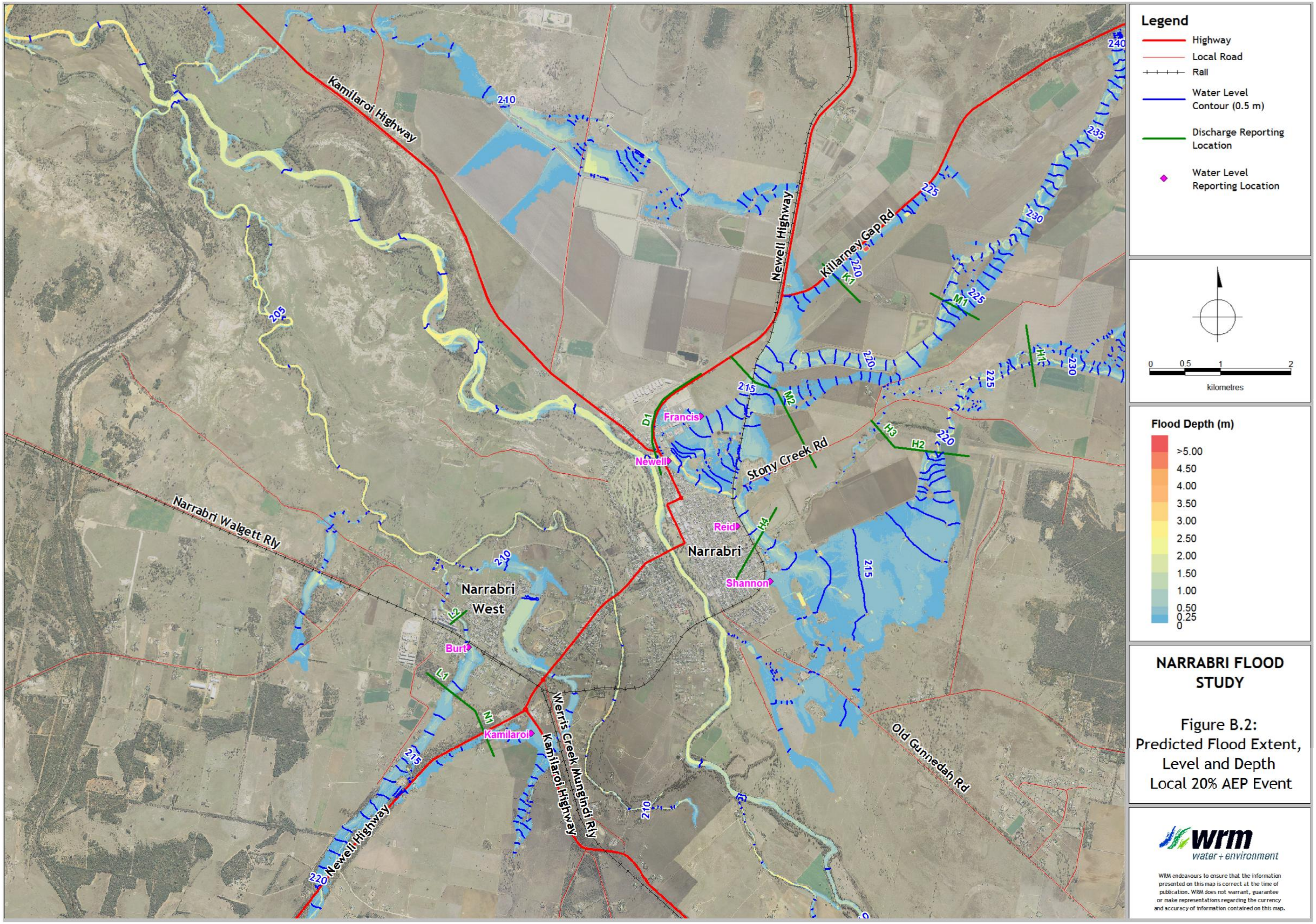
Flood Depth (m)

>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0

NARRABRI FLOOD STUDY

Figure B.1:
Predicted Flood Extent, Level and Depth
Regional 20% AEP Event

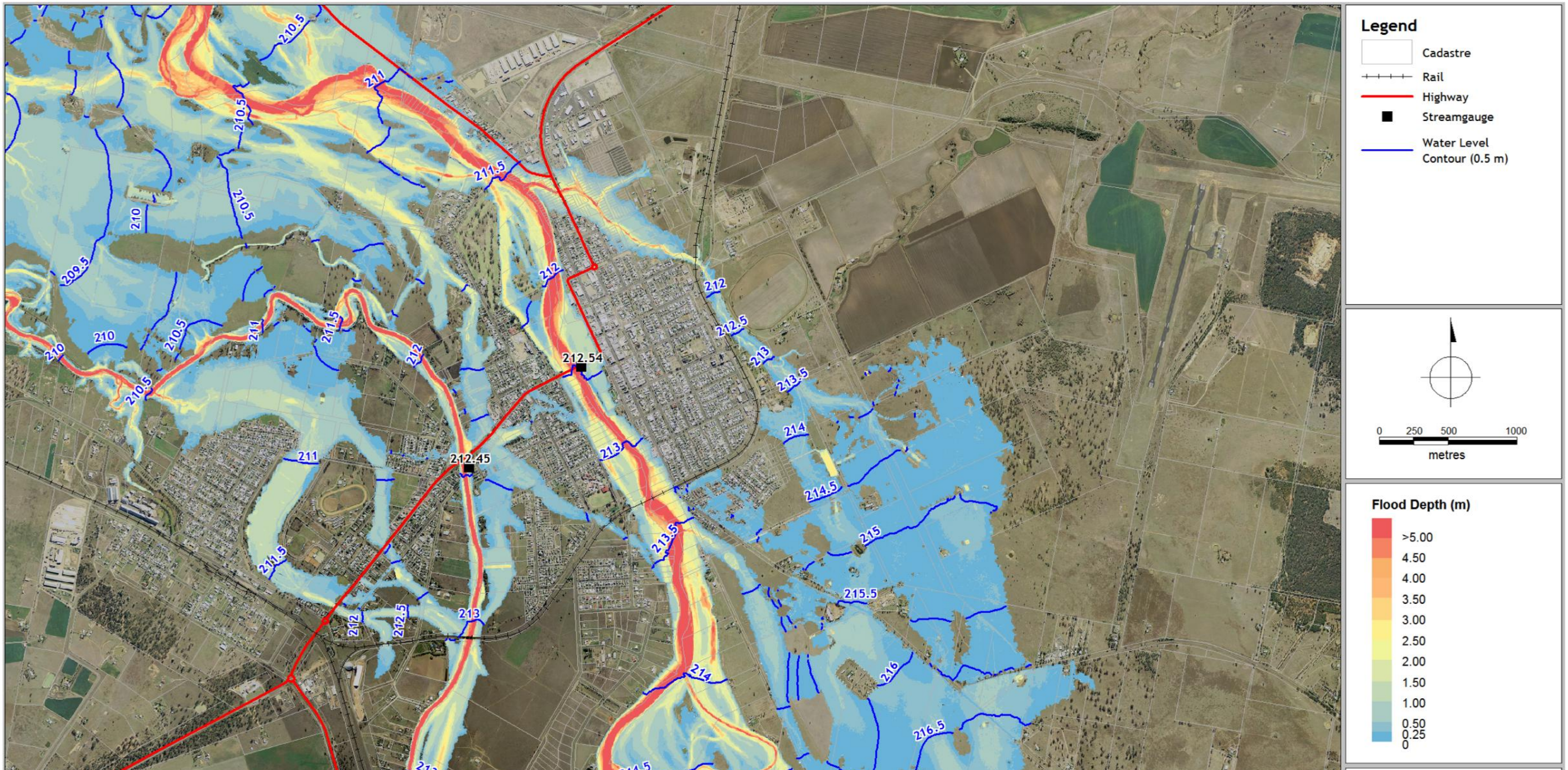
wrm
water + environment



NARRABRI FLOOD STUDY

Figure B.2: Predicted Flood Extent, Level and Depth Local 20% AEP Event

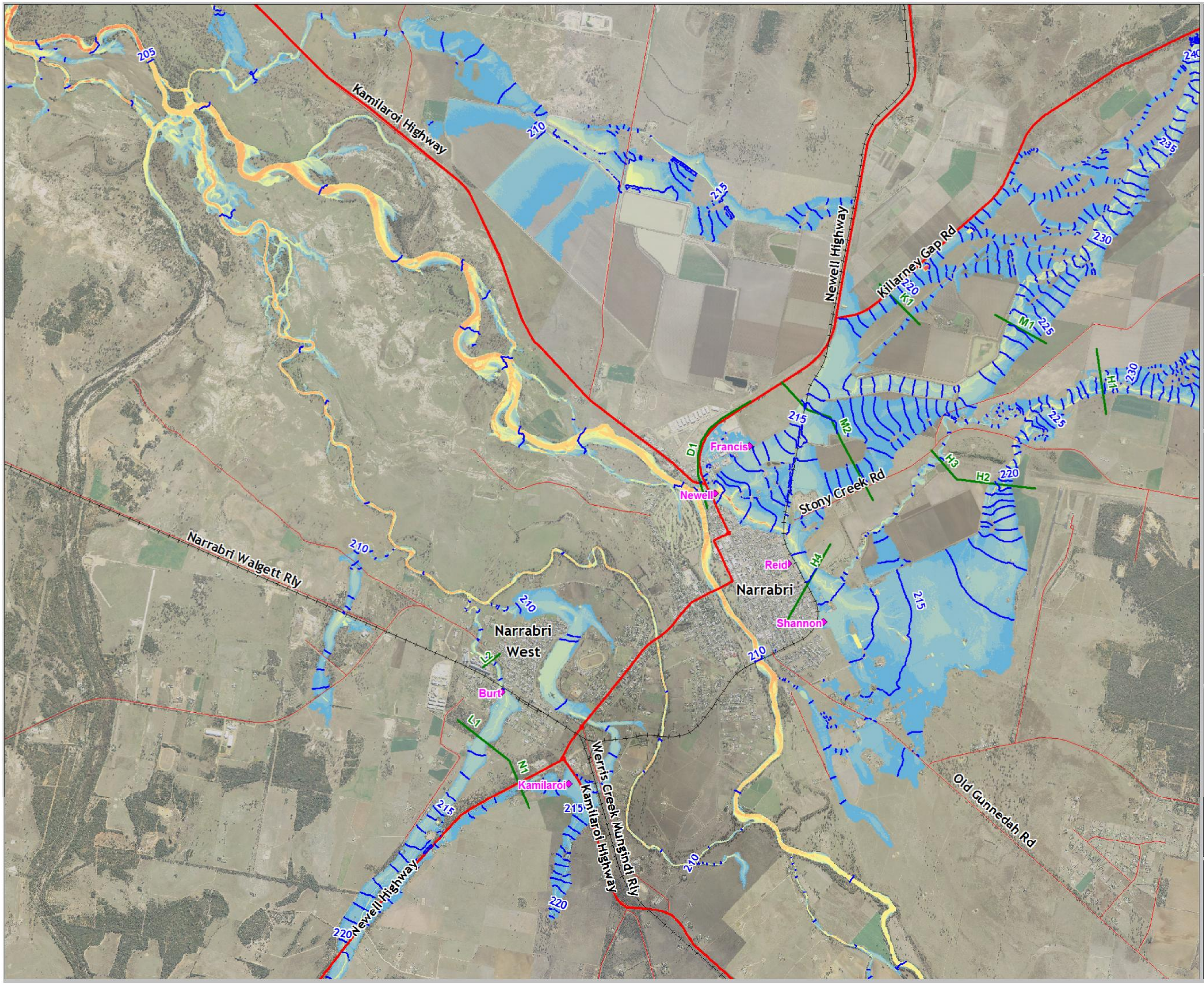
wrm water + environment



NARRABRI FLOOD STUDY

Figure B.3:
Predicted Flood Extent,
Level and Depth
Regional 10% AEP Event

wrm water + environment



Legend

- Highway
- Local Road
- Rail
- Water Level Contour (0.5 m)
- Discharge Reporting Location
- Water Level Reporting Location

0 0.5 1 2
kilometres

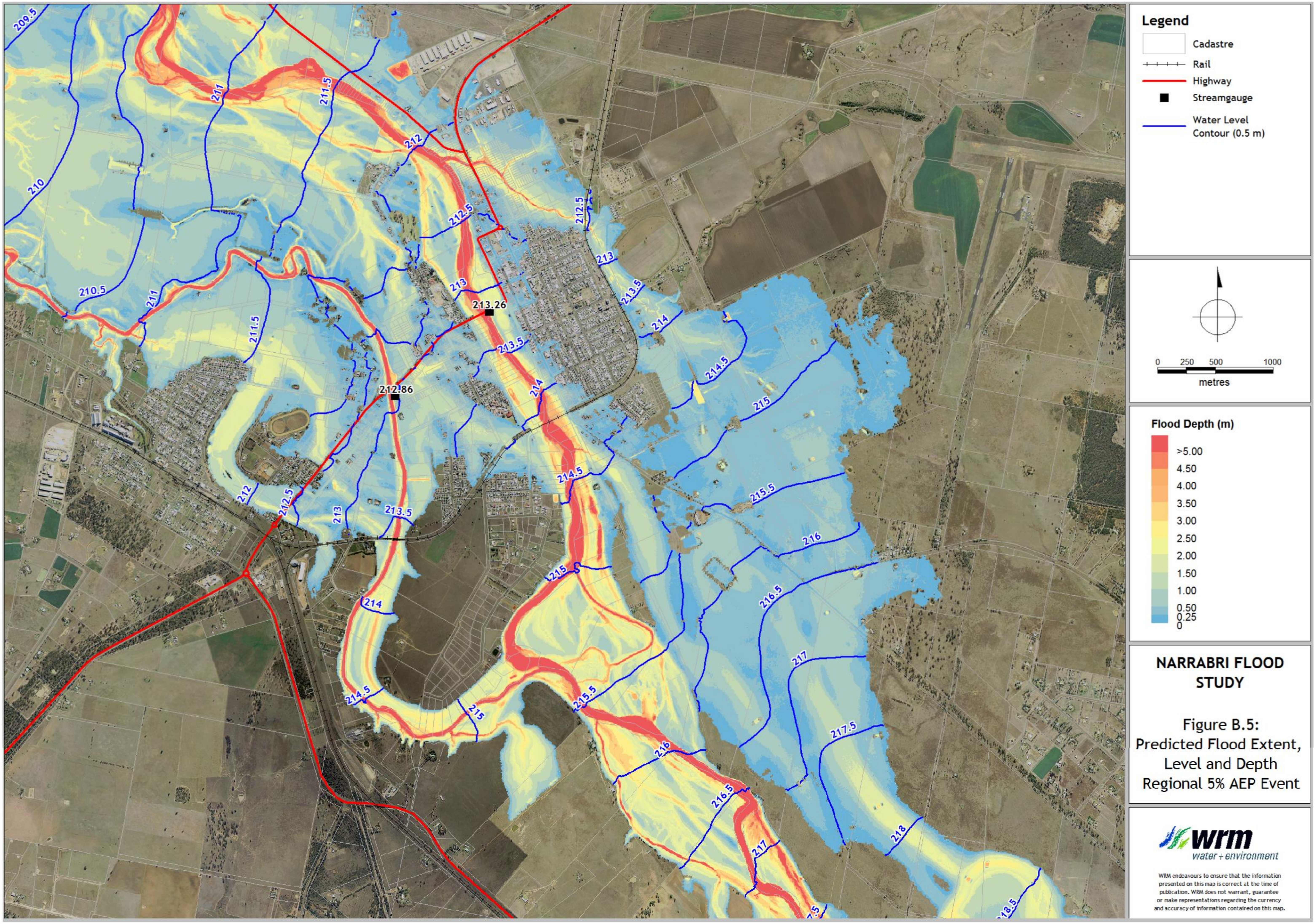
Flood Depth (m)

>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0

NARRABRI FLOOD STUDY

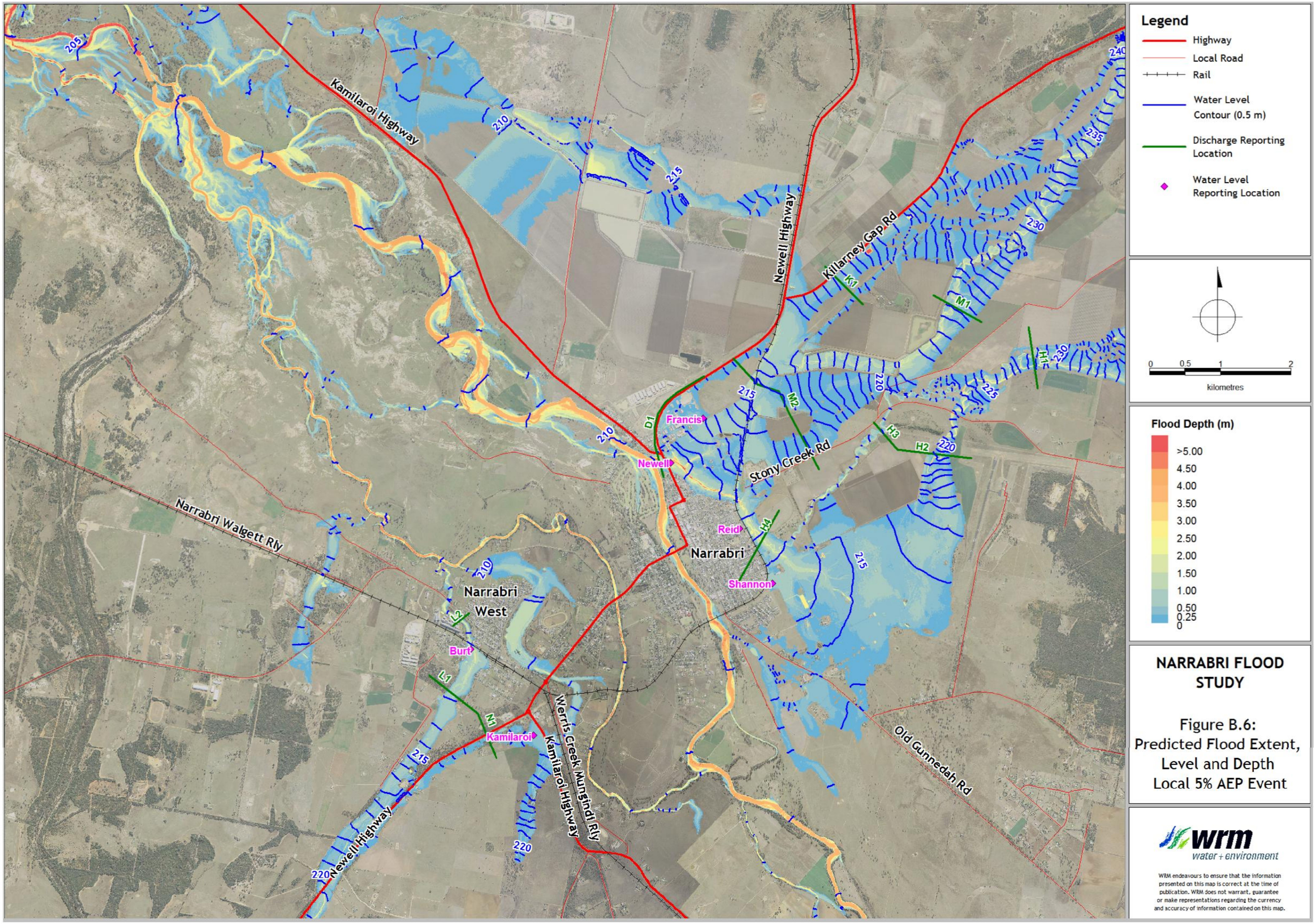
Figure B.4:
Predicted Flood Extent, Level and Depth
Local 10% AEP Event

wrm water + environment



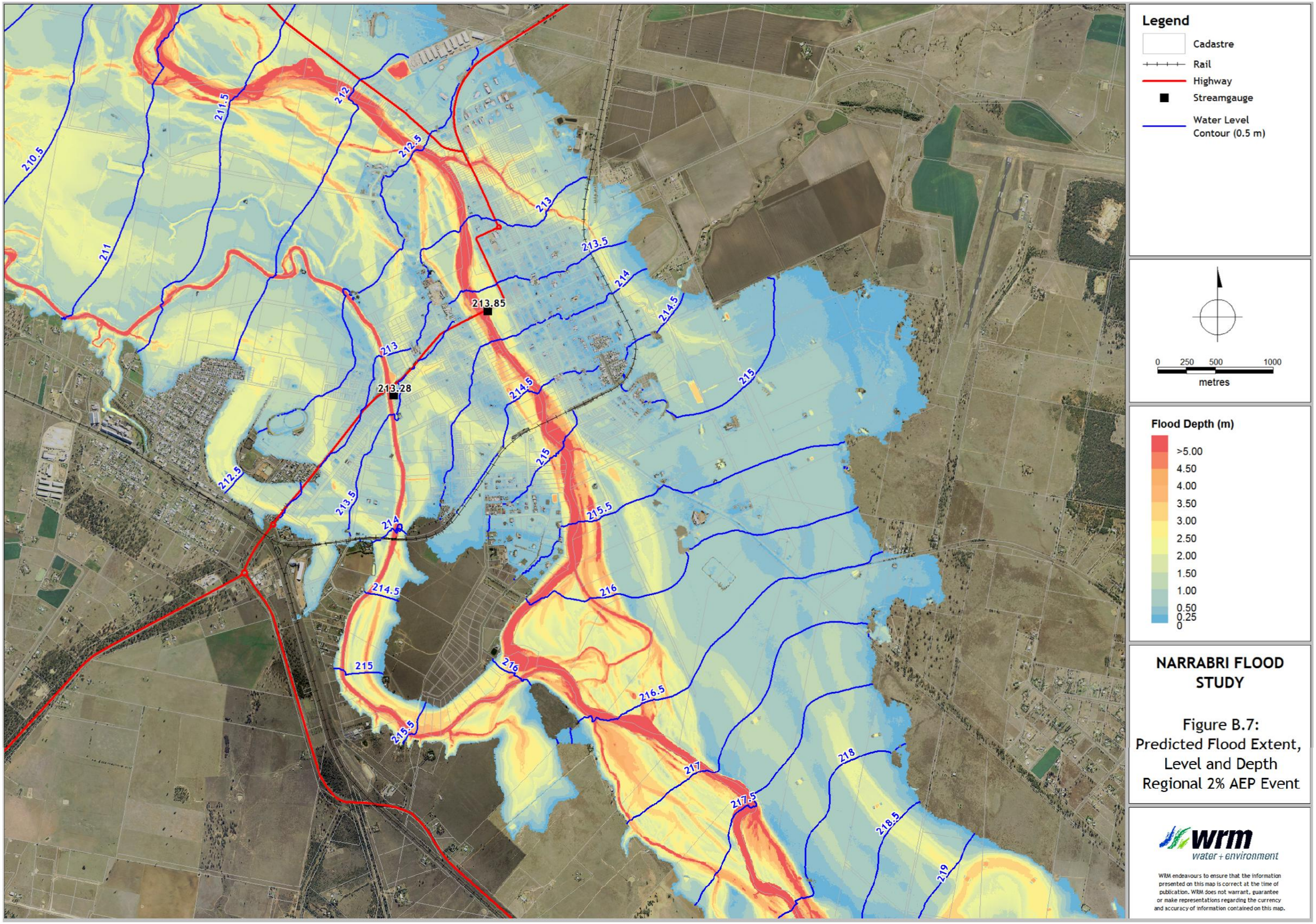
NARRABRI FLOOD STUDY

Figure B.5: Predicted Flood Extent, Level and Depth Regional 5% AEP Event



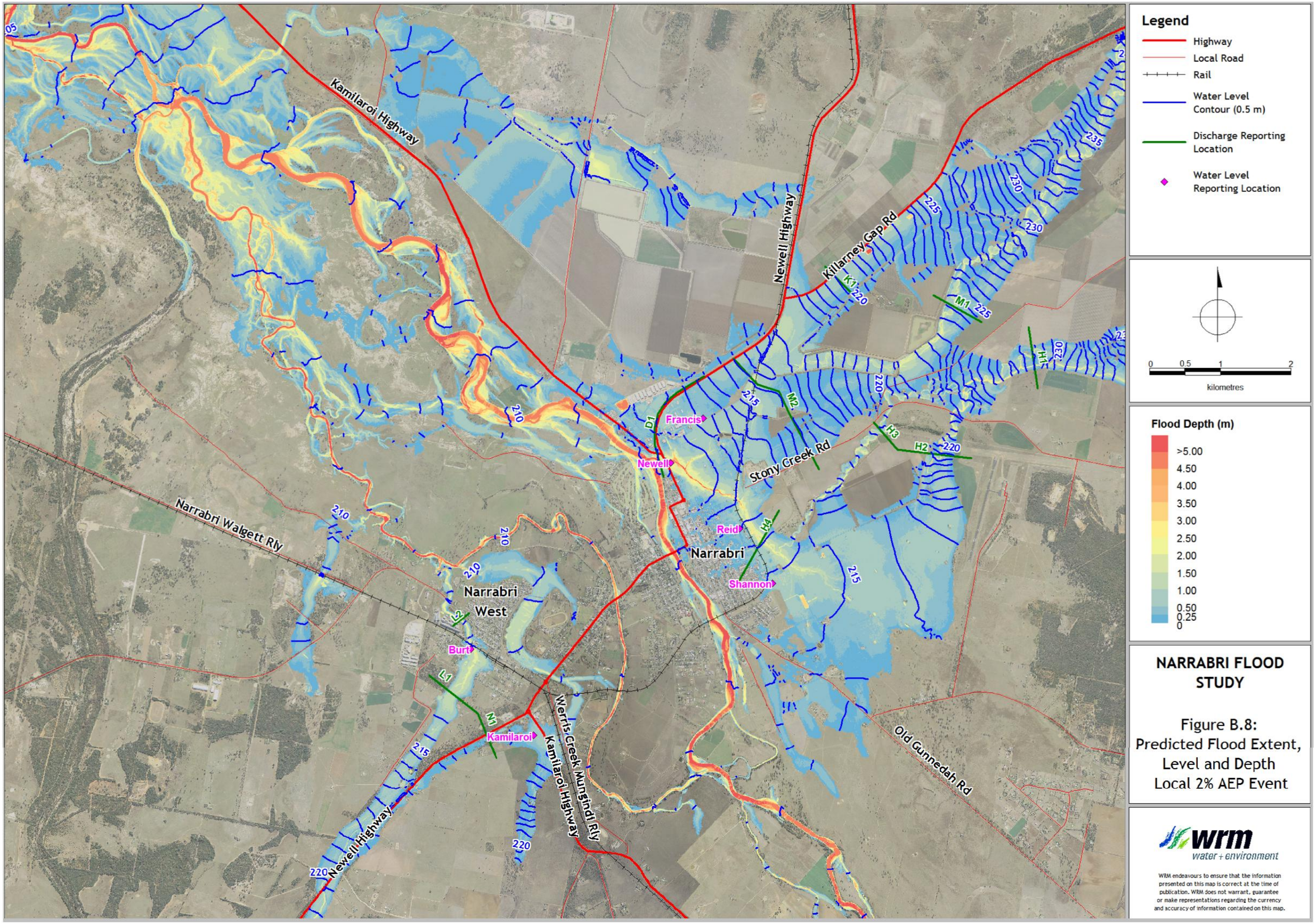
NARRABRI FLOOD STUDY

Figure B.6: Predicted Flood Extent, Level and Depth Local 5% AEP Event



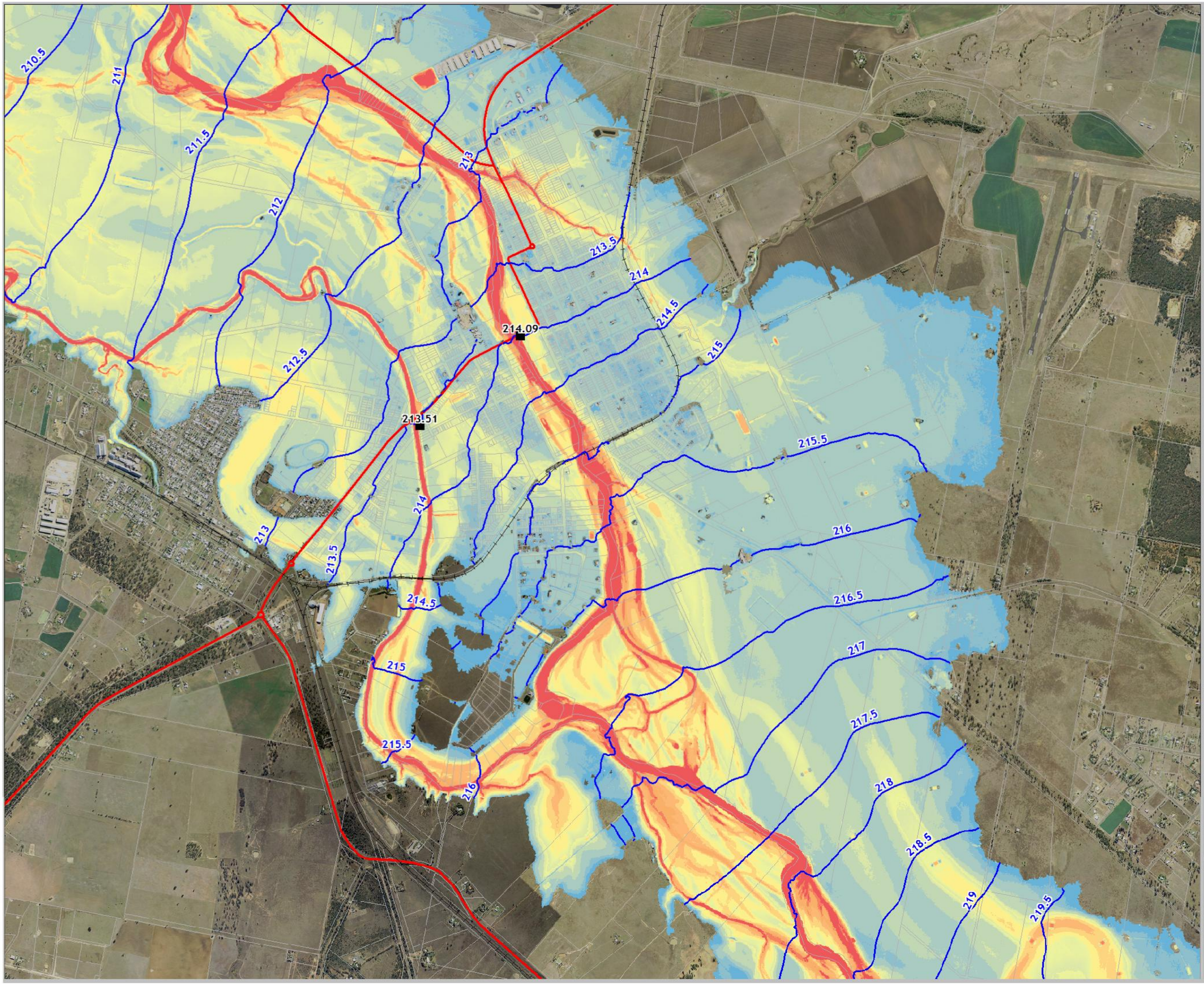
NARRABRI FLOOD STUDY

Figure B.7: Predicted Flood Extent, Level and Depth Regional 2% AEP Event



NARRABRI FLOOD STUDY

Figure B.8:
Predicted Flood Extent, Level and Depth
Local 2% AEP Event



Legend

- Cadastre
- Rail
- Highway
- Streamgauge
- Water Level Contour (0.5 m)

0 250 500 1000
metres

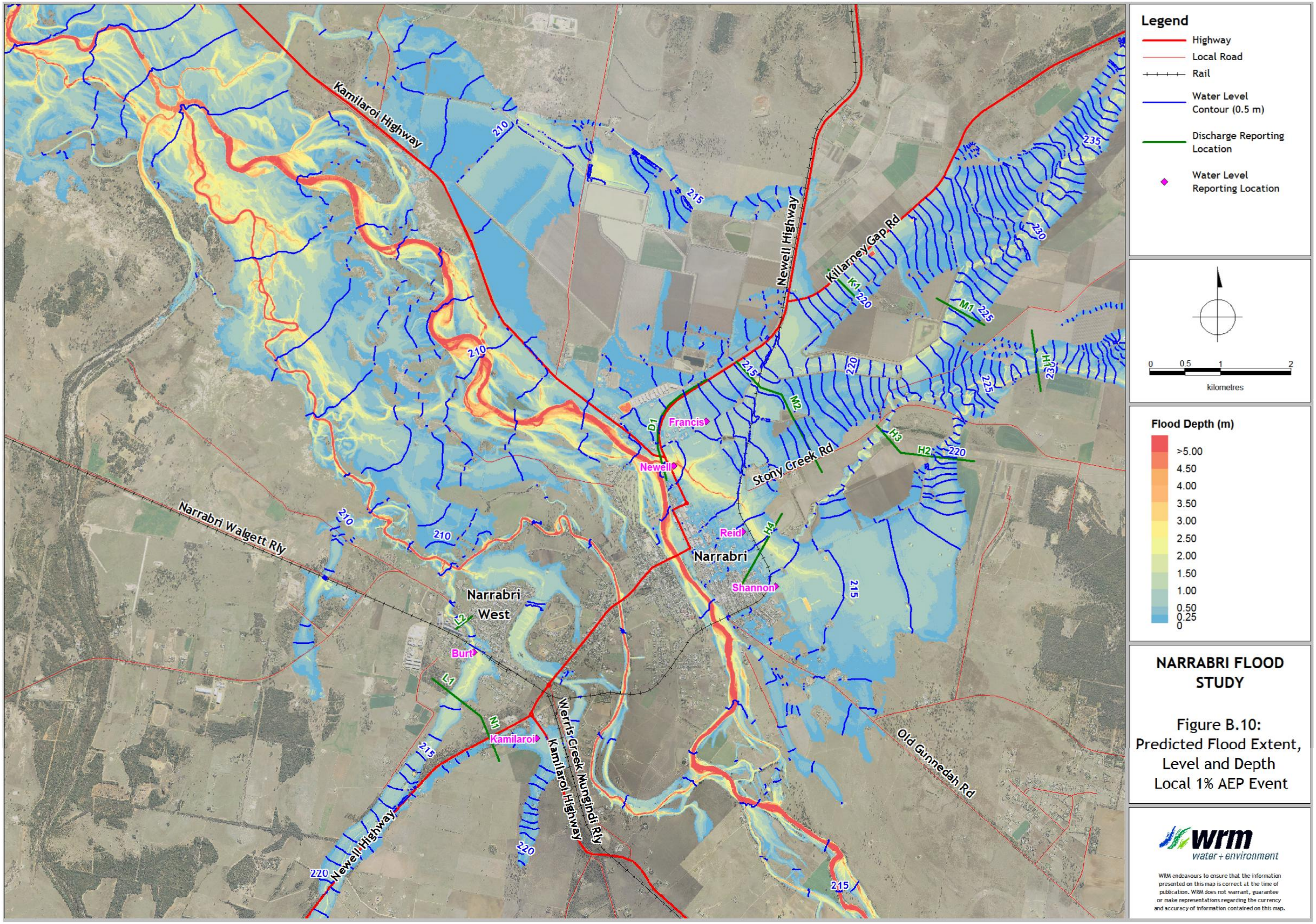
Flood Depth (m)

>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0

NARRABRI FLOOD STUDY

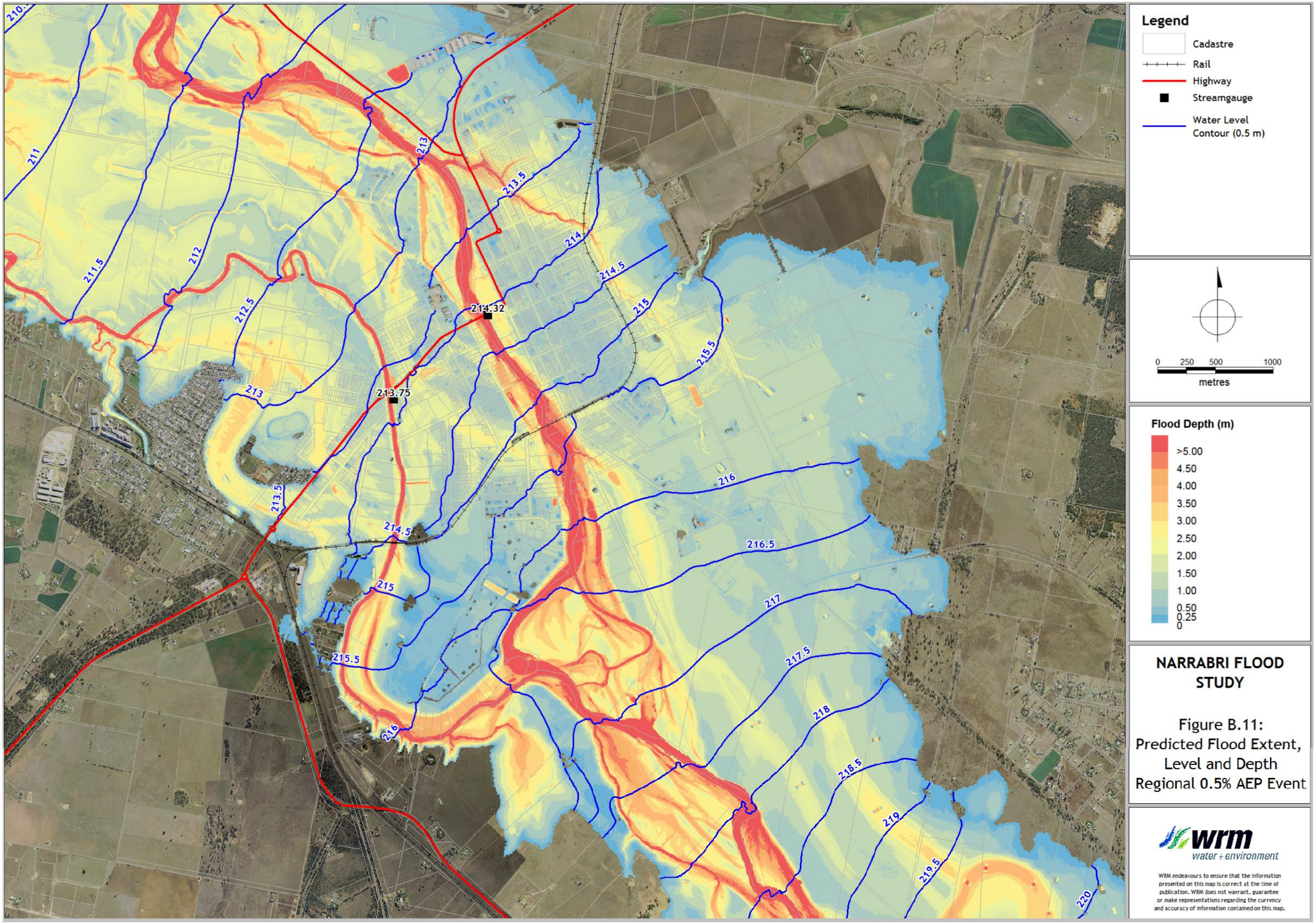
Figure B.9:
Predicted Flood Extent, Level and Depth
Regional 1% AEP Event

wrm
water + environment



NARRABRI FLOOD STUDY

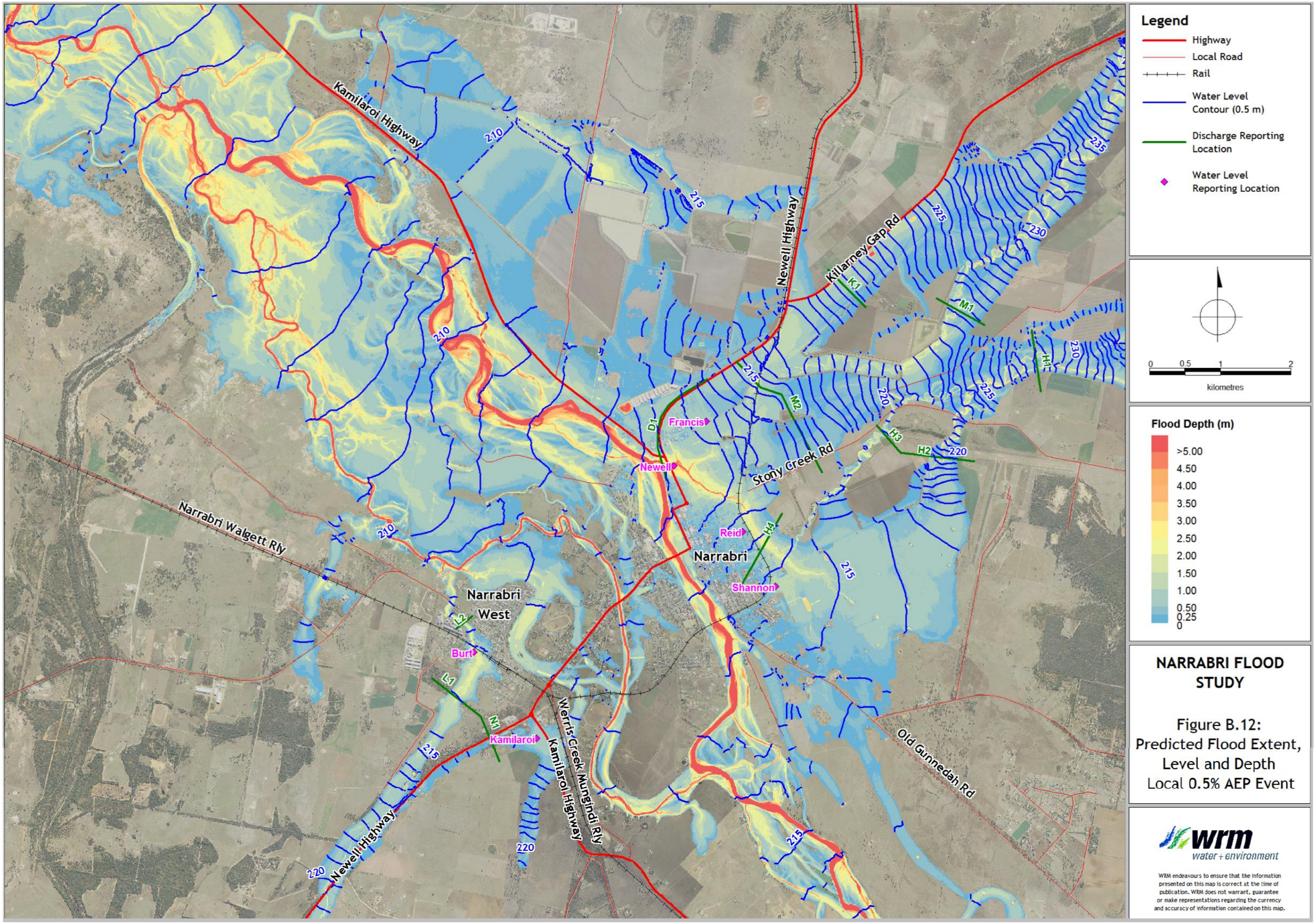
Figure B.10: Predicted Flood Extent, Level and Depth Local 1% AEP Event



NARRABRI FLOOD STUDY

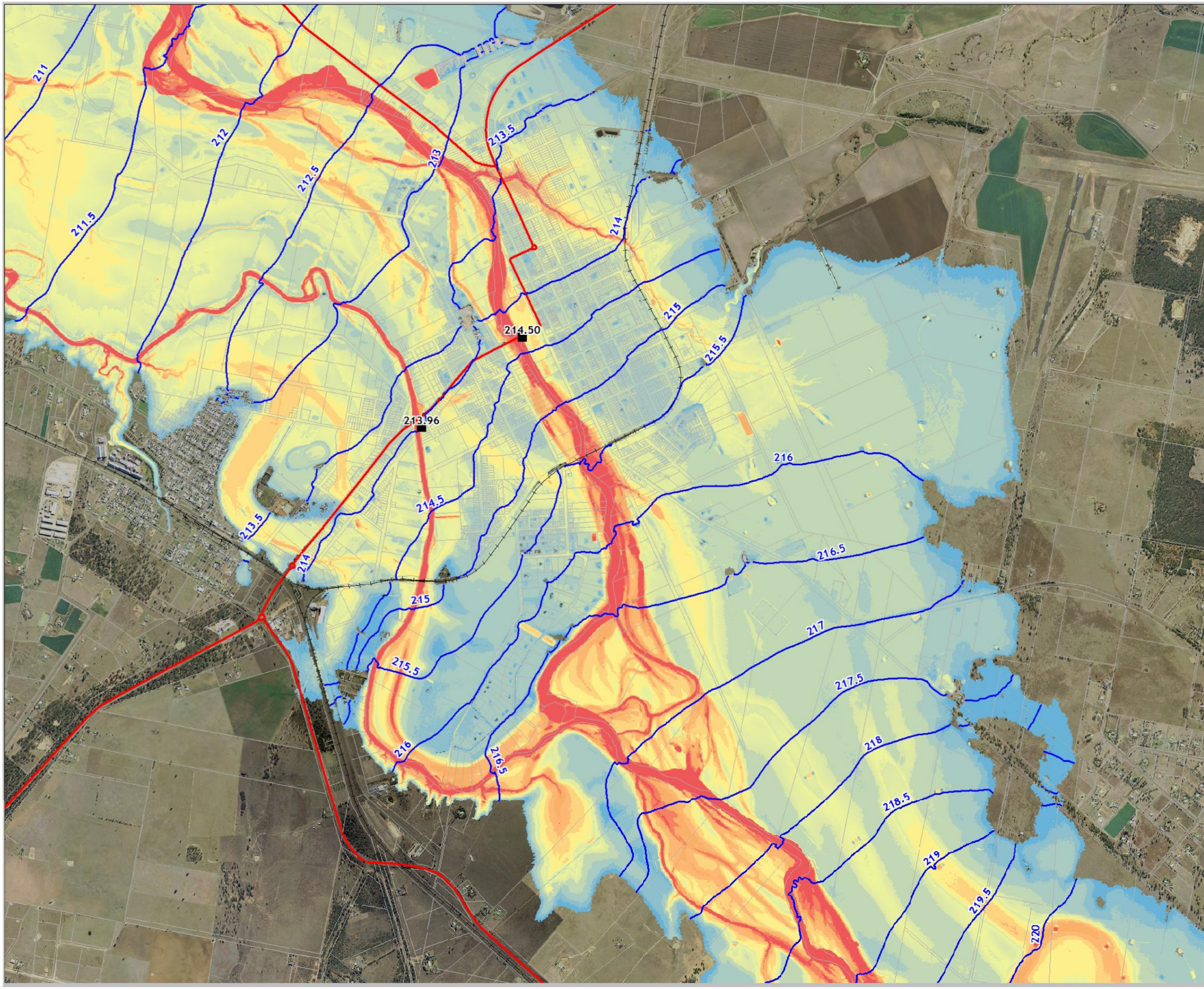
Figure B.11: Predicted Flood Extent, Level and Depth Regional 0.5% AEP Event

wrm water + environment



NARRABRI FLOOD STUDY

Figure B.12: Predicted Flood Extent, Level and Depth Local 0.5% AEP Event



Legend

Cadastre

Rail

Highway

Streamgauge

Water Level Contour (0.5 m)

0 250 500 1000

metres

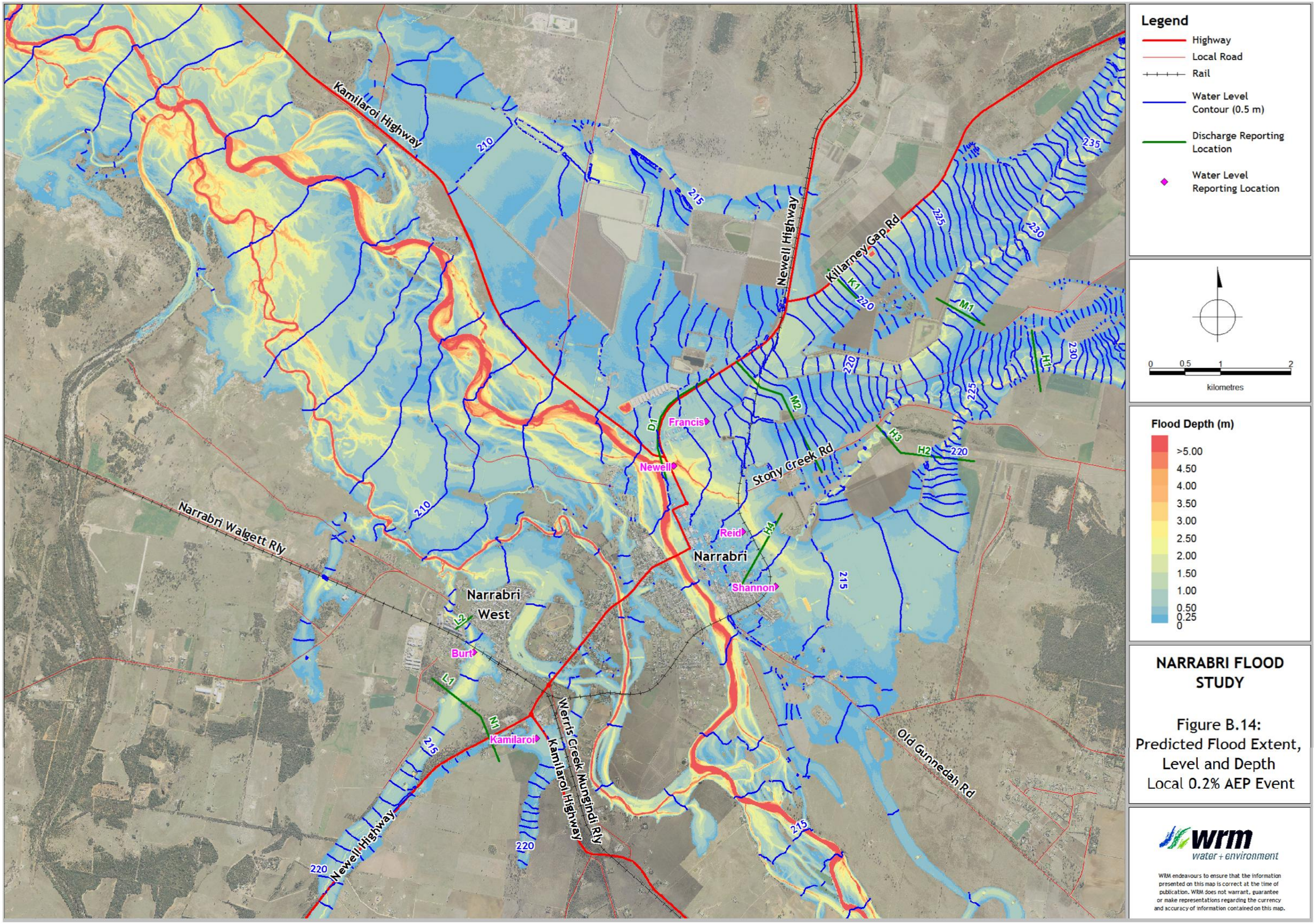
Flood Depth (m)

>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0

NARRABRI FLOOD STUDY

Figure B.13: Predicted Flood Extent, Level and Depth Regional 0.2% AEP Event

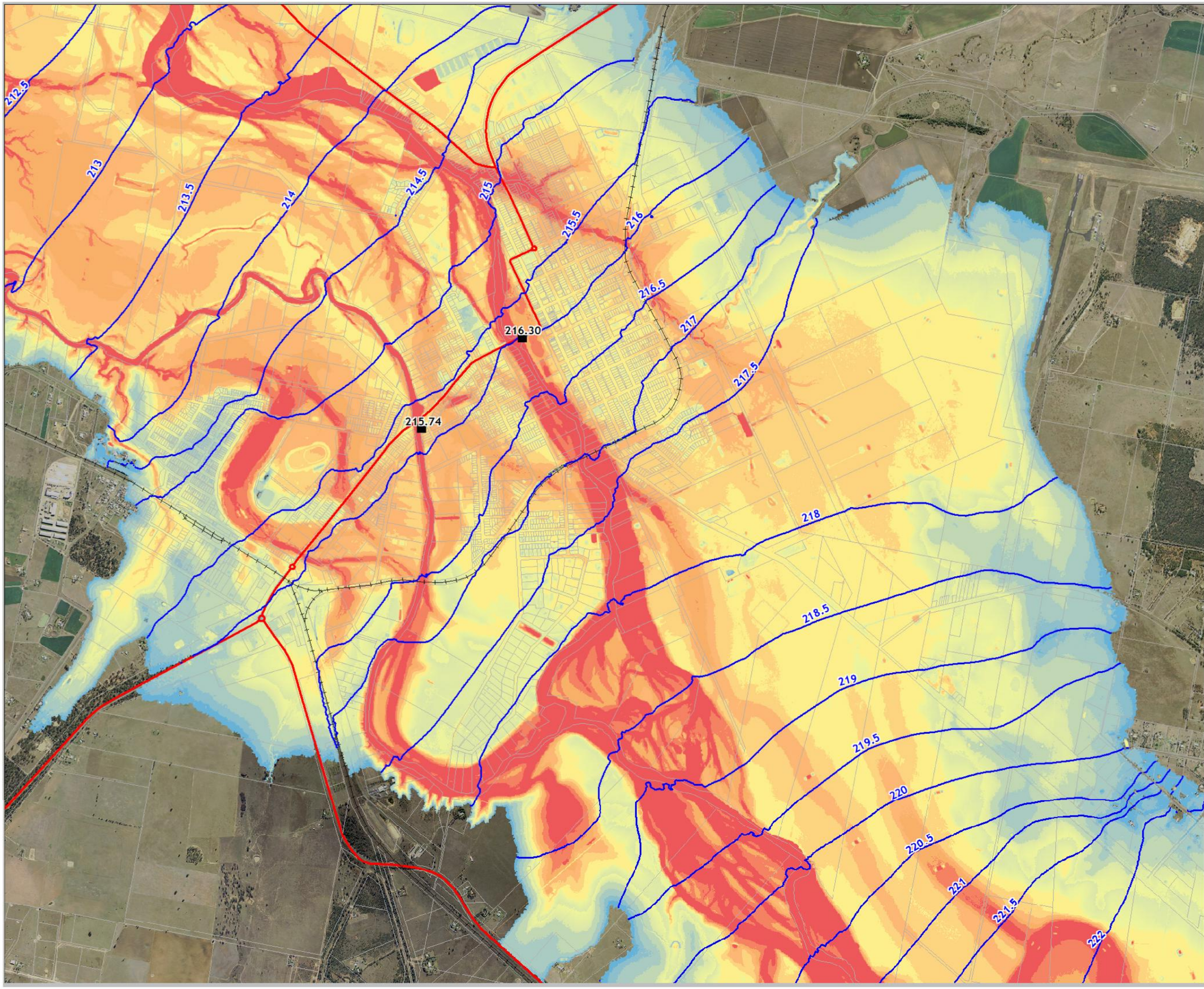
wrm water + environment



NARRABRI FLOOD STUDY

Figure B.14: Predicted Flood Extent, Level and Depth Local 0.2% AEP Event

wrm water + environment



Legend

- Cadastre
- Rail
- Highway
- Streamgauge
- Water Level Contour (0.5 m)

0 250 500 1000
metres

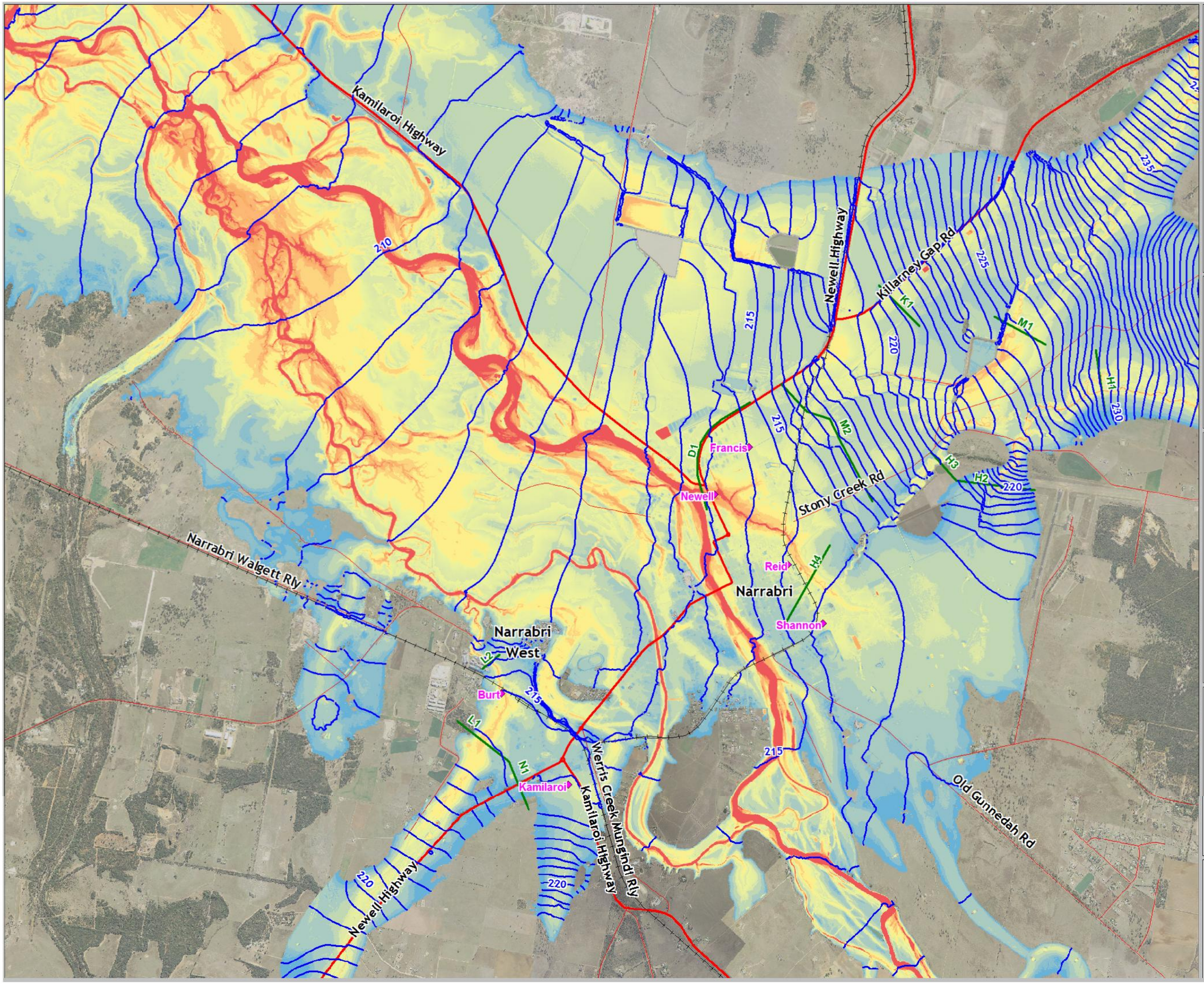
Flood Depth (m)

>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0

NARRABRI FLOOD STUDY

Figure B.15: Predicted Flood Extent, Level and Depth Regional Extreme Flood

wrm water + environment

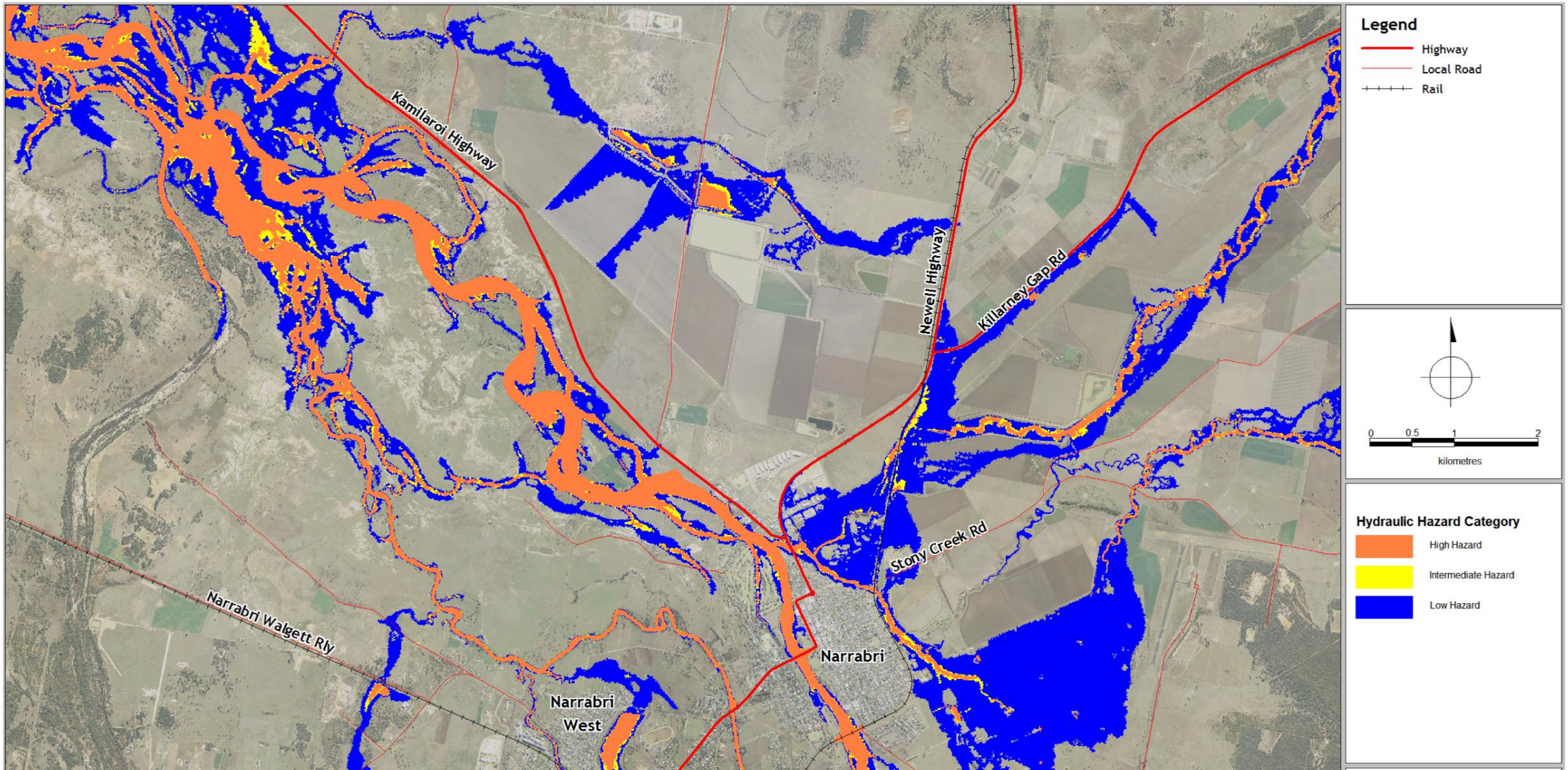


NARRABRI FLOOD STUDY

Figure B.16: Predicted Flood Extent, Level and Depth Local PMF Event

wrm water + environment

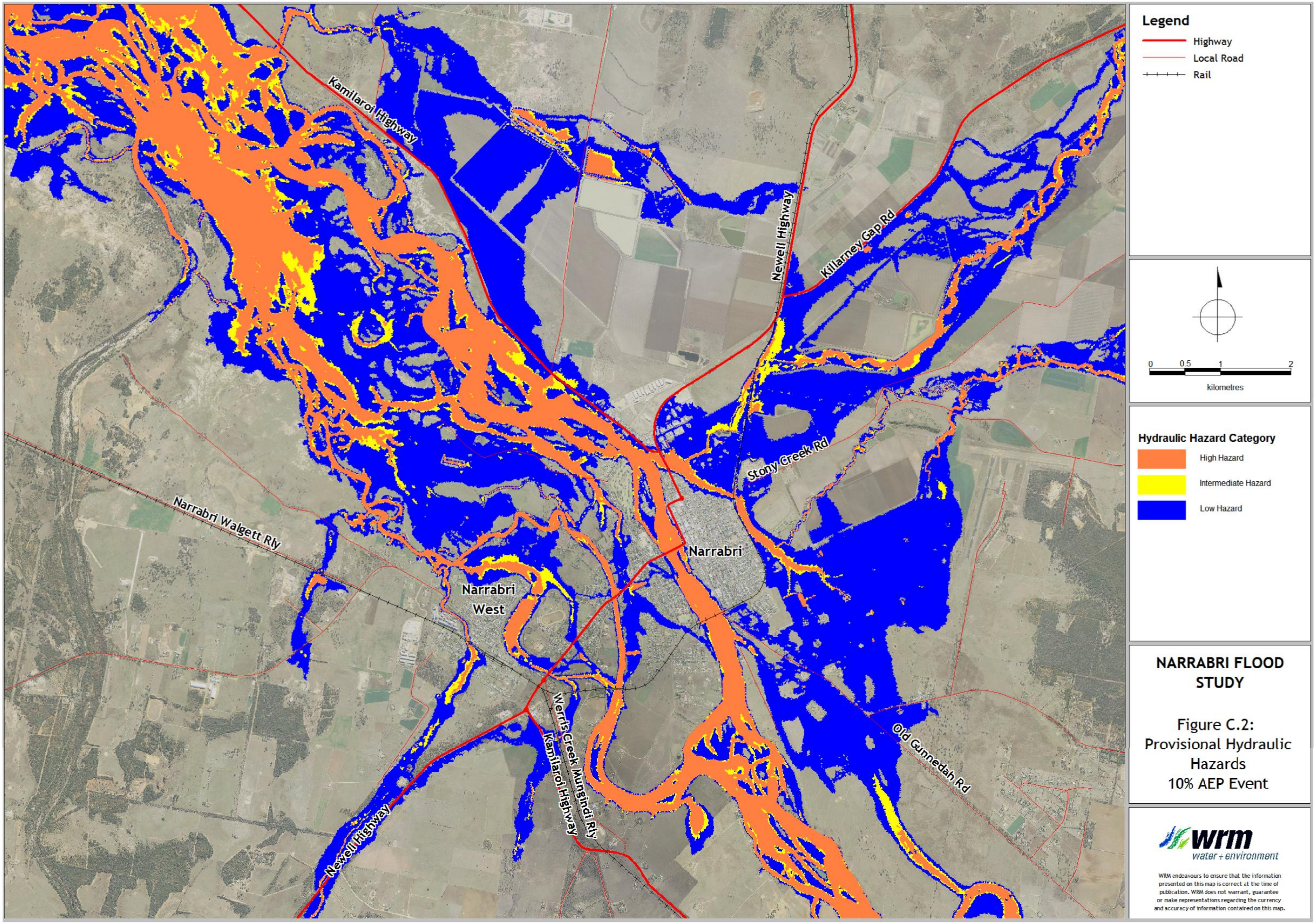
Appendix C - Provisional hydraulic hazard mapping



NARRABRI FLOOD STUDY

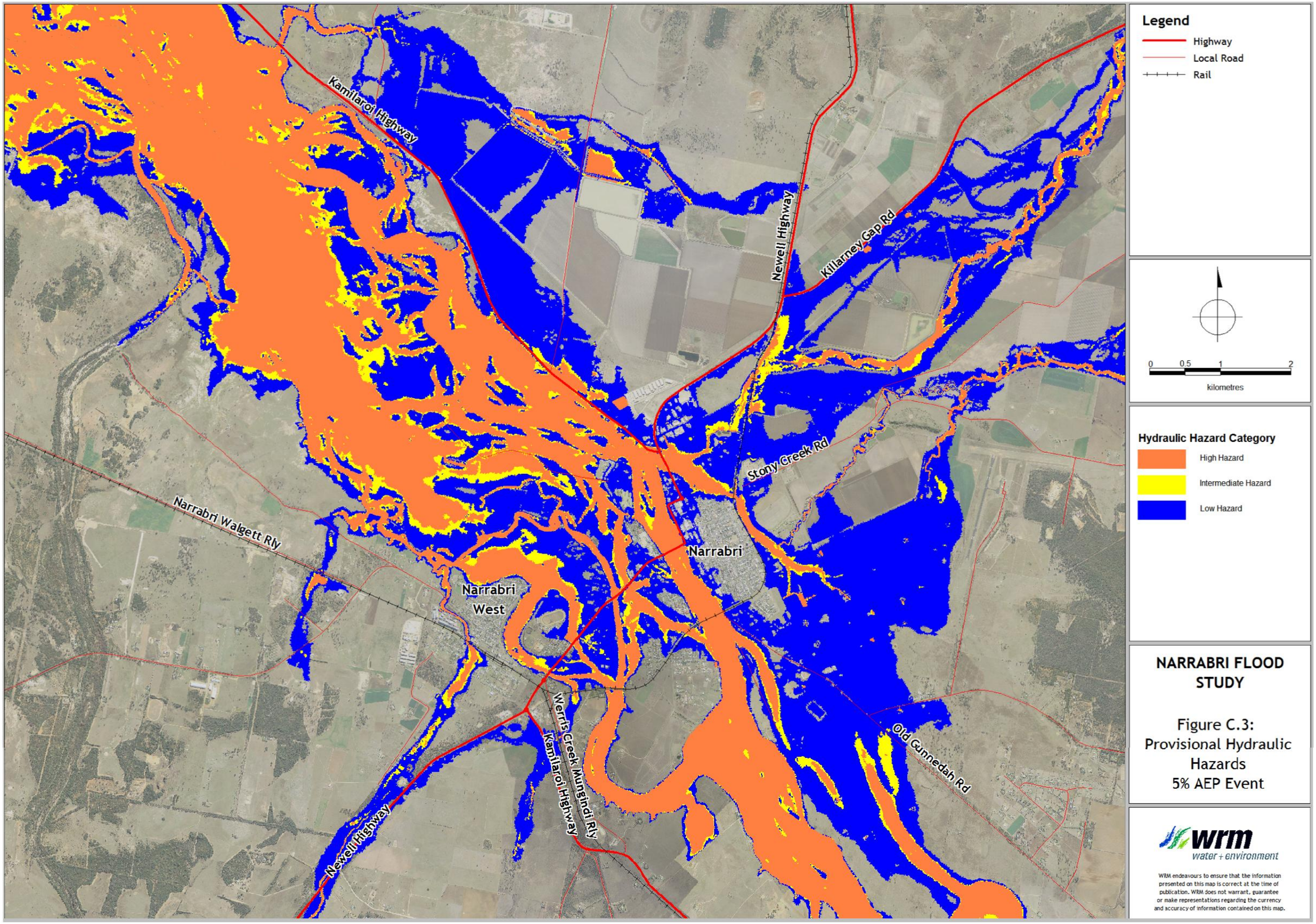
Figure C.1: Provisional Hydraulic Hazards 20% AEP Event

wrm water + environment



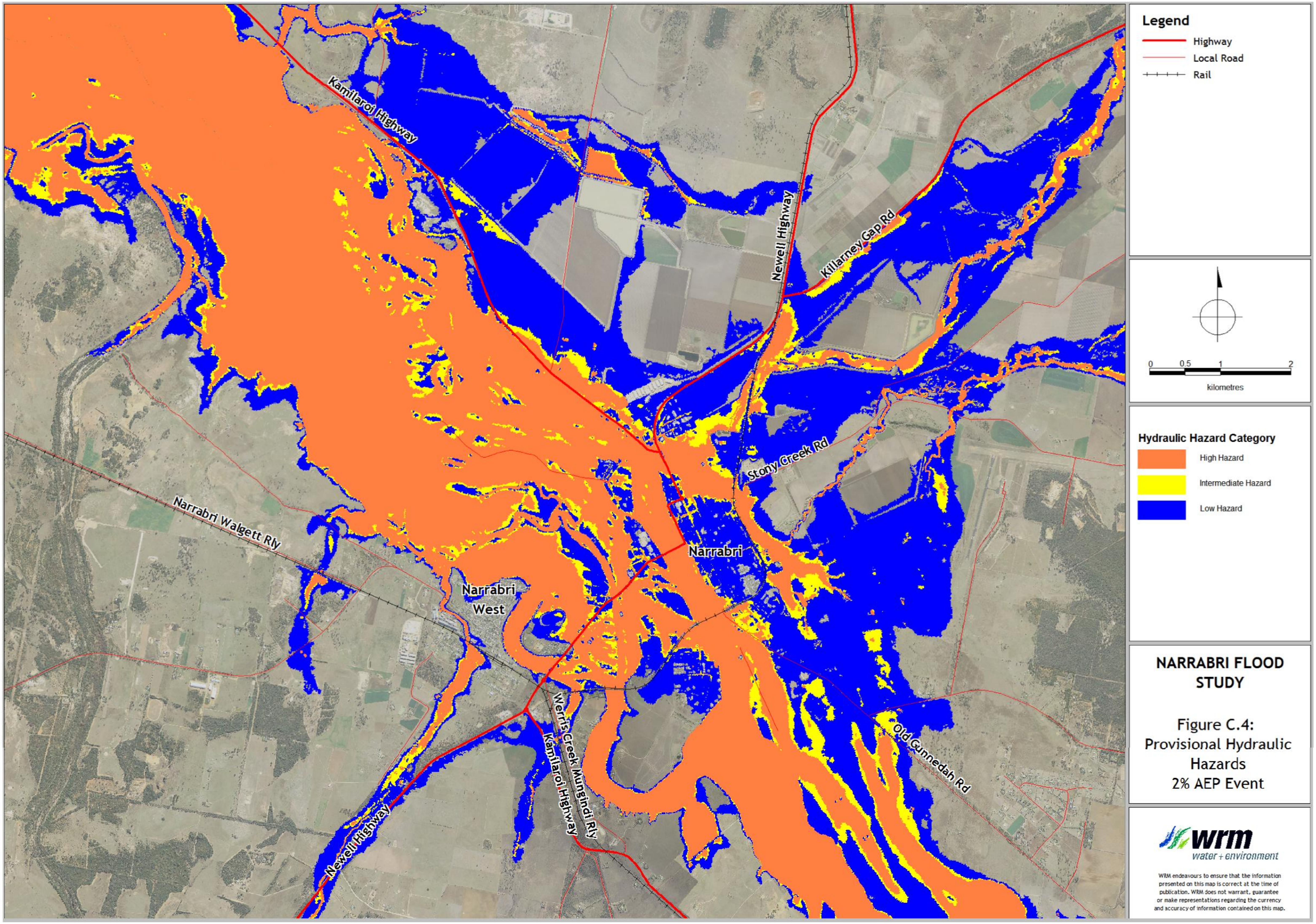
NARRABRI FLOOD STUDY

Figure C.2: Provisional Hydraulic Hazards 10% AEP Event



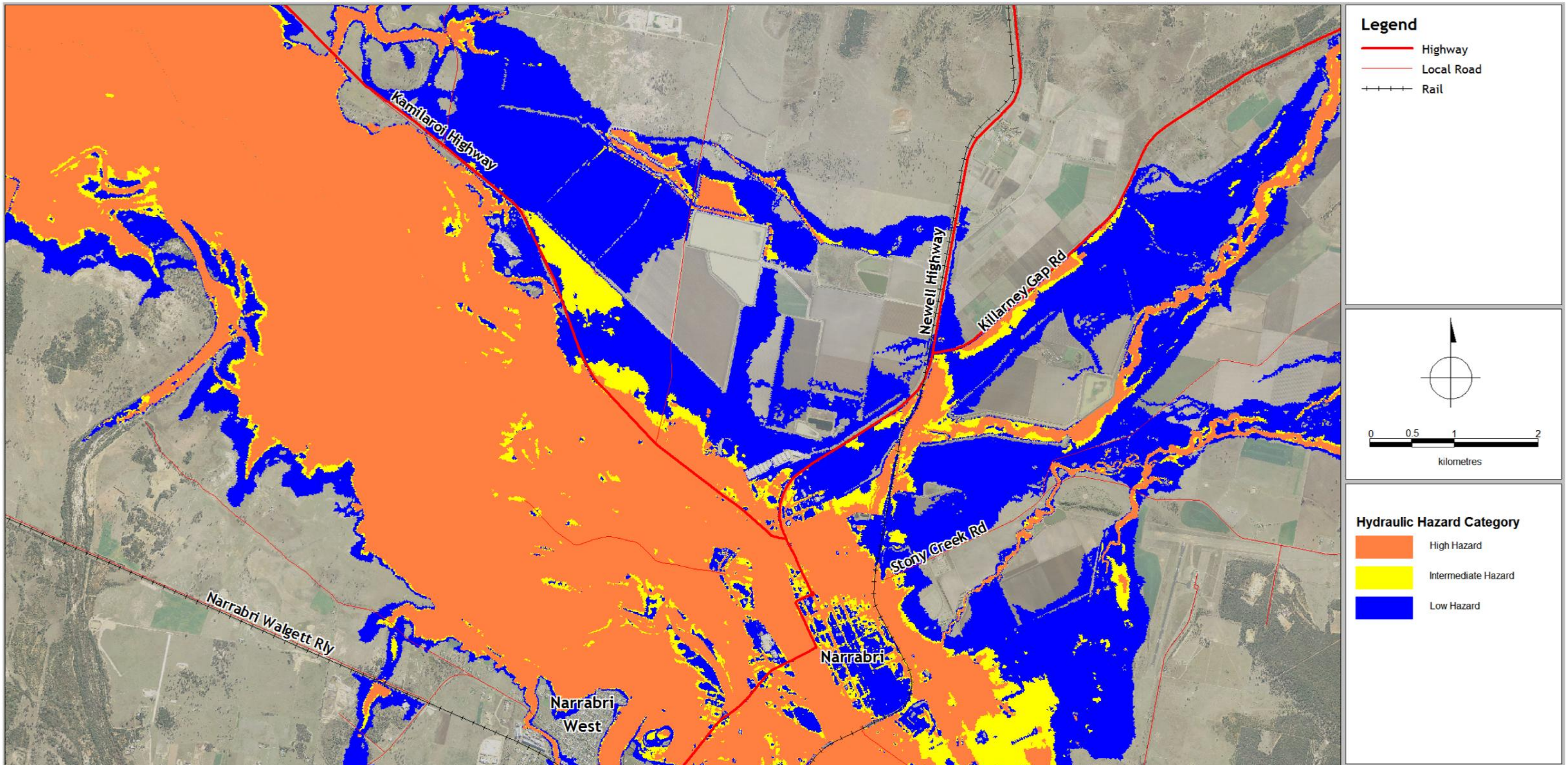
NARRABRI FLOOD STUDY

Figure C.3: Provisional Hydraulic Hazards 5% AEP Event



NARRABRI FLOOD STUDY

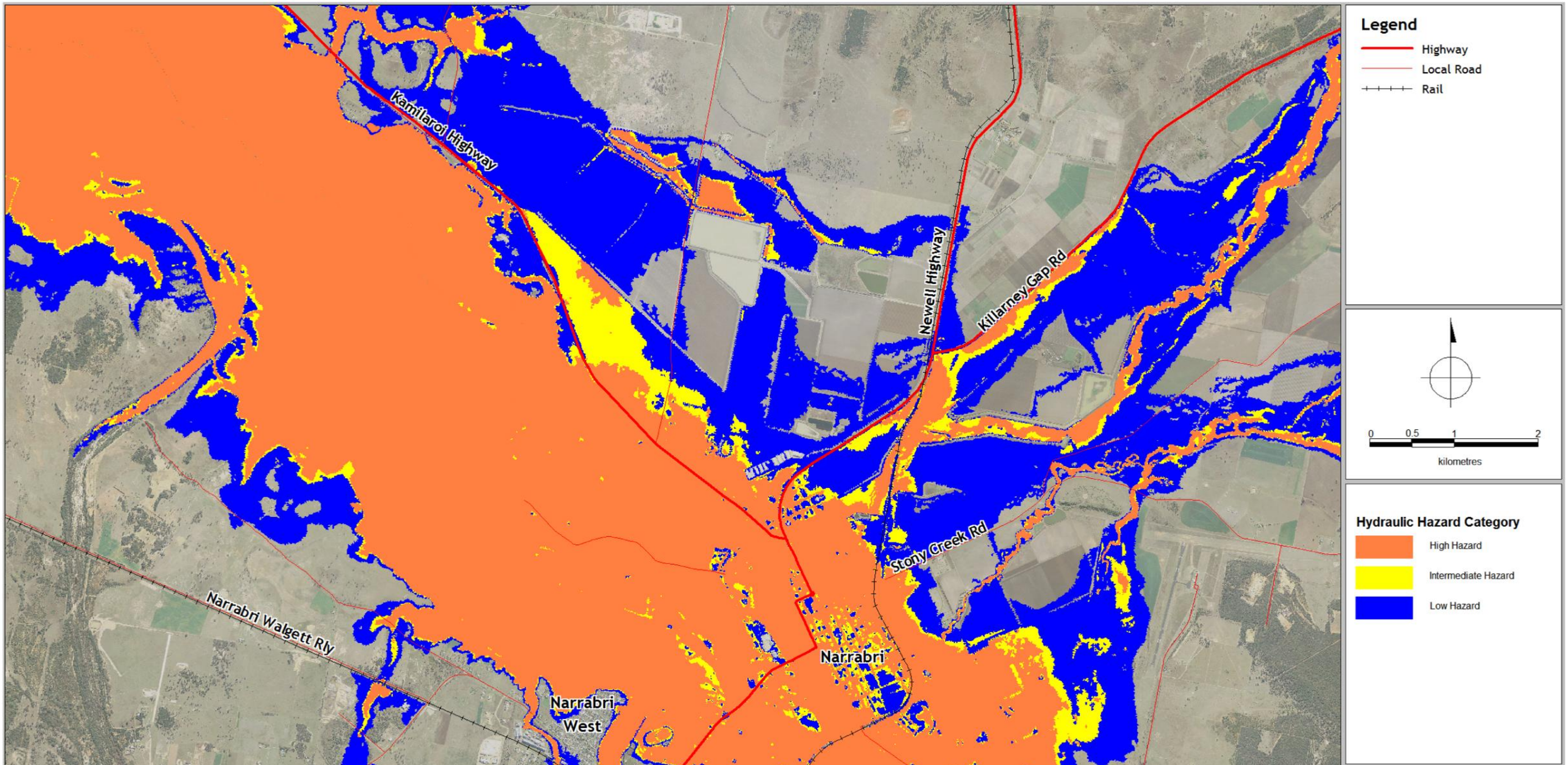
Figure C.4:
Provisional Hydraulic
Hazards
2% AEP Event



NARRABRI FLOOD STUDY

Figure C.5: Provisional Hydraulic Hazards 1% AEP Event

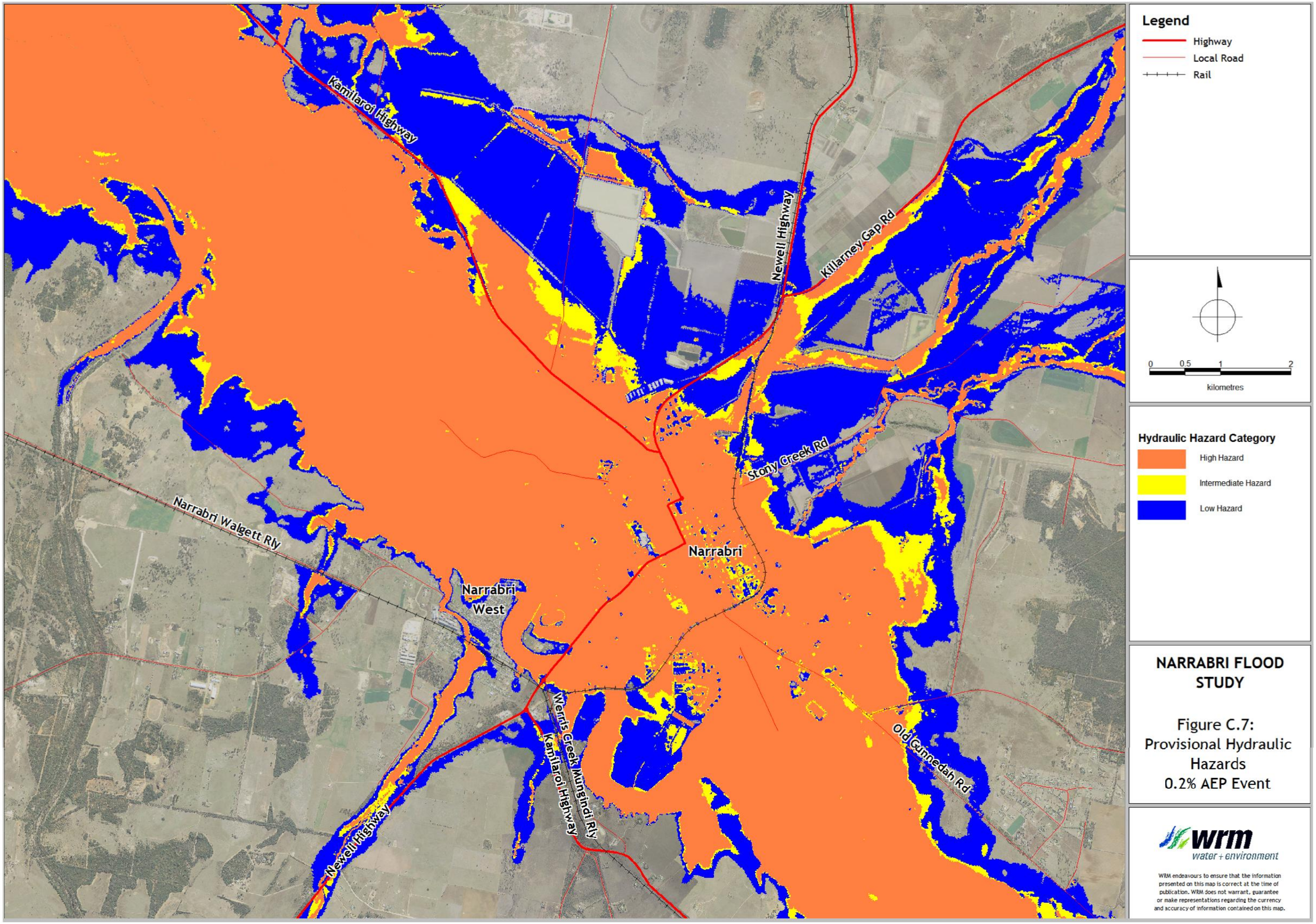
wrm water + environment



NARRABRI FLOOD STUDY

Figure C.6:
Provisional Hydraulic Hazards
0.5% AEP Event

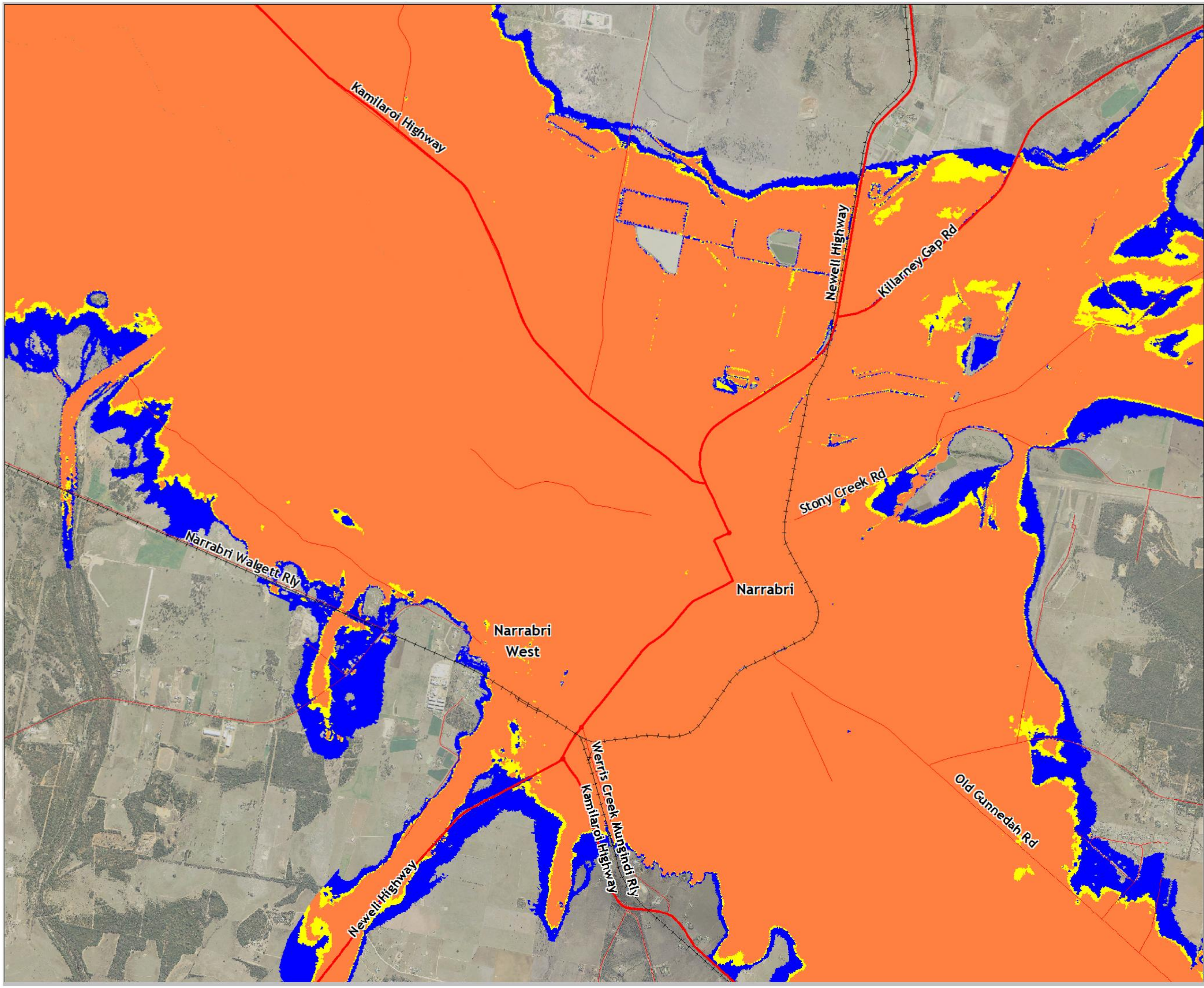
wrm water + environment



NARRABRI FLOOD STUDY

Figure C.7:
Provisional Hydraulic Hazards
0.2% AEP Event

wrm water + environment



Legend

- Highway
- Local Road
- Rail

0 0.5 1 2
kilometres

Hydraulic Hazard Category

- High Hazard
- Intermediate Hazard
- Low Hazard

NARRABRI FLOOD STUDY

Figure C.8: Provisional Hydraulic Hazards Extreme Event

wrm water + environment