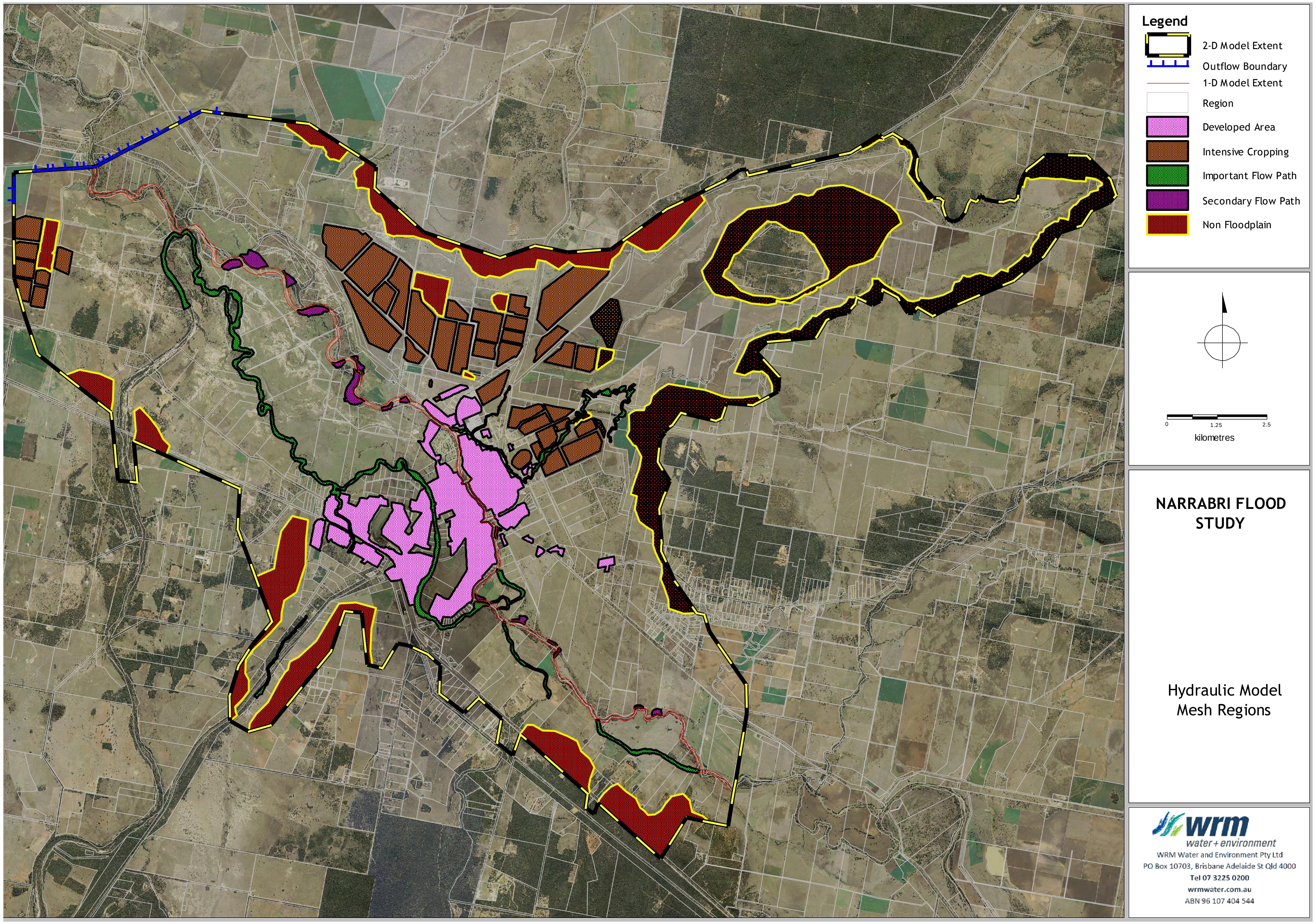

Figure 4.2 - MIKE-21FM mesh regions

- The secondary flow path regions have been applied around breakouts from the 1-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 different Manning's roughness value areas.
- 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 1-D and 2-D 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.

4.3.2 Manning's 'n' values

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 4.2 shows the adopted Manning's 'n' values used in the model and Figure 4.3 shows the locations of the Manning's 'n regions.

Table 4.2 - Manning's n parameters

Region	Manning's 'n' Value
Floodplain	0.080
Flood channel	0.045
Open water/airport	0.030
Buildings	0.300
Road/rail	0.025

4.3.3 Model boundaries

Figure 4.1 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.

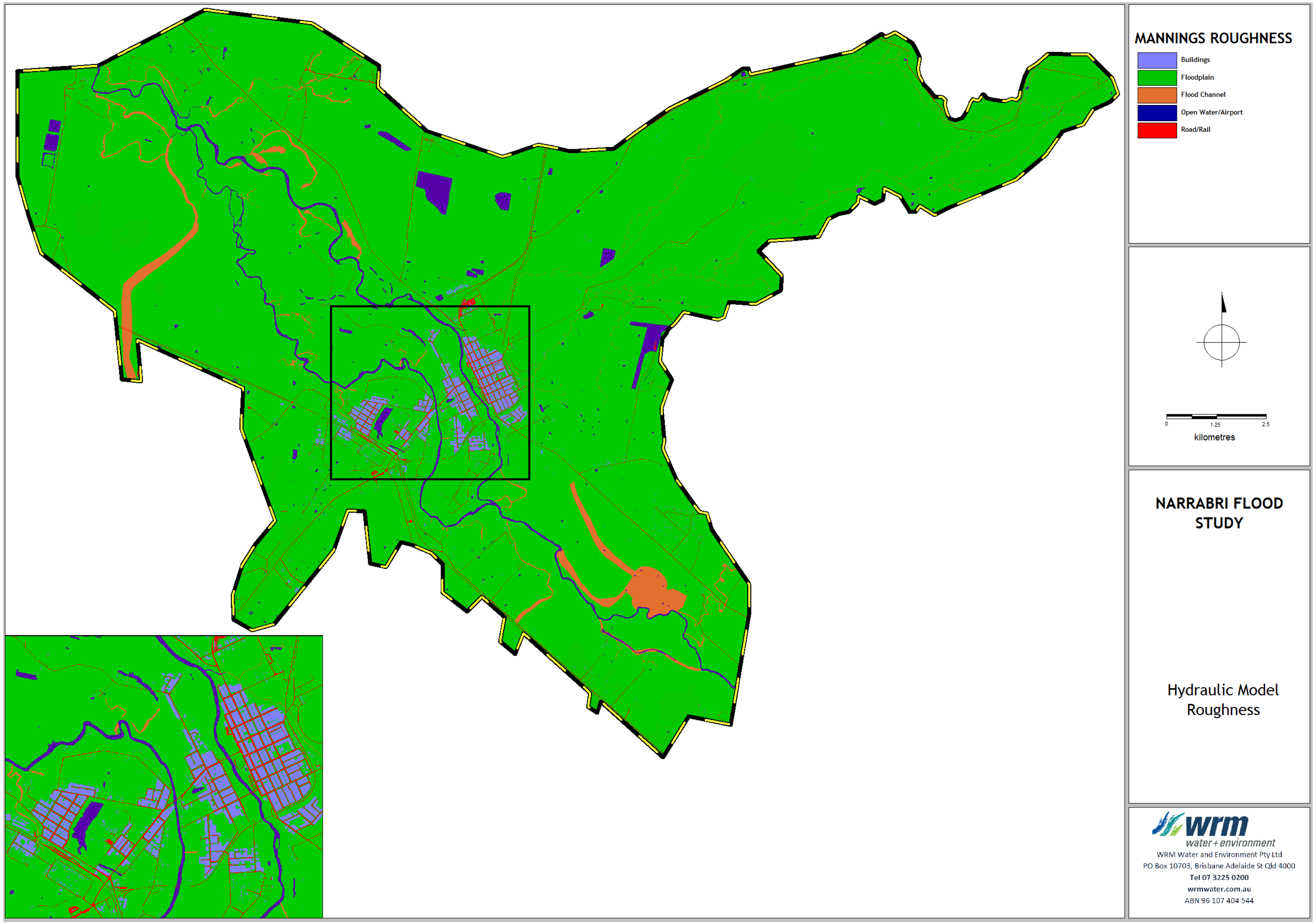

Figure 4.3 – Manning's roughness distribution

A total of 15 outflow boundaries were used at the downstream end of the model. The 14 outflow boundaries in the 2-D domain were specified as Q-H rating curves derived using separate HEC-RAS models. The 1-D 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 @ 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 Section 5.2.1.

4.3.4 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 4.3.

Table 4.3 – Adopted MIKE modelling parameters

Model Parameter	Adopted Value
MIKE Software Version	2014 Service Pack 3
MIKE-FLOOD	
Momentum conservation through couples	Yes
Standard link smoothing factor	0.30 - 0.40
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	0.01 m
Flooding depth	0.05 m
Wetting depth	0.10 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

4.3.5 Bridge, culvert and levee structures

The bridge and culvert structures were modelled within the 1D (MIKE-11) numerical scheme. Details of the bridge and culvert structures included in the study area are given in Table 4.4. The remaining hydraulic structures within the study area were deemed to be too small to affect flood levels or the distribution of flow.

Table 4.4 - Culvert and bridge details

MIKE Name	Road/Rail Crossing	Dimension[a]	U/S Invert (mAHD)	D/S invert (mAHD)	Length (m)	Source
K Hwy 01	Kamilaroi Hwy	1 RCP 0.525	210.05	210.04	13.50	WRM Inspection
K Hwy 05	Kamilaroi Hwy	4 Box 0.9x1.8	209.09	209.08	9.60	RMS Structure Plan
K Hwy 25	Kamilaroi Hwy	4 Box 1.2x2.4	213.52	213.51	9.60	RMS Structure Plan
Misc 03	Stoney Creek Rd	3 Box 1.8x2.75	220.10	220.09	9.60	NSC Spreadsheet
Misc 14	Old Cemetery Rd	3 Span	208.23	209.31	5.20	Detailed Survey
Misc 19	Namoi St	3 Box 1.8x2.44	207.45	207.44	7.00	NSC Spreadsheet
Misc 22	Saleyards Ln	2 Box 0.6x0.4	211.60	211.59	10.00	WRM Inspection
Misc 36	Old Turrawan Rd	3 Box 1.3x0.9	212.20	212.19	10.00	WRM Inspection
Misc 40	Violet St	4 span	200.80	200.70	11.00	NSC Structure Plan
Misc 45	Ugoa St	3 Box 1.8x0.9	209.85	209.84	10.00	WRM Inspection
Misc 53	Yarrie Lake Rd	2 Box 2.1x2.1	208.58	208.51	7.96	Detailed Survey
Misc 54	Mooloobar St	2 span	210.49	210.27	14.20	Detailed Survey
Misc 80	Gould Street	4 Box 1.2x0.75	211.21	211.20	10.00	WRM Inspection
Misc 86	Ugoa Street	3 Box 1.8x0.9	209.9	209.89	10.00	WRM Inspection
N Hwy 01	Newell Hwy	4 Box 2.4x1.2 2 Box 2.4x1.35	217.55	217.54	16.00	WRM Inspection
N Hwy 02	Newell Hwy	1 Tunnel	213.39	217.28	61.50	RMS Structure Plan
N Hwy 03	Newell Hwy	1 Span	215.58	215.57	10.20	RMS Structure Plan
N Hwy 06	Newell Hwy	1 RCP 1.05	211.05	211.04	25.00	WRM Inspection
N Hwy 07	Newell Hwy	2 Box 2.1x2.1	210.00	209.99	28.50	-
N Hwy 08	Newell Hwy	5 Span	206.00	206.00	9.4	RMS Structure Plan
N Hwy 09	Newell Hwy	2 Box 2.1x2.1	210.20	210.19	19.00	-
N Hwy 10	Newell Hwy	7 Span	201.54	201.89	13.2	RMS Structure Plan
N Hwy 13	Newell Hwy	9 Span	210.88	210.88	18.00	RMS Structure Plan
N Hwy 14	Newell Hwy	4 Span	210.13	210.13	13.85	RMS Structure Plan
N Hwy 29	Newell Hwy	2 Box 1.2x0.6	218.90	218.89	17.00	WRM Inspection
N Hwy 30	Newell Hwy	4 Box 3.2x1.8	218.45	218.44	17.50	WRM Inspection
Rail 01	Werris Creek Mungindi Railway	30 CMP 0.6	217.57	217.56	10.00	WRM Inspection
Rail 02	Werris Creek Mungindi Railway	1 CMP 1.2	217.55	217.54	7.50	WRM Inspection
Rail 05	Werris Creek Mungindi Railway	23 Box 0.9x3.8	214.62	214.61	5.00	URS Model
Rail 06	Werris Creek Mungindi Railway	9 Span	208.53	208.69	2.60	Detailed Survey
Rail 07	Werris Creek Mungindi Railway	12 Span	202.03	202.07	4.50	NSC Structure Plan
Rail 08	Werris Creek Mungindi Railway	15 Box 2.74x4.98	212.31	212.32	8.00	Detailed Survey
Rail 10	Werris Creek Mungindi Railway	28 Span	205.64	205.64	5.50	NSC Structure Plan
Rail 12	Werris Creek Mungindi Railway	4 Box 2.56x4.8	210.90	210.88	4.42	Detailed Survey
Rail 15	Narrabri West Walgett Railway	5 CMP 2.1	210.88	210.87	7.20	WRM Inspection
Rail 24	Werris Creek Mungindi Railway	2 Box 1.95x2.95	212.47	212.23	6.70	Detailed Survey

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

Those structures that weren't explicitly modelled 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 2-D domain.

5 Model calibration

5.1 OVERVIEW

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

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

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.

5.2 REGIONAL FLOODING

5.2.1 Historical peak discharge review

The review of the stream flow rating curves at Narrabri, discussed in Section 2.3, shows that the hydraulic model was able to replicate the Narrabri Creek at Narrabri (GS419003) gauge rating curve but could not replicate the Namoi River at Narrabri (GS419002) gauge when using the same parameters, particularly for the high flows. Using the same Manning's 'n' values across the floodplain, the hydraulic model predicted much higher flow peaks at the Namoi gauge than the DPI Water rating (see Figure 2.2).

It was not possible to assign reasonable Manning's 'n' values for the overbank areas to calibrate the model to the Namoi River at Narrabri gauge and be consistent at the Narrabri Creek gauge for high flows. It was also not possible to assign reasonable Manning's 'n' values for the overbank areas to calibrate the model directly to the Namoi River gauge for high flows (ignoring the Narrabri Creek calibration). There have been no physical measurements of the Namoi River and its associated floodplain to derive the DPI Water rating curve above a flow of 500 m^3/s and therefore this curve is an estimate above this flow rate. On this basis, an adjustment to the high flow rating at the Namoi River at Narrabri gauge based on the hydraulic model would appear to better represent the high flows than the estimate made by DPI Water.

Figure 5.1 shows the rating curve adopted to derive high flows at Narrabri based on the Narrabri Creek at Narrabri water levels. The curve is based on the hydraulic model calibration results above 7.8 m gauge height and combines the flows across the entire floodplain, including the Namoi River flows. A combined curve was used because the Namoi River at Narrabri gauge has been discontinued.

It also became apparent that there was an inconsistency between the combined peak discharge estimate at the two Narrabri gauges and the Mollee gauge using the DPI Water gaugings. Table 5.1 shows the peak discharge estimates at the Mollee gauge and the two Narrabri gauges (using the DPI Water ratings) for the three historical regional calibration events. Although the reduction in peak flood discharges between the Narrabri and Mollee (due to attenuation and losses etc.) is reasonable for the 1955 event (6% reduction), the reductions were 25% for the 1971 event and 31% for the 1998 event.

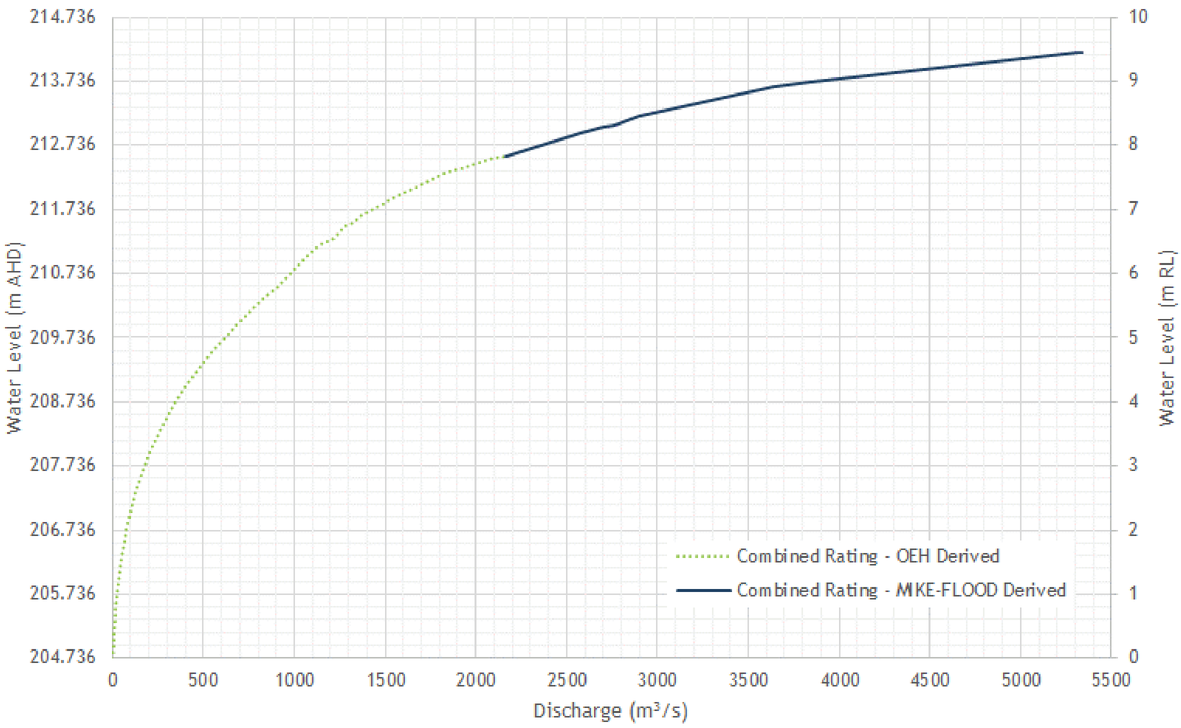

Figure 5.1 – Adopted combined high flow rating curve Narrabri Creek at Narrabri (GS419003)

Table 5.1 - Historical peak discharges at DPI Water gauges, 1955, 1971 and 1998 events

Year	Peak Discharge (m^3/s)					
	Namoi - 419002 (DPI Water rating)	Narrabri- 419003 (DPI Water rating)	Namoi + Narrabri combined (DPI Water rating)	Namoi + Narrabri combined (Figure 5.1)	Mollee - 419039 (DPI Water rating)	Mollee (Figure 2.4)
1955	1,015	2,882	3,897	5,335	3,646	4,767
1971	819	2,356	3,176	3,618	2,396	3,460
1998	643	1,756	2,399	2,408	1,652	2,340

These differences are even more significant if the combined curve in Figure 5.1 is used to derive flows at the Narrabri gauge. The peak discharge decreases by between 31% and 34% between the gauges for the three events when using this curve. Given the short distance between the gauges (12 km) and the fact that these differences could not be replicated by the hydraulic model, it was clear that the Mollee gauge also required adjustment for high flows. The adopted peak discharges at Narrabri (based on Figure 5.1) and at Mollee (based on the MIKE-FLOOD curve in Figure 2.4) for the historical events is shown in Table 5.1.

5.2.2 Historical flood inflows

No hydrologic modelling was undertaken for regional flood modelling. For calibration of regional flood events peak inflows were determined in an iterative manner. Combined discharges at the Namoi River and Narrabri Creek streamgauges were input into the upstream boundary of the hydraulic model (allowance was made for peak attenuation by slightly increasing the peak flow from town). The observed hydrographs at the Narrabri

Creek gauging station were adjusted to produce the inflow discharge applied at the upstream boundary of the hydraulic model.

5.2.3 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 0.02 m with 80th percentile values between 0.14 m low and 0.1 m high. There are two levels along Eathers Creek near the Newell Highway where the model predictions are 0.60 m and 0.34 m low. There are also two levels immediately downstream of Narrabri Township (along the Kamilaroi Highway and Lagoon Creek) that are 0.34 m and 0.48 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.

5.2.4 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 0.01 m with 80th percentile values between 0.16 m low and 0.13 m high.

5.2.5 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 2014 LiDAR, which prevents this area being inundated during this event. Note that predicted flood levels would only have to be about 0.05 m higher to inundate this area as shown in the aerial photograph. Overall a good calibration has been achieved for the July 1998 flood.

5.3 LOCAL FLOODING

5.3.1 Overview

For the local catchments, there is no recorded stream flow for the local flooding events to calibrate the XP-RAFTS and MIKE-FLOOD models. For these events, anecdotal information on flood behaviour was obtained through a community survey in 2016 for the December 2004 and February 2012 historical flood events. Both of these events caused significant damage and disruption to the community. A total of 33 responses were received from the community survey.

The hydrological and hydraulic models were calibrated using an iterative process whereby the XP-RAFTS model produced hydrographs based on the available rainfall data, and the MIKE-FLOOD model produced peak flood levels using these hydrographs. The MIKE-FLOOD calibration parameters determined for the regional events have been adopted for the local events. The predicted peak flood levels were then compared to the anecdotal water level data obtained from the community consultation process and the available photographs of the event. The XP-RAFTS and MIKE-FLOOD parameters were iteratively adjusted to achieve the best possible fit to the available peak flood level data. The final calibration parameters were adopted for both local and regional events.

Peak flood level and rainfall data were available for the December 2004 and February 2012 local rainfall events. In addition, OEH provided oblique aerial photographs of the 2004 event. These events were selected for local catchment model calibration to cover the two largest events that have occurred in the catchment over the past 20 years. Both short duration and daily pluviograph rainfall stations in and near the catchment were used for model calibration. The locations of these rainfall stations are shown in Figure 1.1.

5.3.2 December 2004 event

5.3.2.1 XP-RAFTS modelling

Table 5.2 shows the daily rainfalls recorded at five rainfall stations in the vicinity of the study area over the four days to 0900 hours on 12 December 2004. Significant rainfalls were recorded over this period with the highest falls occurring in the 24 hours to 0900 hours on 10 December 2004.

Anecdotal rainfall data was also available at two properties in the vicinity of the Long Gully catchment for this event. URS (2011) interviewed a number of rural property owners and found that daily rainfalls of between 163 mm and 195 mm on 10 December 2004 were recorded around Long Gully. The anecdotal data has not been used in the assessment as there is some uncertainty as to how the data was collected and exactly where the stations are located. However, it suggests that catchment rainfalls in areas of Long Gully may have been higher than the official data for this event.

Figure 5.2 shows the recorded hourly rainfalls at the Narrabri Airport AWS during the event. This was the only station that recorded sub daily rainfall in the study area at this time. The most intense rainfalls at this station were concentrated over an 18 hour period for this event. A comparison of recorded rainfalls to design rainfalls obtained from Australian Rainfall and Runoff (IEAUST, 1998) suggests that rainfalls of 12 to 24 hours duration at this station had an annual exceedance probability (AEP) of about 4% (25 years annual recurrence interval (ARI)). It is likely that the rainfalls at the two Narrabri and Mount Kaputar rainfall stations were more severe than this, given that higher daily totals were recorded at these stations, than at the Narrabri Airport AWS station.

For XP-RAFTS modelling, each XP-RAFTS subcatchment was assigned the total daily rainfall recorded at the nearest rainfall station but distributed on an hourly basis using the Narrabri Airport AWS rainfall pattern. The Narrabri Bowling Club data was not used as it did not record rainfall on 10 December.

An initial loss of 10 mm and a continuing loss of 2.5 mm/hr were adopted for the simulation based on the model calibration results. Antecedent rainfall conditions were moderately wet prior to the January 2004 event with 47 mm recorded at the Narrabri West Post Office gauge in the four days prior to 10 December.

Table 5.2 – Recorded daily rainfalls for the December 2004 event

Station name	Station No.	Daily rainfall (mm) to 0900 hours			
		9 Dec	10 Dec	11 Dec	12 Dec
Narrabri West Post Office	53030	-	159.0	31.0	0.0
Narrabri Bowling Club	54120	0.6	-	160.4	1.0
Narrabri (Mt Kaputar)	54151	2.0	166.0	49.6	0.4
Narrabri (Murrumbilla)	54149	0.2	116.4	43.0	0.8
Narrabri Airport AWS	54038	0.2	125.2	27.4	1.0

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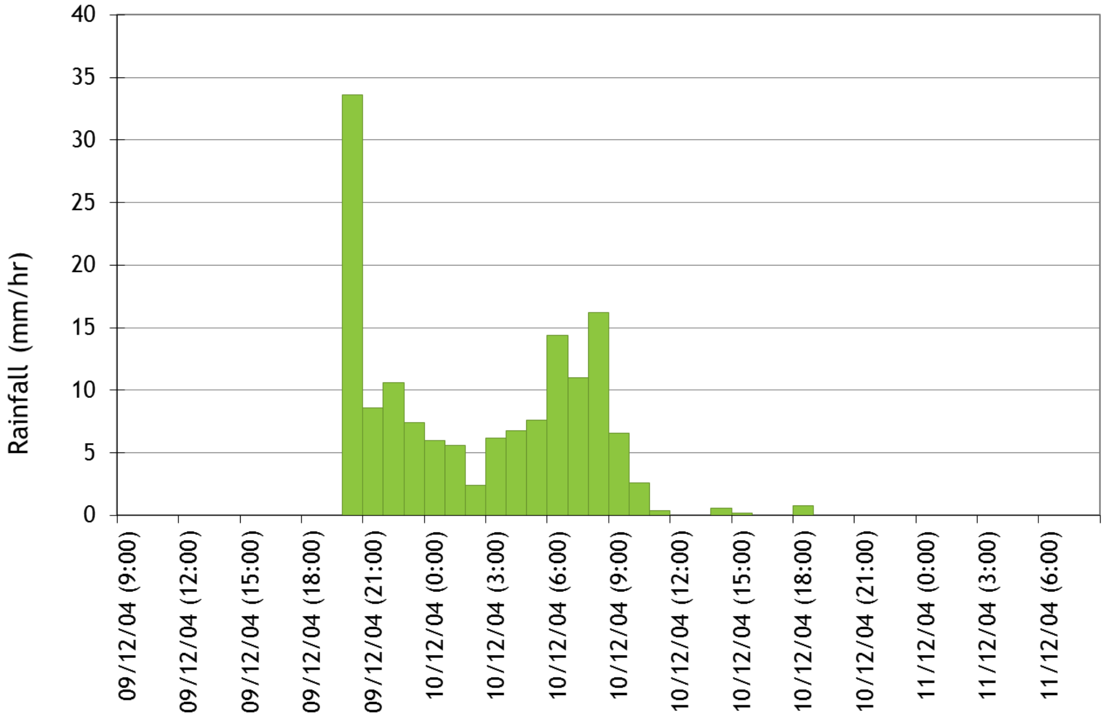

Figure 5.2 – Recorded hourly rainfalls at Narrabri Airport AWS, December 2004 event

5.3.2.2 MIKE-FLOOD modelling

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 stream flows at the Narrabri gauge (GS419003) were used to represent the Namoi River/Narrabri Creek flow that occurred during the event. The peak Namoi River flow during the 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.