Figure 5.3 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 Walgett Rail (Burt St reporting location – see Figure A.6).

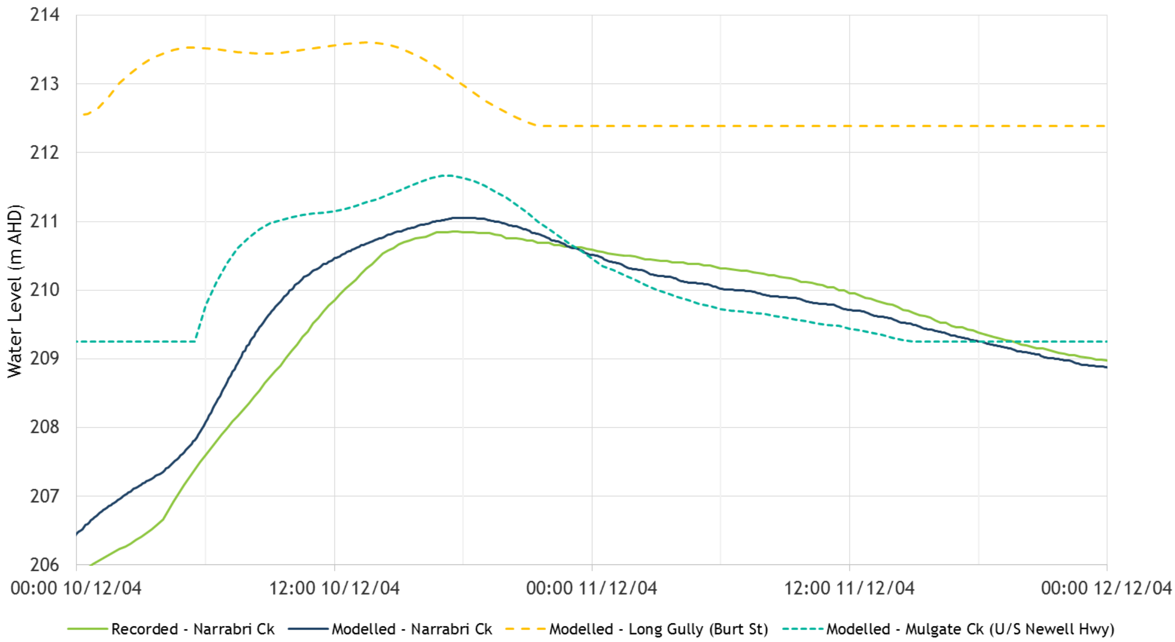

Figure 5.3 – Recorded and predicted water level hydrographs, December 2004 event

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 5.3 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 5.4 and Figure 5.5. The model well represents flooding upstream of the rail (see Figure 5.4) and slightly overestimates the flood extent along Mulgate Creek downstream of the rail (see Figure 5.4 and Figure 5.5). The model could not reproduce the flooding at reporting locations 10, 13, 14, 22 and 23.

The modelling of Long Gully appears to support the available anecdotal flood information. There was 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 shown. However, no information was available as to why the SES were called out to these locations. Given that the URS (2011) study reports much higher anecdotal rainfalls in the upper catchment of Long Gully, the model predictions along Long Gully for the 2004 event look reasonable.

Table 5.3 – Comparison of anecdotal flood information and modelling results, December 2004

ID	Anecdotal information	Modelling results	Comment
2	Office and house inundated	Parts of block inundated up to 0.5 m	Consistent
4	House inundated	Parts of block inundated up to 2.5 m	Consistent
5	Paddocks inundated. Breakout locations and detailed account of flooding provided	Surrounding areas 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	Yard inundation averages 0.25 m	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 consistent, no inundation of property	Consistent
13	Yard inundated up to 0.6 m	No inundation of property. Model predicts 0.23 m inundation on corner of Denison and Gleeson St adjacent	Inconsistent
14	Yard inundated up to 0.6 m	No inundation of property. Model predicts 0.23 m inundation on corner of Denison and Gleeson St adjacent	Inconsistent
16	Water in street	Inundation in street and inundation into property up to 0.1 m	Consistent
17	Yard inundated up to 0.02 m	Inundation in street and inundation into property up to 0.1 m	Consistent
18	Yard inundated up to 0.08 m	Inundation in adjacent street and at rear but doesn't enter property	Consistent
19	Flood water present for more than 5 hours	Water in street for more than 5 hours	Consistent
21	Yard inundated up to 0.4 m	Inundated up to 0.3 m	Consistent
22	Yard inundated up to 0.4 m	No inundation of property. Street inundated up to 0.2 m	Inconsistent
23	Yard inundated up to 0.05 m	No inundation of property	Inconsistent
25	Inundation up to 1.0 m	Inundation up to 0.8 m	Consistent
26	Inundation up to 1.0 m	Inundation up to 1.0 m	Consistent
27	Inundation up to 0.5 m	Average inundation at 0.5 m	Consistent
28	Flood water present for more than 5 hours	Inundated for more than 5 hours	Consistent
29	Inundated up to 0.6 m	Inundated up to 0.7 m	Consistent
30	Inundated up to 2.0 m	Inundated up to 2.4 m	Consistent
32	Inundation in street and surrounds	Inundation in street and surrounds	Consistent
33	Inundation up to 0.1 m	Parts of property inundated	Consistent
34	Inundation up to 0.5 m	Inundation up to 0.3 m	Consistent

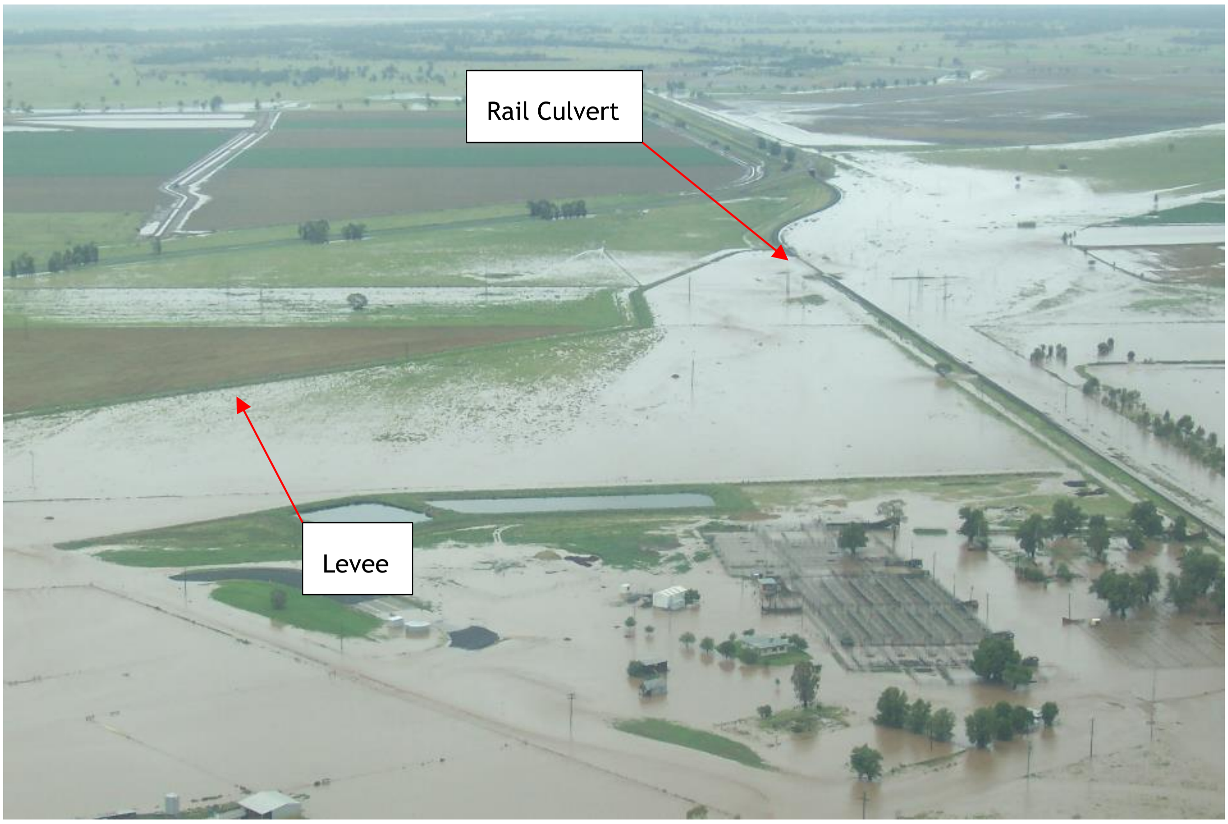

Figure 5.4 – Mulgate Creek flooding at rail line

Figure 5.5 – Mulgate Creek flooding at Francis Street Industrial Estate

5.3.3 February 2012 event

5.3.3.1 XP-RAFTS modelling

Table 5.4 shows the daily rainfalls recorded at five rainfall stations in the vicinity of the study area over the four days to 0900 hours on 3 February 2012. The highest daily rainfall occurred in the 24 hours to 0900 hours on 2 February. Antecedent rainfall conditions prior to the event were also very wet with significant rain falling throughout January 2012.

Table 5.4 - Recorded daily rainfall for the February 2012 event

Station name	Station No.	Daily rainfall (mm) to 0900 hours			
		31 Jan	1 Feb	2 Feb	3 Feb
Narrabri West Post Office	53030	26.2	33.2	128.2	29.0
Narrabri (Mt Kaputar)	54151	52.0	56.0	149.0	26.4
Narrabri (Murrumbilla)	54149	33.2	25.4	182.8	25.0
Upper Horton [a]	54138	97.0	46.4	76.4	21.2
Narrabri Airport [a]	54038	-	-	-	-

- Missing data

Figure 5.6 shows the recorded hourly rainfalls at the Upper Horton rainfall station during this event. The Upper Horton station is located some 67 km to the east-northeast of Narrabri and is unlikely to be truly representative of catchment rainfalls. However, it is the nearest station that recorded sub daily rainfall during this event. The Narrabri Airport AWS station failed during the event. It would appear that the flood event was produced by three storm bursts that occurred over a 36 hour period.

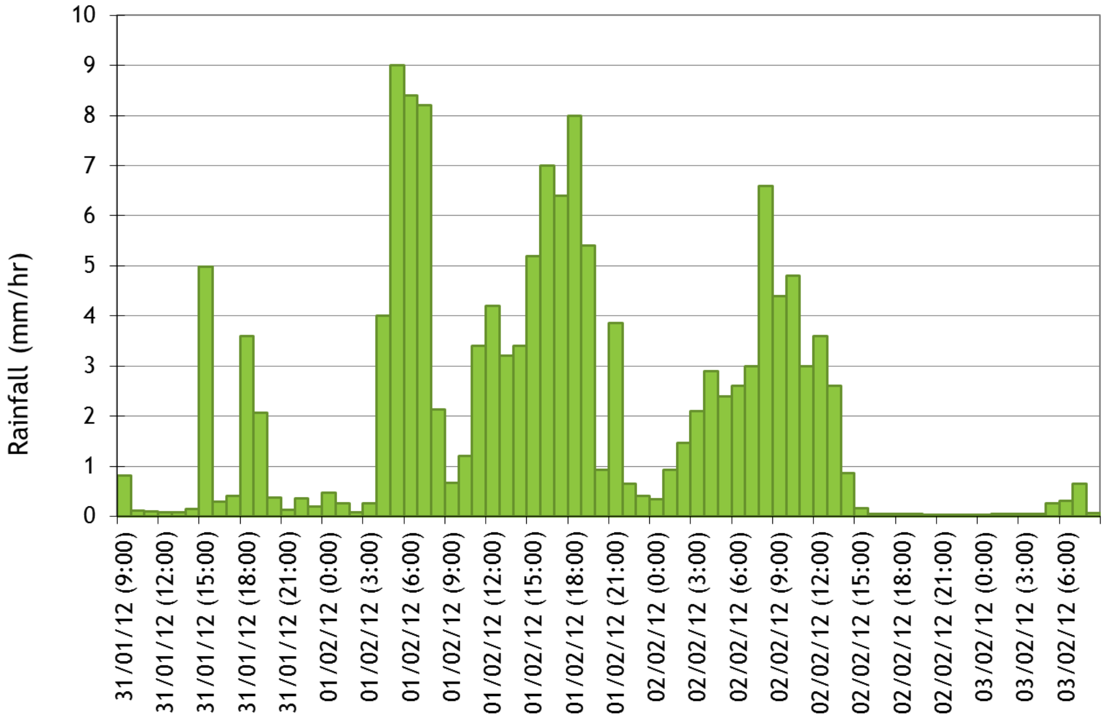

Figure 5.6 - Recorded rainfalls at the Upper Horton rainfall station, February 2012 event

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 Upper Horton rainfall pattern. 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.

5.3.3.2 MIKE-FLOOD modelling

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) gauge flows 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 1,500 m^3/s, which had an AEP of between 10% and 20%.

Figure 5.7 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 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.

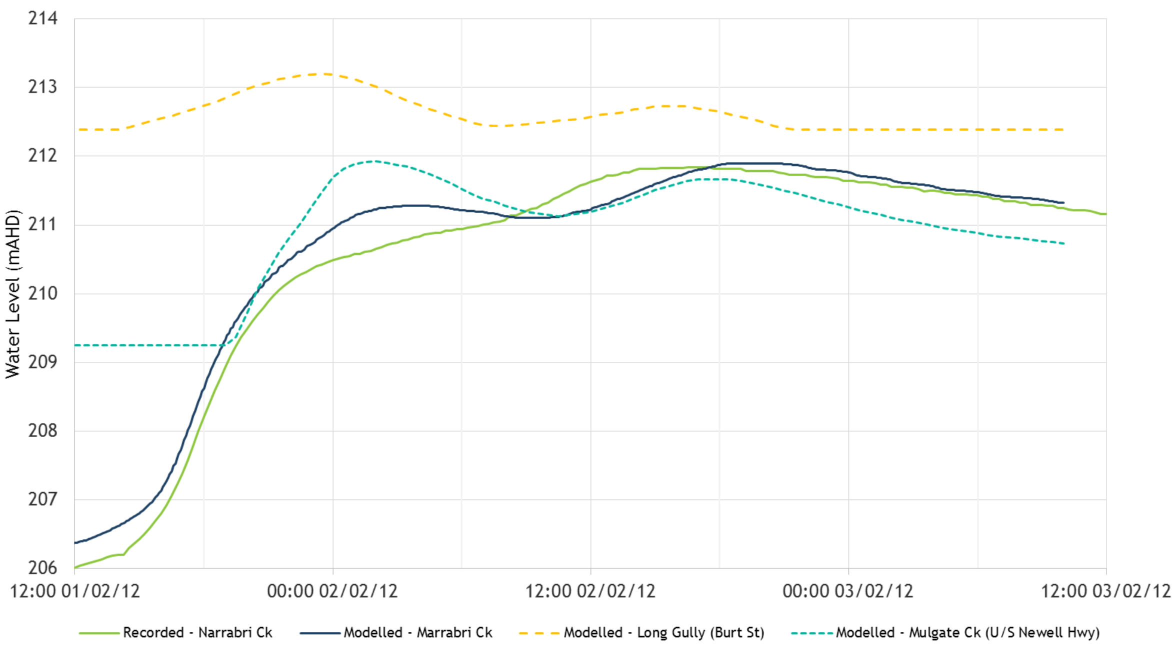

Figure 5.7 - Recorded and predicted water level hydrographs, February 2012 event

Table 5.5 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 5.5 – Comparison of anecdotal flood information and modelling results, February 2012

ID	Anecdotal information	Modelling results	Comment
1	Not inundated	Not inundated	Consistent
2	Office inundated 0.1 m above floor level	Not inundated. Model prediction 0.2 m low	Inconsistent
3	Inundation up to 0.25 m	Inundation to approximately 0.1 m. Model prediction moderately low	Consistent
4	Inundation up to 0.6 m around shed	Most of property inundated to around 0.8 m depth	Consistent
6	Paddocks flooded to many metres depth. Flooding less than 2004	Many paddocks inundated, some to great depth. Flooding less than 2004	Consistent
7	Yard inundated up to 0.3 m depth	Yard inundation up to 0.3 m	Consistent
8	Water up to 1.0 m above road	Goldman St inundated 0.5 m but depth upstream and downstream exceed 1.0 m	Consistent
9	Surveyed peak level - 214.22 mAHD	Predicted peak level - 214.11 mAHD	Consistent
11	Flood water present for more than 5 hours	Duration consistent, no inundation of property	Consistent
12	Flood water present for more than 5 hours	Duration consistent, no inundation of property	Consistent
13	Inundation up to 0.5 m	Inundation 0.1 m. Model prediction low	Inconsistent
14	Inundation up to 0.5 m	Inundation to 0.25 m. Model prediction low	Inconsistent
15	Inundation to floor level	Average inundation to 0.2 m	Consistent
17	Inundation up to 0.3 m	Inundation to 0.25 m	Consistent
18	Inundation up to 0.3 m	Inundation to 0.2 m	Consistent
19	Flood water present for more than 5 hours	Duration consistent, property inundated to 0.1 m	Consistent
20	Inundation up to 0.3 m	Inundation to 0.1 m	Consistent
21	Inundation up to 0.3 m	Inundation to 0.15 m	Consistent
22	Inundation up to 0.3 m	Inundation to 0.1 m	Consistent
23	No property inundation	No inundation on property	Consistent
24	Inundation up to 0.3 m	Inundation to 0.2 m	Consistent
25	Inundation up to 1.0 m	Inundation to 0.9 m	Consistent
26	Inundation up to 1.5 m	Inundation to 1.5 m	Consistent
27	Inundation up to 0.5 m	Inundation to 0.4 m	Consistent
28	Flood water present for more than 5 hours	Duration consistent, property inundated	Consistent
29	Inundation up to 0.6 m	Inundation to 0.55 m	Consistent
30	Inundation up to 1.5 m	Inundation to 1.4 m	Consistent
31	Inundation up to 2.0 m	Inundation to 0.6 m	Inconsistent
32	Inundation in street and surrounds	Inundation in street and surrounds	Consistent
33	Inundation up to 0.2 m	Inundation to 0.2 m	Consistent
34	Inundation up to 0.3 m	Inundation to 0.3 m	Consistent
35	Widespread inundation across site	Almost entire site inundated	Consistent

5.3.4 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 7.3.2 would suggest that Manning's roughness values do not significantly impact on peak levels and therefore other factors are the cause. 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 draft version of the Regional Flood Frequency Estimation (RFFE) approach given in Ball et al. (2016) (see Section 6.2.2).

6 Estimation of design discharges

6.1 REGIONAL FLOODING

6.1.1 General

Design flood discharges for the Namoi River at Narrabri for events up to the 1% 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 the advanced draft update of Australian Rainfall and Runoff (Ball et al, 2016) using the TUFLOW FLIKE software.

6.1.2 Annual series peak discharges

Table 6.1 shows the historical annual peak gauge height levels at the Namoi River at Narrabri (GS419002) and Narrabri Creek at Narrabri (GS419003) stream gauges. The combined discharge derived from the two peak levels is also shown. The process used to define the historical peak levels and discharges was as follows:

- Peak gauge heights at both gauges were obtained from the NSW Government Pinneena database supplemented by information from Kinhill (1991) and Bewsher (1996) for the 1910 and 1955 floods.
- The relationship between the historical peak annual levels at the two gauges, shown in Figure 6.1, was used to define the peak gauge height at the gauge when data was only available at one station. This relationship was used to determine Narrabri Creek levels for the pre 1910 and 1942 to 1959 periods and to determine the Namoi River levels for the post 2000 period (when actual levels were not available).
- Peak discharges at both gauges were determined using the DPI Water curves (see Figure 2.2 and Figure 2.3) when the gauge level was less than 7.8 mRL. Below these levels the DPI Water gauge rating closely resemble the modelled rating. Above these levels, the rating curve shown in Figure 5.1 was used. This change affects the peak discharge estimates for the seven largest floods.

Figure 6.1 shows that there is a strong correlation between the peak water levels at the two gauges for events greater than 6 mRL at the Narrabri Creek gauge with the coefficient of determination (measure of how well the regression line represents the data) of 0.98. A coefficient of determination of 1.0 represents a perfect fit to the data. The correlation is not as strong below this level with a coefficient of determination of 0.78. The weak correlation for the lower events should not impact on the annual series analysis given that the objective of the analysis is to determine design discharges for large events in excess of 6 mRL at the Narrabri Creek gauge.

The results show that the 1955 flood was the highest on record, marginally higher than the 1910 flood. The 1971 flood and 1998 flood were the fourth and tenth largest floods on record, which suggest the selection of calibration events represents a reasonable range of large events at Narrabri. Note that Kinhill (1991) found anecdotal evidence that a flood in March 1864 was 0.15 m higher than the 1910 flood. However Kinhill (1991) did not include this event in their analysis due to a combination of unreliable rating curves and a flood level based only on local reports. As a result of this, the anecdotal 1864 flood has not been used in this analysis. However, it has been assumed that all floods between 1865 and 1910 were lower than the 1955 flood.

Table 6.1 – Combined peak discharges for Narrabri

Year	Peak Gauge Height (mGH)		Peak Discharge (m^3/s)	Year	Peak Gauge Height (mGH)		Peak Discharge (m^3/s)	Year	Peak Gauge Height (mGH)		Peak Discharge (m^3/s)
	Namoi	Narrabri			Namoi	Narrabri			Namoi	Narrabri	
1890	3.96^{P}	3.86^{C}	318	1932	3.51^{P}	2.79^{P}	178	1974	7.95^{P}	8.31^{P}	2,758
1891	N/A	N/A	N/A	1933	5.64^{P}	4.95^{P}	620	1975	2.83^{P}	3.15^{P}	190
1892	7.44^{P}	7.35^{C}	1,673	1934	6.41^{P}	5.79^{P}	886	1976	7.93^{P}	8.50^{P}	2,858
1893	7.54^{P}	7.55^{C}	1,824	1935	5.13^{P}	4.52^{P}	495	1977	6.93^{P}	6.44^{P}	1,139
1894	7.37^{P}	7.22^{C}	1,573	1936	4.58^{P}	4.06^{P}	380	1978	4.80^{P}	4.62^{P}	490
1895	4.78^{P}	4.47^{C}	461	1937	3.48^{P}	3.20^{P}	218	1979	2.15^{P}	2.21^{P}	94
1896	3.61^{P}	3.60^{C}	269	1938	3.91^{P}	3.58^{P}	279	1980	1.00^{P}	1.55^{P}	48
1897	5.26^{P}	4.82^{C}	562	1939	4.12^{P}	3.20^{P}	247	1981	3.80^{P}	3.07^{P}	218
1898	5.54^{P}	5.03^{C}	627	1940	3.97^{P}	3.66^{P}	292	1982	0.88^{P}	1.58^{C}	49
1899	4.14^{P}	3.99^{C}	345	1941	7.14^{P}	6.55^{P}	1,218	1983	3.05^{P}	3.41^{P}	226
1900	N/A	N/A	N/A	1942	7.32^{P}	7.12^{C}	1,505	1984	7.75^{P}	8.26^{P}	2,479
1901	N/A	N/A	N/A	1943	4.22^{P}	4.05^{C}	357	1985	2.49^{P}	3.44^{P}	216
1902	N/A	N/A	N/A	1944	4.63^{P}	4.35^{C}	431	1986	1.54^{P}	3.30^{P}	191
1903	N/A	N/A	N/A	1945	4.40^{P}	4.18^{C}	389	1987	2.26^{P}	3.02^{P}	166
1904	N/A	N/A	N/A	1946	2.85^{P}	3.04^{C}	179	1988	1.89^{P}	3.07^{P}	168
1905	N/A	N/A	N/A	1947	4.91^{P}	4.56^{C}	486	1989	4.70^{P}	5.15^{P}	590
1906	N/A	N/A	N/A	1948	4.50^{P}	4.26^{C}	407	1990	4.42^{P}	4.95^{P}	530
1907	N/A	N/A	N/A	1949	6.68^{P}	5.87^{C}	945	1991	4.10^{P}	4.44^{P}	416
1908	8.00^{N}	8.44^{C}	2,901	1950	7.57^{P}	7.61^{C}	1,871	1992	5.33^{P}	5.50^{P}	713
1909	N/A	N/A	N/A	1951	4.04^{P}	3.92^{C}	330	1993	2.04^{P}	3.30^{P}	194
1910	8.53^{N}	9.44^{N}	5,315	1952	7.22^{P}	6.92^{C}	1,368	1994	0.81^{P}	0.83^{P}	18
1911	N/A	N/A	N/A	1953	2.85^{P}	3.04^{C}	179	1995	2.05^{P}	2.15^{P}	88
1912	1.80^{C}	2.26^{P}	95	1954	4.78^{P}	4.46^{C}	460	1996	4.02^{C}	3.90^{P}	326
1913	5.49^{P}	5.03^{P}	623	1955	8.56^{P}	9.44^{N}	5,336	1997	6.76^{C}	6.03^{P}	998
1914	2.29^{P}	2.89^{P}	154	1956	7.92^{P}	8.29^{C}	2,700	1998	7.87^{C}	8.20^{P}	2,574
1915	5.19^{P}	5.33^{P}	665	1957	1.80^{P}	2.26^{C}	95	1999	3.47^{C}	3.50^{P}	251
1916	7.24^{P}	6.78^{P}	1,318	1958	4.22^{P}	4.05^{C}	357	2000	7.59^{P}	7.81^{P}	2,100
1917	6.71^{P}	5.94^{P}	969	1959	2.77^{P}	2.98^{C}	172	2001	1.19^{C}	1.81^{P}	63
1918	4.58^{P}	3.91^{P}	359	1960	4.04^{P}	4.58^{P}	438	2002	0.89^{C}	1.59^{P}	50
1919	0.92^{P}	2.44^{P}	108	1961	2.24^{P}	2.75^{P}	139	2003	1.77^{C}	2.24^{P}	93
1920	8.31^{P}	8.99^{P}	3,840	1962	6.81^{P}	6.27^{P}	1,071	2004	6.80^{C}	6.12^{P}	1,029
1921	7.77^{P}	7.83^{P}	2,165	1963	4.24^{P}	4.04^{P}	357	2005	4.23^{C}	4.06^{P}	360
1922	4.91^{P}	4.32^{P}	443	1964	7.44^{P}	7.32^{P}	1,649	2006	0.58^{C}	1.36^{P}	38
1923	4.35^{P}	3.58^{P}	302	1965	1.98^{P}	2.44^{P}	110	2007	2.05^{C}	2.45^{P}	111
1924	7.16^{P}	6.73^{P}	1,277	1966	2.54^{P}	2.75^{P}	144	2008	4.72^{C}	4.42^{P}	449
1925	3.13^{P}	2.64^{P}	149	1967	1.27^{P}	1.87^{P}	66	2009	0.95^{C}	1.64^{P}	53
1926	3.30^{P}	3.12^{P}	202	1968	4.80^{P}	4.98^{P}	561	2010	6.18^{C}	5.50^{P}	790
1927	3.28^{P}	4.06^{P}	317	1969	3.56^{P}	3.79^{P}	290	2011	6.42^{C}	5.68^{P}	860
1928	6.02^{P}	5.03^{P}	670	1970	3.66^{P}	3.89^{P}	308	2012	7.31^{C}	7.11^{P}	1,496
1929	4.04^{P}	3.43^{P}	268	1971	8.23^{P}	8.92^{P}	3,637	2013	3.70^{C}	3.67^{P}	282
1930	4.50^{P}	3.88^{P}	350	1972	2.31^{P}	2.36^{P}	107	2014	3.85^{C}	3.78^{P}	302
1931	7.62^{P}	7.64^{P}	1,914	1973	2.85^{P}	3.05^{P}	180	2015	-0.11^{C}	0.85^{P}	19

C = Correlation P = Pinneena N = DPI Water N/A = not available

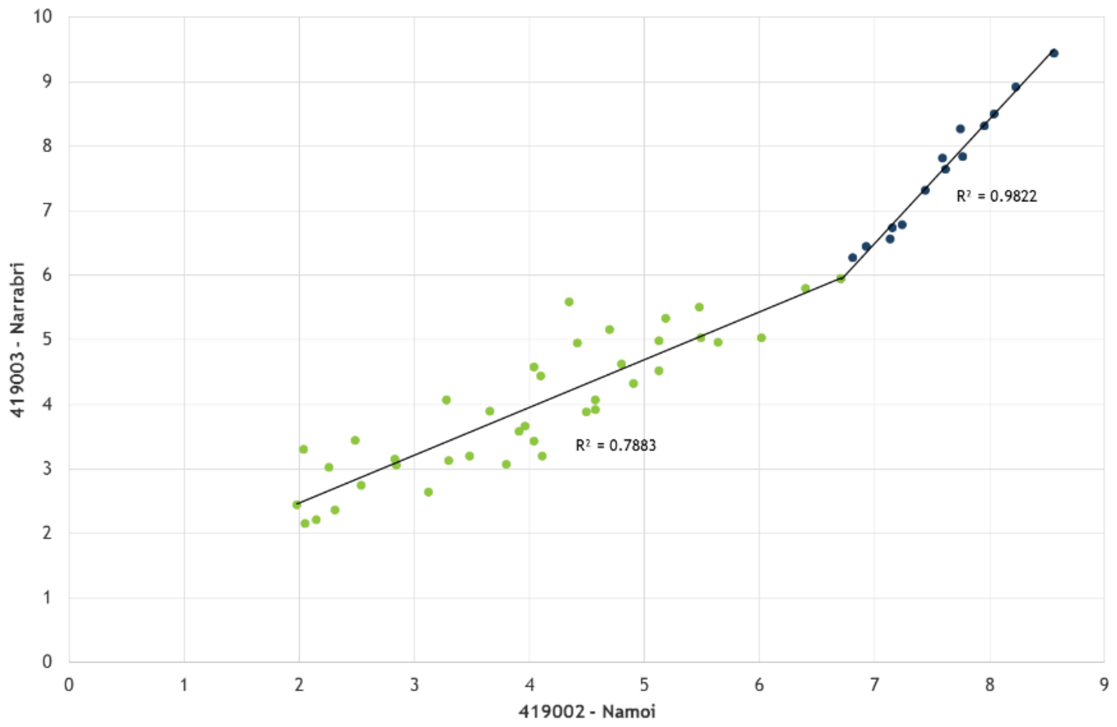

Figure 6.1 – Historical peak water level relationship, Narrabri Creek at Narrabri and Namoi River at Narrabri stream gauges

6.1.3 Flood frequency analysis

The Bayesian Inference approach given in the advanced draft update of AR&R (Ball et al, 2016) has been use to fit an LPIII distribution to the peak annual discharge data given in Table 6.1. This methodology allows the user to more accurately take into account historic data outside the gauged record, as well as the ability to censor data. The analysis was undertaken using the entire 1890 to 2015 data set including assumptions made about data between the anecdotal 1864 flood and the start of the recorded data. The following is of note with respect to the analysis:

- It was assumed that upstream dams had no impact on recorded peak discharges;
- All peak annual discharges smaller than a 500 m^3/s threshold were censored;
- The missing peak discharges in Table 6.1 (where data was not available at either station) were assumed to be below 800 m^3/s; and
- The peak discharges between 1865 and 1890 were assumed to be below the maximum peak discharge of 5,336 m^3/s. The 1864 event was not used.

After censorship, only 43 uncensored data points remain within the 151 year period of analysis. The 500 m^3/s censorship threshold was adopted to improve the fit of the LP3 curve to the recorded flood discharges. Flows of this magnitude are limited to the Namoi River and Narrabri Creek as well as the channels of low-lying flood runners.

Figure 6.2 shows the results of fitting the LPIII distribution to the available data. The estimated 1% AEP (100 year ARI) flood quantile at Narrabri is 4,860 m^3/s and the 90% quantile probability limits are 4,130 m^3/s to 6,410 m^3/s. The expected AEP of the adopted flood quantile of 4,860 m^3/s is 1.14%.

On the basis of these results, the estimated AEP of the 1955 flood is between 1% and 0.5% (i.e. between 100 and 200 year ARI).

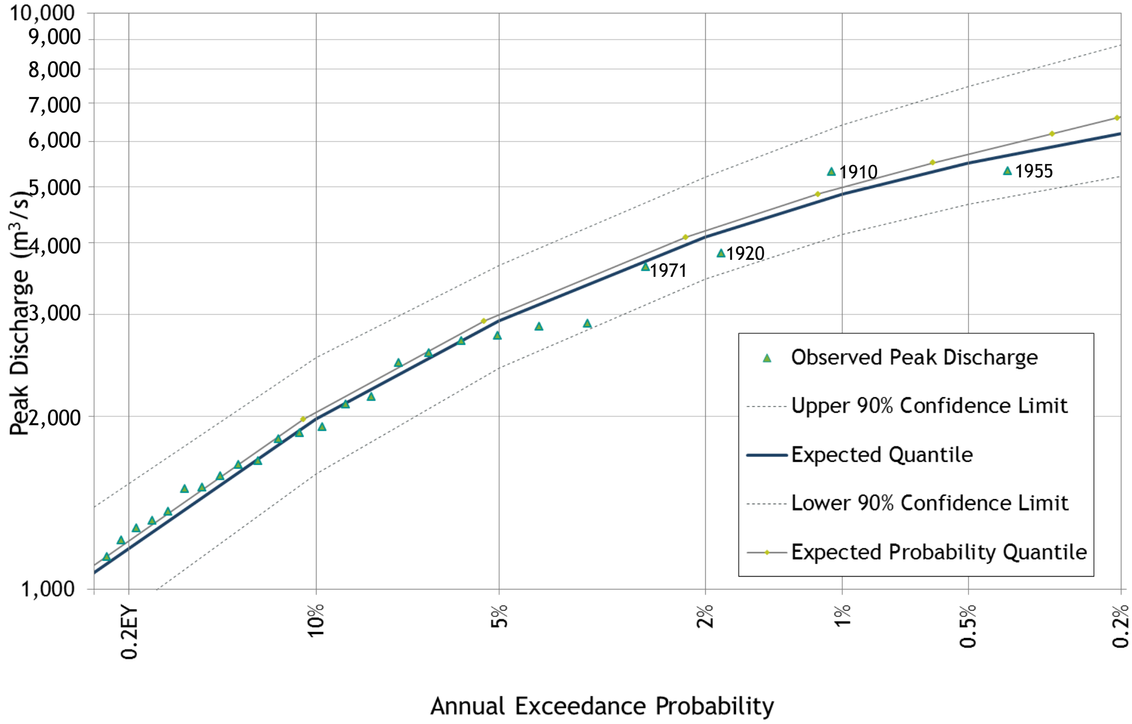

Figure 6.2 – Namoi River at Narrabri annual series flood frequency analysis, 1865-2015

6.1.4 Probable Maximum Flood (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 available data. For this catchment, the PMF has a notional AEP of about 1 in 40,000 using the methodology given in AR&R Book 8 (IEAUST, 1998). Therefore an estimate of a peak discharge for an 'extreme' flood has been made by using three times the 1% AEP discharge estimate.

6.1.5 Comparison with previous estimates

Table 6.2 shows a comparison of the above FFA design discharge estimates and estimates made by Kinhill (1991) and URS (2014). The results show that the updated 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 above 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 6.2 – Comparison of design discharges with previous estimates

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

[a] – PMF (extreme event) given by 3 x 1% AEP
[b] – expected parameter quantiles adopted given minimal difference from AEP quantiles

6.2 LOCAL FLOODING

6.2.1 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% and 1% AEP events and the PMF for existing conditions. All model parameters derived via the model calibration remained unchanged for the design event modelling.

6.2.2 Design discharges

6.2.2.1 Up to 1% AEP event

Table 6.3 and Table 6.4 show the Mulgate Creek (to the Newell Highway) and Long Gully (to the Narrabri 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. The following is of note:

- Design rainfalls were determined in accordance with AR&R (IEAUST, 1998).
- The critical duration for both catchments is 36 hours for all design events.
- An areal reduction factor of 0.945 was applied to the 36 hour design rainfall determined using the methodology given in Ball et al. (2016) for the Mulgate Creek catchment. The same areal reduction factor was applied to Long Gully as the differences in catchment rainfalls were insignificant.
- An initial rainfall loss of:
    - 35 mm was applied to the 20%, 10% and 5% AEP events; and
    - 10 mm was applied to the 2% and 1% AEP events
- A continuing loss of 2.5 mm/hr was applied to all design events up to 1% AEP.

Note that the 36 hour storm is likely to be longer than the actual response time of the local catchments to rainfall. However, the 36 hour ARR design rainfall temporal pattern is a heavily ‘front loaded’ storm pattern that have nested 4 and 6 hour duration rainfalls that are higher than the design rainfalls of that duration. This issue is likely to be addressed during the latest update of ARR.

Given the limited data available for model calibration, the design discharges were validated against estimates made using the draft version of the Regional Flood Frequency Estimation (RFFE) approach given in Ball et al. (2016). 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, 2016). 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 draft version of the method is determined 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 6.3. 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 6.4. 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 draft RFFE program suggests that RFFE estimates for Long Gully may have a lower accuracy because of the odd shape of the catchment.

Table 6.3 – 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	94	96	40	230
10	168	155	64	375
5	265	232	94	575
2	488	367	143	948
1	591	501	189	1,340

Table 6.4 – 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	15	16	7	38
10	24	26	11	62
5	35	38	15	95
2	67	61	24	157
1	87	83	31	222

Table 6.3 shows that the RFFE estimates are consistent with the XP-RAFTS/MIKE-FLOOD discharges in Mulgate Creek for the 20%, 10% and 5% AEP events but are lower for the 2% and 1% AEP events but are still within the confidence limits of the estimate. A good

agreement was achieved between the RFFE and XP-RAFTS/MIKE-FLOOD discharges in Long Gully for all design events, as shown in Table 6.4. On this basis, the XP-RAFTS/MIKE-FLOOD discharges have been adopted for the assessment.

6.2.2.2 Probable Maximum Flood (PMF)

Table 6.5 shows PMF discharge estimates for Mulgate Creek (at the Newell Highway) and Long Gully (at the Narrabri Walgett Railway). Design rainfalls for the PMF were determined in accordance with the Generalised Tropical Storm Method (revised) (BoM, 2005) and the Generalised Short Duration Method (GSDM) (BOM, 2003). Zero rainfall losses were used for both catchments. The critical duration storm for both catchments is the 12 hour event. These discharges were derived using the XP-RAFTS model only because MIKE-FLOOD modelling shows significant inter-basin flow both in and out of the catchment for this event.

Table 6.5 – PMF discharge, Mulgate Creek and Long Gully

Catchment	Peak Discharge (m^3/s)
Mulgate Creek	2,610
Long Gully	480

6.2.3 Coincident Namoi River flooding

The modelling of the December 2004 (see Figure 5.3) and February 2012 events (see Figure 5.7) showed that these two local catchment events coincided with a moderate flow event 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. 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 6.2.2.1, 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 6.6.

Table 6.6 – Coincident Namoi River discharge adopted for each design event

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

7 Design flood events

7.1 OVERVIEW

The calibrated MIKE-FLOOD model described in Section 4 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) and 1% AEP (100 year ARI) design events and an extreme flood event for both local and regional flooding. As discussed in Section 6 the regional extreme event was based on the 3x1% AEP event, while the local extreme event was a PMF event. All model parameters derived via the model calibration remained unchanged for the design event modelling.

7.2 REGIONAL FLOODING

7.2.1 Design discharge hydrograph

The results of the hydraulic modelling of the three historical events, given in Table 5.1, shows that flood peaks attenuate (reduce) between the Narrabri gauges and the downstream Mollee gauge. The modelled attenuation of the peak is greater for the 1955 flood (11%) compared to the smaller 1971 flood (4%) and the 1998 event (3%). This suggests that the shape or duration of the flood hydrograph may impact on the flood peak across the study area.

Figure 7.1 shows the historical water level hydrographs of 12 large flood events that have been recorded at the Narrabri Creek gauge. The largest peak shown is for the 1955 flood. The rapid rise and fall of this hydrograph may explain why this event attenuated more than the other two events. The 1971 event was a very long event with peak flood levels elevated for more than 10 days, whereas the 1998 event, which produced a similar attenuation of the peak, was much lower with less flood volume.

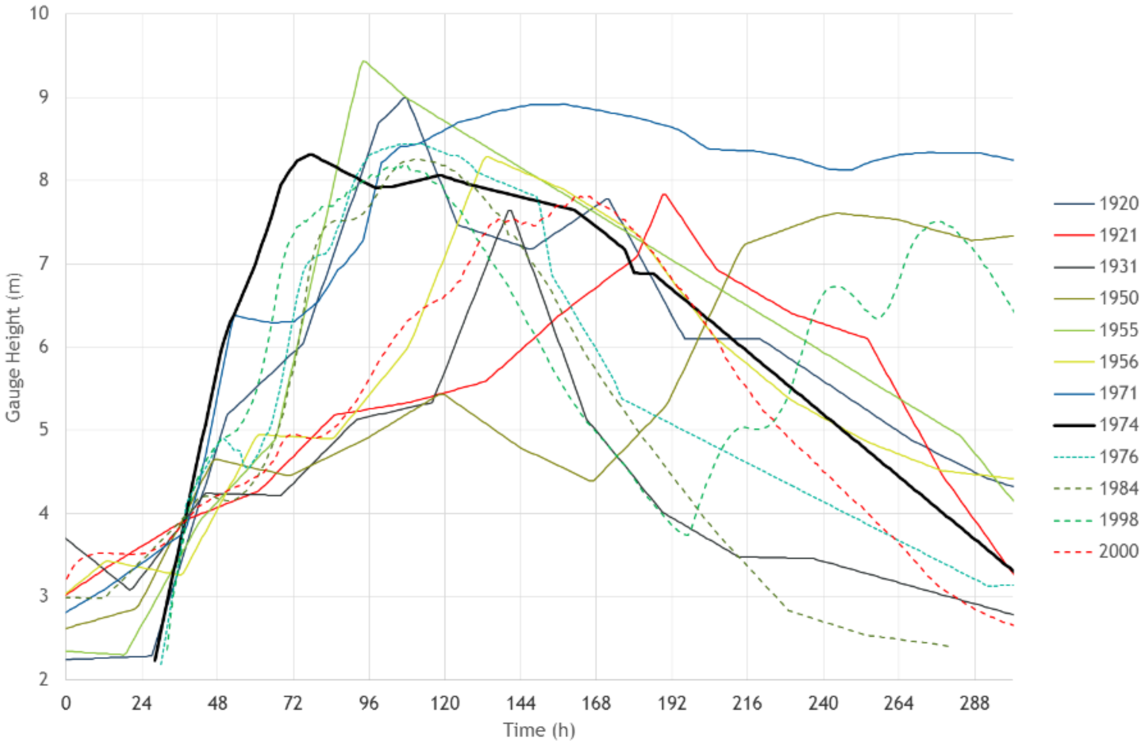

Figure 7.1 – Historical discharge hydrographs, Narrabri Creek at Narrabri

A review of the 1971 and 1998 hydrographs suggests that the lower attenuation was likely due to both of these events being at their peak level or within 0.02 m of their peak level for a number of hours, whereas the 1955 flood peak dropped within 2 hours. For this reason, the 1974 event was adopted to represent the hydrograph shape for the estimation of design flood levels. The 1974 event had 5 hours where the water level was within 0.02 m of the peak. It was also at elevated levels for much longer than the 1998 flood. The 1971 flood was not selected because of the excessive run times.

7.2.2 Design flood depth, levels and extents

Predicted flood extent, depths and flood contours for the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP and the extreme (3x1% AEP) event are shown in Appendix B. Figure 7.2, Figure 7.3 and Figure 7.4, 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.

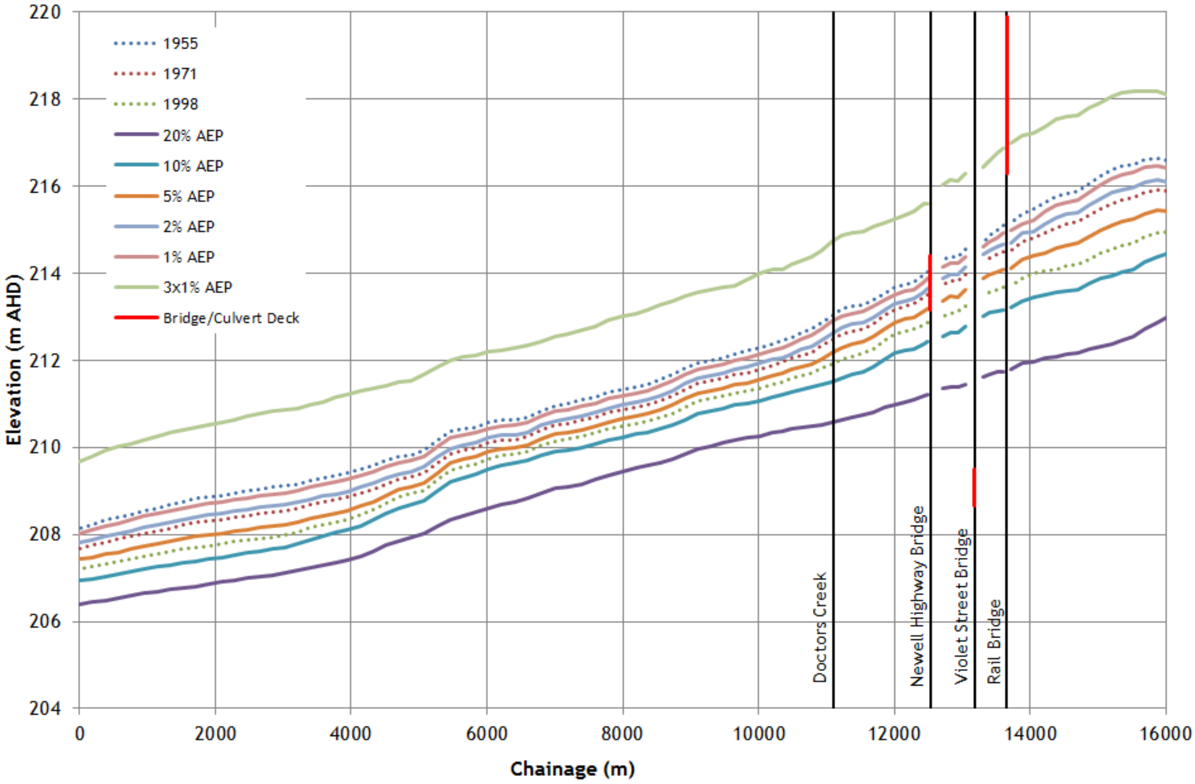

Figure 7.2 – Design and historical event longitudinal flood profiles, Narrabri Creek

7.2.3 Peak flood level comparison to previous estimates

Table 7.1 shows the peak flood level estimates at the Namoi River at Narrabri (GS419002) and Narrabri Creek at Narrabri (GS4519003) stream gauges from the hydraulic model and compares them to previous estimates. The differences in levels are significant with the 1% AEP level at the Narrabri gauge 0.86 m lower than the recent estimate by URS (2014). However, the levels determined from this study are consistent with the recorded water levels for the calibration events with the 1% AEP water level at the Narrabri gauge (9.34 mRL) marginally lower than that recorded for the 1955 flood (9.44 mRL). The previous estimates do not appear to be consistent with the historical data.

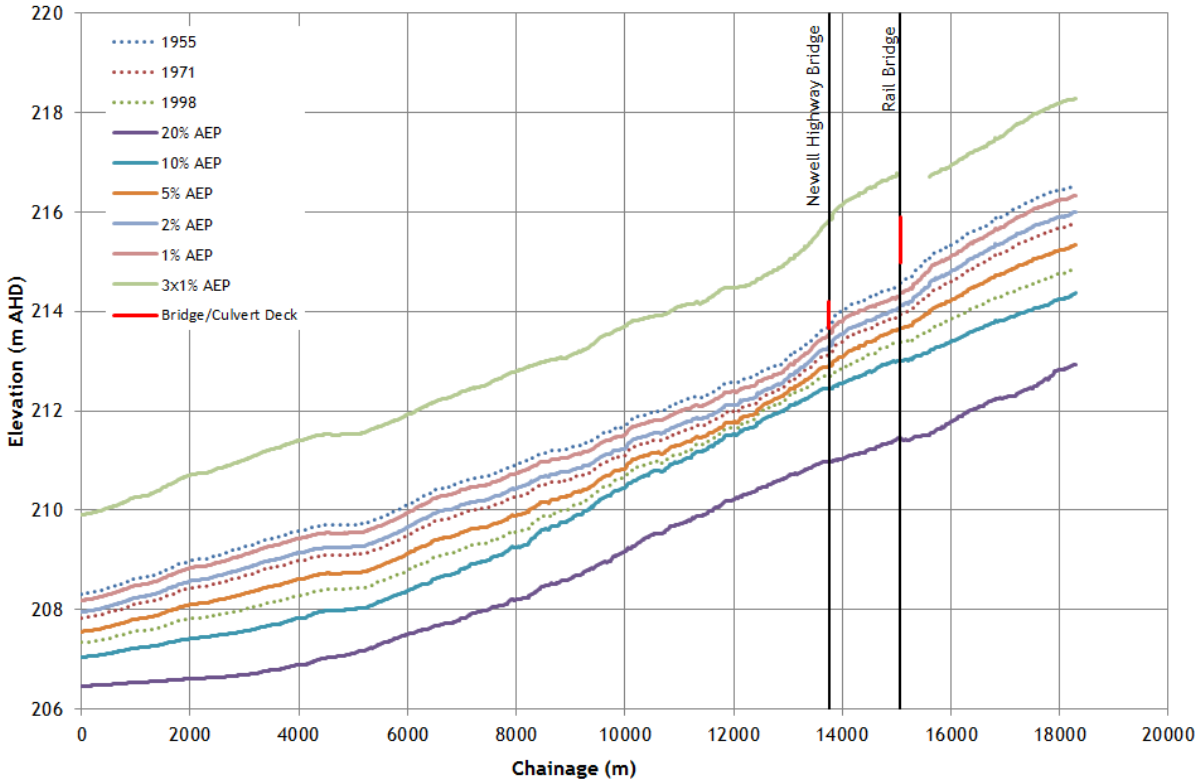

Figure 7.3 – Design and historical event longitudinal flood profiles, Namoi River

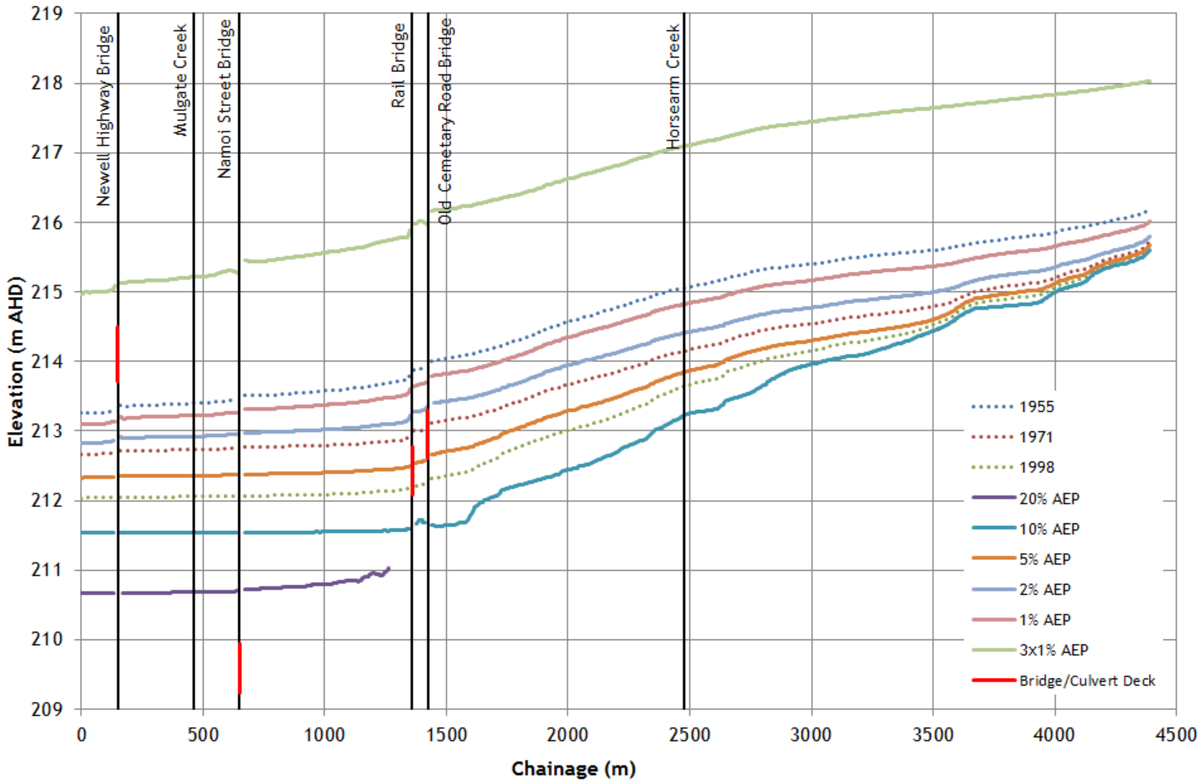

Figure 7.4 – Design and historical event longitudinal flood profiles, Eastern flood runner / Horsearm / Doctors Creek

Table 7.1 – Peak flood level comparison at the gauges, 10%, 5%, 2%, 1% and 3x1% AEP events

Event (AEP)	Kinhill (1991)		Winders (2002)		URS (2014)		WRM (2016)	
	Namoi	Narrabri	Namoi	Narrabri	Namoi	Narrabri	Namoi	Narrabri
3x1%	10.86	12.46	11.41	11.59	11.23	11.77	10.91	11.51
1%	8.86	10.16	9.39	9.99	9.28	10.20	8.62	9.34
2%	8.46	9.56	8.76	9.55	8.69	9.76	8.37	9.08
5%	7.86	8.26	8.05	8.78	7.98	8.88	7.97	8.55
10%	7.06	7.06	7.30	7.76	7.26	7.87	7.51	7.74
20%	-	-	-	-	-	-	6.04	6.56

7.3 LOCAL FLOODING

7.3.1 Design discharge depth, levels and extents

Predicted flood extents, depths and flood contours for the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP and the PMF events are shown in Figures B.2, B.4, B.6, B.8, B.10 and B.12 in Appendix B. Table 7.2 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 2% 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 7.2 – Floodplain flow distribution

Section ID	Peak discharge (m^3/s)				
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Horsearm Creek					
H1	44.6	70.4	109	196	237
H2	66.3	95.7	125	164	178
H3	0	6.2	26.5	49.2	55.9
H4	47.8	78.6	125.7	211	242
Mulgate Creek					
M1	64.5	95.6	121	145	153
M2	67.3	99.3	131	298	379
K1	3.7	6.5	29	139	189
Doctors Creek					
D1	94.1	168	265	488	591
Long Gully					
L1	18.6	29.5	42.1	75.2	95.2
L2	15.2	24.0	34.9	67.0	87.1
N1	0.96	1.09	1.01	1.20	1.21

7.3.1.1 Mulgate Creek

Figure 7.5 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.

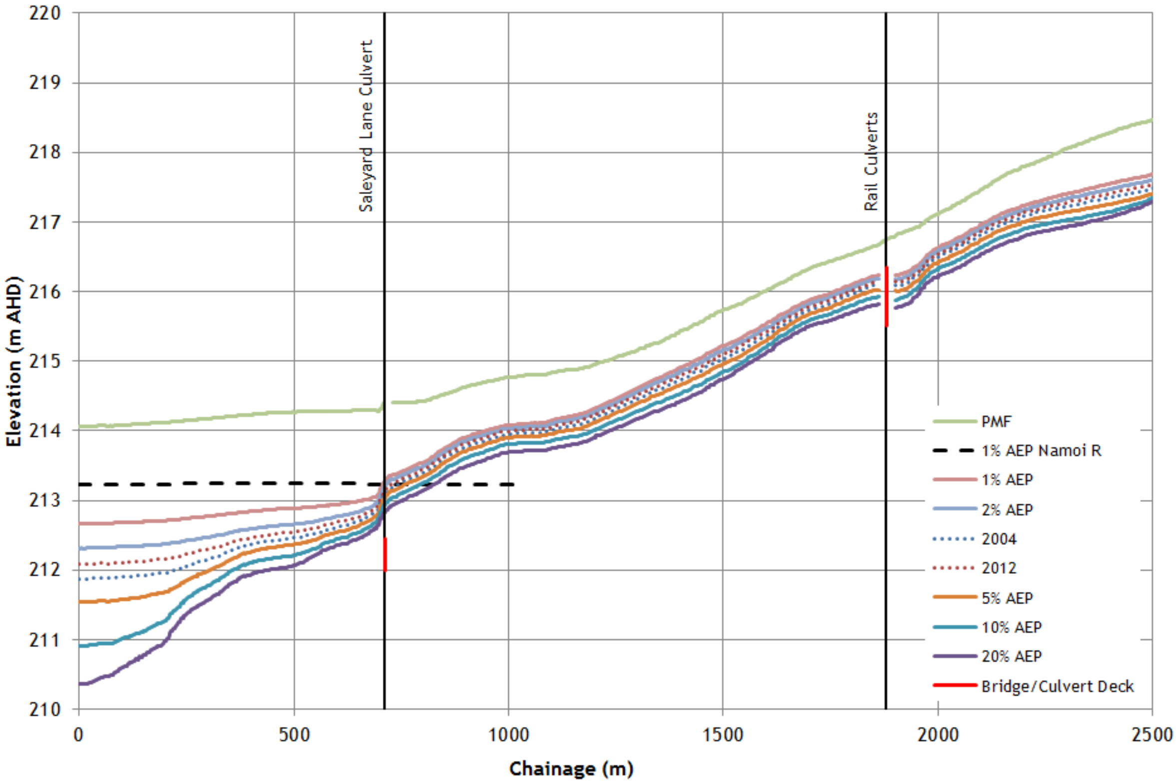

Figure 7.5 - Design and historical event longitudinal flood profiles, Mulgate Creek

Figure 7.6 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.

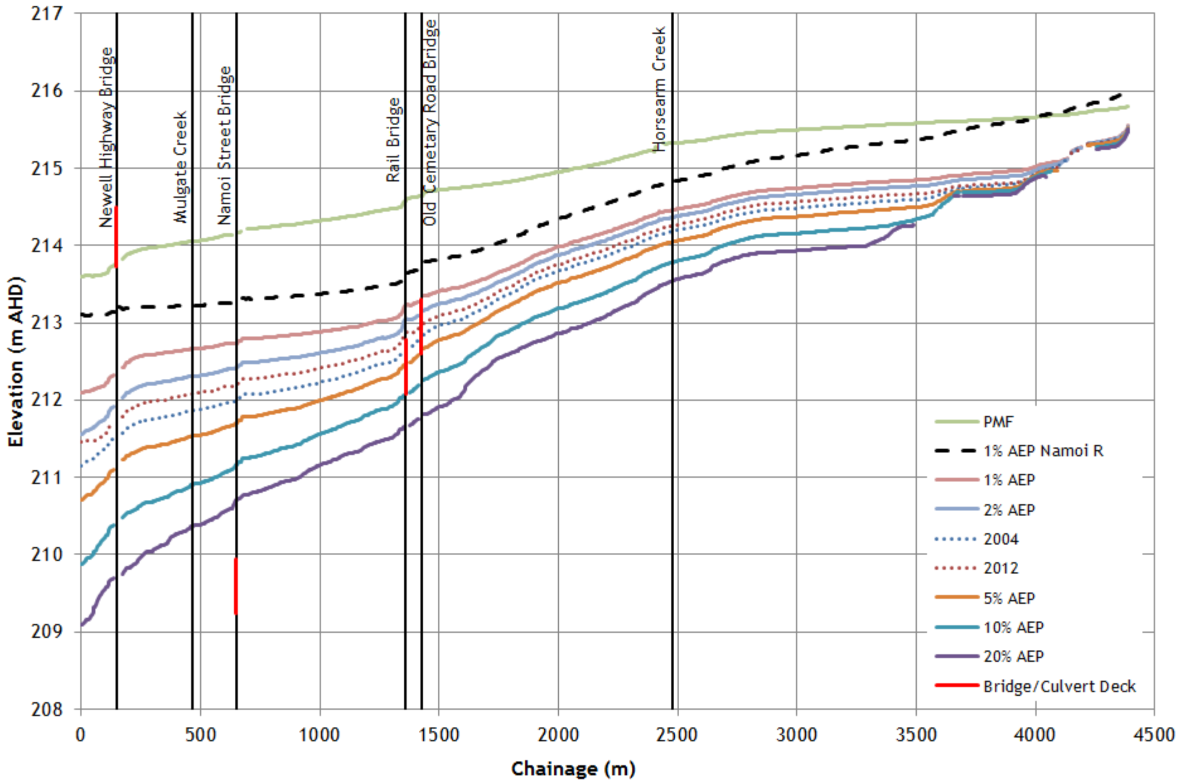

Figure 7.6 – Design and historical event longitudinal flood profiles, Doctors/Horsearm Creek

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 (not Mulgate Creek).
- Mulgate Creek overflows to Killarney Gap Road for the 10% AEP event and carries over half the Mulgate Creek flows for the 1% AEP event. 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 would reduce 1% AEP flows in Doctors Creek (which includes flows from both Mulgate Creek and Horsearm Creek) by 30%.
- Mulgate Creek overflows into Horsearm Creek upstream of the study area along Mulgate Creek Road (about 3km from the Killarney Gap Road turn off). The model predicts that 10% of the 1% AEP flow from Mulgate Creek overflows to Horsearm Creek at this location.
- Flooding of streets between the Francis and Newell reporting locations (Francis St industrial area) occurs for the 20% AEP event and properties are flooded for the 10% AEP event.
- Mulgate Creek overflows the rail upstream of the Francis St industrial area by the 20% 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.
- The 2% AEP event overtops the Newell Highway.

7.3.1.2 Long Gully

Figure 7.7 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.

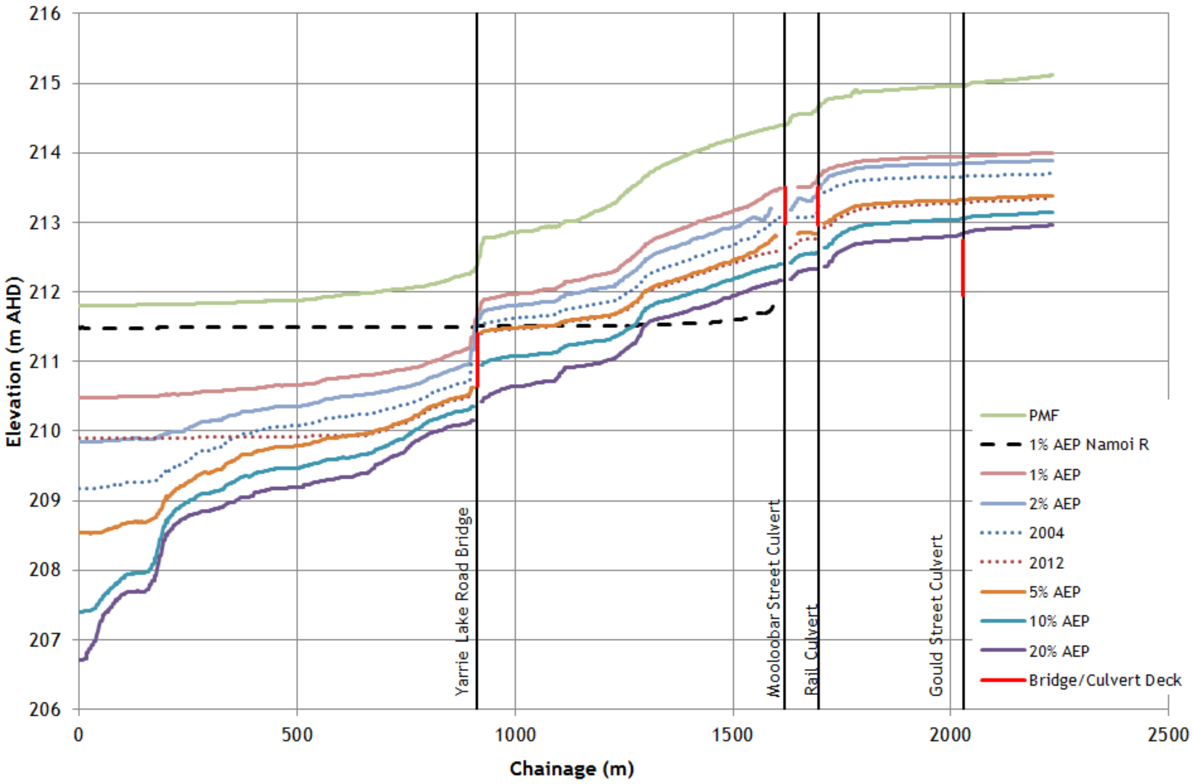

Figure 7.7 – Design and historical event longitudinal flood profiles, Long Gully

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 to the Kamilaroi Highway for all design events but the diverted flows are small in comparison to the total catchment flows.
- Some of the Newell Highway flows drain back to Long Gully at the Kamilaroi Highway junction for the 1% AEP event.
- The 2% AEP event overtops the Narrabri Walgett rail.

7.3.2 Sensitivity analysis

7.3.2.1 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 7.3.

The results show that changes in Manning's 'n values do not significantly impact on flood levels at the Long Gully reporting locations. 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), which is not supported by the anecdotal calibration data.

Table 7.3 – 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 Roughness	Increased Roughness	Decreased Roughness	Increased Roughness	Decreased Roughness
Burt	214.99	214.99	214.99	0.00	0.00
Kamilaroi	213.84	213.87	213.84	+0.03	0.00
Newell	212.52	212.48	212.53	-0.04	+0.01
Francis	213.31	213.35	213.05	+0.04	-0.26
Reid	213.64	213.70	213.43	+0.06	-0.21
Shannon	214.71	214.79	214.52	+0.08	-0.19

7.3.2.2 Climate change

The Floodplain Development Manual (NSW Government, 2005a) 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, 2007) for the 1% AEP flood. This represents the 'worst case' of the three climate change sensitivity analyses recommended by the NSW Government (2007). The results of this sensitivity analysis at the six reporting locations (shown in Figure B.10 in Appendix B) are shown in Table 7.4. The results show that climate change could increase peak 1% AEP flood levels significantly across the study area with an increase of 0.32 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 7.4 - Sensitivity 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	214.99	215.11	+0.12
Kamilaroi	213.84	214.01	+0.17
Newell	212.52	212.84	+0.32
Francis	213.31	213.42	+0.11
Reid	213.64	213.78	+0.14
Shannon	214.71	214.80	+0.09

8 Provisional hazard mapping

8.1 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 these 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 hazard mapping have been prepared by combining the hazards from both local and regional flooding.

8.2 PROVISIONAL FLOOD HAZARD AND PRELIMINARY TRUE HAZARD

Figure C.1 to Figure C.6 in Appendix C show the provisional hazard categories in the study area from a combination of local and regional catchment flooding assessed using the hydraulic model for the 5% and 1% AEP floods and the extreme event. Provisional hydraulic hazards have been defined using the depth and velocity of the floodwaters calculated using the flood model determined in accordance with Figure 8.1 as given in Appendix L of the NSW Floodplain Development (NSW Government, 2005a).

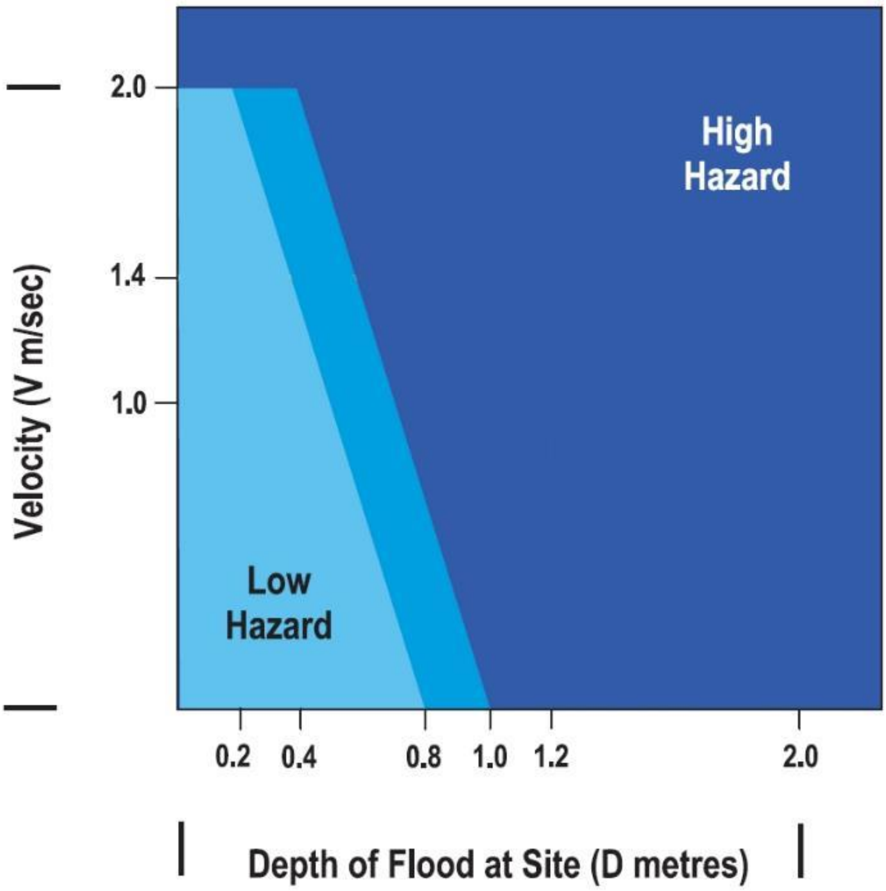

Figure 8.1 – Provisional hydraulic hazard categories (Source: NSW Government, 2005)

These categories of flood prone land have been refined into high and low hazard at each location using an assessment of the factors given in Table 8.1:

Table 8.1 – Weighting assessment for true hazard

Criteria	Weight	Comment
Size of the flood	Moderate	Flood AEP impacts on the hazard categories, which is generally picked up by the provisional hazard criteria.
Effective warning time	Low	There is effective warning time for both Namoi River and Mulgate Creek flooding. However, the warning time for Long Gully flooding is much shorter.
Flood readiness	Low	The Narrabri is a flood aware community with regular flooding from each source in recent history.
Rate of rise of floodwaters	Low	The rate of rise of floodwater is generally slow from all sources with the exception of Long Gully.
Depth and velocity of floodwaters	High	Both the river channel and the overbank areas are subject to high flood depths and velocities, which is generally picked up by the provisional hazard criteria.
Duration of flooding	High	Duration of flooding from the Namoi River can be for several days, which is the dominant source of flooding. Flooding from the local catchments drain within a few hours.
Evacuation problems	Moderate	Areas of concern for evacuation of the hospital area should be considered given access would be cut during large events.
Effective flood access	High	Evacuation of Narrabri during a major Namoi River flood is an issue because main evacuation routes can be inundated isolating vulnerable communities.
Type of development	Low	Generally low given the extent of flooding that has occurred in the past. Potential issues in the industrial areas may arise if chemicals are stored.

For Narrabri, those factors with a high weighting in relation to assessment of true hazard relate to the depth, velocity and duration of flooding. It is likely that most residents would not evacuate their properties for the moderate floods, which may mean evacuation for a very large flood could be a significant issue if roads are cut. Effective warning and management strategies are key to minimising the community risk should a large flood occur.

In general it was found that areas where a high flood hazard would be justified based on consideration of the high-weight criteria in Table 8.1, the area was already designated high hazard as a result of the depth/velocity criteria used to develop the provisional hazard. However, additional information (particularly detailed floor level survey) may warrant revision of the true hazard categories at various properties during the Floodplain Risk Management Study phase.

8.3 PROVISIONAL HYDRAULIC CATEGORISATION

For this study, the initial categorisation of flood prone land has been defined using the depth and velocity of the floodwaters calculated using the flood model. Each area is then assigned a provisional category using the methodology given in Figure 8.1, which has been taken from the NSW Floodplain Management Manual (NSW Government, 2005). The manual defines three types of flood prone land:

- Floodways are those areas where a significant volume of water flows during floods and are often aligned with obvious natural channels. They are areas that, even if only partially blocked, would cause a significant increase in flood levels and/or a significant redistribution of flood flow, which may in turn adversely affect other areas. They are often, but not necessarily, areas with deeper flow or areas where higher velocities occur.

- Flood storage areas are those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.
- Flood fringe is the remaining area of land affected by flooding, after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows.

For this study provisional hydraulic categories have been defined using the following:

- **Floodway** defined by the 5% AEP flood high hazard extent (see Figure C.7 in Appendix C);
- **Flood storage** defined by the 1% AEP flood extent outside the floodway areas
- **Flood fringe** defined by the residual area between 1% AEP extent and the extreme event extent.

8.4 PRELIMINARY FLOOD PLANNING AREA

Figure C.8 in Appendix C shows the properties within the preliminary flood planning area for Narrabri. The flood planning area includes all properties within the emergency response planning classification, with the flood planning level defined by the 1% AEP event including a 0.5 m freeboard.

8.5 PRELIMINARY FLOOD EMERGENCY RESPONSE PLANNING CLASSIFICATION

8.5.1 Overview

Preliminary emergency response planning classification of communities was completed using guidance provided in the associated Floodplain Risk Management Guideline (NSW Government, 2007a). For the purpose of emergency response planning the township of Narrabri was split into the following communities:

- Main Town North;
- Main Town South;
- Old Gunnedah Road;
- The Village South;
- The Village North; and
- Narrabri West.

Figure 8.2 shows the 6 communities adopted for emergency response planning. Approximately 92% of the area enclosed by the 6 communities is affected by the extreme flood with only the southern tip of the Village North and the western side of Narrabri West unaffected. The affected area reduces to approximately 78% in the 1% AEP event and 58% in the 5% AEP event. For many of the areas local roads inundate to great depth prior to escape routed inundating, meaning that early evacuation can be critical.

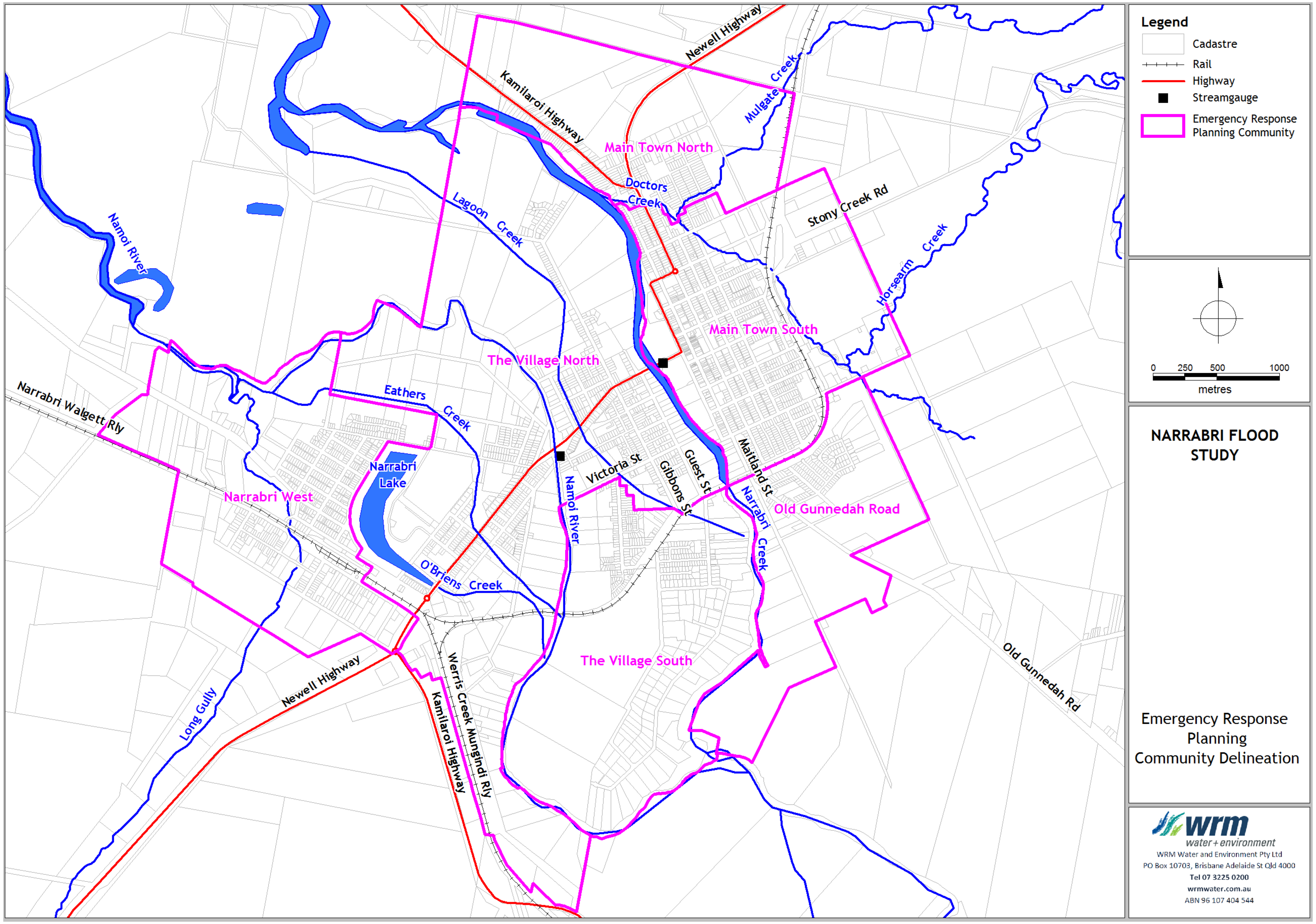

Figure 8.2 - Emergency response planning community delineation

8.5.2 Main Town North

The Main Town North community is the area northeast of Mulgate Creek/Horsearm Creek/ Doctors Creek. This community is susceptible to local flooding from Mulgate Creek as well as regional Narrabri Creek flooding. The primary escape routes from this area are the Kamilaroi Highway travelling west, the Newell Highway travelling north or the Newell Highway travelling south. The Kamilaroi Highway will overtop prior to the Newell Highway during regional flooding. Some overtopping of the Newell Highway north of the Doctors Creek Bridge may occur in the regional 1% AEP event, though the depth of overtopping (<0.5 m) may still allow evacuation by trucks. Local streets are much lower than the highway so evacuation will need to occur while these roads remain trafficable. The Main Town North community would best be described as a low trapped perimeter area.

8.5.3 Main Town South

The Main Town South community is bounded by Mulgate Creek/Horsearm Creek/ Doctors Creek to the north and east, the Werris Creek Mungindi Railway to the south and Narrabri Creek to the west. For the 5% AEP event, the majority of the Main Town South community will not be inundated with egress to the north or south on the Newell Highway feasible. The regional 1% AEP event will almost entirely inundate the Main Town South community. Any evacuation from the Main Town South community needs to occur prior to evacuation routes being cut with the most feasible egress being via the Newell Highway to the north or via Doyle Street and Stony Creek Road to the north. The Main Town South community is best described as a low flood island.

8.5.4 Old Gunnedah Road

The Old Gunnedah Road community is south of the Werris Creek Mungindi Railway and east of Narrabri Creek. The primary escape route for this community is travelling southeast along Old Gunnedah Road. This road would be inundated during the 5% AEP event but the overtopping depth (<0.5 m) should allow evacuation by trucks. Access to the north to the Main Town South community may not be trafficable with inundation along the Maitland Street rail underpass in the order of 0.5 m in the 5% AEP event. The 1% AEP event produces extensive inundation and evacuation prior to the flood peak will likely be required as overtopping along Old Gunnedah Road makes it impassable for this event. The Old Gunnedah Road Precinct is best described as a low trapped perimeter area.

8.5.5 The Village South

The Village South community is bounded by the Namoi River, Narrabri Creek and the Lagoon Creek flood channel and Violet Street to the north. The Village South Precinct is surrounded by major watercourses but is mostly not inundated by the 5% AEP flood. Access to this precinct would be cut at Violet Street and Gibbons Street by the Lagoon Creek flood runner during the 5% AEP event. The Guest Street rail underpass is cut by Narrabri Creek flooding. In the 5% AEP event Violet Street is inundated prior to Gibbons Street, however high hazard is experienced on both roads at approximately the same time (flow over both roads exceed 1 m at the peak). Should residents not evacuate prior to Violet Street and Gibbons Street being cut the extent of inundation increases for the larger events. However there remains significant areas not inundated by the 1% AEP event for residents to gather. The extreme flood inundates the entire precinct, with depths above 1 m throughout. The Village South Precinct community is therefore a low flood island.

8.5.6 The Village North

The Village North community is bounded by Narrabri Creek and Narrabri Lake to the north of the Village South Precinct and has a number of flood runners within its bounds. Much of this precinct is inundated during a 5% AEP event but emergency access via Newell Highway to the northeast remains open. The Newell Highway to the southwest would be inundated to depths <0.5 m for this event but remains trafficable by trucks.

The 1% AEP event inundates much of the area to significant depth which suggests it should be evacuated early in a flood event. The Village North Precinct community is a low flood island.

8.5.7 Narrabri West

The Narrabri West community is on the western side of Narrabri Lake. Inundation during both the local and regional 5% AEP events is minimal. Evacuation south and east via the Newell and Kamilaroi highways respectively should be relatively unhindered for this event. Evacuation may become more difficult for some properties during the 1% AEP event, though if evacuated early the entire community should be able to escape. This community is best described as overland refuge area on high trapped perimeter area.

9 Conclusions

Narrabri Shire Council engaged WRM Water & Environment Pty Ltd (WRM) to prepare flood maps for a range of design events for regional Namoi River and local creek flooding at Narrabri .The primary focus of the study is to map the flooding through Narrabri using a new two-dimensional flood model.

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 the revised update of AR&R (Ball et al, 2016). 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, 2016).

Hydraulic modelling of the study area has been undertaken to derive design flood levels, depths and extents for the 20%, 10%, 5%, 2% and 1% AEP flood events and an extreme flood. Preliminary flood hazard mapping and flood emergency response classifications have 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;
- 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.

10 References

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11 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 1-dimensional and 2-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