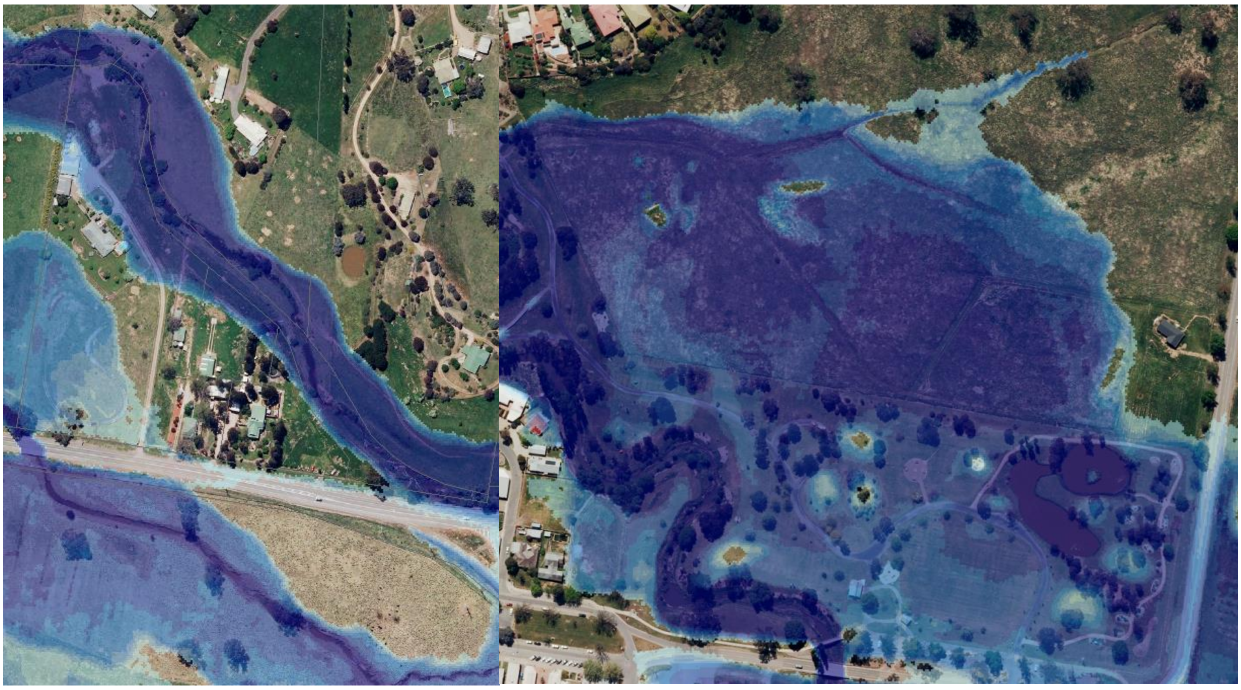

Mansfield 1% AEP Flood Mapping Project

June 2014

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1 INTRODUCTION

The Goulburn Broken CMA, in association with Mansfield Shire, has undertaken hydraulic modelling of flood flows along Ford Creek through the township of Mansfield.

Goulburn Broken CMA has prepared this report to outline the methodology used to model the hydraulics of Ford Creek and summarise the results of the flood mapping. The mapping is for the 1% annual exceedence probability (AEP) flood.

1.1 BACKGROUND

1.1.1 Description

The primary source of flooding in Mansfield is Ford Creek. Ford Creek is a small meandering stream with a partially confined channel and a floodplain of variable width.

Ford Creek flows through Mansfield in a north westerly direction. There is also a risk of flooding from a number of tributaries that flow through the town from the north and south to join Ford Creek (Figure 1-1). Flooding along most of these tributaries is outside the scope of this study.

1.1.2 Previous work

A flood study was completed for Ford Creek, Mansfield approximately 7-years ago (Earth Tech 2005, Earth Tech 2006). The hydrology was based on a frequency analysis at the Mansfield gauge. The hydraulics and mapping in this earlier study were based on a one-dimensional hydraulic model (XP-STORM software), which used surveyed cross-sections along Ford Creek, bridge structures and historic peak water heights.

1.1.3 Requirement for current study

Mansfield Shire Council, in association with the Goulburn Broken CMA, had prepared draft Mansfield Planning Scheme Amendment C15, which incorporated flood mapping from the previous flood study carried out by Earth Tech.

Upon review of the draft planning scheme amendment, Mansfield Shire requested the Goulburn Broken CMA to, amongst other things, extend the flood mapping along Ford Creek to assist in the orderly planning of areas earmarked for future development. The areas for future development identified by Council included the area along Ford Creek downstream of the town to Withers Lane and the areas upstream of the town to Ogilvies Road.

Since the Earth Tech flood study, high resolution ground data has been captured in 2010 (Aerial Laser Survey, ALS or LiDAR). This new ALS data, combined with previous survey (Earth Tech), allowed a new approach to defining the waterway geometry and the use of two-dimensional hydraulic modelling and refined flood mapping outputs as described in this report.

Unfortunately the new ALS data did not extend to Ogilvies Road. Hence, part of the area to the south east of Mansfield of interest to Council has been mapped by field inspection with aerial imagery. This mapping is not included in this report as it was not based on hydraulic modelling, but will be shown in the preparation of the updated Mansfield Planning Scheme Amendment C15.

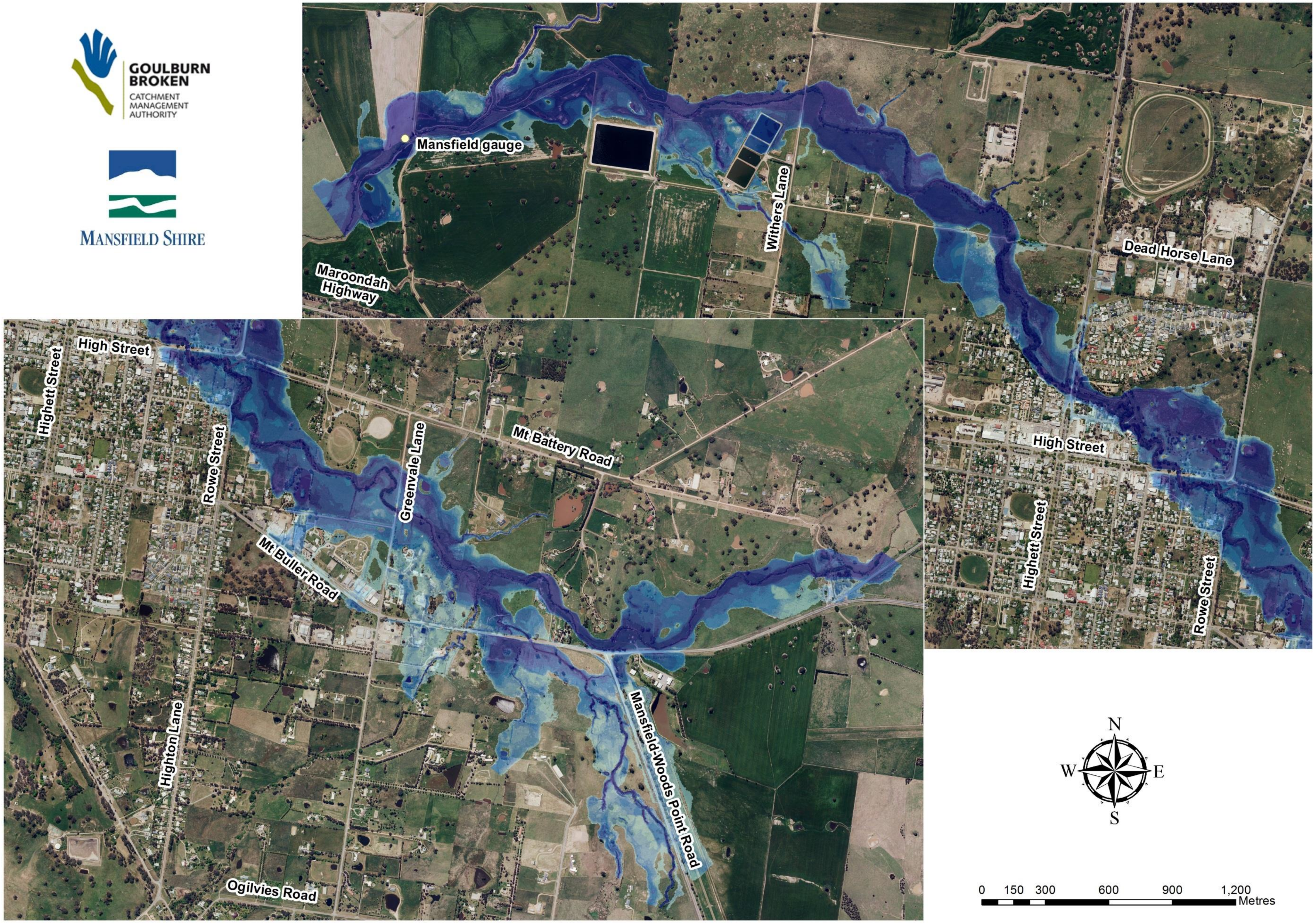


Figure 1-1 **The reach of Ford Creek over which flooding was mapped at Mansfield.**

1.2 Current study

1.2.1 Objectives

The objectives of this study were to reduce the impact of natural disasters on the local community by:

1. Establishing a hydraulic model and mapping the 1% annual exceedence probability (AEP, the 100-year average recurrence interval) flood extent and preparing flood level contours for the area shown in Figure 1-1.

2. Revising the urban flood zone, the floodway overlay and the land subject to inundation overlay in the draft Mansfield Planning Scheme Amendment C15 to improve the planning of land use and development.

1.2.2 Scope

The geographic scope of the study was based on the requirement from Council for flood mapping to the south east of Mansfield and downstream to Withers Lane. The Goulburn Broken CMA extended the scope further downstream to tie in with the gauge (Figure 1-1). The hydraulic modelling was also extended along Ford Creek upstream of the Mansfield-Woods Point Road to utilise all the high quality ALS data and maximise the area with flood mapping.

All the tasks undertaken to improve flood intelligence and planning in Mansfield are listed below. This report sets out the method and results of Task 4.

1. Hydrologic study

    a. Flood frequency analysis from the previous study (Earth Tech 2005, Earth Tech 2006); and

    b. Rational Method (Goulburn Broken CMA).

2. Survey of the creek from the previous study (HJ Macy 2005 & 2009).

3. ALS digital elevation model (Department Environment and Primary Industries, DEPI).

4. Flood intelligence and mapping (Goulburn Broken CMA).

5. Planning scheme amendment (Mansfield Shire).

1.2.3 Hydraulic modelling

The hydraulics of flood flow along Ford Creek was modelled by Earth Tech using the one-dimensional hydraulic model XP-Storm (Earth Tech 2005, Earth Tech 2006).

For this study a two-dimensional hydraulic model was developed using TUFLOW software (build 2012-05-AD). A one-dimensional model in ESTRY was linked to the TUFLOW model to account for the hydraulic behaviour of pipe culverts.

2 HYDROLOGY

Examining the hydrology of floods through Mansfield, the following types of events were considered:

- the flows along Ford Creek in a 1% AEP (100-year ARI) type flood (Section 2.1); and
- the flows in the tributaries on the south eastern side of Mansfield in a 1% AEP (100-year ARI) type flood (Section 2.2).

2.1 FORD CREEK

The basic hydrology of Ford Creek was completed by Earth Tech (2005). The Earth Tech study adopted the peak flow in the flood of September 1975 as the 100-year ARI event. The peak flow at the gauge (Mansfield @Ford Creek, Site Code 405245) in September 1975 was 232 m^3/s, corresponding to a stage reading of 4.34-metres (Earth Tech 2005). The catchment area of Ford Creek at the gauge is 115 km^2 (DSE 2011).

The catchment areas that flow into the hydraulic model are shown in Figure 2-1. The gauge is located some 4 kilometres of Mansfield at the downstream end of catchments M and N (Figure 2-1).

The areas of each of the catchments in Figure 2-1 are shown in Table 2-1. The flow in Ford Creek and the contribution from each of the tributary catchments during the 100-year ARI flood is also shown in Table 2-1.

The tributary flows calculated in Table 2-1 are based on the ratio of contributing catchment areas to the power of 0.5, as set out in Grayson et al. (1996, pg. 84). Grayson et al. state that the exponent varies widely with reported values of between 0.5 and 0.85. Although an exponent of 0.7 is commonly used, this study has been based on the ratio of contributing catchment areas to the power of 0.5. The low value for the exponent was adopted as, in both the 1-dimensional modelling undertaken by Earth Tech and the 2-dimensional modelling described herein, the hydraulics of the 1975 flood tend to over-estimate flood levels at the downstream end of town and under-estimate flood levels at the upstream end of town. A possible explanation for this modelling behaviour is that the rainfall was more intense in the eastern part of the catchment during the 1975 flood. Selecting a power of 0.5 for the ratio of contributing catchment areas increases the proportion of flows from the eastern part of the catchment.

In Table 2-1 the cumulative area to catchment N, the location of the Mansfield gauge, is 116.3 km^2. This area is slightly larger than the 115 km^2 that is listed as the catchment area of the gauge (DSE 2011). This discrepancy has not been resolved as it is not important to this study. The catchment areas were only used to apportion the 100-year ARI flow to different tributaries, not to calculate the 100-year ARI flow.

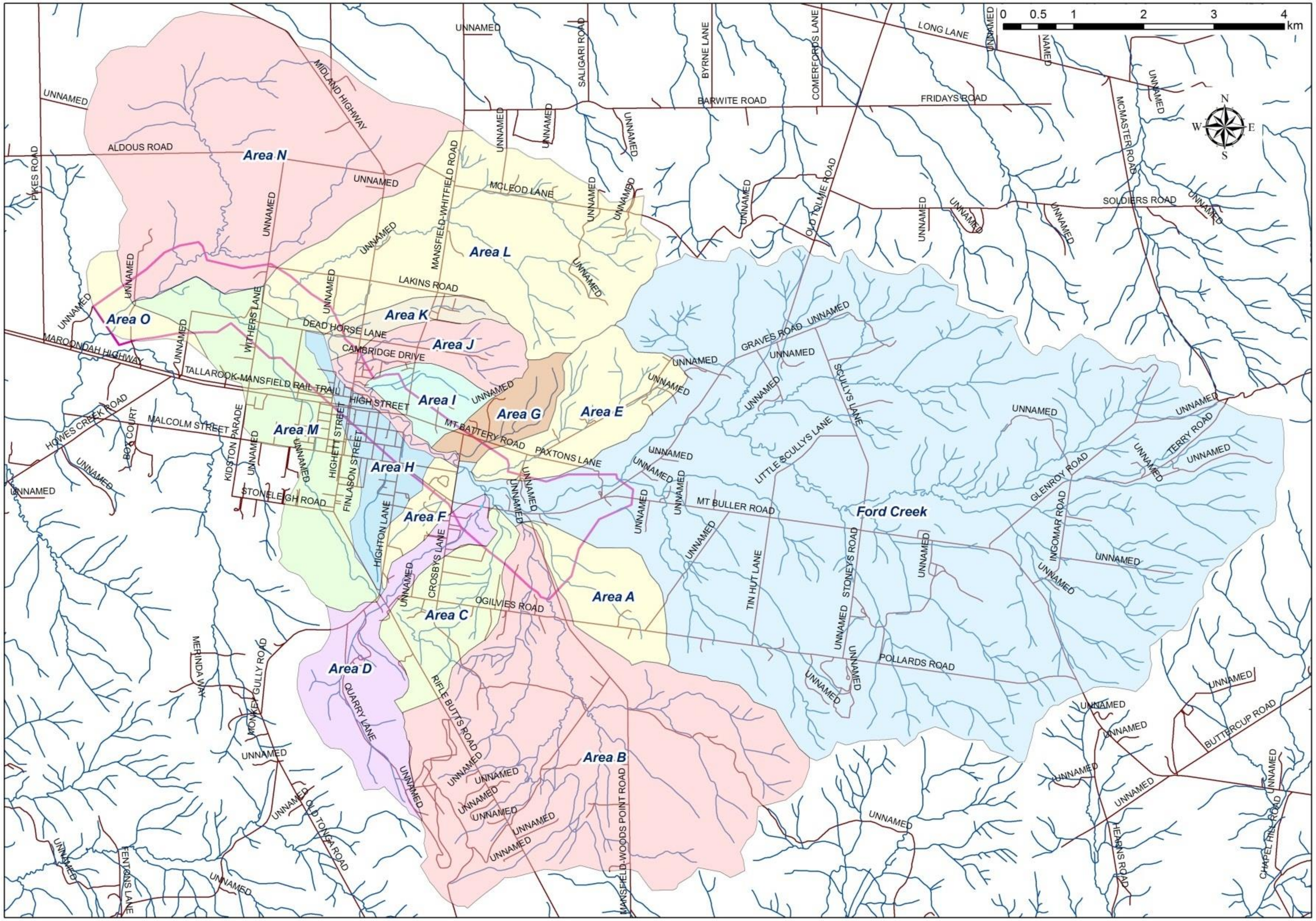


Figure 2-1 The catchment areas for the Mansfield Flood Study. The pink outline that follows Ford Creek is the boundary of the 2-D hydraulic model.

Table 2-1 Catchment areas and design flows for Ford Creek.

Catchment	Area (km^2)	Cumulative catchment area (km^2)	Cumulative flow in Ford Creek (m^3/s)	Tributary inflow (m^3/s)
Ford Creek	50.1	50.1	128.7	128.7
A	2.2	52.3	132.6	3.9
B east	13.5	65.8	155.8	23.1
B west	3.4	69.2	161.3	5.6
C	2.7	71.9	165.7	4.4
D	3.8	75.7	171.8	6.1
E	3	78.7	176.5	4.7
F	0.8	79.5	177.8	1.3
G	1.3	80.8	179.8	2.0
H	1.9	82.7	182.7	2.9
I	1.2	83.9	184.6	1.9
J	2.1	86	187.8	3.2
K	0.9	86.9	189.2	1.4
L	10.1	97	204.3	15.1
M	5.6	102.6	212.5	8.2
N	13.7	116.3	232.0	19.5
O	0.9	117.2	233.3	1.3

2.2 South Eastern Tributaries

Mansfield Shire Council identified the rural living zone on the south eastern side of Mansfield as an area requiring planning for the 100-year ARI flood. This area is bounded by Ogilvies Road to the south, Highton Lane to the west and the Mansfield-Woods Point Road to the east (Figure 1-1). The tributaries of Ford Creek flowing through this area are unnamed streams fed by Areas A, B, C and D (Table 2-1 and Figure 2-1). An additional complication is that the catchment of Area B flows into the rural living zone as two separate streams, known here as Area B east and Area B west.

The intensity of rainfall for the tributaries of Ford Creek on the south eastern side of Mansfield was estimated using the Bureau of Meteorology online Intensity-Frequency-Duration (IFD) tool, found at:

http://www.bom.gov.au/water/designRainfalls/ifd/index.shtml

The south eastern tributaries are located at easting 421,000 and northing 5,893,000 (MGA94, Zone 55). These coordinates were input to the BoM IFD tool to produce the following outputs (Figure 2-2 and Figure 2-3).

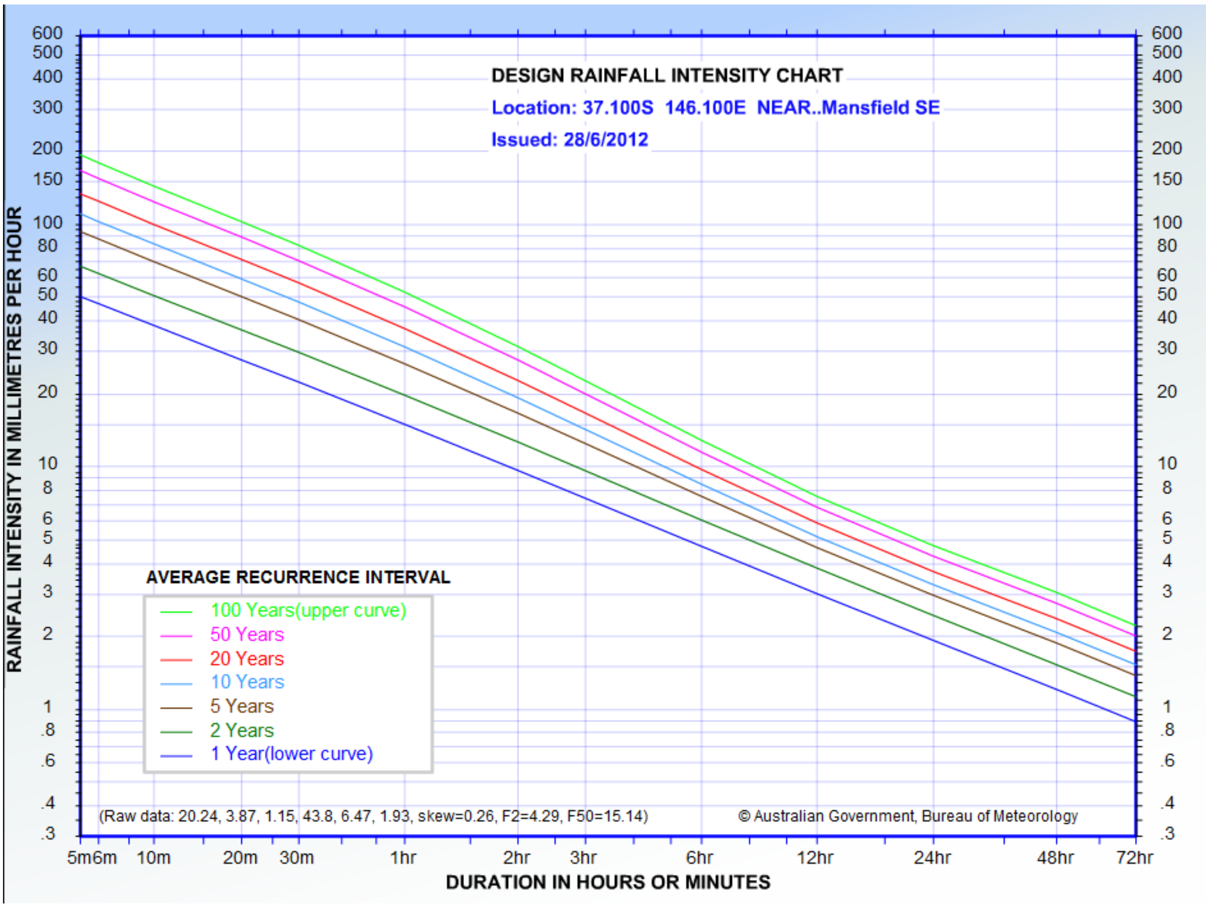
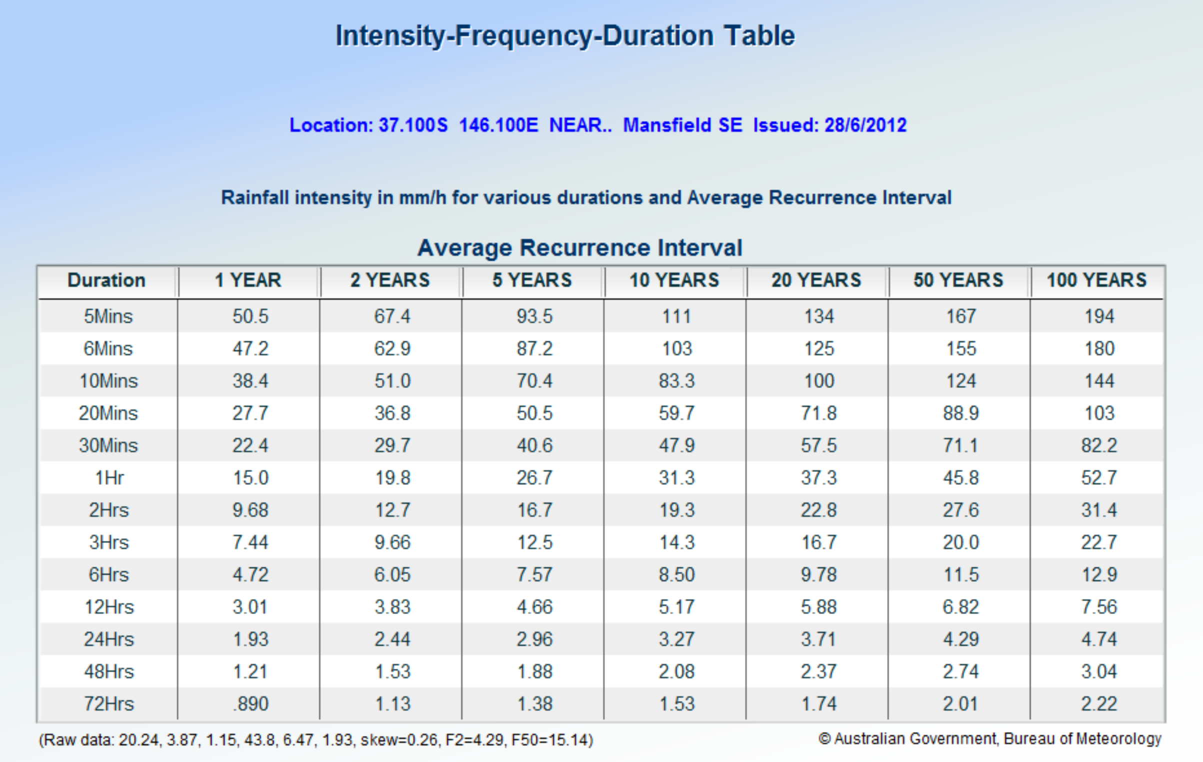


Figure 2-2 IFD chart for the tributaries of Ford Creek south east of Mansfield.

Based on the areas of each of the catchments, the time of concentration for each can be calculated from the formula $t_c = 0.76 * A^{0.36}$ (Pilgram and Doran 1998). The design runoff coefficient in the 10 year ARI event is estimated to be 0.23 (Figure 5.3b, Pilgram and Doran 1998).



Intensity-Frequency-Duration Table

Location: 37.100S 146.100E NEAR.. Mansfield SE Issued: 28/6/2012

Rainfall intensity in mm/h for various durations and Average Recurrence Interval

	Average Recurrence Interval						
Duration	1 YEAR	2 YEARS	5 YEARS	10 YEARS	20 YEARS	50 YEARS	100 YEARS
5Mins	50.5	67.4	93.5	111	134	167	194
6Mins	47.2	62.9	87.2	103	125	155	180
10Mins	38.4	51.0	70.4	83.3	100	124	144
20Mins	27.7	36.8	50.5	59.7	71.8	88.9	103
30Mins	22.4	29.7	40.6	47.9	57.5	71.1	82.2
1Hr	15.0	19.8	26.7	31.3	37.3	45.8	52.7
2Hrs	9.68	12.7	16.7	19.3	22.8	27.6	31.4
3Hrs	7.44	9.66	12.5	14.3	16.7	20.0	22.7
6Hrs	4.72	6.05	7.57	8.50	9.78	11.5	12.9
12Hrs	3.01	3.83	4.66	5.17	5.88	6.82	7.56
24Hrs	1.93	2.44	2.96	3.27	3.71	4.29	4.74
48Hrs	1.21	1.53	1.88	2.08	2.37	2.74	3.04
72Hrs	.890	1.13	1.38	1.53	1.74	2.01	2.22

(Raw data: 20.24, 3.87, 1.15, 43.8, 6.47, 1.93, skew=0.26, F2=4.29, F50=15.14)

Figure 2-3 IFD table for the tributaries of Ford Creek south east of Mansfield.

The runoff coefficient, rainfall intensities and catchment area are sufficient to calculate the design flows for each of the catchments using the Rational Method (Table 2-2 to Table 2-6).

Site: Area A - south eastern tributaries of Ford Creek

Parameter	Units	Symbol	Value	Notes
Area of catchment	km²	A	2.20	Calculate from topographical map
Runoff coefficient for ARI 10 years	%	C_{10}	0.23	From Figure 5.3b, Vol. 2, page 107
Design rainfall duration as the time of concentration	hours	t_c	1.03	(0.76*Area to the power of 0.38)
Number of minutes	minutes	t_c	61.53	
Determine the following Design Rainfall Parameters				Determine from Volume 2, pages 45 - 50
Frequency Factor for **1 year** event		FF_1	0.60	From Table 5.4, Vol. 1, page 103
Frequency Factor for **2 year** event		FF_2	0.75	From Table 5.4, Vol. 1, page 103
Frequency Factor for **5 year** event		FF_5	0.90	From Table 5.4, Vol. 1, page 103
Frequency Factor for **10 year** event		FF_{10}	1.00	From Table 5.4, Vol. 1, page 103
Frequency Factor for **20 year** event		FF_{20}	1.10	From Table 5.4, Vol. 1, page 103
Frequency Factor for **50 year** event		FF_{50}	1.20	From Table 5.4, Vol. 1, page 103
Frequency Factor for **100 year** event		FF_{100}	1.30	From Table 5.4, Vol. 1, page 103
Runoff coefficient for **1 year** event		C_1	0.14	Runoff coefficient x Frequency Factor
Runoff coefficient for **2 year** event		C_2	0.17	Runoff coefficient x Frequency Factor
Runoff coefficient for **5 year** event		C_5	0.21	Runoff coefficient x Frequency Factor
Runoff coefficient for **10 year** event		C_{10}	0.23	Runoff coefficient x Frequency Factor
Runoff coefficient for **20 year** event		C_{20}	0.25	Runoff coefficient x Frequency Factor
Runoff coefficient for **50 year** event		C_{50}	0.28	Runoff coefficient x Frequency Factor
Runoff coefficient for **100 year** event		C_{100}	0.30	Runoff coefficient x Frequency Factor
Complete Table 1a				
Rainfall Intensity for design rainfall duration (Cell D5), **1 year event**	mm/h	I_{tc}	14.86	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **2 year event**	mm/h	I_{tc}	19.62	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **5 year event**	mm/h	I_{tc}	26.45	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **10 year event**	mm/h	I_{tc}	30.99	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **20 year event**	mm/h	I_{tc}	36.93	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **50 year event**	mm/h	I_{tc}	45.34	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **100 year event**	mm/h	I_{tc}	52.16	Derived from IFD Table and Table 1(a)
Design Discharge for **1 year event**	m³/s	Q_1	1.25	
Design Discharge for **2 year event**	m³/s	Q_2	2.07	
Design Discharge for **5 year event**	m³/s	Q_5	3.35	
Design Discharge for **10 year event**	m³/s	Q_{10}	4.36	
Design Discharge for **20 year event**	m³/s	Q_{20}	5.71	
Design Discharge for **50 year event**	m³/s	Q_{50}	7.65	
Design Discharge for **100 year event**	m³/s	Q_{100}	9.54	

Table 1(a) - Rainfall Intensity (mm/h)
Enter from IFD Table

RAINFALL INTENSITY (mm/h)

	1 Year	2 Year	5 Year	10 Year	20 Year	50 Year	100 Year
hr/min							
60	15	19.8	26.7	31.3	37.3	45.8	52.7
120	9.68	12.7	16.7	19.3	22.8	27.6	31.4
61.53	14.864358	19.618974	26.445034	30.994041	36.9303	45.335962	52.15692312

Table 2-2 Spreadsheet for the calculation of design discharge for Area A.

Site: Area B east - south eastern tributaries of Ford Creek

Parameter	Units	Symbol	Value	Notes
Area of catchment	km²	A	13.50	Calculate from topographical map
Runoff coefficient for ARI 10 years	%	C_{10}	0.23	From Figure 5.3b, Vol. 2, page 107
Design rainfall duration as the time of concentration	hours	t_c	2.04	(0.76*Area to the power of 0.38)
Number of minutes	minutes	t_c	122.60	
Determine the following Design Rainfall Parameters				Determine from Volume 2, pages 45 - 50
Frequency Factor for **1 year** event		FF_1	0.60	From Table 5.4, Vol. 1, page 103
Frequency Factor for **2 year** event		FF_2	0.75	From Table 5.4, Vol. 1, page 103
Frequency Factor for **5 year** event		FF_5	0.90	From Table 5.4, Vol. 1, page 103
Frequency Factor for **10 year** event		FF_{10}	1.00	From Table 5.4, Vol. 1, page 103
Frequency Factor for **20 year** event		FF_{20}	1.10	From Table 5.4, Vol. 1, page 103
Frequency Factor for **50 year** event		FF_{50}	1.20	From Table 5.4, Vol. 1, page 103
Frequency Factor for **100 year** event		FF_{100}	1.30	From Table 5.4, Vol. 1, page 103
Runoff coefficient for **1 year** event		C_1	0.14	Runoff coefficient x Frequency Factor
Runoff coefficient for **2 year** event		C_2	0.17	Runoff coefficient x Frequency Factor
Runoff coefficient for **5 year** event		C_5	0.21	Runoff coefficient x Frequency Factor
Runoff coefficient for **10 year** event		C_{10}	0.23	Runoff coefficient x Frequency Factor
Runoff coefficient for **20 year** event		C_{20}	0.25	Runoff coefficient x Frequency Factor
Runoff coefficient for **50 year** event		C_{50}	0.28	Runoff coefficient x Frequency Factor
Runoff coefficient for **100 year** event		C_{100}	0.30	Runoff coefficient x Frequency Factor
Complete Table 1a				
Rainfall Intensity for design rainfall duration (Cell D5), **1 year event**	mm/h	I_{tc}	9.58	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **2 year event**	mm/h	I_{tc}	12.57	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **5 year event**	mm/h	I_{tc}	16.52	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **10 year event**	mm/h	I_{tc}	19.08	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **20 year event**	mm/h	I_{tc}	22.54	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **50 year event**	mm/h	I_{tc}	27.27	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **100 year event**	mm/h	I_{tc}	31.02	Derived from IFD Table and Table 1(a)
Design Discharge for **1 year event**	m³/s	Q_1	4.96	
Design Discharge for **2 year event**	m³/s	Q_2	8.14	
Design Discharge for **5 year event**	m³/s	Q_5	12.83	
Design Discharge for **10 year event**	m³/s	Q_{10}	16.47	
Design Discharge for **20 year event**	m³/s	Q_{20}	21.40	
Design Discharge for **50 year event**	m³/s	Q_{50}	28.25	
Design Discharge for **100 year event**	m³/s	Q_{100}	34.81	

Table 1(a) - Rainfall Intensity (mm/h)
Enter from IFD Table

RAINFALL INTENSITY (mm/h)

	1 Year	2 Year	5 Year	10 Year	20 Year	50 Year	100 Year
hr/min							
120	9.68	12.7	16.7	19.3	22.8	27.6	31.4
180	7.44	9.66	12.5	14.3	16.7	20	22.7
122.60	9.5829206	12.568249	16.517976	19.083305	22.535632	27.270624	31.0229507

Table 2-3 Spreadsheet for the calculation of design discharge for Area B east.

Site: Area B west - south eastern tributaries of Ford Creek

Parameter	Units	Symbol	Value	Notes
Area of catchment	km²	A	3.40	Calculate from topographical map
Runoff coefficient for ARI 10 years	%	C_{10}	0.23	From Figure 5.3b, Vol. 2, page 107
Design rainfall duration as the time of concentration	hours	t_c	1.21	(0.76*Area to the power of 0.38)
Number of minutes	minutes	t_c	72.60	
Determine the following Design Rainfall Parameters				Determine from Volume 2, pages 45 - 50
Frequency Factor for **1 year** event		FF_1	0.60	From Table 5.4, Vol. 1, page 103
Frequency Factor for **2 year** event		FF_2	0.75	From Table 5.4, Vol. 1, page 103
Frequency Factor for **5 year** event		FF_5	0.90	From Table 5.4, Vol. 1, page 103
Frequency Factor for **10 year** event		FF_{10}	1.00	From Table 5.4, Vol. 1, page 103
Frequency Factor for **20 year** event		FF_{20}	1.10	From Table 5.4, Vol. 1, page 103
Frequency Factor for **50 year** event		FF_{50}	1.20	From Table 5.4, Vol. 1, page 103
Frequency Factor for **100 year** event		FF_{100}	1.30	From Table 5.4, Vol. 1, page 103
Runoff coefficient for **1 year** event		C_1	0.14	Runoff coefficient x Frequency Factor
Runoff coefficient for **2 year** event		C_2	0.17	Runoff coefficient x Frequency Factor
Runoff coefficient for **5 year** event		C_5	0.21	Runoff coefficient x Frequency Factor
Runoff coefficient for **10 year** event		C_{10}	0.23	Runoff coefficient x Frequency Factor
Runoff coefficient for **20 year** event		C_{20}	0.25	Runoff coefficient x Frequency Factor
Runoff coefficient for **50 year** event		C_{50}	0.28	Runoff coefficient x Frequency Factor
Runoff coefficient for **100 year** event		C_{100}	0.30	Runoff coefficient x Frequency Factor
Complete Table 1a				
Rainfall Intensity for design rainfall duration (Cell D5), **1 year event**	mm/h	I_{tc}	13.88	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **2 year event**	mm/h	I_{tc}	18.31	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **5 year event**	mm/h	I_{tc}	24.60	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **10 year event**	mm/h	I_{tc}	28.78	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **20 year event**	mm/h	I_{tc}	34.26	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **50 year event**	mm/h	I_{tc}	41.98	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **100 year event**	mm/h	I_{tc}	48.23	Derived from IFD Table and Table 1(a)
Design Discharge for **1 year event**	m³/s	Q_1	1.81	
Design Discharge for **2 year event**	m³/s	Q_2	2.99	
Design Discharge for **5 year event**	m³/s	Q_5	4.81	
Design Discharge for **10 year event**	m³/s	Q_{10}	6.26	
Design Discharge for **20 year event**	m³/s	Q_{20}	8.19	
Design Discharge for **50 year event**	m³/s	Q_{50}	10.95	
Design Discharge for **100 year event**	m³/s	Q_{100}	13.63	

Table 1(a) - Rainfall Intensity (mm/h)
Enter from IFD Table

RAINFALL INTENSITY (mm/h)

hr/min	1 Year	2 Year	5 Year	10 Year	20 Year	50 Year	100 Year
60	15	19.8	26.7	31.3	37.3	45.8	52.7
120	9.68	12.7	16.7	19.3	22.8	27.6	31.4
72.60	13.882945	18.309194	24.600273	28.780327	34.255395	41.978496	48.22758095

Table 2-4 Spreadsheet for the calculation of design discharge for Area B west.

Site: Area C - south eastern tributaries of Ford Creek				
Parameter	**Units**	**Symbol**	**Value**	**Notes**
Area of catchment	km²	A	2.70	Calculate from topographical map
Runoff coefficient for ARI 10 years	%	C_{10}	0.23	From Figure 5.3b, Vol. 2, page 107
Design rainfall duration as the time of concentration	hours	t_c	1.11	(0.76*Area to the power of 0.38)
Number of minutes	minutes	t_c	66.51	
Determine the following Design Rainfall Parameters				Determine from Volume 2, pages 45 - 50
Frequency Factor for **1 year** event		FF_1	0.60	From Table 5.4, Vol. 1, page 103
Frequency Factor for **2 year** event		FF_2	0.75	From Table 5.4, Vol. 1, page 103
Frequency Factor for **5 year** event		FF_5	0.90	From Table 5.4, Vol. 1, page 103
Frequency Factor for **10 year** event		FF_{10}	1.00	From Table 5.4, Vol. 1, page 103
Frequency Factor for **20 year** event		FF_{20}	1.10	From Table 5.4, Vol. 1, page 103
Frequency Factor for **50 year** event		FF_{50}	1.20	From Table 5.4, Vol. 1, page 103
Frequency Factor for **100 year** event		FF_{100}	1.30	From Table 5.4, Vol. 1, page 103
Runoff coefficient for **1 year** event		C_1	0.14	Runoff coefficient x Frequency Factor
Runoff coefficient for **2 year** event		C_2	0.17	Runoff coefficient x Frequency Factor
Runoff coefficient for **5 year** event		C_5	0.21	Runoff coefficient x Frequency Factor
Runoff coefficient for **10 year** event		C_{10}	0.23	Runoff coefficient x Frequency Factor
Runoff coefficient for **20 year** event		C_{20}	0.25	Runoff coefficient x Frequency Factor
Runoff coefficient for **50 year** event		C_{50}	0.28	Runoff coefficient x Frequency Factor
Runoff coefficient for **100 year** event		C_{100}	0.30	Runoff coefficient x Frequency Factor
Complete Table 1a				
Rainfall Intensity for design rainfall duration (Cell D5), **1 year event**	mm/h	I_{tc}	14.42	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **2 year event**	mm/h	I_{tc}	19.03	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **5 year event**	mm/h	I_{tc}	25.62	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **10 year event**	mm/h	I_{tc}	30.00	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **20 year event**	mm/h	I_{tc}	35.73	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **50 year event**	mm/h	I_{tc}	43.83	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **100 year event**	mm/h	I_{tc}	50.39	Derived from IFD Table and Table 1(a)
Design Discharge for **1 year event**	m³/s	Q_1	1.49	
Design Discharge for **2 year event**	m³/s	Q_2	2.46	
Design Discharge for **5 year event**	m³/s	Q_5	3.98	
Design Discharge for **10 year event**	m³/s	Q_{10}	5.18	
Design Discharge for **20 year event**	m³/s	Q_{20}	6.78	
Design Discharge for **50 year event**	m³/s	Q_{50}	9.08	
Design Discharge for **100 year event**	m³/s	Q_{100}	11.31	

Table 1(a) - Rainfall Intensity (mm/h)

Enter from IFD Table

RAINFALL INTENSITY (mm/h)							
	1 Year	**2 Year**	**5 Year**	**10 Year**	**20 Year**	**50 Year**	**100 Year**
hr/min							
60	15	19.8	26.7	31.3	37.3	45.8	52.7
120	9.68	12.7	16.7	19.3	22.8	27.6	31.4
66.51	14.422833	19.02972	25.615099	29.998119	35.726893	43.82548	50.38916066

Table 2-5 Spreadsheet for the calculation of design discharge for Area C.

Site: Area D - south eastern tributaries of Ford Creek				
Parameter	**Units**	**Symbol**	**Value**	**Notes**
Area of catchment	km^2	A	3.80	Calculate from topographical map
Runoff coefficient for ARI 10 years	%	C_{10}	0.23	From Figure 5.3b, Vol. 2, page 107
Design rainfall duration as the time of concentration	hours	t_c	1.26	(0.76*Area to the power of 0.38)
Number of minutes	minutes	t_c	75.73	
Determine the following Design Rainfall Parameters				Determine from Volume 2, pages 45 - 50
Frequency Factor for **1 year** event		FF_1	0.60	From Table 5.4, Vol. 1, page 103
Frequency Factor for **2 year** event		FF_2	0.75	From Table 5.4, Vol. 1, page 103
Frequency Factor for **5 year** event		FF_5	0.90	From Table 5.4, Vol. 1, page 103
Frequency Factor for **10 year** event		FF_{10}	1.00	From Table 5.4, Vol. 1, page 103
Frequency Factor for **20 year** event		FF_{20}	1.10	From Table 5.4, Vol. 1, page 103
Frequency Factor for **50 year** event		FF_{50}	1.20	From Table 5.4, Vol. 1, page 103
Frequency Factor for **100 year** event		FF_{100}	1.30	From Table 5.4, Vol. 1, page 103
Runoff coefficient for **1 year** event		C_1	0.14	Runoff coefficient x Frequency Factor
Runoff coefficient for **2 year** event		C_2	0.17	Runoff coefficient x Frequency Factor
Runoff coefficient for **5 year** event		C_5	0.21	Runoff coefficient x Frequency Factor
Runoff coefficient for **10 year** event		C_{10}	0.23	Runoff coefficient x Frequency Factor
Runoff coefficient for **20 year** event		C_{20}	0.25	Runoff coefficient x Frequency Factor
Runoff coefficient for **50 year** event		C_{50}	0.28	Runoff coefficient x Frequency Factor
Runoff coefficient for **100 year** event		C_{100}	0.30	Runoff coefficient x Frequency Factor
Complete Table 1a				
Rainfall Intensity for design rainfall duration (Cell D5), **1 year event**	mm/h	I_{tc}	13.61	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **2 year event**	mm/h	I_{tc}	17.94	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **5 year event**	mm/h	I_{tc}	24.08	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **10 year event**	mm/h	I_{tc}	28.15	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **20 year event**	mm/h	I_{tc}	33.50	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **50 year event**	mm/h	I_{tc}	41.03	Derived from IFD Table and Table 1(a)
Rainfall Intensity for design rainfall duration (Cell D5), **100 year event**	mm/h	I_{tc}	47.11	Derived from IFD Table and Table 1(a)
Design Discharge for **1 year event**	m^3/s	Q_1	1.98	
Design Discharge for **2 year event**	m^3/s	Q_2	3.27	
Design Discharge for **5 year event**	m^3/s	Q_5	5.27	
Design Discharge for **10 year event**	m^3/s	Q_{10}	6.84	
Design Discharge for **20 year event**	m^3/s	Q_{20}	8.95	
Design Discharge for **50 year event**	m^3/s	Q_{50}	11.96	
Design Discharge for **100 year event**	m^3/s	Q_{100}	14.88	

Table 1(a) - Rainfall Intensity (mm/h)
Enter from IFD Table

RAINFALL INTENSITY (mm/h)							
	1 Year	**2 Year**	**5 Year**	**10 Year**	**20 Year**	**50 Year**	**100 Year**
hr/min							
60	15	19.8	26.7	31.3	37.3	45.8	52.7
120	9.68	12.7	16.7	19.3	22.8	27.6	31.4
75.73	13.605047	17.938314	24.077907	28.153489	33.497966	41.027792	47.11494295

Table 2-6 Spreadsheet for the calculation of design discharge for Area D.

The results of the Rational Method analysis are summarised in Table 2-7 and shown to be slightly higher than the flows given by the regression equation for rural catchments. Due to the substantially shorter time of concentration on the tributaries relative to the time of concentration for Ford Creek, the 100-year ARI flow on the tributaries is generally much greater than the contribution each tributary makes to the 100-year ARI flow in Ford Creek (Table 2-7).

Table 2-7 Summary of design flows for the 1% AEP (100-year ARI) flood along the south eastern tributaries of Ford Creek.

Catchment	Catchment area (km^2)	Rational Method 100-year ARI flood (m^3/s)	Regression equation 100-year ARI flood (m^3/s)[1]	Flow contributed in the 100-year ARI flood on Ford Creek (m^3/s)
Area A	2.2	9.6	8.5	3.9
Area B east	13.5	34.9	34.0	23.1
Area B west	3.4	13.7	11.9	5.6
Area C	2.7	11.4	10.0	4.4
Area D	3.8	14.9	12.9	6.1

In applying the above 100-year flows to the tributaries of Ford Creek, consideration needs to be given to the corresponding flows in Ford Creek and the influence of Ford Creek on backwater conditions in the tributaries. Given the steep slope of these tributaries, the backwater from Ford Creek has little impact on the extent of the 100 year ARI flood on the tributaries. Hence, a 100 year ARI flow will be used along Ford Creek in the scenario for modelling flooding along the tributaries.

Separate flood modelling and mapping was carried out along each of the tributaries using the above 100-year flow estimates and the tail water assumption for Ford Creek. This was carried out to map the tributaries only. The final flood mapping adopted an envelope approach of all the outputs along both Ford Creek and its tributaries.

[1] Based on Equation 7.6.5 Grayson, R. B., R. M. Argent, R. J. Nathan, T. A. McMahon & R. G. Mein. 1996. *Hydrological recipes: estimation techniques in Australian hydrology*. Melbourne: Cooperative Research Centre for Catchment Hydrology..

3 HYDRAULIC MODEL DEVELOPMENT

The two-dimensional model TUFLOW, build 2012-05-AD (64-bit), was used for the hydraulic modelling. A one-dimensional model in ESTRY was linked to TUFLOW to represent the four sets of culvert crossings in the study area.

3.1 GEOMETRY OF THE HYDRAULIC MODEL

The hydraulic model was based on the following input geometry:

- ALS collected in 2010, with an average points spacing of 7.30/m and a vertical accuracy of +/- 0.10m on bare earth (68% confidence), that was processed into a 1m DTM (Digital Terrain Model).
- Level and feature survey conducted in November 2005 and April 2006 by Earth Tech Pty. Ltd. This data was used in the TUFLOW model to:
    - Define the bed of Ford Creek for the small area that was below the water surface at the time the ALS was flown.
    - Define the geometry of the bridges and the bridge approaches (approaches have been removed from the bare earth ALS).
    - Define the high point on a number of road centrelines that are transverse to the flood flow.
- Additional measurements at all culvert and bridge sites by Guy Tierney and Dean Judd of the Goulburn Broken CMA in 2012.

3.2 HYDRAULIC BOUNDARY CONDITIONS

The downstream hydraulic control for the model was set based on a normal depth. The uniform hydraulic grade for this normal depth assumption was calculated from the general gradient of the floodplain of Ford Creek at the downstream end of the model. Based on the ALS the gradient of the floodplain was found to be approximately 3 m/km.

3.3 GRID SIZE

The TUFLOW model of Ford Creek was run with a grid size of 3-metres.

3.4 INVERT OF THE CREEK

The ALS used for the hydraulic model only provides elevations on the water surface in the creek. Hence, in the TUFLOW model files “Z shapes” were used to cut an invert into the ALS.

The invert was based on survey points along the thalweg that were in the cross-sections for the previous 1-dimensional hydraulic model (Earth Tech 2005). However, these survey points along the thalweg do not extend downstream of Dead Horse Land nor upstream of the Mansfield–Woods Point Road.

For the reaches below Dead Horse Lane and upstream of the Mansfield–Woods Point Road a point file was created to represent levels along the invert of Ford Creek. To identify where to place points along the invert, and the level of these points, the ALS was contoured at 0.5-metre intervals. Where every 0.5-metre contour first crossed the bed of Ford Creek a point was placed and assigned the elevation of the contour. This provided a line of points that approximately represented the invert of Ford Creek in the ALS. These points were then lowered by an amount that represented the depth from the ALS to the thalweg of the creek.

Downstream of the reach that had been surveyed the depth from the ALS to the thalweg of the creek was estimated by averaging the depth at the closest 10 survey points, those from Dead Horse Lane to the pedestrian bridge just upstream of Highett Street. The same process was applied to the other reach without survey information, the reach upstream of the Mansfield–Woods Point Road.

The depth from the ALS to the invert of Ford Creek averaged 0.68-metres for the survey points nearest to Dead Horse Lane, varying from 0.20 to 1.04-metres. For the survey points nearest to the Mansfield–Woods Point Road, the depth averaged 0.55-metres, varying from 0.03 to 1.26-metres. The substantial variation in the depth from the ALS to the thalweg highlight the approximate nature of the bed form used in the hydraulic model downstream of Dead Horse Land and upstream of the Mansfield–Woods Point Road.

3.5 Bridges and culverts

Layered 2-dimensional flow constrictions were used in TUFLOW to represent the hydraulic characteristics of the bridges over Ford Creek and its tributaries. The parameters used for each bridge are shown in Table 3-1.

The sets of culverts along Ford Creek and its tributaries were represented in the 1-dimensional ESTRY hydraulic model that linked to the TUFLOW model. The parameters used for each of the culverts are shown in Table 3-2.

At a number of the bridges the processing of the ALS to create the “bare earth” data has wholly or partially removed the abutments of the bridges. As the abutments can block a substantial part of the creek cross-section, it is important that they be accurately represented to replicate the hydraulic influence of the bridges. The abutments of bridges were included in the TUFLOW model using Z shapes with elevations that were based on the survey of the bridges and the raw ALSO data. Abutments were added to the model at the following locations:

- Greenvale Lane (north and south abutments)
- High Street (east and west abutments)
- Pedestrian Bridge A (east and west abutments)
- Pedestrian Bridge B (east and west abutments)
- Highett Street (north and south abutments)

At the culverts at Withers and Dead Horse Lanes the culvert embankment had been cut out of the ALS. Hence Z shapes were used to put in the culvert embankment and the box culverts in the 1-dimensional model were put through this embankment. At the Mt Buller Road Bridge the creek had to be cut through the road embankment such that the 2-dimensional flow constriction could be placed over it to represent the bridge.

Table 3-1 Variables used for TUFLOW computations at each of the bridges over Ford Creek and tributaries.

Bridge	Span between abutments (m)	Width of bridge (m)	Soffit of the bridge (m, AHD)	Bridge piers	Percent blocked by piers	Loss coefficient for piers	Depth of deck (m)	Percent blockage by deck	Loss coefficient for deck	Height of railing (m)	Percent blockage by railing	Loss coefficient for rails
Mt Buller Road	16.60	13.0	326.99	0.375 x 9 x 1 row	4	0.25	0.81	100	0.1	0.80	35	0.5
Greenvale Lane	22.20	4.72	323.39	0.5 x 2 x 2 rows + 0.26 x 3 x 1 row	6	0.18	0.75	90	0.5	0.95	85	0.7
High Street	20.54	9.40	318.08	0.61 x 2 x 1 row	5	0.15	0.67	100	0.1	1.19	30	0.5
Pedestrian Bridge A	21.68	2.28	318.35	None	0	0	0.96	100	0.5	1.02	35	0.5
Pedestrian Bridge B	22.23	2.15	317.59	None	0	0	0.8	100	0.5	1.00	50	0.6
Pedestrian Bridge C	33.87	1.65	315.47	0.41 x 2 x 2 rows	5	0.15	0.65	100	0.5	1.26	40	0.4
Highett Street	23.66	7.40	315.14	0.37 x 3 x 5 rows	8	0.32	0.45	100	0.2	0.85	45	0.4
Bridge u/s of the gauge	4.7	3.62	297.68	None	0	0	1.12	90	0.5	0.00	0	0

Table 3-2 Variables used for TUFLOW computations at each of the culverts over Ford Creek and tributaries.

Culvert	Type	Length of culverts (m)	Invert u/s (RL, m)	Invert d/s (RL, m)	Width or diameter of culverts (m)	Height of culverts (m)	Number of culverts	Height contraction coefficient	Width contraction coefficient	Entry loss coefficient	Exit loss coefficient
290 Mt Buller Road east	Pipe	16.0	325.05	324.85	1.20	-	2	-	1	0.5	1
290 Mt Buller Road west	Pipe	13.8	325.30	325.3	1.65	-	2	-	1	0.5	1
Dead Horse Lane	Box culvert	4.9	307.48	307.48	1.2	0.8	4	0.6	0.9	0.5	1
Withers Lane	Box culvert	5.0	303.73	303.73	1.2	0.9	5	0.6	0.9	0.5	1

3.5.1 Validation of bridges

The impact of the bridges on water levels in the hydraulic model can be partially checked during the calibration process using the historic water levels recorded during floods. These historic water levels provide information on head losses through the following structures:

- The combined influence of Pedestrian Bridge A and the High Street bridge; and
- The combined influence of Pedestrian Bridge C and the Highett Street Bridge.

The culverts across Ford Creek, at Withers Lane and Dead Horse Lanes, are low in the cross-section of the channel. Subsequently these structures are not substantial influences on the hydraulics of the 100-year ARI type flood.

4 CALIBRATION

4.1 HYDRAULIC ROUGHNESS

The roughness values used in the hydraulic model are shown in Table 4-1. Roughness values were set based on those commonly referenced in the literature and determined from the calibration process along Ford Creek (Section 4.2).

Table 4-1 Roughness values used in the TUFLOW model.

Materials layer	Manning's *n* roughness
timbered areas	0.080
residential	0.300
roads	0.022
creek	0.120
pasture	0.070

4.2 CALIBRATION PROCESS

The hydraulic model was calibrated to the 17 high water marks in Figure 4-1 that were recorded after the 1975 flood (LICS 1996). Whilst the hydraulic roughness values used in the modelling are high (Table 4-1), they are relatively consistent with the previous one-dimensional modelling (Earth Tech 2005). Earth Tech used a channel roughness that varied from 0.09 to 0.15 and a floodplain roughness of 0.07.

The high water marks surveyed from the 1975 flood and the corresponding water levels modelled in TUFLOW are shown in Table 4-2.

One of the calibration points was the stream flow gauge known as Mansfield @Ford Creek, Site Code 405245. The gauge is near the downstream end of the hydraulic model, approximately 1.2-kilometres upstream of the Maroondah Highway (Figure 5-1). The location of the gauge was confirmed from the aerial photography and from the Victorian Water Resources Data Warehouse (longitude 146.05354, latitude -37.03843).

There are a number of discrepancies between the modelled and calibrated flood levels in Table 4-2, including at several of the flood marks downstream of Highett Street. The modelled flood level is higher at several flood marks through this reach, potentially indicating that this channel is not as rough as upstream. However, as the creek is relatively confined and there is little impact on flood extent the roughness was not varied for this downstream reach.

There is a significant difference between the modelled and observed flood levels at Mark No. 10. However, this flood mark is essentially on the same flow path as Marks 9, 11 and 12 where modelled levels calibrate reasonably to the measured levels. Hence, the difference at Mark No. 10 was accepted as changes to the model would only increase discrepancies at the three other flood marks.

The modelled flood level is low at Mark No. 8. However, resolving this issue requires a large increase in roughness that the surrounding flood levels do not justify. For instance the modelled water surface at Mark No. 7 is above the recorded level.

There is a substantial difference between the recorded and modelled flood levels at Mark No's 4 and 5. However, these flood marks are essentially on the same total energy line as adjacent flood marks. Hence the difference between the recorded and modelled levels cannot be resolved without causing substantially larger differences at other flood marks.

Figure 4-1 The high water marks surveyed after the 1975 flood and listed in Table 4-2.

Table 4-2 Results of the calibration of the hydraulic model.

Location (Starting from downstream most location – mark numbers coincide with numbers on source plan FPM0017).	**Observed** Sept 1975 Flood Height (m AHD)	**Modelled** Sept 1975 Flood Height (m AHD)	**Difference** (modelled – observed, m)
Stream flow gauge, Mansfield @Ford Creek (Site Code 405245).	300.78	300.98	0.20
Mark No. 17. North east end of Kitchen St on south side of creek.	314.32	314.38	0.06
Mark No. 16. 60 metres upstream of Mark No. 17 on south side of creek.	314.20	314.58	0.38
Mark No. 15. North west end of McDonald St on south side of creek.	314.72	314.92	0.20
Mark No. 14. Immediately downstream of Highett St on south side of creek.	315.35	315.63	0.28
Mark No. 13. Same location as Mark No. 14.	315.53	315.56	0.03
Mark No. 12. East (upstream) side of Highett Street at Baldry St on south side of creek.	316.17	316.32	0.15
Mark No. 11. On south side of Baldry St, 80 metres east of Mark No. 12.	316.81	316.75	-0.06
Mark No. 10. On north side of Baldry St, 35 metres east of Mark No. 11.	317.21	316.88	-0.33
Mark No. 9. On south side of Baldry St, 35 metres east of Mark No. 10 (at 20 Baldry St).	317.12	317.02	-0.10
Mark No. 8. On north (downstream) side of High St 200 metres west of High Street bridge.	317.94	317.58	-0.36
Mark No. 7. At the High St bridge	317.80	318.06	0.26

Location (Starting from downstream most location – mark numbers coincide with numbers on source plan FPM0017).	**Observed** Sept 1975 Flood Height (m AHD)	**Modelled** Sept 1975 Flood Height (m AHD)	**Difference** (modelled – observed, m)
Mark No. 6. On south (upstream) side of High St, 120 metres west of High St bridge.	318.28	318.42	0.14
Mark No. 5. 110 metres south west (upstream) of the High St bridge.	318.74	318.43	-0.31
Mark No. 4. At house located on south side of High St / Mount Battery Road intersection.	319.23	318.90	-0.33
Mark No. 3. On east side of northern end of New Street.	318.53	318.57	0.04
Mark No. 2. At 13 Aisla St.	319.01	318.94	-0.07
Mark No. 1. At 11 Aisla St.	319.15	319.15	0.00

5 FLOOD INUNDATION

The 1975 flood was determined to have an average recurrence interval of 100-years (Section 2.1). The calibration of the hydraulic model to the 1975 flood levels (Table 4-2) produced an extent of inundation for the 100-year ARI flood that is shown in Figure 5-1.

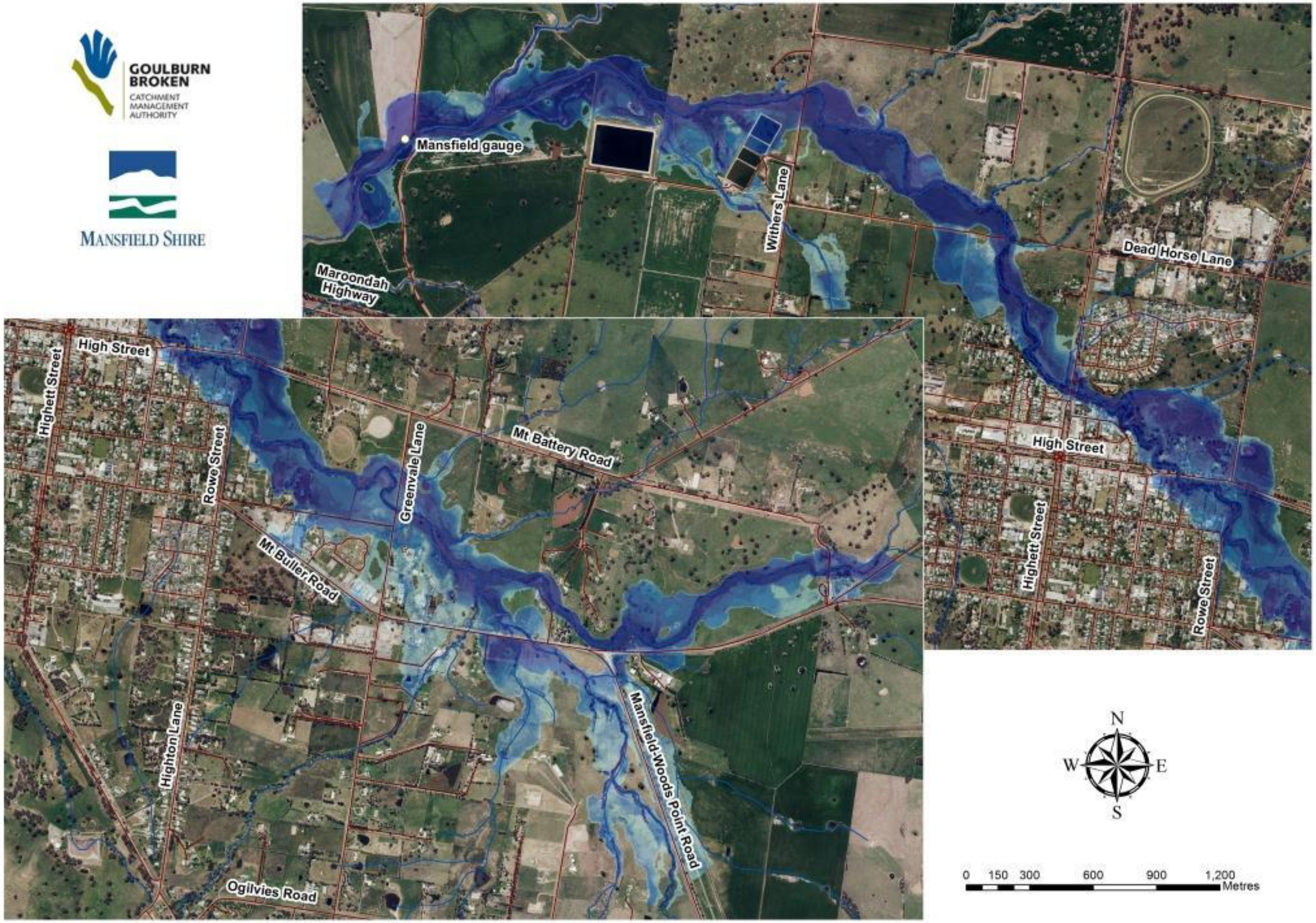


Figure 5-1 The extent of flooding in a 100-year ARI type flood.

6 RECOMMENDATIONS

The recommendations from this hydraulic and flood mapping project are set out in Sections 6.1, 6.2 and 6.3.

6.1 REVISED FLOOD LEVELS

It is recommended that the 1% AEP (100-year ARI) flood levels determined from this flood study (Figure 6-1) are used to set appropriate floor heights for buildings and extensions proposed in the study area.

6.2 MUNICIPAL FLOOD EMERGENCY PLAN

It is recommended that the Municipal Flood Emergency Plan (MFEP) be updated by Mansfield Shire to reflect the outcomes of this flood study.

6.3 FLOOD ZONES AND OVERLAYS IN THE MANSFIELD PLANNING SCHEME

It is recommended that the zones and overlays in the Mansfield Planning Scheme be amended to reflect those shown in Figure 6-2. The Floodway Overlay (FO) and Urban Floodway Zone (UFZ) cover areas where, in the 100-year ARI flood, either the depth of flow exceeds 0.35 metres or the product of depth and velocity is 0.4 m^2/sec or greater. The depth of flooding of 0.35 metres was overwhelmingly the dominant criterion for determining the extent of the FO and UFZ. The Land Subject to Inundation Overlay (LSIO) covers all other areas that are inundated in the 100-year ARI flood.

Note, the overlays and zones from this study have been merged with the existing data in the VFD in Figure 6-2; hence the extent of overlays exceeds the extent of this study.

It is recommended that the zones and overlays shown in Figure 6-2 are to form part of the revised Mansfield Planning Scheme Amendment C15.

GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

MANSFIELD SHIRE

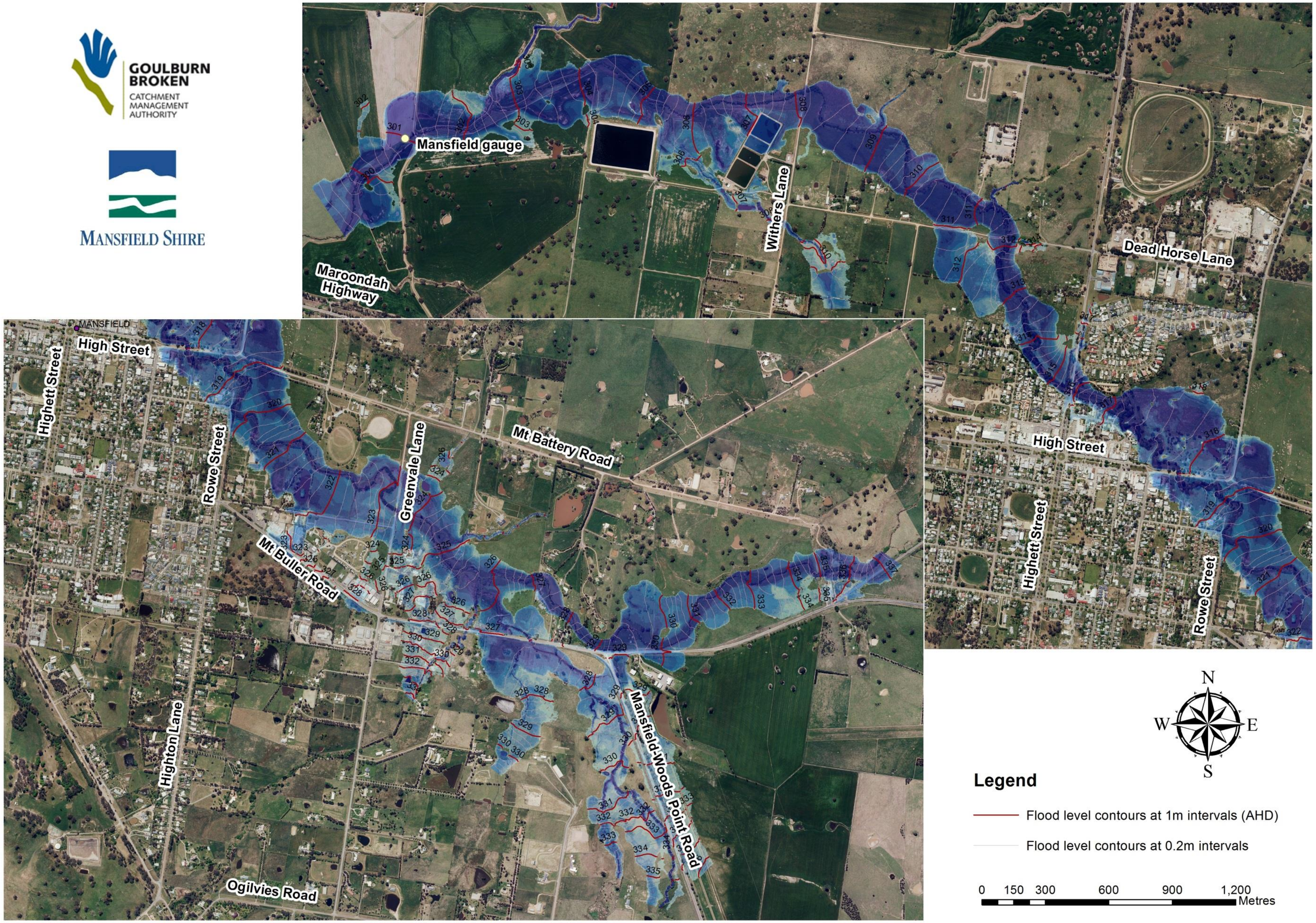


Figure 6-1 Recommended 100-year ARI flood levels determined from this flood study and shown at 1 metre intervals.

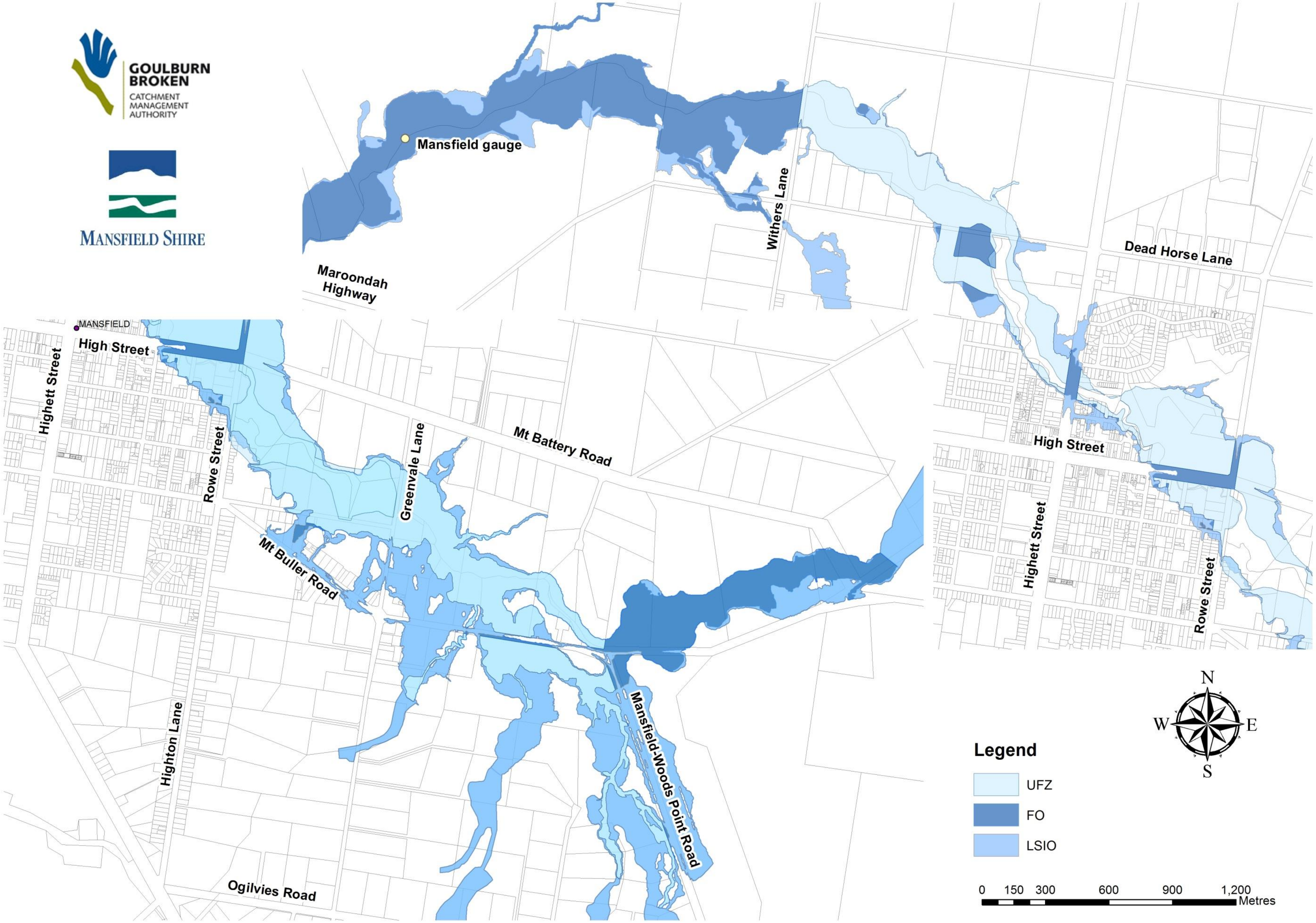


Figure 6-2 Recommended flood zone (UFZ) and overlays (FO & LSIO) for the Mansfield Planning Scheme Amendment C15.

7 REFERENCES

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