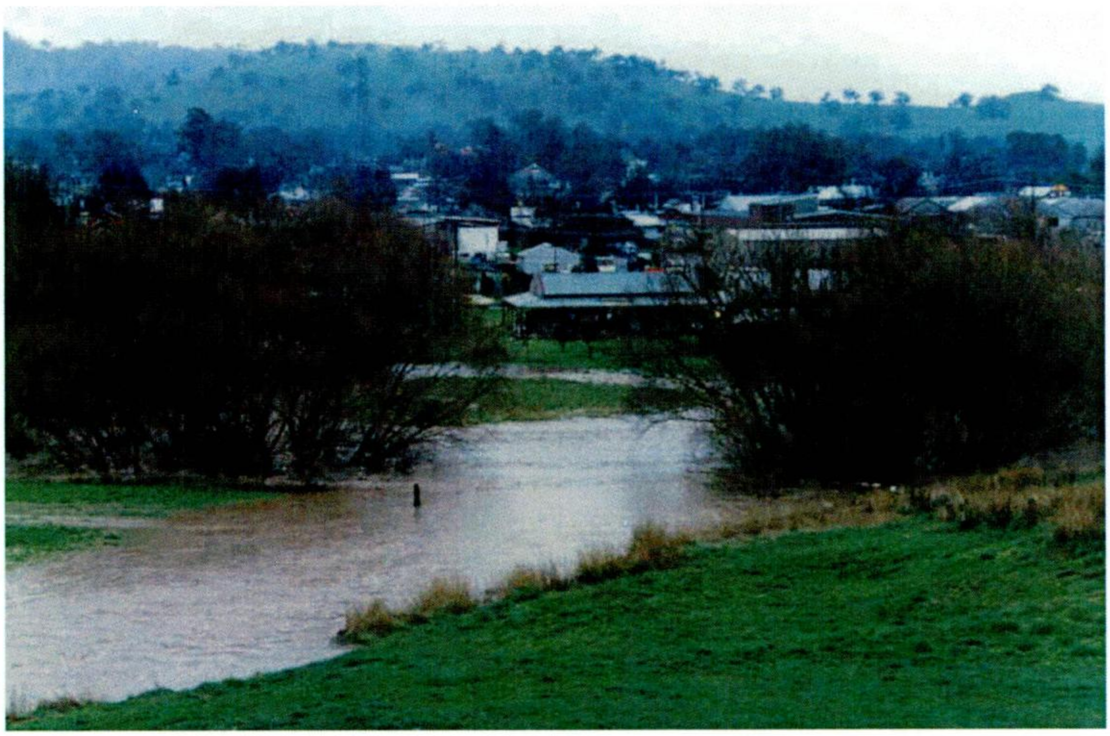
MANSFIELD SHIRE

Mansfield Flood Study

Final Report



November 2005

EarthTech

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Mansfield Flood Study

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Executive Summary

The Mansfield Flood Study was commissioned by the Mansfield Shire Council and the Goulburn Broken Catchment Management Authority (CMA) to gain an improved understanding of the flood risks within Mansfield posed by Ford Creek. Low lying parts of the township have been most notably affected by creek flooding in September 1975 and October 1993 since detailed records commenced in 1970.

Scope

The Flood Study documents the following investigations:

- Hydrologic analysis of the available streamflow data for Ford Creek leading to the adoption of design flood flows.
- Hydraulic analysis of the Ford Creek floodplain between Greenvale Lane and Dead Horse Lane using hydraulic modelling techniques and survey data obtained specifically for the study.
- Flood mapping derived from the hydraulic analysis which delineates the 100-year average recurrence interval (ARI) flood height contours, 100-year ARI flood extents and the extent of the floodway and land subject to inundation (LSI) overlay areas.
- Flood damage estimates derived using the rapid assessment method (RAM).
- Review of the need for flood mitigation measures given the level of risk identified.

All residents on the floodplain were notified of the study via letters mailed to residents in June 2005 and September 2005. Interviews with numerous residents were conducted to draw on their observations during past floods. The two largest floods during the past 35 years (September 1975 and October 1993) both rose, peaked and receded during the course of a single night, thereby severly limiting any opportunties for photographic records.

Outcomes

The following principle outcomes were derived from the study:

- Flood frequency analysis identified the September 1975 flood as being indicative of a 100-year ARI flood.
- Hydraulic modelling undertaken resulted in the successful calibration of an XP-STORM hydraulic model against the available recorded 1975 flood heights (refer Figure A1).
- The resulting defined 100-year average recurrence interval (ARI) flood height contours and flood extents derived directly from the 1975 event calibration are given on Figure A2.
- The resulting defined floodway and land subject to inundation (LSI) overlay areas based on a consideration of the frequency and severity of flooding are given on Figure A3.
- The rapid appraisal method (RAM) computed average annual flood damages for the study area is a relatively low $55,000/annum.

Recommendations

The following recomendations arising from the study outcomes are made:

- The 1975 recorded peak flow is to be adopted as representative of the 100-year ARI flood.
- The newly defined 100-year ARI flood level contours and flood extents are to be added to the Victorian Flood Database and adopted by the Mansfield Shire Council and the Goulburn Broken CMA for planning control purposes. The Goulburn Broken CMA are to declare the 100-year ARI flood level contours under the provisions of the Water Act, 1989.
- The mapped floodway and LSI areas are to be added to the Victorian Flood Database and incorporated into the Mansfield Shire Council's planning scheme.
- A floor level survey should be undertaken to provide a definitive database of those buildings subject to 100-year ARI above floor flooding.
- The development of a detailed flood mitigation strategy for Mansfield is not warranted on the basis of the identified relatively low average annual flood induced damages.

1. Introduction

The township of Mansfield is located on the fringe of the Ford Creek floodplain, 5 km east of Lake Eildon. Past flooding at Mansfield has occurred most notably in 1975 and 1993 leading to flooding of existing development in low lying areas including inundation of some houses.

The Mansfield Flood Study was commissioned by the Mansfield Shire Council and the Goulburn Broken Catchment Management Authority (CMA) to gain an improved understanding of flooding risks at Mansfield. The study will also assist in planning for future development by providing improved flood mapping to enable flood risks to be better taken into account.

The study has been funded by the Natural Disaster Risk Management Studies Program, with matching funding provided by the Victorian State Government, the Goulburn Broken CMA and the Mansfield Shire Council.

The study is the first major investigation into Ford Creek flooding covering the whole of the Mansfield township area. Flood related considerations in relation to new development have for the past thirty years principally relied on a relatively small number of recorded flood heights from the 1975 flood.

The study area extends from Dead Horse Lane (downstream limit) to Greenvale Lane (upstream limit). The study objectives are as follows:

- To obtain and review all available flood related information.
- To review the equivalent frequency of past significant flood events.
- To identify design event flows and flood levels for the 5, 10, 20, 50 and 100-year average recurrence interval (ARI) floods.
- To produce flood level and flood extent mapping for the 100-year ARI flood.
- To map the extent of the floodway and land subject to inundation (LSI) areas.
- To carry out an assessment of flood impacts / damages.
- To carry out a preliminary review of what flood mitigation measures might be considered to minimise future flood damages.

2. Available Data

2.1 Catchment and Study Area Description

The Ford Creek catchment upstream of Mansfield is shown on Figure 2.1. The creek has a catchment area of 84 km^2 at the Highett Street bridge in Mansfield. The township has a population of 2,300.

The catchment headwaters are located 13 km east of Mansfield. The catchment terrain falls from a high of 770 metres AHD at its eastern most point to 320 metres AHD at Mansfield. The catchment is largely cleared, with generally only low density scattered trees remaining. Grazing is the predominant land use within the catchment.

Ford Creek outfalls into Lake Eildon approximately 7 km downstream of Mansfield. The only streamflow measurement station on Ford Creek is located midway between Mansfield and Lake Eildon (refer Figure 2.1).

The study area floodplain extends from Dead Horse Lane at its downstream limit, to Greenvale Lane at its upstream limit.

Ford Creek is an incised stream channel within the study area reach. The bed of the creek is typically 3 to 5 metres below the top of bank level. Rock bars are visible within the stream bed at various location within Mansfield, thereby limiting any further bed incision.

Prior to 1993, the creek channel had extensive willow growth within the township. Extensive willow removal works were undertaken during and after 1993 to address both the bank stabilisation and discharge capacity issues associated with the willows choking the creek.

Existing development is located on much of the southern fringe of the floodplain within the study area. More recent development on the north side of the creek upstream of Highett Street is located on high ground above the floodplain.

2.2 Streamflow Data

A streamflow measurement gauging station was established on Ford Creek in 1970 at a site located 4 km downstream of the Highett Street bridge. The station (405245) has operated continuously since June 1970.

The catchment area draining to the gauge site is 115 km^2 (refer Figure 2.1). The estimated approximate lag between flooding peaking in Mansfield and peaking at the gauge site is 1 hour.

Gauged streamflow data for the Ford Creek station for the 35 years of available records was obtained for flood frequency analysis carried out as part of the current study (refer Section 3).

The ten largest floods to have occurred since the gauging station commenced operating are listed in Table 2.1. Clearly the two largest floods during this period are floods that occurred in September 1975 and October 1993.

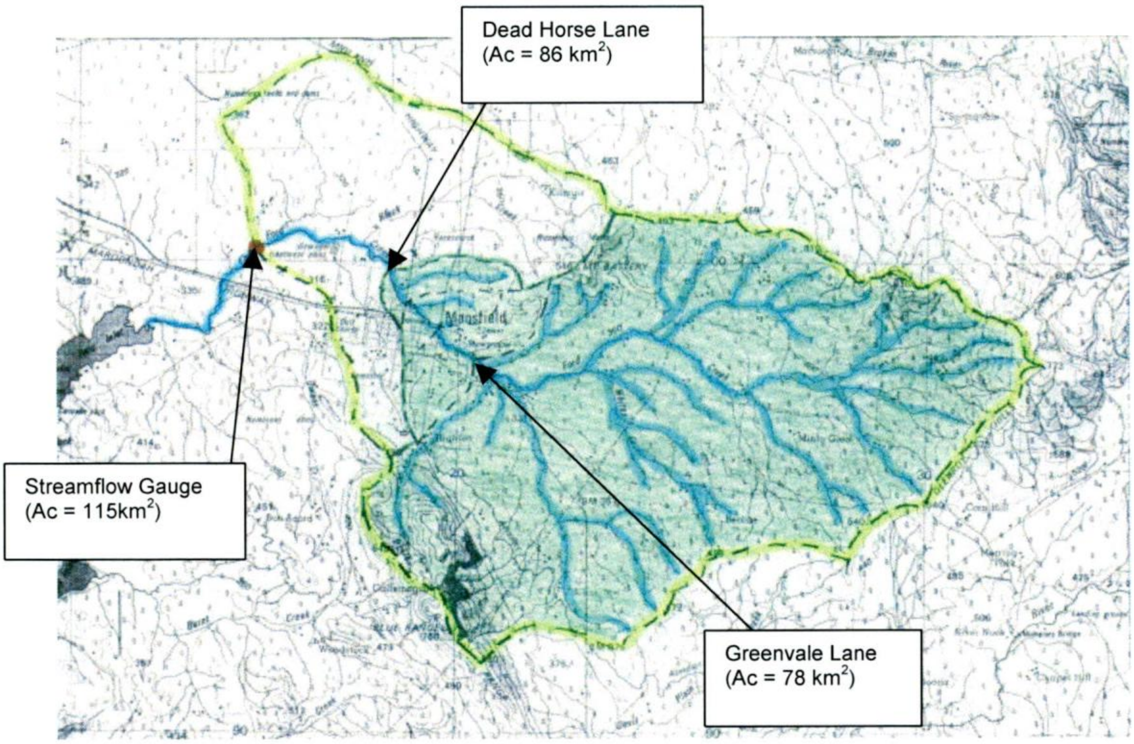


Figure 2.1 Ford Creek Catchment Plan

Table 2.1 Ten Largest Recorded Flood Events (since 1970)

Rank	Event Data	Peak Flow (m^3/s)	Peak Stage (metres)	Equivalent ARI * (years)
1	September 1975	232	4.34	100
2	October 1993	167	3.99	35
3	August 1970	106	3.42	11
4	June 1995	82	3.28	7
5	September 1978	81	3.27	7
6	October 1992	80	3.26	7
7	July 1990	72	3.15	5
8	October 1996	68	3.08	5
9	September 1973	66	2.89	5
10	October 2000	61	2.95	4

Note:

1.*Equivalent ARI based on the results of flood frequency analysis documented in Section 3.

2.3 Description of Significant Past Flood Events

2.3.1 September 1975 flood

The September 1975 flood is clearly the highest flood experienced since records commenced in June 1970. The 1975 flood characteristics are described as follows:

- Moderate flood event occurred 5 days prior to the main flood, peaking at 81 m^3/s on the 13 September 1975.
- Main flood peaked at 12.20am on the 18 September 1975, with a peak flow of 232 m^3/s recorded at the gauging station.
- 24 hour rainfall recorded at the Mansfield post office prior to 9.00am on the 18 September 1975 was 53 mm.
- The time taken from when the creek water level started to rise at the gauging station, to when the peak flow was recorded shortly after midnight, was approximately 6 hours.
- Peak flow had receded to 77 m^3/s by 6.00am on the 18 September 1975.

The September 1975 flood was over within a period of approximately 12 hours during the night. There is therefore no flood photography of this event. The occurrence of the moderate flood only a few days prior to the main flood will have resulted in very low rainfall losses and been a major factor in contributing to the severity of the flood. This is highlighted by the relatively low 24 hour rainfall total of 53 mm at Mansfield on the day of the flood, although significantly higher rainfall totals may have occurred in the upstream catchment areas.

Despite the flood occurring at night, there are a number of recorded flood height marks within Mansfield for this event (refer Figure A1 in Appendix A). These flood height marks were used for the hydraulic analysis detailed in Section 4.

2.3.2 October 1993 flood

The October 1993 flood was a widespread flood principally affecting the Ovens, Broken and Goulburn River catchments. The 1993 flood characteristics at Mansfield are described as follows:

- Minor flood peaks experienced on 2 September (42 m^3/s), 8 September (56 m^3/s) and 15 September (51 m^3/s) prior to the main flood event in early October 1993.
- Main flood peaked at 12.30am on the 4 October 1993, with a peak flow of 167 m^3/s recorded at the gauging station.
- 24 hour rainfall recorded at the Mansfield post office prior to 9.00am on the 4 October 1993 was 113 mm (highest 24 hour total on record dating back to 1901).
- Flood level rose over a period of approximately ten hours prior to peaking 30 minutes after midnight.
- Peak flow had receded to 67 m^3/s by 6.30am on the 4 October 1993.

The 1993 flood was therefore similar to the 1975 flood in that it rose and fell during the night. Rainfall loss rates would appear to have been higher than 1975 given the substantially higher 24 hour rainfall total for the 1993 flood. This is consistent with the absence of significant rainfall in the two weeks prior to the 1993 flood based on recorded rainfall at Mansfield.

2.4 Other Data

2.4.1 Survey Data

Various sources of ground survey information were identified. They are summarised as follows:

- Survey undertaken by the then State Rivers and Water Supply Commission (SR&WSC) in 1978. Survey consisted of 37 cross sections and structure details of road bridges.
- Survey plans prepared for the Mansfield Sewerage Authority in 1967. Survey restricted to certain developed areas on the south side of the creek. Contours prepared at 0.3 metre (1 foot) intervals. Floor levels of buildings given on plans.
- Several surveys undertaken by consultants associated with land development proposals.

2.4.2 Structures

Council provided information in relation to waterway structures within the study area reach. Details are summarised as follows:

- Dead Horse Lane crossing. Low level causeway with low flows conveyed by box culverts.
- Highett Street bridge. Constructed in 1939. Only marginally perched with 30 metre span. Overtopped in 1975 and 1993.
- Footbridge upstream of Highett Street. Constructed between 1975 and 1993. Perched above the adjoining Highett Street road bridge.
- Footbridge 300 metres upstream of Highett Street. Constructed in 1993. Perched significantly above the floodplain.
- Footbridge downstream of High Street. Constructed in 2004. Perched above the adjoining High Street road bridge.
- High Street bridge. Constructed in 1972. Only marginally perched with a 23 metre span.
- Greenvale Lane bridge. Constructed pre 1975. Significantly perched above the floodplain with a 28 metre span.

2.4.3 Photography

There is no aerial flood photography for Mansfield. The two most significant floods by far over the past 35 years occurred at night, with little or no opportunities for aerial or ground level photography for either of these events.

Council provided photographs of flood events in July 1990, December 1992 and September 1993 (prior to main flood in October 1993). These floods are in the vicinity of 5-year ARI events. A number of residents also had photographs of various past minor floods.

2.4.4 Flood Heights

Available recorded flood heights within the study area are principally limited to the September 1975 flood. These heights were of particular use for the hydraulic modelling documented in Section 4. Most of the recorded 1975 heights are documented on a plan prepared in 1996 for the Department of Conservation and Natural Resources (Drawing Number FPM0017). These same heights were later added to the Victorian Flood Database when it was set up in the late 1990's.

There were previously no recorded flood heights from the 1993 flood. This will in part have been due to severe flooding in other towns (e.g. Benalla, Wangaratta) where major efforts were focused on collecting data. A resident at 2 McDonald Street provided a 1993 flood height when interviewed during the course of this study.

2.4.5 Resident Interviews

Interviews with various local residents were held regarding flooding observations. A major limiting factor in the level of detail and reliability of accounts was the occurrence of both major floods (1975 and 1993) during darkness, where both floods rose, peaked and receded during the night.

Notable anecdotal information obtained from various interviews is summarised as follows:

- Residents of the house at 11 Ailsa Street since 1942 have advised that the house has been flooded on three occasions, 1956, 1975 and 1993. Flooding most severe in the 1975 flood.
- House at 9 Ailsa Street was flooded to a depth of '*6 to 9 inches*' in the 1975 flood.
- House at 4 High Street (house closest to west side of creek on the upstream side of High Street) was flooded to above floor level in the 1993 and 1975 floods.
- House located at the corner of the Mount Battery Road and Mansfield Whitfield Road was flooded to above floor level in the 1993 and 1975 events.
- The now abandoned house at 17 Baldry Street was flooded to above floor level in the 1975 flood, with the house not believed to have been flooded previously until at least prior to 1940.

The Mansfield Historical Society provided clippings of articles associated with past flood events. These included the following:

- **November 1887** article referring to largest floods at Mansfield in memory. Highett Street reported as being under water between Ford Creek and Shire Hall. Damage reported to dwellings, bridges and fences.
- **October 1894** article referring to the largest flood ever seen in Mansfield. Article refers to damage to several bridges, residents having to leave their dwellings and rapid rise of flood levels within the space of one hour.
- **September 1916** article referring to the largest flood at Mansfield in 22 years (i.e. since 1894). Article notes that water backed up to corner Chenery and High Streets and makes reference to house flooding, although no addresses given. This flood coincides with the Benalla flood of 24 September 1916. The 24 hour rainfall total at Mansfield to 9.00am on this day was 55mm, with 30 mm on the preceding day.

3. Hydrology

3.1 Methodology

The aim of the hydrologic analysis was as follows:

- To establish the equivalent frequencies of past significant flood events.
- To derive design flows for the study area for subsequent input into the hydraulic modelling.

Flood frequency analysis of the 35 years of available streamflow records was undertaken to derive the above outcomes at the gauging site.

The reduction in design flows within the study area to account for the intervening catchment area between the gauge site and the study area reach were based on the ratio of the respective contributing catchment areas proportional to a recognised regionally based formula (peak flow = 4.67 x catchment area $^{0.763}$).

3.2 Flood Frequency Analysis

The results of flood frequency analysis for the 35 years of available records are given in Table 3.1. The results are based on fitting the data to a log-pearson type III distribution after omitting the five lowest annual recorded flows to achieve a positive skew.

Table 3.1 Flood Frequency Analysis (1970-2004)

ARI (years)	Peak Design Flow (m^3/s)	95% Confidence Limits (m^3/s)
5	74	57 - 96
10	102	74 - 141
20	134	90 - 200
50	183	108 - 311
100	225	119 - 426

The results of the flood frequency analysis give an equivalent ARI of just marginally in excess of 100-year ARI for the September 1975 flood. The period of available record is still relatively short (35 years) with the 95% confidence limit flow range still very wide for the 100-year ARI flood.

In view of the broad confidence limits for the flood frequency derived 100-year ARI flow, it is considered appropriate to adopt the 1975 event recorded peak flow (232 m^3/s) as the 100-year ARI design flow.

An alternative estimate of the 100-year peak flow can be derived from a regression analysis derived equation applicable to catchments exceeding 30 km^2 in area located in the vicinity of the Great Dividing Range. Application of this equation ($4.67 \times Area^{0.763}$) gives a 100-year ARI peak flow of 174 m^3/s at the gauging station site based on the contributing catchment area of 115 km^2.

Consideration of the regression analysis derived 100-year flow estimate would suggest that the 1975 attributed peak of 232 m^3/s is, if anything, likely to lie at the upper range end of estimates for the 100-year ARI flow.

In view of the available data, the recommended 100-year ARI design flow at Mansfield coincides with the September 1975 flood event estimated flows. The adjusted design flows for the study area after taking account of the intervening catchment area between the streamflow gauging station and Mansfield are given in Table 3.2.

Table 3.2 Adopted Design Event Peak Flows

Design ARI (years)	Peak Design Flow (m^3/s)		
	At streamflow gauge site (Ac = 115 km^2)	At Dead Horse Lane (Ac = 86 km^2)	At Greenvale Lane (Ac = 78 km^2)
5	74	59	55
10	102	82	76
20	134	107	100
50	183	147	136
100	232	186	173

Note:

1. Design flow at Mansfield based on the ratio of the respective contributing catchment areas proportional to a recognised regionally based formula (peak flow = 4.67 x catchment area $^{0.763}$).

4. Hydraulics

4.1 Approach

Hydraulic modelling within the study area floodplain was carried out to estimate water surface elevations, velocities and flow distributions. The modelling output directly identifies flood levels for a range of design floods (5, 10, 20, 50 and 100 year ARI events) and provides for an understanding of the severity of flooding across the floodplain. This in turn allowed for the revised delineation of the flood overlay areas for incorporation into Council's planning scheme (i.e. LSI overlay and floodway overlay).

The modelling was carried out using the XP-STORM hydraulic model. This model is a dynamic flood routing model capable of both steady flow and unsteady flow simulations. The model routes inflows through the floodplain system and computes the time history of flows and heads throughout the system.

The XP-STORM model can be used to model open channel flow via a series of floodplain cross sections. It can also simulate flow behaviour through all manner of hydraulic structures including bridges and culverts.

4.2 Model Assembly

As part of this study, a new detailed set of creek and floodplain cross section survey was carried out. This data can be found on the project DVD. The cross sections were used as the basis for the delineation of the floodplain geometry. Model cross section locations are shown on Figure A1 in Appendix A.

Survey data was also obtained at bridge locations. Data obtained included cross sections at the bridge openings, span widths, pier dimensions, soffit elevations, deck levels and a cross section parallel with the road crown centreline.

An anabranch type flow path was set up within the model for simulating flooding behaviour east of the High Street bridge. Flooding behaviour in this reach is somewhat complex, with the low point for road overflows located 200 metres east of the High Street bridge, prior to the Mount Battery Road intersection. Road overflows also occur across Mount Battery Road itself east of the High Street intersection.

4.3 Model Calibration

The hydraulic model was calibrated using recorded flood levels for the September 1975 flood. As discussed in Section 3, the 1975 flood is the largest flood on record and indicative of a 100-year ARI design event.

Recorded flood heights for the 1975 flood are documented on a plan prepared in 1996 for the Department of Conservation and Natural Resources. The recorded flood levels are of varying reliability.

The calibration of the hydraulic model involves adjusting model parameters until a satisfactory level of agreement is achieved between the modelled flood levels and in this instance the recorded 1975 flood levels. This process involved the following:

- Steady state peak flows input into the hydraulic model based on the peak gauged flow for the 1975 flood reduced in accordance with the ratio of the respective contributing catchment areas as determined using a recognised regionally based formula (refer Table 3.2).
- Adjusting the Manning roughness values within both the creek channel and the adjoining floodplain overbank areas for each cross section reach.
- Adjusting the loss coefficients at the two road bridges within the study area (Highett Street and the High Street bridges).

The recorded 1975 flood peak flow at the streamflow gauging station site 3 km downstream of Dead Horse Lane is 232 m^3/s. The reduced peak flows after accounting for the intervening catchment areas are 186 m^3/s at Dead Horse Lane (downstream limit of modelling) and 173 m^3/s at Greenvale Lane (upstream limit of modelling).

The calibration process is complicated by the uncertainty surrounding the reliability of the available recorded flood height marks. Some of the marks assigned a 'good' reliability rating on the source plan are highly suspect given their incompatibility with other nearby marks (e.g. scenario where mark downstream is higher than the mark upstream).

The location of the 1975 flood height marks used in the hydraulic model calibration process is shown on Figure A1 in Appendix A. A summary of the calibrated and modelled flood heights is provided in Table 4.1. The level of agreement achieved was generally within +/- 0.3 metre, considered to represent a good outcome given the uncertainty surrounding the accuracy of some of the marks.

A discussion of the calibration process for the study area is provided as follows.

4.3.1 Dead Horse Lane to Highett Street

Modelling within this reach was complicated by the absence of recorded flood heights in the vicinity of Dead Horse Lane. The downstream boundary water level condition assigned to the model is based on a normal flow depth calculation. The resulting modelled 1975 flood level at the Dead Horse Lane crossing is 312.6 m AHD. The overflow road level at the crossing is 4.1 metres below the modelled flood level.

There are five 1975 recorded flood height marks within the 250 metre reach downstream of the Highett Street bridge. Modelled flood levels vary by up to 0.3 metre in comparison to the observed flood heights, with no consistent trend either above or below. The Mannings roughness values assigned (0.09 for main channel and 0.07 for overbank areas) are if anything considered conservatively high (i.e. higher than actual existing physical conditions would appear to warrant).

The accuracy of Mark No. 15 is considered suspect. A nearby flood height mark for the October 1993 flood of 314.93 m AHD was obtained as part of the current study at 2 McDonald Street. This would suggest Mark No. 15 is overly low as the modelled level suggests.

Table 4.1 Hydraulic Model Calibration Results

Location (mark numbers coincide with numbers on source plan FPM0017).	September 1975 Flood Height (m AHD)		Difference (m)
	Observed	Modelled	
Mark No. 1. At 11 Aisla St.	319.15	319.1	-0.05
Mark No. 2. At 13 Aisla St.	319.01	319.1	+0.09
Mark No. 3. On east side of northern end of New Street.	318.53	318.9	+0.37
Mark No. 4. At house located on south side of High St / Mount Battery Road intersection.	319.23	319.0	-0.23
Mark No. 5. 110 metres south west (upstream) of the High St bridge.	318.74	318.7	-0.04
Mark No. 6. On south (upstream) side of High St, 120 metres west of High St bridge.	318.28	318.6	+0.32
Mark No. 7. At the High St bridge	317.80	318.2	+0.40
Mark No. 8. On north (downstream) side of High St 200 metres west of High Street bridge.	317.94	318.0	+0.06
Mark No. 9. On south side of Baldry St, 35 metres east of Mark No. 10 (at 20 Baldry St).	317.12	317.0	-0.12
Mark No. 10. On north side of Baldry St, 35 metres east of Mark No. 11.	317.21	316.9	-0.31
Mark No. 11. On south side of Baldry St, 80 metres east of Mark No. 12.	316.81	316.7	-0.11
Mark No. 12. East (upstream) side of Highett Street at Baldry St on south side of creek.	316.17	316.2	+0.03
Mark No. 13. Same location as Mark No. 14.	315.53	315.3	-0.23
Mark No. 14. Immediately downstream of Highett St on south side of creek.	315.35	315.3	-0.05
Mark No. 15. North west end of McDonald St on south side of creek.	314.72	315.0	+0.28
Mark No. 16. 60 metres upstream of Mark No. 17 on south side of creek.	314.20	314.5	+0.30
Mark No. 17. North east end of Kitchen St on south side of creek.	314.32	314.2	-0.12

Note: Flood height mark locations are shown on Figure A1 in Appendix A.

4.3.2 Highett Street Bridge

The modelled afflux at the High Street bridge for 1975 event flow conditions is approximately 0.4 metre. The low point in the road is located 90 metres north of the bridge. The road low point is actually 0.36 metre below the bridge soffit level. This means the road is overtopped prior to the water level reaching the bottom of the bridge deck. The depth of overtopping at the road low point is 0.9 metre. The depth of overtopping at the bridge deck itself is 0.2 to 0.3 metre.

The 1975 event modelled flow split at the Highett Street bridge is as follows:

- Flow through bridge opening 85 m^3/s (velocity 1.3 m/s).
- Flow over roadway 101 m^3/s (velocity 0.9 m/s).

Given the degree of overtopping, the modelled afflux is considered reasonable. The modelled upstream flood level a short distance upstream of the bridge is within 0.1 metre of Flood Mark No. 12.

4.3.3 Highett Street to High Street

The observed flood marks towards the downstream end of this reach are all located on the south side of the creek on Baldry Street properties. Modelled flood levels are within 0.3 metre of these observed levels. This level of agreement is again considered good, particularly given that Mark No. 10 is suspect, given its elevation and location relative to Mark No. 9. An interview with a resident in Baldry Street indicates that Mark No. 9 should be within +/- 0.1 metre.

In-channel stream roughness value of 0.12 and overbank roughness values of 0.07 were adopted for this reach. These values are quite high, particularly when compared with current creek conditions.

4.3.4 High Street / Mount Battery Road

Modelling of flows in the vicinity of High Street was carried out as follows:

- Flow path set up for the bridge and road overflows in the immediate vicinity of the bridge.
- Flow path set up for road overflows for the section of High Street extending 160 metres west of the Mount Battery Road intersection.
- Flow path set up for road overflows across Mount Battery Road east of the High Street intersection.

The resulting modelled flow characteristics in the 1975 event are as follows:

- Flow through bridge opening 75 m^3/s, velocity 1.3 m/s, afflux 0.44 metre, no overflows over bridge deck itself (0.1 metre freeboard).
- High Street road overflows west of bride 2 m^3/s, velocity 0.3 m/s, maximum depth 0.14 metre.
- High Street road overflows west of Mount Battery Road intersection 89 m^3/s, velocity 0.4 m/s, maximum depth 0.8 metre.
- Mount Battery Road overflows east of High Street intersection 17 m^3/s, velocity 0.1 m/s, maximum depth 0.6 metre.

The modelled flood levels on the upstream side of High Street and Mount Battery Road are within 0.4 metre of the recorded flood levels (Flood Marks No.'s 4, 5, 6 and 7). Two of these marks (Mark No.'s 4 and 7) are however described as poor or suspect by their source plan.

4.3.4 Rowe Street / Ailsa Street

Three further 1975 flood height marks (Mark No.'s 1, 2 and 3) are located in Ailsa Street and New Street. The modelled levels at Mark No.'s 1 and 2 are within 0.2 metre of the recorded levels. The mark at 11 Aisla Street (Mark No. 1) is considered very reliable as advised by a retired shire engineer who was a resident at this address at the time of the 1975 flood.

The modelled level at Mark No. 3 in New Street is 0.37 metre above the recorded level. The reliability of Mark No. 3 is considered suspect, given that it is higher than the downstream Mark No. 5.

4.3.5 Rowe Street to Greenvale Lane

There are no well documented recorded flood heights for this reach. A 1988 land development plan includes a 1975 flood extent line based on observations by an unnamed landholder on the south side of Reardon Lane for a distance of 400 metres west of Greenvale Lane. The reliability of this data is unknown. The modelled flood levels at this location are up to 0.3 metre lower than the landholder observed levels. The modelled profile is based on using a very high in-channel roughness of 0.15 and overbank roughness values of 0.07.

The 1975 modelled flood profile results in Greenvale Lane being effectively drowned out with negligible afflux. The bridge itself is perched up to 1.5 metres above the adjoining floodplain and remains above the 1975 flood level. Road overflows on the south side approach are up to 0.7 metre deep, whilst road overflows on the north side approach are up to 1.2 metres deep.

4.4 Model Validation

October 1993 Flood

The October 1993 flood was equivalent to around a 35-year ARI flood (refer Table 2.1). Very little data in the form of recorded flood heights and photographic data is available for the 1993 flood. The flood rose, peaked and receded during the night and given the severity of flooding in other locations (e.g. Benalla), efforts to document flooding were focussed elsewhere.

A 1993 flood height mark was obtained at 2 McDonald Street as part of the current survey for this study. The modelled flood level at this location based on the same model set-up and parameter values adopted for the 1975 flood calibration is 314.9 m AHD. This is in very good agreement with the observed level of 314.93 m AHD.

Other modelled output from the October 1993 flood is as follows:

- Highett Street bridge – bridge opening flow 87 m^3/s, afflux 0.38 metre, road overflows 47m^3/s, afflux 0.38 metre, maximum depth road overflows 0.6 metre.
- High Street bridge – bridge opening flow 62 m^3/s, afflux 0.28 metre, no road overflows west of bridge, 62 m^3/s over High Street west of Mount Battery Road intersection, 7 m^3/s over Mount Battery Road east of High Street intersection.

July 1990 Flood

The July 1990 flood was equivalent to around a 5-year ARI flood (refer Table 2.1). The flood peaked during the early afternoon. A photograph of High Street between the bridge and Mount Battery Road (refer Photographs 1 and 2) shows the road overtopped by floodwaters.

The modelled 1990 flood High Street road overflows west of the Mount Battery Road intersection based on the same model set-up and parameter values adopted for the 1975 flood calibration is 9 m^3/s and coincides with a maximum depth of overtopping of 0.25 metre. This would appear to be similar to conditions in Photograph 1. The hydraulic model indicates that Mount Battery Road east of the High Street intersection is only very marginally overtopped (flow less than 0.5 m^3/s).

Photograph 1 High Street looking towards the Mount Battery Road intersection – 18 July 1990 (approximately 5-year ARI flood)

Photograph 2 High Street looking towards the Ford Creek bridge – 18 July 1990 (approximately 5-year ARI flood)

5. Design Flood Hydraulic Modelling Outputs

5.1 Approach

The calibrated hydraulic model described in the preceding section was used to simulate flooding for the 5, 10, 20, 50 and 100-year ARI floods. The steady state peak flow inputs into the hydraulic model are those listed in Table 3.2.

Model parameters (roughness values) were not altered from those derived from the 1975 event calibration. Current floodplain conditions are if anything likely to be more favourable for flood conveyance efficiency compared to the early 1990s (pre 1993) given the willow removal works implemented since early 1993.

5.2 Modelled Flood Levels

Modelled flood levels at cross section locations are given in Table 5.1. Modelling results have identified the following characteristics:

- Flood level differentials between the respective design events are:
    - 50-year ARI flood – average of 0.2 metre below the 100-year ARI flood levels.
    - 20-year ARI flood – average of 0.4 metre below the 100-year ARI flood levels.
    - 10-year ARI flood – average of 0.6 metre below the 100-year ARI flood levels.
    - 5-year ARI flood – average of 0.8 metre below the 100-year ARI flood levels.
- Dead Horse Lane overtopping threshold is equivalent to less than a 1-year ARI flood.
- Highett Street (Midland Highway) overtopping threshold is equivalent to a 10-year ARI flood.
- High Street (Mansfield Whitfield Road) overtopping threshold is equivalent to between a 2 to 5-year ARI flood.
- Mount Battery Road overtopping threshold is equivalent to a 5-year ARI flood.
- Greenvale Lane overtopping threshold is equivalent to a 2-year ARI flood.

Table 5.1 Design Flood Levels

Cross Section No.	Design Flood level (m AHD)				
	5-year ARI	10-year ARI	20-year ARI	50-year ARI	100-year ARI
1	311.68	311.90	312.12	312.38	312.63
2	311.67	311.94	312.16	312.42	312.66
3	312.08	312.26	312.43	312.66	312.87
4	312.47	312.66	312.83	313.07	313.30
5	313.01	313.31	313.50	313.72	313.92
6	314.16	314.40	314.69	314.93	315.10
7	314.45	314.75	314.98	315.20	315.38
8	314.72	315.18	315.44	315.64	315.81
9	314.80	315.26	315.55	315.75	315.94
10	315.16	315.61	315.89	316.17	316.43
11	315.39	315.86	316.18	316.57	316.93
12	316.27	316.47	316.69	317.01	317.31
13	316.73	316.88	317.08	317.40	317.63
14	316.79	317.08	317.26	317.51	317.74
15.1	317.21	317.44	317.55	317.75	317.93
15.2	316.91	317.16	317.35	317.60	317.81
19	317.41	317.68	317.82	318.07	318.17
21.1	317.61	317.88	318.05	318.39	318.61
16.1	317.72	317.99	318.16	318.45	318.66
16.2	317.10	317.35	317.57	317.79	317.97
20.2	318.37	318.49	318.61	318.74	318.86
21.2	318.37	318.50	318.62	318.74	318.86
17.1	318.37	318.50	318.62	318.76	318.89
17.2	317.44	317.51	317.60	317.81	318.00
18	318.05	318.07	318.11	318.13	318.17
20.3	318.37	318.50	318.62	318.76	318.89
21.3	318.37	318.50	318.62	318.76	318.89
22	319.08	319.26	319.40	319.57	319.70
23	320.13	320.38	320.57	320.82	321.02
24	320.78	320.97	321.14	321.38	321.58
25	321.04	321.22	321.42	321.66	321.87
26	321.69	321.87	322.06	322.32	322.51
27	322.14	322.29	322.45	322.68	322.86
28	322.96	323.14	323.31	323.50	323.68
29	323.01	323.20	323.34	323.53	323.69

Note: Cross section locations are shown on Figure A1 in Appendix A.

5.3 Flood Mapping

Flood mapping for the 100-year ARI event is shown on Figure A2 in Appendix A. The following features are shown on this plan:

- 100-year ARI flood height contours. The contours have been defined at 0.2 metre intervals based on interpolating between the modelled flood levels.
- 100-Year ARI flood extent. The extent has been defined based on the modelled flood levels, the surveyed cross sections and additional survey collected around the fringe of the floodplain to enable reliable plotting of the flood extent line between cross sections.

Flood mapping of the extent of the floodway and LSI areas is shown on Figure A3 in Appendix A. The delineation of the floodway and LSI areas was determined as follows:

- Floodway extent boundary generally coincides with a depth of 100-year ARI flooding of 0.5 metre.
- LSI extent boundary coincides with the 100-year ARI flood extent.

Additional ground survey data was collected specifically to allow for mapping of the floodway and LSI extent boundaries between the previously surveyed cross sections. The additional survey involved obtaining ground level elevations at regular intervals between the cross sections in the vicinity of the floodway and LSI boundaries. The survey data can be found on the project DVD.

6. Flood Damage Analysis

The Rapid Appraisal Method (RAM) is a method for estimating the economic consequences of flooding (NRE, 2000). This information is useful for comparing the consequences of flooding in different locations and thereby assists in prioritising the need for flood mitigation measures.

The RAM includes allowance for the following types of damage categories:

- Damage to buildings - distinguishes between damage to residential, commercial and industrial buildings.
- Damage to public infrastructure – distinguishes between damage to major sealed roads, minor sealed roads and unsealed roads.
- Damage to agricultural - distinguishes between damage to pasture, crops, livestock and clean-up costs.
- Indirect damages to account for the costs of emergency response measures and disruption to employment and commercial activities.

6.1 Application of RAM

The RAM was applied to the study area floodplain in accordance with the following procedure:

- The 2-year ARI event was adopted as the threshold event at which flood damages commence to occur. In a 5-year ARI event, there is considerable out of channel flooding within the study area (e.g. refer to Photograph 1 which shows High Street overtopped in a 5-year ARI event).
- The 10-year ARI event was adopted as the event coinciding closest with the extent of the floodway area as determined by the hydraulic analysis and flood mapping carried out for this study.
- Flood damages were computed for the 10 and 100-year ARI floods consistent with the flood extent mapping carried out for this study.

The flood damage analysis required the number of buildings (houses and commercial buildings) and length of roads within the 100-year ARI and floodway extents to be determined. This utilised both the flood extent mapping (refer Figures A2 and A3) and aerial photography. Allowance for agricultural damages was excluded from the analysis given the focus of the study is on urban flood impacts.

Flood damage data within the RAM was increased to allow for inflation since the data was published. Actual direct damages were adopted as 80% of the potential direct damages based on a consideration of the relatively short warning time available (less than 3 hours) consistent with the RAM. Indirect damages were assumed to be 30% of the total direct damages costs in accordance with the RAM.

The results of the computed flood damages are provided in Table 6.1. The average annual damage (AAD) for the study area is $55,000. The total tangible direct and indirect damage for 10 and 100-year ARI floods is $99,000 and $672,000 respectively.

Table 6.1 – RAM Estimated Flood Damages

Damage Category	Description of Damage	Flood Damage ($)	
		Floodway (10-year ARI event)	Combined LSI and Floodway (100-year ARI event)
Direct damage to residential buildings	• 2 potentially affected in 10-year ARI • Up to 20 potentially affected in 100-year ARI	37,000	368,000
Direct damage to commercial buildings	• Nil affected in 10-year ARI • Up to 7 potentially affected in 100-year ARI	0	84,000
Direct damage to major sealed roads	• 180 metres – 10-year ARI • 300 metres – 100-year ARI	13,000	21,000
Direct damage to minor sealed roads	• 660 metres – 10-year ARI • 1350 metres – 100-year ARI	15,000	30,000
Direct damage to unsealed roads	• 1,200 metres – 10-year ARI • 1,410 metres – 100-year ARI	12,000	14,000
	Total direct damages	76,000	517,000
	Indirect damages (30% of direct damages)	23,000	155,000
	Total Direct and Indirect Damages	99,000	672,000
	AAD ($/annum)	**55,000**	

Notes:

1. Actual direct damage to residential buildings. Rate of $18,400 per dwelling used after applying 80% reduction factor.
2. Average rate of $15,000 per commercial building used after taking into account the average size and location of the affected buildings.
3. All buildings located within or partly within the 100-year ARI flood extent line assumed to be subject to damage.
4. Direct damage to infrastructure (roads and bridges). Rate of $71,000/km used for major sealed roads, $22,000/km used for minor sealed roads and $10,000/km for unsealed roads.

6.2 Discussion

The survey of building floor levels to facilitate a more detailed assessment of flood damages was outside the scope of this study. The following buildings are however known to have been subject to past above floor flooding based on discussions with residents and / or Council staff during the course of the study:

- House on the south side of the High Street, Mansfield-Whitfield Road and Mount Battery Road intersection. This house is reported to have been flooded to above floor level in the 1975 and 1993 flood events.
- Buildings on the north side of Ailsa Street between Rowe Street and New Street. In particular, the houses at addresses No. 9 and 11 Aisla Street are reported to have been flooded to above floor level in the 1956, 1975 and 1993 floods.
- House located 70 metres south west of the High Street bridge (4 High Street). This house is reported to have been flooded to above floor level in 1975 and 1993.

There is a possible risk of flooding of further buildings located on the north side of Baldry Street and on the south side of the creek downstream of Highett Street. Investigations have not however identified any existing occupied dwellings confirmed as subject to past above floor flooding. The now abandoned house at 17 Baldry Street is reported to have been flooded to above floor level in the 1975 flood.

In summary, only a total of four houses at Mansfield have been identified as subject to above floor flooding. There may be some additional buildings prone to 100-year ARI above floor flooding. A floor level survey would be required to provide a definitive list of all buildings subject to above floor flooding.

7. Flood Mitigation

The flood damage analysis undertaken using the RAM produced a relatively low predicted average annual flood induced damage of $55,000/annum for the study area. Only four houses have been confirmed as subject to 100-year ARI above flood flooding.

A floor level survey of all buildings located on the floodplain may identify a number of additional buildings subject to 100-year ARI above floor flooding. Even if this was the case, the justification for large scale flood mitigation works is unlikely to be present given the level of computed flood damages.

Both the Highett Street and High Street crossings induce an afflux of approximately 0.4 metre in a 100-year flood. The high cost of replacing the existing bridges with enlarged openings to reduce the afflux cannot be justified when compared to the modest reduction in flood damages that would be achieved.

The current creek waterway vegetation conditions are relatively favourable for flood conveyance, particularly when compared to photographs of the willow choked creek channel prior to 1993. Ongoing management of the in-channel vegetation needs to achieve a balance between flood conveyance efficiency, waterway stability and environmental health objectives.

There is currently no telemetered rainfall gauges within the Ford Creek catchment upstream of Mansfield. The presence of a telemetered rainfall gauge is desirable to provide an improved means for estimating the impending severity of flooding aside from relying on rainfall recorded at Mansfield. The presence of a telemetered rainfall gauge will however only marginally increase the duration of flood warning time available, given the relatively small size of the Ford Creek catchment upstream of Mansfield.

8. Summary and Recommendations

100-Year ARI Flood

Hydrologic investigations undertaken have identified the September 1975 flood as being indicative of a 100-year ARI flood based on the available flow records dating back to 1970. Flood extent mapping and flood height advice associated with the 100-year ARI flood should therefore be similar with the available flow and flood height data recorded for the 1975 flood event (refer to Figure A1 in Appendix A).

Recommendation: The 1975 recorded peak flow is to be adopted as representative of the 100-year ARI flood.

100-Year ARI Flood Levels and Extents

Hydraulic modelling of the study area floodplain between Dead Horse Lane and Greenvale Lane utilising a calibrated XP-STORM model has identified 100-year ARI flood level contours and flood extents. The 100-year ARI flood height contours and flood extents are shown on Figure A2.

Recommendation: The newly defined 100-year ARI flood level contours and flood extents are to be added to the Victorian Flood Database and adopted by the Mansfield Shire Council and the Goulburn Broken CMA for planning control purposes. The Goulburn Broken CMA are to declare the 100-year ARI flood level contours under the provisions of the Water Act, 1989.

Flood Overlays

The extent of the floodway and land subject to inundation (LSI) areas has been delineated as shown on Figure A3. The interface boundary between the floodway and LSI areas is based on a consideration of the flooding severity (depth and velocity) and frequency of flooding.

Recommendation: The mapped floodway and LSI areas are to be added to the Victorian Flood Database and incorporated into the Mansfield Shire Council's planning scheme.

Flood Damages

Flood damages for the study area were calculated using the rapid assessment method. This method takes into account damage to buildings, infrastructure and indirect damages (e.g. emergency response costs, disruption to employment etc). The resulting computed average annual damage for the study area is $55,000. Only four houses have been confirmed as subject to above floor flooding through past observation accounts.

Recommendation: A floor level survey should be undertaken to provide a definitive database of those buildings subject to 100-year ARI above floor flooding.

Flood Mitigation

The level of flood risk at Mansfield is relatively low based on the computed flood damages. Flood mitigation efforts should continue to focus on the management of creek in-channel and riparian vegetation to achieve a balance between flood conveyance efficiency, waterway stability and environmental considerations. A telemetered rainfall gauge within the catchment upstream of Mansfield is desirable to allow improved flood forecasting and therefore slightly longer flood warning times.

Recommendations: The development of a detailed flood mitigation strategy for Mansfield is not warranted on the basis of the relatively low average annual flood induced damages.

9. References

Natural Resources and Environment (May 2000). Rapid Appraisal Method (RAM) for Floodplain Management. Prepared by Read Sturgess & Associates.

Appendix A

Flood Mapping

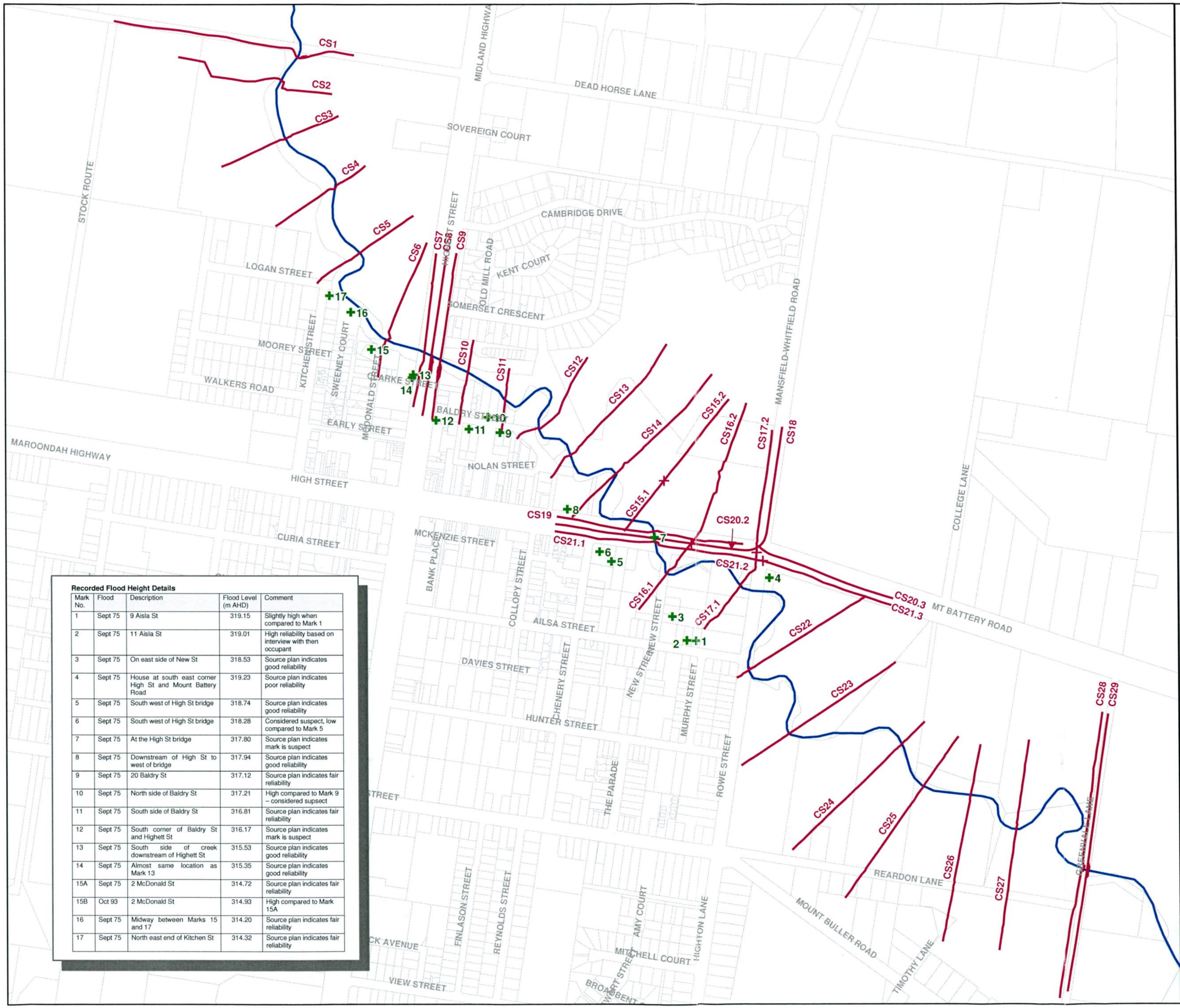
MANSFIELD FLOOD STUDY

Floodway and LSI Extent

November, 2005

Figure A3


200 0 200
Metres
Earth Tech
LEGEND
Proposed Floodway
Proposed 1% Flood Extent
1% Flood Height Contour and Level Value (m AHD)
GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY
MANSFIELD SHIRE
Notes:
1. The flood levels shown on this plan define the surface level of the 1% probability flood. This is the flood prescribed by Sec. 204 of the Water Act – 1989, for floodplain management purposes and has a 1 in 100 chance of being equalled or exceeded in any given year.
2. The derivation of these 1% flood level lines has been based on available historical flood level and flow information, hydrologic and hydraulic modelling.
3. Areas outside the 1% probability flood limit may be inundated by rarer flood events.
4. For the purpose of determining flood levels for locations between flood level lines, it can be assumed that the flood surface levels change at a uniform rate between the flood level lines.
5. The flood level lines shown on this plan can be used to assist in the determination of designated levels in accordance with Clause 6.2 of the Building Regulations – 1994.
6. Although there may be buildings within the area covered by the flood level lines, it should not be assumed that the floor of any individual building is below flood level. Buildings should be surveyed to determine whether their floors are above or below the 1% flood level.
7. The flood levels were declared by the Goulburn Broken Catchment Managment Authority on the ________________ under the provisions of the Water Act 1989.
FORD CREEK - MANSFIELD
Designation of Flood Levels
Drawing Number: 540258
November 2005



Legend

- Ford Creek
- Property Boundary
- ✚ 17 Recorded Flood Level and Identification Number
- CS29 Survey Cross Section and Identification Number

Recorded Flood Height Details

Mark No.	Flood	Description	Flood Level (m AHD)	Comment
1	Sept 75	9 Aisla St	319.15	Slightly high when compared to Mark 1
2	Sept 75	11 Aisla St	319.01	High reliability based on interview with then occupant
3	Sept 75	On east side of New St	318.53	Source plan indicates good reliability
4	Sept 75	House at south east corner High St and Mount Battery Road	319.23	Source plan indicates poor reliability
5	Sept 75	South west of High St bridge	318.74	Source plan indicates good reliability
6	Sept 75	South west of High St bridge	318.28	Considered suspect, low compared to Mark 5
7	Sept 75	At the High St bridge	317.80	Source plan indicates mark is suspect
8	Sept 75	Downstream of High St to west of bridge	317.94	Source plan indicates good reliability
9	Sept 75	20 Baldry St	317.12	Source plan indicates fair reliability
10	Sept 75	North side of Baldry St	317.21	High compared to Mark 9 – considered supsect
11	Sept 75	South side of Baldry St	316.81	Source plan indicates fair reliability
12	Sept 75	South corner of Baldry St and Highett St	316.17	Source plan indicates mark is suspect
13	Sept 75	South side of creek downstream of Highett St	315.53	Source plan indicates good reliability
14	Sept 75	Almost same location as Mark 13	315.35	Source plan indicates good reliability
15A	Sept 75	2 McDonald St	314.72	Source plan indicates fair reliability
15B	Oct 93	2 McDonald St	314.93	High compared to Mark 15A
16	Sept 75	Midway between Marks 15 and 17	314.20	Source plan indicates fair reliability
17	Sept 75	North east end of Kitchen St	314.32	Source plan indicates fair reliability

Earth Tech

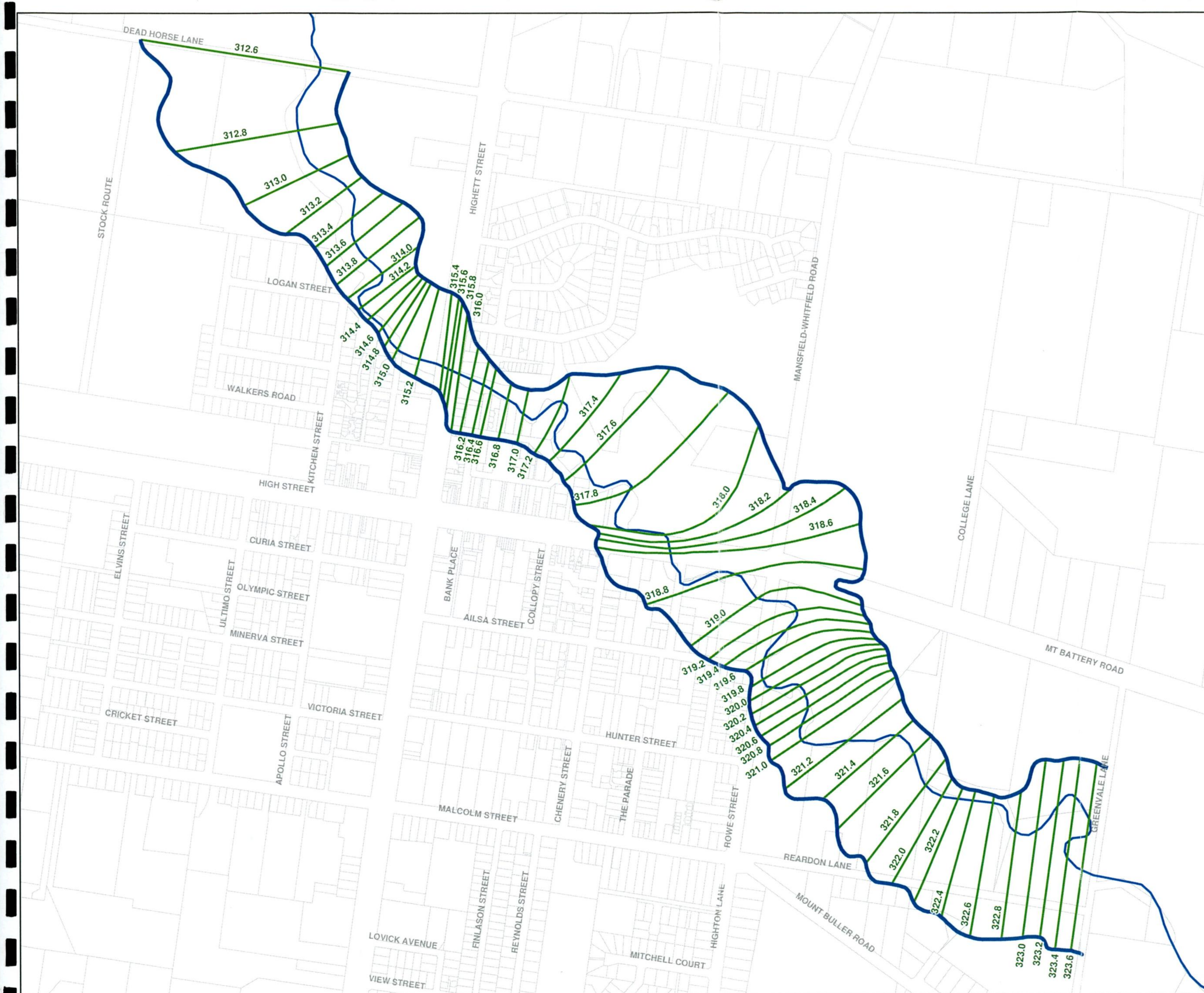
MANSFIELD SHIRE

MANSFIELD FLOOD STUDY

Recorded Flood Levels and Cross Section Survey Locations

November, 2005

Figure A1



N

0 200 400
Metres

Earth Tech

MANSFIELD SHIRE

Legend

Ford Creek

Property Boundary

100 Year ARI (1%) Flood Extent

112.30 100 Year ARI (1%) Flood Height Contour and Level Value (m AHD)

Notes:

1. The flood levels shown on this plan define the surface level of the 1% probability flood. This is the flood prescribed by Sec. 204 of the Water Act – 1989, for floodplain management purposes and has a 1 in 100 chance of being equalled or exceeded in any given year.

2. The derivation of these 1% flood level lines has been based on available historical flood level and flow information, hydrologic and hydraulic modelling.

3. Areas outside the 1% probability flood limit may be inundated by rarer flood events.

4. For the purpose of determining flood levels for locations between flood level lines, it can be assumed that the flood surface levels change at a uniform rate between the flood level lines.

5. The flood level lines shown on this plan can be used to assist in the determination of designated levels in accordance with Clause 6.2 of the Building Regulations – 1994.

6. Although there may be buildings within the area covered by the flood level lines, it should not be assumed that the floor of any individual building is below flood level. Buildings should be surveyed to determine whether their floors are above or below the 1% flood level.

MANSFIELD FLOOD STUDY

100 Year ARI Flood Height Contours and Extents

November, 2005

Figure A2