Australian Government
Department of Transport and Regional Services

GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

MURRINDINDI SHIRE COUNCIL
"Mist of the Mountains"

Yea Flood Study

September 2005

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

AAM SURVEYS

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Report No. J054/R04 Final 3
September 2005

WATER TECHNOLOGY
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Front cover photo: June 1989 flood event at Webster Street looking north (Source Mr. Bruere).

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Numerous organisations and individuals have contributed both time and valuable information to the Yea flood study. The study team acknowledges the contributions made by these groups and individuals, in particular:

- The study's technical steering committee consisting of:
    - Guy Tierney, Floodplain Manager GBCMA
    - Ian Ellett, Manager Assets and Infrastructure Murrindindi Shire
    - Ian Gauntlett, Floodplain Management Unit Manager Sustainability and Environment
    - Peter Zimmermann, Hydrology and Flood Warning Services Section Victorian Regional Office Bureau of Meteorology
    - James Gustus and John Parker, VicSES
    - Russell Wealands, GBCMA
    - Lyn Gunter, Mayor Murrindindi Shire
- The staff of the GBCMA Yea office

The study team also wishes to thank all members of the community that contributed flooding information, returned questionnaires and discussed their experiences with the study team.

Further study team appreciated the efforts of the Bureau of Meteorology Victorian Regional Office Hydrology and Flood Warning Services Section. In particular Alan Baker, Elma Kazazic and Chris Leahy, for their constructive review and comments on the draft study report, and for the provision of the hydrologic model.

This study was funded the Natural Disaster Risk Management Studies Program with contributions from Murrindindi Shire, Victorian State Government and Federal Government.

EXECUTIVE SUMMARY

Study background

This report summarises the findings of the investigations of the existing flood risk for the township of Yea and the identification of potential mitigation measures. In addition, the report provides a review of the existing flood response and alerting procedures with recommendations for suggested revision to the current procedures.

The Goulburn Broken Catchment Management Authority (GBCMA) in association with the Murrindindi Shire Council (MSC) has commissioned the Yea Flood Study. The study area encompasses the floodplains of the Yea River and Boundary Creek adjacent to the township of Yea. This study examined the existing flood risks originating from the Yea River and Boundary Creek.

A reference committee consisting of GBCMA, MSC, VicSES, DSE and BoM personnel has overseen the study.

Study objectives

A study team consisting of Water Technology, LICS and AAM Surveys, was commissioned by GBCMA and MSC to undertake this study, the investigations being carried out in accordance with instructions from GBCMA and MSC.

The flood study objectives are summarised as follows:

- To quantify the nature of flooding (frequency, depth, extent) for a range of flood magnitudes in order to assess the existing flood risk to the township of Yea within a risk management framework in accordance with AS/NZ code.
- To establish and maintain effective two way communications between stakeholders, particularly including the general public of the existing flood risk and possible risk treatment options.

Study area features

Some 1,000 people live within Yea Township, which is located some 80km north-east of Melbourne. In recent years the town has come under continued pressure for development, with this situation expected to continue in the future. Yea lies adjacent to some 4 km of Yea River frontage and associated floodplain. Original town subdivision includes small lots within floodplain areas. Significant historical flooding has occurred in 1934, 1974 and 1989.

The catchment area contributing flood flows to the study area includes the Murrindindi River and Yea River to Yea (including the Boundary Creek).

Two waterways flow through the study area, the Yea River and Boundary Creek. The Yea River passes along the eastern and northern edge of the Yea Township before entering the Goulburn River approximately 10 kilometres downstream of Yea. Within the study area, the Yea River is bordered either side by relatively steep terrain that tends to confine the extent of the floodplain to a width of approximately 500-600 metres. Boundary Creek, a tributary of the Yea River, descends reasonably steeply down the western edge of the Yea Township and outfalls into the Yea River. The features of both these waterways and their interaction influence the nature of flooding within the study area.

Community consultation

A key ingredient in the robust and comprehensive investigation of existing flood risks for Yea was the active engagement of the key residents in the study. This engagement has been developed over the course of the study through several meetings. The meetings took place at the residents' properties.

The first stage community consultation consisted of the following three elements:

- Public notice
- Information brochure and questionnaire
- Key residents meetings

The information brochure and questionnaire were bundled and delivered by the GBCMA to approximately 200 residences/businesses located within the study area.

A total of 5 questionnaire responses have been received. This could be interpolated in two ways:

- A poor response reflecting a lack of major flooding in recent years.
- The general community has little concern that flooding is an issue, particularly as only a limited number of properties are flood affected.

The questionnaire response yielded six historical flood marks. Also ten photos of historical floods were collected.

Five residents indicated a willingness to meet with the study team and GBCMA personnel. Meetings were conducted with the residents at their homes. An additional resident was present at one of the meetings, thus providing a total of 6 residents consulted. The meetings provided an opportunity for the study team and GBCMA to discuss the objectives and scope of the study. The residents provided details of their recollection of past flood events and location of flood marks. One resident showed a video taken during the June 1989 flood.

Hydrologic analysis

The hydrologic analysis determined historical and design flood inflow hydrographs (peak flow and flood volume) for the Yea River and Boundary Creek to the study area. In particular, the historical flood inflow hydrographs were used in the calibration of the hydraulic model as part of the hydraulic analysis. The design flood inflow hydrographs were determined for the 10, 20, 50, 100, 200 and 500 year average recurrence interval (ARI) floods and the probable maximum precipitation (PMP) design flood. The design flood inflow hydrographs were utilised in the hydraulic analysis to determine design flood levels and the existing level of flood risk.

The URBS *Split* model was adopted in this study. The adoption of the split model for this study is principally based on the availability of a recent developed URBS *Split* model. The available URBS *split* model was developed by BoM (Baker pers comm. 2002, Leahy 2002). This model was developed as part of the flood warning system for the Goulburn River from Eildon to Seymour.

The storage characteristics for the sub-catchment and channel can be modified by the use of other catchment characteristics. The Yea River catchment displays significant variation in channel slopes and forested areas from the upland sub-catchments to lowland sub-catchments. It was considered appropriate, given this variation, to include the channel slope and forested area as factors in the determination of sub-catchment and channel storage.

Given this availability of streamflow data, the calibration of the URBS model parameters was undertaken to observed streamflow data at the upstream gauges. This calibration approach resulted in the model parameters determined at the upstream gauges being applied to the entire Yea River catchment. Such extrapolation of model parameters may produce unreliable results for the entire catchment due to changes in catchment characteristics from upstream to downstream. In an effort to reflect change in catchment characteristics and improve the reliability of the model results, the channel slope and forested area were included in the determination of sub-catchment and channel storage.

The routing model parameters α 0.05 and β 0.15, as determined by calibration, were adopted for design flood estimation. Design losses were validated for the Yea River at Devlins Bridge. No validation was possible for the Murrindindi River at Murrindindi and the remaining downstream Yea River catchment due to a lack of suitable streamflow data. URBS (Carroll 2002) adjusts the rainfall losses to according the ratio of (1-(area of forestation as a fraction)/2). This study adopts the same approach to determine losses for the Murrindindi River at Murrindindi and the remaining downstream Yea River catchment based on the validated design losses for the Yea River at Devlins Bridge. Table - 1 shows the area of forestation and the adopted design losses for the three sub-catchments.

Table - 1 Adopted Design Loss Values

Sub-catchment	Proportion of Forested Area	Design loss	
		Initial loss (mm)	Proportional loss (Runoff co-efficient)
Yea River at Devlins Bridge	0.54	9.4	0.76 (0.24)
Murrindindi River at Murrindindi	0.86	9.4	0.97 (0.03)
Downstream Yea River catchment	0.19	9.4	0.39 (0.61)

The adopted design parameters in combination with the design rainfall were employed to determine design flood hydrographs for the Yea River and Boundary Creek at the upstream study area limit for 10, 20, 50, 100, 200 and 500 year ARIs. Table - 2 shows the peak flows for the Yea River and Boundary Creek at the upstream study limit.

Table - 2 URBS Model Design Peak Flows for the Yea River and Boundary Creek at the upstream study limit

Location	URBS Model Design peak flows (m^3/s)					
	10 year ARI	20 year ARI	50 year ARI	100 year ARI	200 year ARI	500 year ARI
Yea River at upstream study area limit	267	322	368	428	546	602
Boundary Creek at upstream study area limit	49	57	64	72	87	94

The 100 year design peak from the URBS model was compared to 100 year design peak flows from regional relationships and adjacent catchments. The regional prediction relationship results in 100 year peak flow estimates at Devlins Bridge and the upstream study area limit, significantly larger than the corresponding flood frequency analysis and URBS model estimates. Further the regional prediction relationship leads to significantly higher 100 year

ARI peak flow estimates than the flood frequency estimates for the Acheron River and King Parrot Creek. This comparison may suggest the regional prediction equation is likely to over predict the 100 year ARI peak flow in this region. Conversely, the period of streamflow records employed for the frequency analyses are relatively short and contains no significant flood events.

Given this uncertainty in the design flood estimation, the Technical Steering Committee resolved to adopt a 100 year ARI design peak flow at upstream study area of 544 m^3/s for planning scheme purposes. The adopted 100 year ARI design peak flow was obtained by scaling the 100 year ARI peak flow for the Yea River at Delvins Bridge.

Hydraulic analysis

The hydraulic analysis determined historical and design flood levels and velocities for the study area. In particular the historical flood levels were used in the model calibration. The design flood levels and velocities were determined for the 10, 20, 50, 100, 200 and 500 year average recurrence interval (ARI) floods and the probable maximum precipitation (PMP) design flood. The design flood hydrographs from the URBS model were employed in the hydraulic analysis. The design flood levels and velocities were utilised to determine the existing level of flood risk.

The two-dimensional unsteady hydraulic model MIKEFLOOD was the principal tool for the hydraulic analysis. MIKEFLOOD is a state of the art tool for floodplain modelling that has been formed by the dynamic coupling of DHI’s well proven MIKE 11 river modelling and MIKE 21 fully two-dimensional modelling systems. The MIKEFLOOD model parameters were determined through calibration of the modelled flood levels with observed flood levels with historical inflow flood hydrographs as an input. Once calibrated the MIKEFLOOD model was applied to estimate design flood levels with design inflow hydrographs as an input.

Through the community consultation process, a number of observed maximum flood levels were identified and surveyed for incorporation into the Flood Data Transfer data set (DNRE 2000). The community consultation and questionnaire responses yielded an additional five flood marks for the June 1989 food event and one flood mark for the 1934 flood event. In total, nine historical flood marks were available for June 1989. The historical floodmarks were utilised for the hydraulic model calibration

The June 1989 flood event was chosen as the principal calibration event. This flood event had an approximate ARI of 12 years. The June 1989 flood event was determined to have a peak discharge at Yea of $293m^3/s$ (25315 ML/d). The peak flow in Boundary Creek during the flood was also determined to be $14m^3/s$ (1210 ML/d).

Calibration of the hydraulic model of the Yea River and Boundary Creek was primarily achieved by adjusting the hydraulic roughness coefficients and head loss factors through the bridge crossings to fit the observed maximum flood levels.

A generally good agreement has been achieved between the observed and modelled maximum flood levels and extents within the study area. The hydraulic model has reproduced the anabranch flow across the corner of Nolan and Craigie Street and the model shows floodwaters encroaching just over Hood St as reported during the community consultation process. Some difficulties were encountered however in reproducing the observed maximum flood level at some of the points used during the calibration process.

Design flood levels and velocities were determined via the calibrated MIKEFLOOD model for the 10, 20, 50, 100, 200 and 500 year average recurrence interval (ARI) floods. The design inflow hydrographs for Yea River and Boundary Creek as determined by the hydrologic analysis were a model input.

Table - 3 displays the peak design flood levels and selected historical peak flood levels at the Court Street gauge adjacent to the caravan park access bridge.

Table - 3 Design and selected historical peak flood levels at Court Street Gauge

Design flood event ARI (Based onURBS model) (years)	Court Street Gauge height[1]	Flood level at Court Street gauge (m AHD)
10	3.99 m	166.71
June 1989[2]	4.16 m	166.88
20	4.22 m	166.94
50	4.40 m	167.12
May 1974[3]	4.45 m	167.17
100	4.55 m	167.27
200	4.75 m	167.47
500	4.83 m	167.55

1. Court Street gauge height determined by subtracting the gauge zero elevation in m AHD (162.72 m AHD) from the flood level elevation in m AHD.
2. Indicative Court Street gauge height for June 1989, obtained from Flood Data Transfer Project Murrindindi shire Flood data maps No. 500058-27
3. Indicative Court Street gauge height for May 1974, obtained from Flood Data Transfer Project Murrindindi shire Flood data maps No. 500058-27

Flood damage assessment

The flood damage assessment was undertaken for the 10, 20, 50, 100, 200 and 500 year ARI design flood events. The design flood hydrographs from the URBS model were employed in the hydraulic analysis. The flood damage assessment considered existing conditions. Table -4 provides a summary of existing flood damages for the study area.

Table - 4 Flood damages in existing conditions

Item	URBS model design flood ARI (years) [1]					
	10	**20**	**50**	**100**	**200**	**500**
Properties Flooded Above Floor	27	28	29	30	30	30
Properties Flooded Below Floor	4	5	5	8	12	15
Total Flooded Properties	**31**	**33**	**34**	**38**	**42**	**45**
Total Direct Damages	$289,000	$417,000	$452,000	$538,8000	$627,600	$678,000
Indirect Damages (30% direct)	$87,000	$125,000	$135,600	$161,600	$188,200	$203,400
Potential Damages	$376,000	$542,000	$587,600	$700,400	$815,800	$881,400
Actual Damages (DRF at 0.8)	**$300,200**	**$443,600**	**$470,200**	**$560,300**	**$652,600**	**$705,200**
Total Inundated Roads (km)	1.2	1.5	2.0	2.6	3.3	3.8
Total Infrastructure Damages	**$11,100**	**$16,700**	**$35,500**	**$55,900**	**$75,200**	**$92,900**
TOTAL DAMAGES (DRF at 0.8)	**$311,300**	**$460,300**	**$505,700**	**$616,200**	**$727,800**	**$798,100**

Average annual damages are calculated as the area under a curve of total monetary damages. The average annual damages (AAD) for existing conditions in the study is estimated at approximately **$60,600** for floods up to the 500 year ARI event.

Identification of potential mitigation measures

An **upstream storage**, located on the Yea River, would provide additional attenuation and results in lower flood magnitudes for a given ARI. The construction and operation of an upstream storage requires significant land at a suitable location. It is likely the costs of an upstream storage would be significant. The benefits of an upstream storage would be limited, given the relatively low flood damages. The study team consider the upstream storage is not a feasible mitigation measure.

Levees or floodwalls can restrict the extent of flooding and limit the area subject to flooding up to a given design flood. Due to relatively low flood damages, the benefits of levees/floodwalls are likely to be limited. The cost benefit ratio of the levees/floodwalls in the Yea township is likely to be low (significantly less than 1). The study team considers the construction of levee and/or floodwalls storage is not a feasible mitigation measure.

Floodways provide additional flood flow paths, and reduce flood levels by providing additional flow carrying capacity and by diverting flow away from areas susceptible to flooding and damage. The nature of the floodplain does not lend itself to the siting of floodways. The Yea River waterway channels are of limited flow capacity and flows across the floodplain occur for events with an ARI approximately greater than 5 years. It is likely little additional flow capacity could be achieved with a constructed floodway. The study team consider the construction of floodways is not a feasible mitigation measure.

Waterway management works can include local widening, deepening, re-shaping and clearing of channels and verges. Generally the benefits of waterway management works will be most evident in small to medium floods. In larger floods, where the waterway carries only a small proportion of the flow, improvements will provide only minor benefit.

Waterway management works do have disadvantages. There are environmental and geomorphologic issues associated with both the clearing of vegetation and the reshaping or enlarging of channels. Removal of large trees should be avoided, for example. For the same reasons, reshaping of land surfaces, sediment removal and alteration to creek cross-sections should to be done sparingly, and with consideration for the likely hydraulic and geomorphologic consequences. Tampering with the beds and banks of streams can trigger hydraulic responses that are undesirable. In any given area, works should be selective – excessive clearing or channel reshaping will inevitably have adverse impacts. Waterway management also has a high maintenance cost.

Improvements to waterway crossing structures (e.g. culverts, bridges, road and rail embankments) can reduce upstream flood levels. Waterway crossing structures within the flood flows potentially act as a barrier or constriction to flood flows and impact on flood levels. The removal of Goulburn Valley Highway embankment and openings results in lowering upstream flood levels. The flood levels would be lower throughout the caravan park and the properties located on the eastern side of Miller Street. This lowering in flood levels would lead to a corresponding reduction in flood damages. Minor increases in flood levels resulted downstream of the Goulburn Valley Highway. No formal costing of the replacement bridge structure has been undertaken in this study. It is likely the cost would be significantly high in comparison to the reduction in flood damages. Given the relatively low reduction in flood damage, the study team consider the replacement of the Goulburn Valley Highway crossing is not a feasible mitigation measure nor cost effective. The study team suggest the reduction of afflux to be considered in any upgrading/replacement undertaken by VicRoads in the future.

Catchment management activities in the upstream catchments can influence the existing catchment runoff characteristics (flood peaks and volumes). The flood volumes and flood peaks are a function of the vegetation cover and land use within a catchment. Land clearing has significantly altered flood response. Further land clearing may lead to increased flood peak and flood volumes resulting from significant rainfall events. Increases in peak flows and flood volumes in turn result in higher flooding likelihood and flood risk. Catchment revegetation, over the longer term may reduce flood volumes. However, in major floods reductions in peak flow would be insignificant.

Flood awareness, preparedness, warning and response aims to reduce the growth in future flood damages by improving community awareness of flooding and emergency services response. Flood awareness within a community reflects the frequency of significant flooding i.e. infrequent insignificant flooding leads to lower community flood awareness. The most recent significant flooding events occurred in May 1974 and June 1989. Given relatively infrequent occurrence of significant flooding with associated damages to property, the study team considers the community awareness of floods to be low. This lower community awareness is likely to be reflected by the small number of questionnaire responses (refer to Section 3).

A flood warning system developed by the Bureau of Meteorology (BoM) provides flood forecasts for the Goulburn River catchment from Eildon to Seymour including the Yea River at Court Street gauge. Hydraulic analysis undertaken by this study has provided a reliable estimate of the stage-discharge relationship for the Court Street gauge. BoM (A. Baker pers. comm. 2005) advised that the BoM have utilised this stage-discharge relationship to provide flood height forecasts at the Court Street gauge. Flood inundation maps for a range of gauge heights provide guidance in flood response.

Land use planning aims to reduce the growth in future flood damages by provide appropriate guidelines/controls for land use and development. The Victoria Planning Provisions (VPPs) allow for zoning of land and the application of controls on the type of land use and permitted activities in areas prone to flooding. The VPPs provide for the following zone and two overlays:

- Land subject to inundation overlay (LSIO)
- Floodway (FO)
- Urban floodway zones (UFZ)

Flood inundation mapping for flood response

The study brief required flood response inundation maps to be prepared for a gauge height increment of 200 mm. From Table – 3, the gauge increment between maps varies from 80 mm to 230 mm for the design flood events. The study team considers the variation of gauge height increment provides a practical range of gauge heights for flood response. The study team proposes the above gauge height be adopted for use.

Consideration of rounding the gauge height to "round intervals" would provide for easy reference e.g. 3.99 m rounded to 4.00 m and 4.22 m to 4.20 m. The study team considers due to relatively contained floodplain the additional flood extent resulting from a gauge of 4.00 m compared with 3.99 m would be trivial.

The flood response inundation maps have been produced on a single B1 sheet, for each flood event, at 1:5,000. The map base is the cadastre obtained from GBCMA as current at July 2002. The cadastre is subject to change.

All properties with floor level survey were shown on the flood response maps as small grey dots with properties flooded above floor level coloured.

For each flood response map produced, property gauge height correlations have been compiled. The correlations provide peak flow, ARI and gauge height at the Court Street gauge for each flood response map.

Recommended mitigation measures

Flood mapping for land use planning

Flood related zone and overlay delineation option maps have been generated to assist GBCMA in the definition of LSIO, FO and UFZ. From these delineation option maps, GBCMA has developed the planning maps in accordance with the Victoria Planning Provisions Practice Notes – Applying the Flood Provisions in Planning Scheme (DoI 2000).

The study team recommends the MSC and GBCMA adopt the Planning Scheme Amendment C14, Part 2. Further the study team recommends the GBCMA declares the 100 year ARI flood levels for planning purposes under the Water Act (1989).

Flood response and alert review

As part of the Goulburn River Catchment – Seymour to Eildon Flood Warning Project undertaken in 2002, a framework for flood warning, preparedness, response and recovery was developed and detailed in the following four documents:

- Murrindindi Shire - Goulburn River Environs Flood Sub-Plan (October 2002)

- Murrindindi Shire - Flood Alert Operation Procedures (October 2002)
- Flood information providers manual (October 2002)
- Goulburn River Catchment – Seymour to Eildon: Flood response guidelines for the affected flood community of the Shire of Murrindindi in the Goulburn River Environs (November 2000)

The above documents have been prepared for use in the entire Goulburn River catchment from Seymour to Eildon with specific references to the Yea Township as required.

Flood warning development and categories

The study team recommends that following flood category levels be adopted for the Year River at the Yea Caravan Park (Court Street) Gauge.

- Minor : 3.0 m
- Moderate : 3.6 m
- Major : 4.4 m

Flood warning data collection network

The study team recommends upgrading the Court Street gauge to include a continuous data logger with telemetry capability.

Flood warning dissemination

The study team endorses the Murrindindi Shire - flood alert operation procedures (October 2002) requirement that each July the following items are to be updated:

- the procedure for the activation and operation of the community radio
- contact details of the fax stream recipients
- contact details of the phone alerting recipients

The study team is aware that an automated telephone alerting system for flood warning is being implemented in Shepparton-Mooroopna, Euroa, Maribyrnong and Benalla. The study team recommends MSC and GBCMA considers the potential to implement a similar automated telephone alerting system for Yea.

Flood response

The study team recommends the flood inundation maps and property listings, as discussed in Section 9, and flood behaviour description, as outlined in Table 11-2, be incorporated into the Murrindindi Shire - Goulburn River Environs Flood Sub-Plan (October 2002). The emergency response flood inundation maps provide details of the flood behaviour and flood affected properties for a range of Court Street gauge heights.

Flood monitoring

The study team recommends the flood information providers contact details are checked and revised where necessary each July.

Potential funding

To aid the implementation of the recommendations related to flood warning and response, the study team considers the MSC and GBCMA apply for funding under the Federal Government's Regional Flood Mitigation Program.

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1 INTRODUCTION

1.1 Background

This report summarises the findings of investigations into the existing flood risk for the township of Yea and identifies potential mitigation measures. In addition, the report provides a review of the existing flood response and alerting procedures with recommendations for suggested revision to the current procedures.

The Goulburn Broken Catchment Management Authority (GBCMA) in association with the Murrindindi Shire Council (MSC) commissioned the Yea Flood Study. The study area encompassed the floodplains of the Yea River and Boundary Creek adjacent to the township of Yea. This study examined the existing flood risks originating from the Yea River and Boundary Creek.

The study outcomes will provide GBCMA and MSC with a sound basis for the appropriate management of the floodplain within a risk management context. Under the Natural Disaster Risk Management Studies Program, the Local, State and Federal governments jointly funding the study.

The flood risk can be expressed as:

*Flood risk = flood likelihood * flood consequences*

The flood likelihood can be assessed as the frequency of flooding for a given flood depth. The flood consequences can be determined as the damages arising from that given flood depth. For each location, the flood risk can be determined with the flood risk to the community the sum of the flood risk for all locations.

A reference committee consisting of GBCMA, MSC, VicSES, DSE and BoM personnel has overseen the study.

A study team consisting of Water Technology, LICS and AAM Surveys, was commissioned by GBCMA and MSC to undertake this study. These investigations were carried out in accordance with instructions from GBCMA and MSC.

This report and our overall approach has been prepared in accordance with the principles as outlined in GBCMA Regional Floodplain Management Strategy (GBCMA, 2002) which is consistent with the Floodplain Management in Australia: Best Practice Principles and Guidelines (CSIRO, 2000) and the Victorian Flood Management Strategy (NRE, 1998).

1.2 Study objectives

The flood study objectives are summarised as follows:

- To quantify the nature of flooding (frequency, depth, extent) for a range of flood magnitudes in order to assess the existing flood risk to the township of Yea within a risk management framework in accordance with AS/NZ code.
- To establish and maintain effective two way communications between stakeholders, particularly including the general public in discussions relating to the existing flood risk and possible risk treatment options.

1.3 Key study tasks and report structure

The key study task and relevant report sections are as follows:

- **Study area features** - determine key waterway, floodplain and catchment features influencing the existing flood risk **(Section 2)**.

- **Community consultation** - inform the community of the study, obtain community knowledge of past floods and gain feedback on study outcomes during the course of the study **(Section 3).**
- **Hydrologic analysis** - estimate historical and design flood events in Yea River and Boundary Creek catchments **(Section 4).**
- **Ground level survey** - collect survey details of the floodplain, waterways and structures (bridges and culverts) via aerial survey (photogrammetry), and field survey **(Section 5).**
- **Hydraulic analysis** - estimate flood levels over the floodplain for historical and design flood events adjacent to the township of Yea (**Section 5**).
- **Flood damage assessment** - estimate economic flood damages for various flood magnitudes **(Section 6).**
- **Flood risk under existing conditions -** determines the existing flood risk for the study area **(Section 7).**
- **Flood mitigation options** – identify potential mitigation measures **(Section 8).**
- **Flood mapping for emergency response** – map flood extents for various flood magnitudes for use in emergency response **(Section 9).**
- **Flood mapping for land use planning** – provide GBCMA and MSC with an understanding of flood behaviour for a range of flood magnitudes to enable appropriate land use planning **(Section 10).**
- **Flood alert review** – review and revise the flood alert procedure for the study area in consultation with GBCMA, MSC, BoM and VicSES **(Section 11).**

The report appendices contain the following:

- Appendix A: Stage 1 community consultation
- Appendix B: Hydrologic analysis
- Appendix C: Photogrammetric survey

2 STUDY AREA FEATURES

2.1 Overview

Some 1,000 people live within Yea Township, which is located approximately 80km north-east of Melbourne. Yea lies adjacent to some 4 km of Yea River frontage and its associated floodplain. The original town subdivision includes small lots within the floodplain area. Significant historical flooding has occurred in 1934, 1974 and 1989. In recent years the town has come under continued pressure for development.

The study area for the Yea flood study consists of the floodplains of the Yea River and Boundary Creek adjacent to the Yea township. The study area covers approximately four square kilometres. Figure 2-1 displays the extent and location of the study area.

This section details the key features which influencing the nature of flooding within the study area. The structure of the section is as follows:

- Catchment features – describes key features located in the catchment areas upstream of the study area (Section 2.2)
- Waterway and floodplain features - describes key waterway and floodplain features located within the study area (Section 2.3)

2.2 Catchment features

The catchment area contributing flood flows to the study area includes the Murrindindi River and Yea River to Yea (including the Boundary Creek) and has a total area of 832 km^2. Figure 2-1 shows the Yea River catchment area.

The Yea River travels through the Yea Township before entering the Goulburn River (some 10-river kilometres downstream of Yea), approximately half way between Eildon and Seymour.

The Murrindindi River joins the Yea River some 10 kilometres upstream of Yea Township. Both rivers have relatively confined floodplains. The Yea River passes along the eastern and northern edge of the township of Yea. A lessor tributary, Boundary Creek, passes along the western side of Yea.

The catchment varies in elevation from approximately 1000 m AHD near Mount St Leonard to approximately 165 m AHD in Yea. Mean annual rainfall varies greatly across the catchment due to the topography. Around Mount St Leonard, the mean annual rainfall is approximately 1400 mm and decreases increases to approximately 750 mm in Yea.

For purposes of the hydrologic analysis the catchment has been divided into three smaller catchments. A brief description of the key features is provided in Sections 2.2.1 to 2.2.3.

2.2.1 Yea River upstream of Devlin's Bridge

Devlin's Bridge is located on the Melba Highway some 20 kilometres south of Yea. The Yea River upstream of Devlin's Bridge has a catchment area of 360 km^2. Downstream of Glenburn the catchment has been extensively cleared. Upstream of Glenburn the catchment is heavily forested and is part of the Toolangi State Forest.

2.2.2 Murrindindi River upstream of Murrindindi above Colwells

As discussed, the Murrindindi River is a tributary of the Yea River with the confluence located some 10 kilometres upstream of Yea. The Murrindindi River catchment upstream of

Murrindindi is heavily forested and is part of Toolangi State Forest. The catchment area upstream of Murrindindi above Colwells is 108 km^2.

2.2.3 Yea River downstream of Devlin's Bridge

Downstream of Devlin's Bridge the catchment has been extensively cleared for agricultural purposes since European settlement particularly the lower areas. The minor tributaries entering upstream of Yea include Limestone Creek, Tea Tree Creek and Caraman Creek

Boundary Creek joins the Yea River within the Yea township. The catchment area of Boundary Creek is approximately 45 km^2.

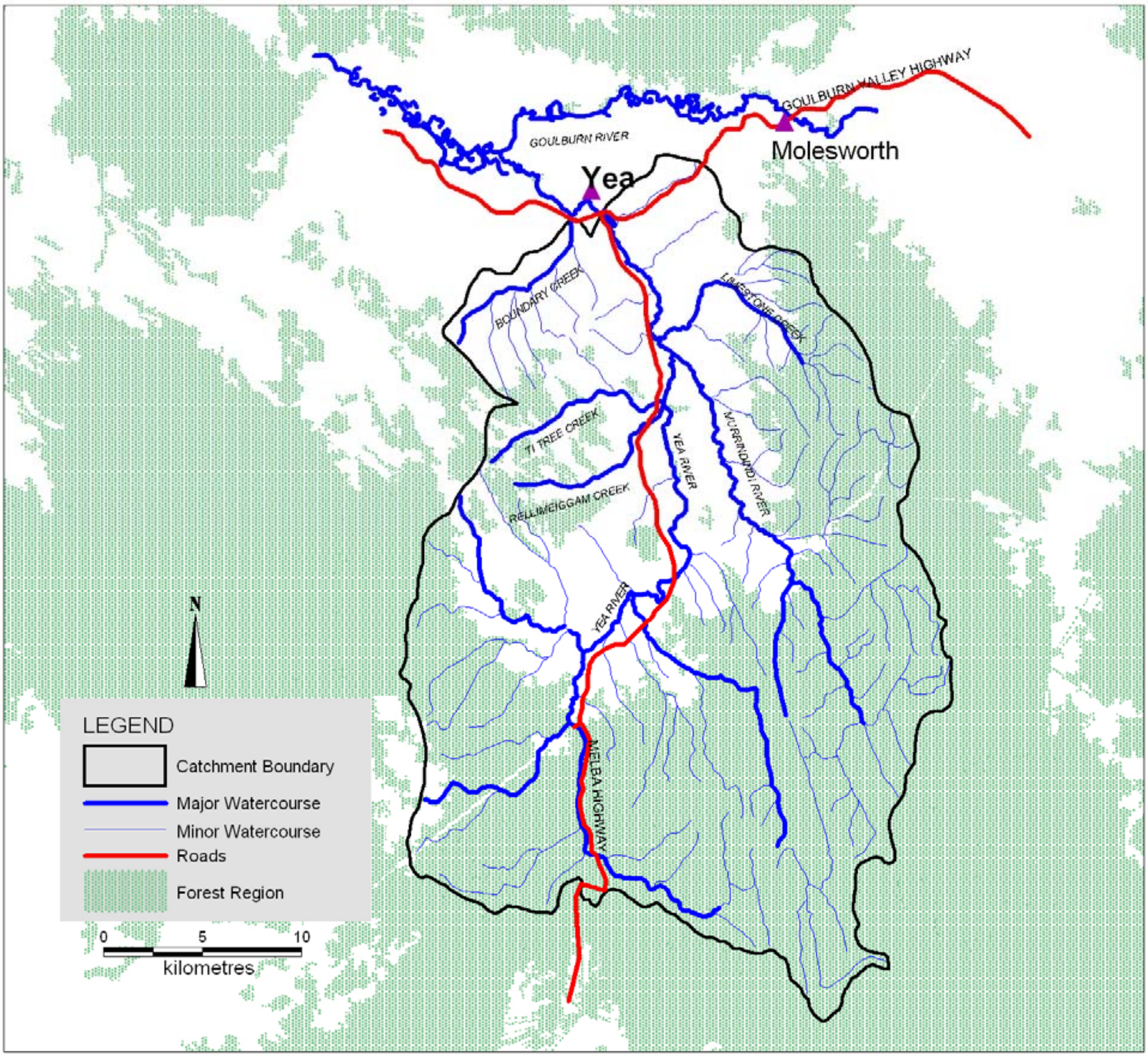


Figure 2-1 Yea flood study area and the Yea River Catchment

2.3 Waterway and floodplain features

Two waterways flow through the study area, the Yea River and Boundary Creek. The Yea River passes along the eastern and northern edge of the Yea Township before entering the Goulburn River approximately 10 kilometres downstream of Yea. Within the study area, the Yea River is bordered either side by relatively steep terrain that tends to confine the extent of the floodplain to a width of approximately 500-600 metres. Boundary Creek, a tributary of the Yea River, descends reasonably steeply down the western edge of the Yea Township and outfalls into the Yea River. The features of both these waterways and their interaction influence the nature of flooding within the study area.

The following sections provide a brief discussion of the key natural and artificial features of these waterways and associated floodplains. Figure 2-2 shows the location of key waterway and floodplain features.

2.3.1 Yea River - Reach from Meadow Road to Goulburn Valley Highway

The Yea River in the reach from Meadow Road to the Goulburn Valley Highway consists of a relatively small main channel. A number of anabranches traverse the floodplain in this reach and provide extra capacity for flows exceeding the main channel capacity. The majority of the floodplain has been cleared except for remanent vegetation surrounding the main channel and anabranches.

The Yea Caravan Park is located at Court Street with access provided by a small bridge cross the main Yea River. The bridge and the caravan park have been inundated in recent flood events. The bridge does not appear to be a major control on flows in this area as the majority of major flood flows leave the main channel and flow down the anabranches and floodplain on the western side of the caravan park.

Adjacent to the upstream side of the Court Street (caravan access) bridge, a series of flood height gauge boards have been installed. The gauge boards enable the estimate of the flood height relative to the gauge zero. The gauge zero was surveyed, as part of this study, at 162.72 m AHD. This study utilised this gauge as the reference point for flood inundation mapping. Section 9 provides details of the flood inundation mapping for emergency response.

Several residential properties located to the east of Miller Street have been subject to flooding in recent events.

The crossing of the Goulburn Valley Highway consists of two bridge structures and an elevated (≈2m above adjacent floodplain) causeway across the full width of the floodplain. Two culverts with very limited capacities also connect the floodplain on either side of the causeway. The Goulburn Valley Highway crossing of the Yea River is a significant control on the passage of floodwaters in this reach of the river. Velocities of up to 2m/s have been modelled through the bridges. In Figure 2-2 the cross section a'-a' represents a typical cross section of the Yea River and floodplain within the reach from Meadow Road to Goulburn Valley Highway. Cross section a'-a' also illustrates the confined nature of the floodplain and the existence of a number of anabranches across the floodplain in this reach of the Yea River.

2.3.2 Yea River - Reach from Goulburn Valley Highway to Providence Bridge (Craigie St)

In the upper portion of this reach of the Yea River, the width of the floodplain increases slightly as the river bends around the north-eastern corner of the Yea Township. Anabranches again traverse the floodplain and a number of cut off meanders exist throughout the reach. Small pockets of extremely thick vegetation exist on the floodplain that has otherwise generally been cleared. From Figure 2-2, cross section b'-b' illustrates the increased width of the floodplain in this reach.

Several residential properties located to the east of Marshbank Street have been subject to flooding in recent events.

At the Providence Bridge crossing of the Yea River, the natural floodplain width is significantly reduced, producing a natural control on flood flows in this area. For floods exceeding the capacity of the main channel and confined floodplain in this reach, flood flows occur along an anabranch beginning near the corner of Nolan and Craigie Street and re-enter the Yea River after crossing Webster Street. From Figure 2-2, cross section c'-c' illustrates the significant reduction in the width of floodplain in this reach. Figure 2-3 show flooding across Webster Street during a recent flood event in June 1989.

Flood flows also breakout on the western side of Providence Bridge. This breakout provides a shorter flow path and bypasses the sharp horse shoe bend of the Yea River downstream of Craigie Street. This breakout inundates Craigie Street on the western approach to Providence Bridge.

Flow along the anabranch and the western breakout results in loss of vehicular access to properties located adjacent to the corner of Craigie and Webster Streets. These properties are located on an island which shrinks as the flood magnitude increases.

2.3.3 Yea River - Reach Downstream of Providence Bridge (Craigie Street)

Downstream of Providence Bridge on Craigie Street the main channel loops back on itself before continuing down the floodplain. The floodplain slope in this reach steepens slightly and the Yea River consists of a single waterway with an increased main channel capacity. Boundary Creek outfalls to the Yea River approximately 700m downstream of Providence Bridge. Cross section d'-d' in Figure 2-2 represents a typical cross section of this reach of the Yea River.

2.3.4 Boundary Creek

Boundary Creek has a catchment of approximately 44.6 km^2. Boundary Creek itself consists of a relatively large main channel that descends quite steeply down the western edge of the township before out falling into the Yea River. From Figure 2-2, cross section x'-x' represents a typical cross section of Boundary Creek.

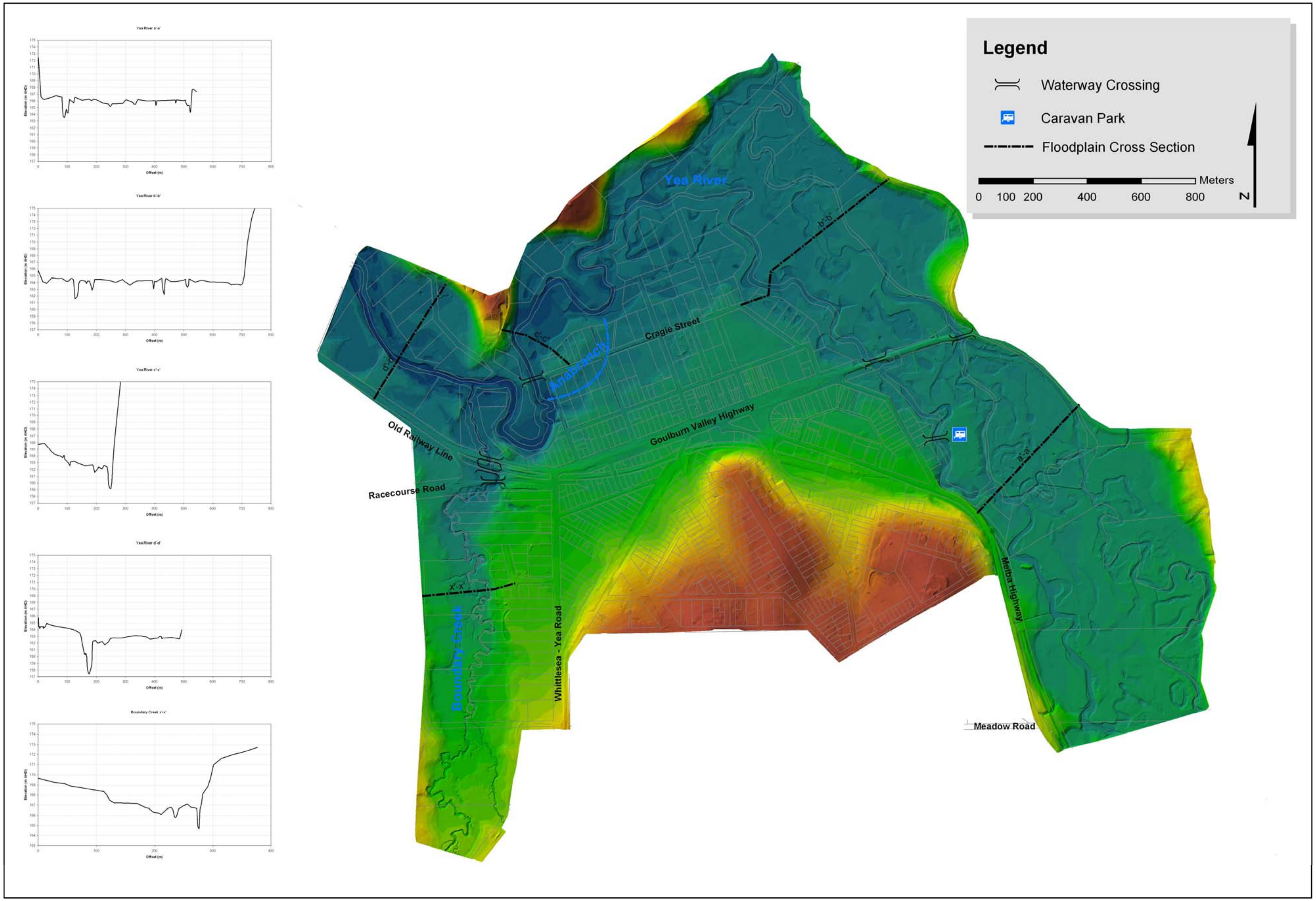


Figure 2-2 Key Waterway and Floodplain Features

Figure 2-3 Anabranch Flow Across Webster St Looking North During the June 1989 Flood (Source Mr. Bruere)

3 COMMUNITY CONSULTATION

3.1 Overview

A key ingredient in the robust and comprehensive investigation of existing flood risks for Yea was the active engagement of the key residents in the study. This engagement was developed over the course of the study through several meetings. The meetings took place at the residents' properties. In an effort to provide regular input into the study from the community, a two stage community process was undertaken. The aims of the two stages were as follows:

- First stage community consultation:- to raise awareness of the study and identify key residents and community concerns
- Second stage community consultation:- to provide information to the community and seek their feedback CRG feedback/input regarding the study outcomes including flood mapping and possible mitigation measures.

This section details the activities undertaken and community feedback received as part of the community consultation. The structure of the section is as follows:

- Stage 1 community consultation – outlines the preparation of the information brochure and questionnaire, and summarises the community feedback (Section 3.2).
- Stage 2 community consultation – outlines the activities undertaken in the Stage 2 (Section 3.3).

3.2 Stage 1 community consultation

3.2.1 Overview

The first stage community consultation consisted of the following three elements:

- Public notice
- Information brochure and questionnaire
- Key residents meetings

Sections 3.2.2 to 3.2.4 detail the above three elements with a summary of the key flooding related concerns raised by the community outlined in Section 3.2.5. Appendix A contains a copy of the information brochure and questionnaire, and a summary of responses.

3.2.2 Press releases and public notices

A public notice outlining the study objective and scope, and providing notice on the information brochure and questionnaire was placed in the Yea Chronicle. A copy of the public notice is provided in Appendix A.

3.2.3 Information brochure and questionnaire

In consultation with GBCMA, the study team developed an information brochure and questionnaire. The purpose of the information brochure and questionnaire was two fold:

- Raise awareness of the study's objectives and scope within the community.
- Provide opportunity for the community to express their knowledge of past flooding and present flood related concerns.

The information brochure was a double-sided colour A4 page folded into thirds. The brochure outlined the objectives and scope of the study, and identified opportunities for the community to be involved in the study. Photographs included in the brochure showing recent flood events. A copy of the brochure is provided in Appendix A.

The questionnaire consisted of a doubled sided A4 page containing seven questions. The questions were aimed at seeking local community flood knowledge and their present flood related concerns. A plan showing the study area was attached to the questionnaire. The intent of the plan was for the respondent to mark the approximate location of their property.

The information brochure and questionnaire were bundled and delivered by the GBCMA to approximately 200 residences/businesses located within the study area.

A total of 5 questionnaire responses have been received. This could be interpolated in two ways:

- A poor response reflecting a lack of major flooding in recent years.
- The general community has little concern that flooding is an issue, particularly as only a limited number of properties are flood affected.

The questionnaire response yielded six historical flood marks. The survey of the flood marks is discussed in Section 5.2.2. Also ten photos of historical floods were collected.

A summary of the community responses to the questionnaire is provided in Section 3.2.5 with a detailed listing of responses in Appendix A.

3.2.4 Key resident meetings

Five residents indicated a willingness to meet with the study team and GBCMA personnel. Meetings were conducted with the residents at their homes. An additional resident was present at one of the meetings, thus providing a total of 6 residents consulted. The meetings provided an opportunity for the study team and GBCMA to discuss the objectives and scope of the study. The residents provided details of their recollection of past flood events and location of flood marks. One resident showed a video taken during the June 1989 flood.

Further key residents provide comment on the hydraulic model calibration (Refer to Section 5.4). This community input enhanced confidence in the hydraulic model reliability.

3.2.5 Summary of questionnaire responses and concerns

Table 3-1 outlines the various aspects of flooding and the community concerns as raised by responses to the questionnaire and/or at the key resident meetings. A detailed listing of the questionnaire responses is provided in Appendix A.

Table 3-1 Summary of community responses

Flooding aspect	**Concerns**
Frequency of flooding and damages (Questionnaire questions No. 1 and 2)	• Land flooded • Access cut • No residences reported to be flooded
Nature of flooding (Questionnaire questions No. 3)	• Generally shallow inundation within properties. • Fast flowing downstream of Goulburn Highway crossings • Inundated Court Street bridge and fast flowing in June 1989
Historical flood marks and flood photographs (Questionnaire questions No. 4 & 5)	• Six historical flood marks identified • Ten flood photographs collected
Flood warning (Questionnaire question	• No formal flood warning source identified

Flooding aspect	Concerns
No. 6)	• Residents base response on observations to rainfall and river levels
Main concerns (Questionnaire No. 7)	• Application of appropriate land use and development controls. • Caravan park operations
General concerns raised at community sessions	• Application of appropriate land use and development controls • Lack of formal flood warning advice

3.3 Stage 2 consultation

The Stage 2 consultation consists:

- Press release: outlining key study outcomes and details availability of community information sheet.
- Community information sheet: summarising the study outcomes for the community and provided as hard copy at GBCMA Yea office.
- Key residents letters: distributed to residents who participated in Stage 1 consultation with community information sheet.

A copy of the community information sheet is provided in Appendix A.

4 HYDROLOGIC ANALYSIS

4.1 Overview

The hydrologic analysis determined historical and design flood inflow hydrographs (peak flow and flood volume) for the Yea River and Boundary Creek at the upstream study limit. The historical flood inflow hydrographs were used in the hydraulic model calibration as part of the hydraulic analysis. The design flood inflow hydrographs were determined for the 10, 20, 50, 100, 200 and 500 year average recurrence interval (ARI) floods and the probable maximum precipitation (PMP) design flood. The design flood inflow hydrographs were utilised in the hydraulic analysis to determine design flood levels and the existing level of flood risk.

A *probability-neutral approach* was adopted for this hydrologic analysis where the design inputs are selected such that the ARI of the flood event was the same as the causative rainfall event. The catchment hydrologic URBS was the principal tool for the hydrologic analysis. The URBS model is an event based conceptual runoff routing model in which rainfall is routed through a network of conceptual storages to the catchment outlet. The network of conceptual storages employed is based on the physical drainage network for a catchment. The URBS model parameters are determined through calibration of the modelled flood hydrographs with observed flood hydrographs for a given event. In the model calibration process, observed rainfall and streamflow data (flood hydrographs) are model inputs. Once calibrated the URBS model is applied to estimate design flood hydrographs with design rainfall events as input.

To assess the reliability, the 100 year design peak from the URBS model was compared to 100 year design peak flows from regional relationships and adjacent catchments. These comparisons reveal uncertainty in the design flood estimation.

This section details the input data, methodology and outputs for the hydrologic analysis. The structure of the section is as follows:

- Study input data – outlines the available historical rainfall and streamflow for use in the model calibration (Section 4.2).
- URBS model development – details the development of the URBS model strucutre (Section 4.3).
- URBS model calibration – details the selection of calibration events and calibration of model paramters (Section 4.4).
- URBS model verification for design flood estimation – discusses the verification of URBS model parameters for design flood estimation (Section 4.5).
- Design flood hydrographs estimation – summaries the estimation of design flood hydrographs with the calibrated URBS model (Section 4.6).
- Historical June 1989 flood hydrographs estimation – summaries the estimation of June 1989 historical flood hydrographs with the calibrated URBS model for use in the hydraulic analysis (Section 4.8).
- Discussion – provide additional discussion of the relaibaility of the histoircal and design flood hydrographs (Section 4.9).

4.2 Study input data

4.2.1 Stremflow data

Historical streamflow data was required for the URBS model calibration and verification. There are two streamflow gauging stations located in the Yea River catchment able to provide historical streamflow data, Yea River at Devlin's Bridge and Murrindindi River at Murrindindi.

Streamflow data available at both gauges consists of average daily streamflow and instantaneous streamflow. The average daily flow streamflow is available since the establishment of the gauge. The instantaneous streamflow data is available for a short period of record since the installation of continuous water level monitors at the gauges.

The details of the streamflow gauging stations are provided in Table 4-1 and their locations are shown in Figure 4-1.

Table 4-1 Details of Streamflow gauges

Gauge Number	Description	Catchment Area (km^2)	Period of record
405217	Yea River at Devlin's Bridge	358.2	Average daily flow - 1954 to date (49 years) Instantaneous flow – 1975 to data (28 years)
405205	Murrindindi River at Murrindindi	108.8	Average daily flow - 1940 to date (63 years) Instantaneous flow – 1975 to data (28 years)

Adjacent to the upstream side of the Court Street (caravan access) bridge, a series of flood height gauge boards have been installed. The gauge boards enable the estimate of the flood height relevant to the gauge zero. The gauge zero was surveyed, as part of this study, at 162.72 m AHD. This study utilises this gauge as the reference point for flood inundation mapping. Section 9 provides details of the flood inundation mapping for emergency response.

4.2.2 Rainfall data

Both temporal and spatial rainfall data were required for the URBS model calibration. Pluviographic rainfall data provides the temporal rainfall variation with daily rainfall data providing further spatial rainfall variation.

Pluviographic rainfall data

Availability of pluviographic data within and adjacent to the Yea River catchment was found to be limited. Table 4-2 shows the pluviographic stations and Figure 4-1 displays their location. Details of the hydrologic model calibration events are provided in Section 4.4.

Table 4-2: Details of pluviographic stations

Site Number	Name	Period of record
405217	Yea River at Devlin's Bridge TBRG	October 1997 to date
405209	Acheron River at Taggerty TBRG	March 1993 to date
405231	King Parrot Ck. at Flowerdale TBRG	September 1992 to date
405274	Home Ck. at Yarck TBRG	November 1997 to date
86142	St. Leonards	October 1957 to date
88023	Lake Eildon	January 1954 to date

Daily rainfall data

The spatial coverage of daily rainfall stations varied across the catchment. Table 4-3 shows the daily rainfall stations and Figure 4-1 displays their location.

Table 4-3 Details of daily rainfall stations

Site Number	Name	Period of record
88000	Alexandra (Acheron)	1877 to date
88023	Lake Eildon	1887 to date
88028	Glenburn	1936 to date
88044	Marysville	1904 to date
88046	Murrindindi	1912-2001
88060	Kinglake West (Wallaby Creek)	1884 to date
88067	Yea (Post Office)	1885 to date
88131	Narbethong	1926 to date
86142	Mt St. Leonards	1957 to date
88153	Spring Creek Basin Two	1973 to date
88158	Strath Creek	1983-to date
86280	Kinglake Garage	1969 -1988

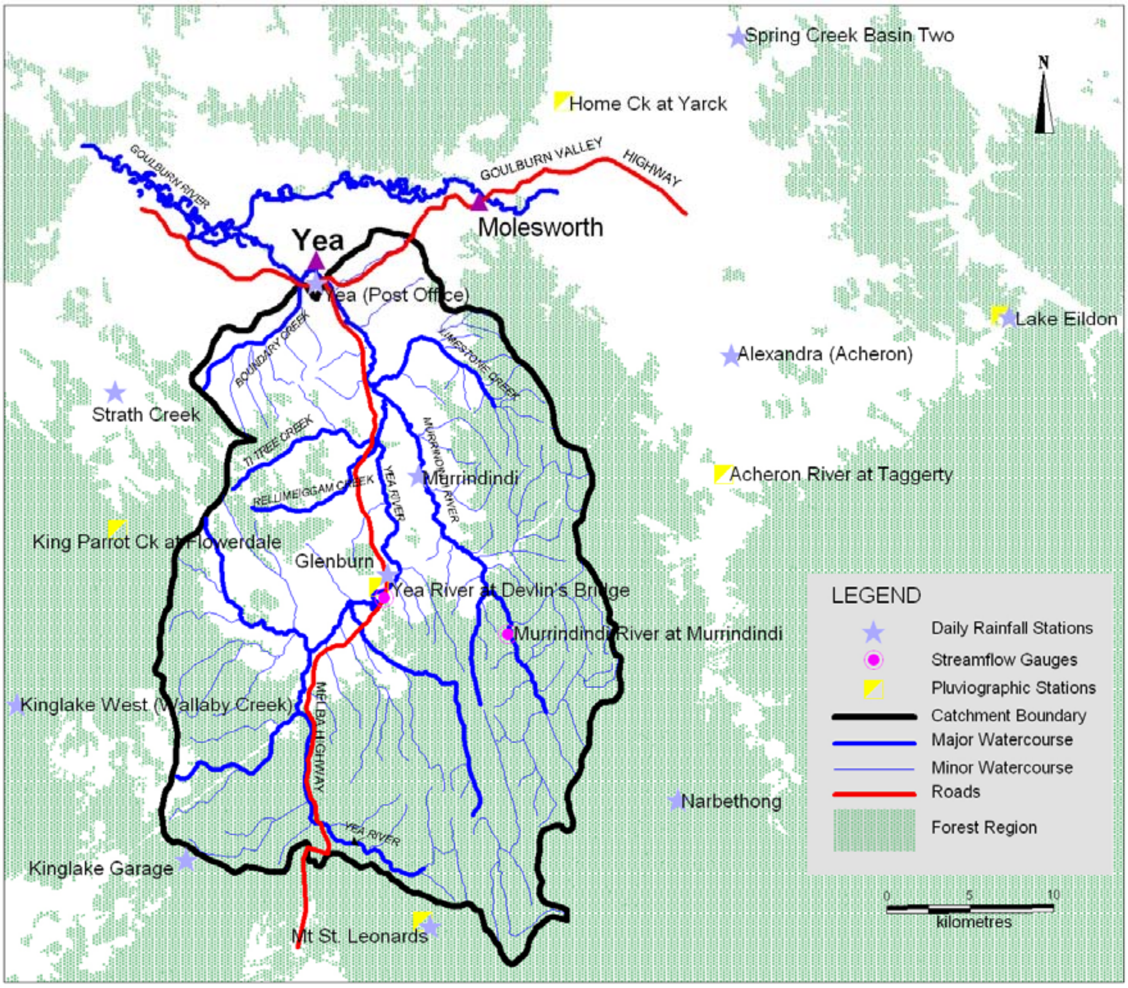


Figure 4-1 Yea River Catchment – streamflow and rainfall gauging stations

4.3 URBS model development

4.3.1 Description of URBS Runoff Routing Model

The hydrologic catchment model developed in this study is based on the URBS rainfall runoff routing model described by Carroll (2002).

URBS is a networked conceptual runoff and streamflow routing program that calculates flood hydrographs from rainfall and other channel inputs. The model is based on catchment geometry and topographic data. It is a spatially distributed, non-linear model that is applicable to both urban and rural catchments. The model can account for both temporal and spatial distribution of rainfall and losses.

Two runoff routing approaches are available within URBS to describe catchment and channel storage routing behaviour. These are the URBS *Basic* and *Split* routing models.

The *Basic* model is a simple RORB-like model (Laurenson & Mein, 1990) where stream length (or derivative) is assumed to be representative of both catchment and channel storage.

The *Split* model separates the channel and catchment storage components of each sub-catchment. The *split* model applies the rainfall to a sub-catchment and then routes the rainfall excess runoff routed through the sub-catchment to the sub-catchment outlet. The sub-catchment storage is assumed to be proportional to the square root of the sub-catchment area. Once at the sub-catchment outlet, the runoff is then routed along the channel network to the catchment outlet with downstream sub-catchment runoff entering at sub-catchment outlets. The channel storage is assumed to be proportional to the length of the channel. There are three principal model parameters in the split model, α (channel storage parameter), β (catchment storage parameter) and m (degree of non-linearity of flood response).

The storage characteristics for the sub-catchment and channel can be modified by the channel slope, catchment slope, fraction urbanised (various degrees), fraction forested and channel roughness. These other variables are included optionally in the modelling process at the discretion of the modeller (Carroll (2002)).

Further details of URBS can be obtained from Carroll (2002).

The rainfall excess (runoff) is determined by the application of rainfall loss model. URBS offers several rainfall loss model including the initial loss/continuing loss model and initial the initial loss/volumetric runoff coefficient model.

4.3.2 URBS model structure

The URBS *Split* model was adopted in this study. The adoption of the split model for this study was principally based on the availability of a recent developed URBS *Split* model. The available URBS *split* model was developed by BoM (Baker pers comm. 2002, Leahy 2002). This model was developed as part of the flood warning system for the Goulburn River from Eildon to Seymour.

The available model was developed for use for the entire Goulburn River catchment downstream of Eildon to Seymour including the Yea River catchment. Several minor modifications were made to the model structure to enable the outputs (flood hydrographs) required for this study.

Within the Yea River catchment, model sub-catchments were then defined to coincide with watershed boundaries, stream junctions, and the location of gauging stations. In total the Yea River catchment was sub-divided into 19 sub-catchments. Figure 4-2 shows the URBS model catchment sub-division.

As discussed in Section 4.3.1, the storage characteristics for the sub-catchment and channel can be modified by the use of other catchment characteristics. As outlined in Section 2, the Yea River catchment displays significant variation in channel slopes and forested areas from the upland sub-catchments to lowland sub-catchments. It was considered appropriate, given this variation, to include the channel slope and forested area as factors in the determination of sub-catchment and channel storage.

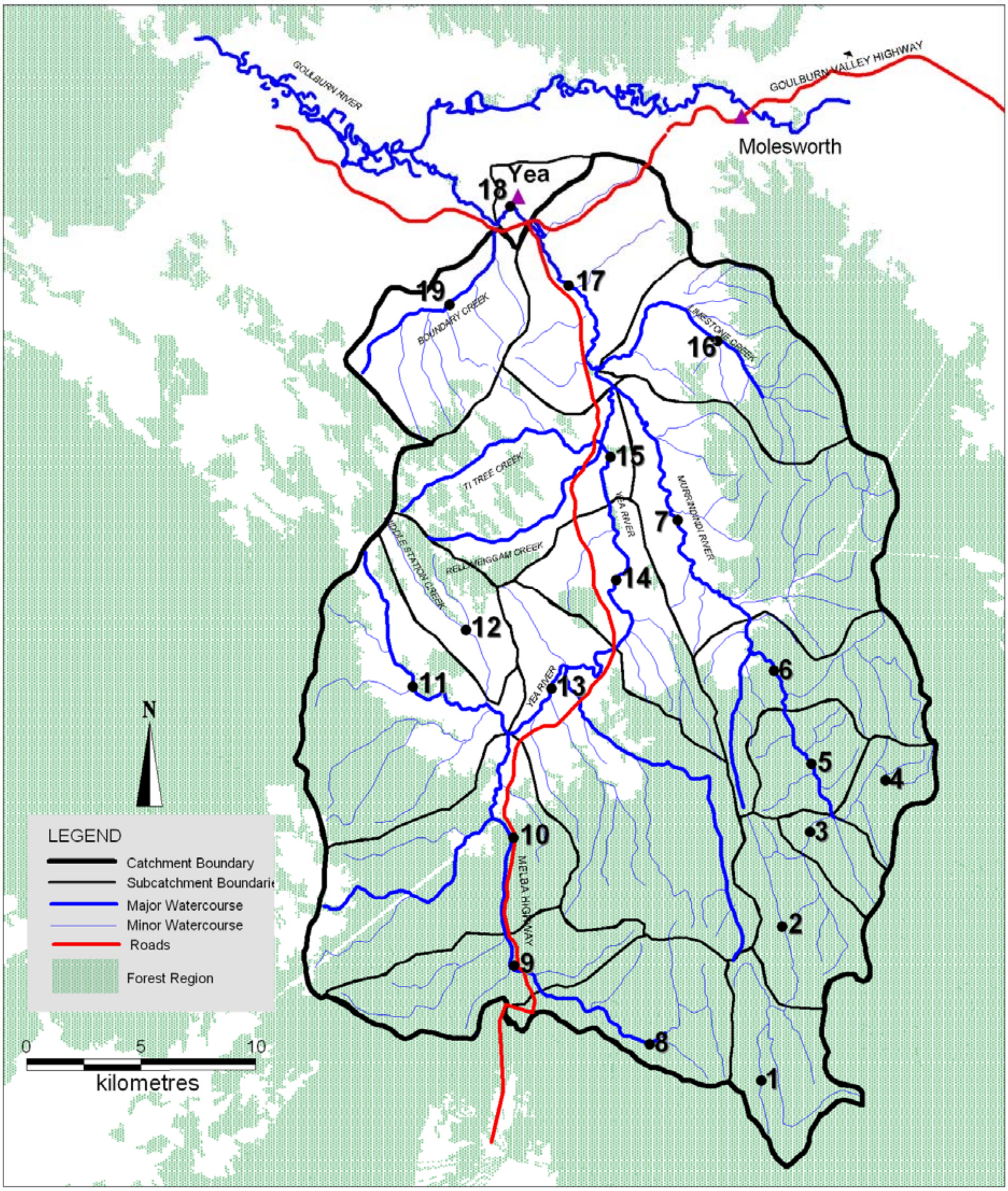


Figure 4-2 URBS model structure – catchment subdivision

4.4 URBS model calibration

4.4.1 Overview

As discussed previously, the URBS split model routes excess runoff through the sub-catchment to the sub-catchment outlet and then routes the excess runoff along the channel network to the catchment outlet. The three model parameters α (channel storage parameter), β (catchment storage parameter) and m (degree of non-linearity of flood response) require determination during the model calibration.

Model parameters (α, β & m) were determined by BoM as part of the Goulburn River flood warning investigations (Baker pers comm. 2002, Leahy 2002). For this previous investigation, the main focus of the model was on estimation of flood heights at Seymour. In turn, the calibration undertaken as part of the flood warning investigations focused on the reliable estimation of observed flood heights at Seymour.

As this study required on the estimation of flood events at Yea rather than at Seymour, it considered appropriate to undertaken a calibration focused on the estimation of historical flood events within the Yea River catchment.

The URBS model calibration requires the comparison of the modelled flood hydrographs with observed flood hydrographs at streamflow gauge(s) throughout the catchment. For this study flood hydrographs were required for the Yea River and Boundary Creek at the upstream study area limits. Ideally the URBS model would be calibrated to observed flood hydrographs at gauges located on the Yea River and Boundary Creek adjacent to the study area. As outlined in Section 4.2, two streamflow gauging stations, Yea River at Devlins Bridge and Murrindindi River at Murrindindi, are located in the Yea River catchment. Both these gauges are located considerably upstream from the study area.

Given this availability of streamflow data, the calibration of the URBS model parameters was undertaken to observed streamflow data at the upstream gauges. This calibration approach results in the model parameters determined at the upstream gauges being applied to the entire Yea River catchment. Such extrapolation of model parameters may produce unreliable results for the entire catchment due to changes in catchment characteristics from upstream to downstream. In an effort to reflect change in catchment characteristics and improve the reliability of the model results, the channel slope and forested area were included in the determination of sub-catchment and channel storage, as discussed in Section 4.3.2.

It should be noted the BoM developed URBS model does not use channel slope and forested area to modify the storage relationships.

Appendix B provides details of the URBS catchment input file.

4.4.2 Selection of model calibration events

The selection of suitable flood events for model calibration was dependent on the availability of concurrent streamflow and pluviographic records. Three flood events selected for calibration were: September 1984, June 1989, and September 1996. The details of the selected calibration flood events are given in Table 4-4.

Table 4-4 URBS model calibration event details

Event	**Event Start & Finish Date**	**Yea River at Devlin's Bridge**			**Murrindindi River at Murrindindi**		
		Recorded Peak flow (m^3/s)	**Date and Time of Peak**	**Rank of peak flow in record**[1]	**Recorded Peak flow (m^3/s)**	**Date and Time of Peak**	**Rank of peak flow in record**
September 1984	16/9/84-20/9/84	104	19/9/84 3:00 am	7	20.1	19/09/84 7:00 am	3
June 1989	9/6/89-12/6/89	244	11/6/89 2:00 am	2	8.9	11/06/89 4:00 pm	28
September 1996	28/9/96-3/10/96	71	1/10/96 10:00 am	11	15.6	1/10/96 7:00 am	8

1. **Since the commencement of instantaneous flow data (1975 to date). Refer to** Table 4-1**.**

Sub-area Rainfalls

For each calibration event, the rainfall depth was estimated for each sub-area to account for the spatial variation of rainfall across the catchment. The rainfall depth on each sub-area was estimated using the Thiessen Polygon Method with the use of the daily rainfall stations as indicated in Table 4-3. However, some of the stations were located at a considerable distance from the study area, and as such only a subset of the stations with records was effectively used to obtain sub-area rainfall depths. The temporal distribution of rainfall was determined by assigning the rainfall pattern from the nearest available pluviographic station (see Table 4-2 for details of pluviographic rainfall stations). Table 4-5 provides the average sub-catchment rainfall for the URBS model calibration events.

Table 4-5 URBS model calibration event catchment rainfalls

Event	Average sub-catchment rainfall (mm)		
	Yea River upstream of Devlins Bridge gauge (sub-catchment area 358.2 km^2)	Murrindindi River upstream of the Murrindindi gauge (sub-catchment area 108.8 km^2)	Yea River downstream of gauges (sub-catchment area 441.2 km^2)
September 1984	81	91	57
June 1989	77	69	41
September 1996	55	95	49

Baseflow Separation

The URBS model transforms the rainfall excesses of a given storm event into a flood hydrograph. This does not include the baseflow component that occurs due to the discharge from the groundwater store replenished by the current and prior events. In order to compare the routed storm excess obtained with the use of URBS models with the actual observed flood hydrograph, it is necessary to remove the baseflow component from the recorded hydrograph of total streamflow (as measured at each gauging station).

There are many methods available for the separation of baseflow from the observed flood hydrograph. This study adopted the following procedure (ARR, 1987):

(i) The streamflow hydrograph on either side of the event was examined in order to provide confirmation of the general magnitude of baseflow contribution in the absence of rainfall;

(ii) The streamflow at the beginning of the hydrograph was assumed to comprise entirely of baseflow;

(iii) A baseflow separation line was drawn by extending the recession curve prior to the stream rise to a point that coincided with the timing of the hydrographs peak;

(iv) The baseflow hydrograph was assumed to peak after the total hydrograph peak due to the storage-routing effect of the sub-surface stores;

(v) The cessation of runoff was assumed to occur at the point of greatest curvature in the total streamflow recession curve;

(vi) The falling limb of the baseflow recession curve was assumed to follow an exponential decay function so as to rejoin the total hydrograph at the cessation of surface runoff; and

(vii) Subtracting the baseflow hydrograph from the total streamflow hydrograph leaves the actual rainfall excess hydrograph that can be used to compare the hydrograph obtained from the URBS model during calibration.

It must be acknowledged that the separation of baseflow may produce errors in the volume and shape of the calibration hydrograph. However the results of Bates and Davies (1988) indicate that the sensitivity of model predictions to differences in baseflow separation procedures lessens with increasing magnitude of the event.

A sample baseflow separation for Yea River at Devlin’s Bridge (Gauge 405217) during June 1989 flood event is presented in Figure 4-3.

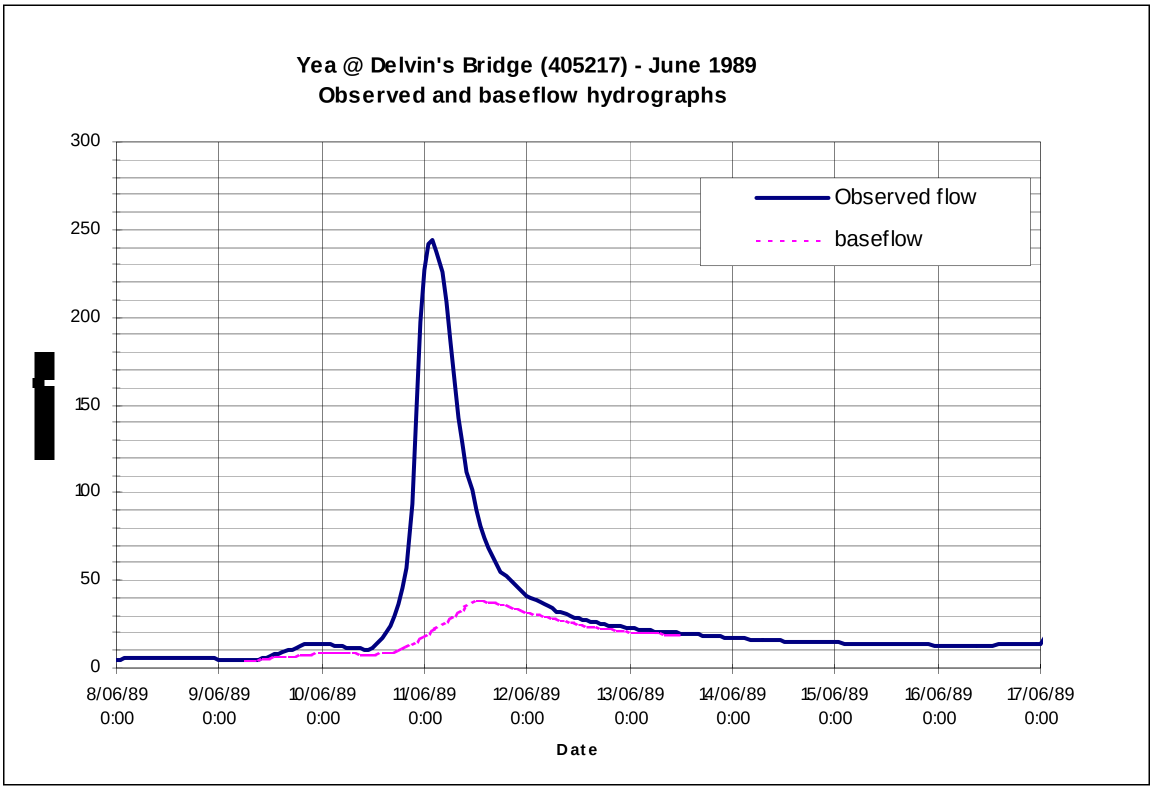


Figure 4-3 Baseflow Separation at Devlins Bridge - June 1989

4.4.3 URBS model parameter calibration

As outlined, there are three model parameters (α, β & m) requiring calibration. The initial calibration approach adopted by this study was as follows:

- Set m = 0.8. This value is acceptable value for the degree of non-linearity of catchment response (ARR87).
- For each calibration event at both Yea River at Devlin's Bridge and Murrindindi River at Murrindindi, the initial loss was determined to result in a reasonable match between the modelled and observed rising limb of the flood hydrograph. The continuing loss/runoff co-efficient was determined to match the modelled and observed runoff volume.
- For each calibration event at both Yea River at Devlin's Bridge and Murrindindi River at Murrindindi, a number of combination of α and β were trialled to achieve reasonable re-production of the peak flow and general hydrograph shape.

Initial model calibration runs indicated difficulty in estimating peak flows for the Murrindindi River at Murrindindi. Discussions with the BoM confirmed similar difficulties were encountered during the investigations for the flood warning system (Baker pers comm. 2002, Leahy 2002). The reliability of the streamflow data from the Murrindindi River at Murrindindi was considered questionable. Due to the low reliability of the streamflow data for the Murrindindi River at Murrindindi, the model calibration was undertaken to observed data for the Yea River at Devlins Bridge only. The model parameters determined to achieve a reasonable simulation of the observed hydrographs for the Yea River at Devlins Bridge were applied to the Murrindindi River at Murrindindi.

The initial loss/proportional loss model was found to provide a better fit of observed and modelled flood hydrographs and was adopted for use in this hydrologic analysis. The rainfall loss parameters, initial loss (IL) and proportional loss (PL), were determined by comparison of observed and modelled hydrographs at both streamflow gauges. The initial loss values were determined by providing a reasonable match in the timing of the rising limb of the observed and modelled hydrographs at both gauges. The proportional loss was set to provide a match in the runoff volume for observed and modelled hydrographs. Two rainfall loss parameter sets were determined for each calibration event corresponding to the two streamflow gauges. A summary of calibration results are provided in Table 4-6.

Table 4-6 URBS model calibration results

Event	Routing parameters		Rainfall loss parameters				Peak flows (m^3/s)			
	α	β	Yea River at Devlins Bridge		Murrindindi River at Murrindindi		Yea River at Devlins Bridge		Murrindindi River at Murrindindi	
			IL	PL	IL	PL	Observed	Modelled	Observed	Modelled
September 1984	0.04	0.15	5	0.75	5	0.84	80.1	75.6	15.0	20.7
June 1989	0.05	0.15	15	0.53	15	0.88	222.9	230.0	6.3	17.6
September 1996	0.05	0.15	5	0.66	5	0.91	55.4	54.6	1.9	9.7

Note: Observed peak flow above after baseflow removal.
IL – initial loss (mm)
PL – proportional loss. Runoff co-efficient RC = 1 – PL

As discussed, due to the questionable reliability of the stream flow data for the Murrindindi River at Murrindindi, the URBS model calibration focused on the simulation of observed hydrographs for the Yea River at the Devlins Bridge gauge. Table 4-6 shows reasonable agreement between the modelled and observed peak flows for the Yea River at Devlins Bridge.

As seen in Table 4-6 modelled peak flows were significantly higher than the observed peak flows for the Murrindindi River at Murrindindi. This over-estimation of peak flows for the Murrindindi River is consistent with the results achieved during the Goulburn flood warning system study (Baker pers comm. 2002, Leahy 2002).

Figure 4-4 to Figure 4-6 show the comparison of the observed and modelled hydrographs for the URBS model calibration events at Devlins Bridge.

Table 4-6 shows a small range in the α values and a constant β value (0.15) for the calibration events. The study team considered the adoption α value of 0.05 for design flood estimation appropriate. This α value provides the best fit of the June 1989 event (the event with largest peak flows).

The URBS routing parameters, α (0.05) and β (0.15), determined by calibration were considerably different than the values adopted by BoM (Leahy 2002). The Goulburn River flood warning study (Leahy 2002) adopted α and β values of 0.30-0.40 and 4.0-4.5 respectively. The differences in the routing parameters are due to the use of the channel slope and forestation in the runoff routing in this study.

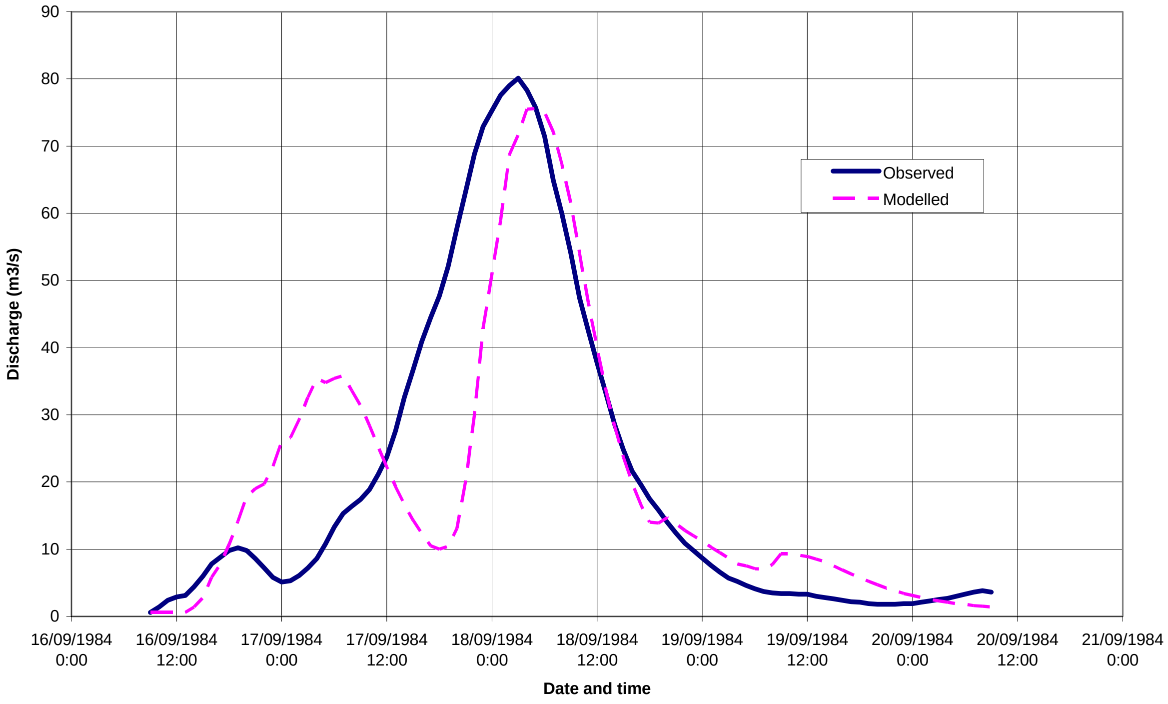


Figure 4-4 URBS model calibration September 1984 for the Yea River at Devlins Bridge

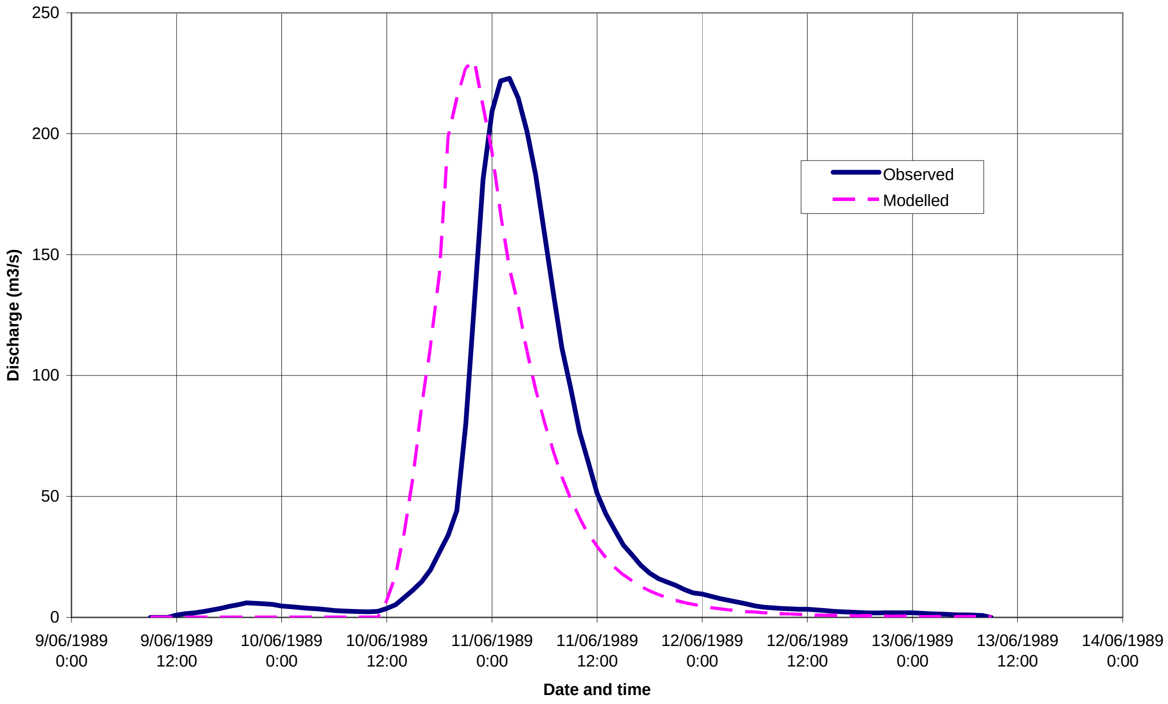


Figure 4-5 URBS model calibration June 1989 for the Yea River at Devlins Bridge

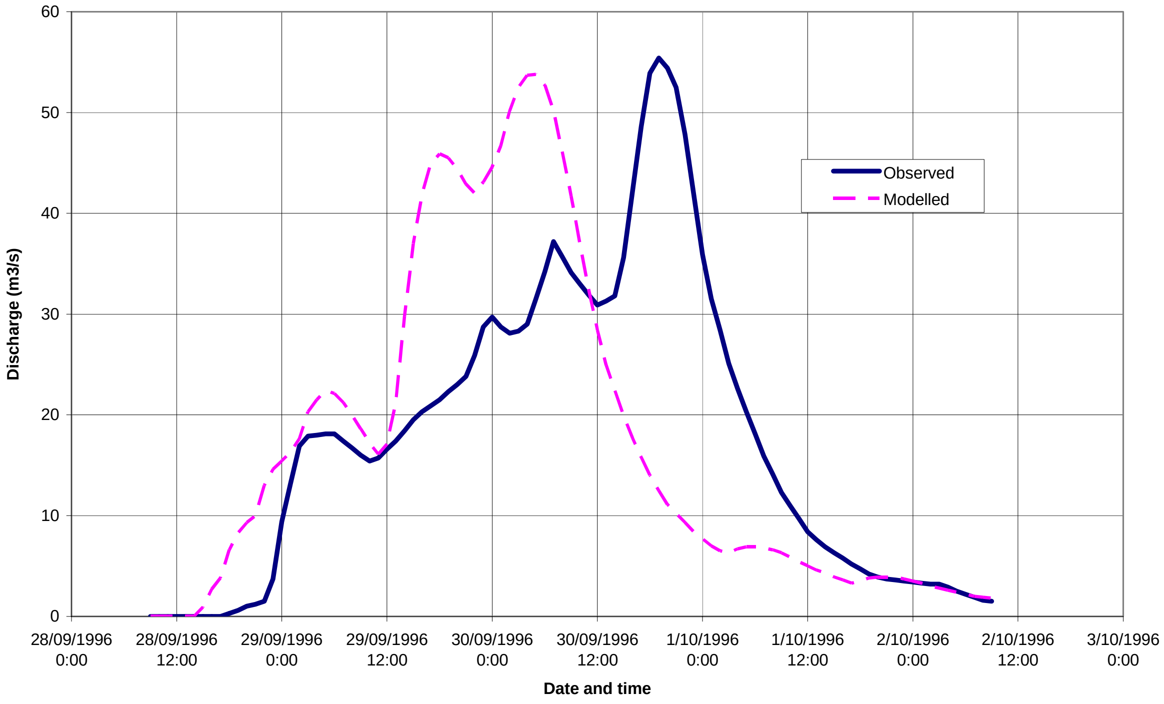


Figure 4-6 URBS model calibration September 1996 for the Yea River at Devlins Bridge

4.5 URBS model verification for design flood estimation

4.5.1 Overview

The model parameters determined from the model calibration need to be verified for their suitability for design flood estimation. The model parameters from the model calibration may contain a bias due to the nature of the calibration flood events. In particular, the rainfall loss parameters from the model parameters are influenced by the catchment soil moisture conditions at the commencement of the calibration flood event. As discussed in Section 4.1, this study has adopted a probability neutral approach to the estimation of design flood events.

Design rainfall loss parameters have been developed for South Eastern Australia by the Co-operative Research Centre for Catchment Hydrology (CRCCH) (Hill et al., 1996). These design rainfall loss parameters have been found to provide design peak flow estimates from runoff routing models in line with design peak flow estimates from flood frequency. A consistency of design peak flow estimates between runoff routing models and flood frequency analyses indicates the runoff routing model parameters are resulting in design peak flow estimates with the same ARI as the causative rainfall event.

The following procedure was adopted by this study to verify the model parameters for use in design flood estimation:

- Determine peak flows for the Yea River at Devlins Bridge using at site flood frequency analysis.
- Determine design rainfall loss parameter using relationships developed by CRCCH (Hill et al., 1996).
- Determine design peak flows using the URBS model with the calibrated routing parameters (α & β) and the design rainfall loss from the CRCCH relationships.

- Adjust the rainfall loss parameters until a reasonable match is obtained between the design peak flow estimates for the Yea River at Devlins Bridge from the URBS model and the flood frequency analysis.

4.5.2 Flood Frequency Analysis

Annual flood frequency analysis was undertaken for the Yea River at Devlins Bridge. For the annual flood series, a Log Pearson 3 (LP3) distribution was fitted by the method of moments (ARR 1987).

As outlined in Section 4.2.1, mean daily flows were available for a period prior to the commencement of continuous water level monitoring. To provide additional stream data for the flood frequency analysis, relationships between the peak daily flows and the mean daily flows were developed. These relationships were then employed to estimate peak daily flows from the mean daily flow for the period prior to the commencement of continuous water level monitoring. Further details are provided in Appendix B.

Figure 4-7 show the flood frequency analyses for the Yea River at Devlins Bridge.

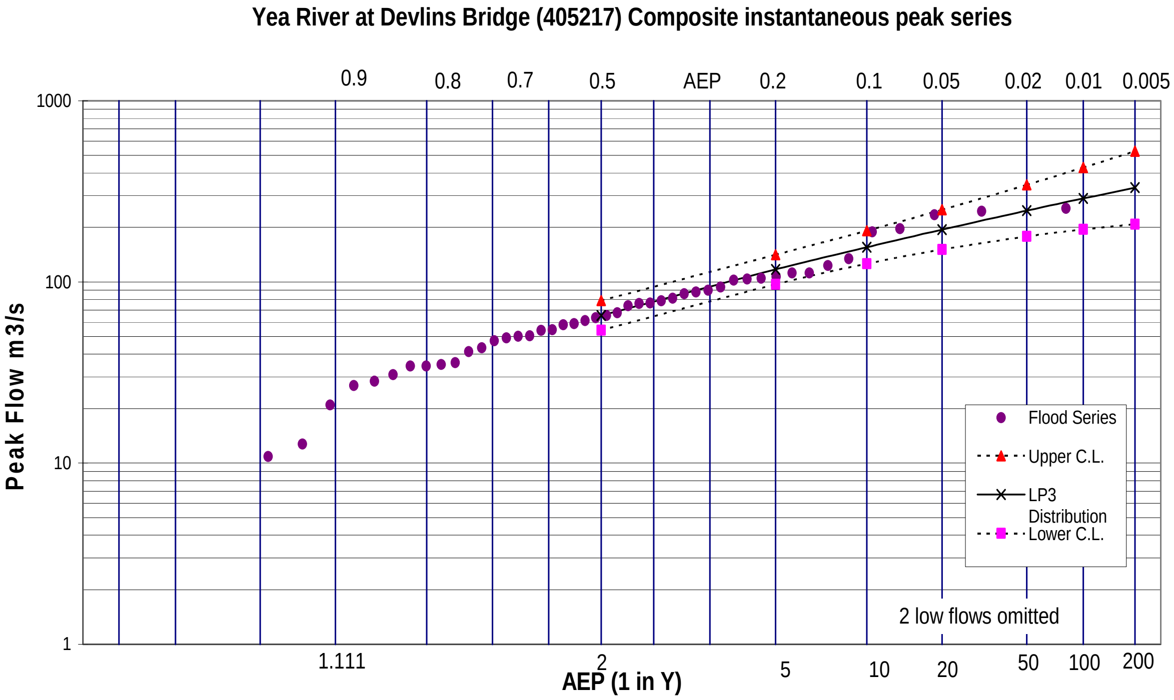


Figure 4-7 Flood frequency analysis: Yea River at Devlins Bridge

4.5.3 Design loss parameters

Design losses have been developed by the CRCCH. The losses currently recommended in ARR87 tend to result in overestimation of the peak flows. The new loss parameters in combination with the new areal reduction factors (Siriwardena and Weinmann, 1996) produced peaks which are far more consistent with the results of flood frequency analysis (Hill et al., 1996).

The CRCCH prediction equations differentiate between complete storm initial losses (IL_S) and burst initial losses (IL_B). The latter are bursts of rainfall within longer duration storms and should be used for design because they account for the embedded nature of the ARR87 design rainfalls (Hill et al., 1996).

The following equations (Hill et al. 1996) were used to predict losses:

$$PL = 0.621BFI - 0.000175 + 0.662 \quad (1)$$

$$IL_S = -25.8BFI + 33.8 \quad (2)$$

$$IL_B = IL_S\left\{1 - \frac{1}{1 + 142\frac{\sqrt{duration}}{MAR}}\right\} \quad (3)\text{, where;}$$

- BFI = the baseflow index is defined as the volume of the baseflow divided by the total streamflow volume. It is a fixed value for a given catchment, determined as an average ratio over a long period of time. For this study the routine BFLOW was employed to determine the BFI. BFLOW is part of the AWBM suite developed by Boughton (1997).
- MAR = the mean annual rainfall for the catchment. For this study the mean annual rainfall was determined from Bureau of Meteorology mean annual rainfall maps (1961-1990).
- duration = the burst duration (hours)

Table 4-7 displays the design rainfall loss values calculated using the above equations.

Table 4-7 CRCCH Design losses

Catchment	BFI	MAR (mm)	Storm initial loss (ILs) (mm)	Proportional loss (PL)
Yea River at Devlins Bridge	0.64	1000	17.3	0.88

4.5.4 Selection of Model Verification Inputs

Rainfall Depths

For the model verification, design rainfall depths were determined by the procedures outlined in Chapter 2 of ARR87 at the centroid of the Yea River catchment upstream of Devlins Bridge.

Rainfall Temporal Patterns

The temporal pattern adopted can also have a major affect on the magnitude of the design flood estimate. The temporal patterns used in the verification process were obtained from ARR87.

The ARR87 temporal patterns are intended for use with design rainfalls up to an ARI of 500 years. The patterns are presented in Volume 2 of ARR87. For this the temporal pattern for ARR87 Zone 2 was applied.

Baseflow Component

As outlined in Section 4.4, it is necessary to add the baseflow component to the surface runoff hydrograph produced by URBS. From the baseflow separations for Yea River at the Devlins Bridge, the baseflow value was determined at the time of the total peak flow (refer to Section 4.4.2 for details of the baseflow separations for the calibration events). The average baseflow for the Yea River at Devlins Bridge at the time of total peak flow was determined from the hydrologic model calibration events. The average baseflow value at Devlins Bridge was scaled by catchment area, to provide a constant baseflow of 25 m^3/s for design purposes at the upstream study area limit. This baseflow of 25 m^3/s was applied to all design flood events i.e. no change with ARI.

Routing parameters

The URBS routing parameters, α (0.05) and β (0.15), as discussed in Section 4.4.3 were used in the model verification.

4.5.5 Verification of Design Parameters

The above model inputs were employed in the URBS model. These were compared with the results of flood frequency analysis. Storm durations ranging from 6 to 72 hours were trialled.

Verification of design parameters was undertaken for the Yea River at Devlins Bridge. Design peak flow estimates using the calibration losses (see Section 4.4.3) and the CRCCH losses (see Section 4.5.3) were compared to the flood frequency results for the 5 year and 50 year ARI events. If necessary, adjustments to the losses were made to produce design peak flows consistent with the flood frequency analysis. The critical storm duration was 72 hours for both 20 and 50 year ARI events. The following model parameters were validated for the Yea River at Devlins Bridge:

- Routing parameters: α 0.05 and β 0.15
- Initial loss: 9.4 mm
- Proportional loss: 0.76 (runoff co-efficient 0.24)

The verification plot for the Yea River at Devlins Bridge is shown in Figure 4-8.

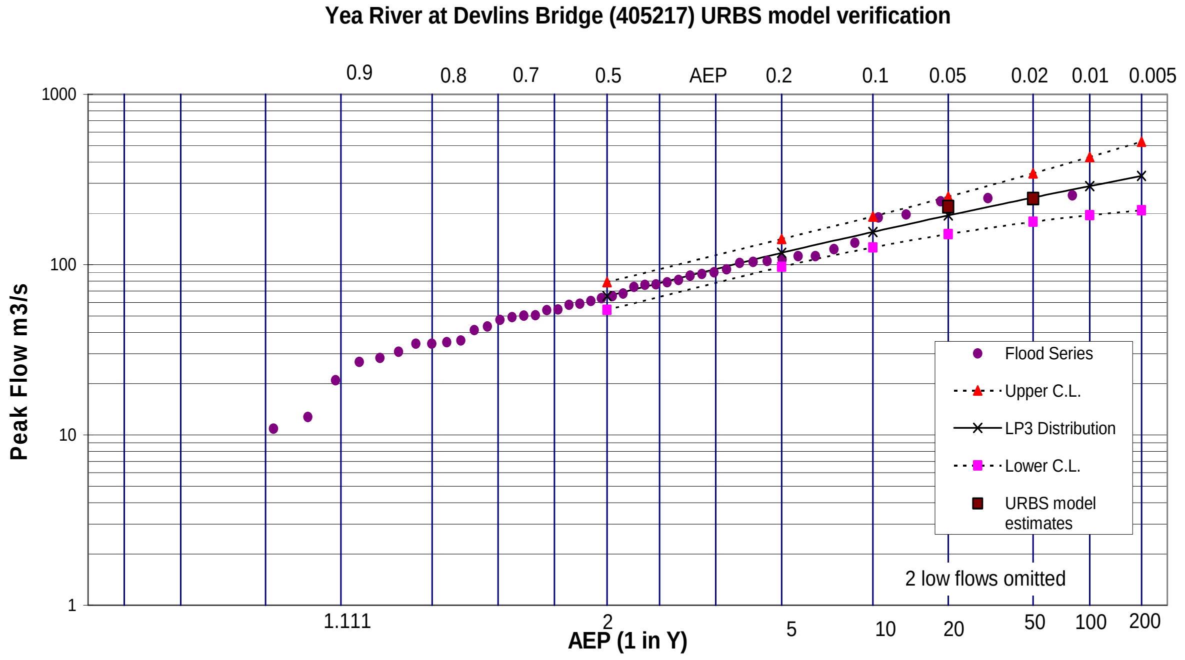


Figure 4-8 Verification of design parameters for the Yea River at Devlins Bridge

4.6 Design Flood Estimation Using URBS Hydrologic Model

The design flood estimation inputs include:

- Design Rainfalls (i.e. depth, temporal and spatial patterns)
- Design Rainfall Losses
- Baseflow
- Routing Parameters

Details of the selection of appropriate design inputs are contained in the following sections.

4.6.1 Design Rainfalls

For design flood estimation, design rainfall events are required for ARIs from 5 to 500 years.

Design Rainfall Depths and Design Spatial Patterns

Design rainfall depths were calculated for ARIs from 5 to 500 years using the IFD analysis in ARR87. The design rainfall depths were determined at the centroids of the following three sub-catchments:

- Yea River catchment upstream of Devlins Bridge.
- Murrindindi River upstream of Murrindindi
- Yea River catchment downstream of Devlins Bridge and Murrindindi

Design Temporal Patterns

The design temporal patterns from ARR87 were used in the study for all ARIs from 5 to 500 years. For this study the ARR87 Zone 2 temporal patterns were applied.

Examination of historical rainfall spatial patterns and of design rainfall information contained in Volume 2 of ARR87 showed a significant spatial variation in rainfall across the study area. As a result, a different design rainfall depth was calculated for each sub-catchment.

The design sub-catchment rainfalls were obtained by applying areal reduction factors (Siriwardena and Weinmann, 1996) to the point design rainfall estimates of each sub-catchment.

4.6.2 Design Loss Values

Design losses were validated for the Yea River at Devlins Bridge as discussed in Section 4.5.5. No validation was possible for the Murrindindi River at Murrindindi and the remaining downstream Yea River catchment due to a lack of suitable streamflow data. URBS (Carroll 2002) adjusts rainfall losses according by a factor (1-(area of forestation as a fraction)/2). This study adopts the same approach to determine losses for the Murrindindi River at Murrindindi and the reminding downstream Yea River catchment based on the validated design losses for the Yea River at Devlins Bridge. Table 4-8 shows the area of forestation and the adopted design losses for the three sub-catchments.

Table 4-8 Adopted Design Loss Values

Sub-catchment	Proportion of Forested area	Design loss	
		Initial loss (mm)	Proportional loss (Runoff co-efficient)
Yea River at Devlins Bridge	0.54	9.4	0.76 (0.24)
Murrindindi River at Murrindindi	0.86	9.4	0.95 (0.05)
Downstream Yea River catchment	0.19	9.4	0.60 (0.40)

Note:

- Sub- Area of forestation was determined as the area weighted sub-catchment average.
- Proportional loss for Murrindindi River at Murrindindi and Downstream Yea River catchment determined by ratio of (1-$F_{\text{Yea upstream of Devlins Bridge}}$/2)/(1-$F_{\text{Other catchment}}$ /2) multiply by the proportional loss for the Yea River upstream of Devlins Bridge)

The adopted design losses were developed for design purposes only. The losses shown in Table 4-8 were consistent with the model calibration losses (refer to Section 4.4). The losses obtained from historical events are only applicable to the historical event in question, and may be biased due to effect of catchment conditions prior to the event. The adopted design losses are different to the CRCCH design losses (refer to Section 4.5). These differences may arise from uncertainties in streamflow data impacting on the flood frequency analysis for each sub-catchment gauge. Further, the design loss equations developed by the CRCCH contain considerable uncertainty due to the scatter in the raw data used in that analysis.

The adopted design losses have been shown to result in design flood estimates consistent with the flood frequency analysis for the Yea River at Devlins Bridge and are considered to be satisfactory for design flood estimation.

Further discussion regarding the use of the above design rainfall losses is provided in Section 4.9.

4.6.3 Routing parameters and design baseflow

Routing Parameters

The routing model parameters α 0.05 and β 0.15, as determined in Section 4.5.5, were adopted for design flood estimation.

Addition of Design Baseflow

The constant baseflow component 25 m^3/s, determined in Section 4.5.4, was added to the surface runoff hydrograph output from URBS.

4.6.4 Design Floods

The adopted design parameters in combination with the design rainfall were employed to determine design flood hydrographs for the Yea River and Boundary Creek at the upstream study area limit for 10, 20, 50, 100, 200 and 500 year ARI design flood events. Table 4-9 shows the peak flows for the Yea River and Boundary Creek at the upstream study limit.

Table 4-9 URBS Model Design Peak Flows for the Yea River and Boundary Creek at the upstream study limit

Location	**Design peak flows (m^3/s)**					
	10 year ARI	**20 year ARI**	**50 year ARI**	**100 year ARI**	**200 year ARI**	**500 year ARI**
Yea River at upstream study area limit	267	322	368	428	546	602
Boundary Creek at upstream study area limit	49	57	64	72	87	94

Details of the design flood hydrographs are shown in **Appendix B**.

4.6.5 Design flood hydrographs for the hydraulic analysis

The design flood hydrographs were determined at the following inflow points to the hydraulic analysis:

- Yea River at upstream study area limit
- Boundary Creek at upstream study area limit
- Two local study area inflows at the Goulburn Valley Highway and Craigie Street

4.7 Probable Maximum Precipitation Design Flood

The study brief required a preliminary estimate of the probable maximum flood (PMF) to be undertaken for this study. In line with this requirement, this study employed a regional prediction equation developed to provide preliminary estimate of peak flow during a PMF event. The regional prediction equation (Nathan el al 1994) was developed for south eastern Australian catchments and has the following form:

$$\textit{Peak flow for PMF event } (m^3/s) = 1.27\,A^{0.616}$$

where:

- A is catchment area (km^2)

Table 4-10 displays the preliminary peak PMF flows for the Yea River and Boundary Creek catchments as determined using the above regional prediction equation.

Table 4-10 Preliminary Peak PMF flow

Catchment	Catchment Area (km^2)	Peak PMF flow (m^3/s)
Yea River at the upstream limit	908.2	8573
Boundary Creek at the upstream limit	45	1346

The above peak PMF estimates are suitable for the purpose of this study as only preliminary PMF estimates were required. More rigorous methods for the determination of the PMF are available for use in other studies/investigations.

4.8 Historical June 1989 flood hydrograph at upstream study area limit

Historical June 1989 flood hydrographs were determined for both the Yea River and Boundary Creek at the upstream study limit. The historical flood hydrographs were used in the hydraulic analysis.

From the URBS model calibration output, flood hydrographs at the upstream study limits for both Yea River and Boundary Creek were extracted. Details of the URBS model calibration were provided in Section 4.4.

As discussed for the design losses in Section 4.6.3, the downstream Yea River catchment losses employed in the June 1989 were adjusted from the calibrated losses for the Yea River at Devlins Bridge. The adjustment was based the ratio of (1-(area of forestation as a fraction)/2). This adjustment is as adopted for the design loss parameters (refer to Section 4.6.2). Table 4-11 shows the area of forestation and the adopted June 1989 losses for the three sub-catchments.

Table 4-11 Adopted June 1989 loss values

Sub-catchment	**Area of forestation**	**Design loss**	
		Initial loss (mm)	**Proportional loss (Runoff co-efficient)**
Yea River at Devlins Bridge	0.54	15	0.53 (0.47)
Murrindindi River at Murrindindi	0.86	15	0.68 (0.32)
Downstream Yea River catchment	0.19	15	0.42 (0.57)

Note:
- Sub- Area of forestation was determined as the area weighted sub-catchment average.
- Proportional loss for Murrindindi River at Murrindindi and Downstream Yea River catchment determined by ratio of $(1-F_{\text{Yea upstream of Devlins Bridge}}/2)/(1-F_{\text{Other catchment}}/2)$ multiply by the proportional loss for the Yea River upstream of Devlins Bridge)

The constant baseflow component 25 m^3/s, determined in Section 4.5.4, was added to the surface runoff hydrograph output from URBS.

Table 4-12 shows the estimated June 1989 peak flows for the Yea River and Boundary Creek at the upstream study limit.

Table 4-12: URBS model June 1989 peak flows for the Yea River and Boundary Creek at the upstream study limit

Location	**June 1989 peak flows (URBS model) (m^3/s)**
Yea River at upstream study area limit	292
Boundary Creek at upstream study area limit	13.9

Details of the historical flood hydrographs are shown in **Appendix B**.

4.9 Discussion

4.9.1 Overview

The study team considers the methodology employed as part of the hydrologic analysis provides robust and rigorous estimates of design flood hydrographs. The reliability of the design flood hydrographs for this study rests upon the following elements:

- Suitability of the URBS model structure
- Quality of the URBS model calibration
- Suitability of the model parameters (routing and rainfall loss parameters) for design flood estimation

4.9.2 URBS model structure

The structure of the URBS model consists of the following elements

- catchment conceptualisation (catchment subdivision and reach lengths)
- catchment characteristics utilised in the routing procedure

The catchment subdivision and reach lengths employed in this study's URBS model were based on the URBS model developed for the Goulburn River Eildon to Seymour Flood Warning Project by the Bureau of Meteorology (Leahy 2002). In total the Yea River and Boundary Creek catchment was subdivided into 19 sub-areas. The study team considers this number of sub-areas to be sufficient to enable proper routing of the surface runoff.

As discussed in Section 4.3, the URBS *Split* model was adopted in this study in line with the BoM's URBS model (Baker pers comm. 2002, Leahy 2002). The BoM's URBS model utilises the catchment area and reach lengths as the routing variables. As outlined in Section 2, the Yea River catchment displays significant variation in channel slopes and forested areas from the upland sub-catchments to lowland sub-catchments. It was considered appropriate, given this variation, to include the channel slope and forested area as routing variables. Also the availability of streamflow data for model calibration added weight to the use of channel slope and forested area to reflect spatial changes in catchment characteristics. Discussion of model calibration quality is provided in Section 4.9.3.

Carroll (2002) advises the role of forestation in the routing of surface runoff is not well understood. Further Carroll (2002) states further research is requires *before quantitative interpretation can be applied to the results produced by the URBS model*.

The study team acknowledges the uncertainty associated with the lack of understanding regarding the impact of forest area on surface runoff routing and resultant peak flows at the catchment outlet.

4.9.3 Quality of model calibration

As discussed in Section 4.9, the hydrologic model was calibrated to the observed streamflow data for the Yea River at Devlin's Bridge. Three historical flood events were selected for use in the model calibration. These three events had the largest three peak flows for which concurrent instantaneous streamflow and pluviographic rainfall data were available.

The June 1989 flood event was the largest of the three calibration events with a peak flow of 244 m^3/s. The June 1989 peak flow has an approximate ARI of 40 years. The URBS model provided a reasonable reproduction of the observed June 1989 flood hydrograph and the other two calibration events. Differences in the timing of the observed and modelled peak flows were due likely to the rainfall temporal patterns recorded at the pluviographic rainfall stations not being truly representative of the temporal pattern experienced within the catchment. .

Given the reasonable reproduction of the three calibration events the study team considers the model calibration satisfactory for the Yea River at Devlins Bridge.

The study requires design flood hydrographs at the upstream study area limit. As discussed, the URBS model was calibrated to the Yea River at Devlins Bridge located some 20 kilometres upstream from the study area. To enable the provision of design flood hydrographs at the upstream study area limit, the hydrologic model was extended. The model calibration provides for model parameter estimates for the Yea River to Devlins Bridge. As discussed, significant variation in catchment characteristics occurs across the Yea River catchment. In effort to reflect this variation, the channel slope and area of forestation were employed as routing variables in addition to the catchment area and reach length. The use of these additional routing parameters provides mechanism by which the model parameters determined to Devlins Bridge can be applied to the entire catchment with allowance for the change in the nature of the catchment.

The study team acknowledges the uncertainty associated with the lack of understanding regarding the impact of forest area on surface runoff routing and resultant peak flows at the catchment outlet.

4.9.4 Suitability of the model parameters for design flood estimation

The availability of streamflow data for the Yea River at Devlins Bridge enables the peak flow estimates to determined using a flood frequency analysis. These alternative peak flow estimates from a flood frequency allows verification of the URBS model parameters (routing and rainfall loss parameters) for the Yea River at Devlins Bridge. The adopted model parameters were shown to provide design peak flow estimates in line with the flood frequency.

As discussed above, design flood hydrographs were required at the upstream study area limit. As such, model parameters for design flood estimation were required to be determined for the remaining catchment. URBS (Carroll (2002)) has provision to scale the rainfall loss parameters (PL) by 1/(1+F/2)) to adjust for spatial change in the forested area. This factor was applied in this study to adjust the verified rainfall loss parameter (PL) for the remaining catchment downstream of Devlins Bridge. Carroll (2002) advises this *modification to losses is at best notional*.

4.9.5 Reliability of design flood hydrographs

As discussed, there is some uncertainty associated with the use of the following elements in the hydrologic analysis:

- Inclusion of forested area as a routing parameter.
- Use of model parameters derived at Devlins Bridge for the entire catchment.
- Adjustments to rainfall losses due to changes in forested area.

Given these uncertainties, the design peak estimates from this study were compared to estimates obtained by alternative approaches. The following relationship (Grayson et al 1996) provides estimates of 100 year ARI peak flows for catchments adjacent to the Great Dividing Range:

$$Q_{100}(m^3/s) = 4.67\,A^{0.763}$$

where:

- A is catchment area (km^2)

The above equation was applied to the Yea River at Devlins Bridge and at the upstream study limit with the 100 year peak flow estimates provided in Table 4-13 and Figure 4-9.

Also provided in Table 4-13 and Figure 4-9 is the 100 year ARI peak flow estimate obtained from the flood frequency and this study's URBS model peak flow estimates.

Grayson et al (1996) provides a method for the determination of peak flow based on the ratio of the catchment areas raised to the power of 0.7. The peak flow based on this method is provided in Table 4-13 and Figure 4-9.

To assess the flood behaviour in the adjacent catchments, flood frequency analyses were undertaken for the following sites:

- Acheron River at Taggerty (405209)
- King Parrot Creek at Hazeldene (405231)

Table 4-13 and Figure 4-9 shows the 100 year ARI peak flows obtained from the flood frequency analyses for Acheron River at Taggerty and King Parrot Creek at Hazeldene.

Table 4-13 100 year ARI peak flow estimates comparison

Catchment	**Catchment area (km^2)**	**100 year ARI peak flow estimate (m^3/s)**			
		URBS model	**Flood frequency**	**Regional prediction equation** $Q_{100} = 4.67\,A^{0.763}$	**Area Ratio[1]**
Yea River at Devlins Bridge	358.2	277	289	415	Not applicable
Yea River at upstream study area limit	884.4	428	Not applicable	827	544
Acheron River at Taggerty	619	Not applicable	219	630	Not applicable
King Parrot Creek at Hazeldene	181	Not applicable	123	246	Not applicable

1. Based on the flood frequency analysis peak estimates at Devlins Bridge. Determined by the ratio of the catchment area raised by 0.7

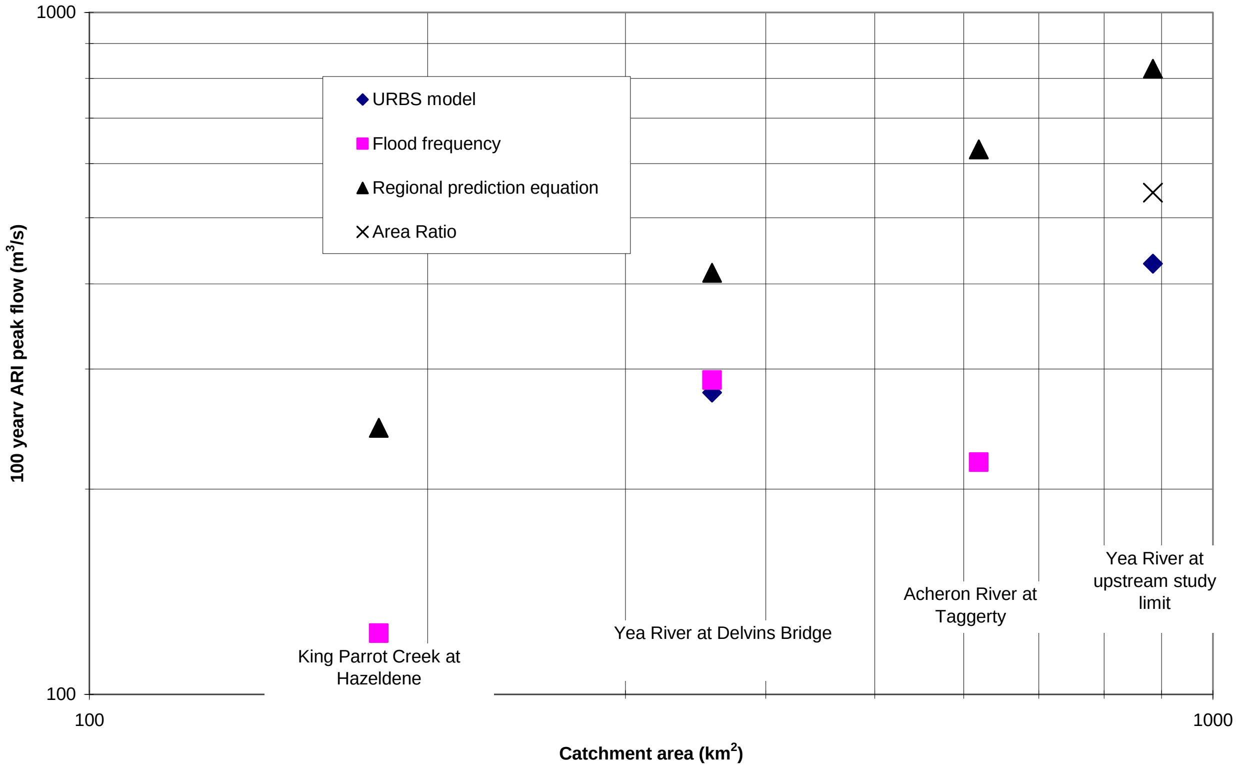


Figure 4-9 100 year ARI peak flow estimates comparison

As seen above, the regional prediction equation results the 100 year peak flow estimates at Devlins Bridge and the upstream study area limit significantly larger than the corresponding flood frequency analysis and URBS model estimates. Further the regional prediction equation leads to significantly higher 100 year ARI peak flow estimates than the flood frequency estimates for the Acheron River and King Parrot Creek. This comparison may suggest the regional prediction equation is likely to over predict the 100 year ARI peak flow in this region.

The flood frequency peak flow estimates show no constant tendency with catchment area. Hence a comparison of the 100 year ARI peak flow estimate for the Yea River at the upstream study limit against a flood frequency estimate is not possible.

4.10 Adopted 100 year ARI design peak flow for planning scheme purposes

The analysis, as discussed in Section 4.9.5, highlights the variability of 100 year ARI peak flow estimates between adjacent catchments and alternative evaluation methods. From the analysis it is difficult to fully assessment of the reliability of the design flood hydrographs determined by the URBS model.

Given this uncertainty in the design flood estimation, the Technical Steering Committee resolved to adopt a 100 year ARI design peak flow at upstream study area of 544 m^3/s for planning scheme purposes. The adopted 100 year ARI design peak flow was obtained by scaling the 100 year ARI peak flow for the Yea River at Delvins Bridge (Refer to Section 4.9.5 for details).

5 HYDRAULIC ANALYSIS

5.1 Overview

The hydraulic analysis determined historical and design flood levels and velocities for the study area. In particular, the historical flood levels were used in the model calibration. The design flood levels and velocities were determined for the 10, 20, 50, 100, 200 and 500 year average recurrence interval (ARI) floods and the probable maximum precipitation (PMP) design flood, as determined by the URBS model. The design flood levels and velocities were utilised to determine the existing level of flood risk.

The two-dimensional unsteady hydraulic model MIKEFLOOD was the principal tool for the hydraulic analysis. MIKEFLOOD is a state of the art tool for floodplain modelling that has been formed by the dynamic coupling of DHI's well proven MIKE 11 river modelling and MIKE 21 fully two-dimensional modelling systems. The MIKEFLOOD model parameters were determined through calibration of the modelled flood levels with observed flood levels with historical inflow flood hydrographs as an input. Once calibrated, the MIKEFLOOD model was applied to estimate design flood levels with design inflow hydrographs as an input.

This section details the input data, methodology and outputs for the hydraulic analysis. The structure of the section is as follows:

- Study input data – outlines the available topographic and historical flood levels or use in the model development and calibration (Section 5.2)
- MIKEFLOOD model development – details the development of the MIKEFLOOD model strucutre (Section 5.3)
- MIKEFLOOD model calibration – details the selection of calibration events and calibration of model paramters (Section 5.4)
- Design flood modelling – summaries the estimation of design flood levels and velocities with the calibrated MIKEFLOOD model (Section 5.5)
- Discussion – provides comparison of the historical and design flood levels and comments regarding the relaibility of hydraulic analysis' results (Section 5.6)

5.2 Study Input Data

5.2.1 Topographic Data

There have been two major sources of topographic information gathered during the course of the investigation, these being:

1. Aerial Photogrammetry
2. Field Survey

Following the collection and processing of the topographic information, a detailed Digital Terrain Model (DTM) was developed as the basis for the establishment of a hydraulic model of the study area. The sources of the topographic information are discussed in more detail below.

Aerial Photogrammetry

Aerial photogrammetry was undertaken specifically for this current investigation. The aerial photogrammetry was undertaken by AAM Pty Ltd on the 27-09-02. Figure 5-1 illustrates the extent of the photogrammetry. AAM's metadata report is presented in Appendix C.

The nominated accuracy for this survey was a standard error (68% confidence level or 1 sigma) of 0.1m in both the horizontal and vertical planes.

Field Survey

Field survey was conducted by LICS Pty Ltd to provide aerial photo control, waterway cross-section and culvert/bridge structure details.

A total of eight cross sections were taken across the Yea River floodplain and four cross sections were taken across Boundary Creek.

Bridge structures along the Yea River were surveyed at the following crossings:

- Goulburn Valley Highway (East and West crossings).
- Court Street
- Providence Bridge (Craigie Street).

Bridge Structures along Boundary Creek were surveyed at the following crossings:

- Racecourse Road
- Old Railway Bridge
- Goulburn Valley Highway

The Bridge structure survey included waterway cross-sections, deck and abutment levels and pier arrangements.

The extent location and extent of the field survey is also illustrated in Figure 5-1.

5.2.2 Historical Flood Marks

Through the community consultation process, a number of observed maximum flood levels were identified and surveyed for incorporation into the Flood Data Transfer data set (DNRE 2000).

The community consultation and questionnaire responses yielded an additional five flood marks for the June 1989 food event and one flood mark for the 1934 flood event. The location and level of the flood marks surveyed as part of this investigation are illustrated in Figure 5-1.

In total, nine historical flood marks were available for June 1989. The historical floodmarks were utilised for the hydraulic model calibration (refer to Section 5.4 for hydraulic model calibration details).

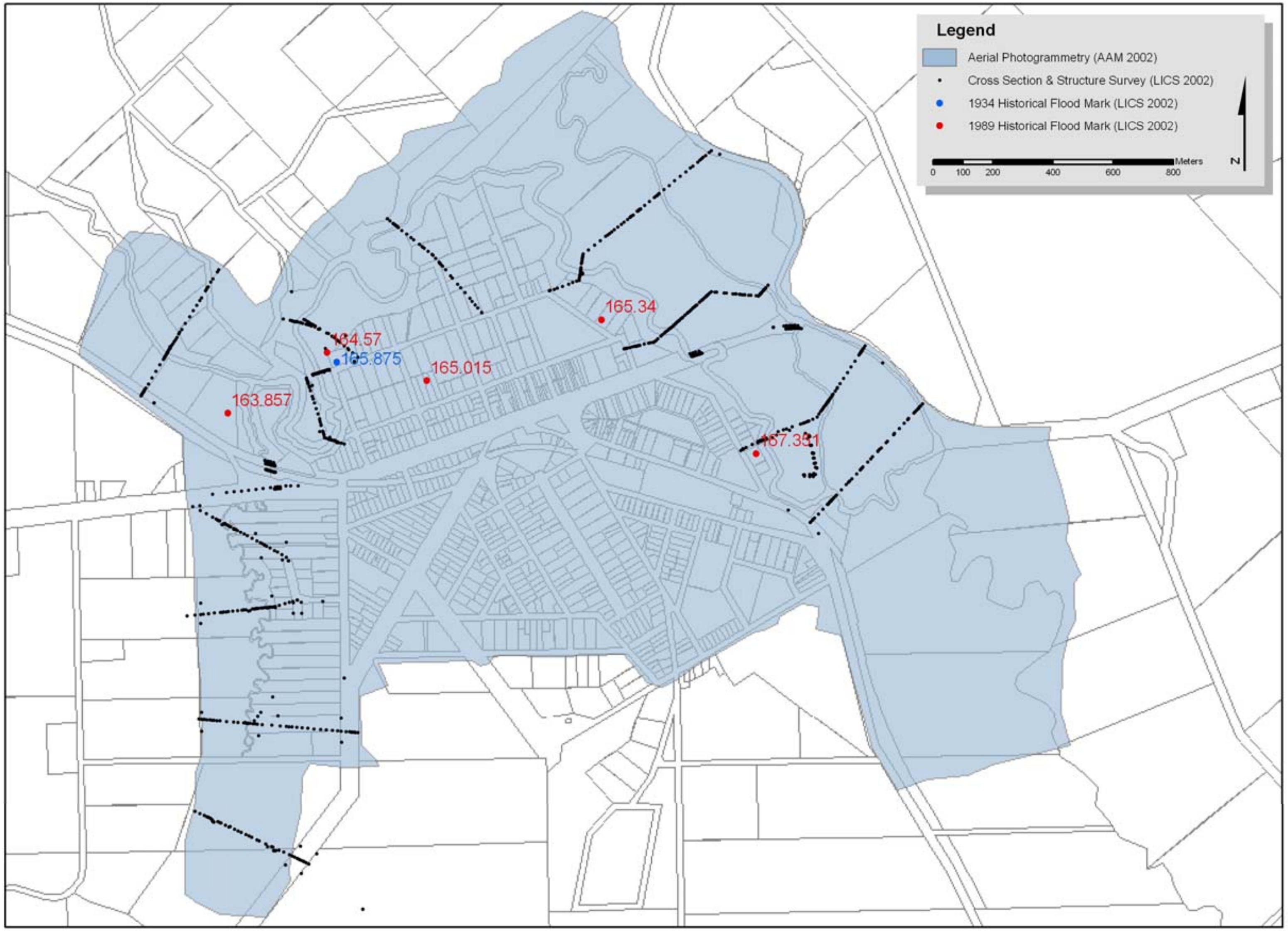


Figure 5-1 Topographic Survey Extent and Historical Flood Marks

5.3 MIKEFLOOD model development

5.3.1 Description of MIKEFLOOD model

Hydraulic modelling of the study area has been undertaken utilising the Danish Hydraulic Institute's (DHI) MIKE FLOOD modelling software. MIKEFLOOD is a state of the art tool for floodplain modelling that has been formed by the dynamic coupling of DHI's well proven MIKE 11 river modelling and MIKE 21 fully two-dimensional modelling systems. Through this coupling it is possible to extend the capability of the 2D MIKE 21 model to include:

- A comprehensive range of hydraulic structure (including weirs, culverts, bridges, etc);
- ability to accurately model sub-grid scale channels;
- ability to accurately model dambreak or levee failures.

For the present study, a two-dimensional (2D) MIKE 21 model has been set up to model the overall floodplain flows. A coupled one dimensional (1D) MIKE 11 model has also been utilised to explicitly model waterway bridge crossings within the study area.

5.3.2 Model structure

The development of a detailed terrain model and subsequent construction of a hydraulic model of the study area enables Yea River and Boundary Creek flood flows to be simulated in great detail. Flow conditions varying from historical flood events to the simulation of hypothetical "design" events can be modelled to investigate the pattern of flooding behaviour within the study area. These flow conditions can be applied to both the existing topography and topographies that have been altered to represent changes eg flood mitigation measures or proposed developments.

The basis of the two dimensional model is the topographic grid which is based on the aerial photogrammetry and field survey. A 7.5m grid has been employed for the purposes of the Yea Flood Study and is illustrated in Figure 5-3.

The bridge crossings within the study area were modelled as MIKE 11 structures and dynamically coupled with the two dimensional model. Head loss through the bridges could therefore be modelled explicitly within the model. The following bridge structures along the Yea River were modelled in MIKE11:

- Goulburn Valley Highway (East and West crossings).
- Court Street
- Providence Bridge (Craigie Street)

The following bridge structures along Boundary Creek were modelled in MIKE 11:

- Racecourse Road
- Old Railway Bridge
- Goulburn Valley Highway

The variation in hydraulic roughness within the study area has been schematised as a hydraulic roughness grid, representing various hydraulic roughness's eg open grassland, roads, thick vegetation. The hydraulic roughness grid was based principally on the aerial orthophoto (AAM 2002). Table 5-1 outlines the initial estimates of the hydraulic roughness parameters. Adjustments to initial roughness parameters were made during the model calibration process. Further details of the adjustments are outlined in Section 5.4.

Table 5-1 Intial hydraulic roughness parameters

Floodplain Element	Manning's M	Manning's n (n = 1/M)
General Floodplain roughness (open space, lightly vegetated)	25	0.04
Waterway channel roughness	33.33	0.03
Vegetated areas	16.67	0.06
Urban areas (buildings, backyards)	5	0.20
Clear, paved areas (streets)	66.67	0.015

To provide conditions at the downstream limit of the hydraulic model, a stage discharge rating curve has developed using Manning's equation. A cross section at the downstream study limit was extracted from the DTM and the hydraulic characteristics (area, radius and conveyance) determined for a range of flood levels (stage). Based on aerial photography and filed inspection, a constant Manning's n of 0.07 was adopted for the purposes of the determination of the downstream rating curve. The general bed slope of the Yea River adjacent to the downstream limit, 0.0014 m/m, was taken as the flood slope in Manning's equation. Figure 5-2 displays the rating curve developed at the downstream study limit.

The above method employed to determine the downstream rating curve assumes there are no significant hydraulic controls downstream to influence flood levels. Section 5.6.3 provides a discussion regarding the possible influence of the Goulburn River flood levels.

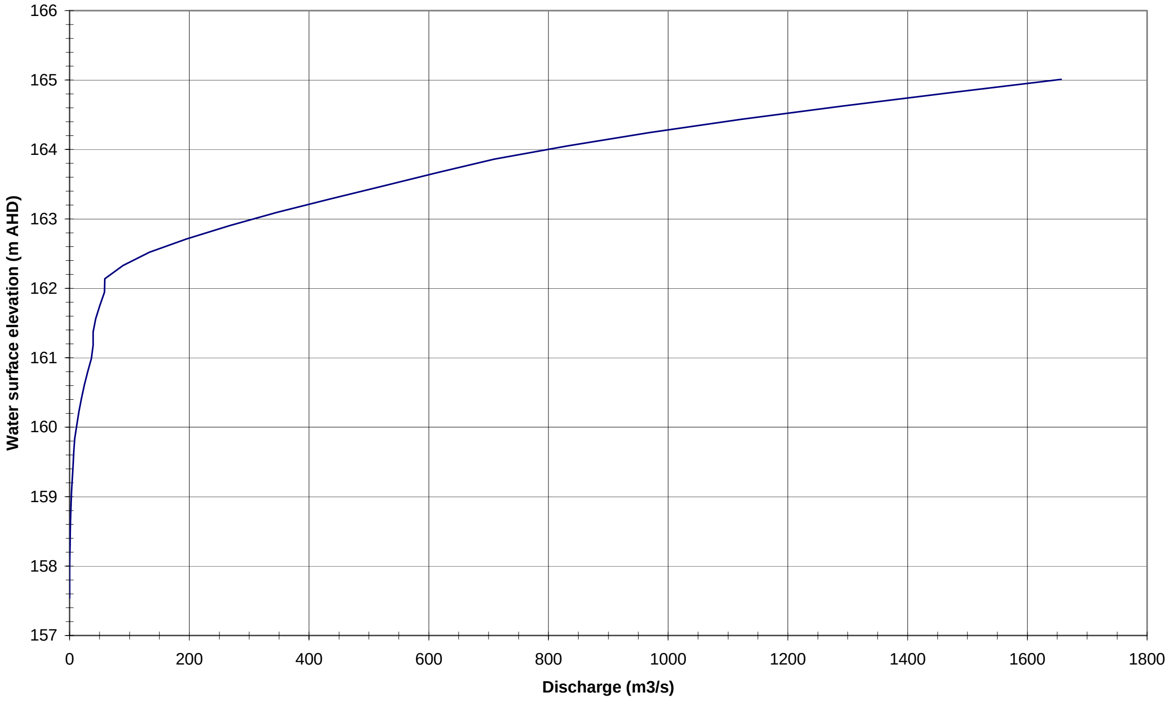


Figure 5-2 Stage discharge rating curve at the downstream study limit

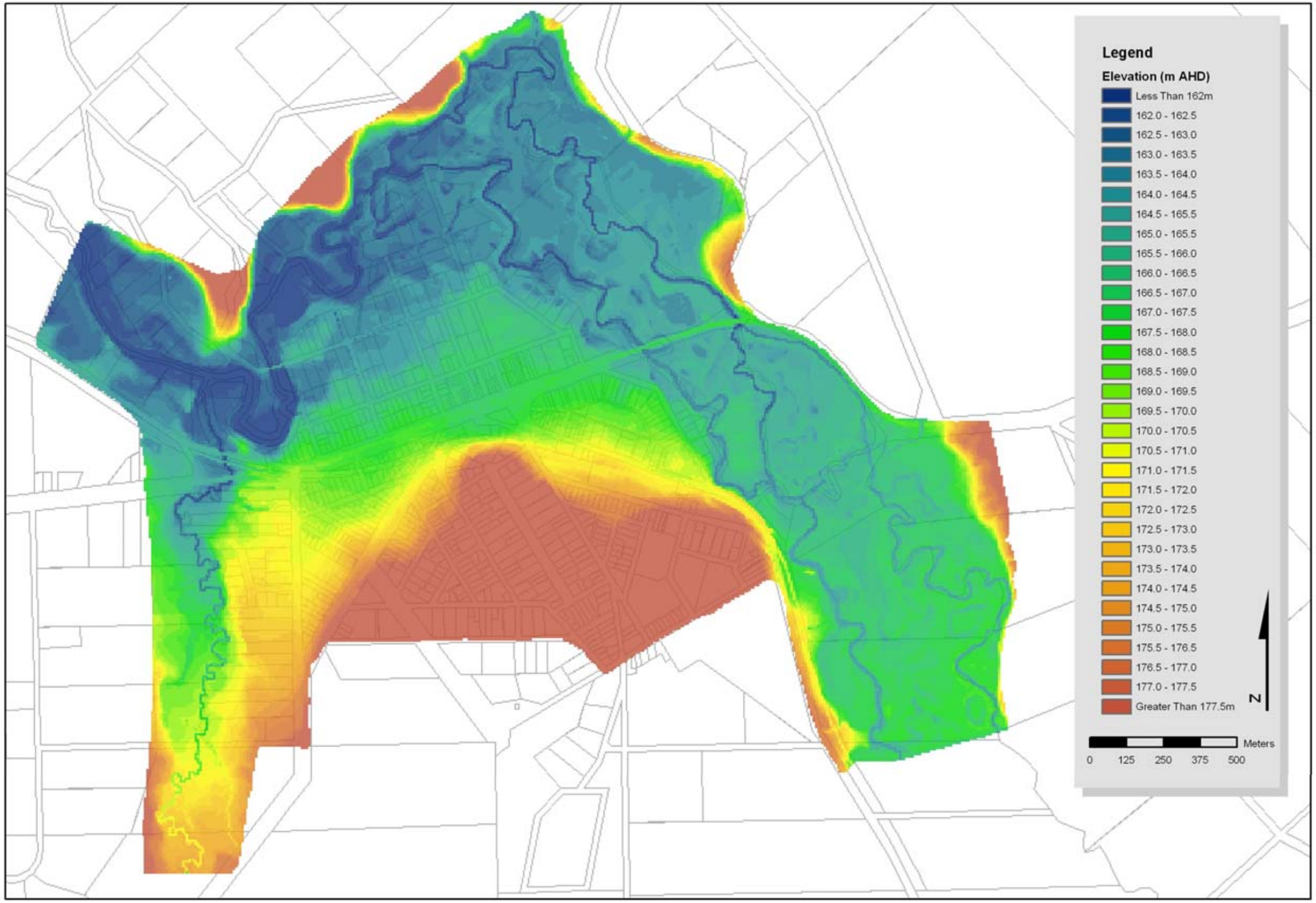


Figure 5-3 Hydraulic Model Topography

5.4 MIKEFLOOD model calibration

5.4.1 Overview

The calibration process requires systematically comparing the hydraulic model's representation of flooding in the study area with observed flooding behaviour. This process may incorporate comparisons between gauged stream flows, observed maximum flood levels, areas of inundation as shown in aerial photography and eyewitness recounts of flooding behaviour. Where the model does not adequately represent what was observed, the reason for the discrepancy is identified and inputs into the model are adjusted as required.

The hydraulic model developed by this study is based on current topographic data and flooding behaviour is therefore influenced by the current topography. As such, the ability of the hydraulic model to simulate observed historical flood behaviour is affected by changes to the topography subsequent to the flood event being modelled.

5.4.2 June 1989 calibration

The June 1989 flood event was chosen as the principal calibration event. This flood event had an approximate ARI of 12 years at Yea. A total of nine maximum observed flood levels for the June 1989 event were used to assist in the calibration. Through the community consultation process a number of photos, videos and eyewitness recounts of the flood event helped to insure the general pattern of flooding behaviour was being reproduced by the model.

The June 1989 flood event was determined to have a peak discharge at Yea of 293m^3/s (25315 ML/d). The peak flow in Boundary Creek during the flood was also determined to be 14m^3/s (1210 ML/d). The discharge hydrographs for the June 1989 flood event in the Yea River and Boundary Creek are presented in Figure 5-4.

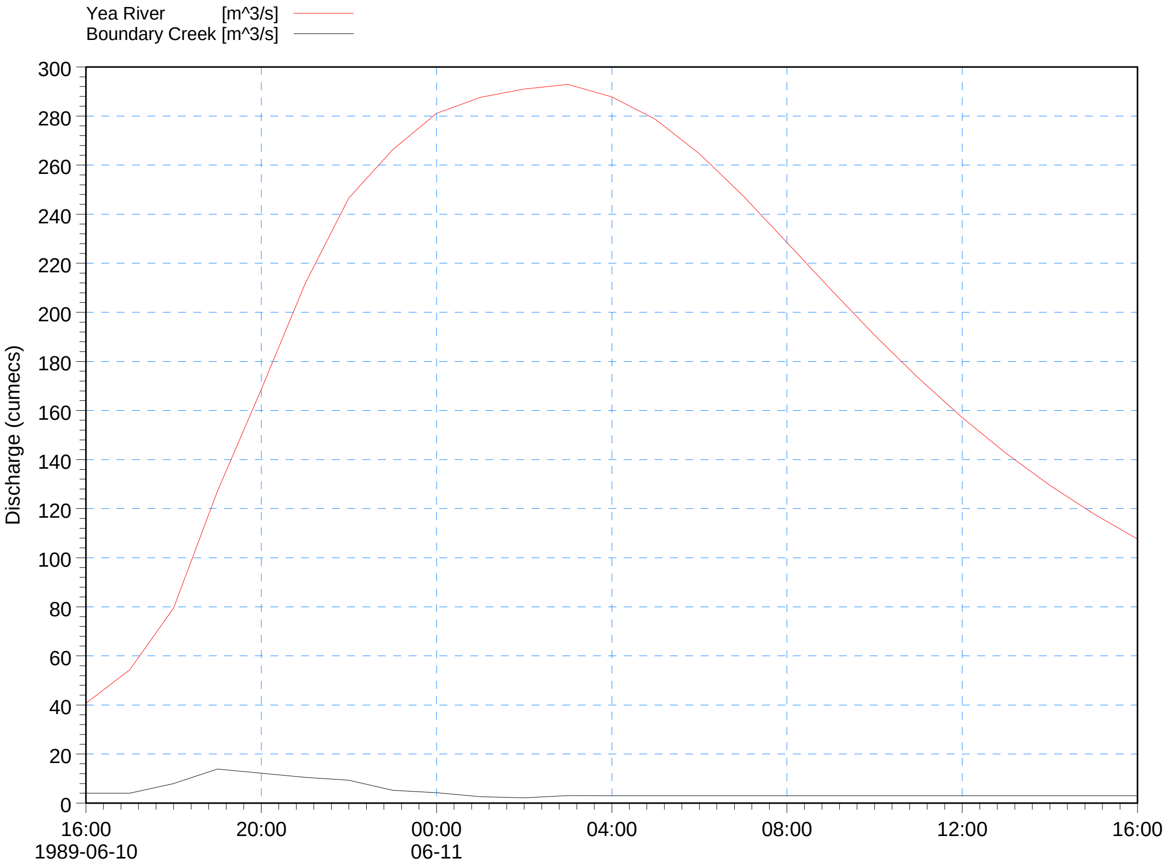


Figure 5-4 Yea River and Boundary Creek Flows, June 1989 Flood

Calibration of the hydraulic model of the Yea River and Boundary Creek was primarily achieved by adjusting the hydraulic roughness coefficients and head loss factors through the bridge crossings to fit the observed maximum flood levels.

During the calibration process it became evident that the extremely thick vegetation that exists on parts of the floodplain, particularly immediately downstream and upstream of the Providence Bridge (Craigie Street), reduces the hydraulic capacity of the Yea River and floodplain in these areas. The hydraulic roughness coefficients in these areas were therefore increased to a Manning's n of 0.15. The adopted hydraulic roughness parameters are displayed in Table 5-2.

Table 5-2 Adopted hydraulic roughness parameters

Floodplain Element	Manning's M	Manning's n (n = 1/M)
General Floodplain roughness (open space, lightly vegetated)	22.2	0.045
Waterway channel roughness	20	0.05
Vegetated areas	8.3	0.12
Densely vegetated areas	6.67	0.15
Urban areas (buildings, backyards)	5	0.20
Clear, paved areas (streets)	66.67	0.015

A generally good agreement has been achieved between the observed and modelled maximum flood levels and extents within the study area. The hydraulic model has reproduced the anabranch flow across the corner of Nolan and Craigie Street and the model shows floodwaters encroaching just over Hood St as reported during the community consultation process. Some difficulties were encountered however in reproducing the observed maximum flood level at some of the points used during the calibration process.

Figure 5-5 presents the maximum depth and extent produced by the model for the June 1989 flood event. Figure 5-5 also displays the comparison between the observed and modelled maximum flood levels.

Generally modelled flood levels were within 150 mm of observed flood levels. A comparison of the modelled and observed flood levels indicates the hydraulic model shows no systematic tendency to under or over-predict flood levels for the June 1989 event. At two locations, Snodgrass Street and Miller Street upstream of the Court Street Bridge, differences between modelled and observed flood levels exceed 150 mm.

For Snodgrass Street, the hydraulic model underpredicts the observed flood level by 170 mm. The observed flood level at Snodgrass Street is based on the flood extent as recollected by the resident. The resident indicated the approximate extent on the ground with the elevation of approximate extent then surveyed. Given the nature of observed flood level, the study team considers this flood level to be of less reliability.

For Miller Street upstream of the Court Street Bridge, the hydraulic model underpredicts the observed flood level by 490 mm. The observed flood level at Miller Street is based on the flood level as recollected by the resident. The resident indicated the approximate flood level observed along the back stairs to the dwelling with the elevation of approximate flood level then surveyed. The observed flood level at Miller Street is 470 mm higher than the observed flood in the caravan park. The observed flood level in the caravan park is located some 150 m downstream. The flood slope, as determined by the hydraulic model, adjacent to the caravan park would give rise to a likely difference in flood levels of about 5 mm between the locations of these two observed levels. The difference of 490 mm between the two observed flood levels appears to be larger than expected. Given this larger than expected difference and the nature of observed flood level at Miller Street, the study team considers this flood level to be of less reliability.

Based on the comparison of the modelled and observed flood levels for the June 1989, study team considers the hydraulic model calibration suitable for the purposes of this study.

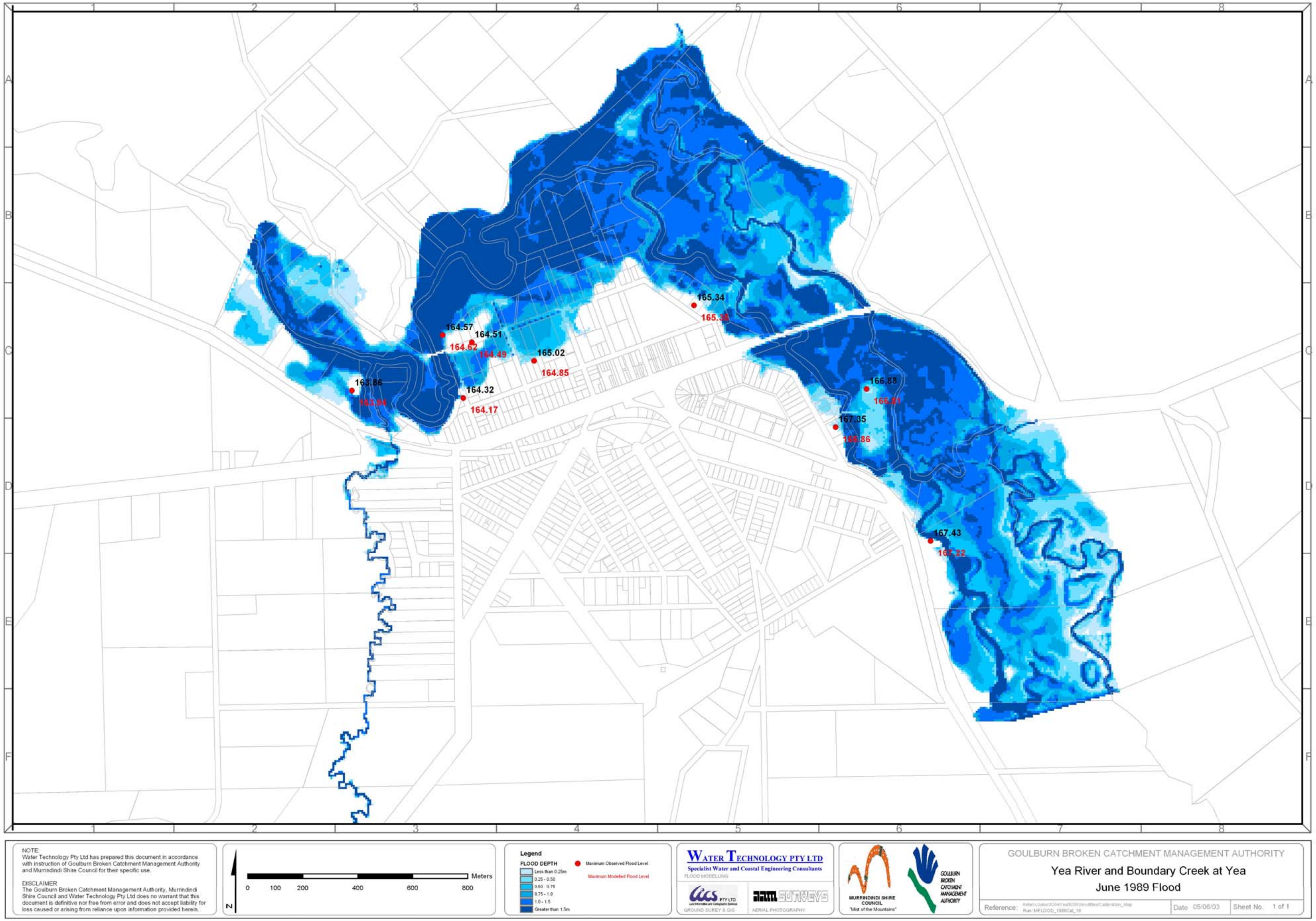


Figure 5-5 Modelled Flood Extent – June 1989 Flood

5.5 Design flood modelling

Design flood levels and velocities were determined via the calibrated MIKEFLOOD model for the 10, 20, 50, 100, 200 and 500 year average recurrence interval (ARI) floods. The URBS design inflow hydrographs for Yea River and Boundary Creek, were a hydraulic model input.

Table 5-3 displays the peak design flood levels and selected historical peak flood levels at the Court Street gauge adjacent to the caravan park access bridge.

Table 5-3 Design and selected historical peak flood levels at Court Street Gauge

URBS Model design flood event ARI (years)	Court Street Gauge height[1]	Flood level at Court Street gauge (m AHD)
10	3.99 m	166.71
June 1989[2]	4.16 m	166.88
20	4.22 m	166.94
50	4.40 m	167.12
May 1974[3]	4.45 m	167.17
100	4.55 m	167.27
200	4.75 m	167.47
500	4.83 m	167.55

1. Court Street gauge height determined by subtracting the gauge zero elevation in m AHD (162.72 m AHD) from the flood level elevation in m AHD.
2. Indicative Court Street gauge height for June 1989, deduced from Flood Data Transfer Project Murrindindi Shire Flood data maps No. 500058-27
3. Indicative Court Street gauge height for May 1974, deduced from Flood Data Transfer Project Murrindindi Shire Flood data maps No. 500058-27

5.6 Discussion

5.6.1 Flooding behaviour overview and critical flood levels

Hydraulic analysis shows the Yea River channel, particularly adjacent to the caravan park, has a limited flow capacity. The flood waters spill onto the floodplain for relatively frequent floods. However, once the floodplain is inundated, the increases in flood extent with increasing magnitudes are small. This behaviour reflects the well relatively confined nature of the floodplain.

A discussion of critical breakout levels is provided in Section 11.3.2.

5.6.2 Comparison of 1934 and 1974 flood levels with design flood levels

A series of flood levels were observed for the 1934 and 1974 flood events (source Flood Data Transfer Project Murrindindi shire Flood data maps No. 500058-27). A comparison of observed 1934 and 1974 flood levels, and computed 100 year design flood levels is shown in Figure 5-6.

The 1974 flood levels and the 100 year design flood levels (based on the URBS model) are generally consistent with the two flood profiles displaying a similar shape. Table 5-3 shows the peak flood level in the 1974 event at the Court Street gauge is approximately 0.1m lower then the 100 year ARI peak flood event (based on URBS model). The observed 1974 flood levels appears to be slightly lower (~ 0.1m) than the 100 year design flood level (based on URBS model) upstream of the Goulburn Valley Highway as expected. Downstream of the

Goulburn Valley Highway, the observed 1974 flood levels appear to be similar or slightly higher (up to 0.1m) than 100 year ARI flood levels (based on URBS model). Possible reasons underlying these differences are discussed below.

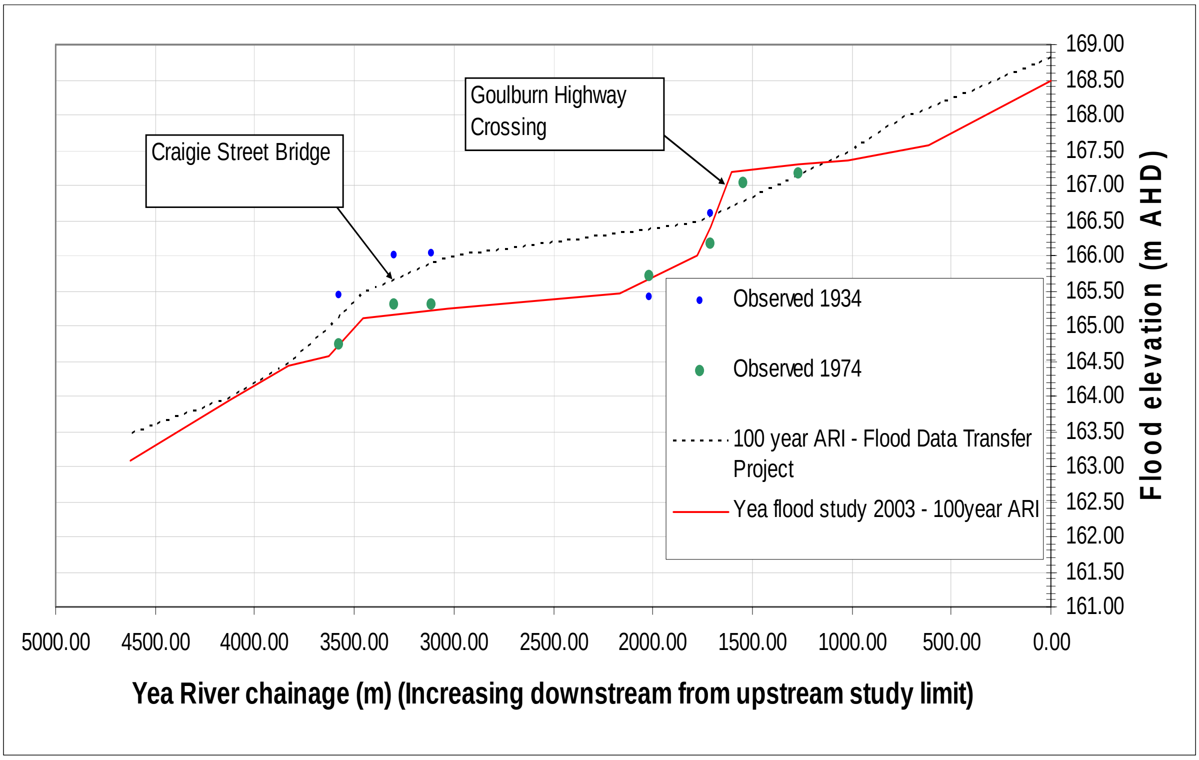


Figure 5-6 Flood profile comparison of historical and design flood levels

The 1934 flood levels are significantly higher then the 1974 and 100 year ARI flood levels (based on URBS model) adjacent to the Craigie Street Bridge (up to 0.7 m). Adjacent to the Goulburn Valley Highway, the 1934 level and 100 year design flood level appear consistent. Downstream of the Goulburn Valley Highway (~chainage 2000 m) the 1934 flood level is lower than the 100 year ARI level. This observed 1934 flood level maybe in error as it is lower than the observed 1934 level adjacent to Craigie Street bridge.

Anecdotal evidence suggests the 1934 flood level was "just under" the floor level of the cottage near the Craigie St bridge. The floor level surveyed by this study is 165.87 m AHD. The observed 1934 flood level is ~ 165.70 m AHD. These two levels appear consistent and would suggest the observed 1934 level in this area is plausible.

The differences in the general shape of the flood profiles from the 1934 and 1974 event, and the 100 year design event (based on URBS model) suggest changes to the nature of the floodplain both within the study and downstream of the study area. These changes may consist of the removal of floodplain vegetation and waterway channel works.

The 1934 flood level profile is steeper through the reach adjacent to the Craigie Street bridge. The steeper flood profile indicates higher resistance (rougher floodplain) through this reach in 1934 than under existing conditions. Removal of waterway and floodplain vegetation in this reach would contribute to the flatter flood profile.

No streamflow data for the 1934 event is available within the Yea River catchment. Streamflow data from the adjacent Yarra River catchment suggests the 1934 flood has an ARI in the upper catchment in excess of 100 years.

5.6.3 Goulburn River influence

The study area is located some 5 kilometres upstream from the confluence of the Goulburn and Yea Rivers. During the course of the study, TSC members and local residents raised concerns regarding the influence of the Goulburn River on flood levels in Yea. The concerns raised suggested a high flood level in Goulburn River at the Yea River confluence occurring concurrently with a flood in the Yea River catchment may increase flood levels in the Yea Township.

The flood planning maps as part of the Flood Data Transfer Project (NRE 2000) shows a difference of 5 metres in 100 year ARI flood levels between the Goulburn River confluence and the downstream study area limit. This represents an approximate flood slope of 1 in 1000. Given the downstream distance and flood slope a large flood event in the Goulburn River unlikely to significant influence the flood level in the study area.

5.6.4 Reliability of design flood levels

The study team considers the methodology employed as part of the hydrologic and hydraulic analyses provides for robust and rigorous estimates of design flood hydrographs and flood levels. As discussed in Section 4.9, the hydrologic model was calibrated to the observed streamflow data at Devlin’s Bridge located some 20 kilometres upstream from the study area. The hydrologic model was extended to provide design flood hydrographs at the upstream study limit. Several assumptions regarding the nature of the catchment downstream of Devlin’s Bridge were required to enable the extension of the hydrologic model to the upstream study limit. These assumptions influence the design hydrographs at the upstream study limit. Section 4.9 provides discussion on reliability of the design flood hydrographs.

Setting aside the reliability of the design flood hydrographs, the reliability of the design flood levels produced by the hydraulic model rests upon the quality of the model calibration. As discussed in Section 5.4.2, a comparison of modelled and observed flood levels for the June 1989 event show the modelled flood levels are generally within 150 mm of the observed. Furthermore there appears to be no systematic tendency to under or over-predict observed flood levels for the June 1989. A comparison of the modelled 100 year ARI (based on URBS model) flood levels with observed May 1974 flood levels, as discussed in Section 5.6.2, shows the modelled flood levels are consistent with expectations.

Given the above discussion, the study team considers the design flood levels are reliable with an indicative accuracy of the 150 mm. Further the study team considers the design flood level suitable for the purposes of this study.

5.7 Court Street Gauge Rating Curve

The hydraulic model was utilised to derive a stage discharge rating curve for the Court Street gauge. Figure 5-7 and Table 5-4 displays the Court Street gauge rating curve derived using the hydraulic model. The gauge zero was surveyed at 162.72 m AHD.

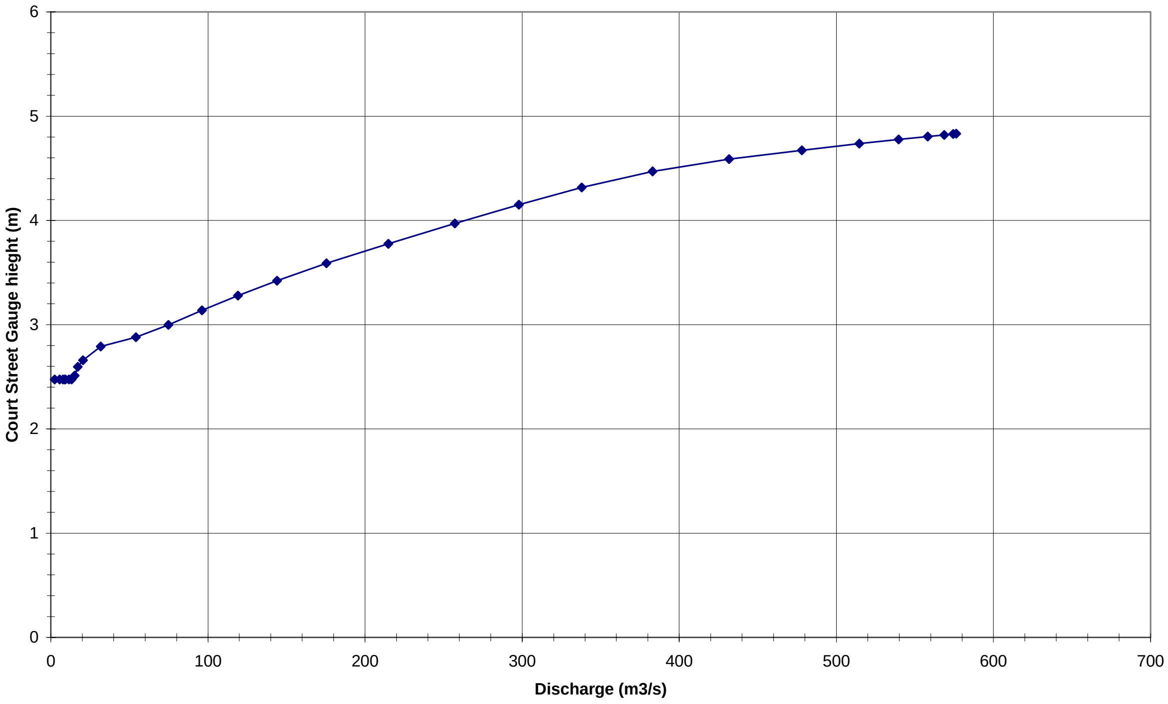


Figure 5-7 Court Street gauge rating curve (derived using the hydraulic model)

Table 5-4 Court Street gauge rating curve (derived using the hydraulic model)

Gauge height (m)	Discharge (m3/s)
2.475	13.16
2.510	15.16
2.596	17.14
2.660	20.36
2.790	31.66
2.880	54.18
2.998	74.73
3.137	96.13
3.278	119.09
3.421	144.02
3.589	175.38
3.775	214.80
3.971	257.14
4.150	297.84
4.317	337.96
4.470	382.92
4.588	431.68
4.672	477.97
4.737	514.64
4.778	539.64
4.803	558.15
4.819	568.58
4.828	574.44
4.832	576.31

BoM (A. Baker pers. comm. 2005) advised that the BoM have utilised this stage-discharge relationship to provide peak height forecasts at the Court Street gauge during recent flood events.

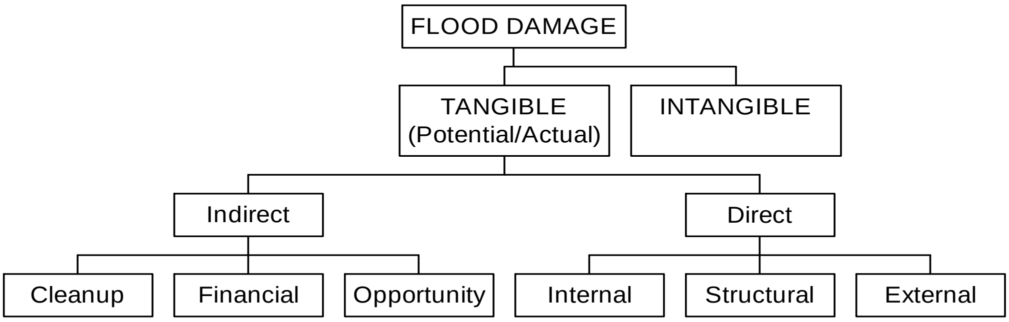
6 FLOOD DAMAGES ASSESSMENT

6.1 Overview

A flood damages assessment has been undertaken for the study area under existing conditions. The flood assessment determined the momentary flood damages for design flood hydrographs as determined by the URBS model. The average annual damage (AAD) was also determined as part of the flood damage assessment.

Damages from flooding can be sub-divided into a number of categories. Figure 6-1 shows the various categories commonly used in flood damage assessments.

Figure 6-1 Categories of flood damage



Tangible flood damages are those to which a monetary value can be assigned and include property damages, business losses and recovery costs. Intangible flood damages are those to which a monetary value cannot be assigned and include anxiety, inconvenience and disruption of social activities. Both are a function of flood magnitude. This flood damages assessment focuses on the tangible flood damages. Intangible damages are important and are considered, but under the broader assessment of existing conditions and flood mitigation options.

Tangible damages can be sub-divided into direct and indirect damages. Direct damages are those financial costs caused by the physical contact of flood waters and include damage to property, roads and infrastructure.

Property damages can be sub-divided into internal and external damages. Internal damages include damage to carpets, furniture and electrical goods. External damages include damages to building structures, vehicles and in rural areas, crops, fencing and machinery.

Indirect damages are those additional financial costs generally incurred after the flood during clean-up and include the cost of temporary accommodation, loss of wages, loss of production for commercial and industrial establishments and the opportunity loss caused by the closure or limited operation of business and public facilities.

Tangible damages can also be treated as potential or actual damages. Potential damages are the maximum damages that could occur for a given flood event. In determining potential damages, it is assumed that no actions are taken (whether months or hours) prior to or during the flood to reduce damage by, for example, lifting or shifting items to flood free locations, shifting motor vehicles or sandbagging. Actual damages, in this context, are the expected damages for a given flood event. Their value - a proportion of potential damages - is based on the community’s flood preparedness, a function of community awareness and the lead-time of flood warnings.

This section details the input data, methodology and outputs for the flood damage assessment. The structure of the section is as follows:

- Damage assessment methodology – outlines the flood damage assessment employed by this study (Section 6.2)
- Damage assessment input data – outlines the properties, infrastructure and flood data used in the flood assessment (Section 6.3)
- Flood damage costs – details the flood damage cost relationships adopted by this study (Section 6.4)

6.2 Damage assessment methodology

Flood damage assessment is based on the comparison of property floor levels and road crest levels to the flood levels for each design flood events. The damage for each property is determined via relationships between flood damages and flood depth (above ground level and above floor level). Similarly, the damage for other infrastructure (roads etc) is determined via flood damage and the flood depth relationship. The damage flood depth relations are known as stage damage curves. The total damages are the summation of damages for each property, combined with estimates for infrastructure and services. A damage reduction factor (DRF) is applied to reflect the reduction in damages due to flood awareness and warning.

The methods and damage data employed in this study is based on the following approach:

- ANUFLOOD (Smith and Greenaway, 1992) developed by the Centre for Resource and Environmental Studies (CRES) at Australian National University – provides stage damage curves for a number of property types and classes
- Rapid Appraisal Method (RAM) for Floodplain Management (NRE, 2000),:- provides additional damage data and recommendations on appropriate adjustments to the ANUFLOOD data.

Details of the stage damage curves, damages data and damage factor reduction are provided in Section 6.3.

6.3 Flood damage assessment input data

6.3.1 Property and floor level data

Property and floor level data were survey for 40 properties within the study area, These properties were identified to lay within the 100 year ARI flood extent or were located immediately adjacent

The following property data were collected:

- Building location:- property address (Street Number and Street Address) and ground coordinates.
- Building type:- urban and rural residential, commercial, industrial and public
- Property damage or value class:- intended to represent dwellings of respectively poor, normal or excellent value. Reflects value of contents value, construction quality.
- Ground and floor levels: ground and floor level data including location (i.e. coordinates)

The two permeant buildings located in the Court Street Caravan Park, whose floor levels were surveyed, were considered urban residential dwellings with a normal value class. Verbal advice suggests (Pers. Com. Peter Zimmermann BoM) about 25 caravans/cabins are located in the park on a permanent basis with an additional 40 caravans during peak holiday periods.

The permanent caravans/cabins were considered as urban residential dwellings with a poor value class. As no floor level survey was undertaken for the caravan, the floor level was taken as 300 mm above the ground level. This assumption regarding the caravan floor level is considered reasonable, as observed during a site visit numerous permanent caravans/cabins are elevated. As the annual caravans are able to be re-located, no allowance in the flood damage assessment was made for the annual caravans.

The remaining properties surveyed were considered urban residential dwellings with a normal value class.

6.3.2 Infrastructure data

For this study, as detailed in NRE (2000), damage to infrastructure was based on the length of infrastructure inundated. NRE (2000) considers this assumption reasonable, as much of the service infrastructure follows the paths of road reserves and the quantity of other infrastructure might be expected to be broadly a function of the length of road.

Roads were subdivided into three categories as used in NRE (2000) – highway, sealed road and unsealed road. Each was determined using the cadastral information supplied by GBCMA and by inspection of aerial photos.

6.3.3 Flood data

The hydraulic analysis provides a regular grid of flood elevations and flood depths across the hydraulic model study area. By overlaying the flood elevations and depths onto the property data, a flood level can be assigned to each flood affected building. Inundated areas and lengths of inundated road can be calculated by overlaying the flood data onto the road data.

6.4 Flood damage costs

6.4.1 Direct internal property damages

Direct stage damage curves have been taken from the ANUFLOOD model. There are eighteen curves, three for residential properties (for 3 damage classes) and fifteen (for 3 size classes by 5 value classes) for commercial properties. Each relates flood depth above floor with monetary internal damage.

As discussed in Section 6.3.1, all properties considered in the flood damage assessment are urban residential dwellings of either a normal or poor value class. The direct stage damage curves for these two building types and value classes were taken from ANUFLOOD.

NRE (2000) considers that the ANUFLOOD data underestimates potential damages by 60%, primarily due to the age of the data. Note however that this also includes an allowance for external damages, which is not part of the ANUFLOOD data. NRE (2000) does not provide separate data for external damages.

For this study, the ANUFLOOD stage direct damage curves were increased by 60 % to reflect the NRE (2000) advice. Separate external damage calculations were not necessary.

Figure 6-2 reproduces the adjusted direct damage curves used for this flood damages assessment for residential buildings.

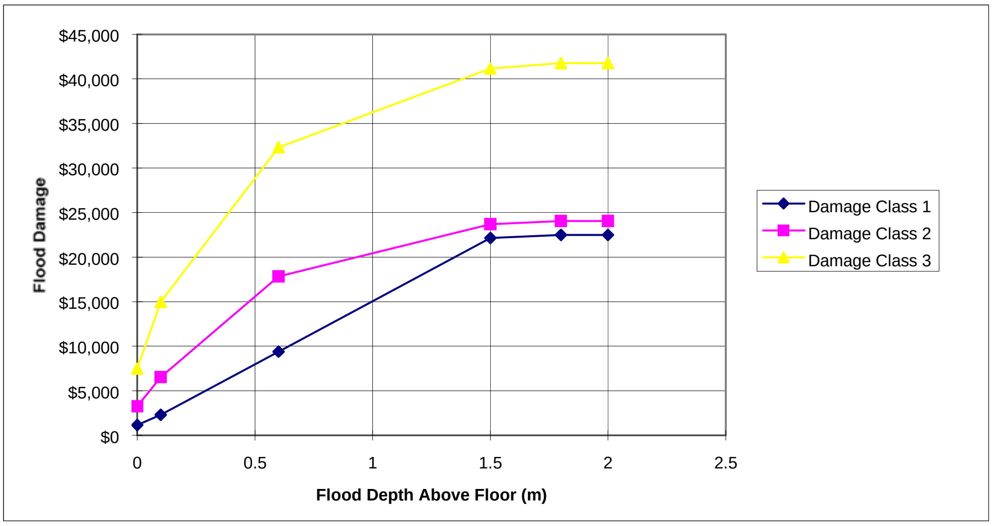


Figure 6-2 Residential Total Damage Curves

6.4.2 Direct external property damages

In this study, separate external damages have been calculated for properties flooded below floor only. An external direct damage curve has been developed using data from Floodplain Management in Australia, Volume 2 (DPIE, 1992). It assumes that external damages commence at a flood depth above ground of 0.05 m and vary linearly to an upper limit of $8 500 at a flood depth above ground of 1 m. No distinction is made between residential and commercial properties.

Figure 6-3 shows the external direct damage curve used for this flood damages assessment for all properties.

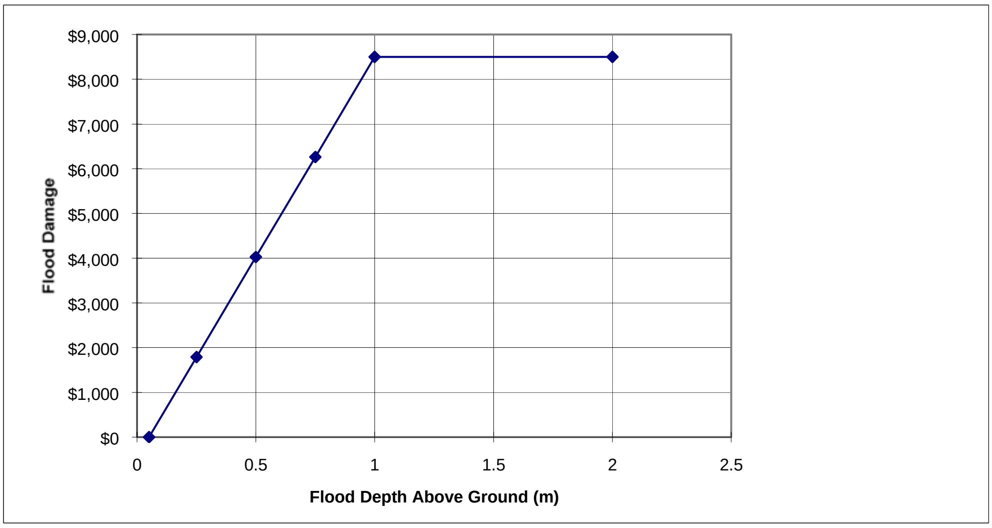


Figure 6-3 External damage curve

6.4.3 Indirect property damages

NRE, 2000 suggests that “in most cases” indirect property damage be calculated as 30% of the total direct property damage. This study adopts the NRE (2000) approach for indirect property damages.

6.4.4 Damage reduction factors

As the above damage data is based on potential damages, damage reduction factors (DRFs) must be applied to reflect expected actual damages. The DRF is simply a ratio of actual damage to potential damage. DRFs can range from 0.9 for inexperienced communities with less than 2 hours flood warning to 0.4 for experienced communities with more than 12 hours flood warning (NRE, 2000). For Yea, a DRF of 0.8 was adopted (inexperienced community, warning time 2 to 12 hours).

6.4.5 Infrastructure damages

Damage to infrastructure includes street and road repairs (including restoration of weakened subgrades), bridge repairs, telephone and telecommunications facilities, electrical connections, water supply and sewerage infrastructure and resulting higher maintenance costs.

The RAM report (NRE, 2000) provides infrastructure data for “roads and bridges”. It does not provide any damage estimate for other infrastructure but notes that “damages for other regional infrastructure (telecommunications, electricity, water, sewerage and other underground services) are small relative to roads and bridges”. In the absence of “other” infrastructure damage data, the “road and bridges” has been used as representative of all infrastructure.

Table 6-1 summarises the adopted monetary damages for the infrastructure represented by inundated road length found in the study area.

Table 6-1 Inundated infrastructure damages (via road lengths)

Road Type	Damage ($/km)
Highway	59 000
Sealed Road	18 500
Unsealed Road	8.400

Note that the analysis did not consider the influence of flood depth, flow velocity or inundation time on infrastructure damages.

7 FLOOD RISK UNDER EXISTING CONDITIONS

7.1 Overview

The flood risk can be expressed as:

*Flood risk = flood likelihood * flood consequences*

The flood likelihood can be assessed as the frequency of flooding for a given flood depth. The flood consequences can be assessed as the damages arising from that given flood depth. For each location, the flood risk can be determined with the flood risk to the community the sum of the flood risk for all locations.

This section summarises the existing flood risk within the study area. The structure of the section is as follows:

- Flood likelihood under existing conditions – outlines the determination of the flood likelihood based on the hydraulic analysis (Section 7.2)
- Flood consequences (damages) under existing conditions – outlines the determination of the flood damages based on the flood damage assessment (Section 7.3)

7.2 Flood likelihood under existing conditions

The hydraulic analysis provides flood extent, flood elevation, flood depth and flow velocity throughout the study area using the design flood hydrographs determined by the URBS model as an hydraulic model input. At any location, the frequency of a given flood depth can be assessed from the hydraulic analysis.

7.3 Flood consequences (damage) under existing conditions

The flood damage assessment was undertaken for the design flood events, 10, 20, 50, 100, 200 and 500 year ARI events. The flood damage assessment considered existing conditions. Table 7-1 provides a summary of existing flood damages for the study area.

Table 7-1 Flood damages in existing conditions

Item	URBS model design flood ARI (years) [1]					
	10	20	50	100	200	500
Properties Flooded Above Floor	27	28	29	30	30	30
Properties Flooded Below Floor	4	5	5	8	12	15
Total Flooded Properties	**31**	**33**	**34**	**38**	**42**	**45**
Total Direct Damages	$289,000	$417,000	$452,000	$538,8000	$627,600	$678,000
Indirect Damages (30% direct)	$87,000	$125,000	$135,600	$161,600	$188,200	$203,400
Potential Damages	$376,000	$542,000	$587,600	$700,400	$815,800	$881,400
Actual Damages (DRF at 0.8)	**$300,200**	**$443,600**	**$470,200**	**$560,300**	**$652,600**	**$705,200**
Total Inundated Roads (km)	1.2	1.5	2.0	2.6	3.3	3.8
Total Infrastructure Damages	**$11,100**	**$16,700**	**$35,500**	**$55,900**	**$75,200**	**$92,900**
TOTAL DAMAGES (DRF at 0.8)	**$311,300**	**$460,300**	**$505,700**	**$616,200**	**$727,800**	**$798,100**

1. Design floods employed in damage assessment were determined by the URBS model.

Average annual damages were calculated as the area under a curve of total monetary damages (from Table 7-1). The average annual damages (AAD) for existing conditions in study is estimated at approximately **$60,600** up to a 500 year ARI event.

Figure 7-1 shows a plot of properties affected, properties inundated above floor and damages for the entire study area. The properties flooded above floor and total flood properties shown in Figure 7-1 includes 25 permeant caravans/cabins.

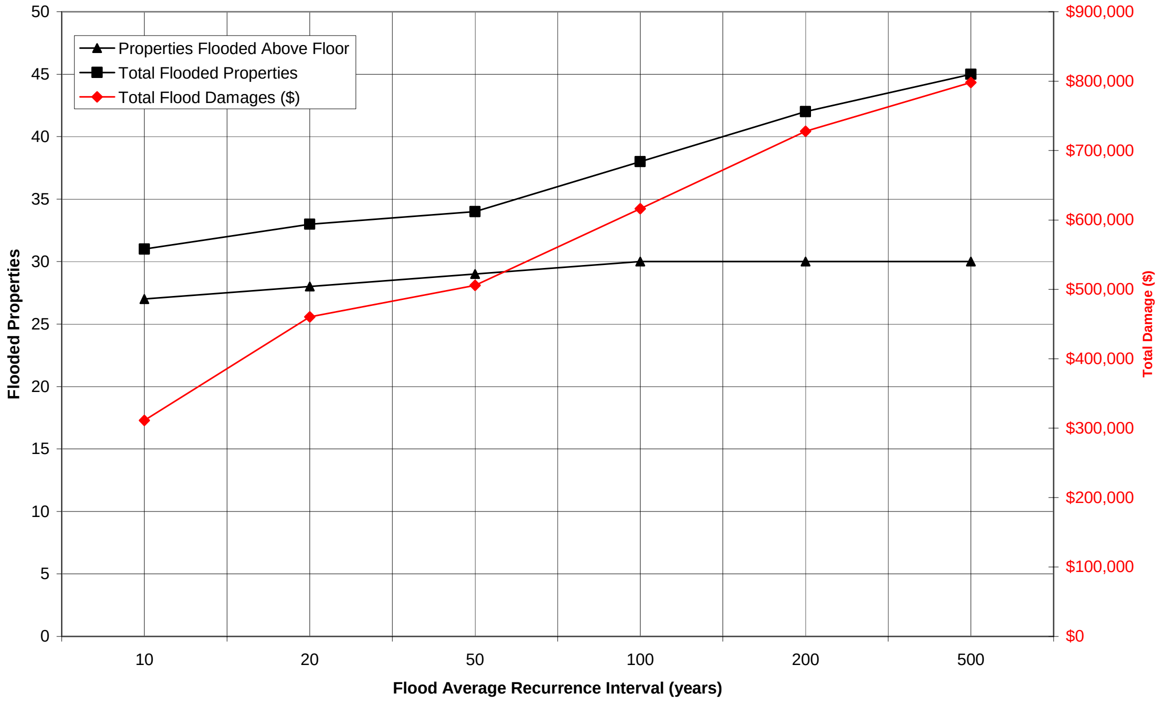


Figure 7-1 Properties affected and damages vs. ARI - Existing conditions

8 IDENTIFICATION OF POTENTIAL MITIGATION MEASURES

8.1 Overview

As discussed in Section 7 the existing flood risk to Yea, expressed as the average annual damage (AAD), was determined at $60,600. Mitigation measures provide a means to reduce the existing flood risk (AAD). Mitigation measures can reduce existing flood risk by lowering the likelihood of flooding and/or lowering the flood damages (consequences) for a given flood depth. Mitigation measures can be broken into:

- Structural – structural works such as levees, floodways waterway works, improvements to hydraulic structures
- Non-structural- land use planning, flood warning

This section identifies and provides a preliminary assessment of the suitability of potential mitigation options. The structure of the section is as follows:

- Structural measures – summarises potential structural measures and assess preliminary suitability (Section 8.2)
- Non-structural measures – summarises potential non-structural measures and assess preliminary suitability (Section 8.3)

8.2 Structural measures

Structural measures are physical barriers or works designed to prevent flooding up to a specific design flood standard. Structural measures aim to reduce existing flood risk flood by lowering flood likelihood at a given location. Structural measures include:

- Upstream storages
- Levees
- Floodways
- Waterway management works
- Improvements to bridge/culvert structures

An **upstream storage**, located on the Yea River, would provide additional attenuation and results in lower flood magnitudes for a given ARI. The construction and operation of an upstream storage requires significant land at a suitable location. It is likely the costs of an upstream storage would be significant. The benefits of an upstream storage would be limited, given the relatively low flood damages. The study team consider the upstream storage is not a feasible mitigation measure.

Levees or floodwalls can restrict the extent of flooding and limit the area subject to flooding up to a given design flood. Levees are usually earth embankments, and can be landscaped to present an attractive appearance through grassing, planting with native shrubs, and/or variation to the alignment, width and height of the embankment. Floodwalls are usually constructed of concrete and/or stone, are more expensive but are convenient where space for levees is restricted or cost of land acquisition is high. The levee and/or floodwalls provide a physical barrier to flood waters. Levee and/or floodwalls result in a lower likelihood of flooding for properties and infrastructure located behind the levee/floodwall. Potential disadvantages of levees/floodwalls include:

- Overtopping/ failure in large flood events

- Failure of levees due to poor construction and/or lack of ongoing maintenance
- Loss of floodplain storage and obstruction to flood flows
- Loss of visual amenity
- Inequality due to increased flood levels elsewhere within the floodplain.

Due to relatively low flood damages, the benefits of levees/floodwalls are likely to be limited. The cost benefit ratio of the levees/floodwalls in the Yea township is likely to be low (significantly less than 1). The study team considers the construction of levee and/or floodwalls storage is not a feasible mitigation measure.

Floodways provide additional flood flow paths, and reduce flood levels by providing additional flow carrying capacity and by diverting flow away from areas susceptible to flooding and damage. Ideally, floodways should make use of existing natural depressions in the floodplain. One of the main limitations of floodways is their often limited effectiveness in significant flood conditions where the bulk of the flow is carried in the floodplain. In these events, floodways provide little additional flow capacity. Their benefit is usually in small to medium floods. This was reflected somewhat in the likely lower design standards of the floodway based mitigation options.

The nature of the floodplain does not lend itself to the siting of floodplain. The Yea River waterway channels are of limited flow capacity and flows across the floodplain occur for events with an ARI approximately greater than 5 years. It is likely little additional flow capacity could be achieved with a constructed floodway. The study team consider the construction of floodways is not a feasible mitigation measure.

Waterway management works can include local widening, deepening, re-shaping and clearing of channels and verges. It also includes clearing of in-channel debris and mostly non-native riparian vegetation. Such works increase the flow capacity of the channels and floodplain, although the benefits are dependent on the existence or severity of channel and floodplain constrictions. Local works are likely to have only local benefits. However, waterway management works have the potential to cover significant lengths of the waterway.

Generally the benefits of waterway management works will be most evident in small to medium floods. In larger floods, where the waterway carries only a small proportion of the flow, improvements will provide only minor benefit.

Waterway management works do have disadvantages. There are environmental and geomorphologic issues associated with both the clearing of vegetation and the reshaping or enlarging of channels. Removal of large trees should be avoided, for example. For the same reasons, reshaping of land surfaces, sediment removal and alteration to creek cross-sections should to be done sparingly, and with consideration for the likely hydraulic, geomorphologic and ecological consequences. Tampering with the beds and banks of streams can trigger hydraulic responses that are undesirable. In any given area, works should be selective – excessive clearing or channel reshaping may have adverse impacts. Waterway management also has a high maintenance cost.

Improvements to waterway crossing structures (e.g. culverts, bridges, road and rail embankments) can reduce upstream flood levels. Waterway crossing structures within the flood flows potentially act as a barrier or constriction to flood flows and impact on flood levels. The hydraulic performance of bridge/culvert structures can be expressed as afflux. The afflux is the change in the flood levels from downstream to upstream across the structure. The magnitude of the afflux reflects the degree to which the structure obstructs the flood.

As discussed in Section 2.3 two waterway crossings are located along the Yea River, Provenience Bridge (Craigie Street) and Goulburn Valley Highway. The hydraulic analysis shows the Provenience Bridge produces no significant afflux for the 100 year ARI event.

The hydraulic analysis enables assessment of the hydraulic performance of the Goulburn Valley Highway crossing of the Yea River. For the 100 year ARI design flood, the afflux across for the Goulburn Valley Highway is approximately 800 mm.

The hydraulic model was run for the 100 year ARI design flood event without the embankment (i.e. similar to providing a bridge over the entire floodplain). Figure 8-1 shows the changes in the 100 year flood levels (a positive difference indicates an increase in flood level after the removal of the embankment compared to the existing conditions). Significant decreases in flood levels occur upstream of the existing Goulburn Valley Highway due to the removal of the embankments. The decreases shown range from 600 mm at the Goulburn Valley Highway to 50 mm at the upstream limit of the study. The decrease across the caravan park is of the order of 500 mm. Immediately downstream of the existing highway increases in flood level of 50 mm to 100 mm occur. Further downstream, the increases are less than 10 mm.

As seen in Figure 8-1, the removal (bridging) of Goulburn Valley Highway results in lowering upstream flood levels. The flood levels would be lower throughout the caravan park and the properties located on the eastern side of Miller Street. This lowering in flood levels would lead to a corresponding reduction in flood damages. No formal costing of the replacement bridge structure has been undertaken in this study. It is likely the cost would be significantly high in comparison to the reduction in flood damages. Given the relatively low reduction in flood damage, the study team consider the replacement of the Goulburn Valley Highway crossing is not a feasible mitigation measure nor cost effective. The study team suggest the reduction of afflux to be considered in any upgrading/replacement undertaken by VicRoads in the future.

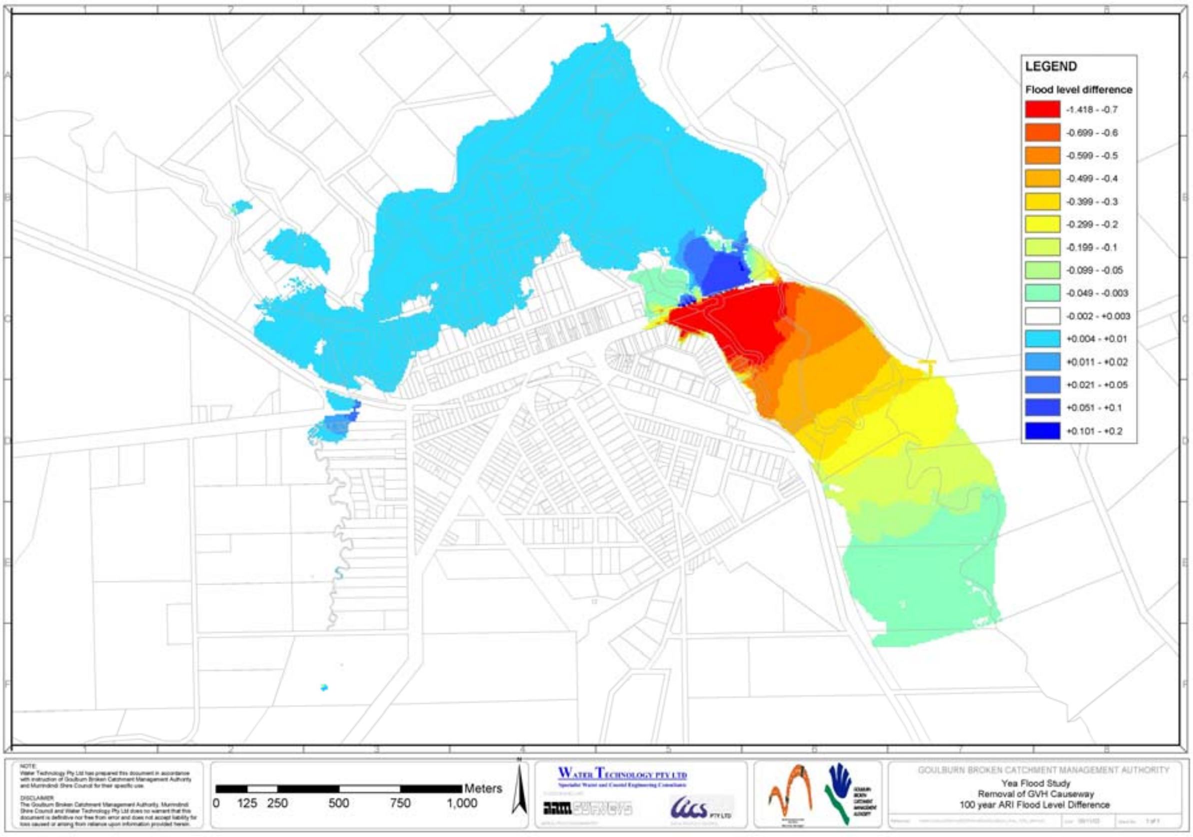


Figure 8-1 Difference in 100 year ARI flood levels – Removal of Goulburn Valley Highway crossing

8.3 Non-structural measures

Non-structural measures are management activities aimed at reducing the growth in future damages. Non-structural measures aim to reduce existing flood risk flood by lowering flood damages (consequences) at a given location. Non-structural measures include:

- Catchment management
- Flood awareness, preparedness, warning and response
- Land use planning

Catchment management activities in the upstream catchments can influence the existing catchment runoff characteristics (flood peaks and volumes). The flood volumes and flood peaks are a function of the vegetation cover and land use within a catchment. Land clearing has significantly altered flood response. Further land clearing may lead to increased flood peak and flood volumes resulting from significant rainfall events. Increases in peak flows and flood volumes in turn result a higher flooding likelihood and flood risk. Catchment revegetation, over the longer term may reduce flood volumes. However, in major floods reductions in peak flow would be insignificant.

Flood awareness, preparedness, warning and response aims to reduce the growth in future flood damages by improving community awareness of flooding and emergency services response. Flood awareness within a community reflects the frequency of significant flooding i.e. infrequent insignificant flooding leads to a lower community flood awareness. The most recent significant flooding events occurred in May 1974 and June 1989. Given relatively infrequent occurrence of significant flooding with associated damages to property, the study team considers the community awareness of floods to be low. This lower community awareness is likely to be reflected by the small number of questionnaire responses (refer to Section 3).

A flood warning system developed by the Bureau of Meteorology (BoM) provides flood forecasts for the Goulburn River catchment from Eildon to Seymour including the Yea River at Court Street gauge. Section 5.7 outlines the stage-discharge relationship developed for the Court Street gauge. BoM (A. Baker pers. comm. 2005) advised that the BoM have utilised the stage-discharge relationship to provide peak height forecasts at the Court Street gauge during recent flood events. Flood inundation maps for a range of gauge heights provide guidance in flood response.

The Court Street gauge is currently a staff gauge with sporadic manual observations undertaken by the caravan park managers. It is likely during a significant flood events safety concerns may limit the opportunities for manual observations of the Court Street gauge. A continuous river level data at the Court Street gauge can aid in the refinement of the flood forecasting and warning.

The study team recommends the installation of a continuous river level recorder with telemetry capability at the Court Street gauge.

A detailed discussion of flood awareness, preparedness, warning and response is provided in Section 11. Flood inundation maps for use in flood response are discussed in Section 9.

Land use planning aims to reduce the growth in future flood damages by provide appropriate guidelines/controls for land use and development. The Victoria Planning Provisions (VPPs) allow for zoning of land and the application of controls on the type of land use and permitted activities in areas prone to flooding. The VPPs provide for the following zone and two overlays:

- Land subject to inundation overlay (LSIO)
- Floodway (FO)
- Urban floodway zones (UFZ)

The VPPs provide guidelines for the appropriate uses and/or development of land in LSIO, UFZ and FO areas. A more detailed discussion of land-use controls is provided in Section 10.

9 FLOOD INUNDATION MAPPING FOR FLOOD RESPONSE

9.1 Overview

The hydraulic analysis undertaken, as outlined in Section 5, enables the mapping of the flood extent and depth for a range of flood magnitude considered. Table 9-1 displays the gauge heights at the Court Street gauge for which flood emergency response maps have been prepared.

Table 9-1 Flood inundation emergency response maps : Court Street Gauge heights for key historical events

Court Street Gauge height[1]	Flood level at Court Street gauge (m AHD)	Key historical flood
3.99 m	166.71	-
4.16 m	166.88	June 1989[2]
4.22 m	166.94	-
4.40 m	167.12	-
4.45 m	167.17	May 1974[3]
4.55 m	167.27	-
4.75 m	167.47	-
4.83 m	167.55	-

1. Court Street gauge height determined by subtracting the gauge zero elevation in m AHD (162.72 m AHD) from the flood level elevation in m AHD.
2. Indicative Court Street gauge height for June 1989, obtained from Flood Data Transfer Project Murrindindi shire Flood data maps No. 500058-27
3. Indicative Court Street gauge height for May 1974, obtained from Flood Data Transfer Project Murrindindi shire Flood data maps No. 500058-27

The study brief required flood response inundation maps to be prepared for gauge height increment of 200 mm. From Table 9-1, the gauge increment between maps varies from 80 mm to 230 mm. The study team considers the variation of gauge height increment provides a practical range of gauge heights for flood response. The study team proposes the above gauge height be adopted for use.

Consideration of rounding the gauge height to “round intervals” would provide for easy reference e.g. 3.99 m rounded to 4.00 m and 4.22 m to 4.20 m. The study team considers due to relatively confined floodplain the additional flood extent resulting from a gauge of 4.00 m compared with 3.99 m would be trivial.

The flood response inundation maps have been produced on single B1 sheets, for each flood event, at 1:5,000. The map base is the cadastre obtained from GBCMA as current at July 2002. The cadastre is subject to change.

This section details the input data, methodology and outputs for the emergency response inundation mapping. The structure of the section is as follows:

- Flood response inundation map format – outlines the features and formats of the flood inundation maps (Section 9.2)
- Incremental flood inundation map – outlines the features and formats of the incremental flood inundation maps (Section 9.3)

- Flood velocity map – details the preparation of the flood velocity map (Section 9.4)
- Propertry gauge height correlations – summaries the preparation of the propertry gauge height correlations estimation (Section 9.5)

9.2 Flood response inundation map format

9.2.1 Flood extent and flood depth zones

The hydraulic analysis provides a regular grid of flood depth across the hydraulic model study area. As the grid size for the MIKEFLOOD model was 7.5 m, the flood depths are determined at a 7.5 m spacing.

The flood extent is defined by the location of the zero flood depth edge. The flood extents were smoothed to reflect the local topography.

Flood depths were classified for mapping employing the following classifications:

- Less than 0.25 m
- 0.25 m to 0.5 m
- 0.5 m to 1.0 m
- Greater than 1.0 m

9.2.2 Flood elevation contours

The hydraulic analysis also provides flood elevations to AHD. The flood elevations were contoured at 200 mm intervals. The automatic contouring procedures can create erroneous flood elevation contours which do not reflect the local topographic and hydraulic features. Manual refinement of flood contours was undertaken to remove any erroneous contours.

9.2.3 Flood Affected Properties

All properties with floor level survey, as outlined in Section 6.3.1, were shown on the flood response maps as small dots. The location of the dots indicates the approximate building location. The proprieties' dots were coloured as follows to indicate the flooding status:

- Ground level at buildings not flooded:- light grey dots
- Buildings affected by below floor flooding:- grey dots
- Buildings affected by above floor flooding:- red dots

Light grey dots denote the location of a building not inundated. It should be noted other areas within the property allotment may be flooded.

9.2.4 Emergency service locations

The locations of the following emergency services were included on the flood response maps:

- Shire Offices
- Fire Station
- Police
- Ambulance

9.3 Incremental flood inundation map

Flood extents from the design flood events were overlayed on a single map. Each design flood extent is coloured differently. The incremental map provides guidance on the gauge height at which access roads are inundated.

9.4 Flood velocity map

The hydraulic analysis provides a grid of flow speed and direction (velocity). For the 100 year ARI design event, flow speeds were mapped using the following categories:

- Less than 0.25 m/s
- 0.25 m/s to 0.5 m/s
- 0.5 m/s to 0.75 m/s
- 0.75 m/s to 1.0 m/s
- 1.0 m/s to 1.5 m/s
- Greater than 1.5 m/s

The flow directions were displayed on the map as arrow with the length of the arrow representing the flow speed.

9.5 Property gauge height correlations

For each flood response map produced, property gauge height correlations have been compiled. The correlations provide peak flow, ARI and gauge height at the Court Street gauge for each flood response map. The detailed listings provide the following property related data:

- street address
- building type (i.e. commercial, public or residential)
- ground level
- floor level
- flood elevation, flood depth above ground, flood depth above floor

Appendix D contains the property gauge height correlations.

10 FLOOD MAPPING FOR LAND USE PLANNING

10.1 Overview

As discussed in Section 8.3, land use planning controls and building regulations provide mechanisms for ensuring appropriate use of land and building construction, given the flooding behaviour. Land use planning controls are aimed at reducing the growth in flood damages over time. The controls balance the likelihood of flooding with the consequences (flood risk).

As part of ongoing municipal reform, the State Government introduced a consistent planning scheme format for application across the State. The Victoria Planning Provisions (VPPs) has been employed by all Victorian municipalities.

Victorian Building Regulations specify that floor levels should be 300mm above a nominated flood level. The nominated flood level is the level of the 100 year ARI flood, or if that has not been determined for a particular area, it is that level nominated by the floodplain management authority usually on the basis of historical flooding. If land is subject to flooding, the municipal council may set conditions that require particular types of construction or particular types of construction materials.

This section details the input data, methodology and outputs for the land use planning flood mapping. The structure of the section is as follows:

- Victoria Planning Provisions – outlines the flood related Victoria Planning Provisions (VPPs) (Section 10.2)
- Flood related planning zones and overlay – details the available flood related planning zone and overlays (Section 10.3)
- Flood related planning zone and overlays delinineation – details the delineantion of the flood related planning zone and overlys for the study area (Section 10.4)

10.2 Victoria Planning Provisions (VPPs)

The VPPs aim to achieve consistency in the application of planning controls for areas subject to flooding throughout the State. The stated objectives are to protect life, property and community infrastructure from flood hazard, and to preserve flood conveyance capacity, floodplain storage and natural areas of environmental significance.

The VPPs (DoI 2000) provide for two overlays and one zone associated with mainstream flooding as follows:

- Land Subject to Inundation Overlay (LSIO),
- Floodway Overlay (FO),
- Urban Floodway Zone (UFZ).

Details of the above zone and overlay are provided in Section 10.3.

The VPPs proceed to specify for each of the relevant zone or overlays the appropriate types of land uses and developments which are to be regulated through a system of permits. These are intended to achieve consistency throughout the State, but local variations to these guidelines are allowed for through planning permit exemptions that may be declared in a schedule and applied to each of the overlays by the local authority.

10.3 Flood related planning zones and overlays

10.3.1 Land subject to inundation overlay (LSIO)

The LSIO identifies land liable to inundation by overland flow, in flood storage or in flood fringe areas affected by the 100 year ARI flood.

The permit requirements of LSIO are intended:

- to ensure that development maintains the free passage and temporary storage of floodwaters,
- to minimise flood damage,
- to be compatible with the flood hazard and local drainage conditions,
- not to cause any significant rise in flood level or flow velocity,
- to protect water quality in accordance with relevant State Environment Protection Policies (SEPPs).

In general, emergency facilities (hospitals, schools and police stations etc) must be excluded from this area (refer Clause 15.02). Similarly, developments or land uses which involve the storage or disposal of environmentally hazardous chemicals or wastes, and other dangerous goods should be not located within LSIO.

Permits are required to construct buildings or carry out works including fencing and works which increase the length or height of embankments or roads. Permits are also required to subdivide land.

These controls do not apply to limited categories of buildings or works, such as:

- buildings or works exempted in the schedule incorporated into planning scheme declared by the local planning authority,
- works carried out by the floodplain management authority,
- routine repairs or maintenance to existing buildings or works,
- post and wire, and rural type fencing,
- underground services, and telephone and power lines, provided they do not alter the land surface topography or involve the construction of towers or poles, and provided they are undertaken in accordance with approved plans.

10.3.2 Floodway overlay (FO)

The floodway overlay identifies waterways, main flood paths, drainage depressions and high hazard regions within rural areas. The identification of floodways was based on NRE's "Advisory Notes for Delineating Floodways." (NRE 1998). The advisory notes provide three approaches to the delineation of FO, as follows:

- Flood frequency
- Flood depth
- Flood hazard

For **flood frequency**, Appendix A1 of the advisory notes suggest areas which flood frequently and for which the consequences of flooding are moderate or high, should generally be regarded as floodway. The 10 year ARI flood extent was considered an appropriate floodway delineation option for Yea.

Flood hazard combines the flood depth and flow speed for a given design flood event. The advisory notes suggest the use of Figure 10-1 for delineating the floodway based on flood hazard. The flood hazard for the 100 year ARI event was considered for this study.

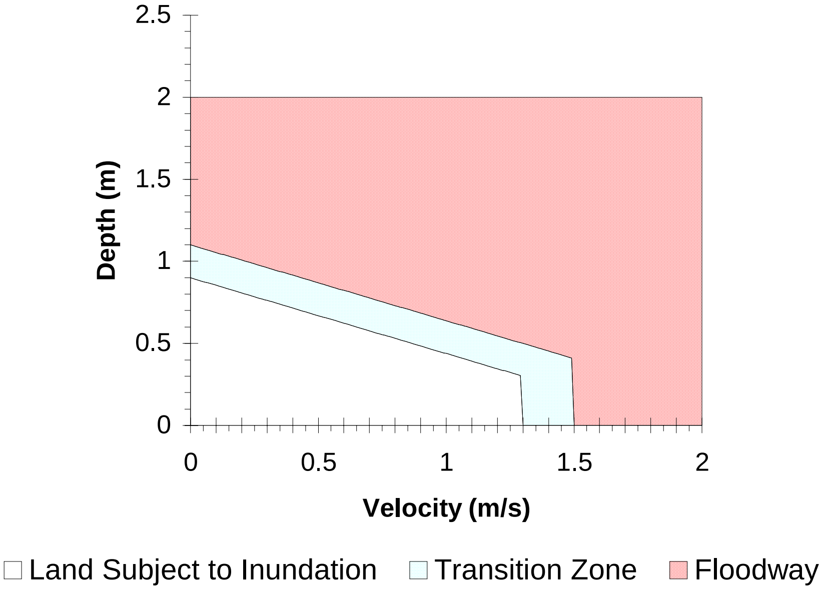


Figure 10-1 Floodway overlay flood hazard criteria

For **flood depth**, regions with a flood depth in the 100 year ARI event greater than 0.5 m were considered as FO based on the flood depth delineation option.

The final extent of the floodway overlay based on the consideration of the three approaches is discussed in Section 10.4.

10.3.3 Urban floodway zone (UFZ)

This zone is used to identify waterways, main flood paths, drainage depressions, and high hazard regions within urban areas. Unlike the flood overlays, which provide for additional controls over and above the underlying land use, this zone places restrictions on the use of the land.

The delineation options of the UFZ are determined as for the FO discussed in Section 10.3.2. The final extent of the UFZ, based on the consideration of the three approaches is discussed in Section 10.4.

Within this zone, permits are not required for use of land for agriculture, natural systems, informal outdoor recreation, mineral exploration, or (subject to conditions) mining or stone quarrying.

Permits are required to construct buildings or carry out works including fencing and roadworks, except for limited categories of buildings or works. These are identical to those stipulated in the LSIO clauses in the VPPs, except only that there are no schedule exclusions of advertising signs.

UFZ and FO have strict controls on subdivisions. Unless a local floodplain development plan specifically provides otherwise, land may only be subdivided to:

- realign lot boundaries,
- excise land to be transferred to the floodplain management authority for public purposes.

10.4 Flood related planning zone and overlays delineation

Flood related zone and overlay delineation option maps have been generated to assist GBCMA in the definition of LSIO, FO and UFZ. The delineation option maps overlay the three FO and UFZ extents previously determined and outlined in Section 10.3.2. These maps have been prepared using the hydraulic analysis for existing conditions.

As discussed in Section 4.10, the adopted 100 year ARI peak flow adopted for planning scheme purposes was 544 m3/s. The adopted 100 year ARI peak flow for planning scheme purposes is equivalent to the 200 year ARI peak flow from the URBS model. For the delineation of flood related planning scheme zone and overlays, hydraulic analysis results for the 200 year ARI URBS model peak flow are adopted.

From these delineation option maps, GBCMA has developed the planning maps in accordance with the Victoria Planning Provisions Practice Notes – Applying the Flood Provisions in Planning Scheme (DoI 2000).

Due to the nature of the floodplain, the 10 year ARI extent option for delineating the FO/UFZ was found to govern. For this study the 10 year ARI flood extent was adopted for the FO/UFZ extent. To reflect the existing and potential for urban development adjacent to Yea, a UFZ was adopted for the area within the 10 year ARI flood extent

The 100 year ARI flood extent (based on the 200 year ARI URBS model peak flow), outside the 10 year flood extent, was adopted as the LSIO.

Figure 10-2 displays the draft flood related planning zone and overlays for the Yea Township for mainstream flooding from the Yea River and boundary Creek.

The study team recommends the MSC and GBCMA liaise in the preparation and adoption of a planning scheme amendment (C14 Part 2) to enable the draft flood related planning zone and overlays.

Further, the study team recommends GBCMA declares the 100 year ARI flood level (based on the 200 year ARI URBS model peak flow) for planning purposes under the Water Act (1989).

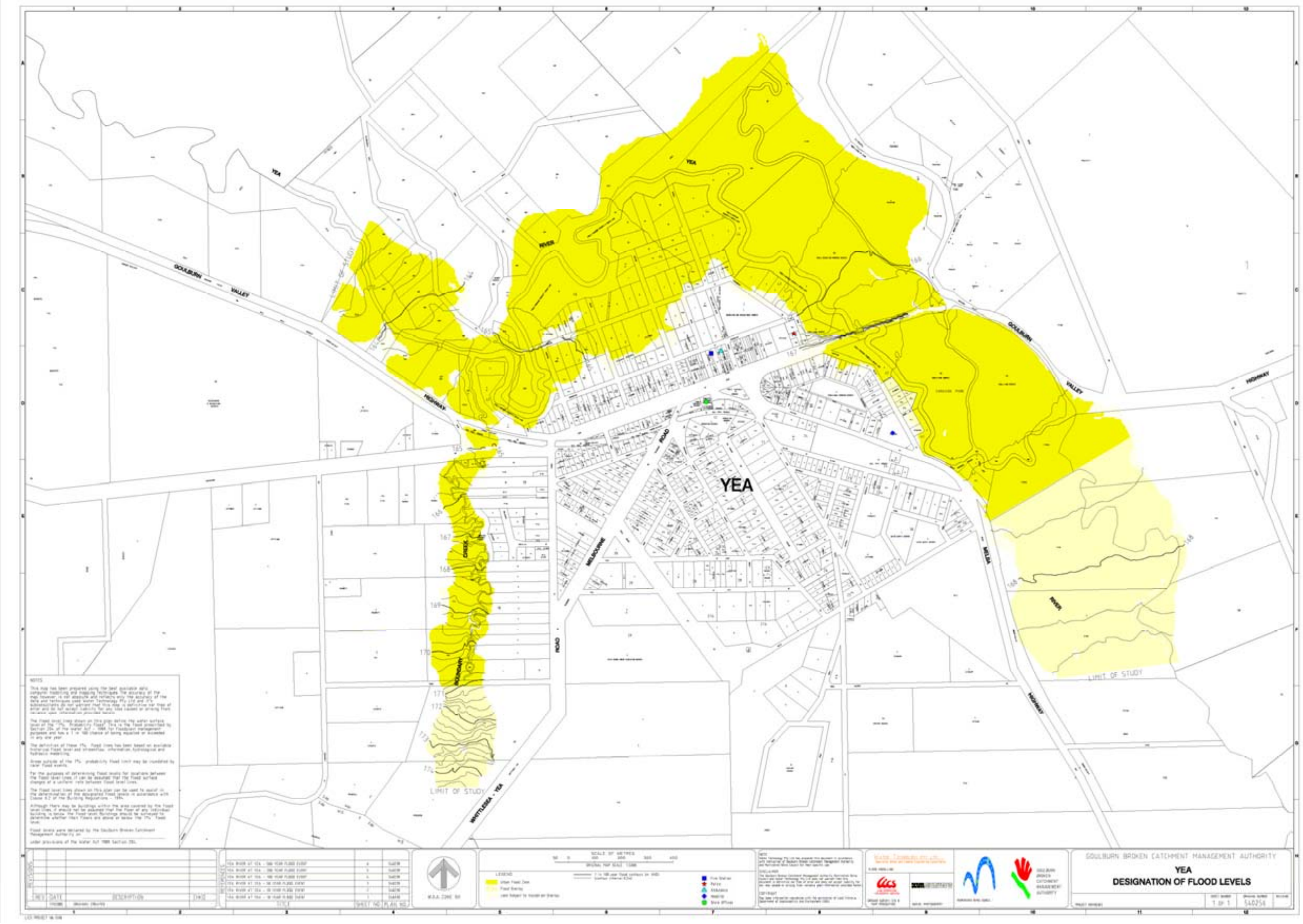


Figure 10-2 Draft flood related zone and overlay delineation

11 FLOOD RESPONSE AND ALERT REVIEW

11.1 Overview

As part of the Goulburn River Catchment – Seymour to Eildon Flood Warning Project undertaken in 2002, a framework for flood warning, preparedness, response and recovery was developed and detailed in the following four documents:

- Murrindindi Shire - Goulburn River Environs Flood Sub-Plan (October 2002)
- Murrindindi Shire - Flood Alert Operation Procedures (October 2002)
- Flood information providers manual (October 2002)
- Goulburn River Catchment – Seymour to Eildon: Flood response guidelines for the affected flood community of the Shire of Murrindindi in the Goulburn River Environs (November 2000)

The above documents have been prepared for use in the entire Goulburn River catchment from Seymour to Eildon with specific references to the Yea Township as required.

This section provides a review of the above four documents with a focus on the Yea Township. Further, recommendations are provided to enable the outcomes of this study, in particular the flood response maps (refer to Section 9), to be utilised within the current flood warning, preparedness, response, monitoring and recovery framework.

11.2 Flood emergency management arrangements

The Murrindindi Shire - Goulburn River Environs Flood Sub-Plan (October 2002) states a Flood Sub-Committee will be formed with representatives from the following agencies and organisations:

- Murrindindi Shire Council (Chair) and MERO, Flood Warning Officer, Recovery Manager
- Victoria State Emergency Service.
- Goulburn Broken Catchment Management Authority.
- Goulburn-Murray Water
- Victoria Police (Municipal Emergency Response Coordinator)
- CFA
- Other Agencies as required.

The sub-plan suggests the flood sub-committee will meet at least once per year. The MERO is responsible for calling and conducting this meeting and updating this plan.

11.3 Flood preparedness

11.3.1 Overview

Flood preparedness refers to activities to be undertaken when flooding is likely to occur. The main tasks and responsibilities for those tasks are provided in Table 11-1.

Table 11-1 Flood preparedness – tasks and responsibilities

MAIN TASKS	RESPONSIBILITY	
	MUNICIPAL LEVEL	REGIONAL LEVEL
Produce Flood Forecasts and Warnings		Bureau of Meteorology
Disseminate Flood Warnings	Murrindindi Shire	VICSES
Public Education	Murrindindi Shire / VICSES	VICSES/ GB CMA
Maintain FM radio access with UGFM/Fax stream/Telephone plan for warnings	Murrindindi Shire	

11.3.2 Flood warning development and categories

A rainfall and flood data collection network has been established for the Goulburn River catchment area from Eildon to Seymour.

Where the Bureau of Meteorology believes weather patterns show a potential for flooding a flood watch will be issued. Where the flood data collection network shows flooding is imminent a flood warning will be issued. For the purposes of dissemination, both flood watch and flood warnings will be treated as flood warnings.

A flood warning issued by the Bureau of Meteorology will outline the likely indicative flooding consequences. For each flood warning a flood warning category will be assigned. The definitions of flood warning categories employed are as follows:

> **MINOR FLOODING:-** causes inconvenience. Low-lying areas adjacent to watercourses are inundated requiring removal of stock and equipment. Minor roads may be closed and low-level bridges submerged.
> **MODERATE FLOODING:**:- In addition to the above, may require the evacuation of some houses. Main traffic routes may be covered. The area of inundation is substantial in rural areas.
> **MAJOR FLOODING:-** In addition to the above, causes inundation of extensive rural areas and appreciable urban areas. Properties and towns are likely to be isolated and major traffic routes likely to be closed. Numerous evacuations may be required.

For the Yea township the Murrindindi Shire - Goulburn River Environs Flood Sub-Plan (October 2002) provides the following examples of consequences for the three flood warning categories:

- Minor flood - Yea River flooding at Yea Caravan Park
- Moderate flood - Yea Caravan Park flooding
- Major flood – No example provided

Flood warning categories are triggered when a forecasted flood level is likely to exceed a defined level. The Murrindindi Shire - Goulburn River Environs Flood Sub-Plan (October 2002) provides the following advice on flood levels and categories for the Yea township:

MINOR	**MODERATE**	**MAJOR**
Yea River @ Goulburn Valley Hwy. TBD 0m	**Yea River @ Goulburn Valley Hwy. TBD 0m**	**Yea River @ Goulburn Valley Hwy. TBD 0m**

As seen above the Murrindindi Shire - Goulburn River Environs Flood Sub-Plan (October 2002) provides no details for assignment of the flood warning category at the Yea Township. However, the flood response guidelines (November 2000) provide flood warning categories for the Yea Township. The following current flood warning categories are based on the forecasted flood level at the Court Street gauge:

- Minor : Yea River @ Caravan Park (Court Street) 3.0 m
- Moderate : Yea River @ Caravan Park (Court Street) 3.9 m
- Major : Yea River @ Caravan Park (Court Street) 4.9 m

A note is provided in the flood response guidelines (November 2000), advising that the above flood levels require confirmation by the relevant authorities.

As discussed in Section 9.1, the flood inundation mapping for flood response have been prepared for the 10, 20, 50, 100, 200 and 500 ARI design flood event. From Table 9-1, the gauge heights at the Court Street vary from 3.99 m to 4.83 m for the 10 to 500 year ARI flood events. There is no flood inundation map prepared for a gauge less than 3.99 m. As seen, the current minor and moderate flood levels are less than the 10 year ARI flood level. The current major flood level is greater than the 500 year ARI event.

The hydraulic analysis, as discussed in Section 5, provides details of the likely flood behaviour for a range of gauge heights. The flood damage assessment as discussed in Section 7, provides details of the likely properties and infrastructure affected for a range of gauge heights.

Table 11-2 outlines the flood behaviour, properties and infrastructure affected over a range of gauge heights up to 4.55 m (100 year ARI flood level).

As discussed in Section 7, a total of 15 properties are affected above floor for the 100 year ARI flood event. No additional properties are flooded above floor for the 200 and 500 year ARI flood events. As such the inclusion of the 200 and 500 year ARI flood events in Table 11-2 was considered unnecessary.

Using the definition of the flood warning categories outlined above, the study team recommends revising to the current flood category levels to the following:

- Minor : Yea River @ Caravan Park (Court Street) 3.0 m
- Moderate : Yea River @ Caravan Park (Court Street) 3.6 m
- Major : Yea River @ Caravan Park (Court Street) 4.4 m

BoM (A.Baker pers. comm. 2005) advised that the BoM have utilised the stage-discharge relationship developed by this study for the Court Street gauge during recent floods. The use of the stage-discharge relationship enables the forecast of gauge heights at Court Street.

The Court Street gauge is currently a manually read staff gauge. Improvements to the reliability of the forecasted gauge heights may be possible with the use of continuous real time river level data. The study team recommends the installation of a continuous river level recorder with telemetry capability at the Court Street gauge.

Table 11-2 Flood behaviour, and properties/infrastructure affected for a range of gauge height

Gauge height at the Court Street gauge	**Flood behaviour, and properties/infrastructure affected**							
	Caravan Park	**Craigie Street west of Provenance Bridge**	**Craigie Street east of Provenance Bridge**	**Webster Street**	**Marshbank Street**	**Miller Street**	**Goulburn Valley Hwy west of Boundary Ck confluence (to Seymour)**	**Goulburn Valley Hwy at eastern end of township (to Yarack)**
3.0 m	Flooding occurs in lower parts of the Caravan Park	No flooding	No flooding to private allotments along Craigie Street	No flooding to private allotments along Webster Street	No flooding to private allotments along Marshbank Street	No flooding to private allotments along Miller Street	Flooding to private allotments (not to dwellings). Vehicular access to these dwellings not flooded	No flooding
3.3 m	Flooding commences in the Caravan Park	No flooding	Flooding commences across Craigie Street adjacent to the corner with Nolan Street Flooding to private properties (allotments not dwellings) along Craigie, Street with flood depths to up 0.2 m	Flooding commences across Webster Street Flooding to private properties (allotments not dwellings) along Webster Street with flood depths to 0.2 m	Flooding to private properties (allotments not dwellings) along Marshbank Street with flood depths to 0.2 m	Flooding to private properties (allotments not dwellings) along Miller Street with flood depths to 0.2 m	Flooding to private allotments (not to dwellings). Vehicular access to these dwellings flooded to a depth of 0.2 m	No flooding

Gauge height at the Court Street gauge	Flood behaviour, and properties/infrastructure affected							
	Caravan Park	**Craigie Street west of Provenance Bridge**	**Craigie Street east of Provenance Bridge**	**Webster Street**	**Marshbank Street**	**Miller Street**	**Goulburn Valley Hwy west of Boundary Ck confluence (to Seymour)**	**Goulburn Valley Hwy at eastern end of township (to Yarack)**
3.6 m	Flooding commences in the Caravan Park Court Street Bridge deck not inundated	No flooding	Flooding commences across Craigie Street adjacent to the corner with Nolan Street with flood depth up to 0.2 m Flooding to private properties along Craigie Street generally limited to allotments. Two buildings flooded above floor level.	Flooding commences across Webster Street with a flood depth up to 0.2 m Flooding to private properties (allotments not dwellings) along Webster Street with flood depths to 0.5 m	Flooding to private properties (allotments not dwellings) along Marshbank Street, with flood depths to 0.5 m	Flooding to private properties (allotments not dwellings) along Miller Street, with flood depths to 0.5 m	Flooding to private allotments (not to dwellings) Vehicular access to these dwellings flooded to a depth of 0.5 m	No flooding

Gauge height at the Court Street gauge	**Flood behaviour, and properties/infrastructure affected**							
	Caravan Park	**Craigie Street west of Provenance Bridge**	**Craigie Street east of Provenance Bridge**	**Webster Street**	**Marshbank Street**	**Miller Street**	**Goulburn Valley Hwy west of Boundary Ck confluence (to Seymour)**	**Goulburn Valley Hwy at eastern end of township (to Yarack)**
3.99 m	Flooding in the Caravan Park with flood depths up to 0.4 m Up to 25 caravans inundated above floor level Approaches to the Court Street Bridge not inundated Court Street Bridge deck not inundated.	Inundated with flood depth up to 0.4 m Properties located adjacent to the corner of Craigie and Webster Street isolated.	Flooding commences across Craigie Street adjacent to the corner with Nolan Street with flood depth up to 0.6 m Flooding to private properties (allotments and two dwellings above floor) along Craigie Street, with flood depths up to 0.9 m	Flooding commences across Webster Street with a flood depth up to 0.6 m. Flooding to private properties (allotments not dwellings) along Webster Street with flood depths to 0.9 m	Flooding to private properties (allotments not dwellings) along Marshbank Street with flood depths to 0.9 m	Flooding to private properties (allotments not dwellings) along Miller Street with flood depths to 0.9 m	Flooding to private allotments (not to dwellings) Vehicular access to these dwellings flooded to a depth of 0.9 m	No flooding

Gauge height at the Court Street gauge	**Flood behaviour, and properties/infrastructure affected**							
	Caravan Park	**Craigie Street west of Provenance Bridge**	**Craigie Street east of Provenance Bridge**	**Webster Street**	**Marshbank Street**	**Miller Street**	**Goulburn Valley Hwy west of Boundary Ck confluence (to Seymour)**	**Goulburn Valley Hwy at eastern end of township (to Yarack)**
4.22 m	Flooding in the Caravan Park with flood depth up to 0.6 m Up to 25 caravans inundated above floor level plus one permanent building in the caravan park Court Street Bridge deck inundated up to 0.1 m	Inundated with flood depth up to 0.6 m Properties located adjacent to the corner of Craigie and Webster Street isolated	Flooding commences across Craigie Street adjacent to the corner with Nolan Street with flood depth up to 0.8 m Flooding to private properties (allotments and two dwellings above floor) along Craigie Street, with flood depths to up 1.1 m	Flooding commences across Webster Street with a flood depth up to 0.8 m Flooding to private properties (allotments not dwellings) along Webster Street with flood depths to 1.1 m	Flooding to private properties (allotments not dwellings) along Marshbank Street with flood depths to 1.1 m Flooding commences across Marshbank Street adjacent to corner with Craigie Street	Flooding to private properties (allotments not dwellings) along Miller Street with flood depths to 1.1 m Flooding commences across Miller Street adjacent to corner with High Street with a flood depth up to 0.25 m	Flooding to private allotments (not to dwellings) Vehicular access to these dwellings flooded to a depth of 1.1 m	No flooding

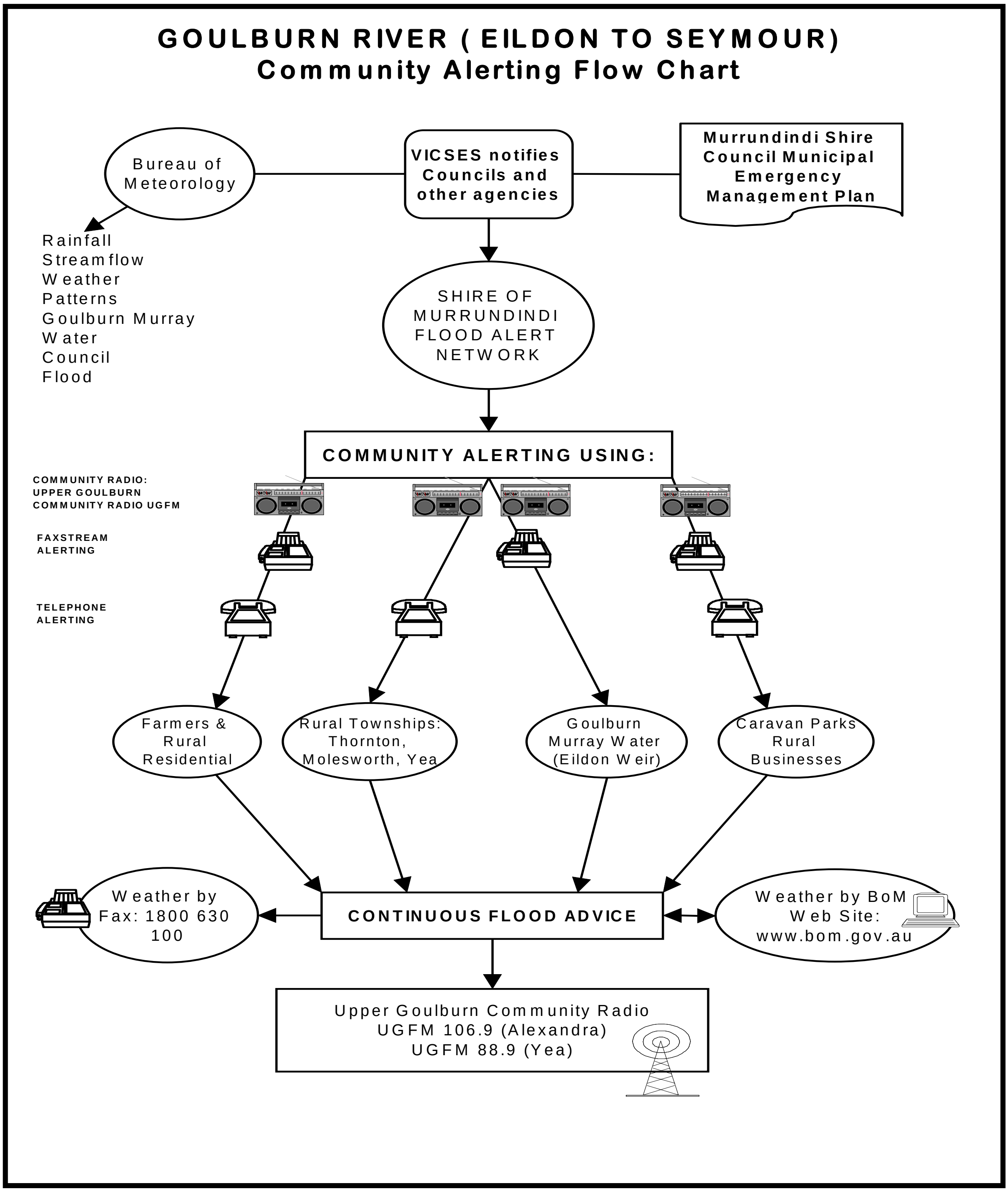
Gauge height at the Court Street gauge	**Flood behaviour, and properties/infrastructure affected**							
	Caravan Park	**Craigie Street west of Provenance Bridge**	**Craigie Street east of Provenance Bridge**	**Webster Street**	**Marshbank Street**	**Miller Street**	**Goulburn Valley Hwy west of Boundary Ck confluence (to Seymour)**	**Goulburn Valley Hwy at eastern end of township (to Yarack)**
4.40 m	Flooding in the Caravan Park with flood depth up to 0.8 m. Up to 25 caravans inundated above floor level plus two permanent building in the caravan park Court Street Bridge deck inundated up to 0.3 m	Inundated with flood depth up to 0.8 m Properties located adjacent to the corner of Craigie and Webster Street isolated	Flooding commences across Craigie Street adjacent to the corner with Nolan Street with flood depth up to 1.0 m Flooding to private properties (allotments and two dwellings above floor) along Craigie Street, with flood depths up to 1.3 m	Flooding commences across Webster Street with a flood depth up to 1.0 m Flooding to private properties (allotments not dwellings) along Webster Street with flood depths to 1.3 m	Flooding to private properties (allotments not dwellings) along Marshbank Street with flood depths to 1.3 m Flooding commences across Marshbank Street adjacent to corner with Craigie Street with a flood depth up to 0.3 m	Flooding to private properties (allotments not dwellings)) along Miller Street with flood depths to 1.1 m Flooding commence across Miller Street adjacent to corner with High Street with a flood depth up to 0.5 m	Flooding to private allotments (not to dwellings) Vehicular access to these dwellings flooded to a depth of 1.3 m	Goulburn Valley Highway inundation up to 0.1 m

Gauge height at the Court Street gauge	Flood behaviour, and properties/infrastructure affected							
	Caravan Park	**Craigie Street west of Provenance Bridge**	**Craigie Street east of Provenance Bridge**	**Webster Street**	**Marshbank Street**	**Miller Street**	**Goulburn Valley Hwy west of Boundary Ck confluence (to Seymour)**	**Goulburn Valley Hwy at eastern end of township (to Yarack)**
4.55 m	Flooding in the Caravan Park with flood depth up to 0.95 m Up to 25 caravans inundated above floor level plus two permanent building in the caravan park Court Street Bridge deck inundated up to 0.5 m	Inundated with flood depth up to 0.95 m Properties located adjacent to the corner of Craigie and Webster Street isolated	Flooding commences across Craigie Street adjacent to the corner with Nolan Street with flood depths up to 1.15 m Flooding to private properties (allotments and two dwellings above floor) along Craigie Street, with flood depths to up 1.45 m	Flooding commences across Webster Street with a flood depth up to 1.15 m. Flooding to private properties (allotments not dwellings) along Webster Street with flood depths to 1.45 m	Flooding to private properties (allotments not dwellings) along Marshbank Street with flood depths to 1.45 m Flooding commences across Marshbank Street adjacent to corner with Craigie Street with a flood depth up to 0.45 m	Flooding to private properties (allotments not dwellings) along Miller Street with flood depths to 1.25 m Flooding commences across Miller Street adjacent to corner with High Street with a flood depth up to 0.65 m	Flooding to private allotments (not to dwellings) Vehicular access to these dwellings flooded to a depth of 1.45 m	Goulburn Valley Highway inundation up to 0.25 m

11.3.3 Flood warning dissemination

The Murrindindi Shire - Goulburn River Environs Flood Sub-Plan (October 2002) provides a flowchart for the dissemination of flood warnings. Figure 11-1 displays the community alerting flow chart.

Figure 11-1 Community alerting flow chart (The Murrindindi Shire - Goulburn River Environs Flood Sub-Plan (October 2002)



The Goulburn River – Seymour to Eildon flood warning system provides three key avenues for alerting the community:

- Community radio
- Fax stream alerting
- Telephone alerting

Three community radio stations are available for the dissemination of flood warning: UGFM 106.9 Alexandra, Marysville UGFM 98.5 & UGFM 89.1 Yea. Murrindindi Shire - Flood Alert Operation Procedures (October 2002) provides details for the activation and operation of the community radio alerting. Murrindindi Shire - Flood Alert Operation Procedures (October 2002) identifies Murrindindi shire as the responsible agency for the activation and operation.

Fax stream alerting provides flood warning to be faxed to selected agencies and residents. Murrindindi Shire - Flood Alert Operation Procedures (October 2002) lists contact details of the fax stream recipients. Murrindindi Shire - Flood Alert Operation Procedures (October 2002) identifies Murrindindi shire as the responsible agency for the activation and operation of the fax stream alerting stream.

Phone alerting provides flood warning to be phoned to selected agencies and residents. Murrindindi Shire - Flood Alert Operation Procedures (October 2002) lists contact details of the phone alerting recipients. Murrindindi Shire - Flood Alert Operation Procedures (October 2002) identifies Murrindindi shire as the responsible agency for the activation and operation of the phone alerting system.

Further the Murrindindi Shire - flood alert operation procedures (October 2002) states that each July the following items are to be updated:

- the procedure for the activation and operation of the community radio
- contact details of the fax stream recipients
- contact details of the phone alerting recipients

The study team emphasises the importance of updating of the above items and endorses updating each July.

The study team is aware that an automated telephone alerting system for flood warning is being implemented in Shepparton-Mooroopna, Euroa, Maribyrnong and Benalla. The study team recommends MSC and GBCMA consider the potential to implement a similar automated telephone alerting system for Yea.

11.4 Flood response

Flood response refers to activities to be undertaken when flooding is likely to occur. The main tasks and responsibilities for these tasks are provided in Table 11-3.

Table 11-3 Flood response – tasks and responsibilities

MAIN TASKS	RESPONSIBILITY	
	MUNICIPAL LEVEL	REGIONAL LEVEL
Erect barriers, signs, close roads and highways	Murrindindi Shire VicRoads	VicRoads
Evacuation	Police in consultation with Control Agency (VICSES) and Murrindindi Shire	Police

Managing Welfare Centres	Murrindindi Shire	VICSES
Rescue	Police & VICSES	Police & VICSES
Advice on drainage and pumping	Shire of Murrindindi	Goulburn-Murray Water
General assistance to Public eg Sandbagging, lifting furniture, safe areas, etc. (Subject to available resources)	VICSES local units and Murrindindi Shire	VICSES
Media Releases	VICSES Police Murrindindi Shire	VICSES Police

The **Victoria State Emergency Service (VICSES) is the designated control agency** (per the Emergency Management Act – Victoria) for response to floods within the State. VICSES will control all flood response activities within the Shire of Murrindindi.

VICSES, Municipal Emergency Response Coordinator and the Municipal Emergency Resources Officer will meet at designated times during the flood events to discuss the ramifications of warnings and to plan appropriate actions.

At the request of the Municipal Emergency Resources Officer, VICSES Controller or the Municipal Emergency Response Coordinator, the Municipal Emergency Co-ordination Centre will be opened.

The primary support agencies for flood events will be the Shire of Murrindindi, Victoria Police, Bureau of Meteorology, Goulburn-Murray Water, Goulburn Broken Catchment Management Authority and the Country Fire Authority, however, all agencies named in the Municipal Emergency Management Plan may be asked to provide assistance.

To ensure effective control can be maintained, agencies directly supporting with response to floods must advise VICSES of all the relevant information, all requests for assistance received directly by them and accept the overall direction of VICSES.

VICSES, Police and the Municipal Emergency Resources Officer will identify the need to evacuate any residents in flood threatened areas. Victoria Police and VICSES will implement the evacuations, assisted by other agencies on an event by event basis. This does not preclude people self evacuating from flood threatened areas. Council will manage welfare centres on a Municipal basis, supported by VICSES.

The study team recommends the flood inundation maps, as discussed in Section 9, and the flood behaviour description, as outlined in Table 11-2, be incorporated into the Murrindindi Shire - Goulburn River Environs Flood Sub-Plan (October 2002). The emergency response flood inundation maps provide details of the flood behaviour and flood affected properties for a range of Court Street gauge heights.

11.5 Flood monitoring

As part of the Goulburn River Catchment – Seymour to Eildon Flood warning system, a number of selected residents have volunteered as flood information providers. The role of a flood information provider is to document and report local data such as roadway flooding, land inundation, local weather patterns and local conditions and key trigger events that have significant effects during flood situations.

The Flood Information Providers Manual (October 2002) outlines the role and activities for a flood information provider. Further the manual contains a flood information worksheet to assist in the documentation of flood information.

Contact details for the flood information providers are listed in the Flood Information Providers Manual (October 2002). In line with the checking of contact details for the fax and phone alerting, the study team recommends the flood information providers contact details are checked and revised where necessary each July.

11.6 Flood recovery

Flood recovery activities commence when people, property or the community are affected by flooding. The main tasks and responsibilities for those tasks are provided in Table 11-4.

Table 11-4 Flood recovery – tasks and responsibilities

MAIN TASKS	RESPONSIBILITY	
	MUNICIPAL LEVEL	REGIONAL LEVEL
Temporary Accommodation	Murrindindi Shire	Dept Human Services
Emergency Grants	Dept Human Services	Dept Human Services
Establish “One Stop Shop” for recovery information and services	Murrindindi Shire	Dept Human Services
Maintain continuous updates of flood information/recovery on UGFM	Murrindindi Shire	

In general, the recovery arrangements detailed in the Municipal Emergency Management Plan will be applied to flood events.

Where considered necessary, Council will establish a “one stop shop” for people affected by flooding to obtain information and assistance in some or all of the following areas:

- Insurance.
- Financial grants.
- Personal needs.
- Clean up information.
- Advice on structural damage.
- Counselling.
- UGFM updates.

11.7 Community flood awareness

As discussed in Section 3, the community awareness of the flood related issues is considered low. As part of the Goulburn River Catchment – Seymour to Eildon Flood Warning Project, community flood response guidelines were distributed in 2002. These guidelines provided details of the flood warning system, general flood related impacts, emergency contacts and practical advice on measures to reduce flood damage. The guidelines consist of a colour booklet, some 20 pages in length.

The study team is aware that the similar style community The study team considers

11.8 Recommended revisions to the existing arrangements

This section summaries the recommendations arising from the review of the flood response and alerting procedures.

To aid the implementation of the following recommendations, the study team considers the MSC and GBCMA apply for funding under the Federal Government's Regional Flood Mitigation Program.

Flood warning development and categories

The study team recommends revising the current flood category levels to the following:

- Minor : Yea River @ Caravan Park (Court Street) 3.3 m
- Moderate : Yea River @ Caravan Park (Court Street) 3.6 m
- Major : Yea River @ Caravan Park (Court Street) 4.4 m

Flood warning data collection network

The study team recommends the installation of a continuous river level recorder with telemetry capability at the Court Street gauge

Flood warning dissemination

The study team endorses the Murrindindi Shire - flood alert operation procedures (October 2002) requirement that each July the following items are to be updated:

- the procedure for the activation and operation of the community radio
- contact details of the fax stream recipients
- contact details of the phone alerting recipients

The study team is aware that an automated telephone alerting system for flood warning is being implemented in Shepparton-Mooroopna, Euroa, Maribyrnong and Benalla. The study team recommends MSC and GBCMA considers the potential to implement a similar automated telephone alerting system for Yea.

Flood response

The study team recommends the flood inundation maps, as discussed in Section 9, and the flood behaviour description, as outlined in Table 11-2, be incorporated into the Murrindindi Shire - Goulburn River Environs Flood Sub-Plan (October 2002). The emergency response flood inundation maps provide details of the flood behaviour and flood affected properties for a range of Court Street gauge heights.

Flood monitoring

The study team recommends the flood information providers contact details are checked and revised where necessary each July.

Community flood awareness

12 STUDY RECOMMEDATIONS

This section summaries the recommendations arising from this study.

Land use planning

The study team recommends the MSC and GBCMA liaise to implement the planning scheme amendment (C14 Part 2) to enable the draft flood related planning zone and overlays.

Further, the study team recommends GBCMA declares the 100 year ARI flood level for planning purposes under the Water Act (1989).

Flood warning development and categories

The study team recommends revising to the current flood category levels to the following:

- Minor : Yea River @ Caravan Park (Court Street) 3.3 m
- Moderate : Yea River @ Caravan Park (Court Street) 3.6 m
- Major : Yea River @ Caravan Park (Court Street) 4.4 m

Flood warning data collection network

The study team recommends upgrading the Court Street gauge to include a continuous river level data logger with telemetry capability.

Flood warning dissemination

The study team endorses the Murrindindi Shire - flood alert operation procedures (October 2002) requirement that each July the following items are to be updated:

- the procedure for the activation and operation of the community radio
- contact details of the fax stream recipients
- contact details of the phone alerting recipients

The study team is aware that an automated telephone alerting system for flood warning is being implemented in Shepparton-Mooroopna, Euroa, Maribyrnong and Benalla. The study team recommends MSC and GBCMA considers the potential to implement a similar automated telephone alerting system for Yea.

Flood response

The study team recommends the flood inundation maps, as discussed in Section 9, and the flood behaviour description, as outlined in Table 11-2, be incorporated into the Murrindindi Shire - Goulburn River Environs Flood Sub-Plan (October 2002). The emergency response flood inundation maps provide details of the flood behaviour and flood affected properties for a range of Court Street gauge heights.

Flood monitoring

The study team recommends the flood information providers contact details are checked and revised where necessary each July.

Potential funding

To aid the implementation of the recommendations related to flood warning and response, the study team considers the MSC and GBCMA apply for funding under the Federal Government’s Regional Flood Mitigation Program.

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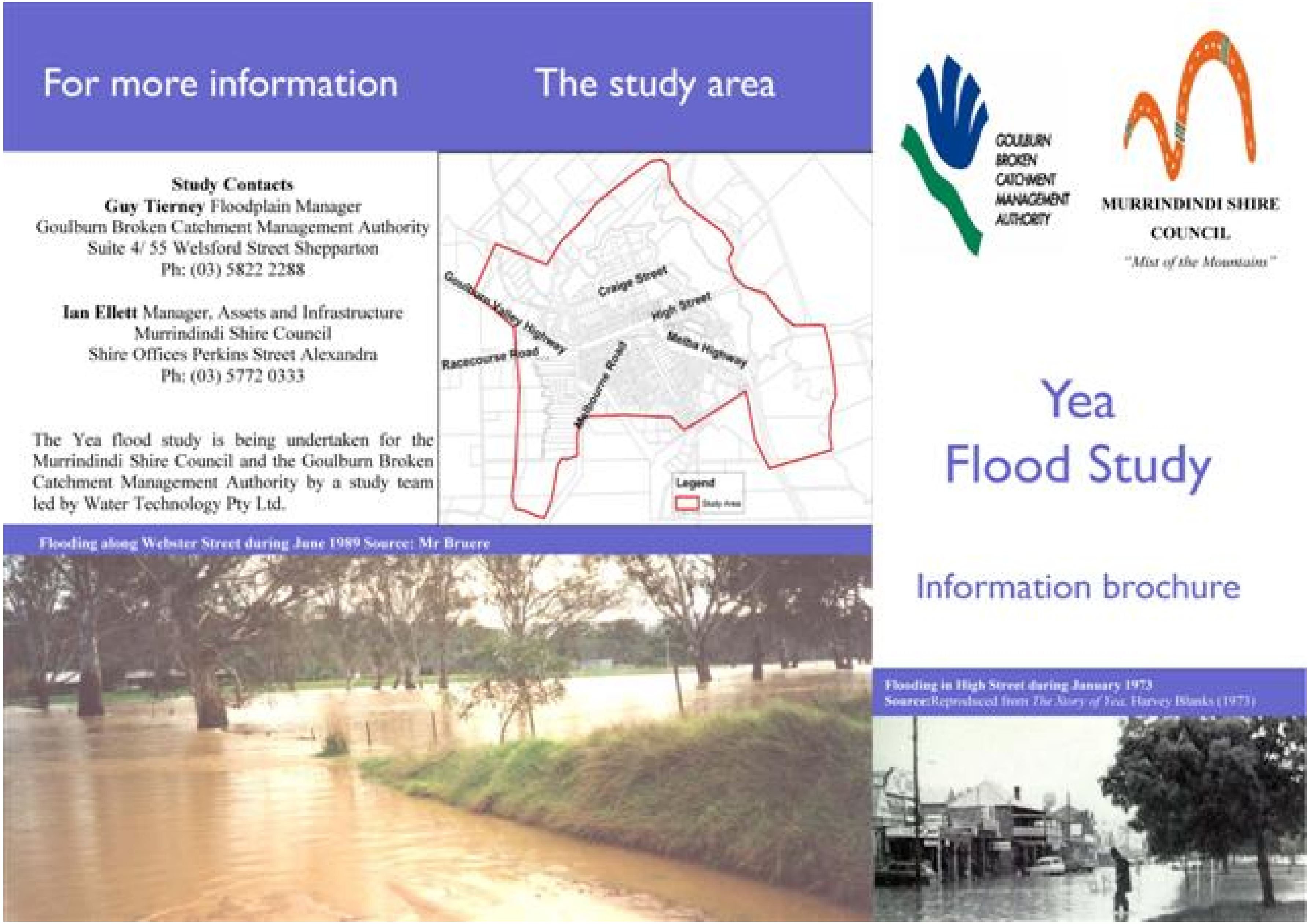
GLOSSARY

Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded; it would occur quite often and would be relatively small. A 1%AEP flood has a low probability of occurrence or being exceeded; it would be fairly rare but it would be relatively large.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. A 10 year ARI flood is expected to be exceeded on average once every 10 years. A 100 year ARI flood is expected to be exceeded on average once every 100 years.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Design flood	A significant event to be considered in the design process; various works within the floodplain may have different design events. e.g. some roads may be designed to be overtopped in the 1 in 1 year or 100%AEP flood event.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Flash flooding	Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall or rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain which causes it.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
Flood frequency analysis	A statistical analysis of observed flood magnitudes to determine the probability of a given flood magnitude.
Flood hazard	Potential risk to life and limb caused by flooding. Flood hazard combines the flood depth and velocity.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Flood storages	Those parts of the floodplain that are important for the temporary storage, of floodwaters during the passage of a flood.
Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.

Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of the principal watercourses in a catchment. Mainstream flooding generally excludes watercourses constructed with pipes or artificial channels considered as stormwater channels.
Management plan	A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. It may also include description and discussion of various issues, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.
Ortho-photography	Aerial photography which has been adjusted to account for topography. Distance measures on the ortho-photography are true distances on the ground.
Peak flow	The maximum discharge occurring during a flood event.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Average Recurrence Interval.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Topography	A surface which defines the ground level of a chosen area.

APPENDIX A COMMUNITY CONSULTATION



For more information

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Ian Ellett Manager, Assets and Infrastructure
Murrindindi Shire Council
Shire Offices Perkins Street Alexandra
Ph: (03) 5772 0333

The Yea flood study is being undertaken for the Murrindindi Shire Council and the Goulburn Broken Catchment Management Authority by a study team led by Water Technology Pty Ltd.

The study area

Flooding along Webster Street during June 1989 Source: Mr Bruere

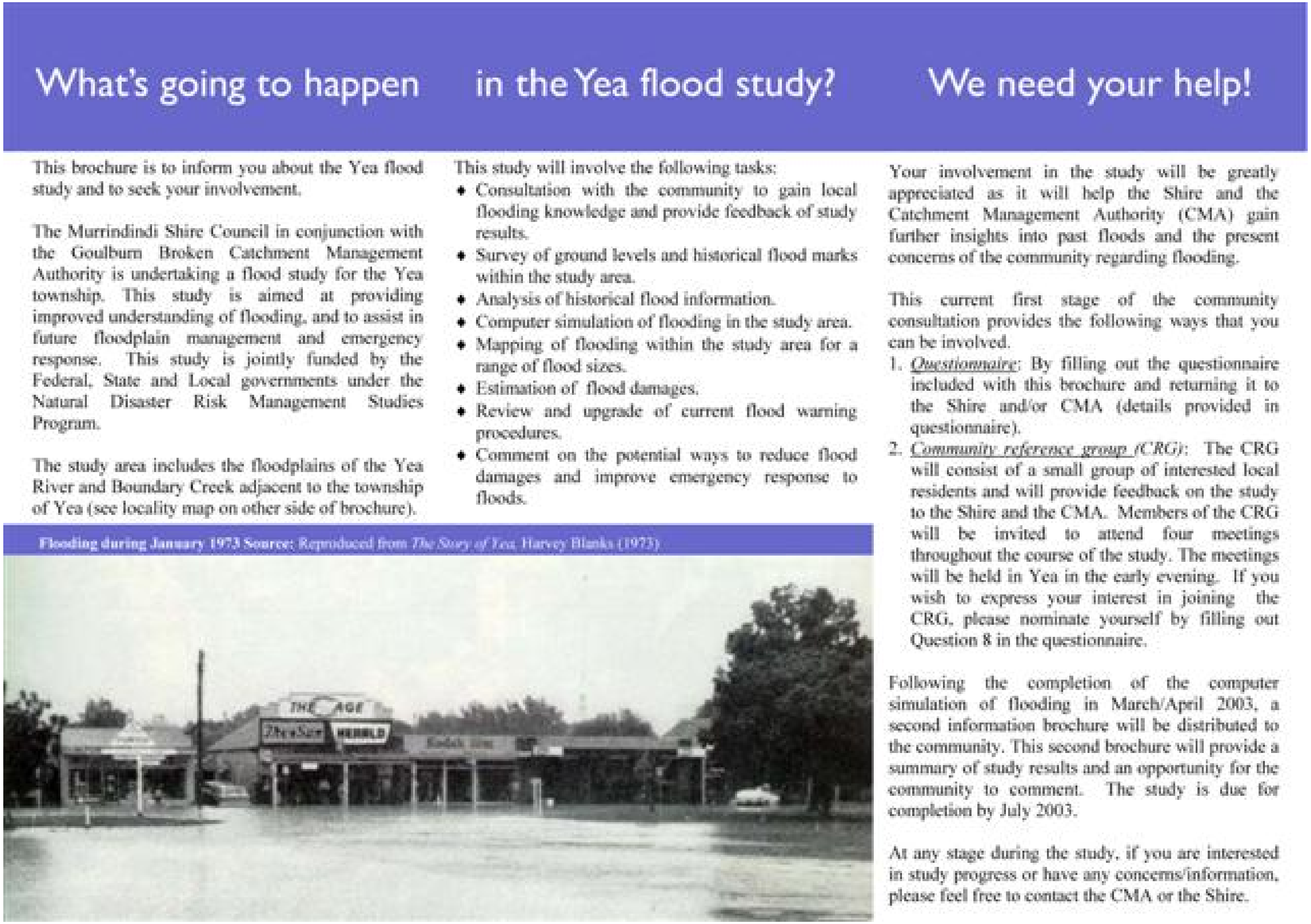
GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

MURRINDINDI SHIRE COUNCIL
"Mist of the Mountains"

Yea Flood Study

Information brochure

Flooding in High Street during January 1973
Source: Reproduced from *The Story of Yea*, Harvey Blanks (1973)



What's going to happen in the Yea flood study? We need your help!

This brochure is to inform you about the Yea flood study and to seek your involvement.

The Murrindindi Shire Council in conjunction with the Goulburn Broken Catchment Management Authority is undertaking a flood study for the Yea township. This study is aimed at providing improved understanding of flooding, and to assist in future floodplain management and emergency response. This study is jointly funded by the Federal, State and Local governments under the Natural Disaster Risk Management Studies Program.

The study area includes the floodplains of the Yea River and Boundary Creek adjacent to the township of Yea (see locality map on other side of brochure).

This study will involve the following tasks:

- Consultation with the community to gain local flooding knowledge and provide feedback of study results.
- Survey of ground levels and historical flood marks within the study area.
- Analysis of historical flood information.
- Computer simulation of flooding in the study area.
- Mapping of flooding within the study area for a range of flood sizes.
- Estimation of flood damages.
- Review and upgrade of current flood warning procedures.
- Comment on the potential ways to reduce flood damages and improve emergency response to floods.

Flooding during January 1973 Source: Reproduced from *The Story of Yea*, Harvey Blanks (1973)

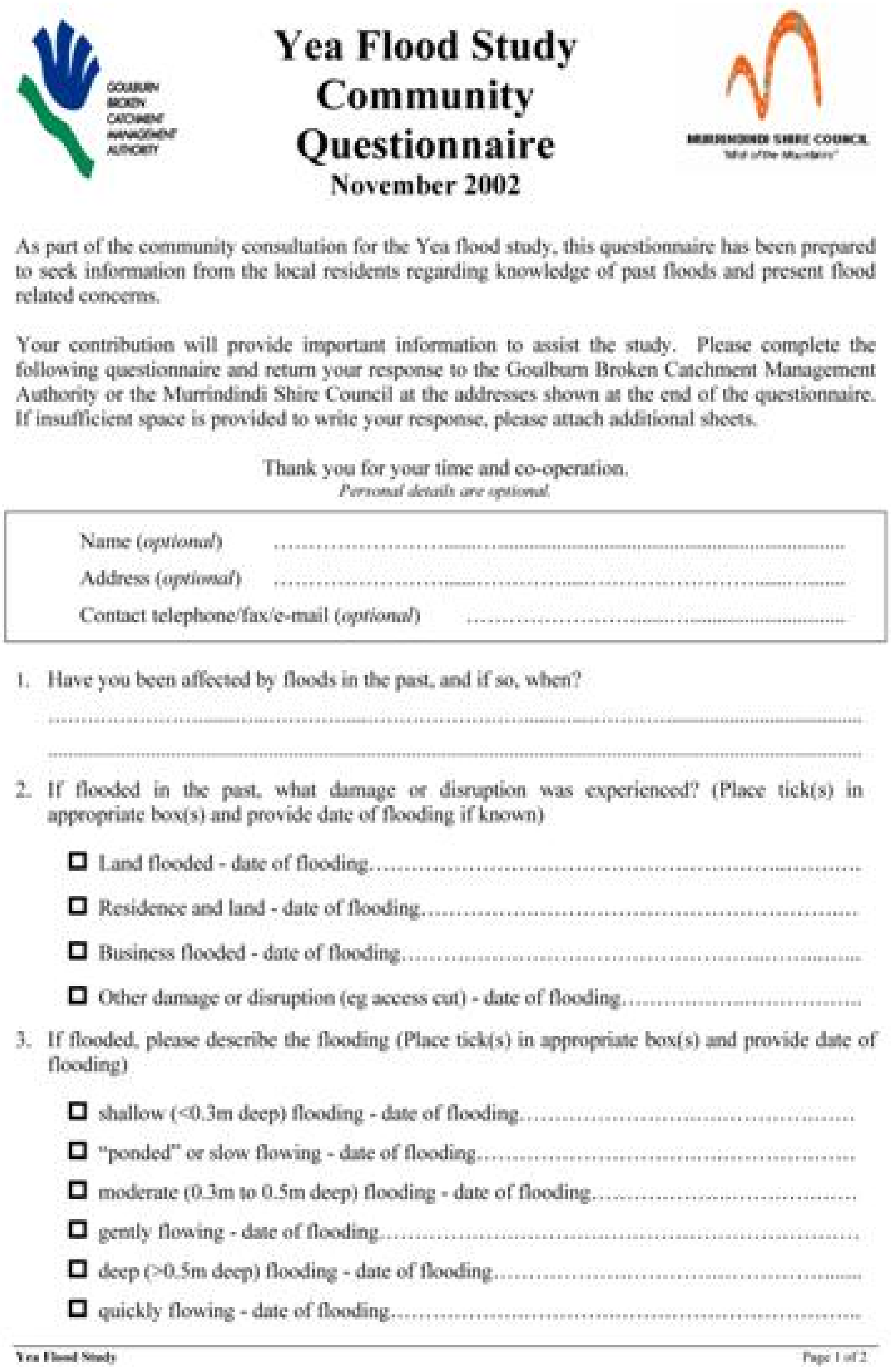
Your involvement in the study will be greatly appreciated as it will help the Shire and the Catchment Management Authority (CMA) gain further insights into past floods and the present concerns of the community regarding flooding.

This current first stage of the community consultation provides the following ways that you can be involved.

1. *Questionnaire*: By filling out the questionnaire included with this brochure and returning it to the Shire and/or CMA (details provided in questionnaire).
2. *Community reference group (CRG)*: The CRG will consist of a small group of interested local residents and will provide feedback on the study to the Shire and the CMA. Members of the CRG will be invited to attend four meetings throughout the course of the study. The meetings will be held in Yea in the early evening. If you wish to express your interest in joining the CRG, please nominate yourself by filling out Question 8 in the questionnaire.

Following the completion of the computer simulation of flooding in March/April 2003, a second information brochure will be distributed to the community. This second brochure will provide a summary of study results and an opportunity for the community to comment. The study is due for completion by July 2003.

At any stage during the study, if you are interested in study progress or have any concerns/information, please feel free to contact the CMA or the Shire.



GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

Yea Flood Study Community Questionnaire

November 2002

MURRINDINDI SHIRE COUNCIL

As part of the community consultation for the Yea flood study, this questionnaire has been prepared to seek information from the local residents regarding knowledge of past floods and present flood related concerns.

Your contribution will provide important information to assist the study. Please complete the following questionnaire and return your response to the Goulburn Broken Catchment Management Authority or the Murrindindi Shire Council at the addresses shown at the end of the questionnaire. If insufficient space is provided to write your response, please attach additional sheets.

Thank you for your time and co-operation.

Personal details are optional.

Name (*optional*) ……………………………………………………………

Address (*optional*) ……………………………………………………………

Contact telephone/fax/e-mail (*optional*) ……………………………………………

1. Have you been affected by floods in the past, and if so, when?

……………………………………………………………………………………

……………………………………………………………………………………

2. If flooded in the past, what damage or disruption was experienced? (Place tick(s) in appropriate box(s) and provide date of flooding if known)

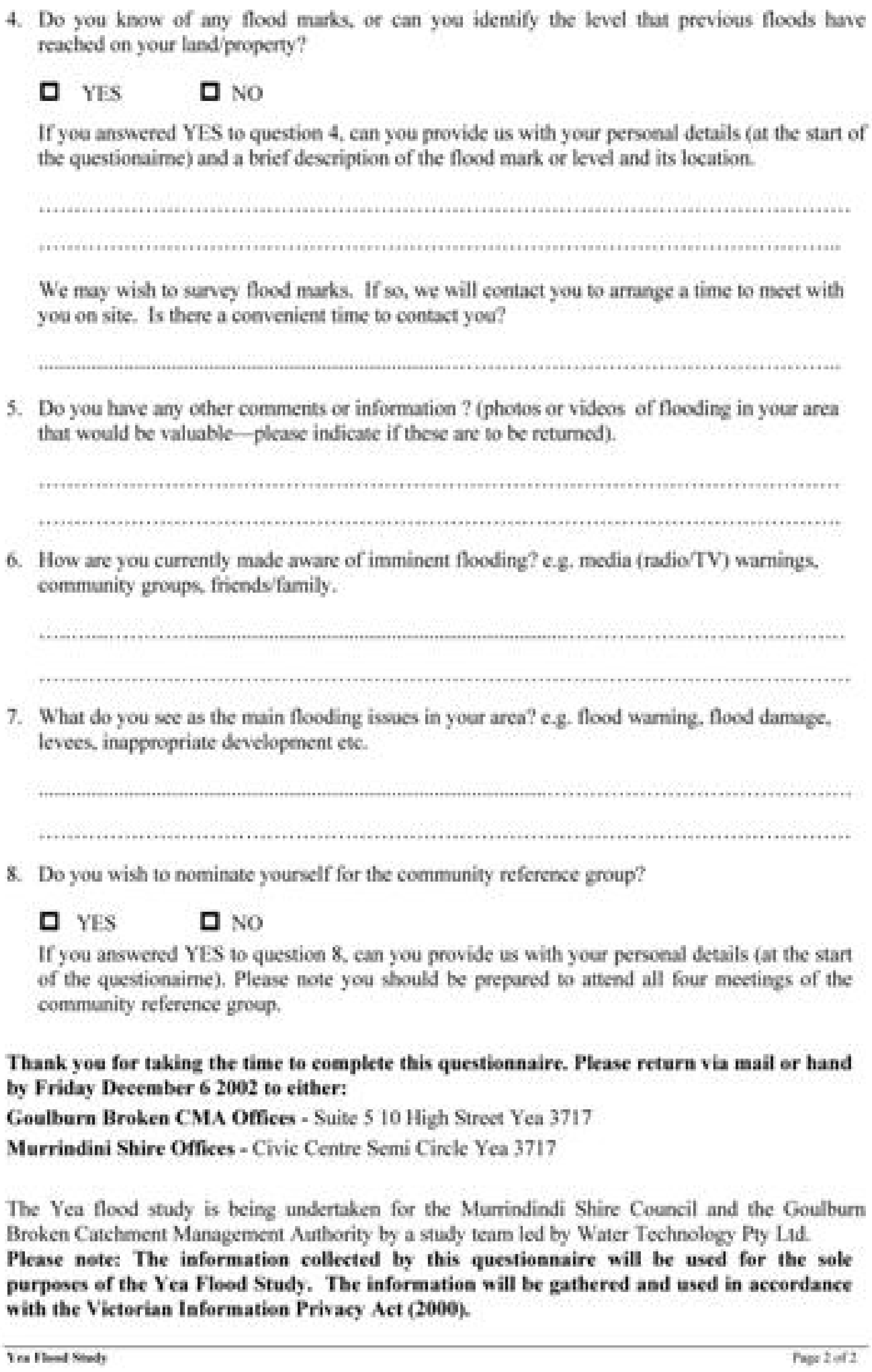
- ☐ Land flooded - date of flooding……………………………………………
- ☐ Residence and land - date of flooding……………………………………
- ☐ Business flooded - date of flooding………………………………………
- ☐ Other damage or disruption (eg access cut) - date of flooding…………………

3. If flooded, please describe the flooding (Place tick(s) in appropriate box(s) and provide date of flooding)

- ☐ shallow (<0.3m deep) flooding - date of flooding………………………………
- ☐ "ponded" or slow flowing - date of flooding……………………………………
- ☐ moderate (0.3m to 0.5m deep) flooding - date of flooding……………………
- ☐ gently flowing - date of flooding……………………………………………
- ☐ deep (>0.5m deep) flooding - date of flooding…………………………………
- ☐ quickly flowing - date of flooding……………………………………………

Yea Flood Study

Page 1 of 2



4. Do you know of any flood marks, or can you identify the level that previous floods have reached on your land/property?

☐ YES ☐ NO

If you answered YES to question 4, can you provide us with your personal details (at the start of the questionairne) and a brief description of the flood mark or level and its location.

....

....

We may wish to survey flood marks. If so, we will contact you to arrange a time to meet with you on site. Is there a convenient time to contact you?

....

5. Do you have any other comments or information ? (photos or videos of flooding in your area that would be valuable—please indicate if these are to be returned).

....

....

6. How are you currently made aware of imminent flooding? e.g. media (radio/TV) warnings, community groups, friends/family.

....

....

7. What do you see as the main flooding issues in your area? e.g. flood warning, flood damage, levees, inappropriate development etc.

....

....

8. Do you wish to nominate yourself for the community reference group?

☐ YES ☐ NO

If you answered YES to question 8, can you provide us with your personal details (at the start of the questionairne). Please note you should be prepared to attend all four meetings of the community reference group.

Thank you for taking the time to complete this questionnaire. Please return via mail or hand by Friday December 6 2002 to either:

Goulburn Broken CMA Offices - Suite 5 10 High Street Yea 3717

Murrindini Shire Offices - Civic Centre Semi Circle Yea 3717

The Yea flood study is being undertaken for the Murrindindi Shire Council and the Goulburn Broken Catchment Management Authority by a study team led by Water Technology Pty Ltd. **Please note: The information collected by this questionnaire will be used for the sole purposes of the Yea Flood Study. The information will be gathered and used in accordance with the Victorian Information Privacy Act (2000).**

Yea Flood Study Page 2 of 2

Australian Government
Department of Transport and Regional Services

GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

MURRINDINDI SHIRE COUNCIL
"Mist of the Mountains"

Yea Flood Study
Community Information Summary

September 2005

Study background

This information sheet summarises the findings of the investigations of the existing flood risk for the township of Yea.

The Goulburn Broken Catchment Management Authority (GBCMA) in association with the Murrindindi Shire Council (MSC) has commissioned the Yea Flood Study. The study area encompasses the floodplains of the Yea River and Boundary Creek adjacent to the township of Yea. This study examined the existing flood risks originating from the Yea River and Boundary Creek. Figure 1 shows the study area.

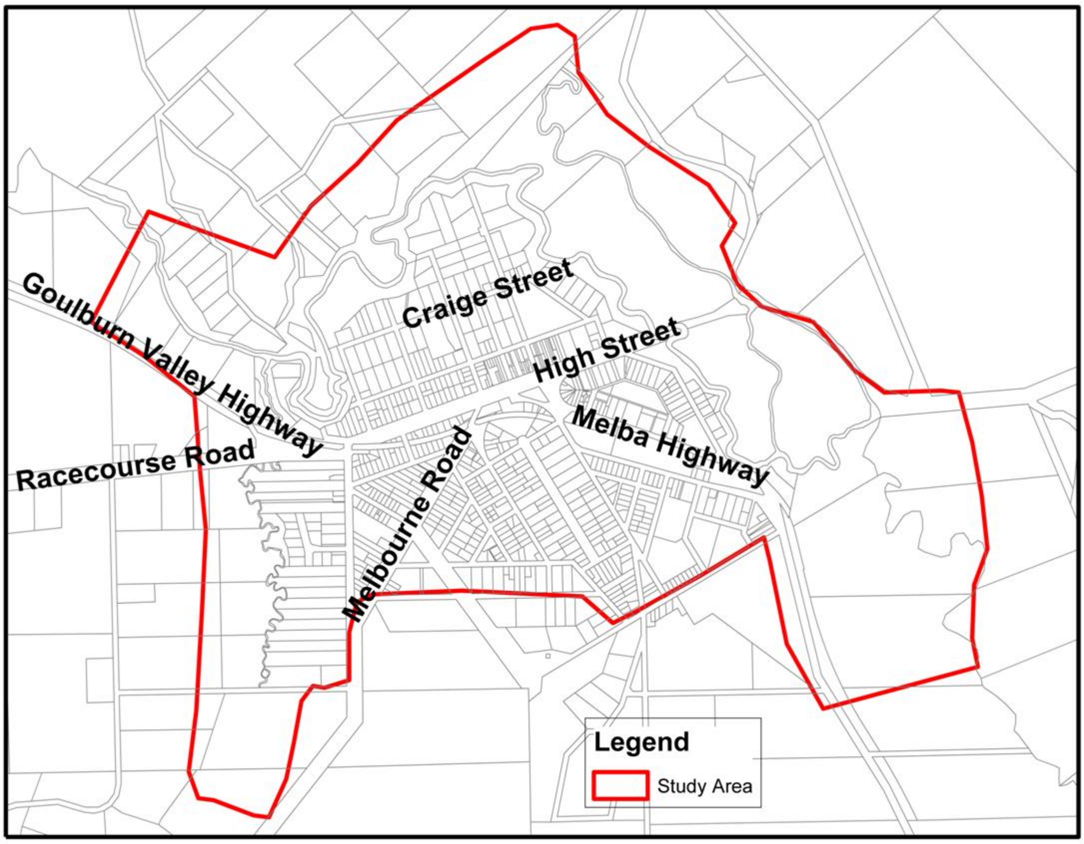


Figure 1 – Study area

A full copy of the Yea Flood Study Report can be view at the Goulburn Broken Catchment Management Authority's Yea office located at 5/10 high Street Yea.

If you wish to further discuss the outcomes of the Yea Flood Study, please contact Guy Tierney, Floodplain Manager, Goulburn Broken Catchment Management Authority (ph. (03) 5822 2288).

Study objectives

The key flood study objective was to:

- To quantify the nature of flooding (frequency, depth, extent) for a range of flood magnitudes in order to assess the existing flood risk to the township of Yea.
- To identify measures to reduce flood damage and raise community awareness regarding floods

Key study outcomes

Flood damage assessment

The flood damage assessment was undertaken for a range of flood magnitude. The 1 in 100 year flood damages was estimated at $616,600 with the average annual flood damages estimated at $60,600.

Identification of potential mitigation measures

The study considered the following mitigation measures to reduce flood damages:

- An **upstream storage**, located on the Yea River, would provide additional attenuation and results in lower flood magnitudes for a given ARI. The construction and operation of an upstream storage requires significant land at a suitable location. It is likely the costs of an upstream storage would be significant. The benefits of an upstream storage would be limited, given the relatively low flood damages. The study team consider the upstream storage is not a feasible mitigation measure.
- **Levees or floodwalls** can restrict the extent of flooding and limit the area subject to flooding up to a given design flood. Due to relatively low flood damages, the benefits of levees/floodwalls are likely to be limited. The cost benefit ratio of the levees/floodwalls in the Yea township is likely to be low (significantly less than 1). The study team considers the construction of levee and/or floodwalls storage is not a feasible mitigation measure.
- **Floodways** provide additional flood flow paths, and reduce flood levels by providing additional flow carrying capacity and by diverting flow away from areas susceptible to flooding and damage. The nature of the floodplain does not lend itself to the siting of floodways. The study team consider the construction of floodways is not a feasible mitigation measure.

Flood warning and response

A flood warning system developed by the Bureau of Meteorology (BoM) provides flood forecasts for the Goulburn River catchment from Eildon to Seymour including Yea. Using outcomes of this study, BoM have provided gauge height forecasts for the Court Street gauge during recent flood events.

Flood inundation maps for a range of flood levels at the Court Street Gauge have been prepared to provide guidance in flood response. These flood inundation maps show property affected both below and above floor levels, flood depths across roads and extent of inundation. Figure 2 shows a flood inundation map produced by the study.

Land use planning

Land use planning aims to reduce the growth in future flood damages by provide appropriate guidelines/controls for land use and development. The Victoria Planning Provisions (VPPs) allow for zoning of land and the application of controls on the type of land use and permitted activities in areas prone to flooding. The VPPs provide for the following zone and two overlays:

- Land subject to inundation overlay (LSIO)
- Floodway (FO)
- Urban floodway zones (UFZ)

Using the output from this study, GBCMA has prepared draft flood related zone and overlays for use in the planning scheme. A planning scheme amendment will be undertaken to implement these draft zone and overlays. Comment from the community will be sought as part of the amendment process. Figure 3 shows the draft flood planning map produced by the study.

Acknowledgements

The study's technical steering committee consisting of members from the Goulburn Broken Catchment Management Authority, Murrindindi Shire, Department of Sustainability and Environment, Bureau of Meteorology and VicSES. The committee was chaired by Lyn Gunter, Mayor Murrindindi Shire.

The study team also wishes to thank the staff of the GBCMA Yea office, and all members of the community that contributed flooding information, returned questionnaires and discussed their experiences with the study team.

Further study team appreciated the efforts of the Bureau of Meteorology Victorian Regional Office Hydrology and Flood Warning Services Section.

This study was funded the Natural Disaster Risk Management Studies Program with contributions from Murrindindi Shire, Victorian State Government and Federal Government.

Front cover photo: June 1989 flood event at Webster Street looking north (Source Mr. Bruere).

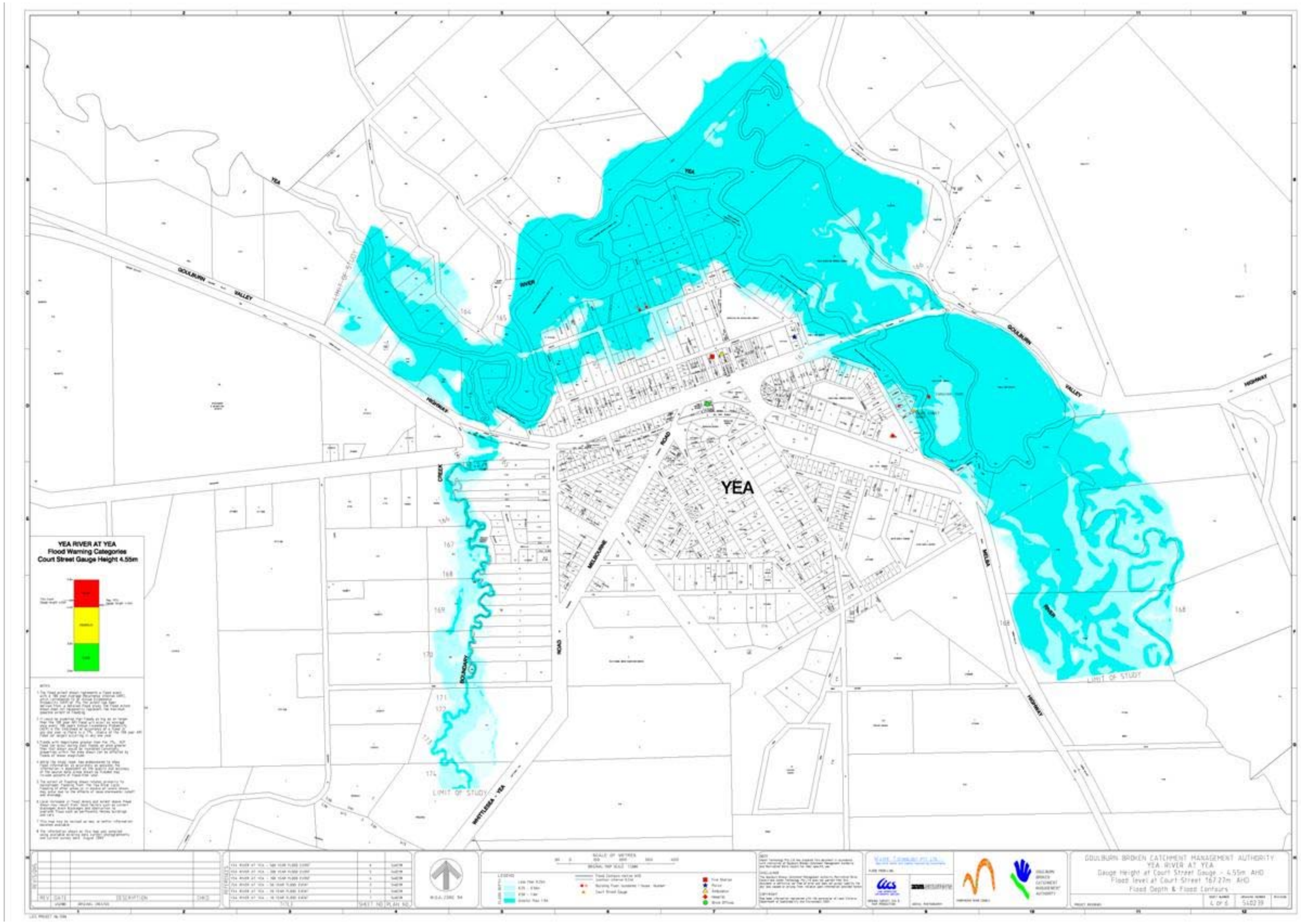


Figure 2 – Flood inundation map

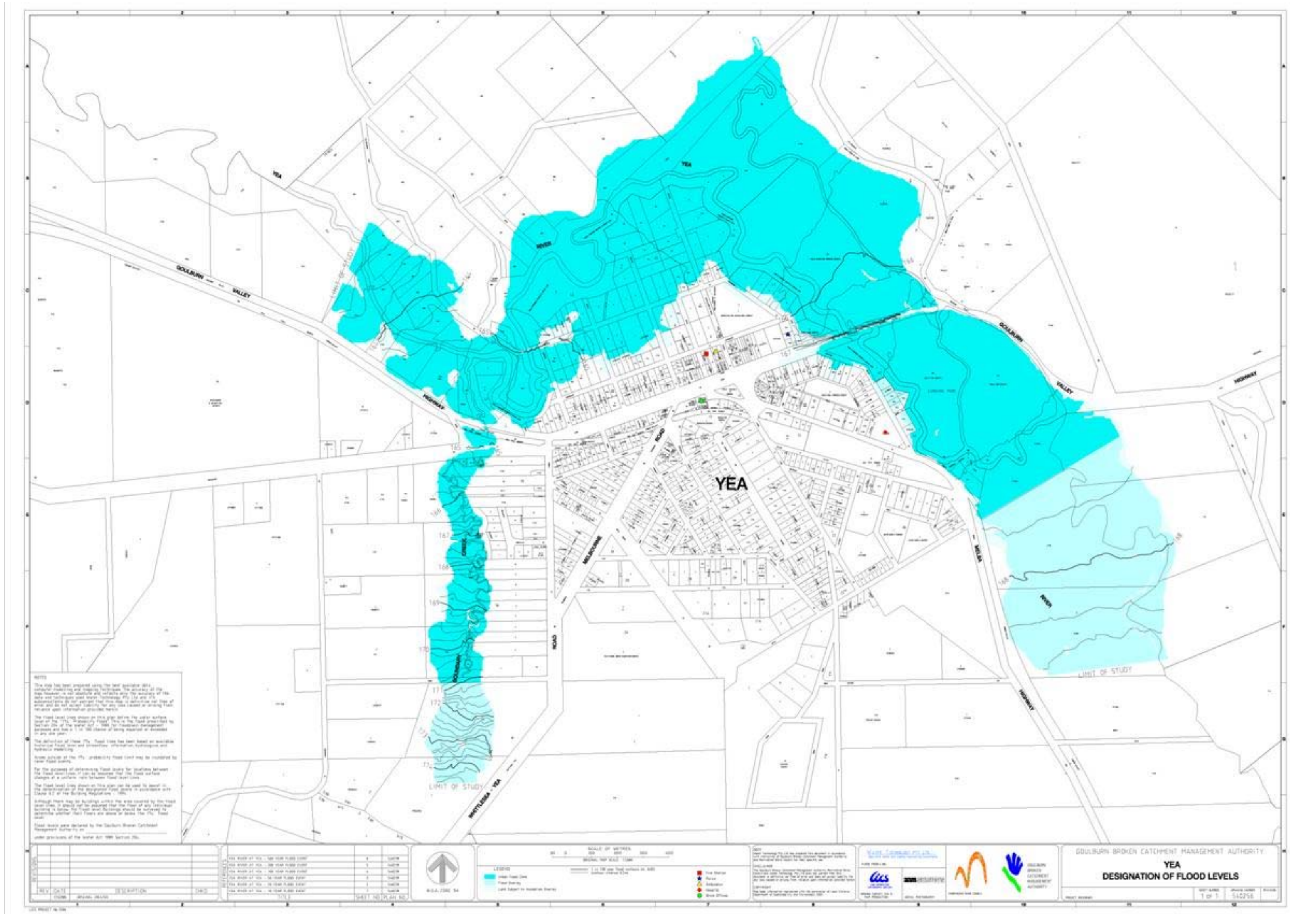


Figure 3 – Draft flood planning map

APPENDIX B HYDROLOGIC ANALYSIS

URBS MODEL STRUCUTURE

URBS catchment file

```
Yea River to Goulburn confluence
{developed by Water Technology 21/11/2002}
{Based on the Bureau of Meteorology Melbourne model 2002}
{Design}
MODEL: SPLIT
USES: L F Sc
DEFAULT PARAMETERS: alpha=1.2 m=0.8 beta = 1.2
19 SUBCATCHMENTS OF AREA:
29.3  31.5   11.3  14.9  21.8  45.0  99.9  35.4  39.0  74.9
79.3  24.1  105.5  41.6  62.7  56.3  59.1   8.7  44.5
RAIN #1         L=3.9  F=0.9    Sc=0.010
ROUTE           L=3.9           Sc=0.021
ADD RAIN#2      L=5.0  F=0.9    Sc=0.018
ROUTE           L =1.2          Sc=0.008
ADD RAIN #3     L =1.2 F=0.9    Sc=0.158
STORE.
RAIN #4         L=4.2  F=0.9    Sc=0.088
GET.
ROUTE           L=2.6           Sc=0.004
ADD RAIN #5     L=2.4  F=0.7    Sc=0.010
PRINT.  405205
ROUTE           L=2.3           Sc=0.007
ADD RAIN #6     L=2.5  F=0.3    Sc=0.012
ROUTE           L=6.0           Sc=0.007
ADD RAIN #7     L=7.0  F=0.3    Sc=0.007
STORE.
RAIN #8         L=5.5  F=0.9    Sc=0.002
ROUTE           L=1.6           Sc=0.025
ADD RAIN #9     L=1.8  F=0.9    Sc=0.006
ROUTE           L=4.3           Sc=0.002
ADD RAIN #10    L=5.4  F=0.8    Sc=0.002
STORE.
RAIN #11        L=4.2  F=0.5    Sc=0.002
STORE.
RAIN #12        L=3.9  F=0.2    Sc=0.003
GET.
ROUTE           L=1.8           Sc=0.006
GET.
ROUTE           L=3.2           Sc=0.006
ADD RAIN #13    L=4.6  F=0.2    Sc=0.002
PRINT. 405217
ROUTE           L=4.2           Sc=0.002
ADD RAIN #14    L=4.1  F=0.2    Sc=0.002
ROUTE           L=2.4           Sc=0.002
ADD RAIN #15    L=3.4  F=0.2    Sc=0.001
GET.
ROUTE           L=1.3           Sc=0.008
STORE.
RAIN #16        L=7.5  F=0.2    Sc=0.017
GET.
ROUTE           L=4.1           Sc=0.005
ADD RAIN #17    L=4.2  F=0.2    Sc=0.002
PRINT. Yea River at upstream study limit
ROUTE           L=1.5           Sc=0.007
ADD RAIN #18    L=1.5  F=0.2    Sc=0.007
STORE.
RAIN # 19       L=4.5  F=0.2    Sc=0.018
```

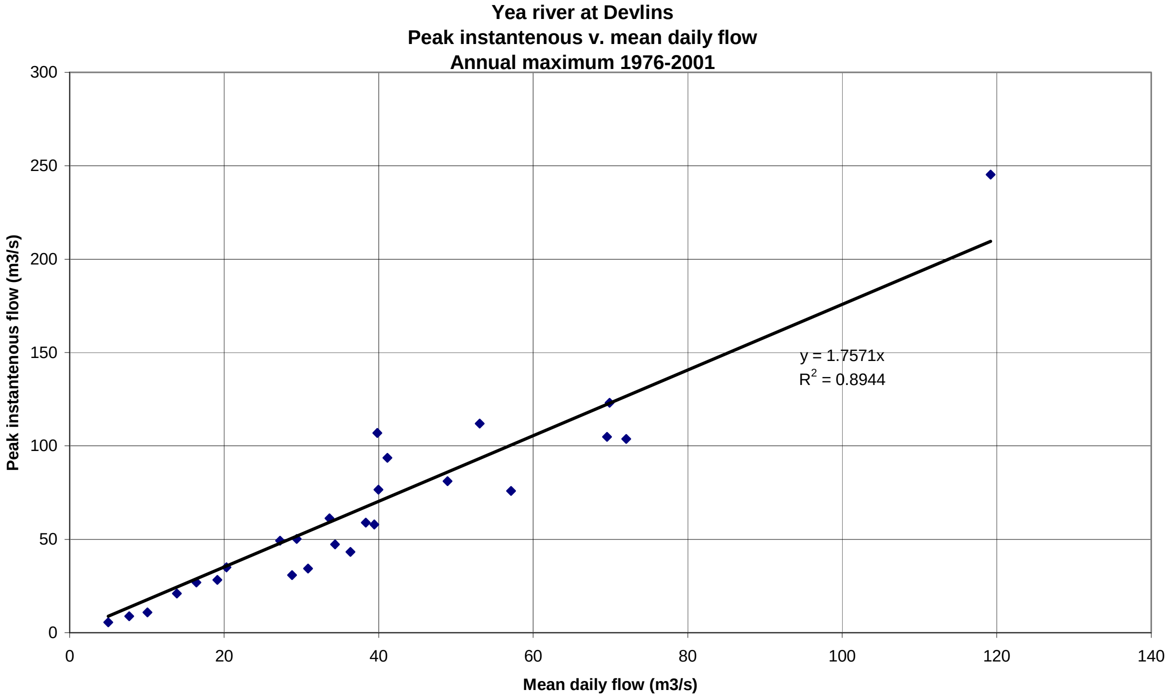
```
PRINT. Boundary creek at Yea confluence
GET.
PRINT.  Yea River at downstream Boundary Creek confluence
END OF CATCHMENT DATA.
```

URBS MODEL VERICATION

Frequency analysis

Yea River at Devlins Bridge

Instantaneous peak flow to mean daily flow



At site flood frequency analysis Yea river at Devlins Bridge

Yea River at Devlins Bridge (405217) Composite instantaneous peak series

Peak Flow **m3/s**

Historical Data n/a

Data	**Year**	**Rank**	**a.Rank**	**Prob**	**Nstdev**

n_rec.	48	**n_hist.**	0	**Sum1**	0.000
L	2	**Z**	0	**Sum2**	0.000
N	46	**H**	48	**Sum3**	0.000
Mean	1.818	**W**	1.000	**a.Mean**	1.818
StDev	0.305	**H-WL**	46.000	**a.StDev**	0.305
Skew	-0.273	**p***	0.958	**a.Skew**	-0.273
				s.StDev	0.311

WARNING - negative skew (between -1 and 0)

2 low flows omitted

5% Confidence limits

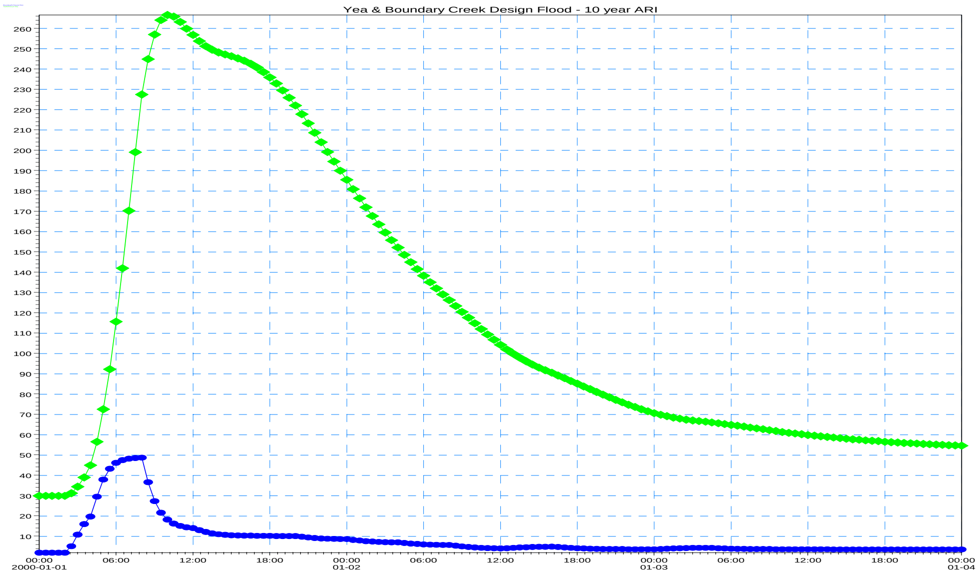
LP3 Distribution

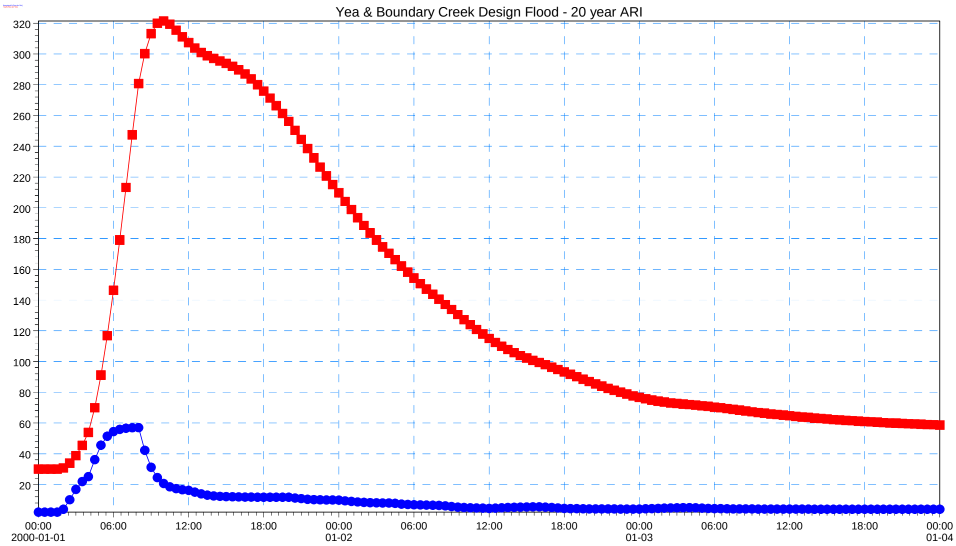
AEP'(%)	**adjAEP**	**Nstdev**	**Ky'**	**delta**	**95.0%**	**Q(y')**	**5.0%**
93.9	90.0	-1.282	-1.60729	1.544	16	**21**	28
83.5	80.0	-0.842	-0.967799	1.253	27	**33**	41
52.2	50.0	0.000	-0.008964	1.086	54	**65**	79
20.9	20.0	0.842	0.823847	1.083	97	**117**	141
10.4	10.0	1.282	1.227201	1.210	126	**156**	192
5.2	5.0	1.645	1.545947	1.450	151	**194**	250
2.1	2.0	2.054	1.890054	1.886	178	**248**	343
1.0	1.0	2.326	2.111161	2.268	195	**289**	428
0.5	0.5	2.576	2.307858	2.675	209	**332**	528

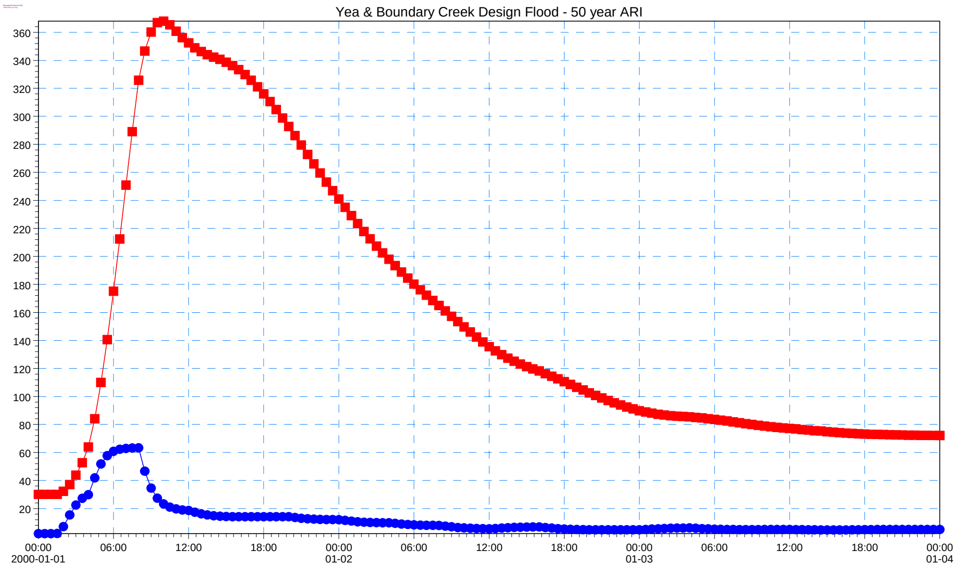
Data	**Year**	**Rank**	**a.Rank**	**Prob**	**NstDev**
255	1974	1	1.00	0.012	2.24
245	1989	2	2.00	0.033	1.84
235	1959	3	3.00	0.054	1.61
197	1956	4	4.00	0.075	1.44
189	1971	5	5.00	0.095	1.31
134	1954	6	6.00	0.116	1.19
123	1996	7	7.00	0.137	1.09
112	1955	8	8.00	0.158	1.00
112	1978	9	9.00	0.178	0.92
107	1986	10	10.00	0.199	0.84
105	1984	11	11.00	0.220	0.77
104	1993	12	12.00	0.241	0.70
102	1958	13	13.00	0.261	0.64
93.7	1987	14	14.00	0.282	0.58
90.0	1973	15	15.00	0.303	0.52
88.1	1960	16	16.00	0.324	0.46
86.1	1963	17	17.00	0.344	0.40
81.1	1988	18	18.00	0.365	0.34
78.7	1970	19	19.00	0.386	0.29
76.5	1981	20	20.00	0.407	0.24
75.9	1977	21	21.00	0.427	0.18
73.9	1975	22	22.00	0.448	0.13
67.7	1968	23	23.00	0.469	0.08
65.2	1966	24	24.00	0.490	0.03
63.4	1969	25	25.00	0.510	-0.03
61.2	2000	26	26.00	0.531	-0.08
58.9	1979	27	27.00	0.552	-0.13
58.0	1992	28	28.00	0.573	-0.18
54.6	1964	29	29.00	0.593	-0.24
54.1	1965	30	30.00	0.614	-0.29
50.4	1961	31	31.00	0.635	-0.34
50.2	1990	32	32.00	0.655	-0.40
49.2	1980	33	33.00	0.676	-0.46
47.3	1983	34	34.00	0.697	-0.52
43.3	1985	35	35.00	0.718	-0.58
41.2	1957	36	36.00	0.738	-0.64
35.8	1962	37	37.00	0.759	-0.70
35.0	1998	38	38.00	0.780	-0.77
34.3	1967	39	39.00	0.801	-0.84
34.3	1995	40	40.00	0.821	-0.92
30.8	1991	41	41.00	0.842	-1.00
28.3	1976	42	42.00	0.863	-1.09
26.8	1999	43	43.00	0.884	-1.19
20.9	2001	44	44.00	0.904	-1.31
12.8	1972	45	45.00	0.925	-1.44
10.9	1994	46	46.00	0.946	-1.61
8.9	1997	47	47.00	1.000	
5.5	1982	48	48.00	1.000	

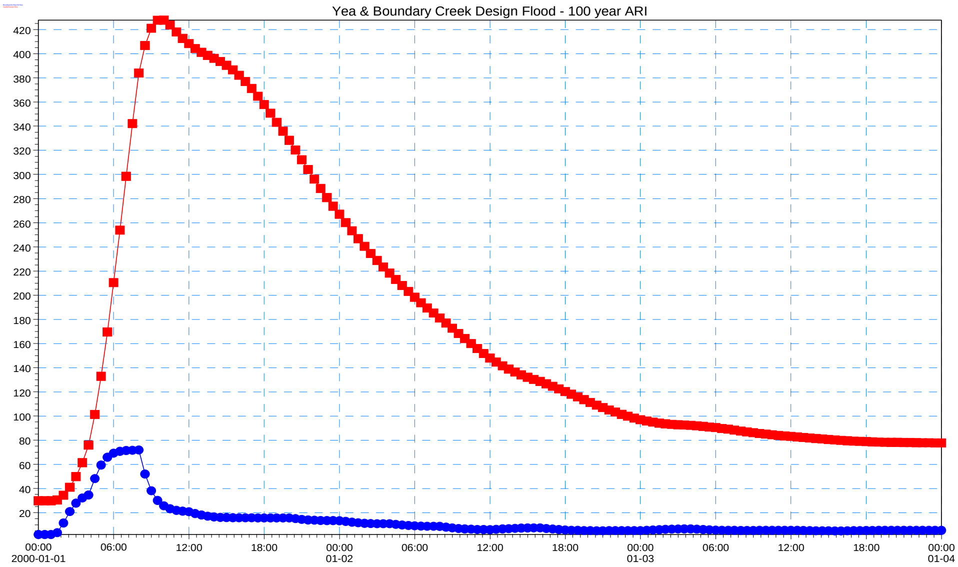
DESIGN FLOOD ESTIMATION

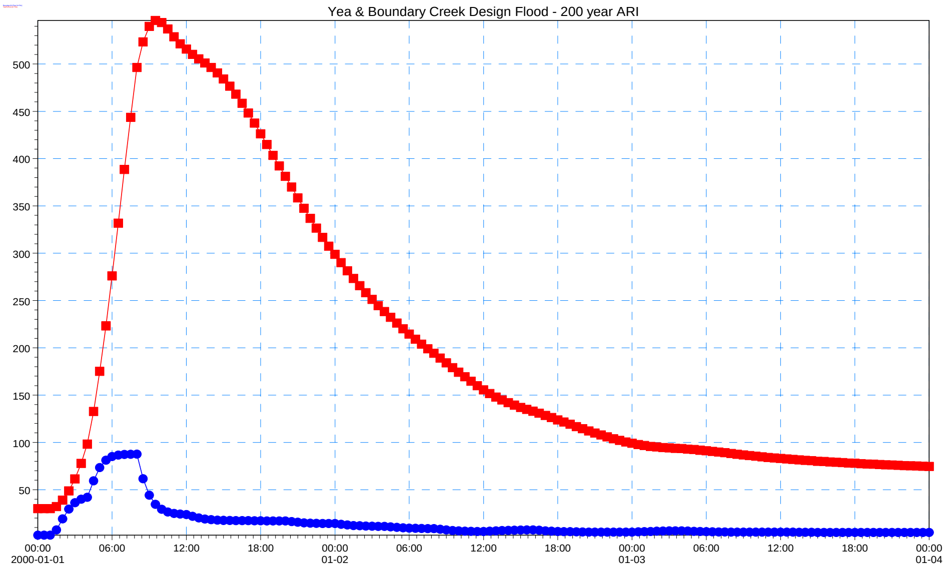
Design flood hydrographs








Yea & Boundary Creek Design Flood - 100 year ARI
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
00:00
2000-01-01
06:00
12:00
18:00
00:00
01-02
06:00
12:00
18:00
00:00
01-03
06:00
12:00
18:00
00:00
01-04


Yea & Boundary Creek Design Flood - 200 year ARI
500
450
400
350
300
250
200
150
100
50
00:00
2000-01-01
06:00
12:00
18:00
00:00
01-02
06:00
12:00
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06:00
12:00
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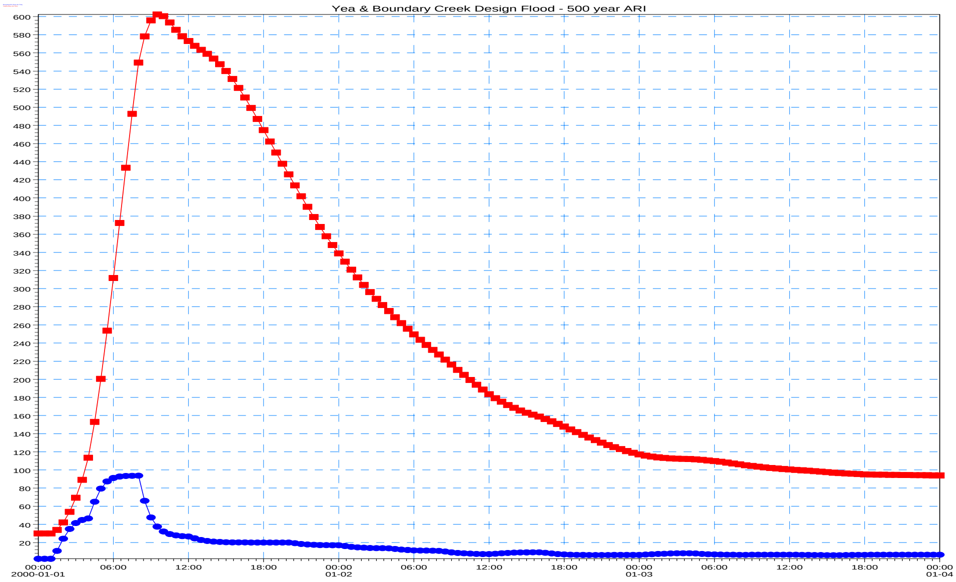
00:00
01-04


Yea & Boundary Creek Design Flood - 500 year ARI
600
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
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40
20
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06:00
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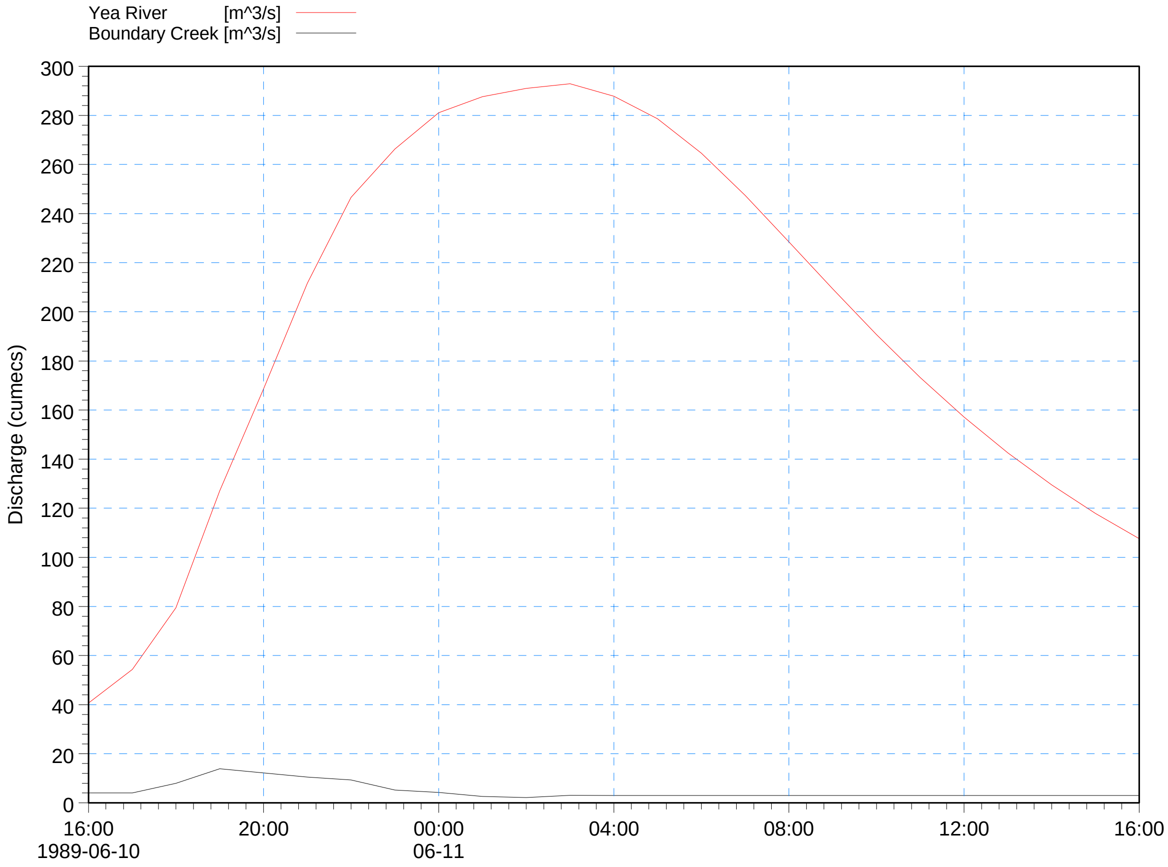
01-04

HISTORICAL FLOOD HYDROGRAPHS

Historical flood hydrograph for June 1989 event at the upstream study area limit



APPENDIX C PHOTOGRAMMETRIC SURVEY

DIGITAL DATA: DOCUMENTATION

WATER TECHNOLOGY

YEA FLOOD STUDY - DATA RESUPPLY

VOLUME 23337504NOM

Summary Data Description

Resupply of DTM and detail data of Yea in DXF format.
Data in this despatch replaces data supplied in despatches 23337501 & 23337503, this data has had 52.26M added to Eastings and 24.93m subtracted from Northings to bring the data onto true GDA values.

GDA *This data is GDA-compliant*

CONTENTS **Page Nos.**

1. DATA INSTALLATION

Data format	:	DXF
Number & type of media	:	One 700MB CD-Rom
Media format	:	CD-Rom
Number of files on media	:	2, viz. 1 data file and README.DOC
Number of files in dataset	:	1
Data formatted on	:	04.03.2003
Disk volume	:	23337504NOM
AAM Surveys Job Manager	:	Mr. B. Francome 03 9572 1033

README FILE

This document (README.DOC) is provided as a MSWord7 file in this volume.

A Microsoft Word Viewer can be supplied upon request.

LOADING NOTES

After downloading data check file sizes.

FILE SIZES AND NAMES

Filename	Contents
`03/04/03  12:58p 8,111,400 Yea_corrected.dxf`	Detail and DTM data
Readme.doc	This file

LEGEND

Layer	Feature	Contourable
BRIDGE	Bridge	No
BUILDING	Building	No
LONGGRASS	Long Grass	No
TANKSTO	Storage tank	No
SWIMPOOL	Swimming pool	No
VEGE	Vegetation	No
ROADEB	EdgeOfBitumen	Yes
ROADUNS	Unsealed road	Yes
KERB	Kerb	Yes
CULVERT	Culvert	Yes
RDLINE	Road CLine	Yes
VTRACK	Vehicle track	Yes
DRAINAPP	Drain approx	Yes
CREEK	Creek	Yes
KERBPARLL	Kerb Parallel	Yes
CREEKAPP	Creek: approx	Yes
STI	S.T.I.	Yes
DRAIN	Drain	Yes
WATERHOLE	Waterhole	Yes
BREAKLAP	Bkline: apprx	Yes

BREAKL SPOTDTM	Breakline Spot Ht: DTM	Yes Yes

SAMPLE LISTING

```
VERTEX
8
VEGE
10
359184.53
20
5878955.09
30
0.00
0
VERTEX
8
VEGE
10
359187.72
20
```

2. METADATA

DATA CHARACTERISTICS

Characteristic	Description
Format	DXF
Size	105,950 data points (approximate)
Contours	None
Terrain model	Breaklines and spot heights

REFERENCE SYSTEMS

	Horizontal	Vertical
Datum	GDA94	AHD
Projection	MGA Zone 55	N/A
Geoid Model	N/A	unknown
Reference Point	7009 359506.485E 5880636.736N	7009 165.638 RL

GDA

This data is GDA-compliant

SOURCE DATA

	Source	Description	Ref No	Date
Photography	Skyview Aviation	1:5000 diapositives	AAM2308-3c	27.09.02
Control	LICS	GPS	Yea-250902	25.09.02
Test points	LICS	GPS	Yea-250902	25.09.02

ACCURACY

	Measured Point	Derived Point	Basis of Estimation
Ground control	0.05		Survey methodology used
Horizontal data	0.10		Deductive estimate
Vertical data	0.10		Deductive estimate
Test Points	0.078		Comparison with 17 test pts

ACCURACY NOTES:

- Values shown represent standard error (68% confidence level or 1 sigma), in metres
- “Derived points” are those interpolated from a terrain model.
- “Measured points” are those observed directly.
- Accuracy estimates of Measured points refer to discrete point-mode observations. Observations taken in string-mode can be two to three times less accurate.
- Standard errors shown above are derived from the differences between data supplied in this volume and test points. No allowance has been made for errors in the test points.
- Comparison with 17 test points revealed a mean elevation difference of 0.037m. This difference has not been removed from the data supplied in this volume.
- Differences between measured data and test points revealed a mean elevation difference of 0.037m and a standard deviation of 0.076m. This elevation difference has not been removed from the data supplied in this volume.

USE OF DATA

- Intended use : Flood water studies
- Intended scale of use : 1:1000

LIMITATIONS OF DATA

- Data was compiled in a process that regularly yields the accuracy estimates reported above; however only field testing can prove the accuracy achieved.
- Features depicted are as shown on the legend.
- Features obscured by foliage or shadow may not appear.
- The definition of the ground under trees or shadow may be less accurate.
- Underground services have not been mapped.
- This data has not been field tested for completeness or accuracy.

3. CONDITIONS OF SUPPLY

The data in this volume has been commissioned by **WATER TECHNOLOGY**.

AAM Surveys Pty Limited holds intellectual property rights to the data and assigns beneficial ownership to **WATER TECHNOLOGY**, subject to the following conditions:

1. This file (README.DOC) is always stored with the unaltered data contained in this volume.

2. The data is not altered in any way without the approval of AAM SURVEYS. The data may be copied from this file to another.

3. The data is not used for purposes beyond that intended.

Any responsibility of AAM SURVEYS is removed if any of these conditions is not observed.

4. AAM SURVEYS maintains an archive copy of the data in this volume together with this README file for at least 7 years after delivery.

Any problems associated with the information in the data files contained in this volume should be reported to:

AAM Surveys Pty Limited

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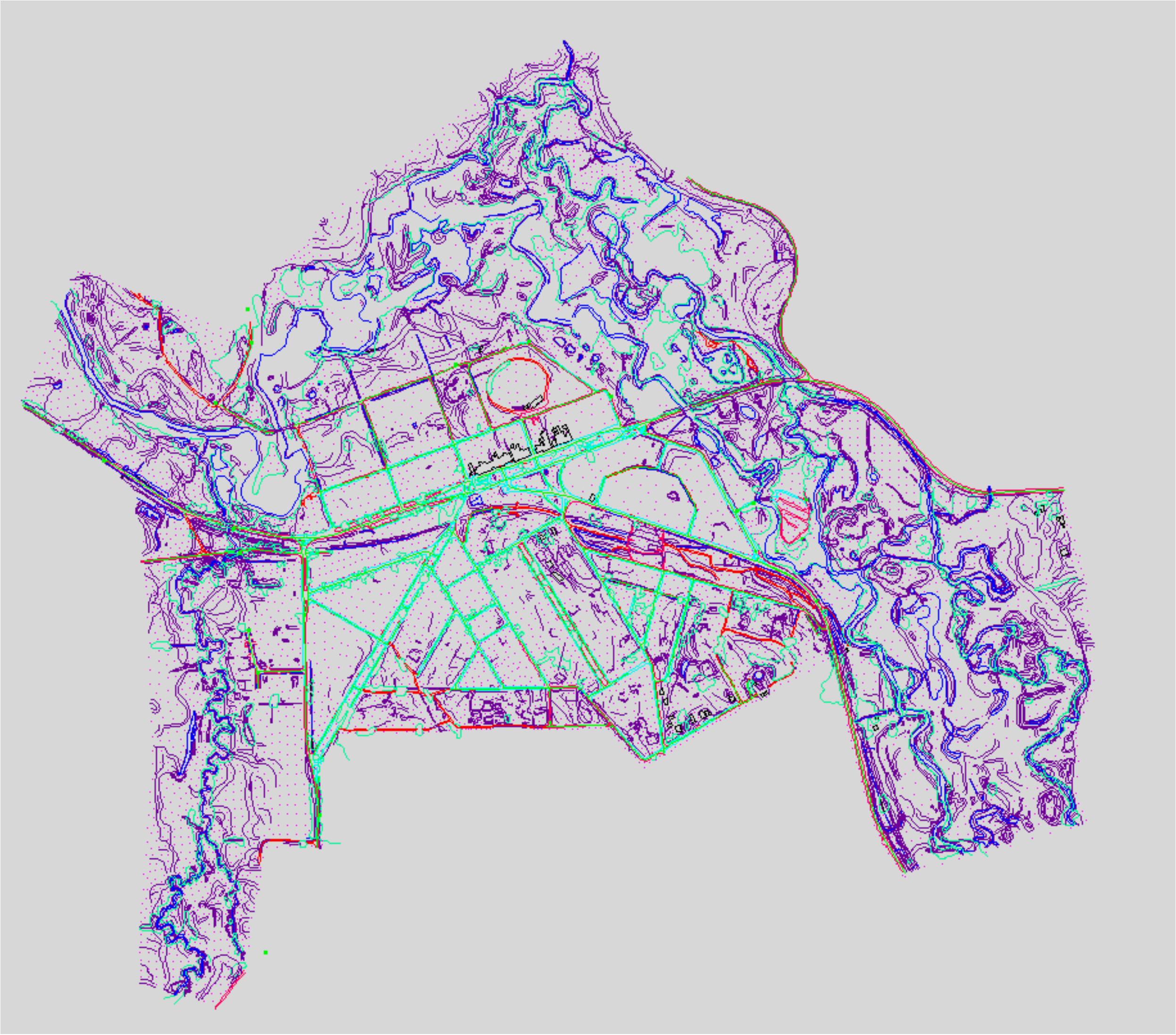
Web www.aamsurveys.com.au

4. VALIDATION PLOT



APPENDIX D PROPERTY INUNDATION LISTS

Yea flood study
GBCMA&MSC September 2004

Listing complied by Water Technology

Last update 28/2/05

Court Street Gauge Height **3.99 m gauge height** **166.71 m AHD**

BOM catergory **Minor**

Property details			Flood level	Status	Flood depth above ground	Flood depth above floor level
Address	Ground level (m AHD)	Floor level (m AHD)	(m AHD)		m	m
5 MILLER STREET	166.45	167.98	166.647	Property flooded below floor level	0.20	-
3 MILLER STREET	166.31	167.65	166.644	Property flooded below floor level	0.33	-
CARAVAN PARK	165.71	167.03	166.677	Property flooded below floor level	0.97	-
CARAVAN PARK	165.88	166.71	166.677	Property flooded below floor level	0.80	-
18 CRAIGIE STREET	164.09	164.27	164.798	Property flooded above floor level	0.70	0.53
20 CRAIGIE STREET	164.02	164.22	164.795	Property flooded above floor level	0.77	0.58
						-

Note: Does not include permeant or casual cabins/caravans. Indicative flood depth within caravan park up to 0.4 m.

Yea flood study
GBCMA&MSC September 2004

Listing complied by Water Technology

Last update 28/2/04

Court Street Gauge Height

3.99 m gauge height **166.71 m AHD**

BOM catergory **Minor**

Caravan Park	Craigie Street west of Provenance Bridge	Craigie Street east of Provenance Bridge	Webster Street	Marshbank Street	Miller Street	Goulburn Valley Hwy west of Boundary Ck confluence (to Seymour)	Goulburn Valley Hwy at eastern end of township (to Yarack)
Flooding in the Caravan Park with flood depths up to 0.4 m	Inundated with flood depth up to 0.4 m	Flooding commences across Craigie Street adjacent to the corner with Nolan Street with flood depth up to 0.6m	Flooding commences across Webster Street with a flood depth up to 0.6m.	Flooding to private properties (allotments not dwellings) along Marshbank Street with flood depths to 0.9 m	Flooding to private properties (allotments not dwellings) along Miller Street with flood depths to 0.9 m	Flooding to private allotments (not to dwellings)	No flooding
Up to 25 caravans inundated above floor level	Properties located adjacent to the corner of Craigie and Webster Street isolated.	Flooding to private properties (allotments and two dwellings above floor) along Craigie Street, with flood depths up to 0.9 m	Flooding to private properties (allotments not dwellings) along Webster Street with flood depths to 0.9m			Vehicular access to these dwellings flooded to a depth of 0.9 m	
Approaches to the Court Street Bridge not inundated							
Court Street Bridge deck not inundated.							

Yea flood study
GBCMA&MSC September 2004
Listing complied by Water Technology
Last update 28/2/05

Court Street Gauge Height **4.22 m gauge height** **166.94 m AHD**

BOM catergory **Minor**

Property details			Flood level	Status	Flood depth above ground	Flood depth above floor level
Address	**Ground level (m AHD)**	**Floor level (m AHD)**	**(m AHD)**		**m**	**m**
9 MILLER STREET	166.54	167.18	166.908	Property flooded below floor level	0.37	-
7 MILLER STREET	166.64	168.12	166.905	Property flooded below floor level	0.27	-
5 MILLER STREET	166.45	167.98	166.9	Property flooded below floor level	0.45	-
3 MILLER STREET	166.31	167.65	166.895	Property flooded below floor level	0.59	-
CARAVAN PARK	165.71	167.03	166.923	Property flooded below floor level	1.21	-
CARAVAN PARK	165.88	166.71	166.923	Property flooded above floor level	1.05	0.22
18 CRAIGIE STREET	164.09	164.27	164.945	Property flooded above floor level	0.85	0.67
20 CRAIGIE STREET	164.02	164.22	164.942	Property flooded above floor level	0.92	0.73
						-

Note: Does not include permeant or casual cabins/caravans. Indicative flood depth within caravan park up to 0.6 m.

Yea flood study
GBCMA&MSC September 2004

Listing complied by Water Technology
Last update 28/2/05

Court Street Gauge Height **4.22 m gauge height** **166.94 m AHD**

BOM catergory **Minor**

Caravan Park	Craigie Street west of Provenance Bridge	Craigie Street east of Provenance Bridge	Webster Street	Marshbank Street	Miller Street	Goulburn Valley Hwy west of Boundary Ck confluence (to Seymour)	Goulburn Valley Hwy at eastern end of township (to Yarack)
Flooding in the Caravan Park with flood depth up to 0.6 m	Inundated with flood depth up to 0.6 m	Flooding commences across Craigie Street adjacent to the corner with Nolan Street with flood depth up to 0.8m	Flooding commences across Webster Street with a flood depth up to 0.8 m	Flooding to private properties (allotments not dwellings) along Marshbank Street with flood depths to 1.1 m	Flooding to private properties (allotments not dwellings) along Miller Street with flood depths to 1.1 m	Flooding to private allotments (not to dwellings)	No flooding
Up to 25 caravans inundated above floor level plus one permanent building in the caravan park	Properties located adjacent to the corner of Craigie and Webster Street isolated	Flooding to private properties (allotments and two dwellings above floor) along Craigie Street, with flood depths to up 1.1 m	Flooding to private properties (allotments not dwellings) along Webster Street with flood depths to 1.1 m	Flooding commences across Marshbank Street adjacent to corner with Craigie Street	Flooding commences across Miller Street adjacent to corner with High Street with a flood depth up to 0.25 m	Vehicular access to these dwellings flooded to a depth of 1.1 m	
Court Street Bridge deck inundated up to 0.1 m							

Yea flood study

GBCMA&MSC September 2004

Listing complied by Water Technology

Last update 28/2/05

Court Street Gauge Height 4.4 **m gauge height** 167.12 **m AHD**

BOM catergory **Moderate**

Property details			Flood level	Status	Flood depth above ground m	Flood depth above floor level m
Address	**Ground level (m AHD)**	**Floor level (m AHD)**	**(m AHD)**			
12 MARSHBANK STREET	165.13	166.20	165.29	Property flooded below floor level	0.16	-
9 MILLER STREET	166.54	167.18	167.10	Property flooded below floor level	0.56	-
7 MILLER STREET	166.64	168.12	167.09	Property flooded below floor level	0.45	-
5 MILLER STREET	166.45	167.98	167.08	Property flooded below floor level	0.63	-
3 MILLER STREET	166.31	167.65	167.08	Property flooded below floor level	0.77	-
CARAVAN PARK	165.71	167.03	167.11	Property flooded above floor level	1.39	0.07
CARAVAN PARK	165.88	166.71	167.11	Property flooded above floor level	1.23	0.40
18 CRAIGIE STREET	164.09	164.27	165.07	Property flooded above floor level	0.97	0.80
20 CRAIGIE STREET	164.02	164.22	165.06	Property flooded above floor level	1.04	0.85
						-

Note: Does not include permeant or casual cabins/caravans. Indicative flood depth within caravan park up to 0.8 m.

Yea flood study
GBCMA&MSC September 2004
Listing complied by Water Technology
Last update 28/2/05

Court Street Gauge Height **4.4 m gauge height** **167.12 m AHD**

BOM catergory **Moderate**

Caravan Park	**Craigie Street west of Provenance Bridge**	**Craigie Street east of Provenance Bridge**	**Webster Street**	**Marshbank Street**	**Miller Street**	**Goulburn Valley Hwy west of Boundary Ck confluence (to Seymour)**	**Goulburn Valley Hwy at eastern end of township (to Yarack)**
Flooding in the Caravan Park with flood depth up to 0.8 m.	Inundated with flood depth up to 0.8 m	Flooding commences across Craigie Street adjacent to the corner with Nolan Street with flood depth up to 1.0 m	Flooding commences across Webster Street with a flood depth up to 1.0 m	Flooding to private properties (allotments not dwellings) along Marshbank Street with flood depths to 1.3 m	Flooding to private properties (allotments not dwellings)) along Miller Street with flood depths to 1.1 m	Flooding to private allotments (not to dwellings)	Goulburn Valley Highway inundation up to 0.1 m
Up to 25 caravans inundated above floor level plus two permanent building in the caravan park	Properties located adjacent to the corner of Craigie and Webster Street isolated	Flooding to private properties (allotments and two dwellings above floor) along Craigie Street, with flood depths up to 1.3 m	Flooding to private properties (allotments not dwellings) along Webster Street with flood depths to 1.3 m	Flooding commences across Marshbank Street adjacent to corner with Craigie Street with a flood depth up to 0.3 m	Flooding commence across Miller Street adjacent to corner with High Street with a flood depth up to 0.5 m	Vehicular access to these dwellings flooded to a depth of 1.3 m	
Court Street Bridge deck inundated up to 0.3 m							

Yea flood study
GBCMA&MSC September 2004
Listing complied by Water Technology
Last update 28/2/05

Court Street Gauge Height **4.55 m gauge height** **167.21 m AHD**

BOM catergory **Major**

Property details					Flood level	Status	Flood depth above ground	Flood depth above floor level
Address			Ground level (m AHD)	Floor level (m AHD)	(m AHD)		m	m
10	MARSHBANK	STREET	165.35	166.00	165.46	Property flooded below floor level	0.11	-
12	MARSHBANK	STREET	165.13	166.20	165.45	Property flooded below floor level	0.32	-
11	MILLER	STREET	166.93	168.19	167.26	Property flooded below floor level	0.33	-
9	MILLER	STREET	166.54	167.18	167.25	Property flooded above floor level	0.71	0.07
7	MILLER	STREET	166.64	168.12	167.24	Property flooded below floor level	0.60	-
5	MILLER	STREET	166.45	167.98	167.23	Property flooded below floor level	0.78	-
3	MILLER	STREET	166.31	167.65	167.23	Property flooded below floor level	0.92	-
	CARAVAN	PARK	165.71	167.03	167.26	Property flooded above floor level	1.54	0.22
	CARAVAN	PARK	165.88	166.71	167.26	Property flooded above floor level	1.38	0.55
18	CRAIGIE	STREET	164.09	164.27	165.22	Property flooded above floor level	1.13	0.95
20	CRAIGIE	STREET	164.02	164.22	165.22	Property flooded above floor level	1.19	1.00
								-

Note: Does not include permeant or casual cabins/caravans. Indicative flood depth within caravan park up to 0.95 m.

Yea flood study
GBCMA&MSC September 2004

Listing complied by Water Technology

Last update 28/2/05

Court Street Gauge Height

4.55 m gauge height **167.21 m AHD**

BOM catergory **Major**

Caravan Park	Craigie Street west of Provenance Bridge	Craigie Street east of Provenance Bridge	Webster Street	Marshbank Street	Miller Street	Goulburn Valley Hwy west of Boundary Ck confluence (to Seymour)	Goulburn Valley Hwy at eastern end of township (to Yarack)
Flooding in the Caravan Park with flood depth up to 0.95 m	Inundated with flood depth up to 0.95 m	Flooding commences across Craigie Street adjacent to the corner with Nolan Street with flood depths up to 1.15 m	Flooding commences across Webster Street with a flood depth up to 1.15 m.	Flooding to private properties (allotments not dwellings) along Marshbank Street with flood depths to 1.45 m	Flooding to private properties (allotments not dwellings) along Miller Street with flood depths to 1.25 m	Flooding to private allotments (not to dwellings)	Goulburn Valley Highway inundation up to 0.25 m
Up to 25 caravans inundated above floor level plus two permanent building in the caravan park Court Street Bridge deck inundated up to 0.5 m	Properties located adjacent to the corner of Craigie and Webster Street isolated	Flooding to private properties (allotments and two dwellings above floor) along Craigie Street, with flood depths to up 1.45 m	Flooding to private properties (allotments not dwellings) along Webster Street with flood depths to 1.45 m	Flooding commences across Marshbank Street adjacent to corner with Craigie Street with a flood depth up to 0.45 m	Flooding commences across Miller Street adjacent to corner with High Street with a flood depth up to 0.65 m	Vehicular access to these dwellings flooded to a depth of 1.45 m	

Yea flood study
GBCMA&MSC September 2004
Listing complied by Water Technology
Last update 28/2/05

Court Street Gauge Height **4.75 m gauge height** **167.47 m AHD**

BOM catergory **Major**

Property details					Flood level	Status	Flood depth above ground	Flood depth above floor level
Address			Ground level (m AHD)	Floor level (m AHD)	(m AHD)		m	m
6	MARSHBANK	STREET	165.73	166.62	165.79	Property flooded below floor level	0.06	-
8	MARSHBANK	STREET	165.67	166.34	165.78	Property flooded below floor level	0.11	-
10	MARSHBANK	STREET	165.35	166.00	165.77	Property flooded below floor level	0.42	-
12	MARSHBANK	STREET	165.13	166.20	165.76	Property flooded below floor level	0.63	-
11	MILLER	STREET	166.93	168.19	167.47	Property flooded below floor level	0.54	-
9	MILLER	STREET	166.54	167.18	167.44	Property flooded above floor level	0.90	0.26
7	MILLER	STREET	166.64	168.12	167.43	Property flooded below floor level	0.79	-
5	MILLER	STREET	166.45	167.98	167.42	Property flooded below floor level	0.97	-
3	MILLER	STREET	166.31	167.65	167.41	Property flooded below floor level	1.10	-
	CARAVAN	PARK	165.71	167.03	167.45	Property flooded above floor level	1.74	0.42
	CARAVAN	PARK	165.88	166.71	167.45	Property flooded above floor level	1.57	0.75
2	CRAIGIE	STREET	165.34	166.30	165.74	Property flooded below floor level	0.40	-
18	CRAIGIE	STREET	164.09	164.27	165.54	Property flooded above floor level	1.44	1.27
20	CRAIGIE	STREET	164.02	164.22	165.54	Property flooded above floor level	1.51	1.32
30	CRAIGIE	STREET	165.18	166.15	165.43	Property flooded below floor level	0.25	-
34	CRAIGIE	STREET	165.38	165.66	165.47	Property flooded below floor level	0.09	-
5	HIGH	STREET	167.26	167.93	167.31	Property flooded below floor level	0.05	-
1	WHATON	STREET	167.31	167.72	167.32	Property flooded below floor level	0.01	-
								-

Note: Does not include permeant or casual cabins/caravans. Indicative flood depth within caravan park up to .1.15 m.

Yea flood study
GBCMA&MSC September 2004
Listing complied by Water Technology
Last update 28/9/04

Court Street Gauge Height **4.83 m gauge height** **167.55 m AHD**

BOM catergory **Major**

Property details			Flood level	Status	Flood depth above ground m	Flood depth above floor level m
Address	Ground level (m AHD)	Floor level (m AHD)	(m AHD)			
6 MARSHBANK STREET	165.73	166.62	165.89	Property flooded below floor level	0.17	-
8 MARSHBANK STREET	165.67	166.34	165.88	Property flooded below floor level	0.22	-
10 MARSHBANK STREET	165.35	166.00	165.87	Property flooded below floor level	0.53	-
12 MARSHBANK STREET	165.13	166.20	165.87	Property flooded below floor level	0.73	-
11 MILLER STREET	166.93	168.19	167.54	Property flooded below floor level	0.61	-
9 MILLER STREET	166.54	167.18	167.51	Property flooded above floor level	0.97	0.34
7 MILLER STREET	166.64	168.12	167.50	Property flooded below floor level	0.86	-
5 MILLER STREET	166.45	167.98	167.49	Property flooded below floor level	1.04	-
3 MILLER STREET	166.31	167.65	167.48	Property flooded below floor level	1.17	-
13 MILLER STREET	167.36	167.74	167.57	Property flooded below floor level	0.21	-
CARAVAN PARK	165.71	167.03	167.53	Property flooded above floor level	1.81	0.49
CARAVAN PARK	165.88	166.71	167.53	Property flooded above floor level	1.65	0.82
2 CRAIGIE STREET	165.34	166.30	165.85	Property flooded below floor level	0.50	-
18 CRAIGIE STREET	164.09	164.27	165.62	Property flooded above floor level	1.53	1.35
20 CRAIGIE STREET	164.02	164.22	165.62	Property flooded above floor level	1.60	1.41
30 CRAIGIE STREET	165.18	166.15	165.52	Property flooded below floor level	0.34	-
34 CRAIGIE STREET	165.38	165.66	165.53	Property flooded below floor level	0.14	-
36 CRAIGIE STREET	165.32	165.88	165.34	Property flooded below floor level	0.02	-
5784 GOULBURN VALLEY HIGHWAY	165.22	165.96	165.84	Property flooded below floor level	0.62	-
8 CRAGIE STREET	166.47	166.85	166.77	Property flooded below floor level	0.29	-
GOULBURN VALLEY WATER	165.92	165.92	167.34	Property flooded above floor level	1.42	1.42
1 HOOD STREET	166.67	167.30	167.34	Property flooded above floor level	0.67	0.04
1 HOOD(POLICE STN) STREET	167.03	167.64	167.34	Property flooded below floor level	0.31	-
7 HIGH STREET	167.35	167.66	167.36	Property flooded below floor level	0.01	-
5 HIGH STREET	167.26	167.93	167.31	Property flooded below floor level	0.05	-
1 WHATON STREET	167.31	167.72	167.32	Property flooded below floor level	0.01	-

Note: Does not include permeant or casual cabins/caravans. Indicative flood depth within caravan park up to .1.23 m.