Glenelg Hopkins CMA

Beaufort Flood Study
Study Report

Report No. J558/R04 Final

June 2008

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WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

Glenelg Hopkins CMA

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It is the responsibility of the reader to verify the currency of revision of this report.

Acknowledgements

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

- Johanna Theilemann (Glenelg Hopkins CMA & Project Manager)
- Geoff Pearce and Bruce Andrews (Pyrenees Shire Council)
- The landowners and residents of Beaufort who responded to the questionnaire and participated in interviews

The study team also wishes to thank all those stakeholders and members of the public that attended the information sessions, contributed flooding information and discussed their experiences with the study team.

EXECUTIVE SUMMARY

This report details the input data, approach and outcomes for the Beaufort Flood Study.

The study has been initiated by the Glenelg Hopkins Catchment Management Authority (GHCMA) and Pyrenees Shire Council (PSC) in response to concern over uncertainties in understanding and definition of flood risk for the township.

The study provides information on flood levels and flood risks within the township.

Community consultation was undertaken during the study, primarily in order to gather data and accounts of flooding. The flood information provided by residents was invaluable in the development of the study outcomes.

The flood study was based on survey data gathered using aerial (photogrammetry) and land-based techniques. The photogrammetry provided a base Digital Terrain Model (DTM) for the study area with the land-based survey used to define critical hydraulic structures (bridges and culverts) as well as key waterway cross-sections.

A hydrologic analysis was undertaken to determine the 5, 10, 20, 50 and 100 year Average Recurrence Interval (ARI) design flood flows for the Yam Holes, Ding Dong, Cemetery and Cumberland Creeks at Beaufort. Due to the lack of available flow data within the catchment, a regional analysis was applied. A hydrologic model was developed for a neighbouring catchment with suitable hydrologic data for calibration. The parameters from this local calibrated model were then applied to the Yam Holes Creek catchment using a standard scaling technique. The adopted design flood flows, listed in Table 1 for the downstream study boundary, are considered appropriate for the definition of flood risk at Beaufort.

Table 1 Beaufort - Design Flood Estimates

ARI (years)	Peak Flow at Study Area Outlet (m^3/s)
5	56.3
10	68.0
20	85.1
50	104.3
100	123.3
PMF	1,420

An estimate of the Probable Maximum Flood (PMF) was calculated using standard techniques. This peak flow is approximately 10 times the 100 year ARI flow magnitude and represents the “worst possible case” for flooding in Beaufort.

A detailed two-dimensional hydraulic model of the study area was developed using the gathered survey information. As there are no formal flood records available for Beaufort, a typical model calibration process was not possible. In lieu of a standard calibration process, anecdotal evidence of flooding patterns at Beaufort from community representatives and council officers was been used to determine the reliability of the predicted flood extents. Draft flood maps were presented to the community during stakeholder consultations for comment and feedback on the patterns of flooding with respect to observed behaviour. Feedback from these sessions suggested that the general pattern of flooding was consistent with the observed behaviour although the extent was greater than expected in some areas. This was understandable given no significant flood events (similar in magnitude to the 100 year ARI design event) are known to have occurred in living memory.

The hydraulic model was used to develop flood information including maps and electronic data sets to describe potential flooding in Beaufort. This information includes flood extent, flood depth and velocity; and can be utilised to assist in future land use planning in Beaufort.

A flood risk assessment was undertaken which involved the estimation of tangible flood damages for a range of design events. The average annual damage (AAD) was calculated to be approximately $383,000 per year with current topography and flows. These results showed that even in a 5 year ARI event, significant flood damages are predicted with around 12 floors flooded from a total of 181 flood affected properties. Table 2 below summarises the flood damage calculations.

Table 2 - Flood Damage Assessment Costs for Existing Conditions

Item	Design Flood ARI (years)					
	5	**10**	**20**	**50**	**100**	**PMF**
Properties Flooded Above Floor	12	21	31	32	41	211
Properties Flooded Below Floor	169	176	178	179	173	50
Total Flooded Properties	181	197	209	211	214	261
TOTAL DAMAGES	**$1,193,000**	**$1,605,000**	**$2,002,000**	**$2,205,000**	**$2,494,000**	**$10,796,000**

Potential flood mitigation measures were investigated. Mitigation measures provide a means to reduce existing flood risk by reducing the likelihood of flooding and/or lowering the flood damages (consequences) for a given flood. Both **structural** (works such as levees, floodways, waterway works and improvements to hydraulic structures) and **non-structural** (land-use planning, flood warning and catchment management) measures were considered, although hydraulic modelling of these options was not part of the scope of this project.

Potential structural measures that may warrant further investigation include:

- Use of upstream storage to reduce flood peaks
- Improved flow conveyance through floodways
- Improved hydraulic structures (particularly railway culverts)

The third of these measures is considered to provide the most feasible structural option at this preliminary stage.

Non-structural measures that could be pursued include:

- Flood warning systems
- Community Awareness
- Planning controls

It is considered that all of these non-structural measures could provide benefit in terms of reduced flood damages over time.

Draft flood related planning overlay maps (FO and LSIO) have been prepared to reflect the study outcomes. These define areas subject to inundation in a 100 year ARI flood events and areas of active floodway that are important to maintain flood capacity and reduce flood risk.

In light of the study outcomes it is recommended that:

- The GHCMA and Council adopt the determined design flood levels and in turn proceed with a declaration process.
- The Pyrenees Shire and GHCMA continue to engage the community in the treatment of flood risks through the development of a full Floodplain Management Plan for Beaufort that involves broad community involvement and consultation with stakeholders.
- The Pyrenees Shire and GHCMA explore options for enhanced flood response measures through co-operation with SES and Police utilising the flood inundation maps produced from the study.
- The Pyrenees Shire and GHCMA explore options for the development of a flash flood monitoring and warning system for Beaufort in conjunction with the BoM and SES.
- The GHCMA consider the collection of hydrologic data that would facilitate future improvements in hydrologic and hydraulic modelling.

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GLOSSARY

Term	Description
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.
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 1 00%AEP flood event.
Development	The erection of a building or the carrying out of work; or the use of land or of a building or work; or the subdivision of land.
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.
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 fringe	The remaining area of flood-prone land after floodway and flood storage areas have been defined.
Flood hazard	Potential risk to life and limb caused by flooding.
Flood-prone land	Land susceptible to inundation by the probable maximum flood (PMF) event, i.e. The maximum extent of flood liable land. Floodplain Risk Management Plans encompass all flood-prone land, rather than being restricted to land subject to designated flood events.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Floodplain management measures	The full range of techniques available to floodplain managers.
Floodplain management	The measures which might be feasible for the management of

options	a particular area.
Flood planning area	The area of land below the flood planning level and thus subject to flood related development controls.
Flood storages	Those parts of the floodplain that are important for the temporary storage, of floodwaters during the passage of a flood
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often, but not always, aligned with naturally defined channels. Floodways are areas which, even if only partially blocked, would cause a significant redistribution of flood flow, or significant increase in flood levels. Floodways are often, but not necessarily, areas of deeper flow or areas where higher velocities occur. As for flood storage areas, the extent and behaviour of floodways may change with flood severity. Areas that are benign for small floods may cater for much greater and more hazardous flows during larger floods. Hence, it is necessary to investigate a range of flood sizes before adopting a design flood event to define floodway areas.
Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
High hazard	Possible danger to life and limb; evacuation by trucks difficult; able-bodied adults would have difficulty wading to safety; potential for significant structural damage to buildings.
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.
IFD	Intensity Frequency Duration, method of determining design rainfalls according to procedures in Australian Rainfall and Runoff. This includes total rainfall for a given design (ARI) storm event and the pre-determined temporal pattern over which this rainfall is distributed.
Low hazard	Should it be necessary, people and their possessions could be evacuated by trucks; able-bodied adults would have little difficulty wading to safety.
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.
Mathematical computer models	The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with rainfall, runoff, pipe and overland stream.
Peak discharge	The maximum discharge occurring during a flood event.
Probable maximum flood	The flood calculated to be the maximum that is likely to occur.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Annual Exceedance Probability.
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.
Stormwater flooding	Inundation by local runoff. Stormwater flooding can be caused by local runoff exceeding the capacity of an urban stormwater drainage system or by the backwater effects of mainstream flooding causing the urban stormwater drainage system to overflow.
Topography	A surface which defines the ground level of a chosen area

ABBREVIATIONS

AAD	Average Annual Damage
ABS	Australian Bureau of Statistics
AEP	Annual Expectance Probability
ARI	Average Recurrence Interval
AR&R	Australian Rainfall and Runoff
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BoM	Bureau of Meteorology
CAD	Computer Aided Design
CL	Continuing Loss
DEM	Digital Elevation Model
DOI	Department of Infrastructure
DPI	Department of Primary Industries
DSE	Department of Sustainability and Environment
EPA	Environment Protection Authority
FDTP	Flood Data Transfer Project
FFA	Flood Frequency Analysis
FO	Floodway Overlay
GHCMA	Glenelg Hopkins Catchment Management Authority
GIS	Geographical Information System
IFD	Intensity-Frequency Duration
IL	Initial Loss
LP3	Log-Pearson III
LSIO	Land Subject to Inundation Overlay
MC	Monte Carlo
MEMP	Municipal Emergency Management Plan
NDMP	Natural Disaster Mitigation Program
PMF	Probable Maximum Flood
SRWSC	State Rivers and Water Supply Commission
VFD	Victorian Flood Database
VPP	Victoria Planning Provisions

1 INTRODUCTION

1.1 Background

Water Technology was commissioned by the Glenelg Hopkins CMA in partnership with Pyrenees Shire Council to undertake a Flood Study for the township of Beaufort.

The report has been prepared for the following purposes:

- Document the analysis undertaken to adequately define the hydrologic behaviour of the Yam Holes Creek catchment (including tributaries) through Beaufort.
- Document the level of uncertainty associated with the Ding Dong, Yam Holes, Cemetery and Cumberland Creeks design flood flows.
- Document the hydraulic analysis of the Beaufort Floodplain
- Describe the risk assessment undertaken
- Document the flood mapping outputs from the study
- Document overall study outcomes and recommendations

1.2 Study Catchment

The township of Beaufort has a population of approximately 1,500 (ABS, 2006 Census) and is situated some 45 km west of Ballarat on the Western Highway, midway between Ballarat and Ararat. It is situated within a circle of hills, at the confluence of Ding Dong, Cemetery, Cumberland and Yam Holes Creeks. Yam Holes Creek is the main waterway through the town and a major tributary of Mount Emu Creek. The confluence of Yam Holes Creek with Mount Emu Creek is approximately 10 km downstream of the Beaufort township. Mount Emu Creek is a major tributary of the Hopkins River which flows into the Southern Ocean just east of Warrnambool.

The total contributing catchment at the downstream boundary of the study area is approximately 49 km^2. The flood study area within the township (as specified in the brief) is approximately 5 km^2. The study area and surrounding catchment are shown in Figure 1-1.

The sub-catchments for each of the streams within the Yam Holes Creek catchment are depicted in Figure 1-2. The areas associated with each sub-catchment are listed in Table 1-1. The Yam Holes Creek tributaries vary significantly in size, from the smallest (Ding Dong Creek) which is only about 5% of the total area to the largest (Cemetery Creek) which is close to 30% of the total catchment area to the study outlet.

Table 1-1 Yam Holes Creek Catchment Areas

Waterway	Catchment (km^2)
Ding Dong Creek	2.2
Cemetery Creek	14.5
Cumberland Creek	5.1
Yam Holes Creek	27.2
Study outlet (total)	49.0

While Yam Holes Creek upstream of Beaufort has a larger area than the tributary streams, it has a significantly smaller longitudinal slope with large areas available for floodplain storage which attenuate flood flows. Cemetery Creek has a significant recreational online storage, Lake Beaufort. Lake Beaufort has a maximum surface area of approximately 16 Ha and a reported volume of 297 ML (TGM, 2004). This implies an average depth of about 1.8 m which is considered reasonable based on observations, however a source for this value was not quoted in the TGM report. An alternative estimate of 172 ML by DPI (2008) seems to be an underestimate of the likely volume of the lake at full capacity. It is speculated that this estimate may correspond to a drawn-down level in the lake, however this is not stated in the DPI information and could not be verified. No lake bathymetry data was available for the study, however the lake profile below normal water level is not critical for flood calculation purposes.

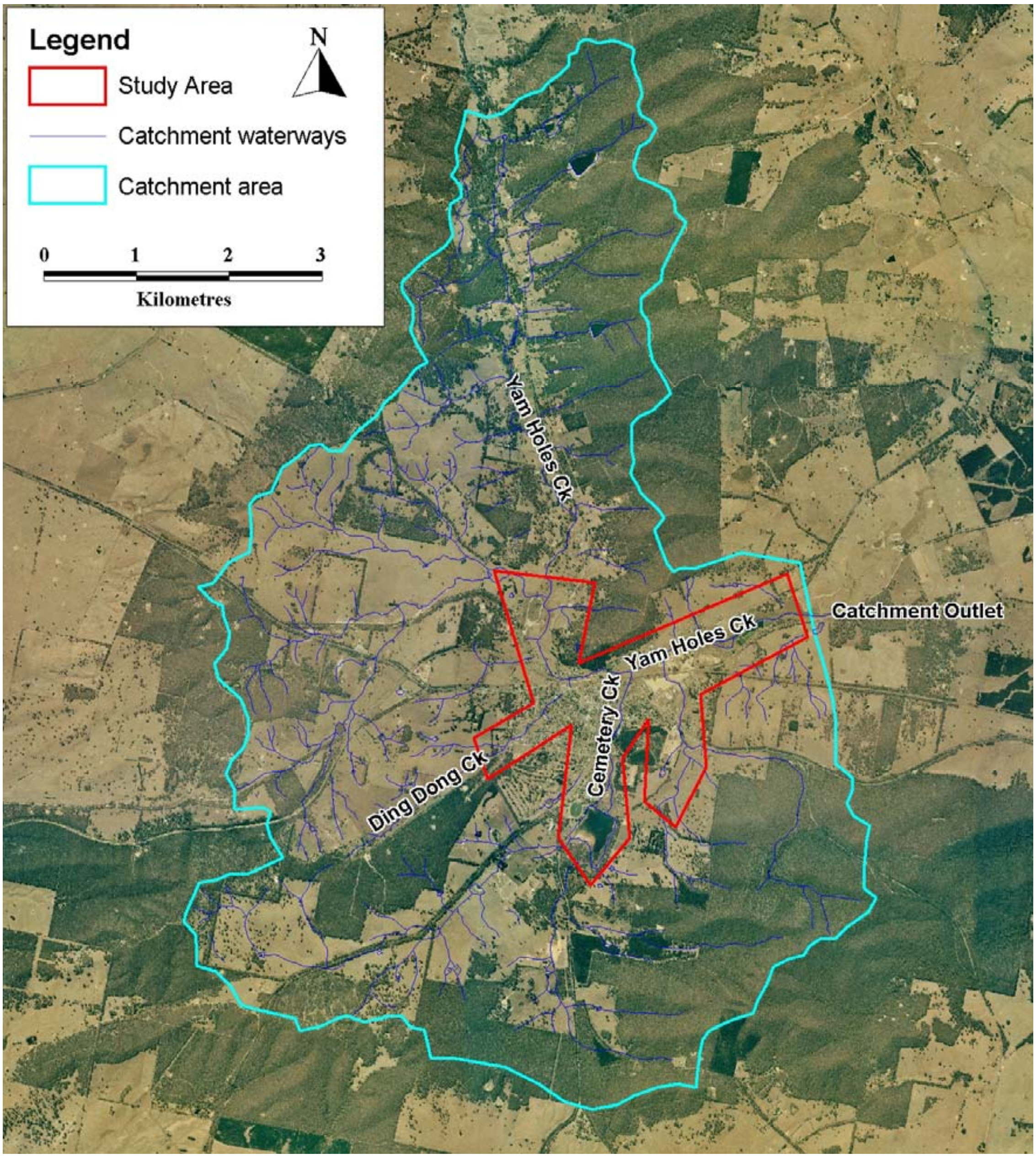

Figure 1-1 Study Area and Catchment

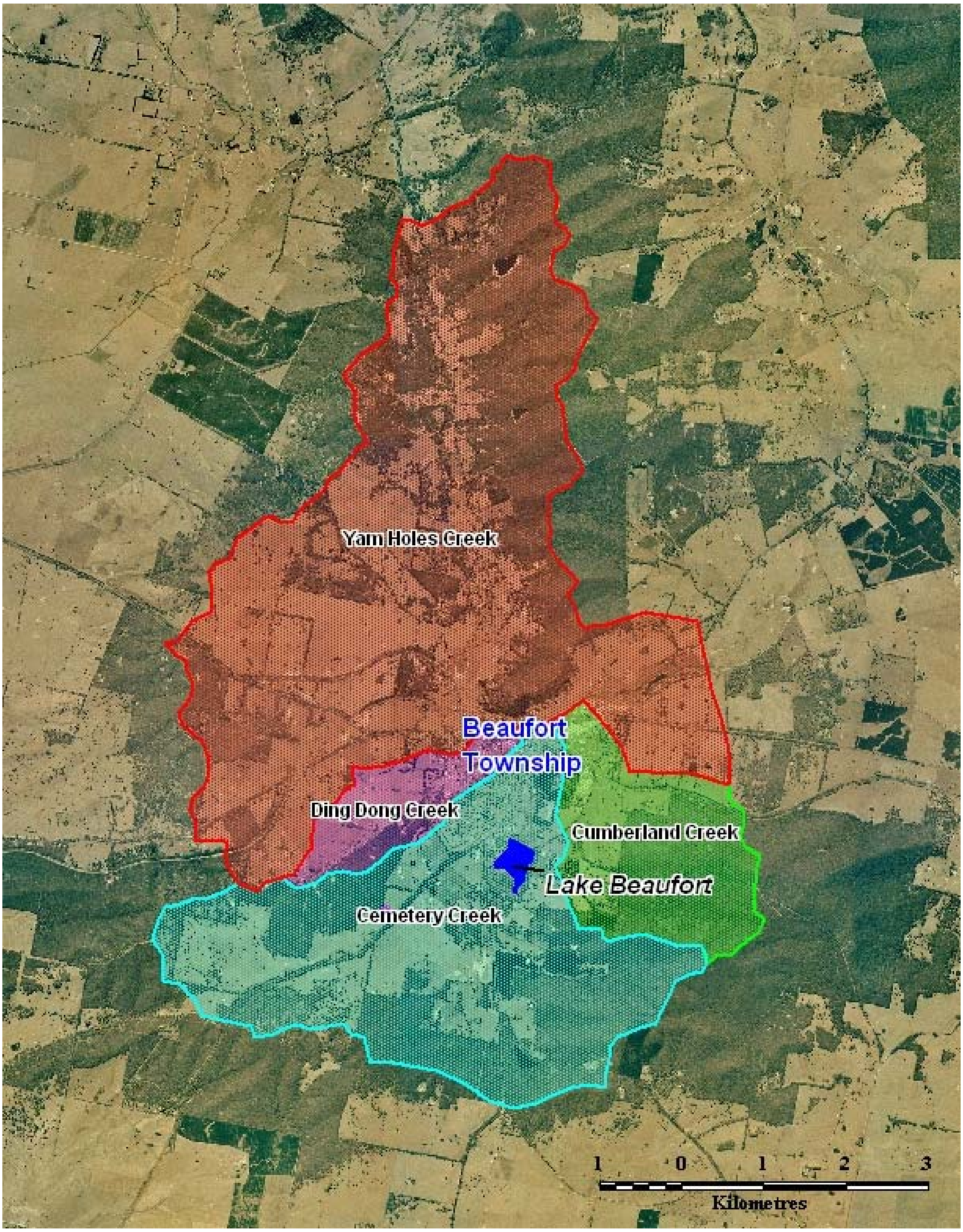

Figure 1-2 Beaufort Sub-catchments

2 AVAILABLE INFORMATION

2.1 Streamflow Data

There are no streamflow gauges within the study area or upstream in the Ding Dong, Yam Holes, Cemetery or Cumberland Creek catchments. The nearest streamflow gauge is downstream of Beaufort on Mt Emu Creek. The Mena Park streamflow gauge on Mt Emu Creek is approximately 17 km downstream of its confluence with Yam Holes Creek. Details of this gauge are listed below in Table 2-1 and its location is displayed in Figure 2-3.

Table 2-1 Details of Streamflow Gauge

Station No.	Station Name	Catchment Area (km^2)[1]	Period of Record
236213	Mena Park	322	1967 – 2006

The Mena Park gauge, situated on Mount Emu Creek, records flow from three primary tributaries, one of which is the Yam Holes Creek Catchment (approximately 15% of total catchment). The rating for Mt Emu Creek at Mena Park is displayed in Figure 2-1 (as supplied by Thiess Services).

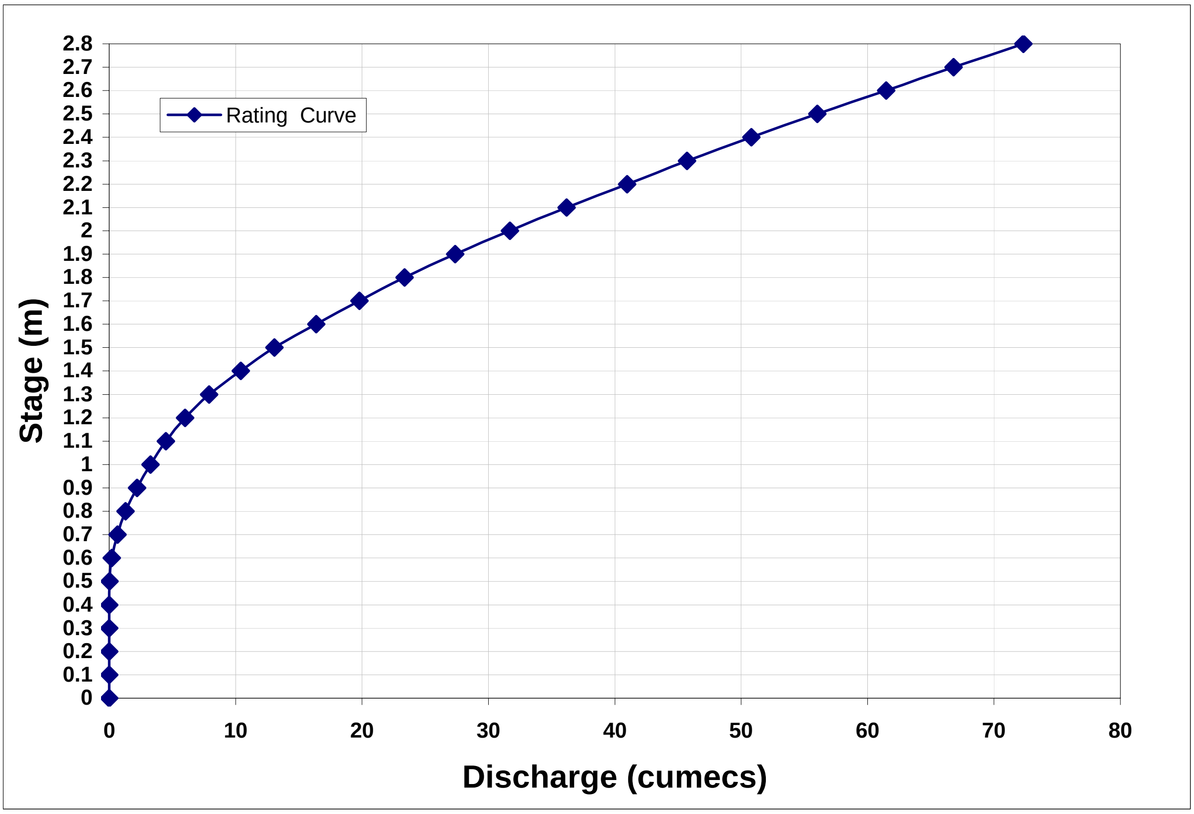

Figure 2-1 Mount Emu Creek Gauge at Mena Park Rating (236213)
Source: Victorian Data Warehouse

[1] There is some inconsistency in the quoted areas for the Mt Emu Creek to Mena Park. The study brief suggests a catchment area of 899 km^2 whilst the Victorian Data Warehouse suggests the catchment at this location is 452 km^2. For this study the catchment area was carefully digitised in a GIS from 1:25,000 topographic mapping and 10 m contours. The study estimate of 322 km^2 provides a more reliable value than those previously quoted. The value in the study brief is most likely a typing error whilst the gauge value could be in error due to hand digitising from 1:100,000 scale mapping.

As Yam Holes Creek is a tributary of Mt Emu Creek, it is considered that hydrologic behaviour determined for the entire catchment at the Mena Park gauge may be used to infer expected behaviour in the Yam Holes Creek sub-catchment at Beaufort. Whilst the Yam Holes Creek Catchment area is much smaller than Mt Emu Creek at Mena Park, the catchments have similar characteristics such as topography and underlying geology. Figure 2-2 shows that Yam Holes Creek and Mt Emu Creek have predominantly similar geological compositions consisting of sandstone and siltstone in the higher elevations with quaternary alluvial deposits on the lower floodplain areas. Along the east boundary of the Mt Emu Creek catchment there is an area of volcanic deposits that is not replicated in the Yam Holes Creek catchment, however this is a relatively small proportion of the overall catchment and would not be expected to have a significant effect on hydraulic behaviour.

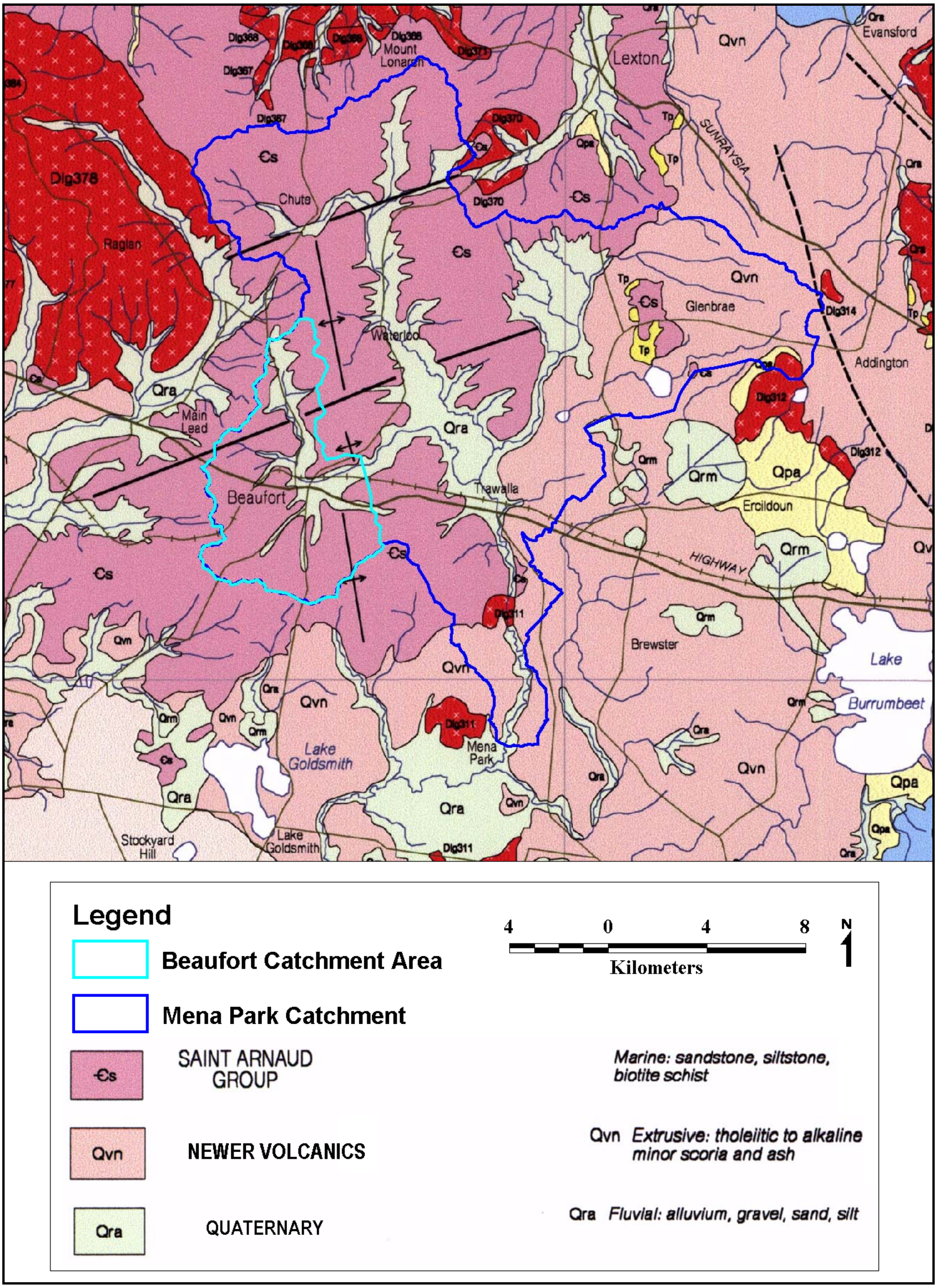

Figure 2-2 Yam Holes Creek and Mt Emu Creek, Geology Map (source Ballarat 1:250,000 Geologic Map, DNRE 1997)

2.2 Rainfall Data

Bureau of Meteorology (BoM) rainfall records indicate that only one daily rainfall station is located within the Yam Holes Creek catchment upstream of Beaufort. However, BoM records identified a number of daily rainfall stations with significant periods of record that are situated in the vicinity of the Yam Holes Creek catchment boundary.

Two pluviographic (rainfall intensity) stations in the vicinity of the catchment were identified, the closest being at Beaufort Sheepwash (approximately 7 km southwest of Beaufort township) and Ballarat Aerodrome (approximately 40 km to the east). Details of selected daily rainfall stations are presented in Table 2-2 below. The locations of appropriate rainfall stations and stream gauges are displayed in Figure 2-3. Whilst there are a number of other rainfall stations within close proximity to the study area, these do not have a significantly long period of record.

Review of the available data suggests there is sufficient rainfall information to provide a good understanding of the historic rainfall patterns over a significant length of time (30 to 50 years).

Table 2-2 Selection of Rainfall Stations with long records

Station No.	Station Name	Type	Period of Record
89005	Beaufort	Daily	1922 - Present
89082	Beaufort Sheepwash	Daily	1949 – Present
		Pluvio	1974 - Present
89030	Trawalla	Daily	1872 - Present
89002	Ballarat Aerodrome	Daily	1907 - Present
		Pluvio	1954 - Present
79014	Eversley	Daily	1888 - Present
89007	Burrumbeet	Daily	1949 - Present
89090	Waubra	Daily	1970 - Present
88038	Lexton	Daily	1903 - Present

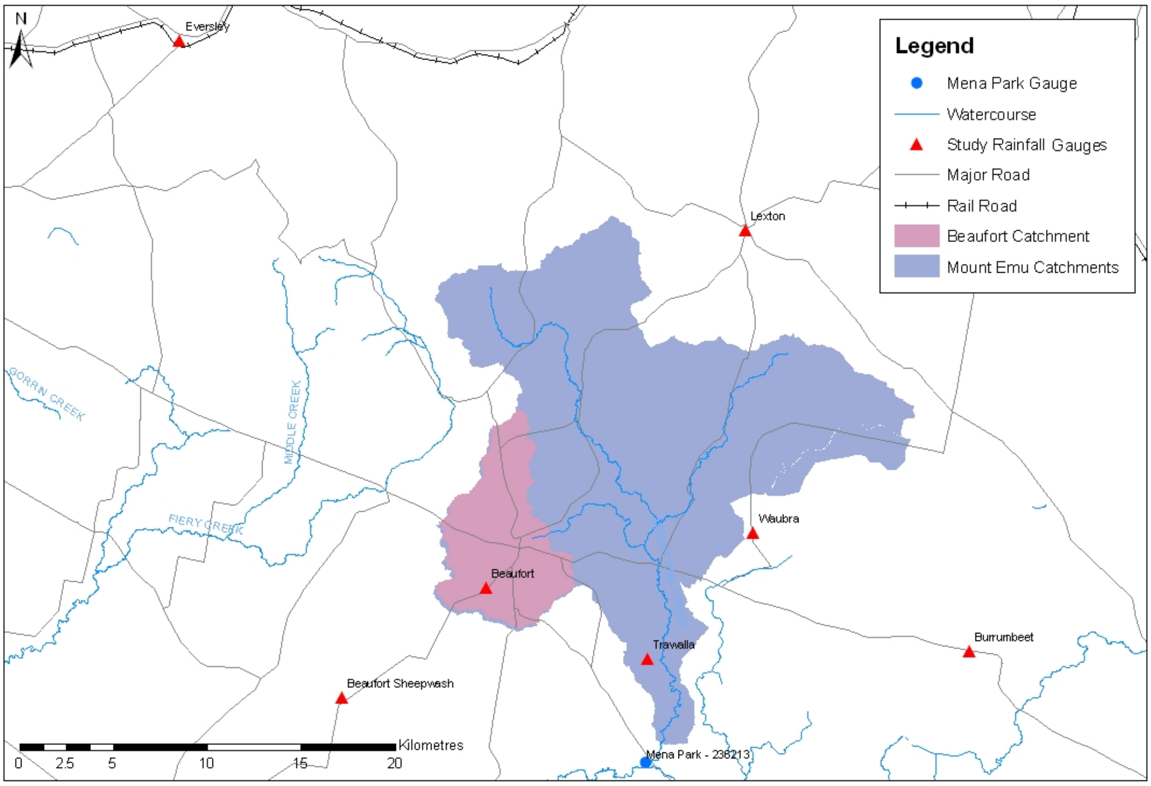

Figure 2-3 Daily Rainfall Stations and Streamflow Stations

2.3 Cadastral Information

Digital cadastral information for Beaufort in MapInfo format was provided by the Pyrenees Shire Council. This information includes typical parameters such as street name, number and property boundary. This information can be used to identify flood-prone properties.

2.4 Photogrammetry

Three-dimensional Photogrammetry data for the study area was supplied by QASCO in a CAD drawing file. The photogrammetry comprises of points and polylines, and is split into different layers describing different physical features. The points are spaced in a 20 m grid pattern and the polylines represent linear features or breaklines, such as drainage channels and road edges.

2.5 Aerial Photography

Aerial photos are an invaluable resource in flood studies. They can be used to interpret physical features and land-use on the ground and provide a context and background to flood model results and aid in presentation. Aerial photography was supplied by the Glenelg Hopkins CMA, flown on 6th February 2001 and at 1:25,000 scale. In addition to this, ortho-imagery was supplied by QASCO as an output of the photogrammetric survey. This was flown in March 2007 and is shown in Figure 2-4 below.

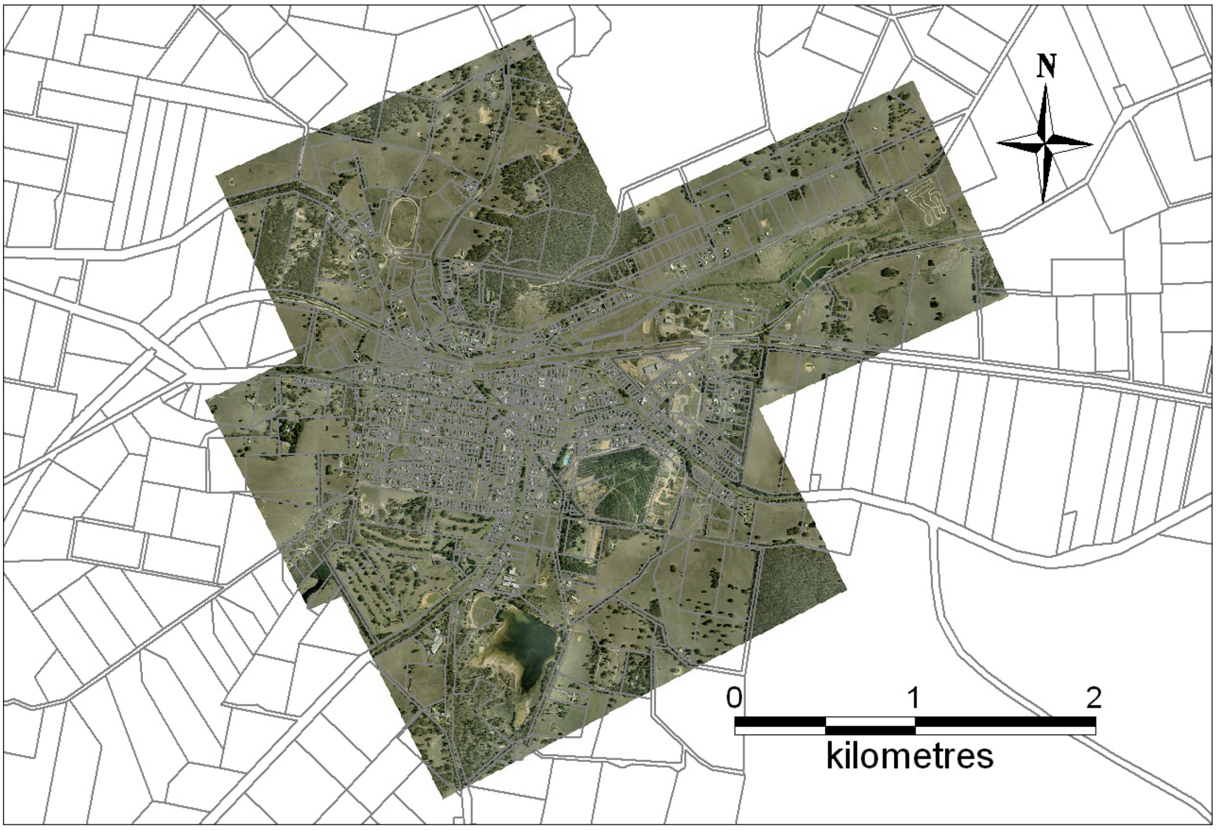

Figure 2-4: Ortho Imagery as Supplied by QASCO with Cadastral Overlay

2.6 Field Survey

Field survey was required to:

- Supplement the photogrammetry to define watercourse cross-sections below the water-line and other features obscured from the photogrammetry such as bridge and waterway structure details.
- Provide information in areas where data accuracy was compromised due to excess vegetation cover, such as on cemetery creek.
- Measure floor levels of affected properties to determine which buildings are flooded above floor.

Indicative locations of field survey data is presented in Figure 2-5.

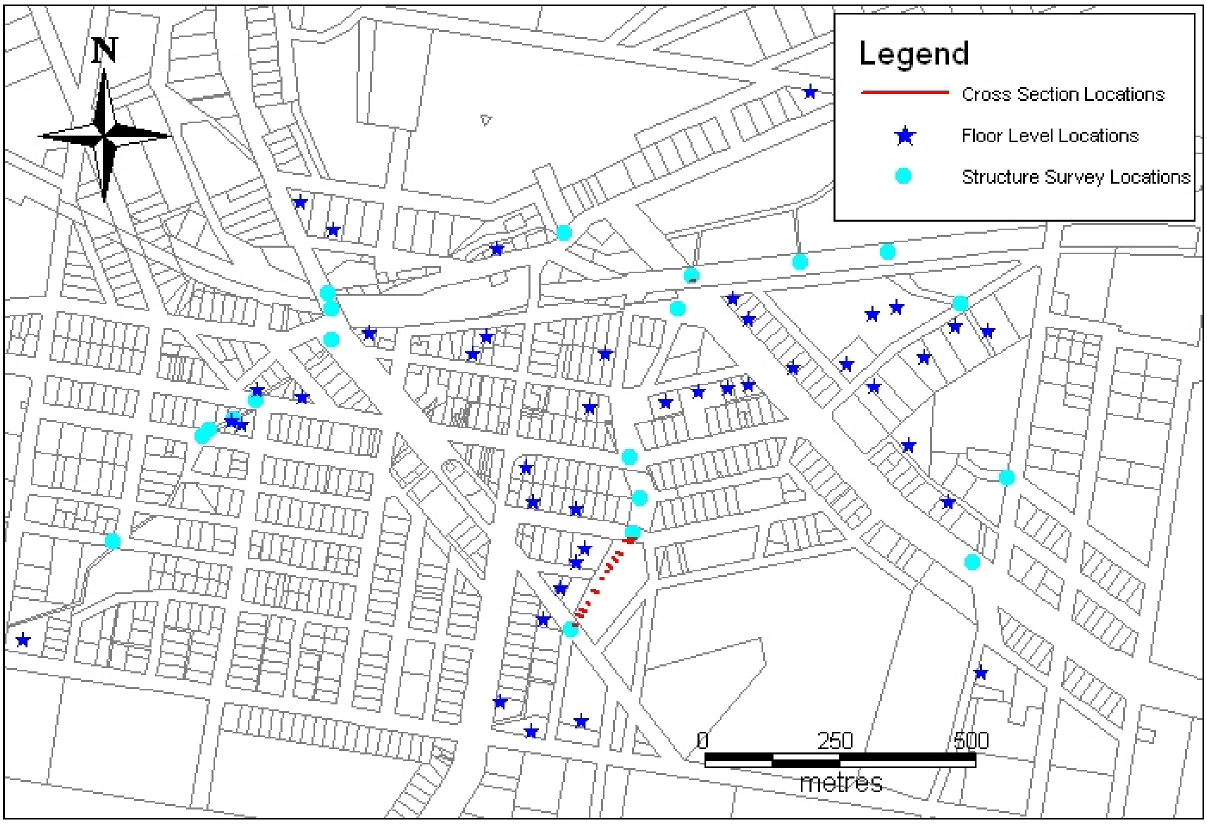

Figure 2-5: Field Survey Locations

3 COMMUNITY CONSULTATION

3.1 Overview

A key ingredient in the robust and comprehensive investigation of existing flood risks for Beaufort was the active engagement of residents in the study. This engagement was developed over the course of the study through several different means including public advertisements, community information sessions, a questionnaire and individual meetings with residents. The aims of the community consultation were as follows:

- To raise awareness of the study and identify key residents and community concerns.
- To provide information to the community and seek their feedback/input regarding the study outcomes including flood mapping.

3.2 Public Notices

A public notice outlining the study objectives and scope, and providing notice on the questionnaire was advertised to the local community.

3.3 First Community Information Session

A community information session was held on the evening of the 7th March 2007. An open invitation was made to the community to come and discuss concerns regarding flooding and any available experiences and information regarding historical flooding. Water Technology, GHCMA and Pyrenees Shire staff were on hand to enable one-to-one discussions. There were a number of people that attended over the evening and useful information was gathered.

3.4 Working Group Session

A working group session was held with local residents on the 16th August 2007 to discuss preliminary model results. People that had provided details at the first community information session or who had otherwise registered an interest in the study with the Council or CMA were directly invited to this session. The residents were shown the design flood extents and depths and were asked to comment and provide feedback.

3.5 Community Questionnaire

A community questionnaire was distributed to local residents of Beaufort in March 2007 to seek information regarding knowledge of past floods and an understanding of community concerns in relation to flooding. The questionnaire consisted of a doubled sided A4 page containing seven questions. A total of 96 questionnaire responses were received. The results of the survey are summarised in Table 3-1 and a copy of the survey is provided in Appendix D. In general the feedback from the questionnaire reflected the fact that no severe flooding has been experienced in Beaufort for a number of years and many residents have not lived in the area long enough to have experienced significant floods.

Table 3-1: Summary Of Feedback From Community Questionnaire

Flooding Aspect	Concerns
Frequency of flooding and damages (Questionnaire questions No. 1 and 2)	• Only about 10% of respondents had experienced flooding • No recent significant flooding
Nature of flooding (Questionnaire question No. 3)	• Range from shallow to deep flooding • Range from gentle flooding to fast flowing
Historical flood marks and flood photographs (Questionnaire questions 4 & 5)	• 3 historical flood marks identified • Flood photographs collected
Flood warning (Questionnaire question No. 6)	• No formal flood warning source identified • Residents base response on observations of rainfall and weather reports in the media
Main concerns (Questionnaire question No. 7)	• Concern regarding development in the floodplain and appropriate land-use controls • Maintenance of creeks and drains with the level of vegetation and debris in channels too high • Flood warning and information to the community regarding flooding

3.6 Second Community Information Session

A community information session was held on Saturday 8th December 2007 from 9am to 3pm. A shop front was set-up on the main street of Beaufort to allow residents to view and discuss flood maps with Water Technology and GHCMA staff. The aim of this process was to provide information to the community as well as to seek their feedback regarding the study outcomes including flood mapping.

4 HYDROLOGIC ANALYSIS

4.1 Overview

Design flood hydrographs were required for the 5, 10, 20, 50 and 100 year Average Recurrence Interval (ARI) design flood events for the Yam Holes, Ding Dong, Cemetery and Cumberland Creeks at Beaufort. As described in Section 2.2, there are adequate rainfall records available including several daily and pluviographic gauges within a reasonable proximity of the study area.

It was identified early in the analysis that no streamflow records for any of the waterways under consideration exist. In order to consider a regional approach to flood estimation at Beaufort, a search for any neighbouring streamflow gauging stations was undertaken. The nearest gauge is at Mena Park on Mt Emu Creek. This gauge is a considerable distance from the study area and has a relatively short period of observed streamflow record. Consequently the reliability of design flood estimates from a conventional flood frequency analysis and/or calibration of a runoff-routing model for Mt Emu Creek to Mena Park are questionable, with particular suspicion surrounding approximation of high flows.

A number of methodologies have therefore been explored in order to improve confidence in the design flow estimates for Beaufort. These are:

- Flood frequency analysis of Mt Emu Creek gauge at Mena Park; scaling back design peak flows by catchment area
- RORB rainfall-runoff model development and calibration to design flow estimates at Mena Park Gauge; scaling calibrated *kc* and *m* values based on average routing distance
- Rational method and other empirical techniques (CRC Catchment Hydrology)

4.2 Flood Frequency Analysis for Mt Emu Creek at Mena Park

An annual series flood frequency analysis (FFA) on the recorded streamflow data available at the Mena Park gauge was undertaken. Thirty years of instantaneous streamflow records between 1975 and 2005 were available.

An additional 9 years of historical mean daily flow data between December 1966 and 1975 also exists for the Mena Park gauge. A regression analysis comparing maximum annual average daily flows to maximum annual instantaneous peak flow for 9 years of the record (from 1975 to 1984 where overlapping data-sets exist) showed a strong correlation (see Appendix A). The regression relationship was therefore used to convert the additional nine years of historical daily flows to instantaneous peak flows (1966 excluded due to incomplete record). This allowed the FFA to be undertaken with a combined total of 39 years of streamflow record for the Mena Park gauge as listed in Table 4-1.

A Log-Pearson III (LP3) distribution was fitted to the annual maximums. Four low-flows were omitted from the analysis in an attempt to bring the skewness of the observed data back to acceptable limits. The observed data and fitted LP3 curve is depicted in Figure 4-1. Design flow estimates are summarised in Table 4-2.

Table 4-1 Annual Flood Series for Mt Emu Creek at Mena Park

Rank	Year	Peak Flow (ML/d)	Peak Flow (m^3/s)
1	1983	4990	57.8
2	1975	4360	50.5
3	1988	4220	48.8
4	1986	4140	47.9
5	1992	4120	47.7
6	1980	4040	46.8
7	1993	3950	45.7
8	1981	3920	45.4
9	1996	3220	37.3
10	1973	3154	36.5
11	1968	2982	34.5
12	1984	2690	31.1
13	1974	2084	24.1
14	1978	1790	20.7
15	1977	1750	20.3
16	1971	1504	17.4
17	1990	1420	16.4
18	1989	1400	16.2
19	1979	1340	15.5
20	2000	1180	13.7
21	2003	1170	13.5
22	1998	1030	11.9
23	1987	954	11.0
24	1991	862	10.0
25	1995	861	10.0
26	1969	606	7.0
27	1999	600	6.9
28	1985	528	6.1
29	1972	384	4.4
30	1976	359	4.2
31	1997	334	3.9
32	2005	222	2.6
33	2001	188	2.2
34	2004	171	2.0
35	1994	61	0.7
36	1970	52	0.6
37	2002	50	0.6
38	1967	42	0.5
39	1982	2	0.0

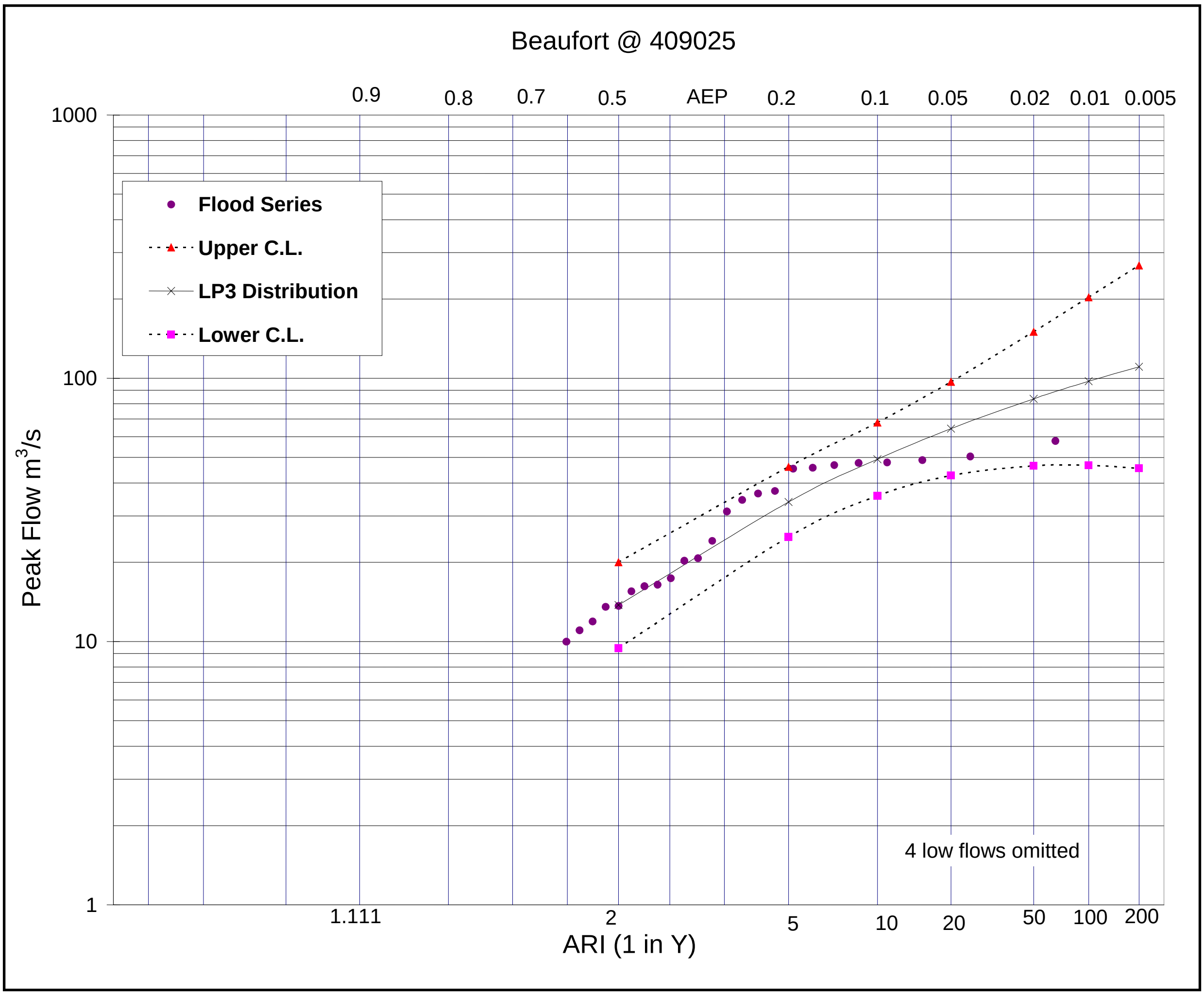

Figure 4-1 Flood Frequency Analysis of the Mt Emu Creek at Mena Park Gauge

Table 4-2 Summary of Flood Frequency Analysis for Mt Emu Creek at Mena Park

ARI (Years)	Peak Design Flow (m^3/s)	5% & 95% Confidence Limits (m^3/s)
5	34	25 - 46
10	49	36 - 68
20	64	43 - 97
50	84	47 - 150
100	97	47 - 203

Significant negative skewness is exhibited in the observed data. The skewness is most likely attributed to the apparent flattening of higher flow events. The study team speculates that this is caused by a catchment reaction (i.e. channel breach and gauge bypass) during high flow events. The use of a relatively short length of streamflow record is reflected in the wide confidence intervals around the design flow estimates. Anecdotal evidence supported by the Beaufort flood scoping study (TGM, 2004) also suggests that a number of significant floods occurred before the installation of the streamflow gauge, ie 1894, 1909, 1939 and 1964. The study team concluded that no reliable estimate of the 100 year ARI event can be derived from the FFA given the poor fit of the LP3 distribution.

4.3 RORB Model Application to the Mt Emu Creek and Yam Holes Creek Catchments

4.3.1 Background

The runoff-routing model RORB, developed by Laurenson and Mein (1975), was used to estimate the design flood hydrographs for the Mt Emu Creek at Mena Park, together with the Ding Dong, Yam Holes, Cemetery and Cumberland Creeks at Beaufort.

RORB is a general runoff and streamflow routing program that calculates flood hydrographs from rainfall and other catchment characteristics. The model subtracts losses from rainfall to determine surface runoff, which is then routed through a network of storages to produce flood hydrographs at points of interest. RORB is an areally 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.

The model is based on catchment geometry and topographic data. RORB has two principal parameters, k_c and m. The parameter m describes the degree of non-linearity of the catchment's response to rainfall, while the parameter k_c describes the storage available with the catchment. The rainfall loss parameters relate to the conversion of rainfall into surface runoff. The RORB model can represent these losses either by the initial-loss/continuing-loss model, or by the initial-loss/volumetric-runoff-coefficient model. The catchment is divided into sub-areas based on topographical features. This catchment sub-division allows for spatial variation of catchment characteristics and rainfall inputs.

Given that no stream flow data exists for the Yam Holes Creek Catchment, two RORB models were developed for this hydrological assessment. The Mt Emu Creek model has been developed in order to run a number of calibration events which will enable the selection of appropriate catchment parameters k_c and m and the magnitude of design loss parameters. Subsequently a RORB model for the Yam Holes Creek catchment at Beaufort was developed, drawing on scaled parameters from the Mt Emu Creek model calibration.

4.3.2 RORB model development

4.3.2.1 Background

The RORB model of the Mt Emu Creek catchment was developed by dividing the area into a number of sub-catchments based on topography and drainage characteristics. For design flood estimation purposes all reach types within the catchment were assumed natural. Figure 4-2 depicts the conceptual structure of the Mt Emu Creek RORB model, illustrating the sub-catchment delineation and stream network structure.

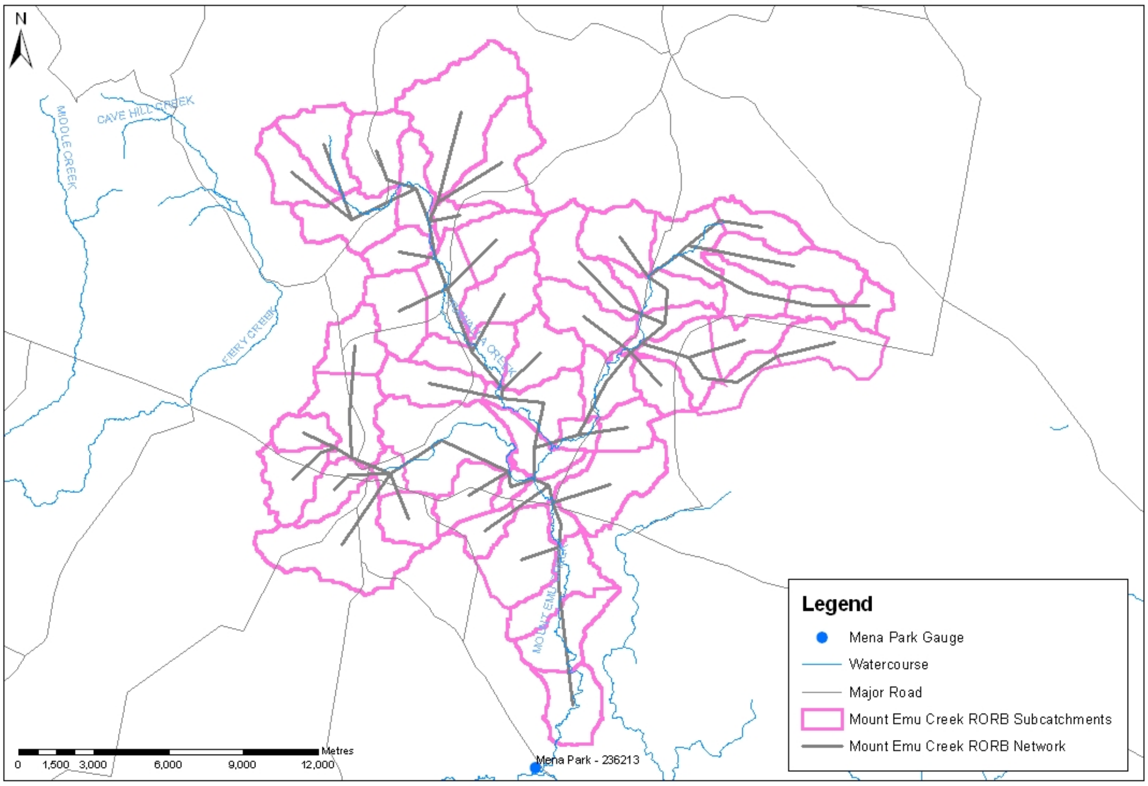

Figure 4-2 RORB Model Sub-catchment Delineation Mt Emu Creek- Mena Park Gauge

Given that the Yam Holes Creek catchment lies within the Mt Emu Creek catchment, it is reasonable to assume that the two would share very similar *kc* and *m* values due to their proximity, similar land use and topographic characteristics. Figure 4-3 presents the RORB catchment delineation for the Yam Holes Creek at Beaufort.

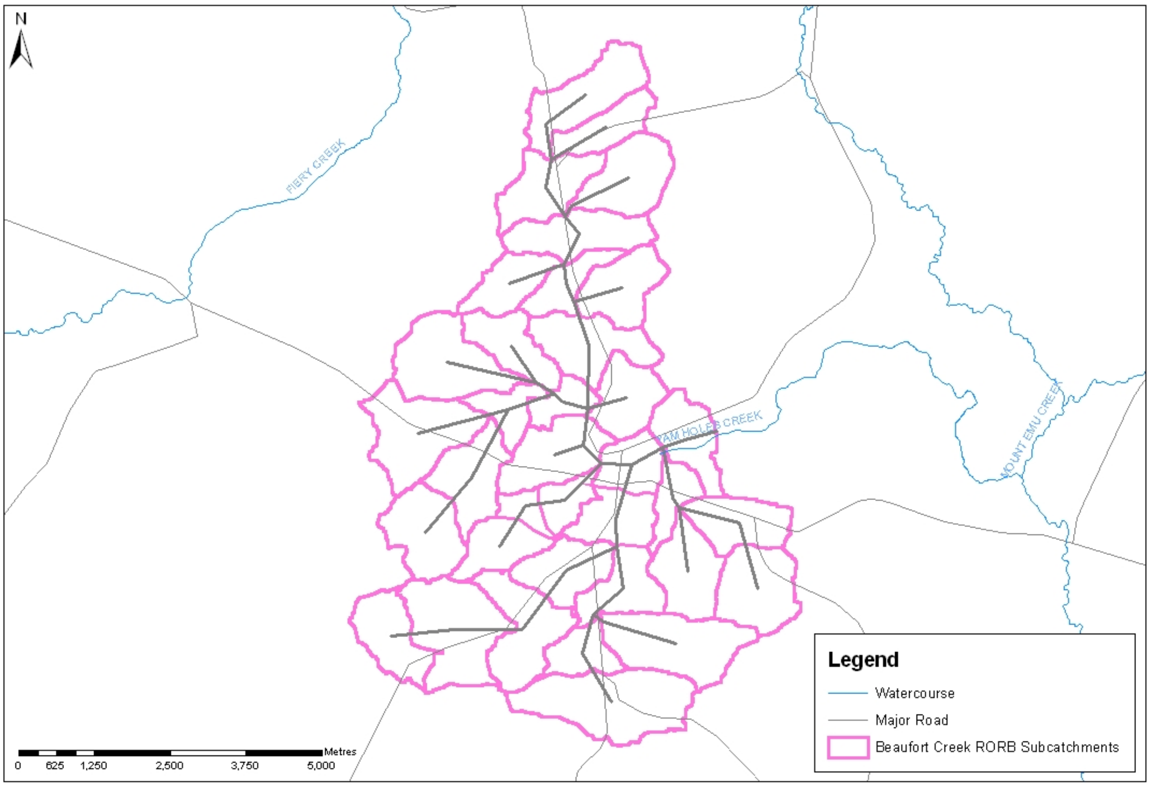

Figure 4-3 RORB Model Sub-catchment Delineation Yam Holes Creek Catchment

4.3.2.2 RORB model parameter selection approach

The selection of appropriate RORB model parameters ideally requires calibration through the comparison of the modelled flood hydrographs with observed flood hydrographs at streamflow gauge(s) throughout the study catchment. The selection of suitable historical flood events for RORB model calibration is, however, also dependent on the availability of concurrent streamflow and pluviographic rainfall data. There are two pluviographic stations on which to base the RORB model assessments for the Mt Emu and Yam Holes Creek catchments; Beaufort Sheepwash and Ballarat Aerodrome. These two stations were used in the calibration of the Mt Emu Creek RORB model to historical streamflow data. The calibration events used were in 1979, 1983 and 1989.

The flood frequency analysis on the 39 year annual series for Mt Emu Creek is not considered to provide a good estimate of the magnitude of larger flood events. However, given the frequency and number of observed smaller order events, the 5 year ARI flood is considered to give a good representation of more frequent flooding on which to base initial assessment.

4.3.2.3 Design rainfall depths

Design rainfall depths were calculated for the 1 in 20, 50 and 100 year events using the Intensity-Frequency Duration (IFD) procedures outlined in Australian Rainfall and Runoff (AR&R, 1987). The IFD parameters are listed in Table 4-3 below.

Table 4-3 Yam Holes Creek Catchment IFD parameters

IFD Parameter	Value
1 hour duration 2 year ARI	18.19
12 hour duration 2 year ARI	3.83
72 hour duration 2 year ARI	0.97
1 hour duration 50 year ARI	40.00
12 hour duration 50 year ARI	7.00
72 hour duration 50 year ARI	1.94
Regional skew G	0.37
Geographic factor F2	4.34
Geographic factor F50	14.81
Zone	6

4.3.2.4 Areal reduction factor

The Siriwardena and Weinmann (AR&R, 1987) areal reduction factor was applied. This computed to be 0.97 for the 47 km^2 Yam Holes Creek catchment.

4.3.2.5 Design temporal patterns

The design filtered temporal patterns from AR&R (1987) were used. Detailed discussion of the temporal patterns adopted is provided in Section 4.3.4.2.

4.3.2.6 Design spatial patterns

Due to the size of the catchment, a uniform spatial rainfall pattern (i.e. same rainfall depths applied to the entire catchment) was adopted for the generation of design flood hydrographs.

4.3.3 RORB model parameter selection and verification

4.3.3.1 Overview

For the RORB modelling, the Initial Loss/Continuing Loss model was chosen. This is a broadly accepted approach for rural catchments where published data on initial/continuing loss parameters is readily available.

The following approach was adopted to determine the RORB model parameters (*kc* & *m*) and design loss parameters, initial loss (IL) and continuing loss (CL) for the Yam Holes Creek catchment:

- Three historical flood hydrographs were simulated to provide an indication of the general hydrograph shape and volume for the Mt Emu Creek Gauge at Mena Park. This allows comparative loss estimations to be investigated and *kc* and *m* values to be verified for use in the RORB model for the Yam Holes Creek Catchment.
- Sub-catchment averaged rainfalls derived from a number of daily rainfall stations situated around the Mt Emu Creek and Yam Holes Creek catchment were analysed to provide an indication of the historical event rainfall depths. Pluviograph data was also analysed to provide accurate storm durations and temporal patterns.
- Rainfall losses were adjusted to provide an appropriate rainfall to rainfall-excess ratio for Mt Emu Creek. This ensures that the right amount of runoff occurs from the catchment (irrespective of matching flow peaks at this stage).
- The RORB model parameter *kc* was adjusted to provide a broadly similar initial response, peak, volume and recession in the modelled hydrographs for the Mt Emu Creek catchment. The parameter *m* was adopted as 0.8. This value is a generally accepted value for the degree of non-linearity of catchment response (AR&R, 1998).
- The measured flow data was not adjusted for base flow as no significant base flow was apparent in the Mena Park gauge records.
- RORB model parameter *kc* was appropriately scaled from the Mt Emu Creek calibrated model and applied with the same *m* and losses as adopted for the Mt Emu Creek model.

Available rainfall and streamflow data for the Mt Emu Creek catchment was employed to inform the selection of appropriate RORB model parameters. The study team considers that this approach provides for more representative design flood hydrographs for the Yam Holes Creek catchment than would be provided by the adoption of a solely regional-based equation methodology for the following reasons:

- For a given depth of rainfall, a similar ratio of rainfall is converted to streamflow in the model as is observed for the catchment under historical flood flow conditions, this would be expected to be matched closely in the neighbouring Yam Holes Creek catchment.
- The model reproduces similar critical storm durations observed in the catchment.
- Similar hydrograph durations observed in the catchment are reproduced by the model.
- For a given depth of rainfall and approximate storm duration, the modelled peak flow is similar to that observed for historical events.

4.3.3.2 Mt Emu Creek routing parameter selection

Three historical events were used to calibrate the model parameters for the Mt Emu Creek RORB model. Each event is unique in its characteristic flow duration and catchment response, as is briefly described below.

January 1979 – This event occurred in response to one of the highest rainfall totals recorded in the catchment, which was around 95 mm over a 24 hour period. The gauge at Mena Park registered a modest peak flow of 15 m^3/s. This emphasises the impact of antecedent conditions on flood response.

September 1983 – This event produced between 60-75 mm across the catchment over several days. The gauge at Mena Park registered one of the highest flows on record with a peak observation of 57 m^3/s. The most informative characteristic of this event was the very wet antecedent conditions of the catchment, with a main rainfall burst of only 30 mm of rain instigating a significant response in streamflow.

May 1989 – This event produced approximately 40-45 mm of rain over a 24 hour period. The gauge at Mena Park recorded a peak instantaneous flow of approximately 13 m^3/s.

Due to the three different calibration scenarios used for verification of the *kc* and *m* parameters, considerable variation was found in the IL and CL for these events. Anecdotal evidence regarding antecedent conditions provides an additional verification for IL and CL development.

The RORB model parameters and rainfall losses developed from the approximation of historical floods are displayed in **Table 4-4**.

Table 4-4 Calibrated RORB Model Parameters for Mt Emu Creek to Mena Park

Historic Flood Event	Calibrated RORB Model Parameter			
	kc	***M***	**IL(mm)**	**CL(mm)**
1979	29	0.8	25.0	12.0
1983	38	0.8	15.5	0.6
1989	40	0.8	10.0	2.0

The calibration resulted in three sets of routing parameters. Only one *kc* may be used for the generation of design flood hydrographs so a representative value must be selected. The 1983 and 1989 calibration events are thought to be the most suitable due to their low loss values. This indicates very damp antecedent conditions in the catchment and is consistent with anecdotal evidence as both years are widely reported as particularly wet. Figure 4-4, Figure 4-5 and Figure 4-6 illustrate the calibrated hydrographs of the RORB model calibration for each of the calibration events.

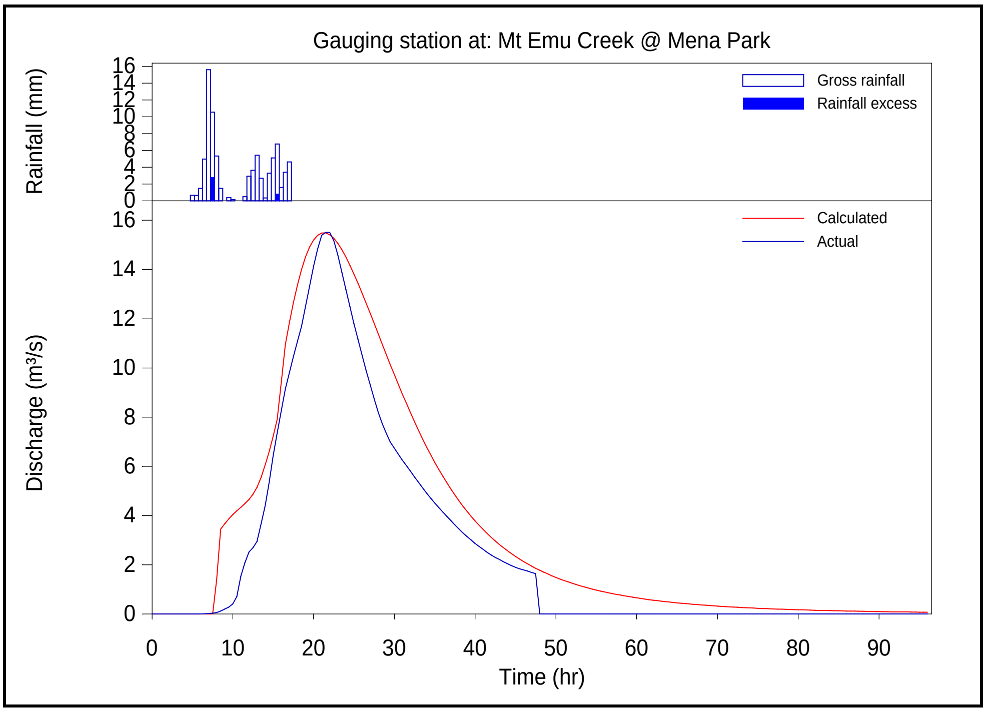

Figure 4-4 RORB Hydrograph January 1979

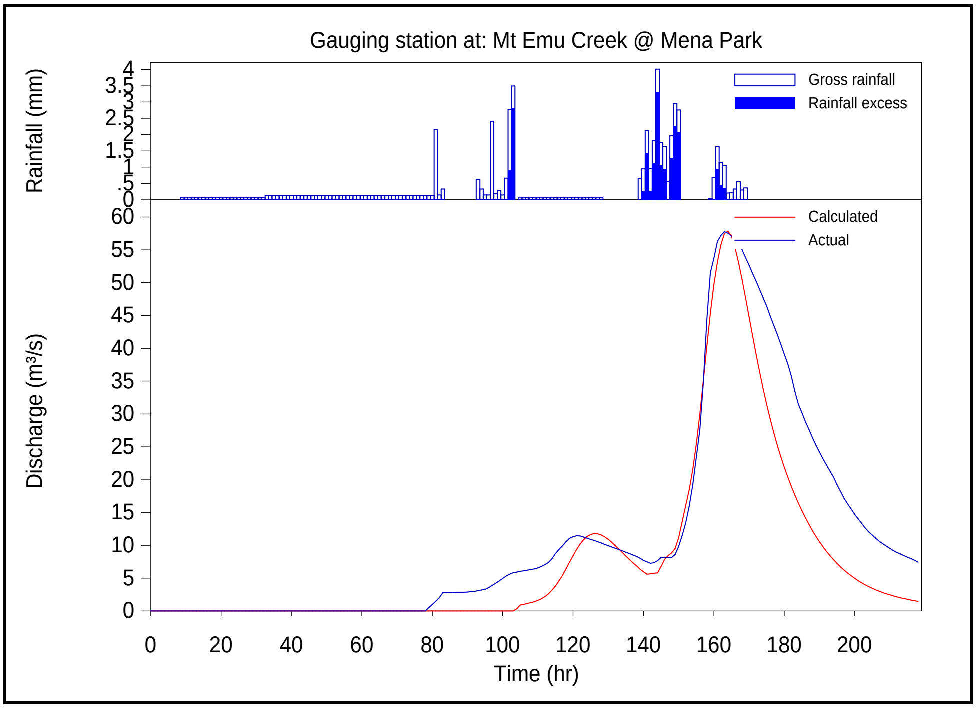

Figure 4-5 RORB Hydrograph September 1983

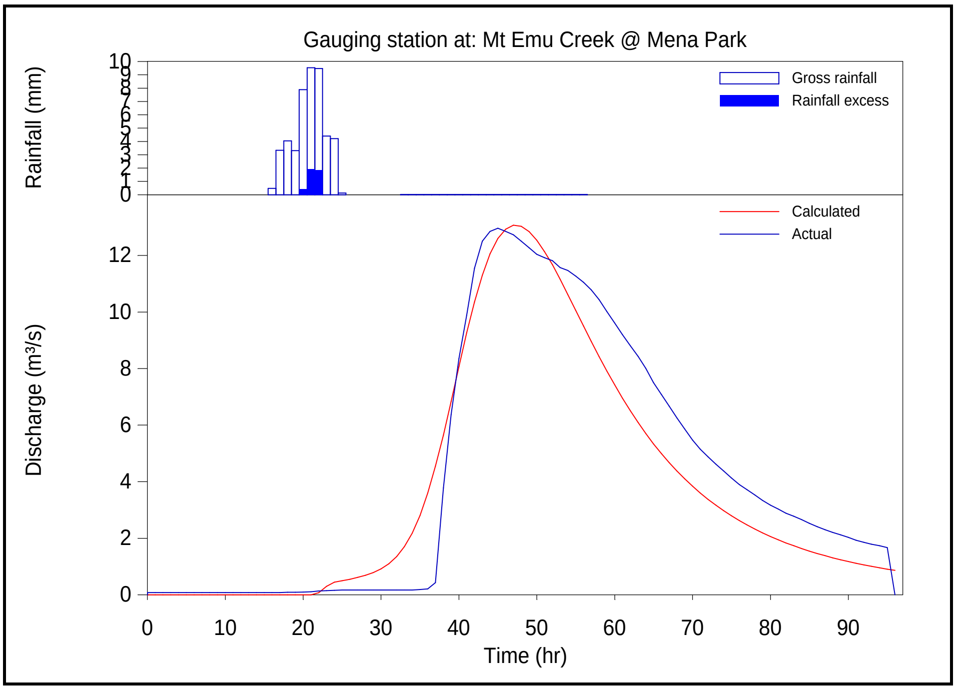

Figure 4-6 RORB Hydrograph May 1989

4.3.3.3 Design rainfall loss estimation

The selection of design rainfall losses has a significant impact on the magnitude of design flood estimates. As the flood magnitudes employed in the calibration of the RORB model are significantly smaller than the magnitude of the design floods to be estimated, loss values derived from the calibration are not considered applicable for design flood estimation.

Subsequently it was decided to determine design loss values based on regional regression relationships. The study team have adopted the methodology developed by Hill et al. (1996). This methodology requires the estimation of storm initial loss (IL_s) along with continuing loss (CL) and then burst initial loss (IL_b). Burst initial loss accounts for the embedded nature of rainfall bursts within larger storms used to calculate design rainfall in AR&R (1998). Burst initial loss is used for design flood estimation as opposed to the storm initial loss.

Application of the above methodology produced the design loss estimates shown in **Table 4-5** for use in the RORB simulation of design events.

Table 4-5 Design Flood Loss Parameters

Initial Loss	Continuing Loss
19.75 mm	1.0 mm

4.3.3.4 Yam Holes Creek routing parameter selection

When the Mt Emu Creek RORB model was satisfactorily calibrated, the model routing parameters (*kc* and *m*) were scaled for use in the Yam Holes Creek model. The scaling of the parameters was based on the average routing distance (D_{av}) of the models. **Table 4-6** presents the D_{av} of both Mt Emu Creek and Yam Holes Creek RORB models.

Table 4-6 RORB Model Average Routing Distance

RORB Model	Average Routing Distance (D_{av})
Yam Holes Creek (YHC)	4.9 km
Mt Emu Creek (MEC)	22.4 km

Using the calculated average routing distances, the calibrated Mt Emu Creek routing parameter (kc) was scaled for the Yam Holes Creek catchment. The scaling process is as follows:

$$D_{av(YHC)}/ D_{av(MEC)} = kc_{(YHC)}/kc_{(MEC)} \quad (1)$$

$$kc_{(YHC)} = kc_{(MEC)} * D_{av(YHC)}/ D_{av(MEC)} \quad (2)$$

$$= 40 * 4.9/22.4$$

$$= 8.8$$

The scaled kc for Yam Holes Creek was calculated to be 8.8. This *kc* was subsequently utilised for the generation of design flood hydrographs

.

4.3.4 Discussion

4.3.4.1 Design RORB parameters

Analysis of daily rainfall records and historic flood hydrographs provides useful information on the rainfall runoff characteristics of the catchment. The rainfall runoff characteristics developed from this analysis have been used to inform the selection of appropriated RORB model parameters for the Mt Emu Creek catchment. These have then been scaled for production of the design hydrographs utilising the Yam Holes Creek RORB model.

It is recognised that the methodology employed to select the RORB model parameters assumes a *neutral probability* relationship between rainfall ARI and streamflow ARI exists. In practice, however, this is not always the case due to the complex effects of antecedent catchment conditions on flood flow generation.

The three calibration events clearly illustrate the very significant effect of antecedent catchment conditions with particular regard to catchment losses. In addition to soil moisture processes, floodplain storage may have a significant impact on flooding as most large historical floods have tended to follow periods of considerable rainfall and catchment wetness.

Despite the effort applied to the hydrologic analysis, considerable uncertainty remains in the adoption of appropriate RORB model parameters for the Yam Holes Creek catchment RORB model. Due to the imprecise nature of the parameter selection approach, various RORB model parameters could be modified to produce broadly similar results as has been produced with the parameters developed. However it is considered that the calibration process for the Mt Emu Creek model has provided a reasonable basis for describing the runoff generation process within the Mt Emu and Yam Holes Creek catchments.

4.3.4.2 Design temporal patterns

The adoption of scaled RORB model parameters for design flood modelling using the Yam Holes Creek RORB model is expected to provide reasonably reliable design flood estimates for the streams flowing through Beaufort.

The centroid of the Yam Holes Creek catchment resides in Zone 6 of the temporal pattern map provided by the BoM in AR&R (1987). However, the study is in close proximity to the boundary between Zone 6, Zone 1 and Zone 2. The design temporal pattern selected for rainfall-runoff modelling can have significant influence on the design flood magnitudes produced. To test the sensitivity of the RORB model output, the temporal patterns associated with the three different Zones above were trialled and their impact on design flood hydrographs noted. The results of this analysis are given in Table 4-7 and show that the Zone 1 and Zone 6 temporal patterns result in higher 100 year ARI design flood peaks than Zone 2 for Yam Holes Creek at Beaufort.

From inspection of the Temporal Zone Map in Volume 2 AR&R (1987) it could be argued that the study area, which is situated on the southern slopes of the Great Dividing Range in Central Victoria, is more closely related to catchments in Zone 1 than Zone 6. In order to further investigate the impact of temporal patterns on design flows and the adoption of Zone 1 for use in design hydrograph development, a Monte Carlo analysis was undertaken in RORB using a range of temporal patterns derived from historical pluviograph data.

The Monte Carlo (MC) analysis function available in RORB involves drawing on historical rainfall events from a local pluviograph to develop a distribution of temporal patterns from which individual patterns can be iteratively selected and tested. The results of such an assessment therefore return a distribution of flood peaks in contrast to the single peak returned by the conventional approach utilising the design temporal pattern suggested by AR&R (1987).

Utilising the temporal pattern extraction tool provided in RORB, the pluviographic record for the Sheepwash station was analysed and historic events of various durations extracted. A MC analysis was then undertaken for the Yam Holes Creek catchment. The MC result is presented in Table 4-7 together with the conventional design temporal pattern results.

Table 4-7 Design Temporal Pattern Analysis for Yam Holes Creek at Beaufort

Event	Zone 6	Zone 1	Zone 2	MC Analysis Sheepwash Pluviograph
100 year ARI	122.4 m^3/s (36 hour)	123.3 m^3/s (36 hour)	102.2 m^3/s (30 hour)	126.3 m^3/s (18 hour)

The MC analysis indicates that the Zone 1 design temporal pattern results match closest to the output based on the local pluviograph record. Therefore, based on the MC results and consideration of the catchment location, Zone 1 temporal patterns were utilised for the generation of design flood hydrographs for Beaufort.

4.4 RORB design flood estimates

The RORB model parameters developed were used to estimate design flows for the Yam Holes Creek Catchment over a number of ARIs. The design flood RORB model parameters are presented in Table 4-8.

Table 4-8 RORB Design Flood Parameters

RORB Routing Parameter	Rainfall Loss Parameters (mm)	
kc	***IL***	***CL***
8.8	19.75	1.0

Table 4-9 lists relevant characteristics of the design flood hydrographs generated. This shows that critical durations for the different sub-catchments are 9 hours for the smaller catchments and 36 hours for the larger areas, depending on the ARI. In order to provide results with a consistent ARI throughout the study area, boundary conditions for both the 9 and 36 hour duration storms were extracted for later simulation in the hydraulic model. The locations for the boundary condition for each sub-catchment are shown in Figure 5-3 in section 5.3.3.

Table 4-9 RORB Design Flood Estimates

ARI	Tributary	Yam Holes North	Yam Holes West	Ding Dong	Cemetery Creek West	Cemetery Creek East	Cumberland East	Cumberland South	Model Outlet
5 year	Peak (m^3/s)	14.2	11.7	2.9	8.3	8.3	4.3	3.6	56.3
	Duration	36 hr	36 hr	9 hr	36 hr	9 hr	36 hr	9 hr	36 hr
10 year	Peak (m^3/s)	17.6	14.9	3.7	10.1	11	5.7	4.7	68.0
	Duration	36 hr	9 hr	9 hr	36 hr	9 hr	9 hr	9 hr	36 hr
20 year	Peak (m^3/s)	22.1	19.5	4.8	12.9	14.4	7.5	5.9	85.1
	Duration	36 hr	9 hr	9 hr	36 hr	9 hr	9 hr	9 hr	36 hr
50 year	Peak (m^3/s)	26.3	25.1	5.8	16.6	18.3	9.5	6.9	104.3
	Duration	36 hr	9 hr	9 hr	9 hr	9 hr	9 hr	9 hr	36 hr
100 year	Peak (m^3/s)	30.9	30.1	6.9	20.1	21.7	11.3	8.1	123.3
	Duration	9 hr	9 hr	9 hr	9 hr	9 hr	9 hr	9 hr	36 hr

4.5 Design Flood Estimates - Discussion

The hydrological analysis undertaken has highlighted the uncertainty that exists in determining appropriate design flows for the Yam Holes Creek and tributaries. The approaches employed to estimate the magnitude of the design flows for Mt Emu Creek are discussed below.

The FFA undertaken in section 4.2 for the Mena Park gauge uncovered an inconsistency in the gauging of high flows. It appears that during extreme flows a characteristic of the catchment causes a plateau in flow gauging. This suggests that a possible channel breach and overflow occurs during large events upstream of the gauge. Thus, the results from the FFA are not considered suitable for use in verifying generated design flows, as large flood events are not accurately gauged.

A RORB model for the Yam Holes Creek catchment at Beaufort was developed and design flows produced. The RORB model produces peak flow estimates that are considered reasonable and representative, with consistent critical durations across the various contributing waterways.

Based on the observations above and results of the parameter selection and validation exercises in the development of the RORB model, the study team consider the design flood estimates produced by the RORB model for Beaufort as the best available estimate of design flow magnitudes (both in terms of peak flow and volume).

Given the uncertainty in their development, analysis of the sensitivity of the design flood estimates on the study outcomes is warranted. It is considered, however, that while the analysis of the sensitivity of hydrologic model parameters provides an indication as to the possible range of design flood estimates for Beaufort, it does not in itself provide a good indication of the reliability of the study outcomes (flood extent and depth). It is suggested that the hydraulic model of the study area can provide more meaningful results for quantifying the sensitivity of the study outcomes (such as flood height) to changes in design flows. This sensitivity analysis is discussed in the following hydraulic modelling section of the study report (Section 5.4.2).

Design flood hydrograph verification was undertaken drawing on a regional estimation technique by Nikolaou and von't Steen (CRC-CH, 1996). Table 4-10 presents the results of the design flood peak verification.

Table 4-10 Design Flood Hydrograph Verification for the Yam Holes Creek Catchment

Design Flood ARI (years)	RORB Model Peak Discharge (m^3/s)	Regional Equation[1] (m^3/s)
5	56.3	--
10	68.0	--
20	85.1	--
50	104.3	--
100	123.3	91.0

[1] Based on regression equations for 1% flood flows near the Great Dividing Range in Victoria (CRC-CH, 1996)

Table 4-10 illustrates the variability and thus uncertainty in design flood estimates at Beaufort. However, the study team consider the estimates made as part of this study to be the best available considering the limited hydrologic data available for the study area.

4.6 Extreme Flood - PMF Estimation

For the purposes of this study the regression equations for estimating Probable Maximum Floods in South Eastern Australia from Hydrological Recipes (Grayson et al, 1996) have been applied. These regression equations enable the development of a triangular hydrograph by predicting the PMF peak flow, volume and time to peak. The subsequent estimated PMF parameters for the Yam Holes Creek Catchment are provided in Table 4-11. It should be noted that these parameters are approximate only and should be considered as indicative. Definition of more accurate PMF values would require a significant effort that is not required for the present study purposes.

Table 4-11: PMF Design Flow Estimates

	Peak Flow (m^3/s)	Hydrograph Volume (ML)	Time to Peak (hours)
Ding Dong Creek	210	1,081	1.1
Cemetery Creek West	437	3,496	1.7
Cemetery Creek East	437	3,496	1.7
Cumberland Creek East	274	1,659	1.3
Cumberland Creek South	179	839	1
Yam Holes Creek North	683	7,130	2.3
Yam Holes Creek West	604	5,853	2.1
Study outlet (total)	1,419	22,915	3.5

5 HYDRAULIC ANALYSIS

5.1 Introduction

A hydraulic model has been developed to investigate the extent of flooding, flood height, and velocities in Beaufort for the design 5 year, 10 year, 20 year, 50 year and 100 year ARI events as well as the PMF flow conditions. This section documents the findings of these investigations.

5.2 Model Description

A numerical hydraulic model of Beaufort and surrounding floodplain area was established to assist in determining flood behaviour. The hydraulic model was developed based on the captured photogrammetry data in addition to terrestrial survey information, providing a detailed description of flood flow distribution and behaviour.

The model used for these assessments was developed using DHI Software's MIKE Flood modelling system. MIKE Flood is a comprehensive modelling package for modelling the complex flow paths often encountered on floodplains. It consists of a two-dimensional model (MIKE 21 – used for analysis of broad scale floodplains) linked to a one-dimensional model (MIKE 11 – used for analysis of river channels). This combination provides a comprehensive range of tools. Of particular relevance to flooding in Beaufort are its capabilities for:

- Floodplain mapping and result animation tools
- Modelling of hydraulic structures eg pipes, culverts, bridges etc
- GIS integration.

5.3 Model Development

5.3.1 Topography

A Digital Elevation Model (DEM) was established primarily using Photogrammetry survey supplied by QASCO, as described in Section 2.4. This information has been supplemented by historic survey plans and more recent field data captured by our survey team. They were then combined with the points and breaklines from the photogrammetry to produce a TIN. The TIN interpolates linearly between the polylines and points to produce a continuous surface. A 1m grid was then produced and elevations read of the TIN for each grid cell. The resulting topography is illustrated in Figure 5-1.

The grid has been compared to permanent survey marks (PSM) within Beaufort and the results are illustrated in

Table 5-1. A positive difference value implies that the PSM has a higher elevation than the TIN. In most instances you would expect the PSM to be lower as they are often situated below the ground surface. In the three highlighted instances where the PSM is significantly higher, the TIN has a high gradient. The discrepancy is likely to be caused by the interpolation. These points are also situated well outside the PMF flood extent and hence do not have an impact on the flood predictions for Beaufort.

Table 5-1: Comparison of Permanent Survey Marks to interpolated Photogrammetry

Name	Easting	Northing	AHD Height	TIN Height	Difference
BEAUFORT PM 2 C359-22	711943.66	5854609.07	389.18	389.429	-0.2494
BEAUFORT PM 14 C359-34	710173.93	5855174.04	388.012	387.891	0.1208
BEAUFORT PM 15 C359-12	710018.75	5854891.29	396.644	396.795	-0.1509
BEAUFORT PM 17 C359-30	710408.83	5855354.9	388.664	388.483	0.1808
BEAUFORT PM 18 C359-29	710544.56	5855037.99	386.634	386.683	-0.0494
BEAUFORT PM 27 C359-23	711935.06	5854378.1	388.115	388.197	-0.0818
BEAUFORT PM 30 1314-12	710432.65	5854833.39	387.563	387.834	-0.2714
BEAUFORT PM 32 A31-1	710698.89	5854828.22	388.477	388.434	0.043
BEAUFORT PM 44 C359-18	711054.4	5855178.09	384.763	384.834	-0.0706
BEAUFORT PM 53 C359-33	710095.5	5855376.93	388.595	388.708	-0.1128
BEAUFORT PM 64 C359-14	710045.46	5854897.1	395.151	395.283	-0.1318
BEAUFORT PM 65 C359-1	710691.08	5854791.73	389.175	389.296	-0.1212
BEAUFORT PM 72 1216-1	711569.7	5855401.11	382.747	382.819	-0.0722
BEAUFORT PM 77 C359-32	710142.45	5855664.74	389.382	389.72	-0.3378
BEAUFORT PM 78 C359-2	710893.49	5854759.91	387.038	386.974	0.0642
BEAUFORT PM 79 C359-5	710810.72	5854248.76	387.845	387.729	0.1156
BEAUFORT PM 80 C359-6	710689.15	5854268.71	392.065	391.612	0.4534
BEAUFORT PM 81 C359-7	710483	5854302.77	395.198	395.312	-0.1138
BEAUFORT PM 82 C359-9	710228.43	5854342.74	396.69	396.708	-0.0178
BEAUFORT PM 83 C359-10	709936.73	5854391.29	393.464	393.379	0.0851
BEAUFORT PM 84 C359-11	710020.37	5854736.26	405.514	404.668	0.8465
BEAUFORT PM 85 C359-13	710018.64	5854901.52	395.961	396.23	-0.2693
BEAUFORT PM 86 C359-31	710419.7	5855619.06	397.406	397.632	-0.2258
BEAUFORT PM 89 C359-19	711955.72	5855344.66	384.763	384.994	-0.2308
BEAUFORT PM 90 C359-21	712007.31	5854994.73	392.236	392.042	0.1939
BEAUFORT PM 91 C359-37	711881.65	5854047.91	391.515	391.359	0.1557
BEAUFORT PM 92 C359-36	711439.83	5854121.92	398.759	398.031	0.728
BEAUFORT PM 93 C359-35	711199.5	5854159.59	398.24	398.457	-0.2166
BEAUFORT PM 94 C359-28	711118.06	5854750.63	385.019	384.97	0.0492
BEAUFORT PM 95 1390-13	711417.11	5854818.06	386.681	386.635	0.0455
BEAUFORT PM 96 C359-24	711590.09	5854656.12	390.362	390.6	-0.2381

5.3.2 Hydraulic Roughness

The hydraulic roughness of the study area was divided into five types, being roads, floodplain, drains, dense vegetation and buildings. Areas with different roughness types were defined by overlaying digital aerial photography in a GIS. The resulting roughness map is shown in Figure 5-2. The adopted values for the model are shown in Table 5-2. These were based on literature and study team experience from previous flood studies.

5.3.3 Boundary Conditions

Beaufort flood flow conditions were established from hydrological modelling discussed in Section 4 Hydrologic Analysis. These comprised a range of design events including the 100 year ARI flood event. There are a total of seven inflow boundaries and one outflow boundary along with another nine small spot inflows within the model.

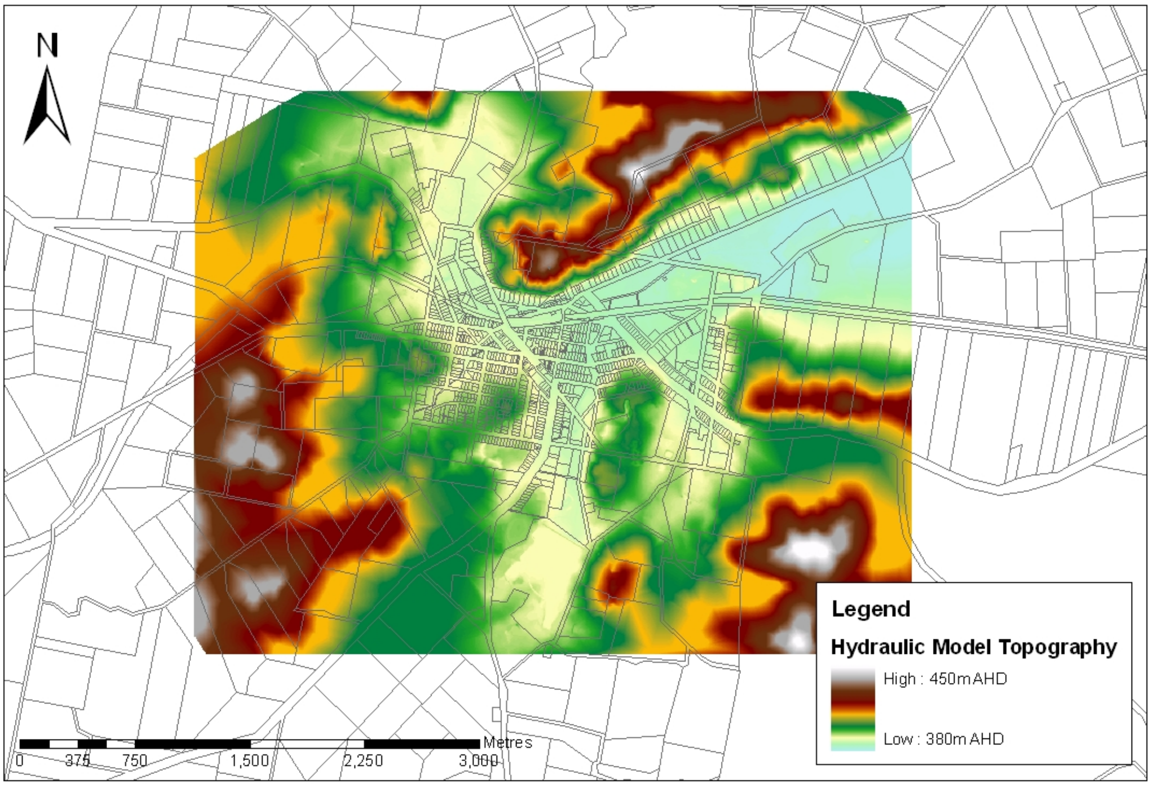

Figure 5-1: Topography for Flood Model

Table 5-2: Hydraulic Roughness Parameters

Land type	Roughness (Manning's "n")
Roads	0.02
Floodplain	0.04
Drains	0.07
Dense Vegetation	0.08
Buildings	0.10

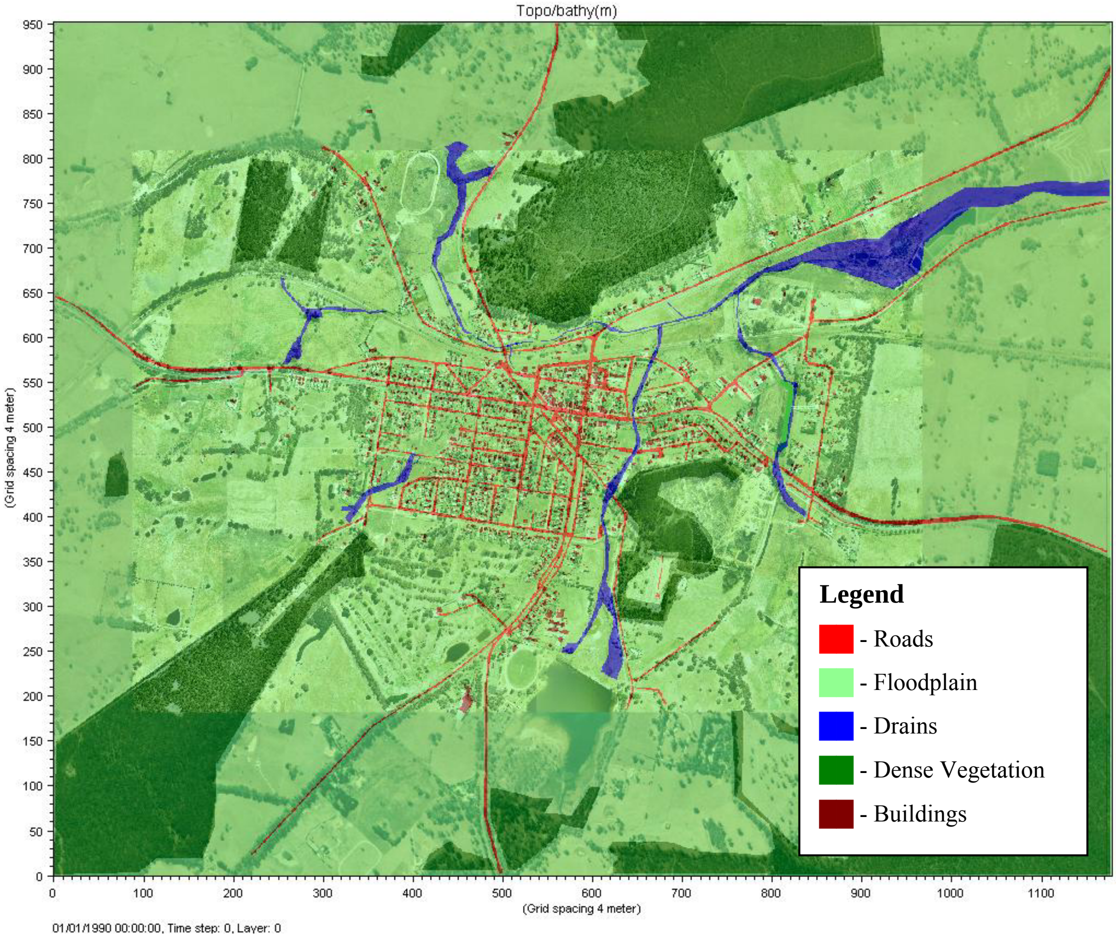

Figure 5-2: Hydraulic Roughness Map for Flood Model

5.3.4 Model Validation

There are no formal records of flooding either in authority archives or gained through community consultation efforts. The three flood marks noted in Table 3-1 were found to be either the result of localised flash flooding or related to unknown flood events. Hence these recorded flood levels were not able to be utilised for model calibration purposes. Subsequently, detailed calibration of the hydraulic model was not possible. However, in lieu of a standard calibration process, anecdotal evidence of flooding patterns at Beaufort from community and council officers has been used to determine the reliability of the predicted flood extents. Draft flood maps were presented to the community during stakeholder consultations for comment and feedback on the patterns of flooding with respect to observed behaviour. Feedback from these sessions suggested that the general pattern of flooding was consistent with the observed behaviour although the extent was greater than expected in some areas. This is not unusual given no extreme flood events (similar in magnitude to the 100 year ARI) are known to have occurred in living memory.

5.4 Design Flood Behaviour

5.4.1 Model Boundary Conditions

Flood flows from the hydrological assessment were used as boundary conditions to the hydraulic model. These flow hydrographs were applied at appropriate locations and allowed to propagate through the model to simulate flood behaviour. Table 5-3 summarises the model flow boundary conditions, with the locations illustrated in Figure 5-3 below.

For the purposes of the design flood analysis, Lake Beaufort has been assumed to be full when the design floods occur. This is a slightly conservative assumption, however it is considered reasonable given:

- The limited regular water extraction from this storage that would draw down the lake
- The likelihood of floods occurring during late winter or spring when lake levels are highest
- The lack of records that would enable a correlation between lake level and catchment flows

Table 5-3: Hydraulic Model - Boundary Conditions, Peak Flow

Location	5 yr 36hr (m^3/s)	5 yr 9hr (m^3/s)	10 yr 36hr (m^3/s)	10 yr 9hr (m^3/s)	20 yr 36hr (m^3/s)	20 yr 9hr (m^3/s)	50 yr 36hr (m^3/s)	50 yr 9hr (m^3/s)	100 yr 36hr (m^3/s)	100 yr 9hr (m^3/s)
Yam Holes Creek Nth	14.2	10.3	17.6	13.9	22.1	18.7	26.3	25.0	30.7	30.9
Yam Holes Creek West	11.7	11.1	14.4	14.9	18.1	19.5	21.6	25.1	25.3	30.1
Ding Dong Creek	2.4	2.9	2.8	3.7	3.4	4.8	3.9	5.8	4.5	6.9
Cemetery Creek West	8.3	7.2	10.1	9.5	12.9	12.6	15.5	16.6	18.3	20.1
Cemetery Creek East	8.0	8.3	9.9	11.0	12.2	14.4	14.3	18.3	16.7	21.7
Cumberland Creek East	4.3	4.3	5.3	5.7	6.5	7.5	7.5	9.5	8.8	11.3
Cumberland Creek Sth	2.5	3.6	2.9	4.7	3.5	5.9	4.0	6.9	4.6	8.1

A Q-h boundary (tailwater condition) has been applied at the downstream boundary for Yam Holes Creek. The assumed Q-h relationship was calculated with a slope of 2% and Manning's "n" roughness of 0.04 and applied to a 1D channel of length of 800 m and a cross sectional profile extracted from the photogrammetry. The purpose of the 1D channel is to minimise the effect of the downstream boundary on the study area by applying a stage discharge relationship representative of the floodplain.

Small additional inflows on top of those mentioned in Table 5-2 were added within the model extent at selected locations along the drainage channels. These represent the additional rainfall that falls within study boundary and contribute only very minor flows.

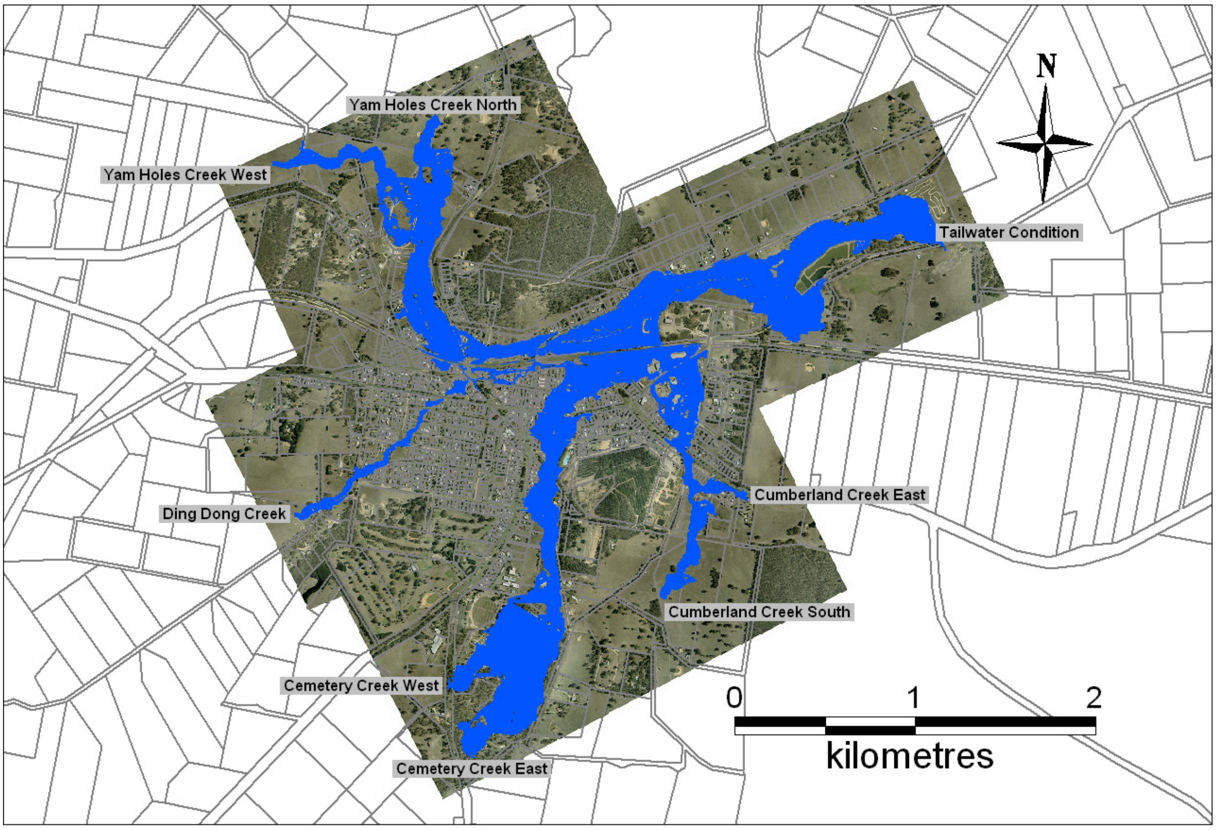

Figure 5-3: Hydraulic Model Boundary Condition Locations

5.4.2 Sensitivity Testing

As described above for the design flood event modelling it was assumed that Lake Beaufort would be full at the beginning of the flood event. In order to test the sensitivity of the model results to this assumption, the model was run for the 100 year ARI and 10 year ARI events with the initial water level in Lake Beaufort set at 0.5 m below the spillway level. The change in initial water level in the lake for the 100 year ARI event had little effect on water levels downstream through the township, with 68% of the floodplain decreasing by less than 0.025cm and 93% by less than 0.05m. For the 10 year ARI event the change was more noticeable, with 55% of the floodplain decreasing by more than 0.1m and 20% decreasing by more than 0.2m. The results from the sensitivity testing are shown in Figure 5-5 and Figure 5-5, which shows the change in water levels through the catchment as a result of 0.5 m reduction in the initial lake level. The 100 year ARI flood inundation depths appear to have been slightly affected along Cemetery Creek and Yam Holes Creek downstream of Cemetery Creek. For the 10 year ARI the affect is more substantial, significantly reducing water levels along Cemetery Creek and Yam Holes Creek, including a minor change on Yam Holes Creek upstream of Cemetery Creek.

Sensitivity testing was also carried out on the effect of a 20% increase in inflows for the whole catchment. The results of this testing can be seen in Figure 5-6. This shows that 40% of the floodplain increased by less than 0.05m in water depth, and 75% increased by less than 0.1m. The majority of the increases occur allow the lower section of Yam Holes Creek, along with minor increases along the upper section of Yam Holes Creek and along Cemetery Creek.

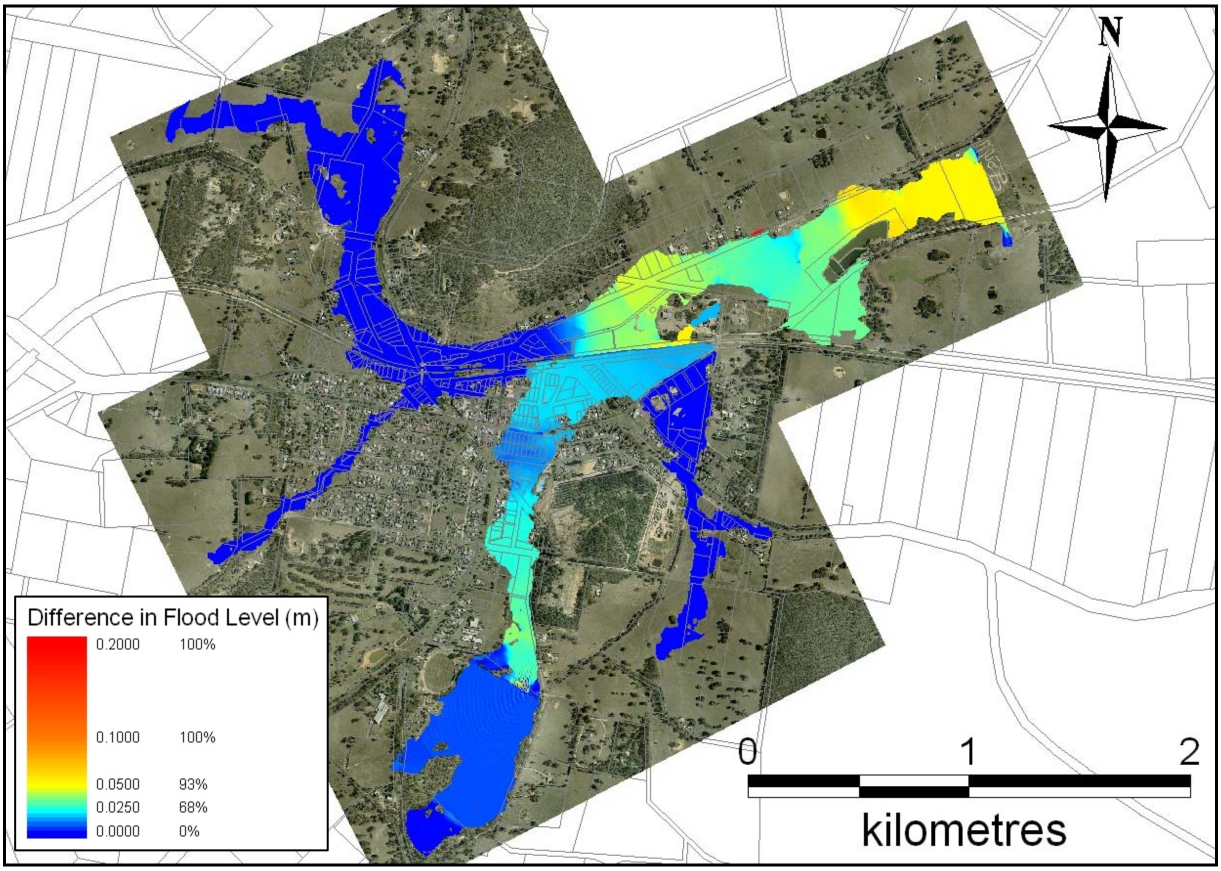

Figure 5-4: Impact on 100 year ARI flood depths of a 0.5 m reduction in initial lake level

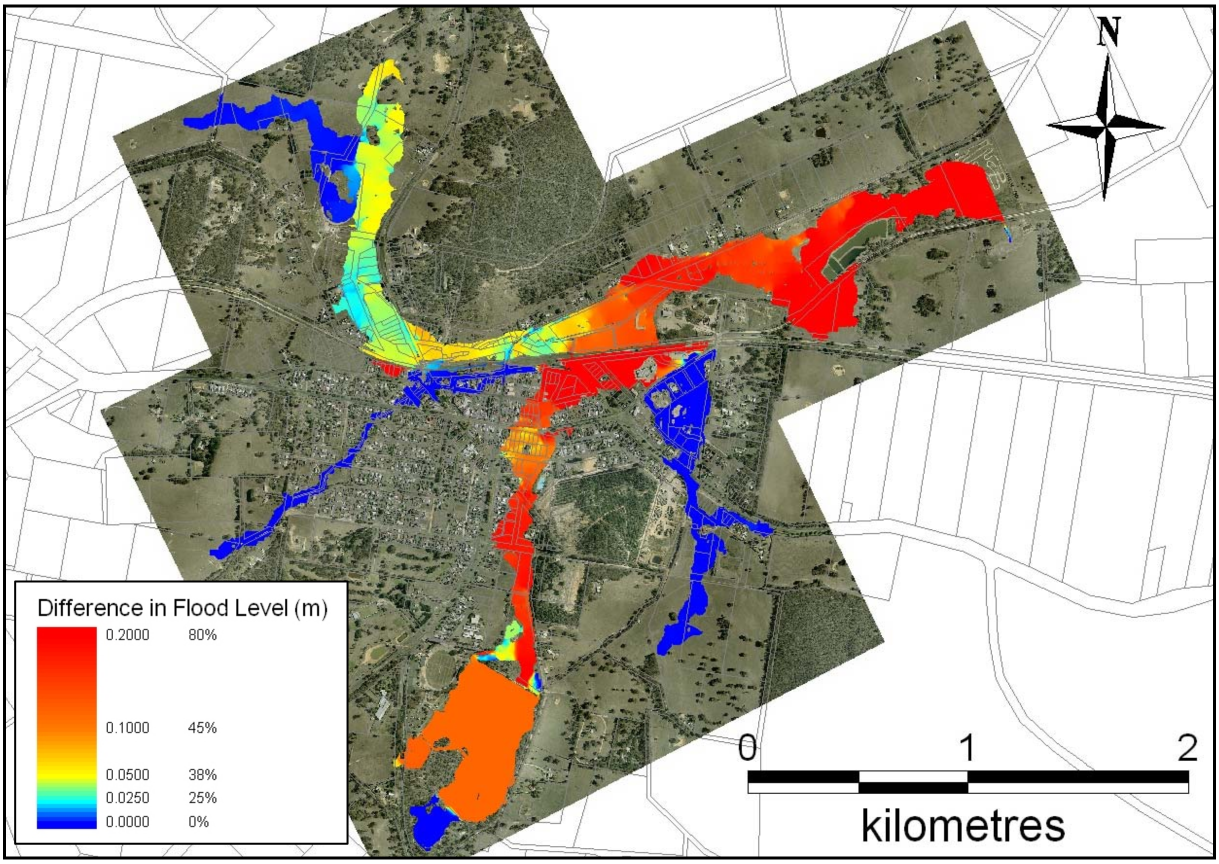

Figure 5-5: Impact on 10 year ARI flood depths of a 0.5 m reduction in initial lake level

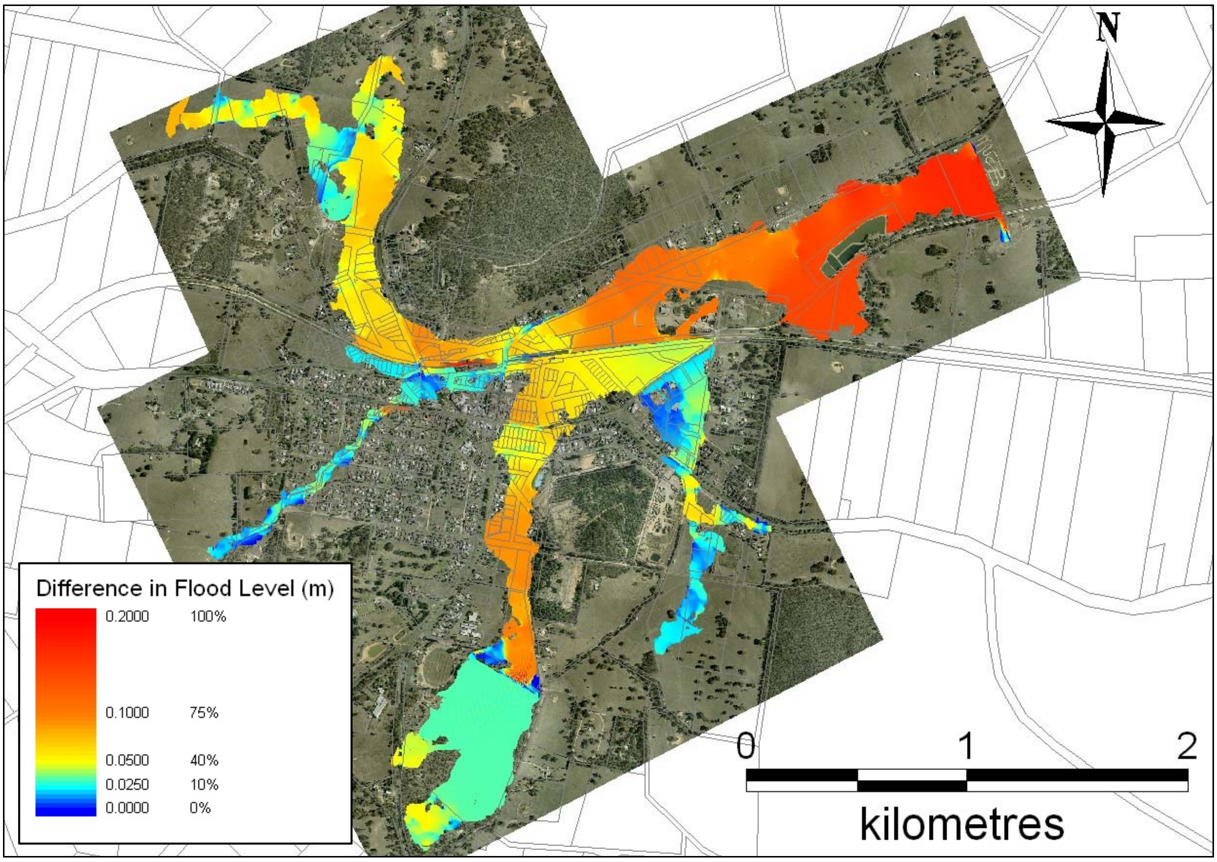

Figure 5-6: Impact on 100 year ARI flood depths of an increase of inflows of 20%

5.4.3 Hydraulic Model Results

The hydraulic model was run for the 5, 10, 20, 50 and 100 year ARI design flood events. Figure 5-7 depicts the results of the 10 year ARI design flood event, and the 100 year ARI is shown in Figure 5-8. Figure 5-9 shows properties flooded above floor level along with their frequency of flooding. These show the areas of most significant flood depth are along Cemetery Creek, the area upstream of the Railway Line and the downstream portion of Yam Holes Creek.

5.4.4 Approximate PMF simulation

In order to provide an indication of the probable maximum flood extent through Beaufort, an approximate PMF simulation was undertaken using the peak PMF flow estimates as described in section 4.6. Table 4-11 gives the peak inflows for the PMF event. A plot of flood extent and depth for the PMF event is shown in Figure 5-10. This shows there is a significant increase in both flood depth and extent relative to the 100 year ARI design flood event. This is reasonable since the PMF is what can be expected from the most severe combination of meteorological and hydrological conditions that are reasonably possible.

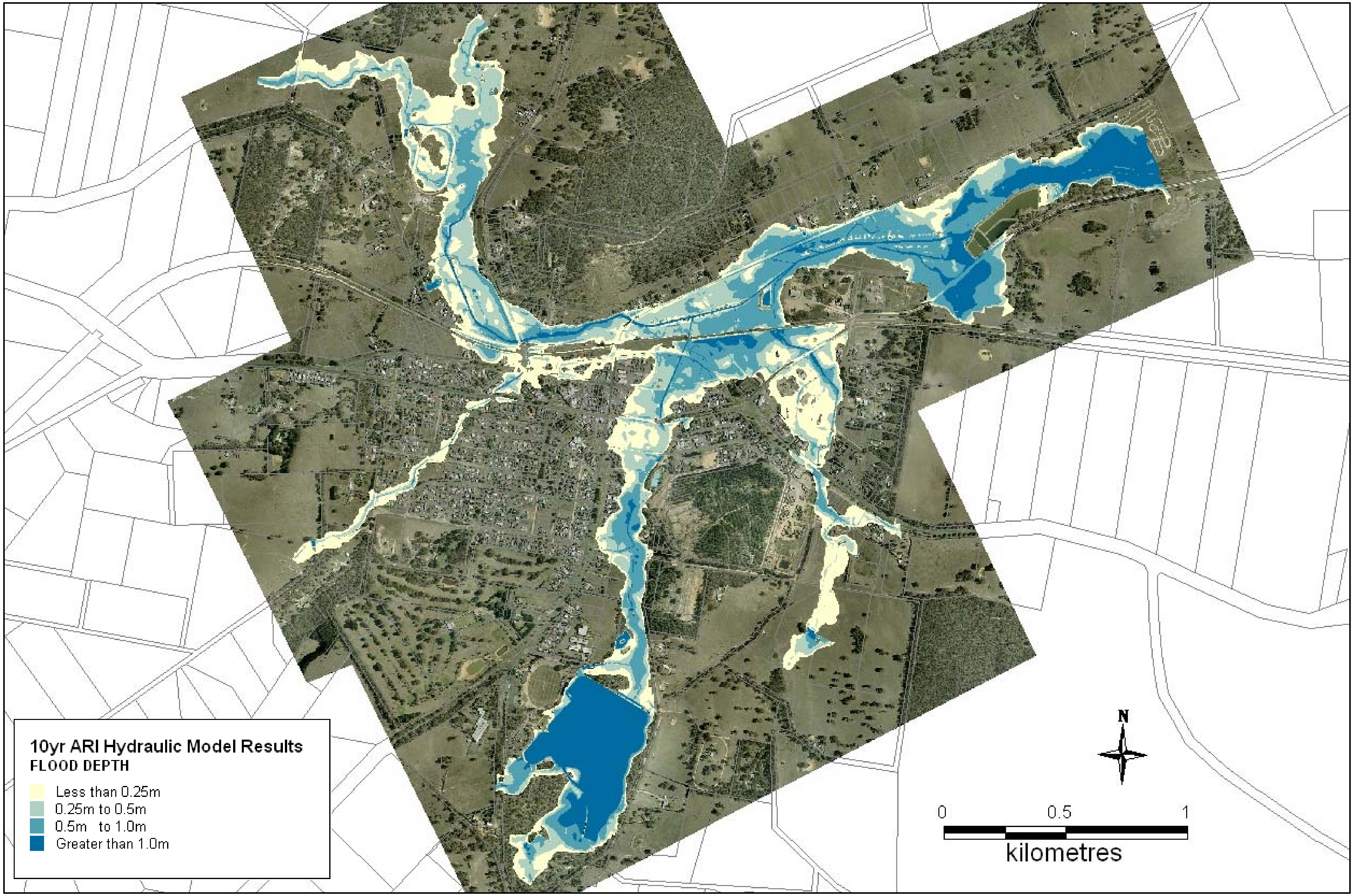

Figure 5-7: Design 10 Year Flood Inundation Depth

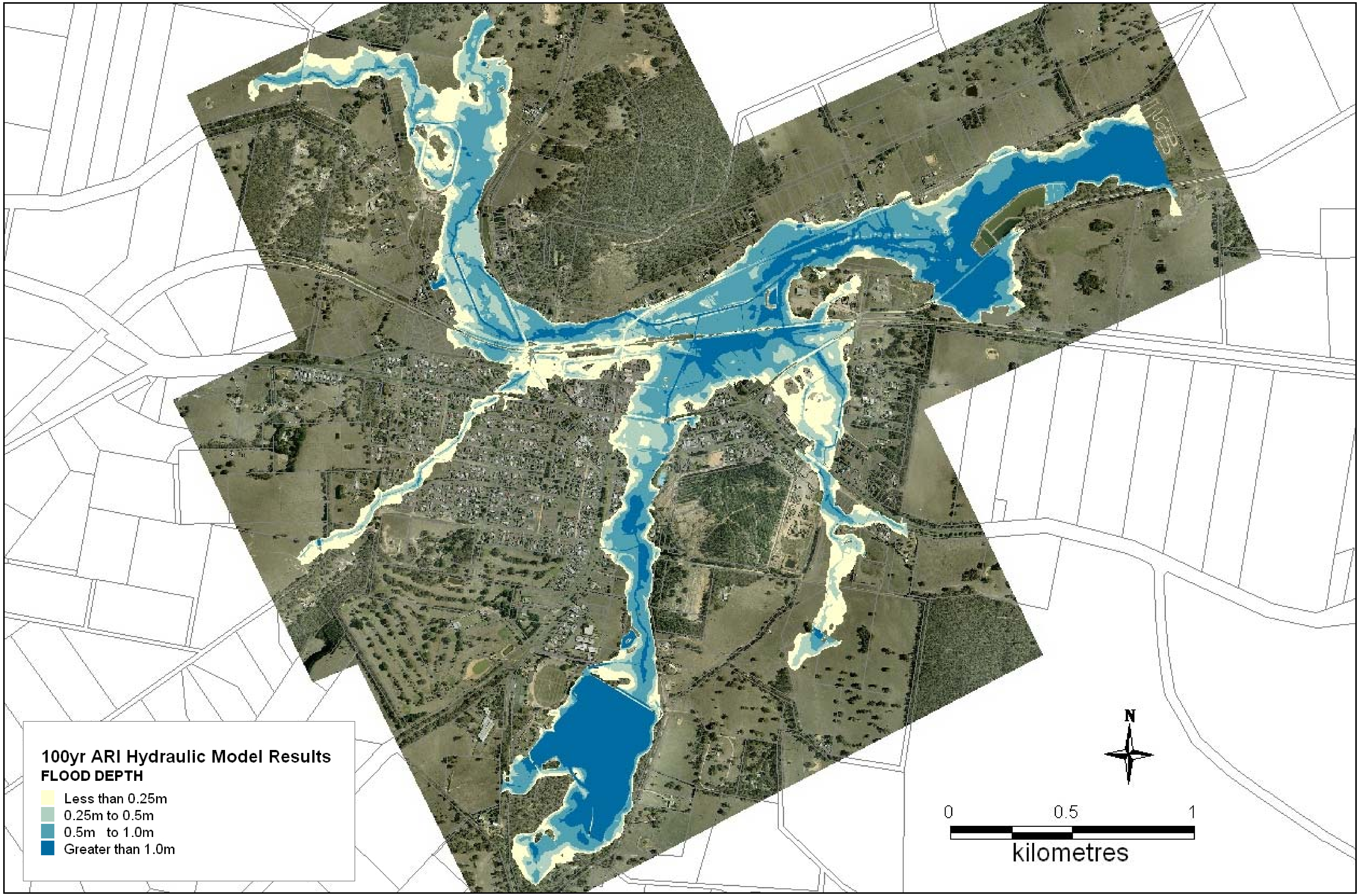

Figure 5-8: Design 100 Year Flood Inundation Depth

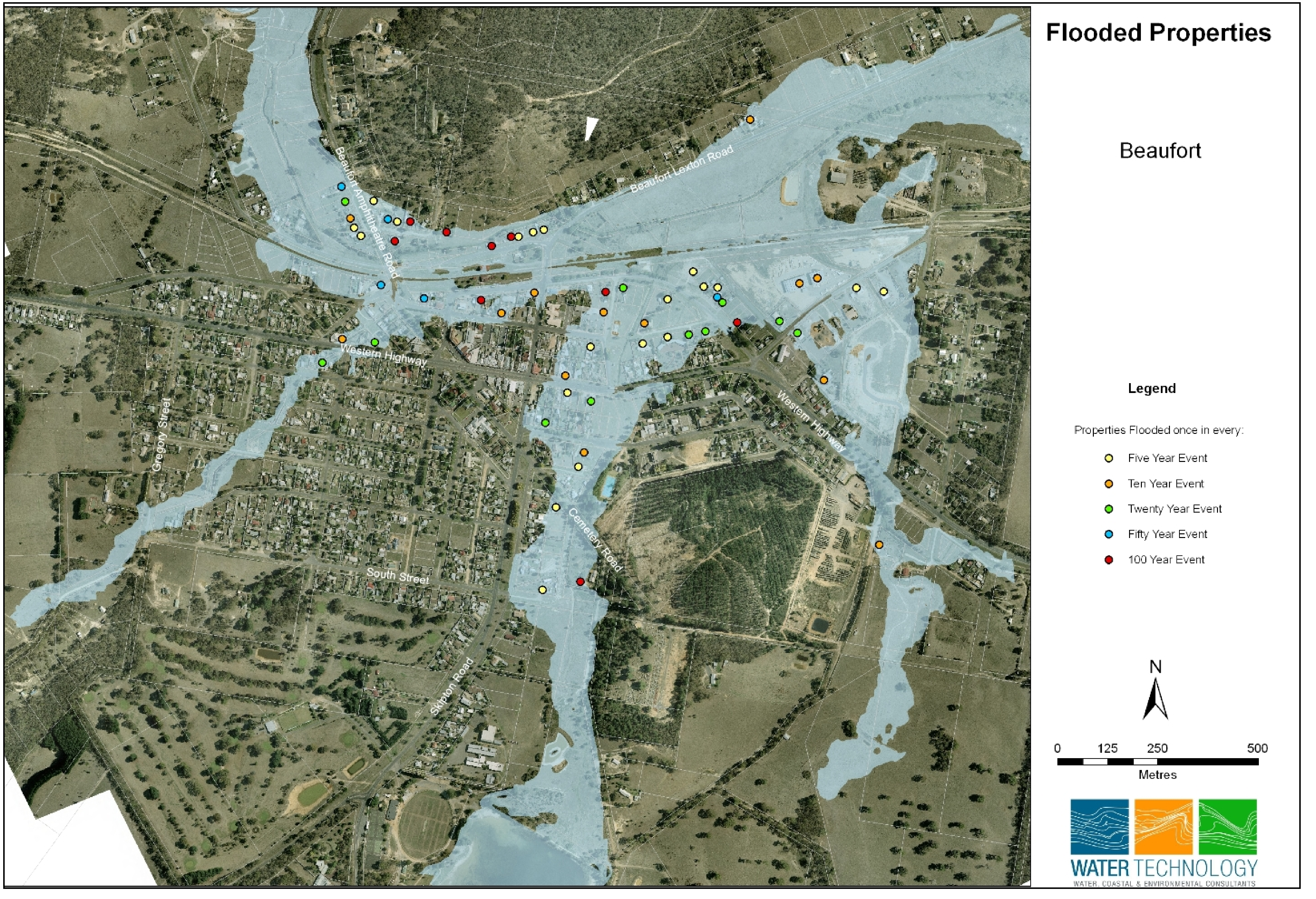

Figure 5-9: Locations of flooded properties in Beaufort with frequency of flooding

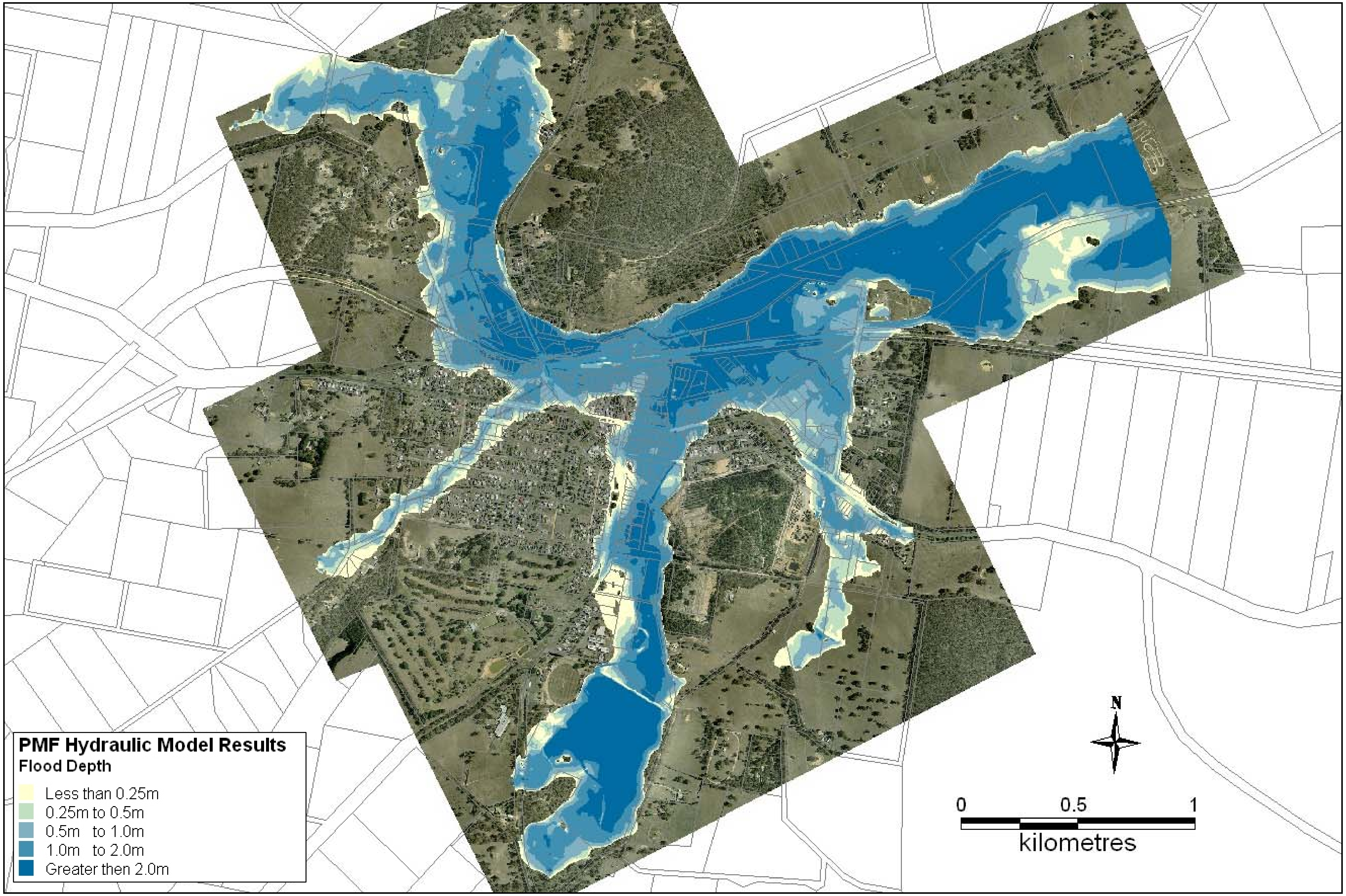

Figure 5-10: Design PMF Flood Inundation Depth

5.5 Discussion

The model results indicate the area south of the railway line in the Cemetery Creek and Cumberland Creek catchments is the most flood-affected area within Beaufort. A large amount of water pools in this area due to the limited culvert and bridge structures that restrict water movement through the railway line. There is a difference in water surface in the 100 year ARI event of approximately 0.5 m at the railway bridge on Cemetery Creek, and approximately 0.8 m difference though the culverts on Cumberland Creek. Further checks of the model results for these structures using culvert routines confirmed these results.

These results are considered reasonable due to the limited size of the structures at the railway line and the potential for them to become blocked from debris during large flows. It may be possible to reduce water levels in this area by upgrading the structures underneath the railway line.

The Cemetery Creek catchment contributes most of the flows upstream of the railway line and also contributes the greatest potential damage to property, which predominantly occurs along its channel. Lake Beaufort was assumed to be full at the beginning of the design storm events, based on the assumption that large events are likely to occur during the wet winter-spring period. Sensitivity testing showed that the initial level of the dam had little effect on downstream flood levels for large events.

Ding Dong Creek, due to its relatively small catchment size, was mostly contained within its drainage channel and poses little threat to property. The downstream end of Cumberland Creek breaches its channel considerably, however this is mostly due to the large backwater pool caused by flows down Cemetery Creek.

The constructed channel on Yam Holes Creek has insufficient capacity to convey 100 year ARI flows, hence water breaks out upstream of Beaufort-Amphitheatre Road. The large floodplain downstream of the Beaufort Township on Yam Holes Creek becomes significantly inundated for all design events.

The railway embankment significantly impedes floodwaters flowing into Yam Holes Creek and is a major cause of flooding in Beaufort. Options to reduce its effect, such as increasing conveyance under the railway line and increasing the capacity of Lake Beaufort, as well as other options for flood risk reduction are discussed in Section 6.2.

6 RISK ASSESMENT

6.1 Flood Risk under Existing Conditions

6.1.1 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 flood risk can be determined, with the overall flood risk to the community being the sum of the flood risk for all locations.

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

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

6.1.2 Flood Likelihood under Existing Conditions

The hydraulic analysis provides flood extent, flood elevation, flood depth and flow velocity throughout the study area based on the design flood hydrographs determined by the hydrologic analysis. At any location, the frequency of a given flood depth can be assessed from the hydraulic analysis.

6.1.3 Flood Consequences under Existing Conditions

A flood damage assessment was undertaken for the design flood events, 5, 10, 20, 50 and 100 year ARI events. The flood damage assessment considered existing catchment conditions. Table 6-1 provides a summary of existing flood damages for the study area. A full description of the flood damages assessment is provided in Appendix C.

The Average Annual Damage (AAD) was then calculated. The AAD is a measure of the flood damage per year averaged over an extended period. It is calculated by the area under the flood frequency and total flood damage curve, Figure 6-1. The AAD for existing conditions for the study area is estimated at approximately **$383,000**, assuming no damages below the 5 year ARI event, and considering floods of up to the PMF event.

Table 6-1 Flood damages assessment costs for existing conditions

Item	Design Flood ARI (years)					
	5	10	20	50	100	PMF
Properties Flooded Above Floor	12	21	31	32	41	211
Properties Flooded Below Floor	169	176	178	179	173	50
Total Flooded Properties	**181**	**197**	**209**	**211**	**214**	**261**
Total Direct Potential Damages	$985,000	$1,302,000	$1,698,000	$1,898,000	$2,145,000	$11,056,000
Total Direct Actual Damages *(0.8*Potential)*	$788,000	$1,042,000	$1,359,000	$1,518,000	$1,716,000	$8,845,000
Indirect Damages	$161,000	$220,000	$276,000	$292,000	$342,000	$1,100,000
Road Infrastructure Damages	$244,000	$339,000	$354,000	$364,000	$384,000	$704,000
Rail Infrastructure Damages	$0	$2,000	$7,000	$15,000	$26,000	$148,000
TOTAL DAMAGES	**$1,193,000**	**$1,605,000**	**$2,002,000**	**$2,205,000**	**$2,494,000**	**$10,796,000**

Note: Costs are rounded to the nearest thousand, rounding not carried through the calculations.

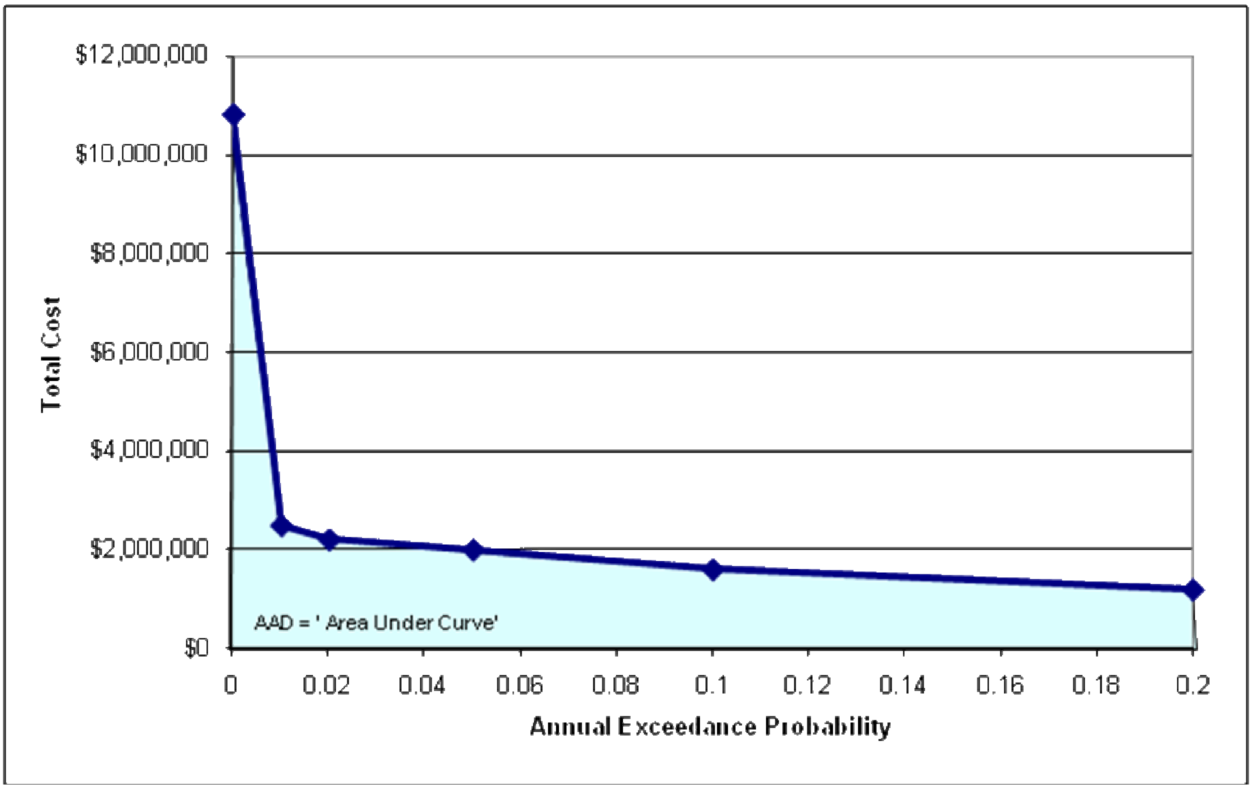

Figure 6-1: Average Annual Damages Plot

6.2 Options for Risk Reduction

6.2.1 Overview

As discussed in Section 6.1 the existing flood risk to Beaufort, expressed as the Average Annual Damage (AAD), was determined as $383,000. Mitigation measures provide a means to reduce the existing flood risk. 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 and improvements to hydraulic structures
- ***Non-structural***- land use planning, flood warning and catchment management

6.2.2 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 by lowering flood likelihood at a given location. Structural measures include upstream storages, levees, floodways or modifications to bridge/culvert structures. For the Yam Holes Creek Catchment the construction of levees and the modification to floodways may not be an effective means of flood mitigation.

Lake Beaufort on Cemetery Creek is the only main upstream storage. Modifications to the dam are unlikely to have any major effect on large floods, however there is potential to reduce the impact of smaller, more common flooding. Through the sensitivity testing of the hydraulic model it was determined that the reductions are not likely to be significant and may not be great enough to justify the economic, social and environmental costs involved in modifying the structure. This option would require further analysis to more accurately determine the potential costs and benefits.

A major issue concerning flooding in Beaufort is water passing under the railway line through the culverts and bridge structures. By increasing the capacity of these structures it is likely that flood levels on the upstream side of the railway line will be significantly reduced. This would lead to slightly higher flood levels downstream of the railway bridge, however this land is predominantly rural and has a large capacity to convey flood water, hence the increased levels will have little impact on flood extent downstream. This is likely to be the most feasible flood mitigation option for the township and would reduce flood levels over a range of flood events.

6.2.3 Non-structural Measures

6.2.3.1 Introduction

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

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

6.2.3.2 Catchment Management

Catchment management activities in the upstream catchments can influence the existing catchment runoff characteristics (flood peaks and volumes). Flood volumes and peaks are a function of the vegetation cover, land use and drainage practices within a catchment. Land clearing and drainage can significantly alter flood response. Land clearing generally leads to increased flood peaks and volumes. Increased flood flows and 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 (e.g. 100 year ARI) reductions in peak flow would be insignificant.

6.2.3.3 Flood Awareness, Preparedness, Warning and Response

Flood warning and associated activities aim to reduce growth in flood damages by improving community awareness of flooding and emergency response in the event of a flood. The degree of flood awareness within a community often reflects the frequency of significant flooding (i.e. infrequent insignificant flooding generally leads to lower community flood awareness). Questionnaire responses and contributions at public meetings during the course of the study showed that the Beaufort community is generally unaware of the existing flooding issues and sensitivities. It is likely that the absence of flooding within the Beaufort area in recent times coupled with population mobility has contributed to this lack of awareness.

The Bureau of Meteorology does not provide a flood warning service for the creeks surrounding Beaufort.

A brief introduction to the concepts that underpin flood warning system development and operation within Victoria along with relevant background is available in VFWCC (2005), VFWCC (2001) and EMA (1999).

The RORB modelling undertaken as part of this study suggests there is only a small delay (of order 3 to 6 hours) between rainfall in the upper parts of the catchments around Beaufort and flood peaks reaching Beaufort. Thus by definition (Bureau of Meteorology, 1996) the township is subject to flash flooding as response time is less than 6 hours.

The principles applying to the provision of flash flood warning services are different from those applying to areas with longer response times and are detailed in VFWCC (2001). Essentially these principles can be summarised as:

- The Bureau of Meteorology has a responsibility to provide predictions of weather conditions likely to lead to flash flooding (e.g. thunderstorms);
- Local Government has prime responsibility for flash flood warning extending from system establishment and operation through to the provision of predictions of stream levels if required; and
- The Bureau of Meteorology will provide specialist technical assistance and advice to Local Government to assist in system establishment and in relation to flood prediction techniques.

What this means is that any flood warning system established for the Beaufort creeks would need to be paid for and managed by the Pyrenees Shire Council but that the Bureau of Meteorology would provide advice aimed at assisting the Shire establish and develop the system. Operational responsibility would also reside with the Shire. The Bureau would however assist through the supply of operational software for data management and alerting and continue delivery of existing severe weather and flood warning related services (e.g. flood watches[1]).

There are a number of building blocks, consistent with the Total Flood Warning System model, that make up a flash flood warning system. These are identified in Table 6-2 along with a brief description of the basic tools needed to deliver against each block and an outline of a possible solution that would be applicable to Beaufort. A total system considers not only the production of a timely alert to a potential flash flood but also the efficient dissemination of that alert to those, particularly the threatened community, who need to respond in an appropriate manner.

Experience shows that flood warning systems, and this applies even more so to flash flood warning systems, that are not designed in an integrated manner and that over-emphasise flood detection (say) at the expense of attention to the dissemination of warnings, local interpretation and community response, invariably fail to elicit appropriate responses within the at-risk community. However, systems that rely on environmental indicators (e.g. the occurrence of heavy or persistent rain) and concentrate on building local flood awareness in terms of impacts and appropriate responses (i.e. that are aimed at building a community that is informed and flood aware) is more likely to be effective in reducing flood looses.

It therefore follows that actions to improve flood response and community flood awareness using technically sound data (such as produced by this study) will, by themselves, result in some reduction in flood losses. The key issue is to gather what is known about flooding and what is at risk from flooding (essentially what is presented in this report) and ensure that it is accessible to, and in a form that is easily understood and assimilated by those who need to use it. It is after all people's reactions to impending flooding that substantially affects the losses that subsequently occur.

[1] Flood watches are issued by the Bureau of Meteorology to notify the Victorian community of the potential flood threat from a developing weather situation: they are a "heads-up" for possible flooding. There is a degree of uncertainty attached to flood watches as they are based on an assessment of current catchment wetness indicators over a fairly wide area and meteorological forecasts of future rainfall.

Flood watches contain short generalised statements about the developing weather situation including forecast rainfall totals, describe in general terms the current state of catchments across the target area and indicate the streams at risk from flooding. An example of a typical Flood Watch is included on the Bureau's website at http://www.bom.gov.au/hydro/flood/vic/brochures/flood_watch/flood_watch.shtml.

Normally, the Bureau would issue a flood watch 24 to 36 hours in advance of any likely flooding and issue updates as required. Flood Watches are intended to assist individuals and communities prepare for possible flooding: they are not a warning of imminent flooding.

Table 6-2: Flash Flood Warning System Building Blocks and Possible Solution for Beaufort

[with due regard for the Emergency Management Manual Victoria, the 1987 Commonwealth-State arrangements for flood warning service provision, VFWCC (2001) and EMA (1999)]

Building Blocks of a Flash Flood Warning System	Basic Tools	Possible Solution
DATA COLLECTION & COLLATION	Data collection network (i.e. rain and stream gauges)	Install an ERRTS flood monitoring system. ERRTS systems are commercially available radio telemetry system that reports in real-time to a base station. Establish a new base station at a local office and perhaps also at SES RHQ. The existing base station at the Bureau's office will also receive data.
	System to convey data from field to forecast centre (e.g. radio or telephone telemetry).	
	Data management system to check, store, display data.	ENVIROMON – software provided and maintained by the Bureau.
	Arrangements and facilities for system/equipment maintenance and calibration.	Commercial arrangement between the Shire and a service provider for maintenance. Inclusion of all capitalised system components on the Shire's asset management register.
DETECTION & PREDICTION (i.e. Forecasting)	Establish rainfall rates and depths likely to cause flooding as well as appropriately representative flood class levels at key locations plus information on critical levels/effects.	Use to set alarm criteria (on rainfall) at gauges and to initiate local alerting of potential flooding from river level gauges. This may lead to the establishment of flood class levels if desirable.
	Flood forecast techniques (e.g. hydrologic rainfall - runoff model, stream flow and/or height correlations, simple nomograms based on rainfall).	Simple nomograms based on rainfall may be useful but may take some time to develop due to lack of data. Council would be responsible for maintaining the tool but the Bureau would assist in developing the first version of it. Decide how this tool is to be used and who by – Council?, SES?, community?
INTERPRETATION (i.e. an ability to answer the question "*what does this mean for me - will I be flooded and to what depth*".	Interpretative tools (i.e. flood inundation maps, flood information cards, flood histories, local knowledge, flood response plans that have tapped community knowledge and experience, flood related studies and other sources, etc).	Outputs from this study consolidated into a Flood Response Plan and into tools that enable those at risk to determine whether they are likely to be flooded.
MESSAGE CONSTRUCTION	Warning messages/products and message dissemination system.	Unlikely to be required at Beaufort due to short hydrologic response time.

Table 6-2 Continued……

Building Blocks of a Flash Flood Warning System	Basic Tools	Possible Solution
MESSAGE DISSEMINATION (i.e. Communication and Alerting)	Media – TV, radio and print.	On exceedance of alarm criteria ENVIROMON will send an SMS message to key Shire and/or SES personnel as well as perhaps to key community members who could then initiate a local phone-based information dissemination tree. An opt-in system that must be heavily community driven. Alternative alerting mechanisms could include use of a siren.
	Fax/faxstream, phone/pager (e.g. SMS, voice), voice messaging systems (e.g. Xpedite), tape message services, community radio, internet (e.g. http://www.bom.gov.au, email).	
	Informal local message/information dissemination systems or 'trees'.	
	Opportunity for at-risk communities to confirm warning details.	
RESPONSE	Flood management tools (e.g. Council Flood Response Plan complete with inundation maps and 'intelligence' extracted from community knowledge and from this study report, effective public dissemination of flood information, local flood awareness, individual and business flood action plans, etc).	Following (or perhaps in concert with) development of the Council flood response plan (i.e. the MEMP Flood Sub-Plan) encourage and assist residents and businesses to develop individual flood response plans. A package that assists businesses and individuals is available from NSW SES and provides an excellent model for community use. VicSES can also assist in this regard.
	Flood response guidelines and related information (e.g. Standing Operating Procedures).	
	Comprehensive use of available experience, knowledge and information.	
REVIEW	Post-event debriefs (agency, community), etc.	Review and update of alarm criteria, local flood intelligence (i.e. flood characteristics, impacts, etc), local alerting arrangements, response plans, local flood awareness material, etc (initially) after every flood that triggers an alarm. Best done by Council with input from a community flash flood action group (championed by Council) and established in the lead up to system installation. Council to develop review and update protocols => who does what when and process to be followed to update material consistently across all parts of the flash flood warning and response system.
	Collection of flood 'intelligence' and flood damage data from the event.	

Table 6-2 Continued……

Building Blocks of a Flash Flood Warning System	Basic Tools	Possible Solution
AWARENESS	Identification of vulnerable communities and properties (i.e. flood inundation maps, information on flood levels/depths and extents, etc).	Develop, print and distribute flood awareness material, including information on how the flash flood warning system operates, within the community using information collated for the MEMP Flood Sub-Plan and available within the study report and from the web. Load and maintain material on Council's website with appropriate links to relevant useful sites. Routinely revisit and update awareness material to accommodate lesson leant, additional or improved material and to reflect advances in good practice. Routinely repeat distribution of awareness material. Decide whether to alert residents and visitors of the risk of flooding in more direct ways. This could include the installation of flood depth indicator boards at key locations.
	(Flood) risk communication.	
	Community education and flood awareness raising.	
	Flood response guidelines, residents' kits, flood markers, flood levels in meter boxes and on rate notices, etc for properties identified as being subject to flooding through this study.	

Flash Flood Warning System

It is considered that a flash flood monitoring and warning system would provide some benefit to the Beaufort community. However, this would come at some cost: a cost that would need to be met by Council and that may exceed benefits. While there are recent examples of flash and longer term flood warning system development being funded from the Natural Disaster Mitigation Program (NDMP) on a $^1/_3$:$^1/_3$:$^1/_3$ (Commonwealth : State : Local) basis, all on-going costs, including asset replacement, would need to be funded by Council.

It is therefore suggested that Council consider the costs and potential benefits of a flash flood monitoring and warning system for Beaufort and in the first instance, provided that on-going costs can be met from within Council and that benefits are sufficient to support a case, submit an application for funding[2] for flash flood warning system establishment. Part of the work scope would include consultation with the community on how they would want to be warned of a potential flash flood and the championing of the establishment of a community-based flash flood action group.

Flood Sub-Plan

It is apparent that flood response at Beaufort is current predominantly reactive and based on ad-hoc arrangements that rely on a mix of local and corporate knowledge. It is suggested that a more structured approach founded on knowledge of potential flood impacts (in terms of those areas/properties likely to be affected, areas of high hazard and of deep and/or fast flowing water, flood progression, etc) would result in an improved and more targeted response and reduce losses, particularly during a future severe event.

A Pyrenees Shire Municipal Emergency Management Plan (MEMP) Flood Sub-Plan should be developed for Beaufort using existing corporate knowledge and information which includes the results of this study. The Plan should identify flood effects within the township versus increased flood severity and document the response required to minimise risk to life and property. It is suggested the Plan should give attention to flooding up to the probable maximum flood (PMF) if possible but to the 1% AEP (100 year ARI) event as a minimum. A suggested framework for the Plan can be provided by the study team if required.

In summary the work required to develop the Flood Sub-Plan would include:

- Inclusion of linkages to the MEMP and other reference documents (e.g. the EMMV) along with details of relevant statutory and corporate responsibilities and associated arrangements (e.g. including ensuring that linkages between planning scheme requirements, floodplain management plan requirements and permissible flood preparedness and response actions are accurately reflected).
- Extraction and interpretation of relevant flood related intelligence and information from study consultations, investigations and deliverables (e.g. inundation maps, etc) including:
    - Information on past floods, their impacts and behaviours;
    - The function and attributes of local features that have an influence on flows;
    - Identification of properties, roads and other community assets (e.g. stormwater outlets, septic tanks, pumps, etc) affected by flooding;
    - The depth of flooding within individual properties and over-floor at selected levels or flows (tabulated by height or flow, street name and number); and

[2] There are a number of funding avenues available for specific, bounded and targeted projects – e.g. the Natural Disasters Mitigation Program, the Emergency Management Australia Local Grants Scheme and the Community Help Grants Program.

  - Other intelligence and/or data considered to be relevant to a timely and effective response to flood.
- Inclusion of flood response actions and prompts in a tabulation of flood effects against creek level/flow;
- Comprehensive capture of flood intelligence as well as information on flood behaviour and characteristics;
- Extend the above to a consideration of regional impacts – for example in terms of access to or egress from Beaufort, demands on SES and/or Council staff, etc;
- Information on past floods and their impacts;
- Details on the availability of relevant flood related information (e.g. FDTP maps, aerial flood photos, etc);

In other locations flood "intelligence cards" have been developed as a means of consolidating known information into an easily assimilated format that can be shared with the at-risk community. It is suggested that similar intelligence cards should be developed for Beaufort and shared with the local community as part of a program to raise community flood awareness.

Community Flood Awareness

Following is a list (not exhaustive) of some of the more common misconceptions held by people who live in flood-prone areas. These misconceptions often act as a major barrier to improving flood preparedness and awareness within the community and thus hinder efforts to minimise flood damages and the potential for loss of life.

- The largest flood seen by the community/individual is often confused with the maximum possible flood (i.e. the next flood couldn't be bigger). This idea becomes more entrenched the bigger the flood witnessed previously.
- Areas that haven't flooded before will not flood in the future. This is an extension of the first bullet point.
- The stream cannot be seen from the house so the house couldn't possibly be at risk.
- A levee designed to hold the 100 year ARI flood will protect the community from all floods and therefore a flood warning system is not required.
- The 1 in 100 year ARI flood, once experienced, will not occur for another 100 years.
- The statistics and estimates that underpin hydrology are exact.

Studies repeatedly show that communities that are not aware of flood hazard are less capable of responding appropriately to flood warnings or alerts and experience a more difficult recovery than a flood-aware community. Plain language flood awareness campaigns should aim to erase these misconceptions.

There are a number of activities that could be initiated to maintain and renew awareness at Beaufort. The emphasis should be on an awareness of public safety issues (including, if installed, the flash flood monitoring system and how it will help) and on demonstrating what people can do to stay safe and protect their property from flooding. Typical initiatives of relevance to Beaufort include:

- Making the MEMP Flood Sub-Plan and flood intelligence cards publicly available (Council offices, library, website) with a summary provided in Council welcome packages for new residents and business owners and with annual rate notices;
- Championing a community flash flood action group (or similar);
- Development, public discussion and periodic review of a Floodplain Management Plan;

- Installing flood markers indicating the height of design events such as the 100 year ARI event (e.g. on power poles, street signs, public buildings, sides of bridges, etc);
- Installing flood depth indicators where there is appreciable danger to human life due to flood depth and/or velocity, such as at road crossings that will overtop during flood; and
- Preparing and distributing (as an on-going program) a flash flood action guide or brochure (e.g. recent work at Shepparton and Mooroopna as described by Crapper et al, 2005 and the NSW SES FloodSafe program) aimed specifically at encouraging local residents and businesses to take a pro-active role in preparing their property and themselves for a flood as well as describing what people need to do in a flood event. These could be given out at community shows and field days, to schools and with council rate notices and/or other council communications.

It is suggested that the Pyrenees Shire Council prepare a flash flood action guide or brochure for the Beaufort community. Funding could be sought from the Natural Disaster Mitigation Program. It is suggested that if a flash flood monitoring and warning system is contemplated for Beaufort that the scope of work and funding sought include preparation of the MEMP Flood Sub-Plan together with appropriate flood awareness raising activities and materials.

6.2.3.4 Land Use Planning

Land use planning aims to reduce the growth in future flood damages by providing 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 (a third overlay, the SBO - Special Building Overlay applies to stormwater flooding in urban areas only and is not relevant to this study):

- Land Subject to Inundation Overlay (LSIO)
- Floodway Overlay (FO)

The VPPs provide guidelines for the appropriate uses and/or development of land in LSIO and FO areas. A more detailed discussion of land-use controls is provided in Section 7.

7 DATASETS AND MAPPING

7.1 Overview

Land use planning controls and building regulations provide mechanisms for ensuring appropriate use of land and building construction, given flood risk at a site. Land use planning controls are aimed at minimising growth in flood damages over time. The controls balance the likelihood of flooding with consequences.

In Victoria there is consistent planning scheme format for application across the State. The associated Victoria Planning Provisions (VPPs) are employed by all Victorian municipalities.

Victorian Building Regulations specify that floor levels should be 300 mm above a nominated flood level. The nominated flood level is generally that of the 100 year ARI flood, or if this has not been determined for a particular area, it is the 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.

The Victoria Flood Data Transfer Project (FDTP), now the Victorian Flood Database (VFD), involves the collation of flood information for regional urban and rural floodplains into GIS-compliant datasets. Data from subsequent flood and related studies has been captured and entered into the VFD datasets. In line with current requirements, the results of this study will also be loaded to the VFD.

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

- Victoria Planning Provisions – outlines the flood related Victoria Planning Provisions (VPPs) (Section 7.2)
- Flood related planning zones and overlay – details the available flood related planning zone and overlays (Section 7.3)
- Flood related planning zone and overlays delinineation – details the delineantion of the flood related planning zone and overlys for the study area (Section 7.4).
- VFD compliant datasets (Section 7.5)

7.2 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 associated with mainstream flooding as follows:

- Land Subject to Inundation Overlay (LSIO),
- Floodway Overlay (FO),

Details of the above overlays are provided in Section 7.3.

The VPPs proceed to specify for each of the relevant 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.

7.3 Flood Related Planning Zones and Overlays

7.3.1 Land Subject to Inundation Overlay (LSIO)

The LSIO identifies land liable to inundation by overland flow, in flood storage areas 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 a limited category 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.

7.3.2 Floodway Overlay (FO)

The floodway overlay identifies waterways, main flood paths, drainage depressions and high hazard regions within rural areas. Many of the floodway areas contained within the FDTP were delineated on the basis of NRE's "Advisory Notes for Delineating Floodways." (Edwards, 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 guide for floodway delineation in Beaufort.

Flood hazard combines the flood depth and flow speed for a given design flood event. The advisory notes suggest the use of Figure 7-1 for delineating the floodway based on flood hazard. The flood hazard for the 100 year ARI event was considered for this study.

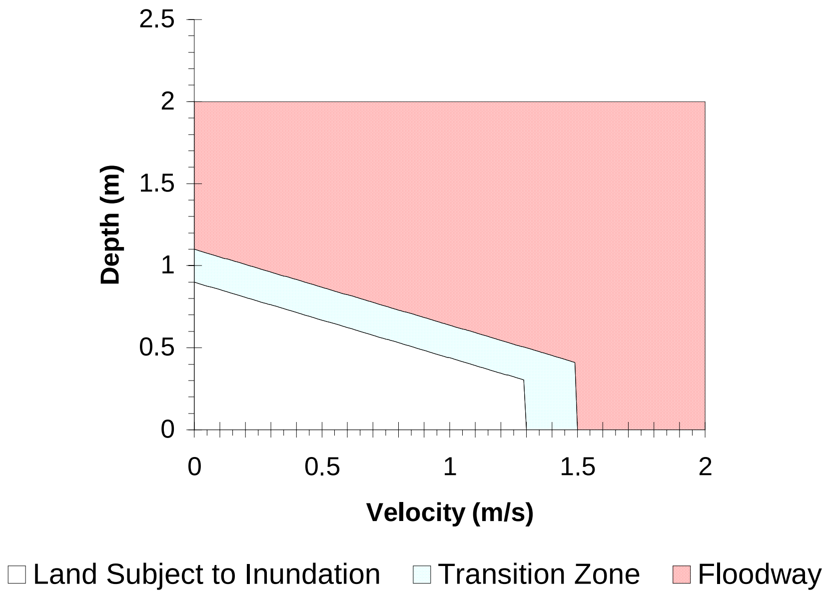

Figure 7-1 Floodway overlay flood hazard criteria

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

The final extent of the floodway overlay based on the consideration of the three approaches is discussed in Section 7.4.

7.4 Flood Related Planning Zone and Overlays Delineation

Draft flood related zone and overlay delineation maps, developed in accordance with the Victoria Planning Provisions Practice Notes – Applying the Flood Provisions in Planning Scheme (DoI 2000), have been generated to assist GHCMA and Pyrenees Shire in the identification of LSIO and FO areas. The delineations, under existing conditions, result from application of each of the FO criteria outlined in Section 6.3.2 laid over the 100 year ARI flood extent

Due to the nature of the floodplain, the three suggested methods for delineating the FO (Edwards, 1998) were found to provide varied results. The 10 year ARI flood extent was found to be very similar to the 100 year ARI flood extent with extensive shallow flooded areas that weren't considered to be floodway. Due to the significant backwater effect of the railway line, the flood depth delineation option contained many areas that were over the depth criteria but not considered to provide significant flow conveyance. The flood hazard delineation method which combines flood depth and velocity was considered to be the most appropriate method as it defines significant flow paths which are critical to maintaining flow conveyance and providing adequate flood capacity within the floodplain. The transition zone in Figure 7-1 was included in the flood hazard delineation as it gave a better representation of significant flow paths.

To reflect existing flood risk and define areas that should be specifically preserved for flood conveyance, the FO is recommended for the area defined by the 100 year ARI flood hazard as calculated using the methods described by Edwards (1998) with some slight modifications to account for local topography conditions.

The 100 year ARI flood extent (outside the floodway extent) was adopted as the recommended LSIO.

Figure 7-2 displays the draft flood related planning overlays for Beaufort for mainstream flooding from Yam Holes Creek, Ding Dong Creek, Cemetery Creek and Cumberland Creek.

The study team recommends the Pyrenees Shire Council and GHCMA liaise in the preparation and adoption of a planning scheme amendment to enable the draft flood-related planning overlays.

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

7.5 FDTP Datasets

In order to update the previous FDTP maps and to provide consistency between the local planning maps and state flood database, flood inundation maps have been prepared that adopt the same scale and format as the previous FDTP plans.

The maps include:

- The extent of the 1% AEP flood (i.e. LSIO)
- The extent of the draft floodway (i.e. FO)
- 1% AEP flood level contours at 200 mm contour intervals
- Indicative flood levels and extents for the PMF event.

The data is supplied in digital format to VFD specifications as published by the Department of Sustainability and Environment (DES 2000). The digital map data is provided on the attached study CD.

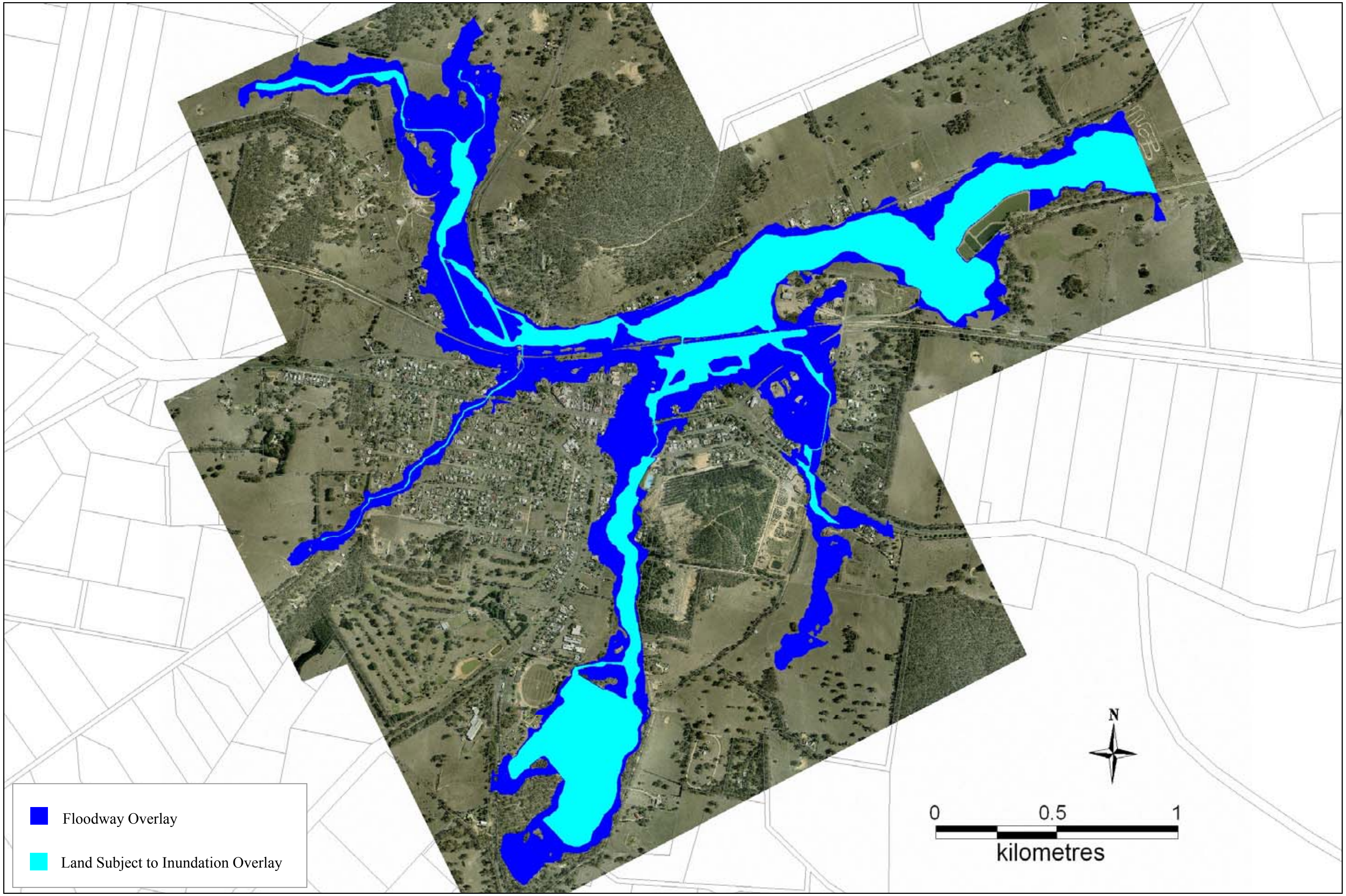

Figure 7-2 Draft Flood Related Zone and Overlay Delineation

8 CONCLUSIONS AND RECOMMENDATIONS

The Beaufort Flood Study provides a detailed examination of existing flood risks for Beaufort Township by defining the likelihood of flooding (in terms of flood extent for various recurrence intervals) and the consequences of flooding (primarily described through tangible flood damages).

Mainstream flooding within Beaufort can be attributed to a combination of streams converging on the township after heavy rainfall within the nearby catchment areas. It is noted that this study does not address local stormwater flooding (or flash flooding) that results from direct roof or street runoff within the town area. Yam Holes Creek has a relatively small channel capacity and most flood waters escape the town area via a wide floodplain. Subsequently there is predicted to be significant ponding of flood waters, particularly upstream (south) of the railway line. The limited hydraulic capacity through the railway embankment elevates flood levels through this part of the town.

These investigations show that, whilst relatively sparse formal records of flooding exist, there is significant anecdotal evidence to suggest that flooding has been an issue in low-lying parts of the township. Whilst no significant floods have been recorded in living memory, hydrologic and hydraulic modelling predicts that many areas of the town are susceptible to flooding in large flood events (greater than 10 year ARI). The main areas of predicted flood impact are:

- Along Cemetery Creek, downstream of Lake Beaufort
- The northern section of the township, between the Western Highway (Neill Street) and the railway line.

The main source of uncertainty in this study is the design hydrology (due to lack of recorded flow information). Whilst the techniques applied in this investigation are considered to provide a sound and reliable basis for defining flood behaviour in Beaufort, the design flood predictions could be improved in the future through the collection of additional hydrologic data.

Following the investigations undertaken for the study and the conclusions reached it is recommended that:

- The GHCMA and Council adopt the determined design flood levels and in turn proceed with a declaration process.
- The Pyrenees Shire and GHCMA continue to engage the community in the treatment of flood risks through the development of a full Floodplain Management Plan for Beaufort that involves broad community involvement and consultation with stakeholders.
- The Pyrenees Shire and GHCMA explore options for enhanced flood response measures through co-operation with SES and Police utilising the flood inundation maps produced from the study.
- The Pyrenees Shire and GHCMA explore options for the development of a flash flood monitoring and warning system for Beaufort in conjunction with the BoM and SES.
- The GHCMA consider the collection of hydrologic data that would facilitate future improvements in hydrologic and hydraulic modelling.

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APPENDIX A – CORRELATION OF DAILY AND INSTANTANEOUS FLOW

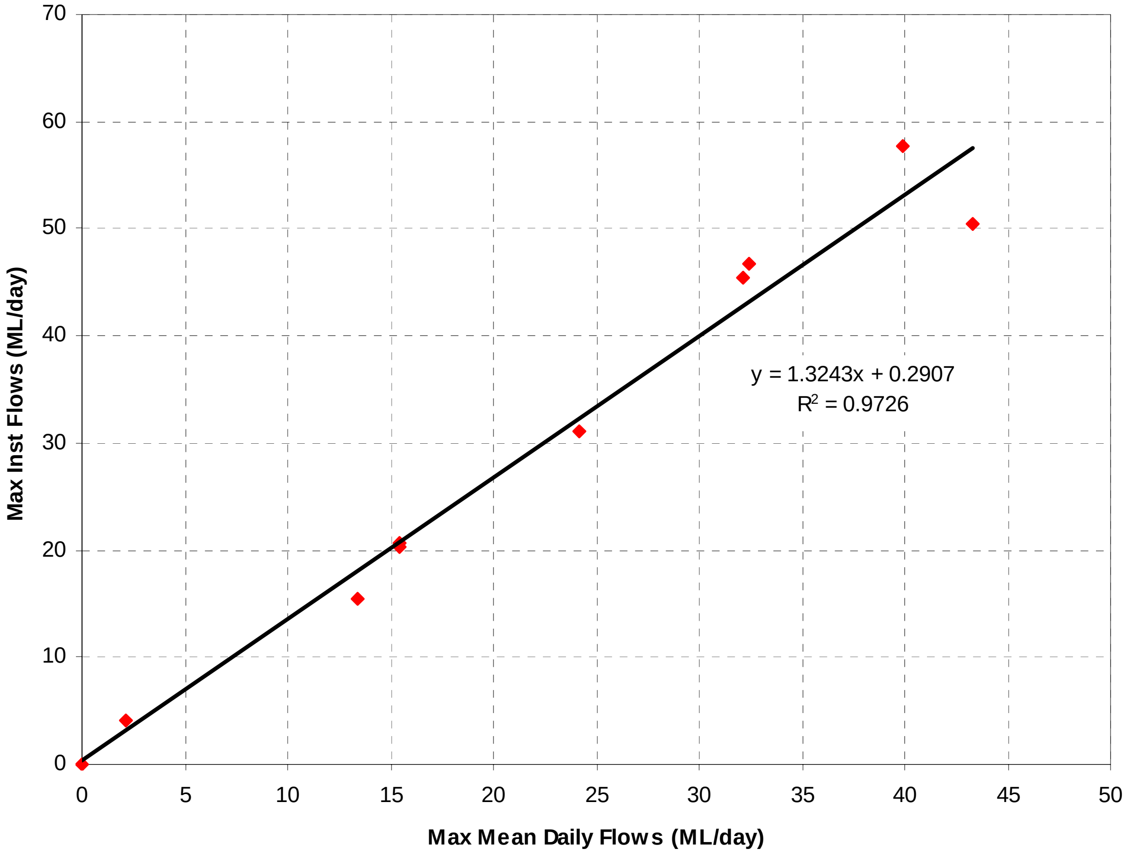

Figure A1 - Maximum Annual Daily Flow and Maximum Annual Instantaneous Flow Correlation for Mt Emu Creek

APPENDIX B – DETAILS OF MODELLED CULVERTS

Each of the culverts modelled in this flood study are listed below in Table B1, along with a photo and the dimensions of the culverts. The diameters, widths and heights were all measured manually, whilst the lengths of each culvert were taken from the GIS. Figure B1 shows the locations of these culverts.

Table B1: Names, Photos and Dimensions of Culverts in the Hydraulic Model

	**Dingdong Creek 1** **Geometry –** Circular **Diameter –** 1.52m **Length –** 32.0m **Number of Culverts** – 1
	**Dingdong Creek 2** **Geometry –** Circular **Diameter –** 1.22m **Length –** 12.2m **Number of Culverts** – 2

	**Dingdong Creek 3** **Geometry –** Circular **Diameter –** 1.55m **Length –** 40.0m **Number of Culverts** – 1
	**Dingdong Creek 4** **Geometry –** Rectangular **Width –** 1.5m **Height –** 0.9m **Length –** 33.7m **Number of Culverts** – 3
	**Dingdong Creek 5** **Geometry –** Rectangular **Width –** 2.05m **Height –** 0.93m **Length –** 13.7m **Number of Culverts** – 1

	**Dingdong Creek 6** **Geometry –** Rectangular **Width –** 1.9m **Height –** 0.8m **Length –** 4.0m **Number of Culverts** – 1
	**Dingdong Creek 7** **Geometry –** Rectangular **Width –** 3.6m **Height –** 0.7m **Length –** 9.7m **Number of Culverts** – 1
	**Dingdong Creek 8** **Geometry –** Rectangular **Width –** 1.5m **Height –** 0.6m **Length –** 7.3m **Number of Culverts** – 1

	**Cemetery Creek 1** **Geometry –** Rectangular **Width –** 3.7m **Height –** 1.4m **Length –** 8.0m **Number of Culverts** – 1
	**Cemetery Creek 2** **Geometry –** Rectangular **Width –** 2.8m **Height –** 1.0m **Length –** 9.0m **Number of Culverts** – 1
	**Cemetery Creek 3** **Geometry –** Rectangular **Width –** 3.0m **Height –** 1.1m **Length –** 15.6m **Number of Culverts** – 1

	**Cemetery Creek 4** **Geometry –** Rectangular **Width –** 2.45m **Height –** 0.7m **Length –** 118.7m **Number of Culverts** – 1
	**Cemetery Creek 5** **Geometry –** Rectangular **Width –** 3.0m **Height –** 1.6m **Length –** 9.7m **Number of Culverts** – 1
	**Cemetery Creek 6** **Geometry –** Rectangular **Width –** 2.1m **Height –** 1.2m **Length –** 7.5m **Number of Culverts** – 2

	**Cumberland Creek 1** **Geometry –** Rectangular **Width –** 2.4m **Height –** 1.2m **Length –** 8.0m **Number of Culverts** – 3
	**Cumberland Creek 2** **Geometry –** Rectangular **Width –** 1.2m **Height –** 0.9m **Length –** 9.9m **Number of Culverts** – 3
	**Cumberland Creek 3** **Geometry –** Rectangular **Width –** 1.2m **Height –** 0.9m **Length –** 18.4m **Number of Culverts** – 2

	**Cumberland Creek 4** **Geometry –** Rectangular **Width –** 1.2m **Height –** 0.6m **Length –** 14.8m **Number of Culverts** – 2
	**Yam Holes Creek 1** **Geometry –** Rectangular **Width –** 3.2m **Height –** 2.0m **Length –** 8.5m **Number of Culverts** – 3
	**Railway Drain 1** **Geometry –** Circular **Diameter –** 1.50m **Length –** 8.0m **Number of Culverts** – 1

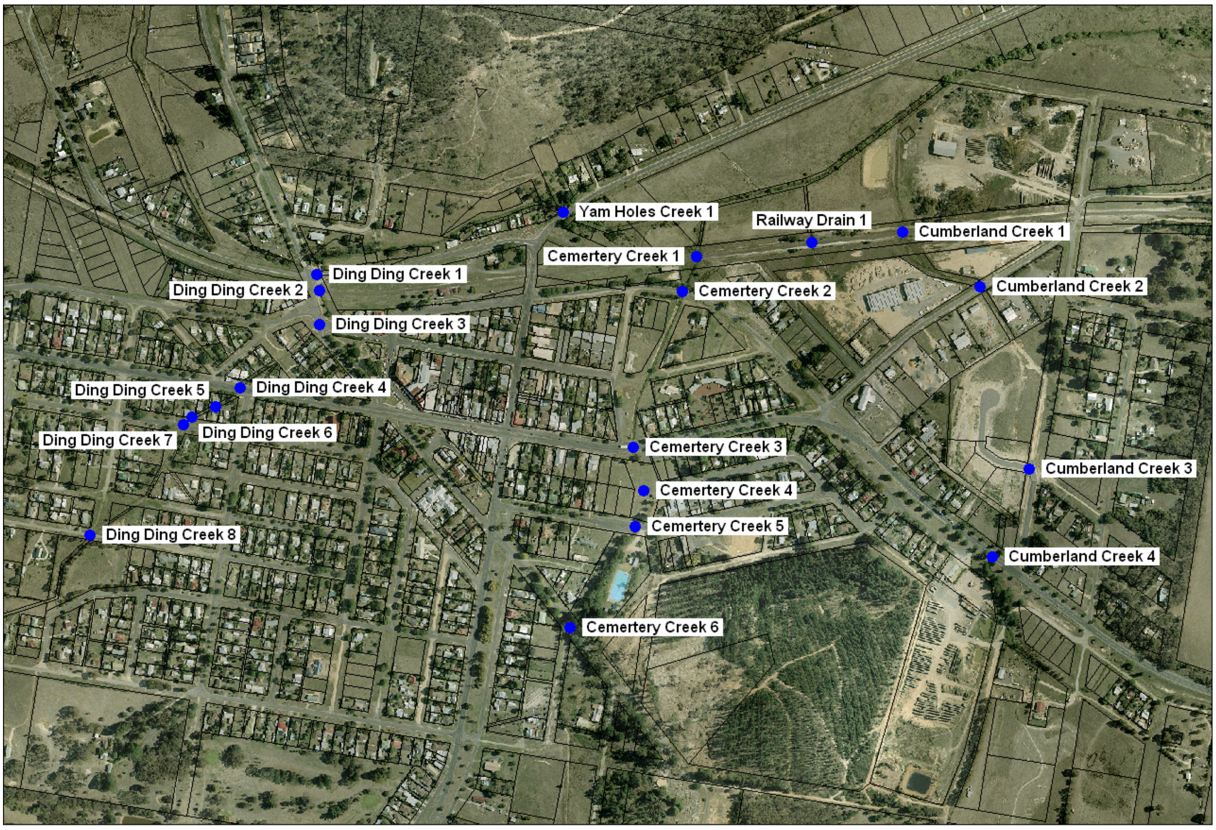

Figure B1: Names and Locations of Culverts in the Hydraulic Model

APPENDIX C – FLOOD DAMAGES ASSESSMENT DETAILS

See also spreadsheet on report CD

Flood Damage Assessment Overview

A flood damages assessment has been undertaken for the study area under existing conditions. The flood damage assessment determined the monetary flood damages for design floods. 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 C-1 shows the various categories commonly used in flood damage assessments.

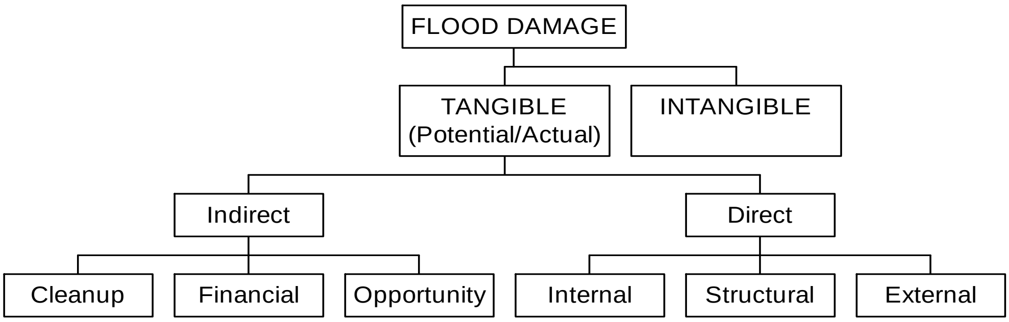

Figure C-1 Categories of flood damage

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 but have not been directly accounted for in this flood damage assessment.

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.

Tangible direct damages are further defined as either 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 are the expected damages for a given flood event, allowing for some degree of community flood damage control. The actual damage is calculated as a proportion of the potential damage, based on the community's flood preparedness, a function of community awareness and the lead-time of flood warnings.

Indirect damages are additional costs incurred after a 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. These indirect costs are extremely hard to quantify.

The remainder of this appendix details the input data, methodology and results for the flood damage assessment.

Flood Damage Assessment Input Data

Property and Floor Level Data

Property and floor level data were surveyed for 142 properties within the study area. These properties were identified to be within or immediately adjacent to the 100 year ARI flood extent.

The following property data were collected:

- Building location:- GIS coordinates in MapInfo Table, with limited information regarding street address.
- Building type:- Short description, enabling identification of residential, commercial, industrial and public use.
- Ground and floor levels: ground level obtained from a digital elevation model, and floor level data from survey including location (as above).

The residential properties surveyed were considered urban residential dwellings with a normal value class. The commercial or public use buildings surveyed were sorted into various classes as described later.

Infrastructure Data

Infrastructure damage was calculated from the Rapid Appraisal Method (RAM). Damage to roads was assessed for major and minor sealed roads taking into account initial repairs, accelerated depreciation of the roads and damage to bridges. Values for damage per 1Km of road were derived from Vic Roads data. For each design event the length of both major and minor roads that are inundated was calculated from the hydraulic analysis to obtain a cost. The railway line was also assessed using the same method. Since no values for railway lines were given in RAM, it was assumed that the damage to the railway line was the same as that of a major road.

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.

Damage Assessment Methodology

The flood damage assessment was based on the RAM and current best practice from a number of more recent literature sources.

The flood damage assessment first estimated costs associated with direct flood damage (e.g. structural building, contents and external property damage), then considered the costs associated with indirect flood impacts (e.g. emergency services, clean-up costs, alternative accommodation costs).

Direct Flood Damage

For each property in the study area it was first decided if the building was inundated above floor level or below floor level by querying the design flood depths and the floor level from the property survey. Adjusted ANUFLOOD (Smith & Greenway, 1992) stage-damage curves were then applied to each property for above floor flooding and an adjusted stage-damage curve from DPIE (1992) was used for properties with below floor flooding. The ANUFLOOD stage-damage curves were factored up by 60% to bring them up to a 1999 flood damage cost level as recommended by the Rapid Appraisal Method (RAM) for Floodplain Management (NRE, 2000). The ANUFLOOD and DPIE stage-damage curves were factored by the Consumer Price Index (CPI) ratio to September 2007. There are a total of three residential stage-damage curves (small, medium and large houses) and fifteen commercial stage-damage curves (small, medium and large buildings of value class from one to five). The medium residential curve and the small and medium value class one and two commercial curves were used in this study. The stage-damage curves used in this study are displayed in Figures C-2 to C-4.

The stage-damage curves were applied to each inundated property and the costs summed to calculate the total direct potential flood damage cost.

The total direct potential flood damage cost is the cost that would be incurred if no mitigation measures are taken prior to or during a flood. In reality communities generally have some degree of warning, and particularly if a community has had previous flood experience, may reduce the effect of the flood significantly. Measures such as evacuation, doorstep sandbagging or the removal of valuable items to a safe level above flood waters have the potential to reduce the flood damage cost. A potential to actual direct flood damage reduction factor from RAM (NRE, 2000) of 0.8 was adopted. This conservatively assumes that the community has no flood experience and that they have less than 12 hours warning time.

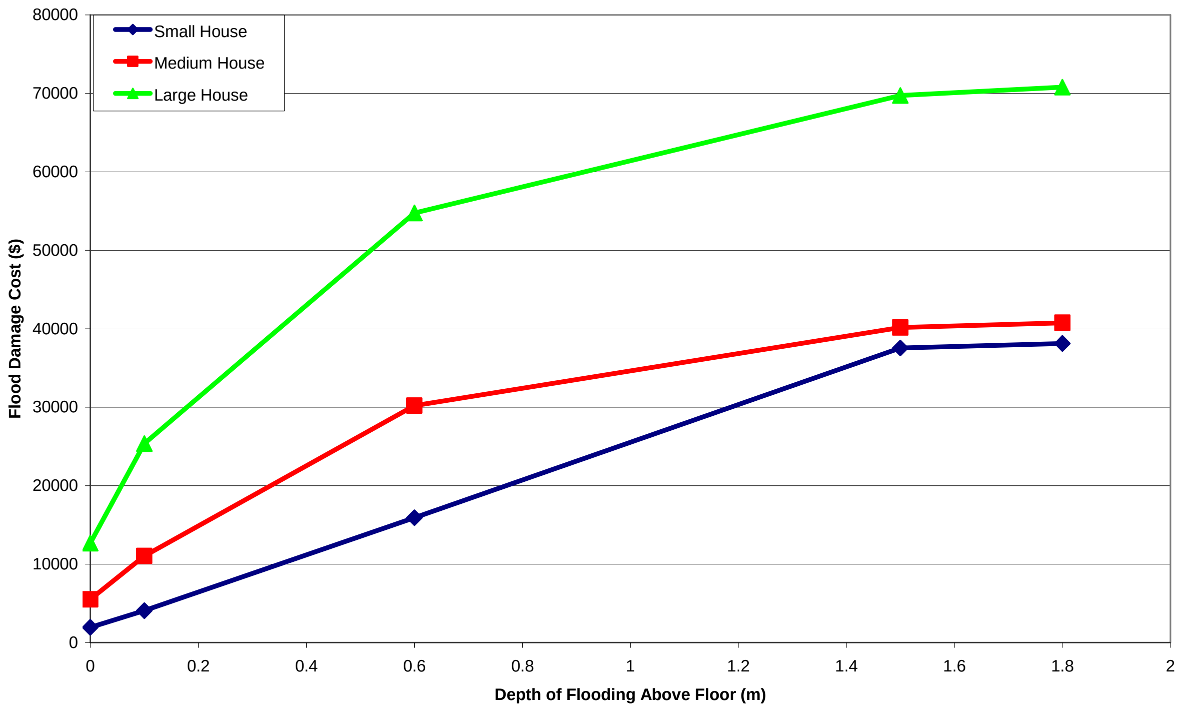

Figure C-2 Stage-damage curves used in this study for residential above floor flooding

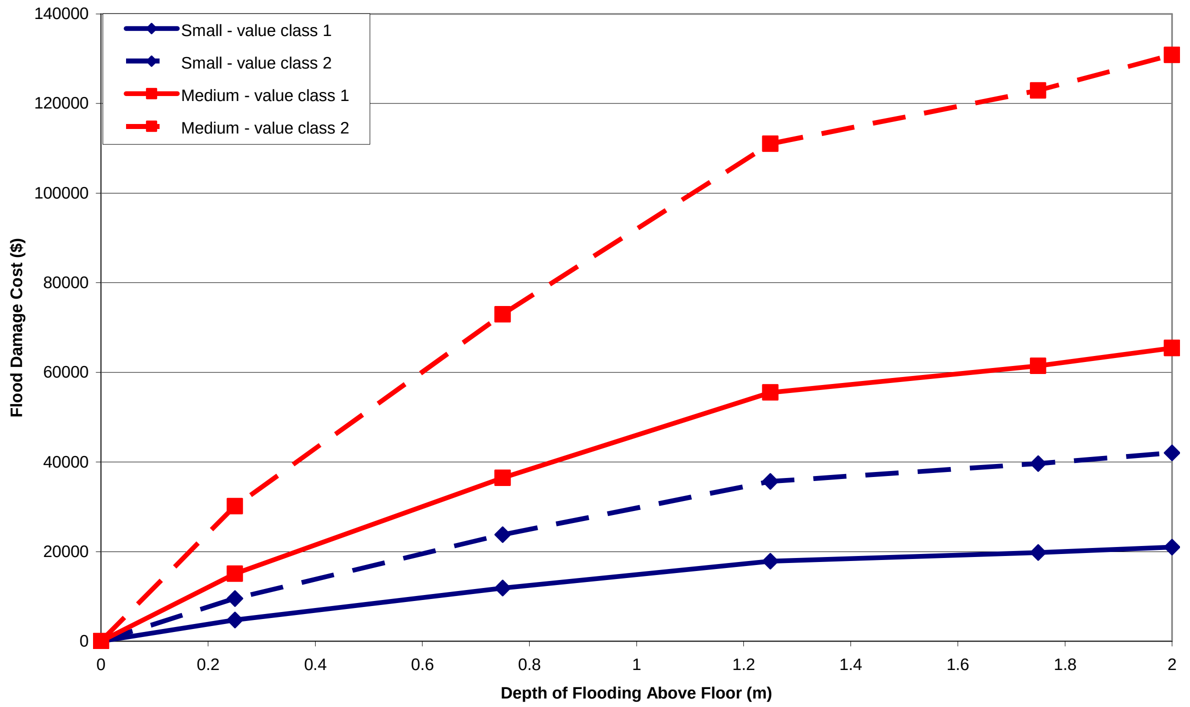

Figure C-3 Stage-damage curves used in this study for commercial above floor flooding

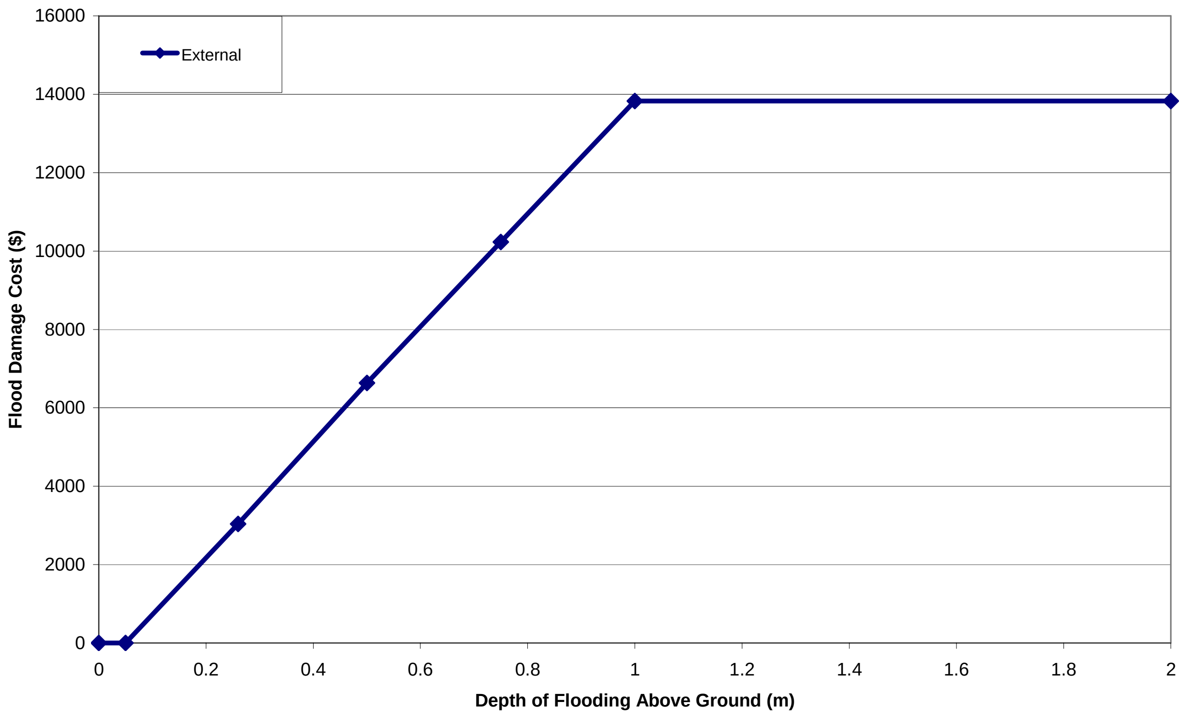

Figure C-4 Stage-damage curve used in this study for external below floor flooding

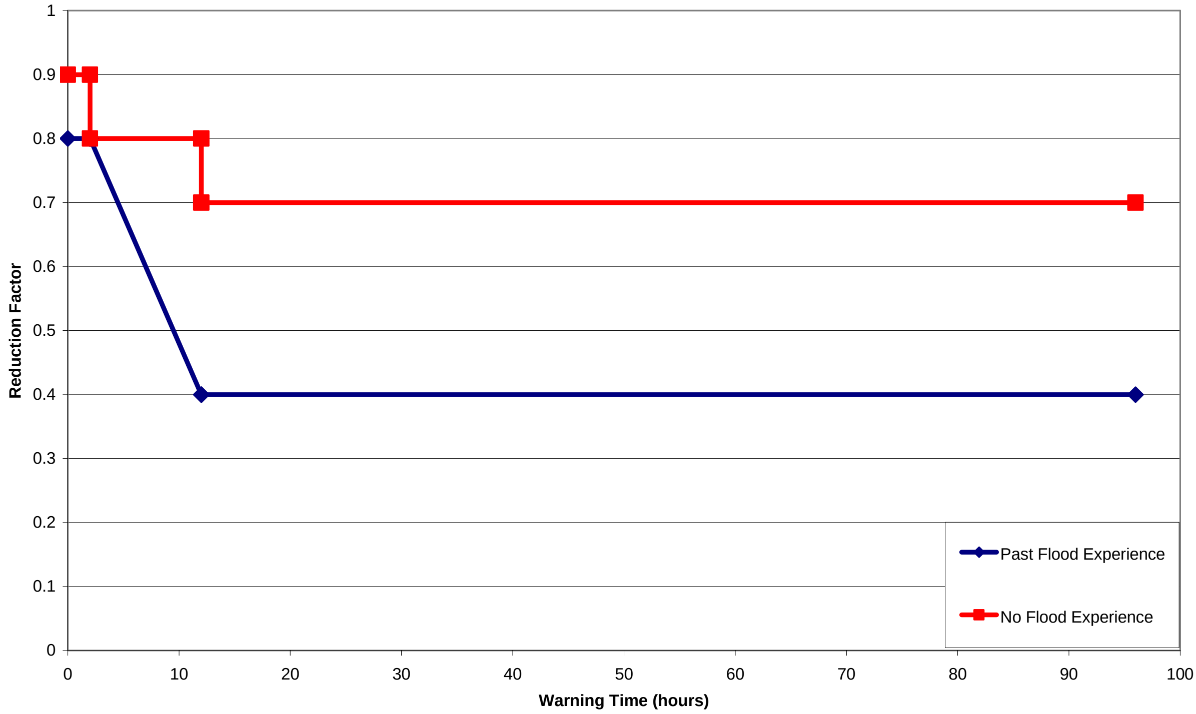

Figure C-5 Reduction factor curves for potential to actual direct damage ratio

Indirect Flood Damage

Indirect flood damages are damages incurred as a consequence of a flood but are not due to the direct impact of the flood itself (e.g. emergency services, clean-up costs, alternative accommodation, lost business opportunity, etc.). Indirect damages are extremely hard to estimate and are often calculated by assuming they equal 30% of the total actual direct flood damage cost, as in the RAM (NRE, 2000), however it is recommended that this be revised to best suit population density. The Bureau of Transport Economics (2001) suggest adopting a more rigorous approach, and provide estimates on the cost of post flood clean-up, relocation and emergency response actions. BTE (2001) suggest that post flood residential clean-up may cost approximately $330 for materials and approximately 160 hours in labour (an average weekly wage of $1,102 for September 2007 was adopted from the Bureau of Statistics website). The total commercial clean-up was estimated as $2,400 for inundated properties (BTE, 2001). BTE (2001) estimates the cost of residential relocation per property as $53 per house for relocation of household goods and $26 per person per night for alternative accommodation (assuming an average of 2.6 people per household from Bureau of Statistics, and a requirement of seven nights accomodation). BTE (2001) also suggest that volunteer emergency response costs be considered and that estimates of volunteer hours be made. It has been assumed for this study that for the 100, 50, 20, 10 and 5 year ARI design flood events that 50, 40, 30, 20 and 10 volunteers respectively worked for fifteen hours (assuming average weekly wage above).

To put all these figures into perspective, when applying the calculations to each design event it works out that the indirect flood damage costs are approximately 15 to 20% of that of the total actual direct flood damage costs, similar to that suggested by RAM (NRE, 2000). The BTE (2001) estimates are adopted in this study.

Total Flood Damage

The total flood damage cost is then calculated as the sum of the direct actual flood damage cost and the indirect flood damage cost, as well as any infrastructure damage. These results are outlined in Section 6.1.3 of this report.

APPENDIX D – COMMUNITY QUESTIONNAIRE

Beaufort
Flood Study
Community Questionnaire March 2007

As part of the community consultation for the Beaufort 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 Pyrenees Shire Council at the address 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, but if provided will be used to provide further information during the course of the study.

Telephone/fax/e-mail (*optional*) ....

1. Have you been affected by floods in the past, and if so, when (month/year)? ....

   ....

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 ....

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.

....

....

Thank you for taking the time to complete this questionnaire. Please return via mail in the accompanied reply paid envelope or hand deliver by Friday 6 April 2007 to: Pyrenees Shire Offices – Lawrence Street, Beaufort, Victoria 3373

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

APPENDIX E – CROSS SECTION SURVEY

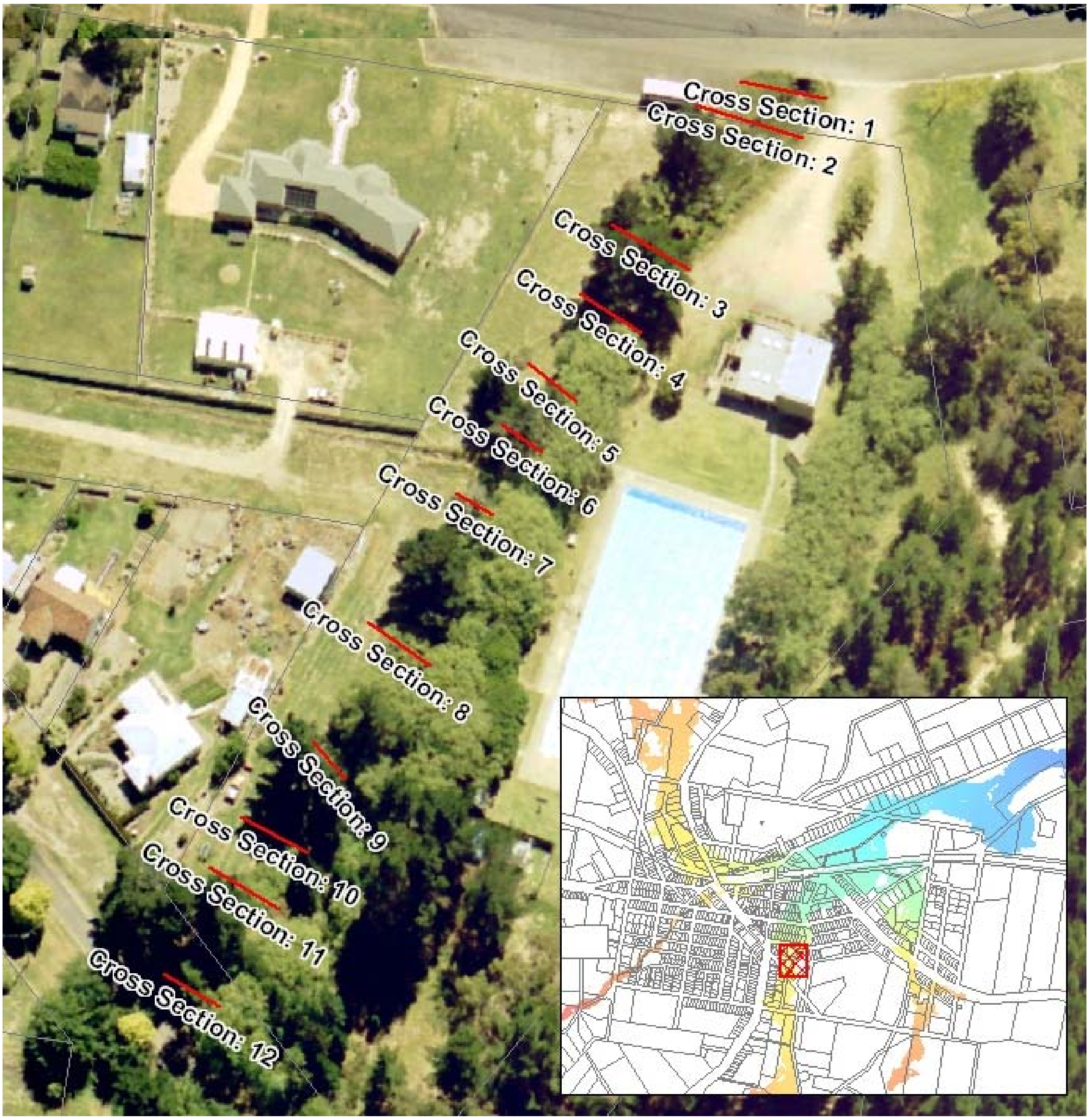

Figure E1 Locations of surveyed cross sections

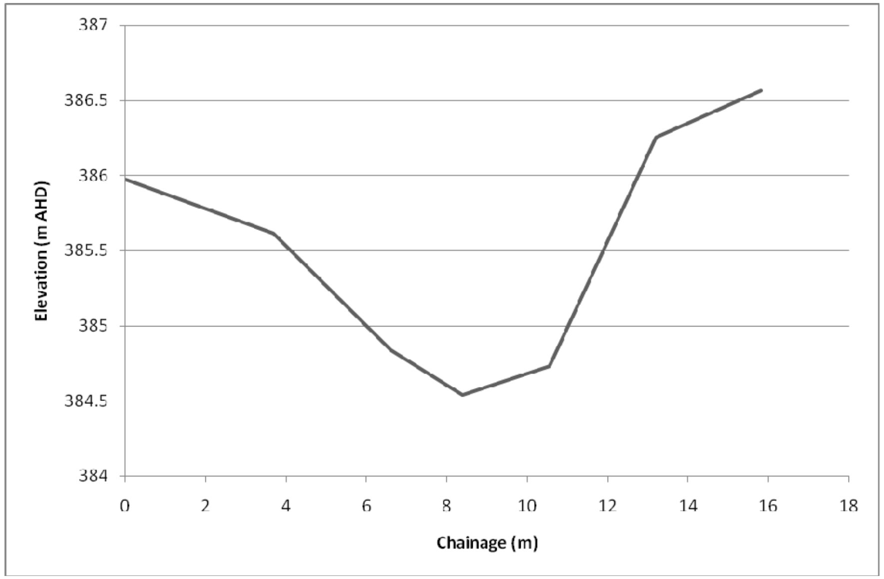

Figure E2 - Cross section 1

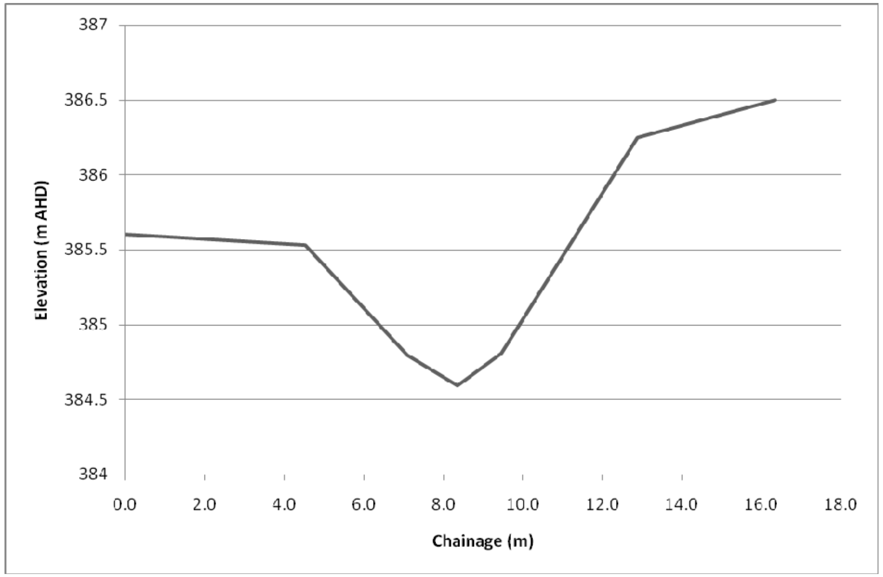

Figure E4 - Cross section 3

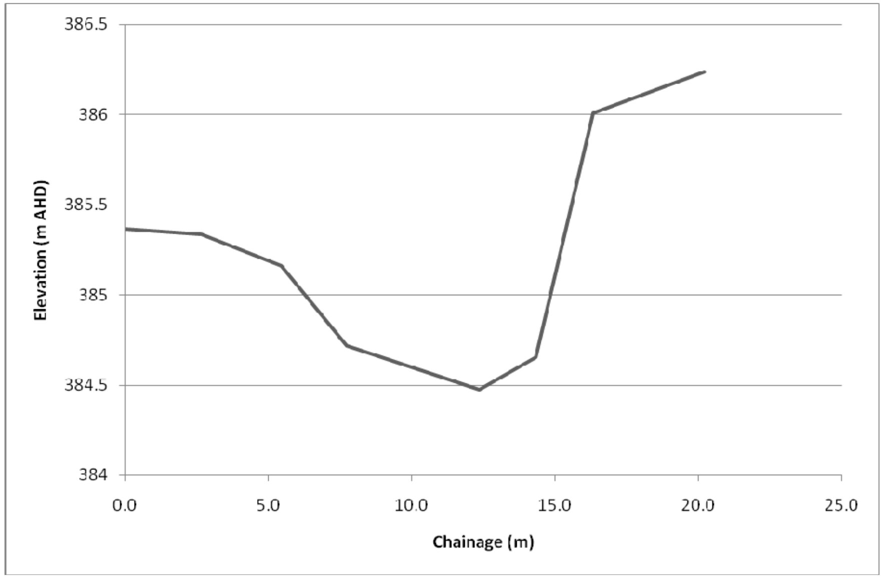

Figure E3 - Cross section 2

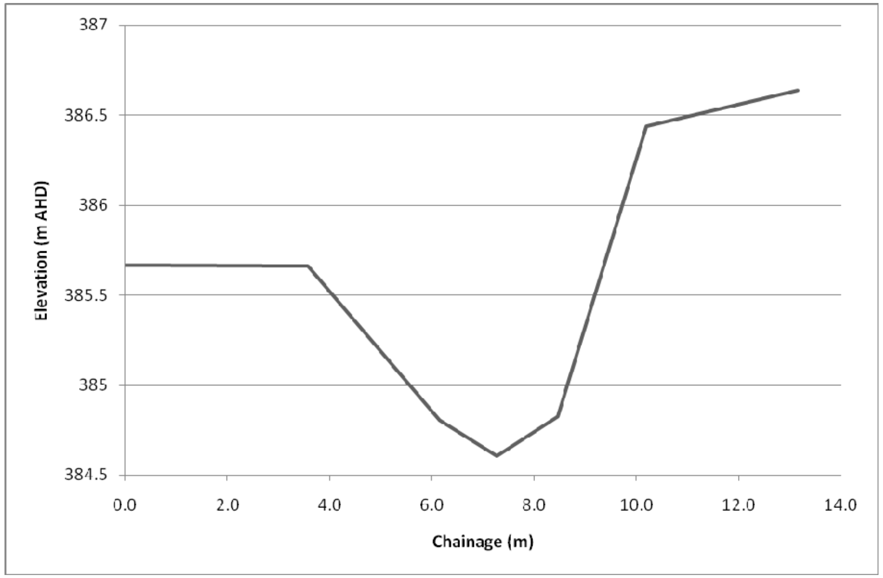

Figure E5 - Cross section 4

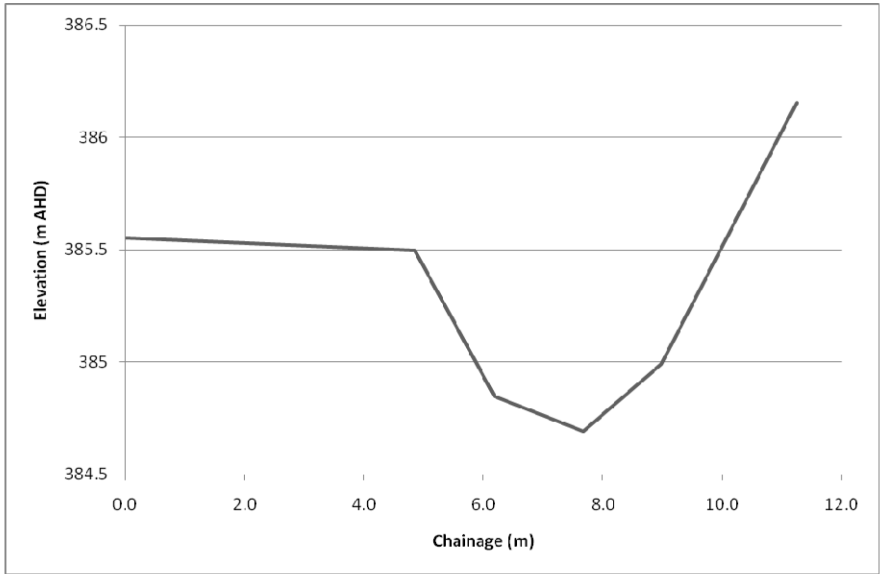

Figure E6 - Cross section 5

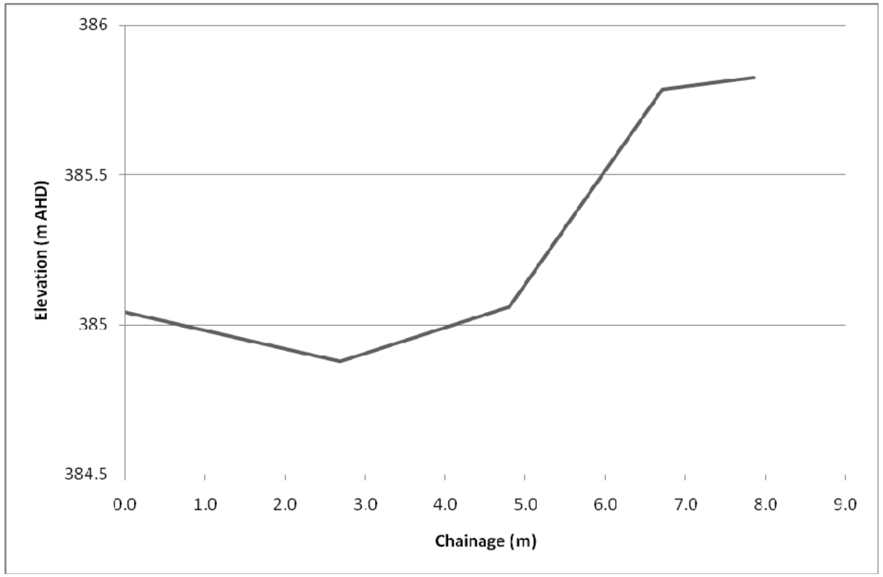

Figure E8 - Cross section 7

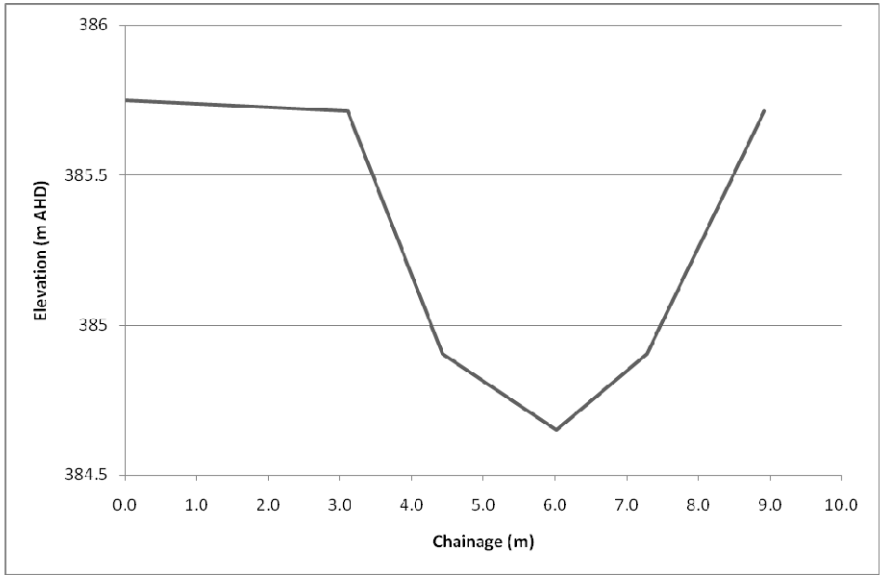

Figure E7 - Cross section 6

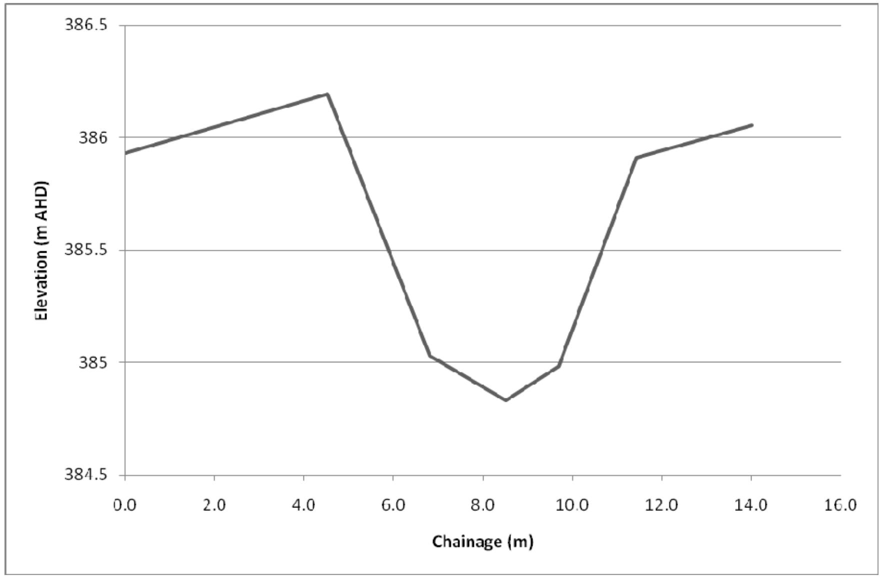

Figure E9 - Cross section 8

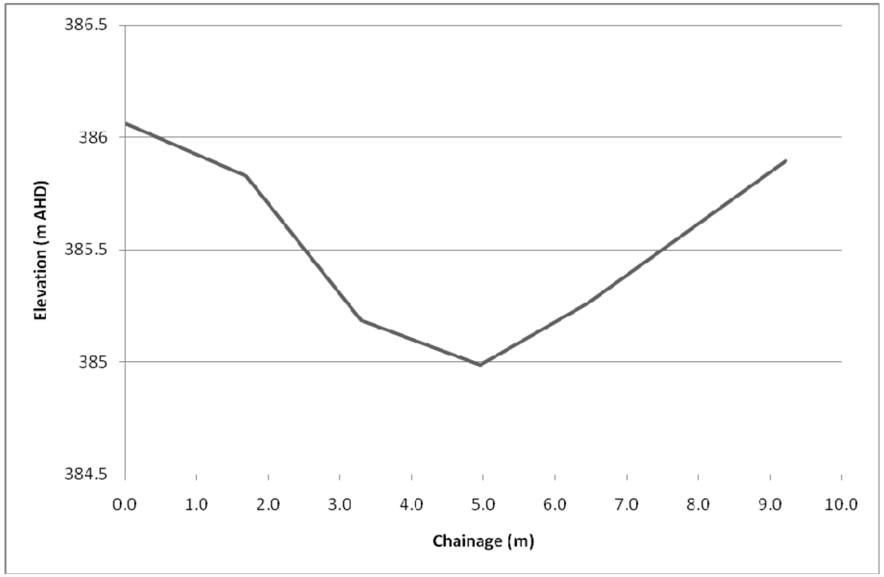

Figure E10 - Cross section 9

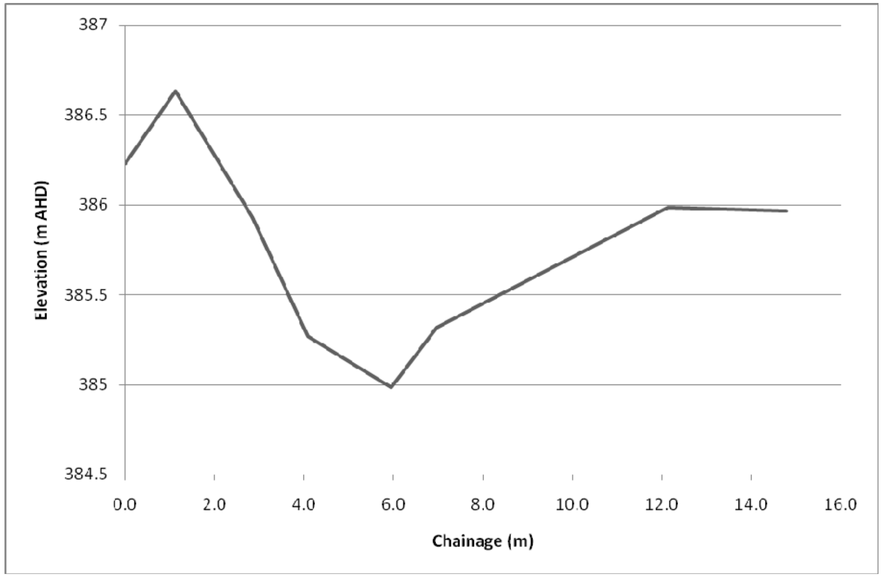

Figure E12 - Cross section 11

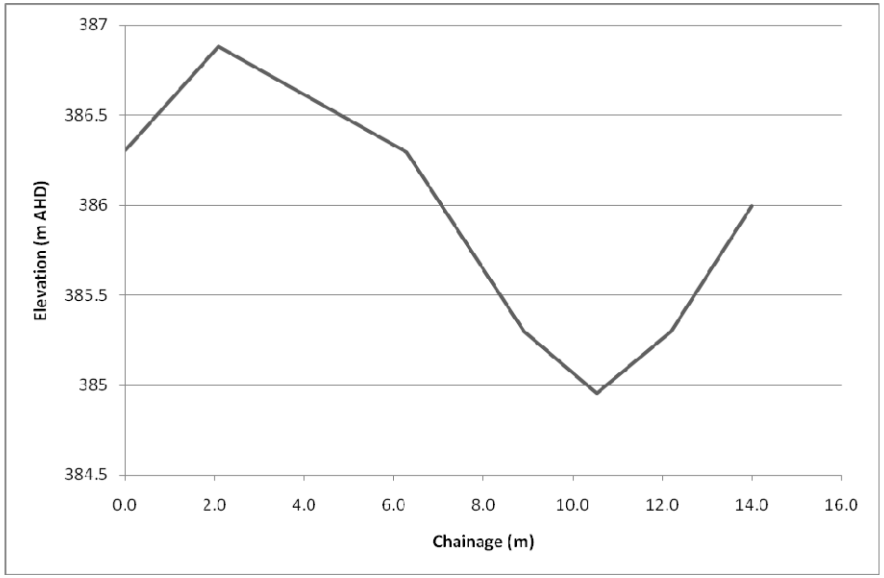

Figure E11 - Cross section 10

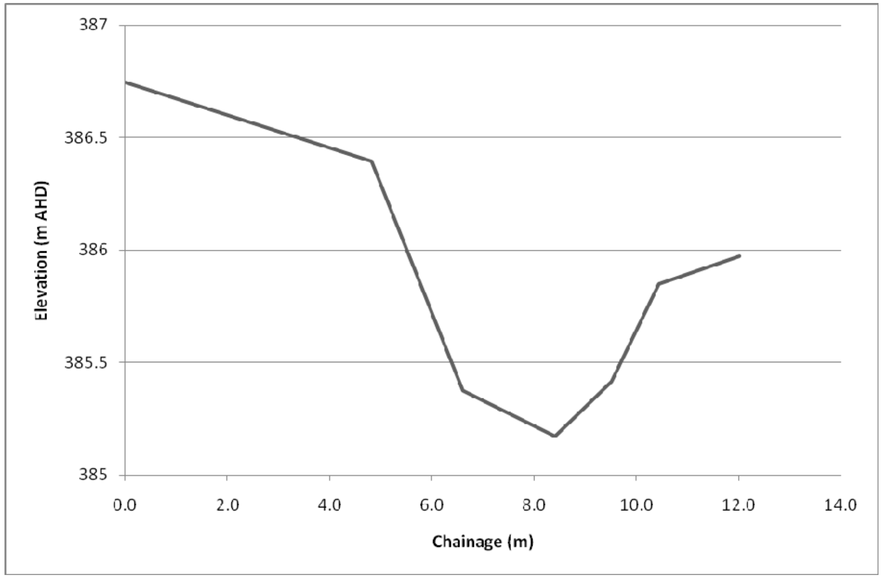

Figure E13 - Cross section 12