Glenelg Hopkins CMA
Warrnambool City Council

Dennington Flood Study
Study Report

Report No. J478/R01 Final
August 2007

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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.
Best Practice	Practices which incorporate latest technology and/or processes from a particular industry/s to result in the most effective or beneficial outcome
Biodiversity	The number of species in an area and the extent of genetic variability within them
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 1 d
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.
Ecologically Sustainable Development (ESD)	Development which aims to meet the needs of people today while conserving our ecosystems for the benefit of future generations. The National Strategy for ESD, agreed by the Council of Australian Governments in December 1992, defines ESD as: *"using, conserving and enhancing the community's resources so that ecological processes on which life depends are maintained and the total quality of life, now and in the future, can be increased."*
Flash flooding	Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall or rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain which causes it.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse

	and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
Flood 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 options	The measures which might be feasible for the management of a particular area.
Flood planning area	The area of land below the flood planning level and thus subject to flood related development controls.
Flood planning levels	Flood levels selected for planning purposes, as determined in floodplain management studies and incorporated in floodplain management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of land use and for different flood plains. The concept of FPLs supersedes the "Standard flood event" of the first edition of the Floodplain Development Manual. As FPLs do not necessarily extend to the limits of flood prone land (as defined by the probable maximum flood), floodplain management plans may apply to flood prone land beyond the defined FP s.
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.
NPER	National Professional Engineers Register. Maintained by the Institution of Engineers, Australia.
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

ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
GHCMA	Glenelg Hopkins Catchment Management Authority
WCC	Warrnambool City Council
DOI	Department of Infrastructure
DSE	Department of Sustainability and Environment
EPA	Environment Protection Authority
FFG	Flora and Fauna Guarantee Act 1988
HAT	Highest Astronomical Tide
ISC	Index of Stream Condition
LCC	Land Conservation Council
LH	Landholder
LG	Local Government
LWD	Large Woody Debris
LWRDC	Land and Water Resources Research and Development Corp.
MHHW	Mean High High Water
MLHW	Mean Low High Water
MSL	Mean Sea Level
MHLW	Mean High Low Water
MLLW	Mean Low Low Water
NHT	Natural Heritage Trust
NRE	(Department of) Natural Resources and Environment
RCS	Regional Catchment Strategy
SRWSC	State Rivers and Water Supply Commission
VPPs	Victoria Planning Provisions

1 INTRODUCTION

1.1 Study Objectives

The aims of the investigations were as follows:

- Production of a sound Dennington Flood Study that includes:
    - (a) Development of a detailed terrain model based on existing and new survey of Dennington and environs;
    - (b) Comprehensive hydrological review of existing studies and models and revision and updating as necessary to produce robust design flows for the study;
    - (c) Detailed and accurate hydraulic analyses/modelling of the Merri River and floodplain at Dennington;
    - (d) Compilation of a range of flood related products to assist in management of the Merri River floodplain at Dennington; and

- Review of flood risk including preparation of a Flood Damage Assessment.
- Production of a report and plans that will allow the Warrnambool City Council to inform and engage the community in flooding issues.

1.2 Structure of Report

This report details the investigations undertaken to achieve the above aims. The structure of this report is as follows:

- Section 2 – describes features of the study area
- Section 3 – outlines the input data gathered for use in the study
- Section 4 – details the hydrologic analysis
- Section 5 – details the hydraulic analysis
- Section 6 – outlines the flood risk study
- Section 7 – describes the study mapping and deliverables
- Section 8 – provides a summary of the study recommendations

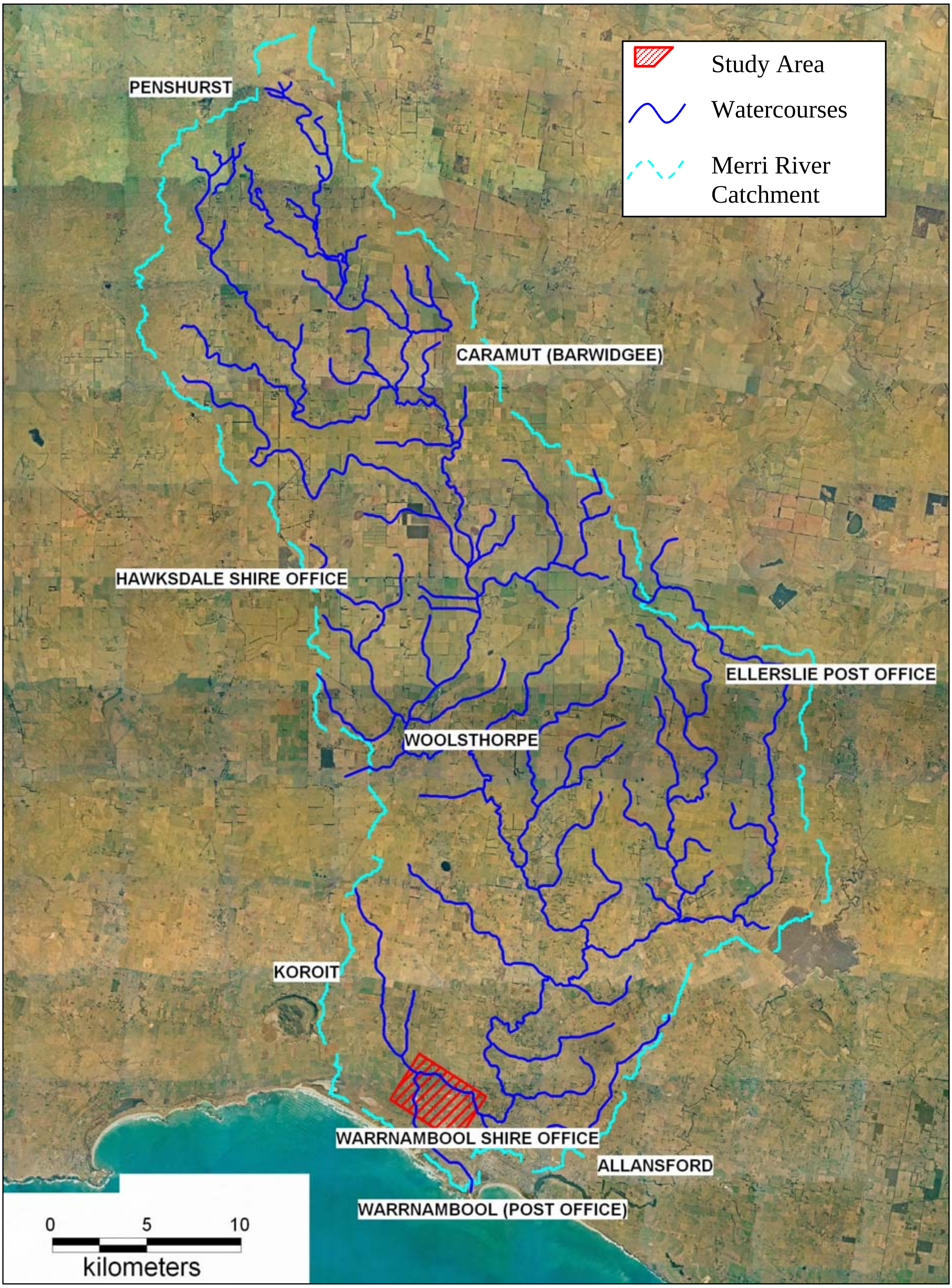

Figure 1-1: Study Area Locality and contributing catchment

2 STUDY AREA

The study area consisted of the Merri River channel from the Caramut Rd Bridge down to the Princes Hwy Bridge and associated floodplain. A small tributary called Yangery Creek enters the Merri River upstream of the Railway Bridge as can be seen in Figure 2-1 below. The Merri River in this section consists of a deep navigable channel with high banks on either side. The only hydraulic feature of any significance in this stretch is the derelict Railway Bridge just upstream of the Princes Highway bridge.

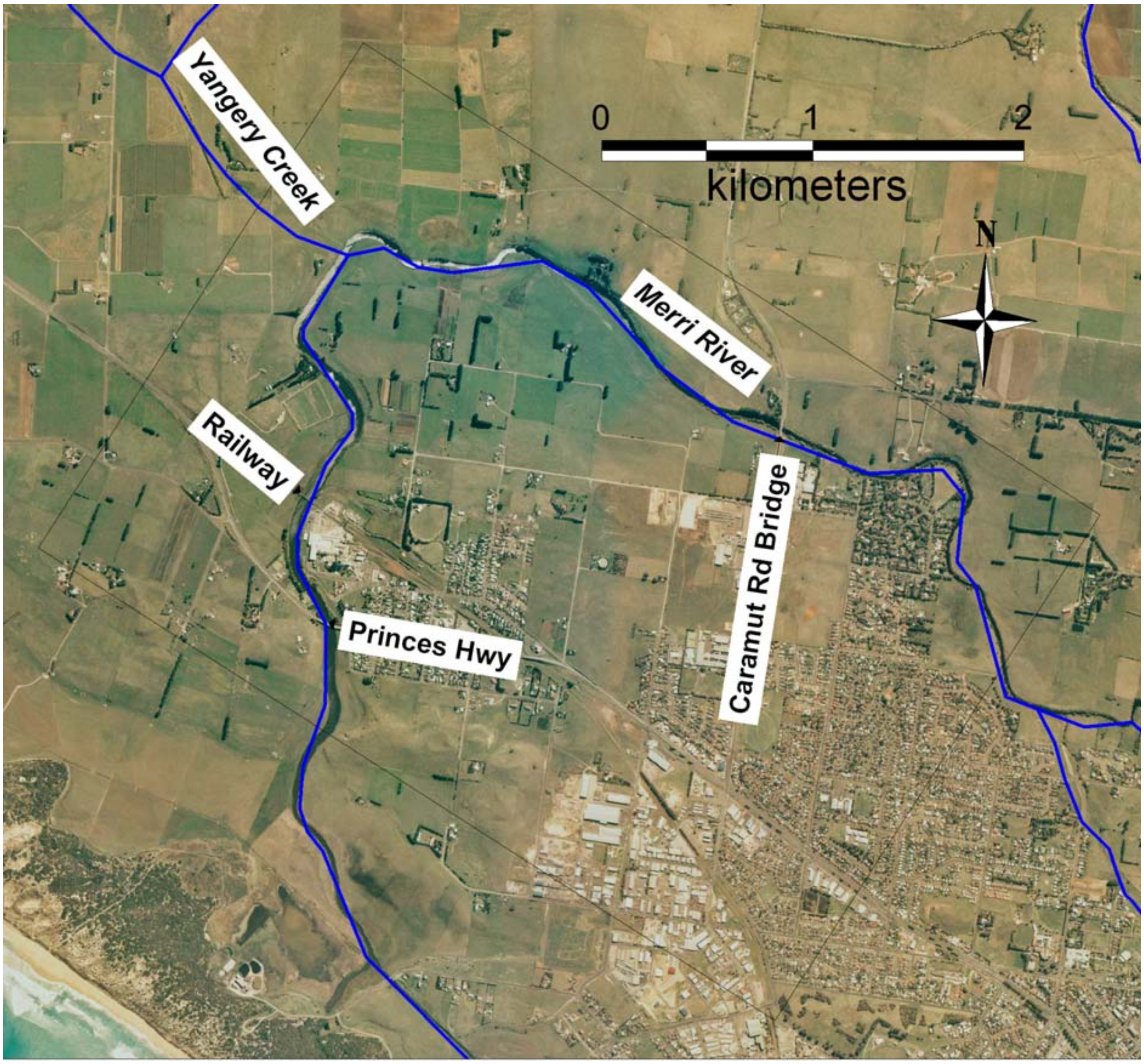

Figure 2-1: Study Area, Key Hydraulic Features

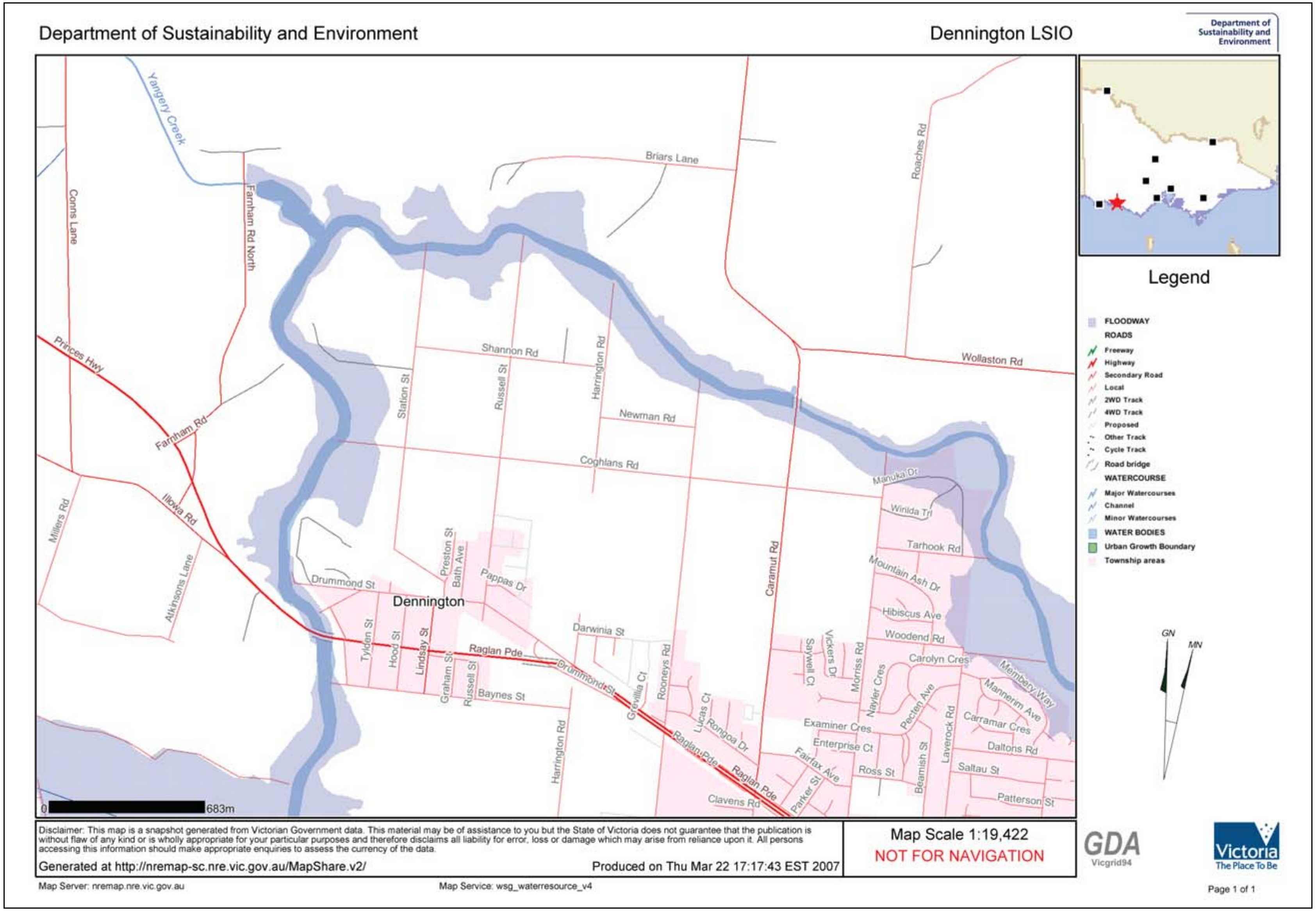

Figure 2-2: Previous 100 year ARI Flood Outline (from DSE Catchment Information Mapper)

3 AVAILABLE INFORMATION

This section outlines the different types of information utilised within the study including reference reports and documents as well as data, both previously available and collected specifically for this study.

3.1 Previous Studies

Previous hydrologic and/or hydraulic studies relevant to the present project and region include:

- South Warrnambool Flood Study (WT 2007) – This study investigated flooding for the Merri River in the South Warrnambool area. Hydrologic and Hydraulic information from this previous study overlaps the downstream boundary of this study.
- Report on the Western District Floods of March 1946 (SR&WSC 1946) – This report documented and examined the severe flooding that occurred on the 16th to 19th March 1946. This flood event is the largest on record and hence this information is particularly beneficial to the hydraulic model calibration process.
- North Warrnambool Flood Study (GHD 2003) – This study investigated flooding for the Merri River and Russell Creek catchments in the North Warrnambool area. Hydrologic information from the GHD study is a reference point for the present investigations.
- Previous investigations undertaken by the SRWSC/RWC during the 1980's involved estimating design flood levels based on preliminary methods and interpolation of 1946 levels.
- Review of Flood Studies (Weinmann 2006) – This was a review of the South Warrnambool Flood Study by Water Technology and the North Warrnambool Flood Study by GHD.

3.2 Topographic and Cadastral Survey Data

3.2.1 Overview

Topographic and cadastral data have been collected from a number of sources as outlined in Table 3-1 below.

Table 3-1: Available Topographic and Cadastral Data

Data	Estimated Nominal Accuracy	Source
Photogrammetric points and breaklines (City of Warrnambool)	Vertical +/- 2 m Horizontal +/- 5 m	Warrnambool City Council (QASCO)
Cadastre	Vertical n/a Horizontal +/- 10 m	GHCMA and Land Victoria
Waterway cross-sections	Vertical +/- 0.05 m Horizontal +/- 1 m	Brian Consulting
Digital Aerial Photography	Horizontal +/- 0.5 m	GHCMA

Note: As appropriate meta-data is not available for most data sources, reasonable estimates of survey accuracy have been made based on the capture techniques used and experience with previous, similar data sets.

A copy of all survey information collected as part of this study is provided in the study data CD.

3.2.2 Aerial Photogrammetry

Photogrammetry data of the study area was supplied by the Warrnambool City Council. It contains points and break-lines defining the surface topography which can be used to create the digital terrain model for the study.

3.2.3 Field survey

The field survey was required to supplement the photogrammetry to define the watercourse cross-sections below the waterline and other features obscured in aerial photos such as bridges. Six cross-sections were surveyed between Caramut Rd Bridge and the Railway Bridge, including detailed cross-sections of both bridges. The field survey was carried out by Brian Consulting in November 2006.

3.2.4 Cadastre

Cadastral information was provided by the Glenelg Hopkins CMA for the study area. This information includes typical parameters such as Street Name, Number and property boundary. This information can be used to identify flood-prone properties.

3.2.5 Aerial Photos

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. Typically these photos are digitised and registered in a GIS system for analysis. Digital aerial photos were provided by the GHCMA (Feb 2003), and while not showing any development since 2003, give a reasonably accurate representation of project area conditions.

3.3 Hydrologic and Hydraulic Data

3.3.1 Stream Gauge Data

Stream flow data is required for the hydrologic analysis and modelling. There are four stream gauging stations (past and present) located within the Merri River catchment, these are listed in Table 3-2. Only one of these gauges, at Woodford, was able to provide stream flow data that is suitable for the hydrologic analysis, whilst information at the other gauges can be used to assist in the hydraulic model calibration and verification

Table 3-2: Details of Stream Gauges

Station Number	Station name	Catchment Area (km2)	Period of record
236205	Merri River @ Woodford, at Woodford - Bushfield Road bridge	899	August 1948 to date*
236217	Merri River at Warrnambool, at Swinton Street bridge (Levy's Point Bridge)	1,040	January 1977 to December 1985
236218	Merri River at Denington, at Princes Highway bridge	1,020	July 1979 to July 1985
236226	Merri River @ North Warrnambool, at Bromfield Street Weir	910	January 2000 to date

* Note: minor gaps in records after 1965. Discontinuous records available for period 1948 to 1965.

3.3.2 Flood Marks

Observed flood marks for the 1946 and 2001 flood events have been gathered to assist with the calibration of the hydraulic model. A total of seven water surface elevation marks were collected for the 1946 event (RWC File), and another three marks for the 2001 event from council records. Flood marks were also available for other events, however they were not significant enough in number for calibration purposes.

3.3.3 Other Historic Flood Data

Photos of the 2001 flood event have been provided by the GHCMA depicting high flood levels at various locations in the Dennington study area. These photos, although not necessarily at the peak flood height, provide excellent indications of flood extents.

3.3.4 Previous Hydrologic Analysis and Modelling

A RORB model for the Merri River catchment was developed for the South Warrnambool Flood Study (WT, 2006). The model was able to be used in this study to produce hydrographs for the Dennington study Area.

4 HYDROLOGIC ANALYSIS

4.1 Overview

The Dennington Flood Study area is physically situated between the North Warrnambool Flood Study area (GHD, 2003) and South Warrnambool Flood Study area (Water Technology, 2006). Significant hydrologic investigations of design flows in the Merri River have been undertaken as part of these bounding studies. Subsequently, much of the hydrology for the present study has been previously defined.

The GHCMA recently commissioned an independent review of all the available hydrology from recent studies in the Warrnambool area (Keller and Associates, 2006). The outcome of this review was a confirmation that the design flows derived for the North and South Warrnambool Flood Studies were in the right order of magnitude and are consistent with regional estimates. Subsequently design peak flood flows derived for the South Warrnambool Flood Study have been adopted for the present investigation.

One point raised by the Keller and Associates review was that the major 1946 flood event could be investigated using the RORB model developed for South Warrnambool. Modelling of the 1946 flood using RORB can provide further useful information in relation to this notable historical flood and benefit hydraulic model calibration for the Merri River.

4.2 Design Peak Flows

Design peak flows were required for the 5, 10, 20, 50 and 100 year ARI flood events. A rigorous hydrologic investigation of design flows for the Merri River was recently undertaken for the South Warrnambool Flood Study (Water Technology, 2006). Through discussion with the Glenelg Hopkins CMA it was decided that the Merri River design flows from the South Warrnambool Flood Study would be appropriate for the present study. Adoption of this design hydrology in turn provides consistency between the Dennington Flood Study and the North and South Warrnambool Flood Studies. Table 4-1 displays the adopted design peak flows, whilst Figure 4-1 shows the relevant design flood hydrographs. These flows include the contribution from the Yangery Creek catchment, which enters the Merri River approximately midway through the study area. The Yangery Creek catchment is small relative to the Merri River at Warrnambool and subsequently does not contribute significantly to design flood peaks in the study area. Hence the flows presented below are considered appropriate for the whole study reach of the Merri River.

Table 4-1: Adopted peak flows from South Warrnambool Flood Study

Location	**5 yr ARI**	**10 yr ARI**	**20 yr ARI**	**50 yr ARI**	**100 yr ARI**
Adopted Peak Design Flow (m^3/s) for Merri River at Warrnambool	144	200	250	340	410

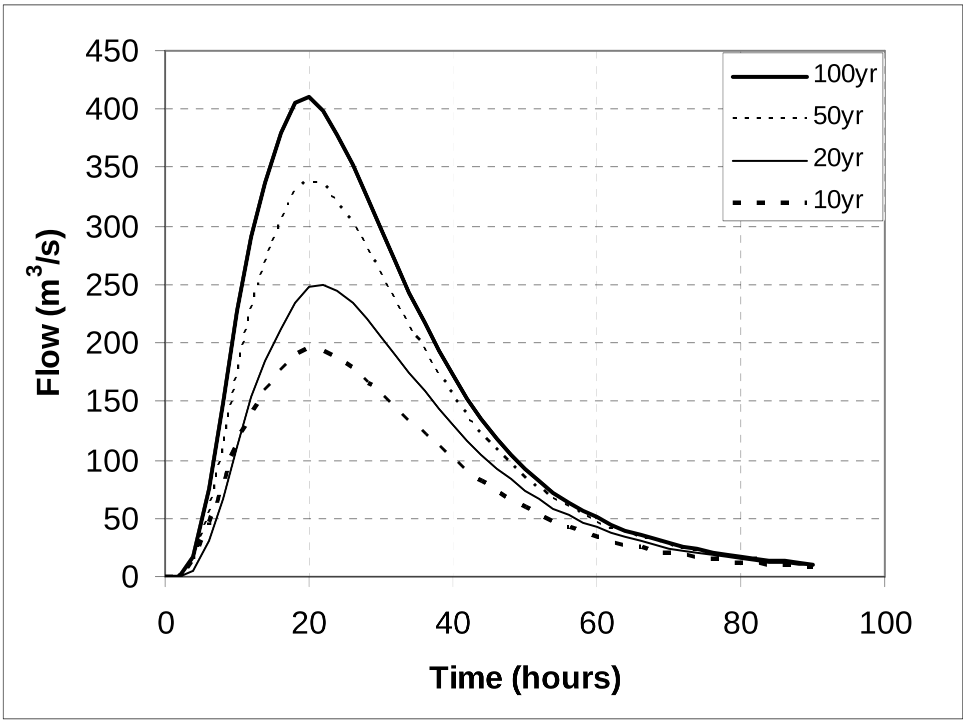

Figure 4-1: Merri River at Warrnambool – Adopted Design Flood Hydrographs

4.2.1 Extreme Flood – PMF Estimation

The North Warrnambool Flood Study produced an estimated PMF flow of 2141 m^3/s. The exact method for determination of this flow is unclear. 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 Merri River catchment are provided in Table 4-2. 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 4-2: PMF Design Flow Estimates

Parameter	PMF Estimate
Peak flow (m^3/s)	9,000
Event volume (m^3)	445,000
Time to peak (hrs)	10.5

4.3 Review of 1946 Flood Event

4.3.1 Background

The March 1946 event is the highest flood on record for the Merri River. The weather system associated with this event caused widespread flooding in south-west Victoria with the highest rainfall totals (327 mm at Macarthur over 3 days) recorded in the Warrnambool area. Significant damages occurred, particularly to bridges at Woodford and Warrnambool (Cassidy's Bridge) according to the Report on the Western District Floods (Schiller and Forbes, 1946).

As part of the North Warrnambool Flood Study (GHD, 2003), an estimate of the magnitude of the peak flow for the 1946 flood at Warrnambool was undertaken. This estimate was based on a calibrated daily water-balance model of the Merri River catchment and historic daily rainfall values. This modelling provided an estimated 1946 flow of 470 m^3/s compared to 410 m^3/s for the 100 year ARI design event produced from a frequency analysis of the same model output. Based on the FFA and PMF estimate, it can be deduced that the nominal frequency of the 1946 event from the North Warrnambool Flood Study was approximately 200 years.

A review of previous investigations and file information from the former State Rivers and Water Supply Commission (SRWSC) suggests the magnitude of the 1946 flood at Warrnambool was significantly larger than a 100 year ARI flood. A preliminary flood investigation by the SRWSC in 1979 estimated the 1946 peak flood flow to be 950 m^3/s based on:

- A calibrated water surface profile from a one-dimensional hydraulic model of the Merri River through North Warrnambool based on observed flood levels and;
- A reference to an estimated flow of 1050 m^3/s calculated by the Country Roads Board (CRB, later VicRoads) at Cassidy's Bridge using a measured cross-section and estimated flow velocity.

The above analyses are not documented and hence it is difficult to place levels of certainty on the flow estimates provided without knowing the assumptions applied etc. At this stage we would place a reasonable level of reliability on these numbers, however recognising that they should be considered as indicative rather than definitive.

In order to provide further information in relation to the 1946 flood, a RORB model of the Merri River catchment has been applied using recorded daily rainfalls across the catchment with nominal temporal patterns and a range of losses.

4.3.2 Historical rainfall analysis

A total of nine rainfall stations in and around the Merri River catchment were identified from Bureau of Meteorology records. Table 4-3 shows each station and the depth of rainfall occurring on each day of the event. Figure 4-2 below shows the spatial distribution of rainfall over the catchment along with the rainfall stations used.

Table 4-3: Historical rainfall for March 1946 event and rainfall stations used

Station Number	Site Name	Rainfall Depth (mm)			
		16th	17th	18th	Total
90000	Allansford	32.5	133.4	20.3	186.2
90016	Caramut (Barwidgee)	15.7	74.9	27.4	118
90039	Ellerslie Post Office	20.1	81.3	13.7	115.1
90046	Hawksdale Shire Office	34	158.2	42.2	234.4
90051	Koroit	45.2	201.9	19.1	266.2
90063	Penhurst	26.9	143.3	17	187.2
90081	Warrnambool Shire Office	59.7	167.1	11.7	238.5
90082	Warrnambool (Post Office)	49.8	167.1	12.4	229.3
90084	Woolsthorpe	32.3	128	27.2	187.5

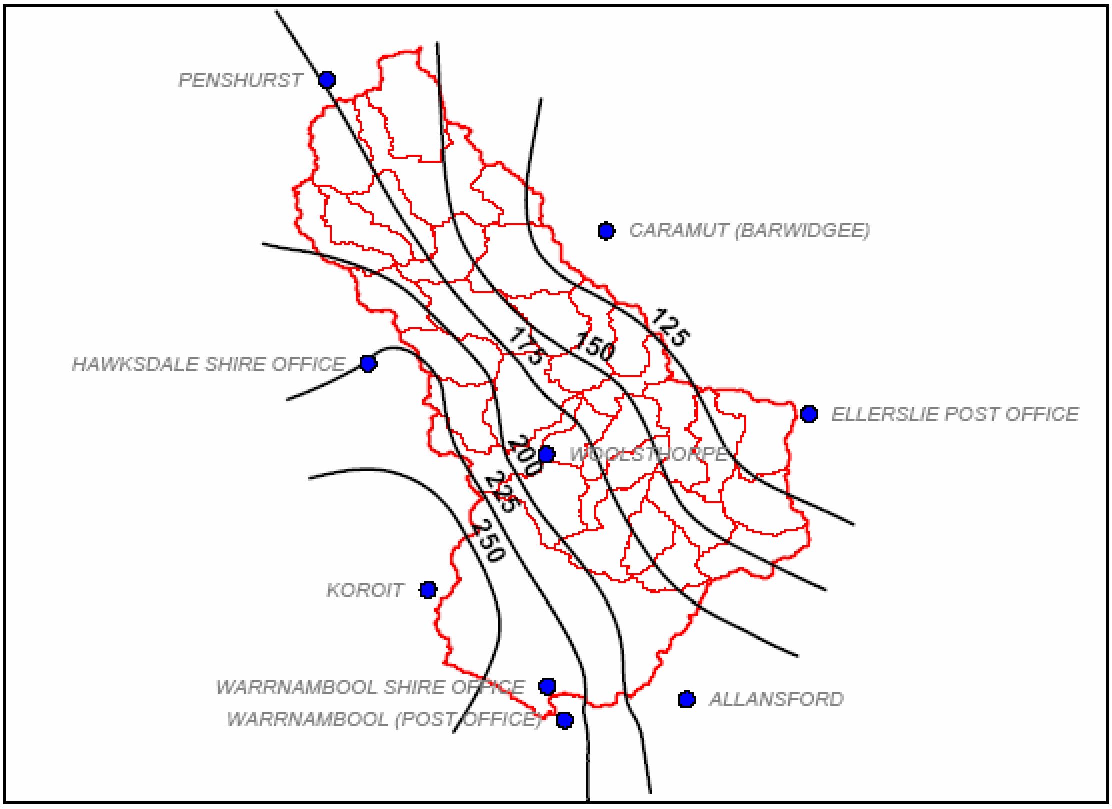

Figure 4-2: 3 day Rainfall Isohyets for March 1946 flood Event

The average total rainfall depths for 24, 48 and 72 hours were then compared to the design rainfall totals for Warrnambool derived from an IFD analysis according to ARR 1987. The results of this analysis are shown in Table 4-4 below. It can be seen that the 1946 event is consistently just below the design 500 year ARI event.

Table 4-4: Rainfall Intensity Frequency Duration Table for Warrnambool

	Event Rainfall (mm)				
Storm Duration (hrs)	**50 Yr ARI**	**100 Yr ARI**	**200 Yr ARI**	**500 Yr ARI**	**1946**
24	95.0	108.0	122.8	143.3	138.4
48	116.2	132.5	151.4	177.8	172.2
72	127.4	145.4	166.3	196.1	194.7

Table 4-5 shows the total rainfall depths at Woolsthorpe for the months leading up to the March 1946 event and compares them to the long term averages for each month. This shows that for the two months before the event, rainfall was almost three times the long term average. This suggests that late summer in 1946 was an unusually wet period in the Merri River catchment. Subsequently it can be deduced with some confidence that prior to the 1946 flood the catchment was reasonably wet.

Table 4-5: Monthly rainfall leading up to 1946 event at Woolsthorpe

Monthly Rainfall (mm)				
	Dec	**Jan**	**Feb**	**Mar**
Dec 1945 – Mar 1946	36	95	115	343
Long Term Average	46	36	33	45

There were no pluviograph stations operating within the Merri catchment or the south-west district of Victoria in 1946. Subsequently there are only daily rainfall data available for the 1946 flood and we do not know the sub-daily temporal pattern for the storm. Figure 4-3 shows that the majority of the rainfall fell on the middle day of the three day event.

Without sub-daily rainfall records available a temporal pattern for the storm must be assumed in order to simulate the flood in RORB and develop peak flows with some degree of confidence. An adoption of constant rainfall rates according to the daily rainfall record would be likely to lead to an underestimate of the flood peak due to the reality that rainfall is not typically uniform over a 24 hour period.

Two sets of design temporal patterns have been produced by the Bureau of Meteorology Australia. Those published in Australian Rainfall and Runoff (ARR, 1987) and the Temporal Distributions of Large and Extreme Design Rainfall Bursts Over Southeast Australia (BOM, 1998). It has been determined that the 1946 rainfall event was in the order of a 500 year ARI. Hence, it is reasonable to adopt the temporal pattern for Large and Extreme Rainfall Bursts (BOM, 1998) rather than the ARR patterns which are typically used for more frequent events. Warrnambool lies in the GSAM Coastal zone and the catchment of the Merri River is 1018 km^2, hence the GSAM Coastal temporal patterns for 1000 km^2 were considered appropriate. The 48 hr pattern starting halfway through the first day was chosen as it provides the best fit to the daily temporal pattern, as seen in Figure 4-3.

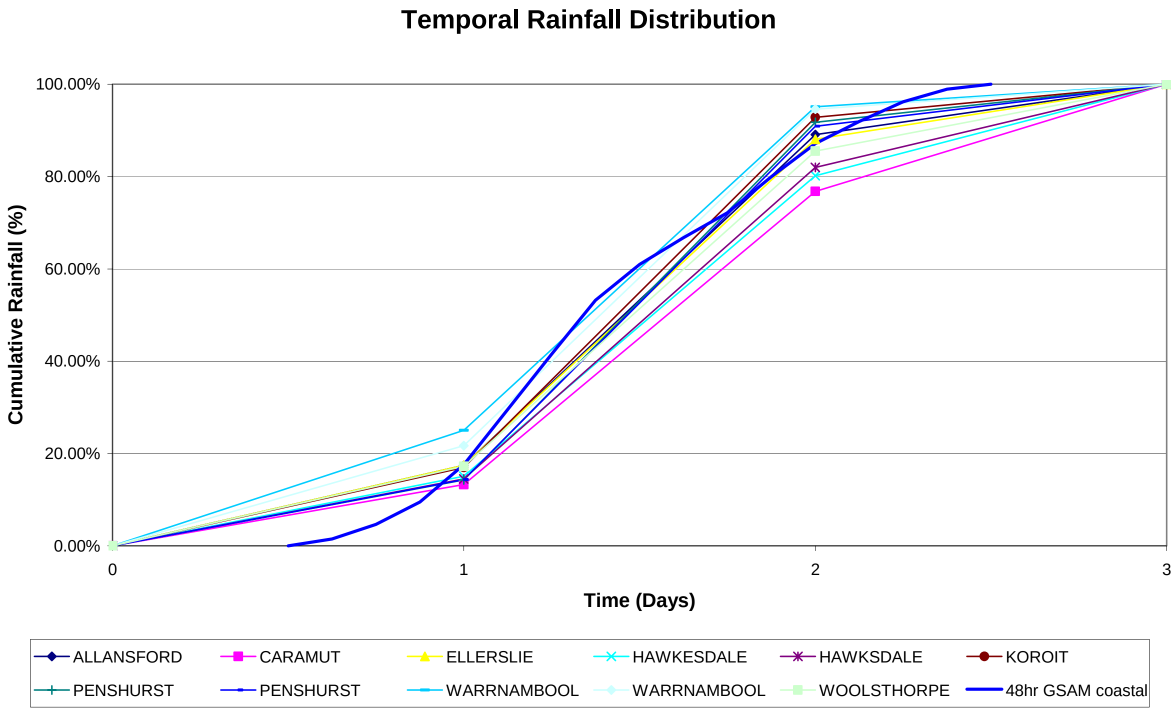

Figure 4-3: Historical temporal pattern compared to 48hr GSAM coastal pattern

4.3.3 RORB application to the 1946 flood event

The existing RORB model from the South Warrnambool Flood Study was utilised for the purposes of this study (Appendix A). The model was calibrated so that the design flood events correlated closely with the Flood Frequency Analysis. The parameters used in the model are as follows.

- Set m =0.8. This value is an acceptable value for the degree of non-linearity of catchment response (ARR, 1987).
- Determine k_c=58, based on k_c regional relationships for Victoria. As the study area was near the boundary of mean annual rainfall above or below 800mm, the relation for mean annual rainfall less than 800mm was adopted. The relation used is:

$$k_c=0.49A^{0.65} \qquad \text{Equation 1}$$

where: A is the catchment area (km^2)

The rainfall depths for each sub-catchment in the model were calculated from the spatial rainfall pattern. The spatial rainfall pattern was determined by interpolating a surface of rainfall depths from the nine rainfall stations. The 48 hr GSAM Coastal temporal pattern for 1000 km^2 catchments was then applied to the spatial distribution to estimate the overall pattern of rainfall in the catchment during the 1946 flood. It is noted that this methodology does not aim to reproduce the temporal distribution of rainfall for the 1946 event but produce a pattern that is the best estimation of the relationship between daily rainfall and peak storm burst for this magnitude of event, as it is typically the burst within the overall storm that produces a flood peak. Preliminary sensitivity testing with the RORB model confirmed that the assumed temporal pattern has a significant impact on flood peak, as can be seen in Figure 4-4 and Figure 4-5 below.

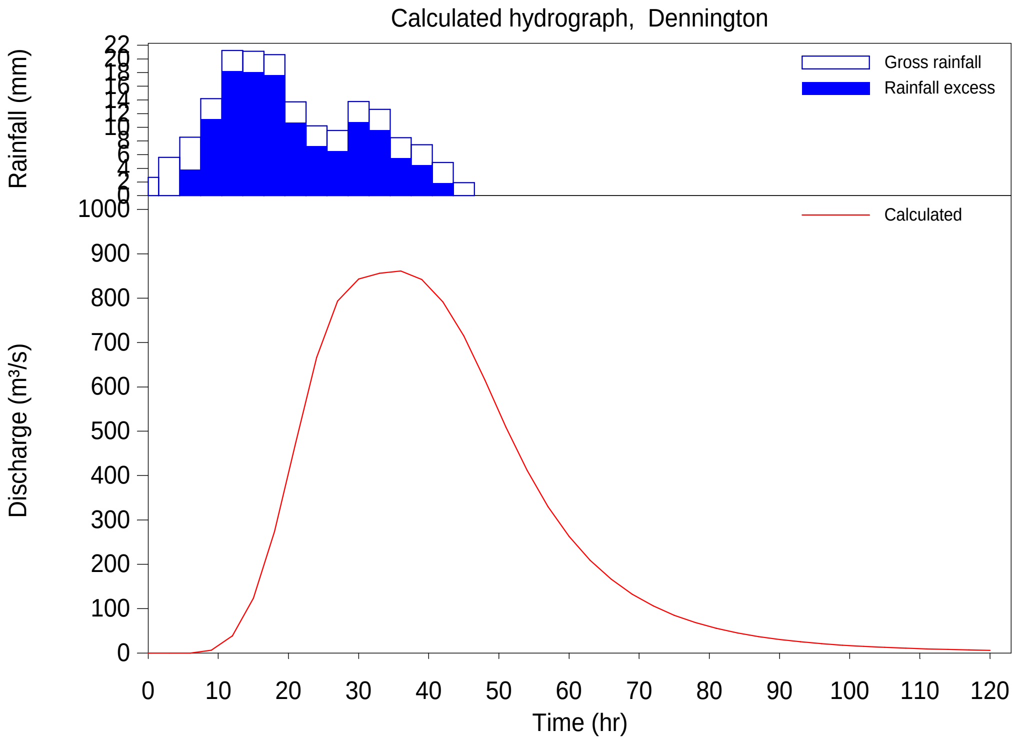

Figure 4-4: Adopted 48hr GSAM Coastal Temporal Pattern with flood peak of 861 m^3/s

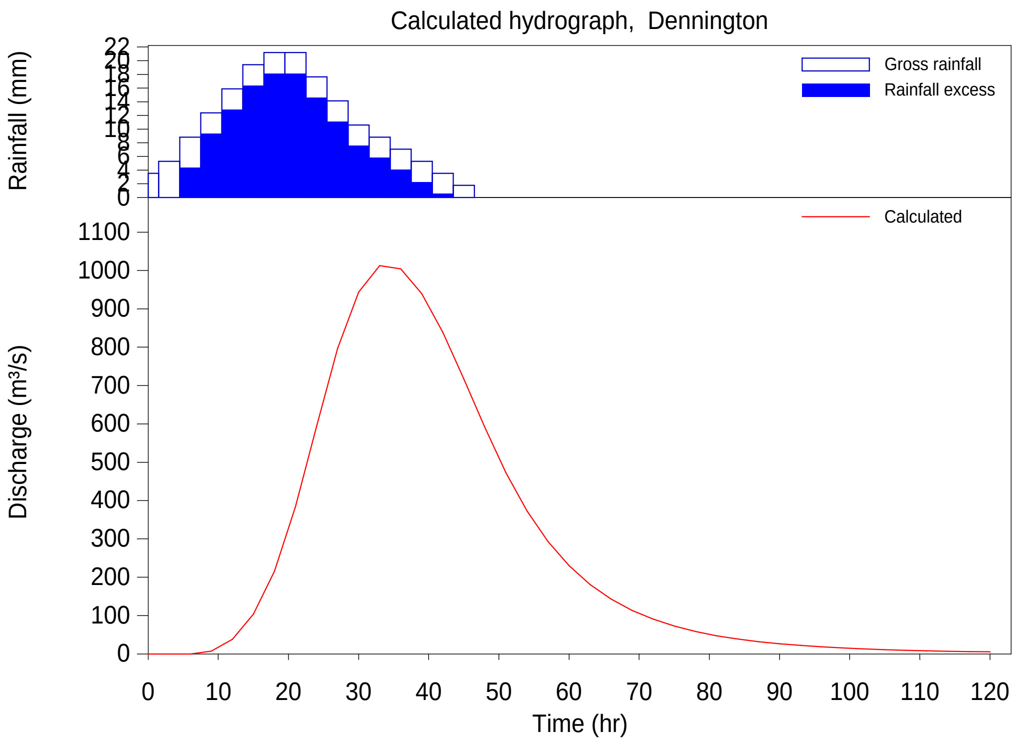

Figure 4-5: Smoothed Temporal Pattern with flood peak of 1012 m^3/s

A range of typical parameters for Initial Loss and Continuous Loss were applied to the RORB model to gauge their sensitivity. The Continuous Loss parameter was found to have the greatest effect on peak flow. Table 4-6 shows the various peak flows calculated for the range of input loss parameters, whilst Figure 4-6 shows the hydrographs produced for each parameter set. Given the large amount of rainfall leading up to the event, it is reasonable to assume that the catchment was reasonably wet and that losses were low, hence a peak flow in the higher range of those presented in Table 4-6 is quite plausible.

Table 4-6: Peak flows (m^3/sec) for varying parameter values

Continuous Loss (mm/hr)	Initial Loss (mm)			
	10	15	20	25
1	861	845	822	797
2	618	606	587	566
3	413	405	391	367

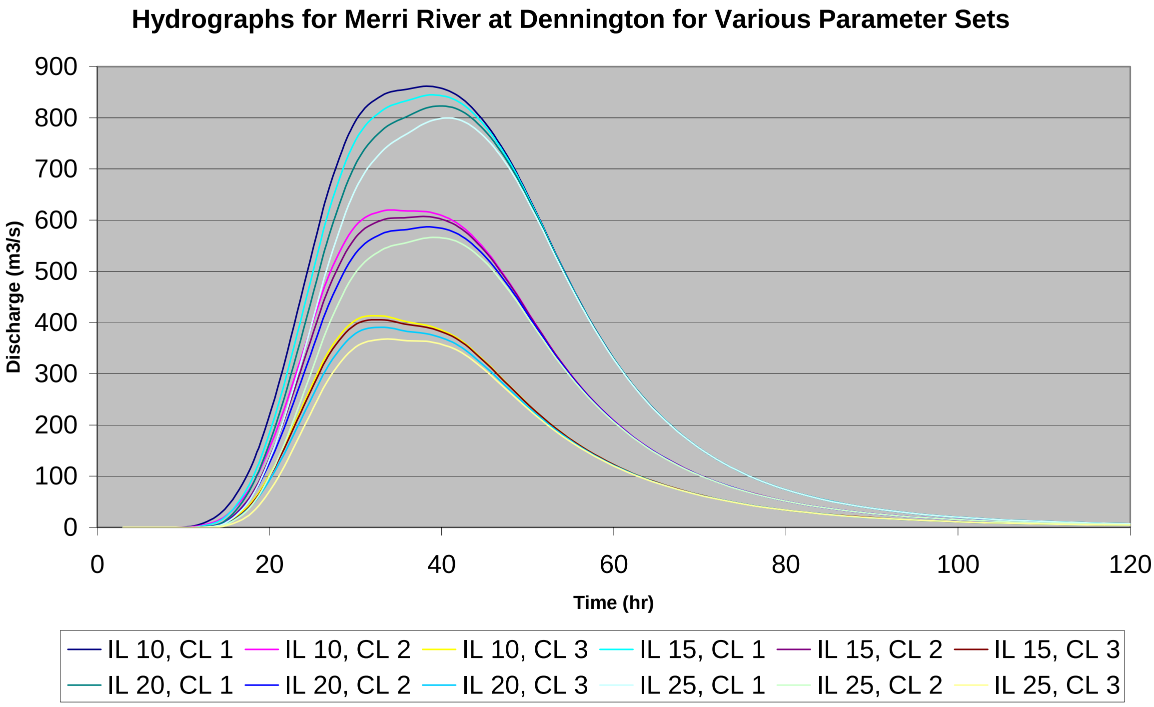

Figure 4-6: Hydrographs comparing values of initial loss and continuous loss

4.3.4 Discussion

The existing RORB model has been used to provide estimates of peak flood flows for the 1946 flood event that are based on actual rainfall volumes and a model that represents the physical characteristics of the catchment in terms of area and routing parameters.

The RORB modelling shows that the predicted peak Merri River flow at Warrnambool is quite sensitive to the temporal pattern for the sub-daily rainfall and the continuing rainfall losses assumed. Due to the lack of sub-daily rainfall information, a design temporal pattern has been adopted. Given the size of the 1946 event, this is considered a reasonable assumption. An analysis of antecedent conditions based on the preceding rainfall in the catchment provides some confidence that rainfall losses would have been relatively small for this event. This is consistent with the generally accepted trend that loss rates become smaller for more extreme intensity and longer duration events, as a catchment tends towards a saturated state. Hence a peak flow of 860 m^3/s representing relatively small losses will be used.

It is recommended that the predicted 1946 flows above be used in the hydraulic modelling as part of a sensitivity analysis for flood levels when comparing modelled to recorded values.

5 HYDRAULIC ANALYSIS

A hydraulic model has been used to investigate the extent of flooding, flood height, and velocities in the Merri River over the Dennington area for the design 5 year, 10 year, 20 year, 50 year and 100 year ARI flow conditions, as well as the 1946 and 2001 calibration flood events. This section documents the findings of those investigations.

5.1 Model Development

5.1.1 Topography

The basis for the development of the hydraulic model is a comprehensive description of the surface topography of the study area including the river bed. The model topography was derived from information provided through photogrammetry from QASCO and surveyed cross-sections by Brian Consulting. This information was established and processed within a GIS system to produce an appropriate terrain model from which the hydraulic model could be developed. The two-dimensional model topography is illustrated in Figure 5-1 below. The adopted grid size of 5 m is considered to be of sufficient resolution to accurately define hydraulics of the river channel and floodplain features. The model extents chosen ensure hydraulic model boundaries are sufficiently offset from the study boundary to eliminate any model edge effects.

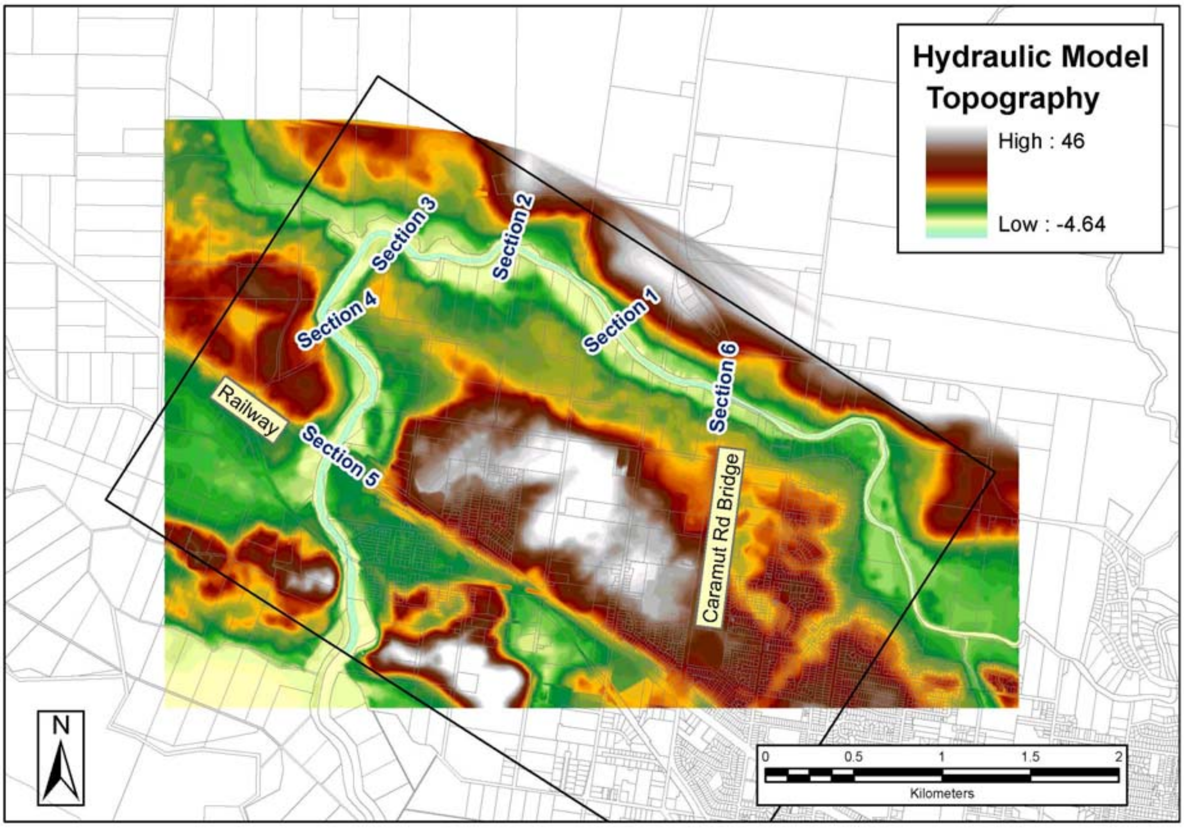

Figure 5-1: Topography for Flood Model Including Surveyed Cross-section Locations

5.1.2 Hydraulic Roughness Map

The hydraulic roughness of the study area was divided into three types, being river-channel, floodplain and streamside vegetation. Areas with different roughness types were defined by overlaying digital aerial photography from the GHCMA in a GIS system as well as an inspection of Google Earth imagery and notes and photographs taken during a site inspection. The resulting roughness map is shown in Figure 5-2. The adopted values for the model are shown in Table 5-1. These were based on literature and study team experience from previous flood studies.

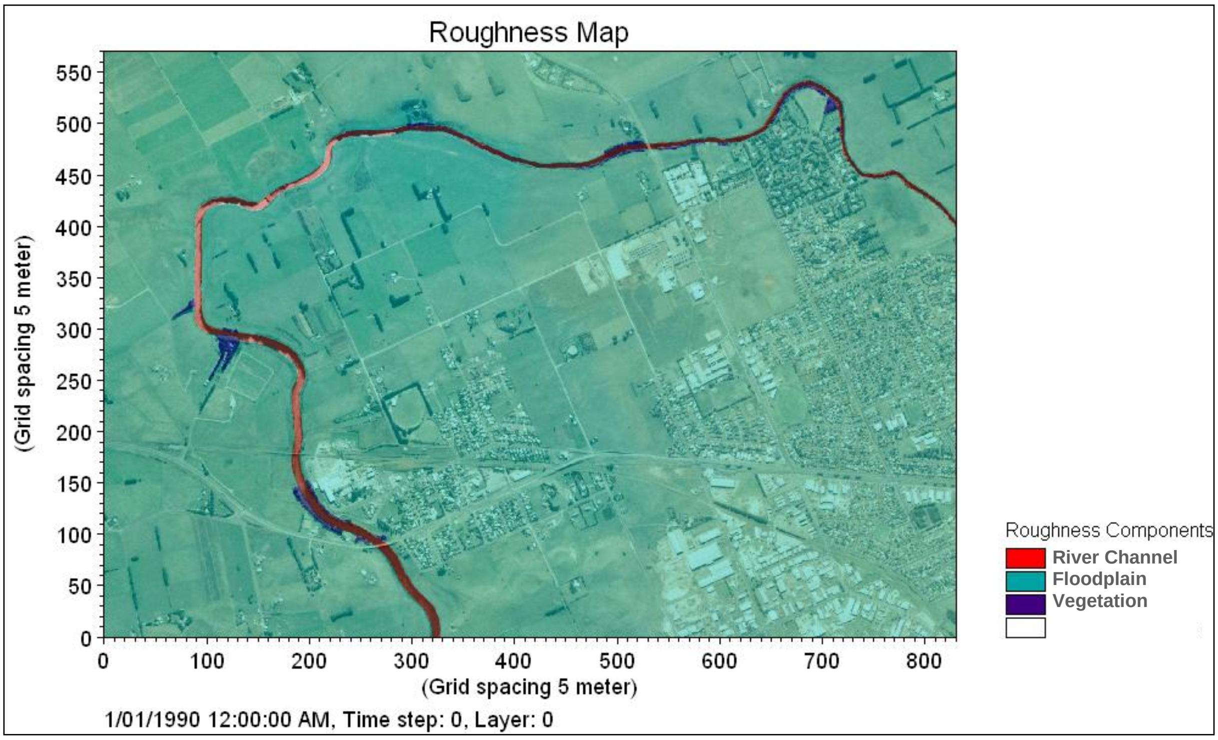

Figure 5-2: Hydraulic Roughness Map for Flood Model

Table 5-1: Nominated Hydraulic Roughness Parameters

Land type	Roughness (Manning's "n")
River Channel	0.03
Floodplain	0.05
Streamside Vegetation	0.08

5.1.3 Model Boundary Conditions

The model was run in steady-state mode. This was due to the relatively confined nature of the floodplain in the study area and the long length of the design storms, causing the model to be less dynamic. In addition, it was considered that no significant floodplain storage areas exist within the study area that would be likely to impact peak flood flows.

The model requires inflows at the upstream (eastern) boundary at Caramut Road and a water level at the downstream (southern) boundary. Calibration inflows were derived from gauge records when available, otherwise estimates were used from the hydrological modelling discussed in Section 4. Inflows for the design flood cases used the hydrologic modelling results.

5.2 Model Calibration

5.2.1 Overview

Two historical flood events were selected for calibration of the model. The 1946 flood was selected as it is the largest event on record and there are a number of recorded flood levels available. The 1946 flood event is estimated to be much greater in magnitude than a 100 year ARI flood (Water Technology, 2006). The 2001 flood was much smaller than the 1946 event, however it is the second largest flood for which reliable gauge records are available (at Woodford) and is estimated to be approximately a 20 year ARI flood event. Observations collected from the 1946 and 2001 flood events were used to assist in model calibration.

As discussed in the hydrology report, the magnitude of the 1946 flood peak is uncertain due to the absence of gauging data at that time. There are a number of previous estimates (CRB, SRWSC and GHD), based on different techniques that range from 470 to 1000 m^3/s. As part of the hydrologic analysis for this study an alternative methodology involving the application of a RORB hydrologic model has been used to estimate the magnitude of the 1946 flood. Subsequently the *calibration* to the 1946 event is as much a validation of the 1946 flow estimate as a test of the hydraulic model. For this reason it was considered imperative that at least one other flood event be used for calibration in order to ensure the robustness of the hydraulic model.

5.2.2 Calibration Data

Calibration data for the 1946 flood event was derived from RWC files, summarised in Table 5-2. A long section of the channel calibration data has been plotted in Figure 5-3.

Table 5-2: Observed Flood Levels March 1946 (RWC File)

Location	Flood Level (m AHD)
Princes Highway Bridge @ Dennington	5.01
Nestle's Factory	5.12
Railway Bridge	5.18
Cross Section No. 3	5.63
Just Downstream of Cross Section No. 7	6.18
Cassidy's Bridge Downstream	6.25
Cassidy's Bridge Upstream	6.58

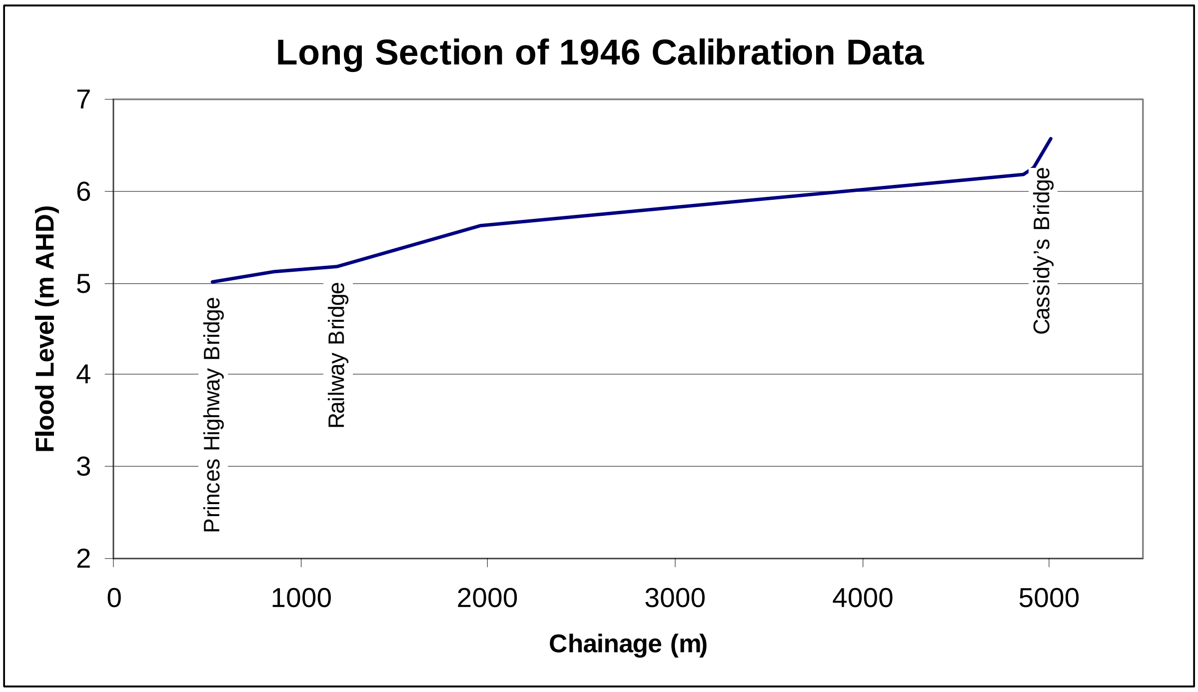

Figure 5-3: Plot showing flood profile from 1946 observed data

For the 2001 flood event, calibration data was gathered for the stretch of river upstream of Cassidy's Bridge from council records, as well as a level upstream of the Princes Hwy Bridge surveyed by GHCMA.

Table 5-3: Observed Flood Levels August 2001

Location	Flood Level (m AHD)
Woodend Rd	4.38m
Cassidy's Bridge	3.40m
U/S Princes Hwy Bridge	2.89m

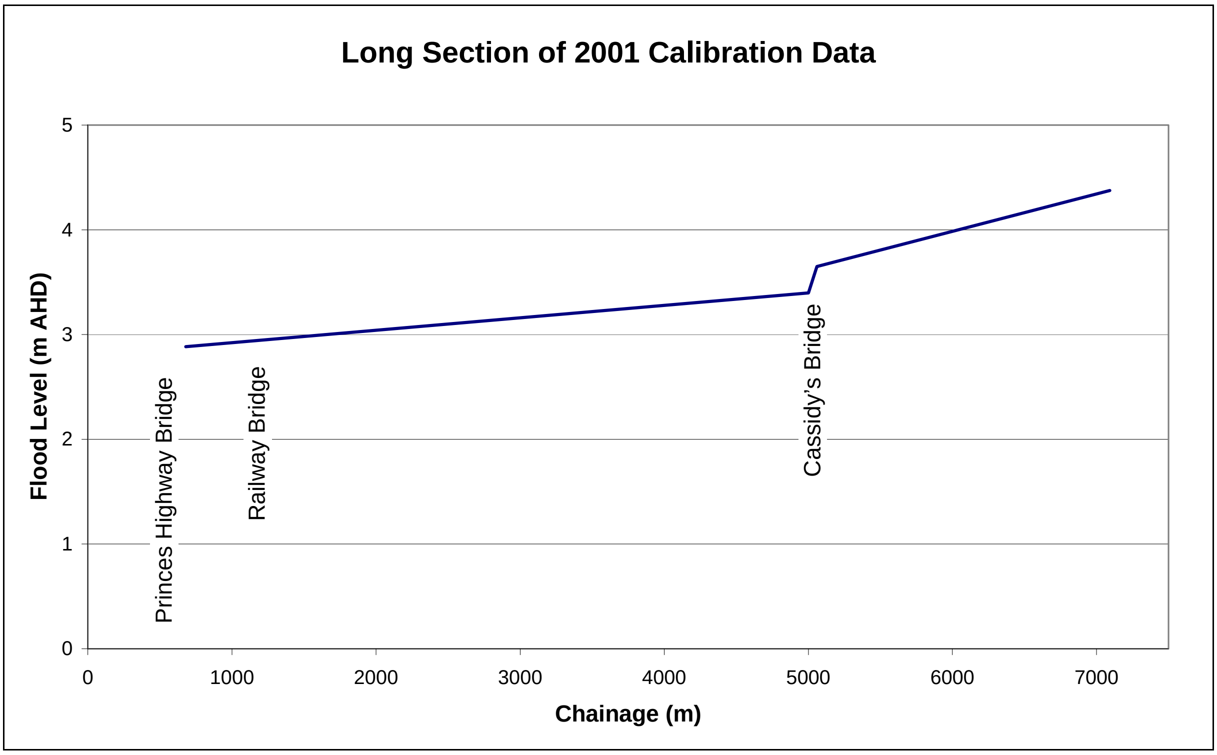

Figure 5-4: Plot showing flood profile from 2001 observed data

It should be noted that observed flood levels have a degree of uncertainty associated with them that depends on a number of factors, notably:

- the time at which the marks were generated (during flood or afterwards)
- the nature of mark (water line on building, debris line on fence)
- the location (in main flow path or in a backwater)
- whether the location was influenced by local factors (stormwater runoff etc)
- the reliability of the survey used to accurately level the marks

Principal among these uncertainties is the time between when the flood occurred and when a mark is recorded. This can often be many years, in which case considerable uncertainty may be attached to the data and care must be used in the application of this information to flood studies. Simple checks for consistency between data through long section plots, for example, can provide greater confidence in the use of flood mark data.

For the purposes of model calibration, the level of expected agreement between recorded and measured levels may vary depending on the flood depth, topography and specific circumstances of a historic event (say physical changes in a catchment or blocking of a structure for example). Typically we would expect good-quality flood level records to be in the range of +/- 10 mm of actual levels. Levels for which the origin of the data is unknown or where there are doubts about the timing etc may be in a range of +/- 200 to 300 mm of actual levels. For the purposes of this study, the flood marks are considered to be of reasonable quality and we expect should be within +/- 100 to 200 mm of actual levels.

5.2.3 Model Boundary Conditions

The upstream and downstream boundaries of the model lie a distance away from the study area to reduce any influence they may have on model results. The upstream (eastern) boundary condition for the model requires peak inflows. These were determined using the RORB model as described in the Section 4. At the downstream boundary the model requires a water level. The calibration levels were extracted from either observed levels where available or modelled levels from the South Warrnambool Flood Study results. The boundary conditions are described in Table 5-4.

Table 5-4: Boundary Conditions for Calibration Flood Events

Calibration Event	Upstream Inflows	Downstream Water Level
1946	860 m^3/s	4.9 m
2001	243 m^3/s	2.81 m

5.2.4 Hydraulic Model Calibration Results

The model was run for both the 1946 and 2001 flood events and the results were compared to the calibration data. For the 1946 event, Table 5-5 shows a summary of these results, Figure 5-5 is a plot showing the locations and Figure 5-6 shows a comparison between the modelled and observed long sections. Similarly, for the 2001 calibration event, a summary of the observed versus modelled results are presented in Table 5-6, whilst a plot of calibration point locations and a long section comparison are shown in Figure 5-7 and Figure 5-8 respectively.

Table 5-5: 1946 Flood - Model Results versus Observed Levels

Location	Observed Level (m)	Model Level (m)
Princes Highway Bridge @ Dennington	5.01	4.99
Milk Factory	5.12	5.30
Railway Bridge	5.18	5.50
Cross Section No. 3	5.63	5.71
Just Downstream of Cross Section No. 7	6.18	6.28
Cassidy's Bridge Downstream	6.25	6.28
Cassidy's Bridge Upstream	6.58	6.46

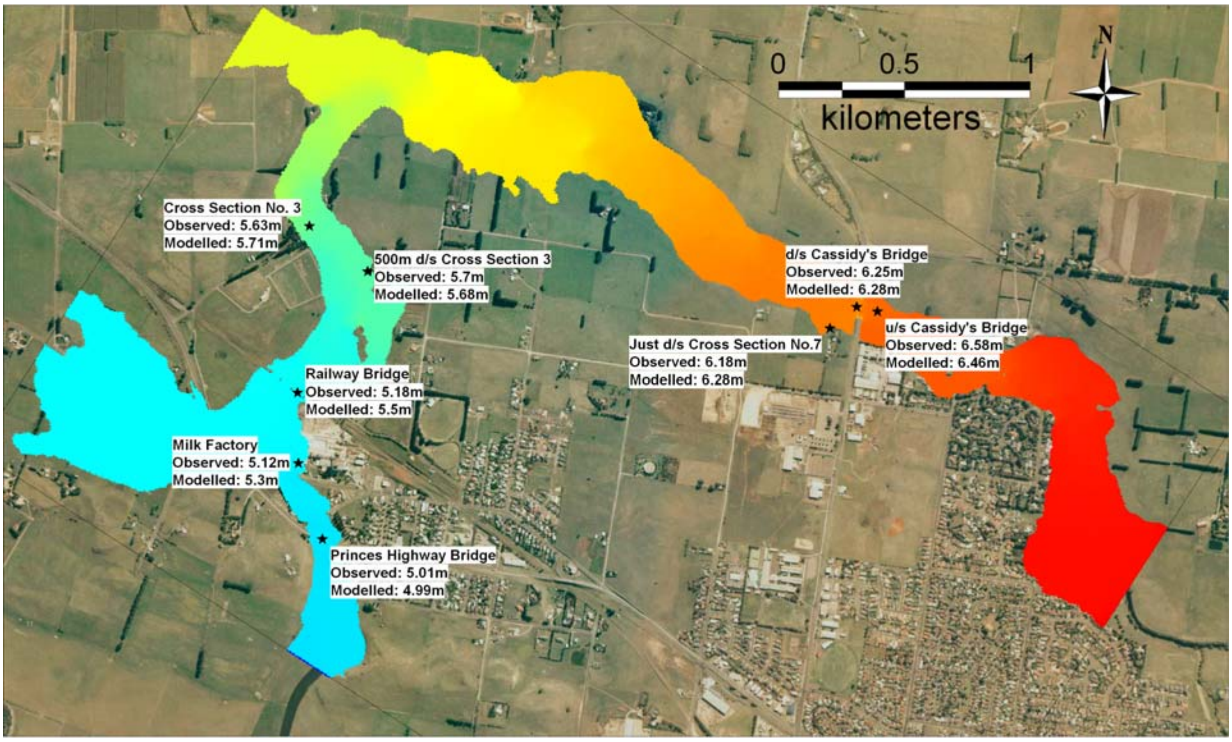

Figure 5-5: Plot of 1946 Observed Levels versus Modelled Levels

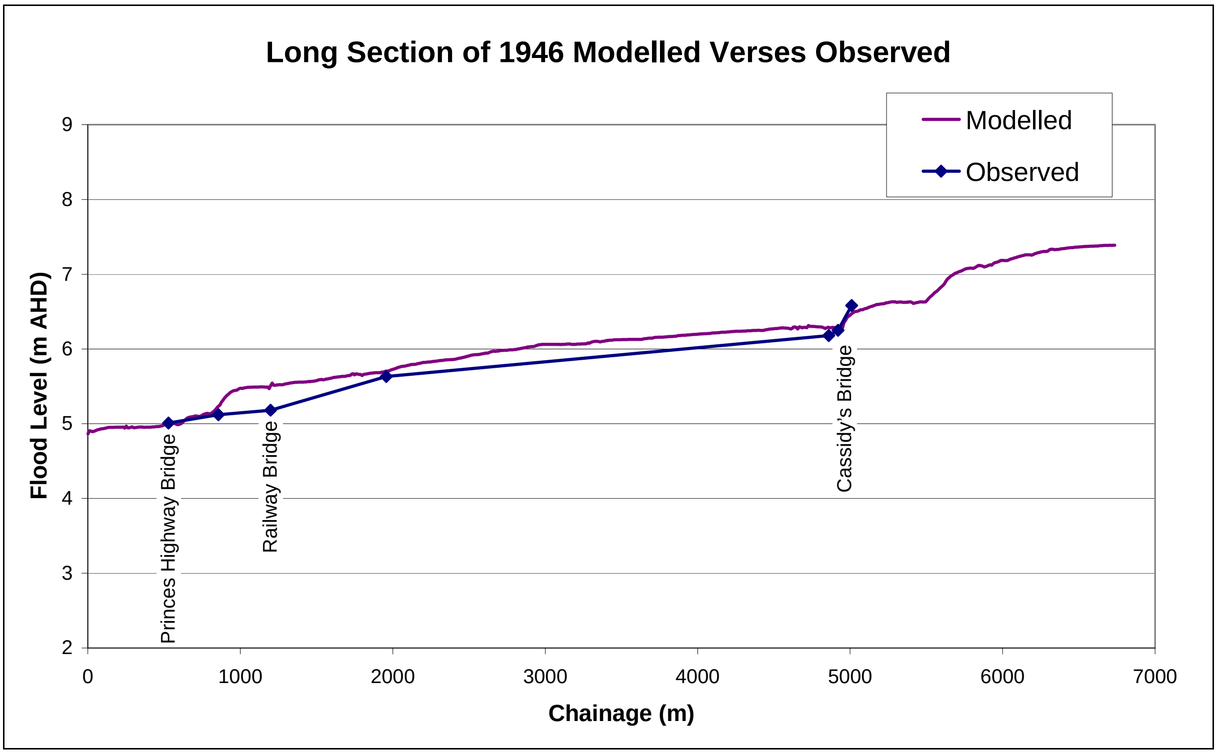

Figure 5-6: Long Section of 1946 Modelled Levels versus Observed Levels

The results for the 1946 flood show good agreement between observed and modelled flood levels with the maximum discrepancy of 0.32 m with most less than 0.1 m, which is considered to be quite acceptable given the magnitude of the event, the absolute levels (5 m above normal water level in the river), and the degree of uncertainty in the observed flood marks (nominally +/- 0.2 m).

Table 5-6: 2001 Model Results verses Observed Levels

Location	Observed Level	Model Level
Woodend Road	4.38 m	4.62 m
U/S Cassidy's Bridge	3.65 m	3.63 m
D/S Cassidy's Bridge	3.40 m	3.58 m
U/S Princes Hwy Bridge	2.89 m	2.90 m

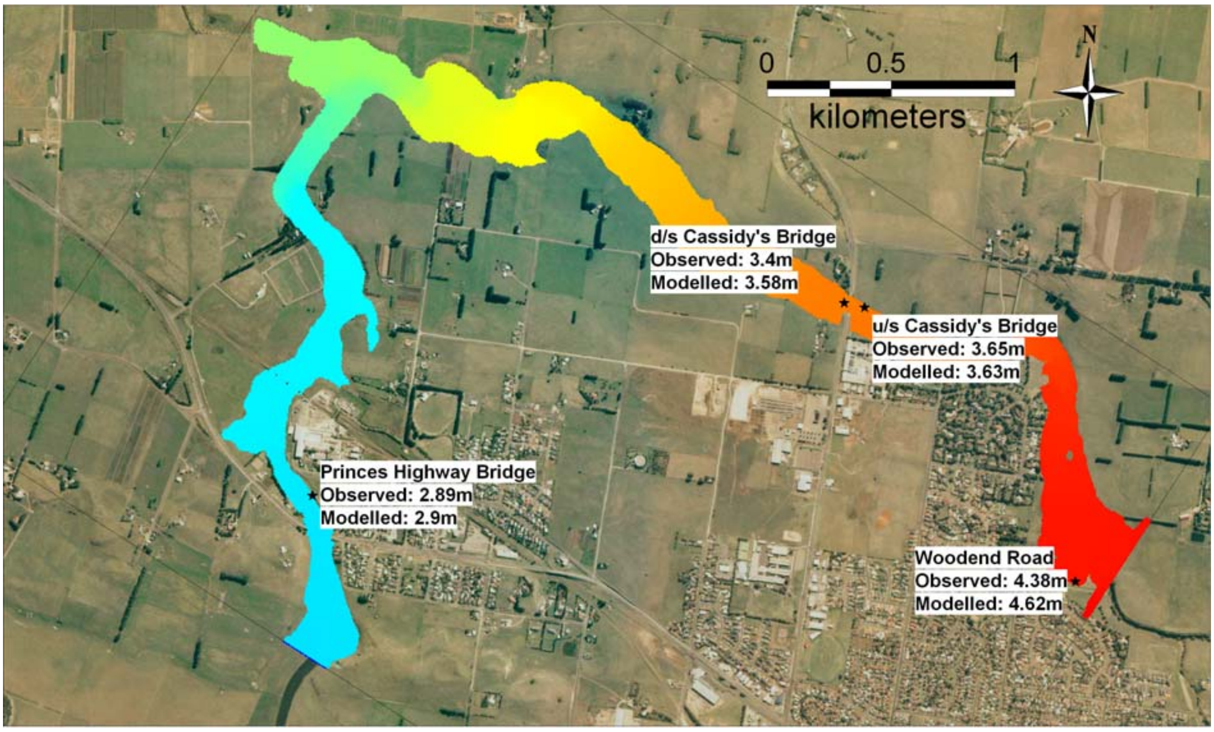

Figure 5-7: Plot of 2001 Observed Levels versus Modelled Levels

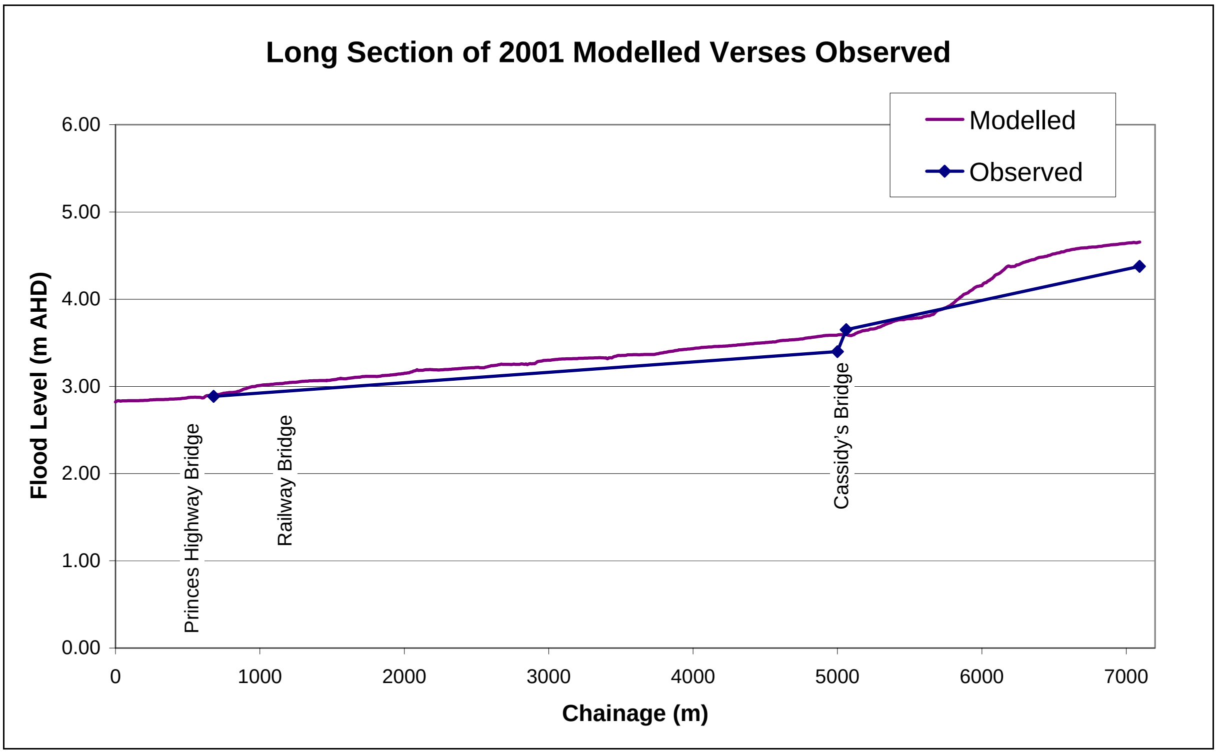

Figure 5-8: Long Section of 2001 Modelled Levels versus Observed Levels

The results for the 2001 calibration show good agreement between observed and modelled flood levels with a maximum discrepancy of 0.24m, which is also considered to be quite acceptable.

5.2.5 Calibration Summary

When applying a two-dimensional hydraulic modelling approach, there are three main sources of uncertainty in the hydraulic results, namely:

- The adopted boundary conditions (inflows/levels)
- The model topography and schematisation
- The hydraulic roughness parameters

Through the hydrology investigations, the issues in relation to flows have been addressed and are not investigated here. Sensitivity of the model results to changes in flows is addressed later in the report. The model topography is dependent on the quality of the survey input data which, for this study, is considered to be satisfactory. The model schematisation relates to the grid resolution, orientation and extent. For this study the adopted 5 m two-dimensional model grid is considered adequate to resolve the flow behaviour within the main river channel and floodplain.

Based on the calibration events modelled to date, the adopted hydraulic roughness parameters are considered appropriate for the study area. It is important to note that for two-dimensional models where the topography is well defined there is less need to compensate for "lumped" loss factors such as bend losses, compared to one-dimensional models (Bishop et al, 1995). It follows that if unrealistic or unexpected hydraulic roughness parameters are required in order to calibrate to observed flood levels then either the observed flood marks are incorrect, the hydrology is incorrect or some physical characteristic of the system is not described adequately in the model such as a constriction or blockage. This was not the outcome in this case as the roughness parameters were neither unrealistic nor unexpected.

5.3 Design Flood Behaviour

5.3.1 Model Boundary Conditions

The boundary conditions for the design flood events were extracted from the RORB model (as described in the Hydrology Report) and the South Warrnambool Flood Study hydraulic model. These values are summarised in Table 5-7.

Table 5-7: Boundary Conditions for Design Flood Events

Design Event (ARI years)	Upstream Inflows (m^3/s)	Downstream Water Level (m)
5	144	2.35
10	200	2.61
20	250	2.78
50	340	3.02
100	410	3.19

5.3.2 Hydraulic Model Results

The hydraulic model was run for the 5, 10, 20, 50 and 100 year ARI design flood events. A plot of 10 year and 100 year ARI flood extents is provided in Figure 5-9 and a long-section plot of the design flood profiles along with the 1946 event in Figure 5-10.

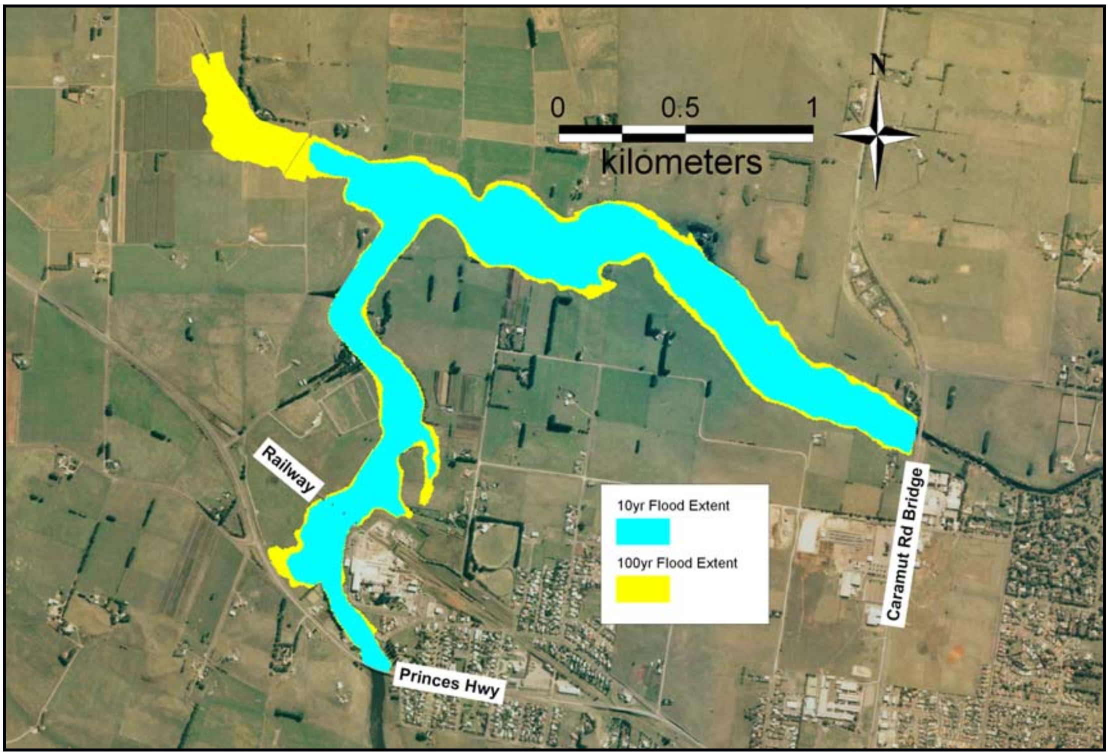

Figure 5-9: Plot of 10yr and 100yr Design Flood Extents

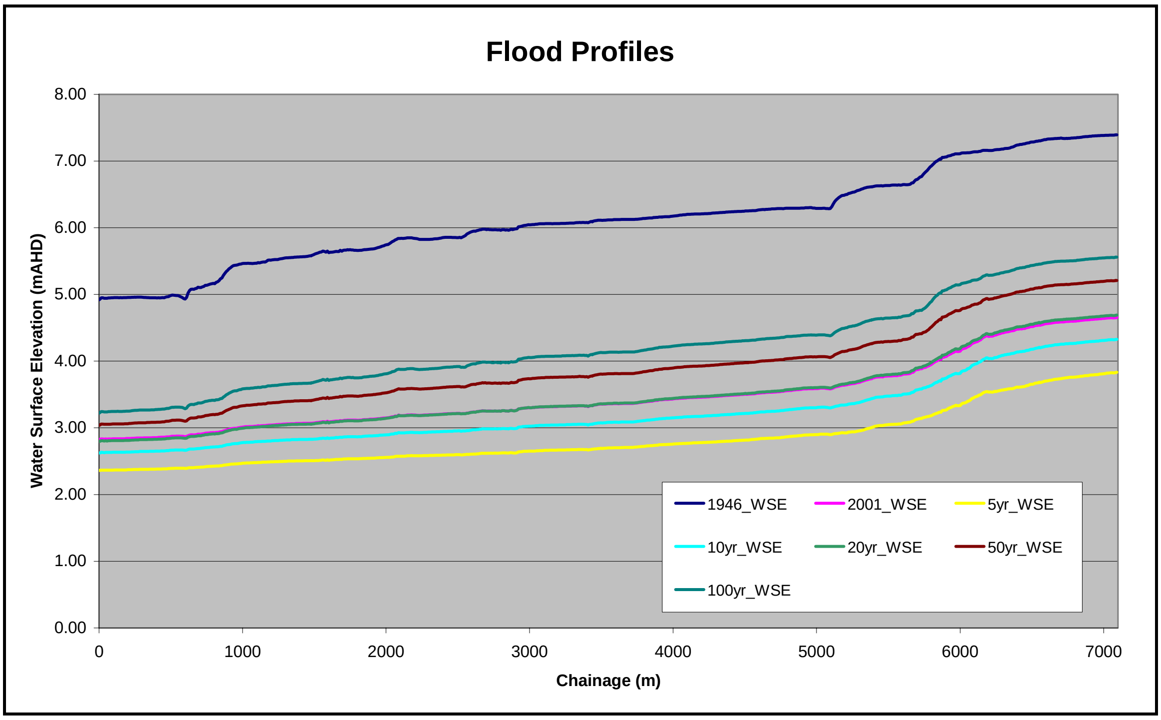

Figure 5-10: Long sections of water surface elevations for calibration and design flood events

5.3.3 Approximate PMF Simulation

In order to provide an indication of the maximum possible flood extent through Dennington, an approximate PMF simulation was undertaken using the peak PMF flow estimate as described in section 4.2.1. A plot of flood extent and depth for the PMF event is shown in Figure 5-11. This shows there is an increase in both flood depth and extent relative to the 100 year ARI design flood event.

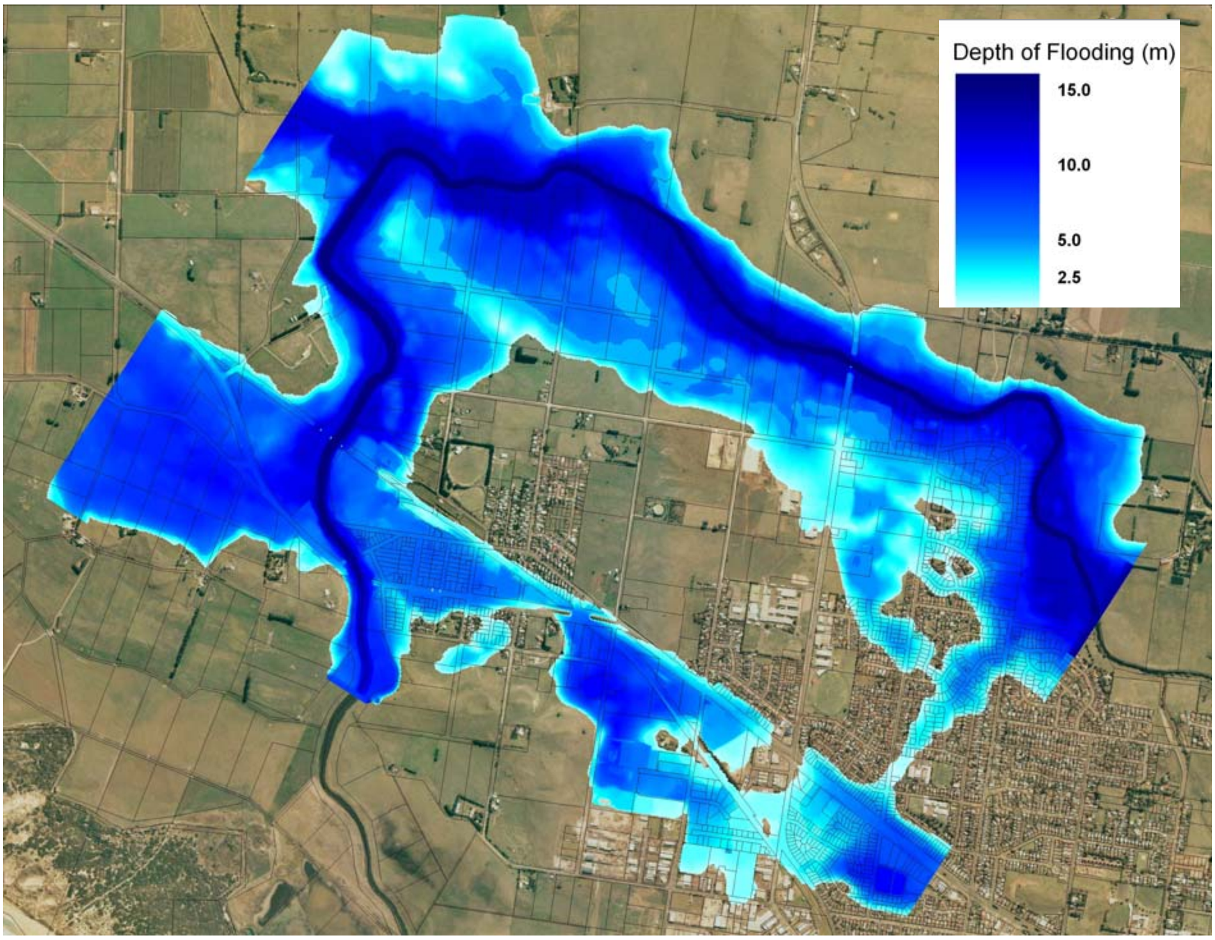

Figure 5-11: PMF Design Flood Depths

5.3.4 Model Sensitivity

Three additional model runs were completed to assess the hydraulic model's sensitivity to inflows, hydraulic roughness and build up of debris at the railway bridge. The sensitivity tests were carried out for the 100 year ARI design event. In the first instance the inflows to the model were increased by 20%, from 410 m^3/s to 492 m^3/s. In the second instance the Manning's "n" roughness coefficients in the model were increased by 20% for each roughness component, as outlined in Table 5-8 below. In the third instance the Manning's "n" roughness coefficients at the Railway Bridge were increased to 0.15 to simulate build up of debris trapped by the bridge.

Table 5-8: Manning's Roughness Coefficients for Sensitivity Testing

Roughness Component	Original Roughness	20% Increased Roughness
Channel	0.03	0.036
Floodplain	0.05	0.06
Vegetation	0.08	0.096

The model sensitivity testing showed that the peak flow into the model has a slightly greater impact on results than hydraulic roughness for the test cases investigated. The increase of 20% in flow resulted in a 0.35 m rise in water levels at the beginning of the model, and a 0.29 m rise at Cassidy's Bridge. Increasing the hydraulic roughness by 20% caused a rise of 0.25m at the beginning of the model and 0.23m at Cassidy's Bridge. If we consider that the 100 year ARI flood level is approximately 3.5 m above still water level at Cassidy's Bridge, these changes of 20% in model parameters, equate to a 5% change in peak water surface elevation. When we consider the effect on flood extent, we found that the 20% increase in flow and roughness produced increases in flood extent of 3.6% and 2.6% respectively. This percentage change would be expected to be greater in smaller and more frequent events. This result demonstrates that the model is not particularly sensitive in relation to the assumptions made during the study and that a good level of confidence can be placed on the model results.

In the instance with increased roughness at the railway bridge, there was a rise of 0.05m just upstream of the Railway Bridge and 0.02m at Cassidy's bridge. Below the Railway Bridge there was little change in water level, as expected. The overall increase in flood extent was less than 1%.

Table 5-9: Results from sensitivity testing of 20% increases in flows and roughness

Sensitivity Tests	Water Level Rise @ Cassidy's Bridge	Flood Extent
Original 100yr Event	3.50m	1.391 sq km
20% Increase in Roughness	3.73m	1.427 sq km
20% Increase in Flows	3.79m	1.442 sq km

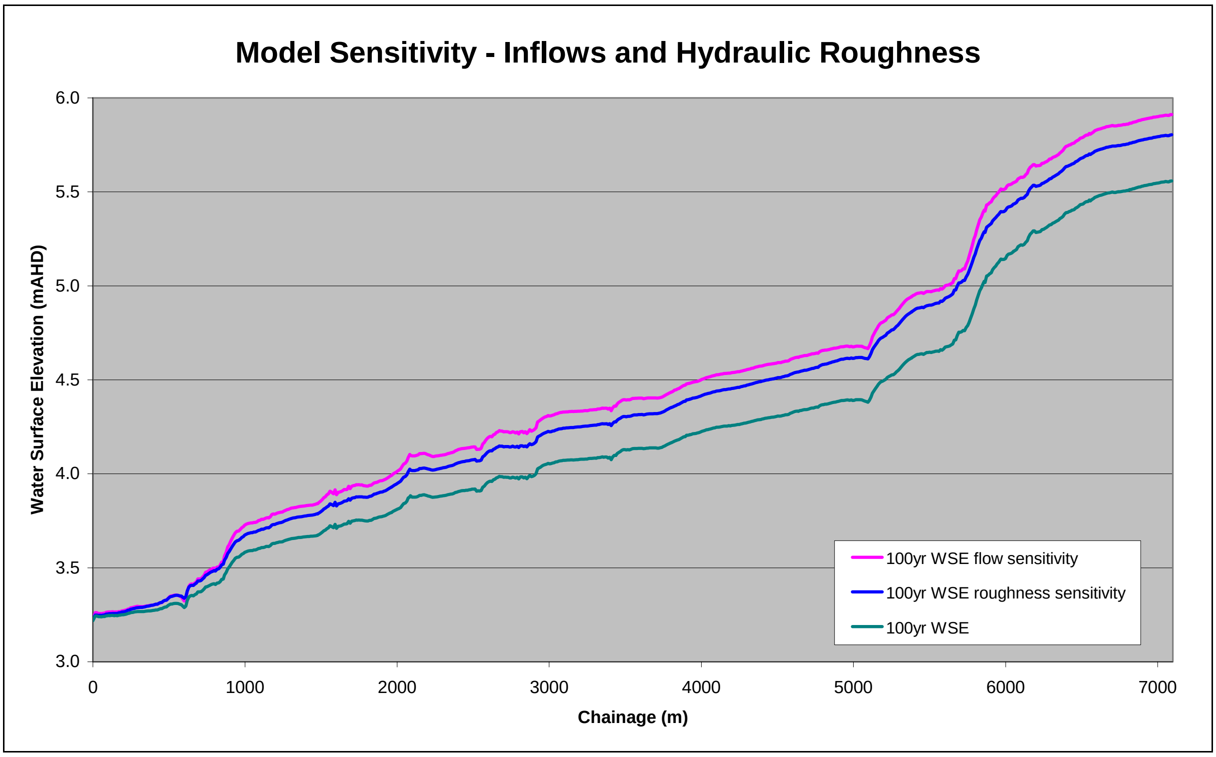

Figure 5-12: Comparisons showing sensitivity of the model to flow rates and roughness coefficients.

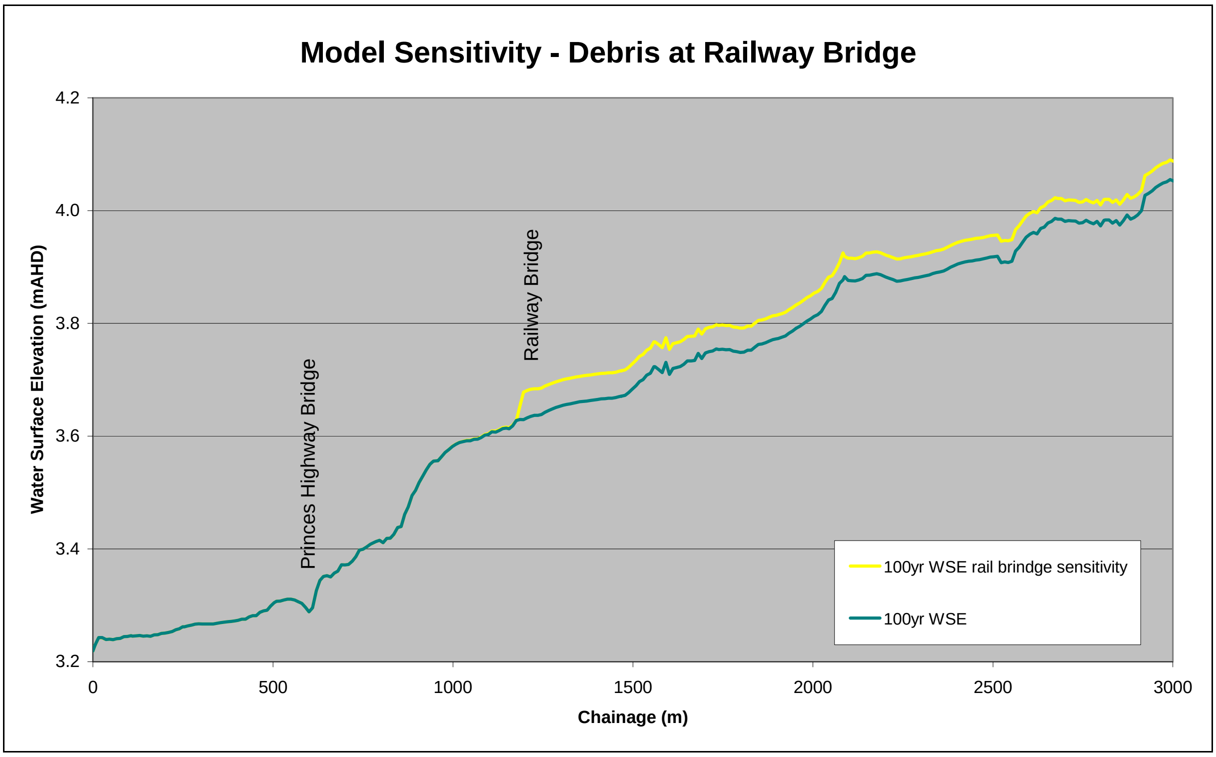

Figure 5-13: Sensitivity of model to increased resistance at the Railway Bridge due to build up of debris.

6 RISK ASSESSMENT AND REDUCTION MEASURES

An assessment of flood damages was carried out for the Dennington study area. It was found that no dwellings or commercial infrastructure were inundated in the 100 year ARI flood extent. Since there is no property damage the Rapid Appraisal Method (RAM) was used to assess any damages to agricultural areas. Utilising our GIS system we calculated approximately 90 Ha of pasture, around 6 km of fencing and a 150 m section of road were inundated under the 100 year ARI flood extent, producing a flood damages estimate of less than $50,000. Due to the relatively small damages occurring within the study area for the 100 year ARI event, further analysis of flood damages and estimation of annual damage is not warranted.

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 the flooding behaviour. Land use planning controls are aimed at reducing the growth in flood damages over time. The controls balance the likelihood of flooding with the consequences (flood risk).

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

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

The Victoria Flood Data Transfer Project (FDTP), now the Victorian Flood Database (VFD), involves the collation of the latest available flood information for regional urban and rural floodplains. The flood study results are presented in digital formats, compatible with this system.

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).
- FDTP 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 and one zone associated with mainstream flooding as follows:

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

Details of the above zone and overlay are provided in Section 7.3.

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

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 or in flood fringe areas affected by the 100 year ARI flood.

The permit requirements of LSIO are intended:

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

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

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

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

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

7.3.2 Floodway Overlay (FO)

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

- Flood frequency
- Flood depth

- Flood hazard

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

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.

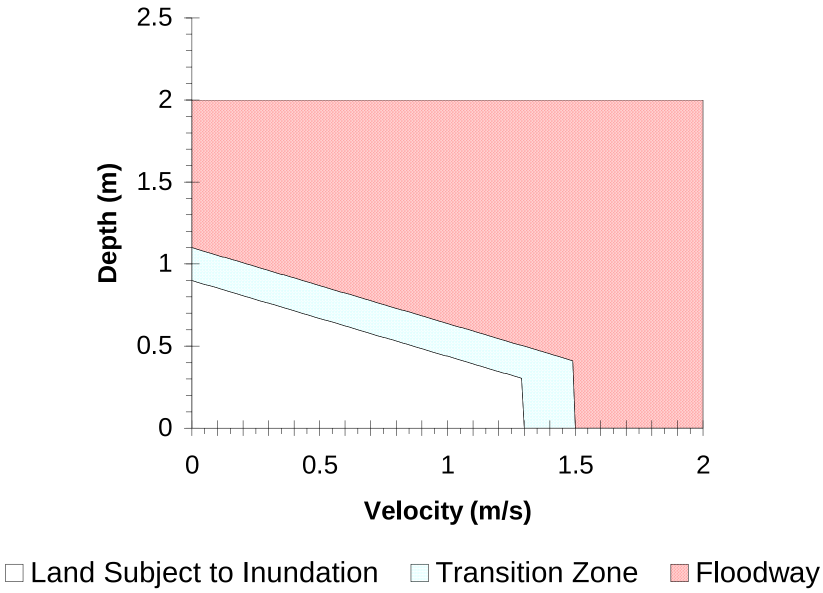

Figure 7-1 Floodway overlay flood hazard criteria

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

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

7.3.3 Urban Floodway Zone (UFZ)

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

The delineation options of the UFZ are determined as for the FO discussed in Section 7.3.2. The final extent of the UFZ, based on the consideration of the three approaches is discussed in Section 7.4.

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

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

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

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

7.4 Flood Related Planning Zone and Overlays Delineation

Flood related zone and overlay delineation option maps have been generated to assist GHCMA in the definition of LSIO and FO. The delineation option maps overlay the three FO extents previously determined and outlined in Section 7.3.2. These maps have been prepared using the hydraulic analysis for existing conditions.

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

Due to the nature of the floodplain, the three options for delineating the FO/UFZ were found to provide similar results, hence the 10 year ARI flood extent was initially adopted for the FO/UFZ extent. To reflect the potential for urban development within and adjacent to Dennington, a FO is recommended for the area defined by the 10 year ARI flood extent.

The 100 year ARI flood extent, outside the 10 year flood extent, was adopted as the LSIO.

Figure 7-2 displays the draft flood related planning zone and overlays for Dennington for mainstream flooding from the Merri River.

The study team recommends the WCC and GHCMA liaise in the preparation and adoption of a planning scheme amendment to enable the draft flood related planning zone and overlays.

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

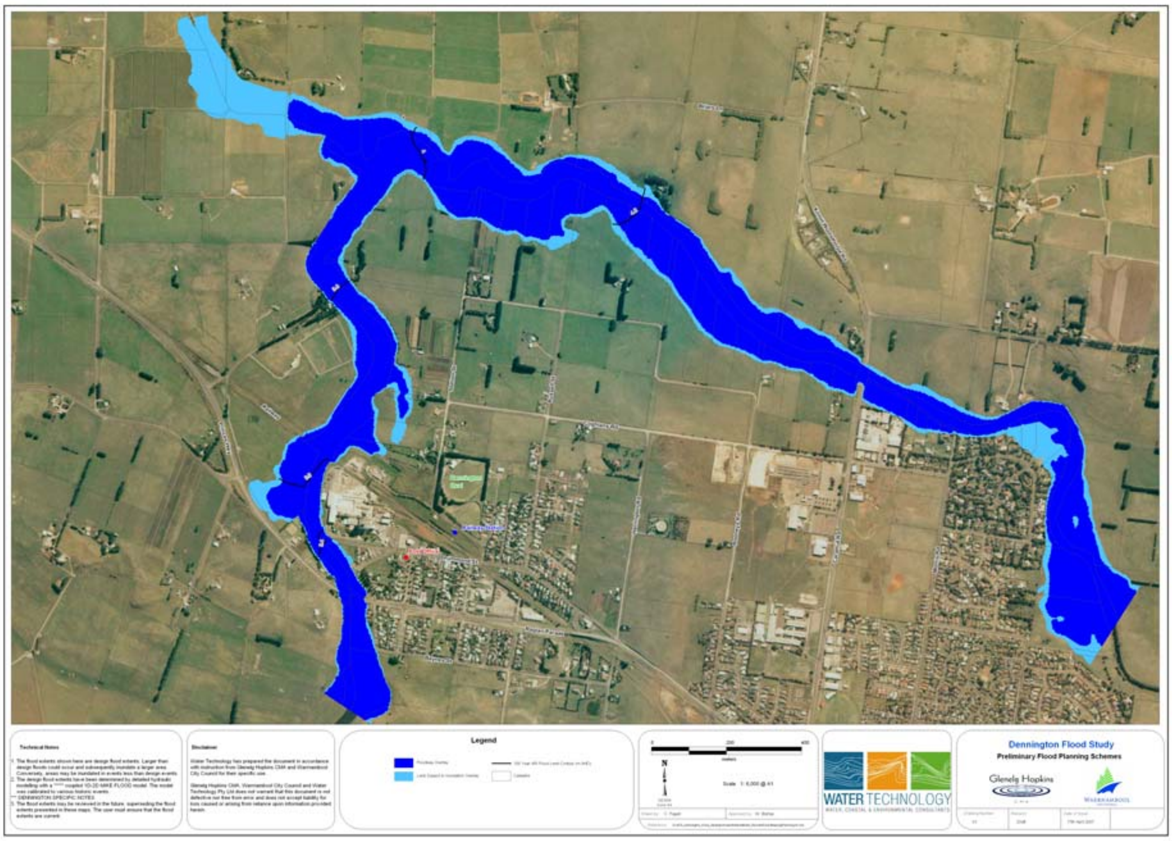

Figure 7-2 Draft Flood Related Zone and Overlay Delineation

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 floodway (i.e. UFZ and FO)
- 1% AEP flood level contours at 200mm contour intervals
- Indicative flood levels and extents for the PMF event.
- Flow directions and velocities
- Flood hazards (as per Melbourne water guideleines)

The data is supplied in digital format to FDTP specifications as published by DSE. The digital map data is provided on the attached study CD.

8 STUDY RECOMMEDATIONS

This section summaries the recommendations arising from this study. These include issues such as the adoption of outcomes of this study as well as the need for further investigations and implementation of floodplain management measures.

Land use planning

The study team recommends the WCC and GHCMA liaise to implement a planning scheme amendment to enable the draft flood related planning zone and overlays. Further, the study team recommends GHCMA declares the 100 year ARI flood levels for planning purposes under the Water Act (1989).

Floodplain Management Plan

The results of the Dennington Flood Study should be used in the development and implementation of a floodplain management plan or incorporated into other existing or future floodplain management plans that are based on a risk management approach in accordance with the Victoria Flood Management Strategy and River Health Strategy. As such, options could be investigated for mitigation of flood impacts (albeit these are small in the study area) such as improved community awareness, flood response planning and flood warning systems.

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APPENDIX A – ROUGHNESS TYPES

Estimates for Manning's Roughness Coefficients have been determined through both previous experience with flood studies and also measured values documented in literature. Figure 9-1 shows an example of a natural channel of approximate width 30m, similar to the section of channel in this study. The measured coefficient of roughness ranges from 0.030 to 0.038, increasing as the water level rises above the vegetation line. Hence a value of 0.030 is considered appropriate for channel roughness. Figure 9-2 shows an example of a heavily vegetated floodplain, slightly more dens than the streamside vegetation in this study. The computed roughness coefficient of 0.11 for that floodplain is slightly higher than the 0.08 adopted in this study, correlating to the vegetation being slightly less dense. The value of 0.05 adopted for the floodplain areas of this study indicates that the roughness is somewhere in between the channel and the vegetation, which is appropriate given the floodplain is mostly grazing land. This value also corresponds to calibrated floodplain roughness coefficients in previous flood studies.

Natural Channel of Embarrass River near Charleston, Illinois. Approximate bottom width 100 feet. Picture taken in 1926.

A

Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient of roughness n	Description of channel
	Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*			
Apr. 13, 1926	8.7	139.3	1,974.9	945.3	2.09	6.52	0.000136	0.030	*Course*, straight; 1,000 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 20, A. *Side slopes*, somewhat irregular. *Bottom*, fairly even and regular. *Soil*, lower part, light gray silty clay; upper part, light tan silt loam. *Condition*, bottom comparatively clean and smooth, upper part of side slopes covered with large trees; natural channel. (Pl. 24, A and fig. 19, A.)
Feb. 27, 1926	9.9	146.4	2,500.7	1,119.2	2.23	7.32	.000128	.030	
Apr. 10, 1926	13.5	180.0	4,265.4	1,700.1	2.51	9.04	.000128	.031	
Sept. 14, 1926	13.7	182.1	4,318.9	1,740.7	2.48	9.15	.000128	.032	
Sept. 12, 1926	16.2	219.1	5,868.6	2,275.5	2.58	9.95	.000140	.034	
Sept. 9, 1926	17.6	237.4	6,237.4	2,605.8	2.39	10.45	.000087	.030	
Oct. 5, 1926	[1] 19.3	243.2	8,857.0	3,011.6	2.94	11.72	.000175	.038	

[1] Average maximum depth at bankful stage.

Figure 9-1: Example of measured Manning's Coefficients for a natural channel (*Guide for Selecting Roughness Coefficient 'n' Values for Channels,* G.B. Fasken, 1963, pp 24)

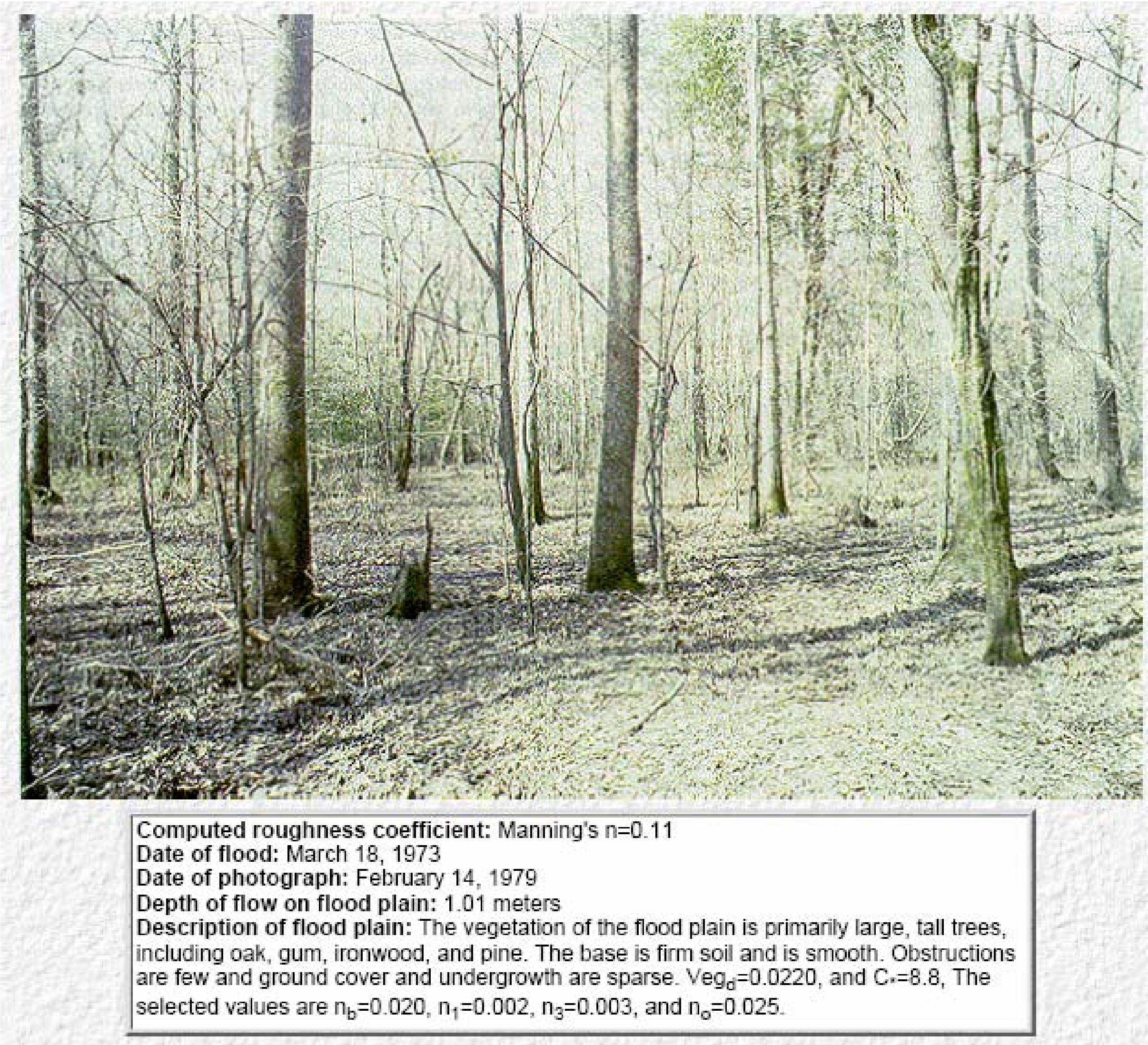

Figure 9-2: Example of measured Manning's Coefficients for a floodplain (*Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains*, G.J. Arcement, Jr. and V.R. Schneider, USGS, pp 27)