Port Fairy Regional Flood Study

Volume 1 – Summary Report

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Cover Photo: View of Port Fairy Harbour from the Gipps Street bridge

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EXECUTIVE SUMMARY

This report details the input data, approach and outcomes for the Port Fairy Regional Flood Study.

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

The study provides information on flood levels and flood risks within the township for both catchment and ocean based flooding. The study has involved a rigorous technical analysis of the drivers for flooding, which provides confidence in the use of this information to guide floodplain management in and around Port Fairy.

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

A hydrologic analysis of the Moyne River catchment was undertaken to determine design flood hydrographs for 5, 10, 20, 50, 100 and 200 year Average Recurrence Interval (ARI) (also expressed as 20%, 10%, 5%, 2%, 1% and 0.5% Annual Exceedence Probability (AEP)) flood events at key locations around Port Fairy. Due to limitations of the available rainfall and flow data, some uncertainty surrounds the design flood estimates developed by this study. However, strenuous efforts have been made to limit uncertainty and recommendations are made for further investigations. A rigorous approach has been applied to test and validate the design flows by utilising a number of hydrologic approaches including Flood Frequency Analysis, rainfall-runoff modelling, regional comparisons and analysis of ungauged historic events. The adopted design flood inflows for the study, listed in Table 1, are considered appropriate for the definition of flood risk in Port Fairy.

Table - 1 Design peak flows at Port Fairy

Location	Moyne Catchment Design Peak Flow ML/d (m^3/s)					
	20% AEP (5 yr ARI)	10% AEP (10 yr ARI)	5% AEP (20 yr ARI)	2% AEP (50 yr ARI)	1% AEP (100 yr ARI)	0.5% AEP (200 yr ARI)
Moyne River at Toolong	6,250 (72.3)	9,015 (104.3)	12,241 (141.7)	17,457 (202.1)	22,323 (258.4)	28,181 (326.2)
Murray Brook	2,431 (28.1)	3,483 (40.3)	4,594 (53.2)	6,337 (73.3)	7,951 (92.0)	9,853 (114.0)
Holcombe's Drain	360 (4.2)	497 (5.7)	626 (7.2)	823 (9.5)	994 (11.5)	1,195 (13.8)
Reedy Creek	1,016 (11.8)	1,383 (16.0)	1,729 (20.0)	2,232 (25.8)	2,626 (30.4)	3,087 (35.7)

To place the design peak flows in a historical context, the approximate AEP's of significant historical flood events are provided in Table 2. The 1978 event is the equal largest gauged event since the gauge was established in 1948. Evidently there have been no major flood events in this catchment over the past 50 years. Accurate estimations of the probability of occurrence of large floods rely on long hydrological records and a thorough understanding of the prevailing climate conditions. Assuming a stable climate, many thousands of years of data are required to accurately estimate the 0.1% AEP (1000 year ARI) flood magnitude. Nevertheless, using all the available data and tools, an estimate of the AEP of the 1946 flood event in Port Fairy was determined to be around 0.1% or 1000 years ARI. However, if current climate trends continue (as predicted by CSIRO), this may be substantially reduced.

Table - 2 Moyne River, Approximate AEPs/ARIs for Significant Historical Flood Events

Historical event (year)	Approximate AEP/ARI (based at Toolong)
1946	Around 0.01% / 1000 years
1978	Around 7% / 15 years
2001	Around 33% / 3 years

A digital terrain model (DTM) was developed from field and aerial survey. Using the DTM, a hydraulic model was established to simulate flood behaviour within the study area. Flood behaviour was assessed for flooding originating from the Moyne River and the ocean. The hydraulic model was calibrated to three historic flood events. The model was thoroughly examined with the available data and a sensitivity analysis was undertaken to test the robustness of the resulting flood level predictions. Flood hydrographs have been produced from the models that show how flood routing influences the onset of flooding at strategic locations around Port Fairy. Animations of significant flood events have also been produced that show the progress of floods from Toolong to the ocean. The outputs of the hydraulic modelling are considered appropriate for the definition of flood risk in Port Fairy.

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 then calculated to be approximately $219,200 per year with current topography and flows. These results showed that up to and including the 10% AEP flood event relatively minor flood damages are predicted with only 4 properties flooded above floor from a total of 43 flood effected properties. From the 5% AEP flood, damages increase more rapidly. Table 3 below summarises the flood damage calculations.

Table 3 - Flood Damage Assessment Costs for Existing Conditions

ARI (years) AEP	200yr 0.005	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1
Properties Flooded Above Floor	88	50	29	14	4
Properties Flooded Below Floor	135	141	121	100	39
Total Properties Flooded	**223**	**191**	**150**	**114**	**43**
Direct Potential External Damage Cost	$823,925	$225,705	$125,177	$53,782	$19,268
Direct Potential Residential Damage Cost	$2,142,761	$1,116,354	$578,850	$190,491	$67,046
Direct Potential Commercial Damage Cost	$179,544	$256,910	$138,044	$12,673	$0
Total Direct Potential Damage Cost	**$3,146,230**	**$1,598,969**	**$842,071**	**$256,946**	**$86,314**
Total Actual Damage Cost *(0.8*Potential)*	**$2,516,984**	**$1,279,175**	**$673,657**	**$205,557**	**$69,051**
Infrastructure Damage Cost	**$249,954**	**$191,838**	**$116,938**	**$29,635**	**$13,010**
Indirect Clean Up Cost	$430,712	$266,125	$174,506	$94,736	$41,085
Indirect Residential Relocation Cost	$53,260	$29,743	$17,292	$8,992	$2,767
Indirect Emergency Response Cost	$12,402	$8,268	$4,961	$3,307	$2,067
Total Indirect Cost	**$496,375**	**$304,135**	**$196,759**	**$107,035**	**$45,919**
Total Cost	**$3,263,312**	**$1,775,149**	**$987,353**	**$342,226**	**$127,980**

In order to assess sensitivity and provide a more complete picture of flood risk at Port Fairy into the future a range of climate change scenarios were modelled and evaluated for their broad impact on flood damages. These scenarios included nominally *moderate, intermediate* and *high* impacts which included a combination of sea level rise and increased rainfall intensity leading to higher catchment flows. There is considerable uncertainty as to the magnitude and timing of future climate change impacts, particularly with respect to rainfall. Therefore the scenarios modelled in the report should be considered as indicative only. Prediction of the likely impacts of climate change are expected to improve significantly over coming years as more data becomes available and climatic models become more sophisticated and reliable.

For the purposes of this report, the scenarios demonstrate that particular areas within Port Fairy are more susceptible to the impacts of climate change than others. The areas north of Regent Street and Gipps Street bridge are most affected by the climate change scenarios. This includes properties along the west side of Belfast Lough around the Model Lane area and on the east side of Belfast Lough along Griffiths Street. The main risk to properties along the ocean side of Griffiths Street is lack of safe access, as the road is quite low whilst most houses are located on the sand dune, well above flood level.

A number of flood mitigation options were trialled as part of the flood risk analysis which included changes to the Gipps Street bridge structure, a number of levee configurations and utilisation of additional catchment storage in the floodplain immediately upstream of Rosebrook. Of the options tested, the use of strategically located levees provided the most benefit in terms reduction in flood damages. These options have the advantage of providing protection from high river levels driven by either sea storms or catchment flows.

Draft flood related planning overlay maps (FO and LSIO) have been prepared to reflect the study outcomes. These define areas subject to inundation in 1% AEP flood events and areas of active floodway that are important to maintain flood capacity and reduce flood risk.

Flood response maps have also been produced that relate flood extents in Port Fairy to gauge heights on the Moyne River at Toolong. These and other outputs such as flood hydrographs will assist SES and Council in planning for and responding to flood situations.

A preliminary assessment of flood warning potential is provided in the report. It is concluded that sufficient warning time is available for an effective flood warning system to potentially be implemented. Additional stream and rainfall gauges would greatly improve the ability to providing flood warning information in the future. A flood warning system for the community will translate to reduced flood damages and trauma for residents.

A preliminary assessment of flood warning issues has been addressed in the report. It is concluded that sufficient warning time is available for a flood warning system to potentially be implemented. Additional stream and rainfall gauges would greatly improve the ability to providing flood warning information in the future. More warning for the community will translate to reduced flood damages and trauma for residents.

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 Moyne Shire and GHCMA continue to engage the community in the treatment of flood risks through the development of a full Floodplain Management Plan for Port Fairy that involves broad community involvement and consultation with stakeholders.
- The Moyne 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 Moyne Shire and GHCMA explore options for the development of a flood warning system for Port Fairy in conjunction with the BoM and SES.
- The Moyne Shire and GHCMA continue to monitor developments in the knowledge base for climate change impacts and adapt their response accordingly. This could involve a regular review of flood-related impacts based on revised inputs.
- GHCMA and Moyne Shire Council should try to improve data capture with the aim of reducing uncertainties in the catchment's response to rainfall.

ACKNOWLEDGEMENTS

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

- Matt Hayes (Glenelg Hopkins CMA Project Manager)
- Russell Guest (Moyne Shire Council)
- Johanna Theilemann (Glenelg Hopkins CMA)
- Marcus Little (Glenelg Hopkins CMA)
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- Erwin Weinmann and Bob Keller (Expert Project Reviewers)

The study team also wishes to thank all those stakeholders and members of the public who participated in the community information sessions and provided valuable records (including historic photos) and discussed their experiences and views on flooding in and around Port Fairy.

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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.
ANUFLOOD	ANUFLOOD is an inter-active program designed to assess tangible urban flood damage. ANUFLOOD uses building descriptions (including location, ground and floor heights, construction material etc), stage-damage curves and flood level information to calculate flood damages. ANUFLOOD was developed during the 1980s and early 1990s at the Centre for Resource and Environmental Studies at The Australian National University.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
Average Recurrence Interval (ARI)	The average, or expected, value of the periods (in years) between exceedances of a given rainfall or flood event. It is implicit in this definition that the periods between exceedances are generally random. ARI is equivalent to 1/AEP and vice versa. i.e., a 100 Year ARI is equivalent to a 1% AEP, i.e., 100ARI = 1/0.01AEP
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% 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 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 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.
GDA94	The Geocentric Datum of Australia (GDA) is the new Australian coordinate system, replacing the Australian Geodetic Datum (AGD).
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.
LIDAR	**Li**ght **D**etection **a**nd **R**anging is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. The range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal. Also known as Aerial Laser Scanning (ALS).
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.
RAM	**R**apid **A**ppraisal **M**ethod for Floodplain Management, is a guide for calculating flood damages based on broad criteria rather than specific property-based methods such as ANUFLOOD.

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

AEP	Annual Exceedence Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
BoM	Bureau of Meteorology
GHCMA	Glenelg Hopkins Catchment Management Authority
MSC	Moyne Shire Council
DSE	Department of Sustainability and Environment
EPA	Environment Protection Authority
HAT	Highest Astronomical Tide
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
SRWSC	State Rivers and Water Supply Commission
SES	State Emergency Service
RWC	Rural Water Commission

1. INTRODUCTION

1.1 Overview

Water Technology was commissioned to undertake the Port Fairy Regional Flood Study by the GHCMA in accordance with their study brief (May 2007). This report summarises the investigations and outcomes of the study which define flooding behaviour in the Moyne River Floodplain downstream of Toolong, through the Belfast Lough and Moyne River Estuary to the sea. The study area locality is shown in Figure 1-1 including the whole Moyne River catchment.

The study has been undertaken using a risk-based approach, emphasising the uncertainties and consequences of a range of factors that influence flooding such as rainfall intensity and sea level conditions. The risks associated with both existing conditions and potential future conditions under the influence of climate change have been considered.

Whilst this study does not incorporate a Floodplain Management Plan, a preliminary assessment of mitigation options and their relative effectiveness is provided. The results of this analysis give direction for future studies into the treatment of risk for Port Fairy.

Output from the Port Fairy Regional Flood Study project will enable the Moyne Shire Council (MSC) to incorporate reliable Flood Planning Maps (FPM's) into the Port Fairy Planning Scheme. The flood information produced by these investigations may be readily used by Moyne Shire Council, Glenelg Hopkins Catchment Management Authority (GHCMA), the Victoria State Emergency Service (SES) and the community to facilitate land use planning and emergency preparedness and response to flood events.

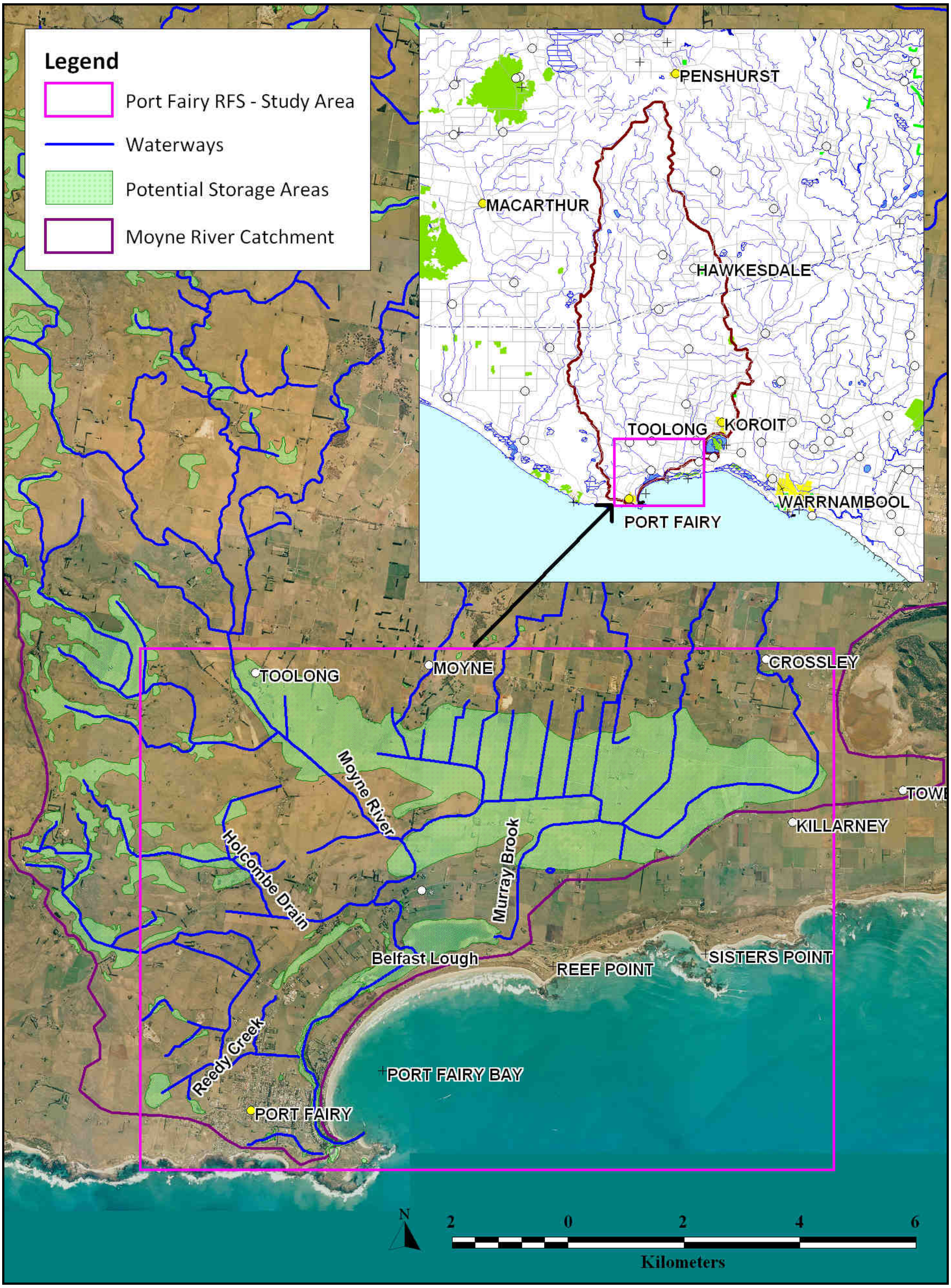

Figure 1-1 **Study Area**

1.2 1.1 Study Context

Coastal communities along the Victorian coastline, including the south-west, are under increasing pressure from competing interests such as land and economic development, conservation of the environment and maintenance of the character that makes them so popular. In addition to these social pressures, coastal towns are commonly subject to environmental risks such as flooding, as they are typically located, as is Port Fairy, at the interface between a river catchment, an estuary and/or the ocean. Factors such as rainfall patterns, catchment/waterway characteristics and sea level conditions all contribute to the flood risk profile for a coastal area.

Severe flooding occurred through south-west Victoria in March 1946, this resulted in significant social impact and flood damage in and around Port Fairy. There are many visual and descriptive records relating to this flood and some recorded flood levels, however no gauged data are available. Hence the hydraulic details of this event (apart from good daily rainfall records, and some level data) are not well understood (for example flood flows and volume/storage).

Previous investigations have explored the relationship between flood risk and consequent damages. This study builds on existing information through a thorough examination of all aspects of flooding over an extended study area around the township of Port Fairy.

1.3 Risk-Based Floodplain Management

This investigation has been undertaken in accordance with the risk management approach described in the following standards, policies and guidelines:

- AS/NZS 4360:1999 : Risk Management
- Best Practice Principles for Floodplain Management in Australia
- Victorian Flood Management Strategy
- Victorian Planning Provisions
- Glenelg Hopkins CMA Regional Floodplain Management Strategy

The study has been undertaken in accordance with best practice principles for floodplain management as described in the following document:

- *Floodplain Management in Australia: Best Practice Principles and Guidelines, (Agriculture and Resource Management Council of Australia and New Zealand, Report No 73, CSIRO Publishing, 2000)*

In addition the following strategic documents provide the overall contextual framework for the investigation:

- *Victoria Flood Management Strategy (State Flood Policy Committee, 1998)*
- *Victoria Planning Provisions: Applying for a Planning Permit under the Flood Provisions: A Guide for Councils, Referral Authorities and Applicants (DOI, 2000)*
- *Victoria Planning Provisions: Applying the Flood Provisions in Planning Schemes: A Guide for Councils (DOI, 2000).*

The risk management process as relevant to floodplain studies is shown in Figure 1-2. As highlighted by blue shading in the figure, this project has focused primarily on the flood study components that are associated with defining risk rather than treating risk. However, risk treatment measures have been investigated in the form of a preliminary flood mitigation option assessment and review of flood warning. The study outcomes can be applied to a full floodplain management plan at a later date

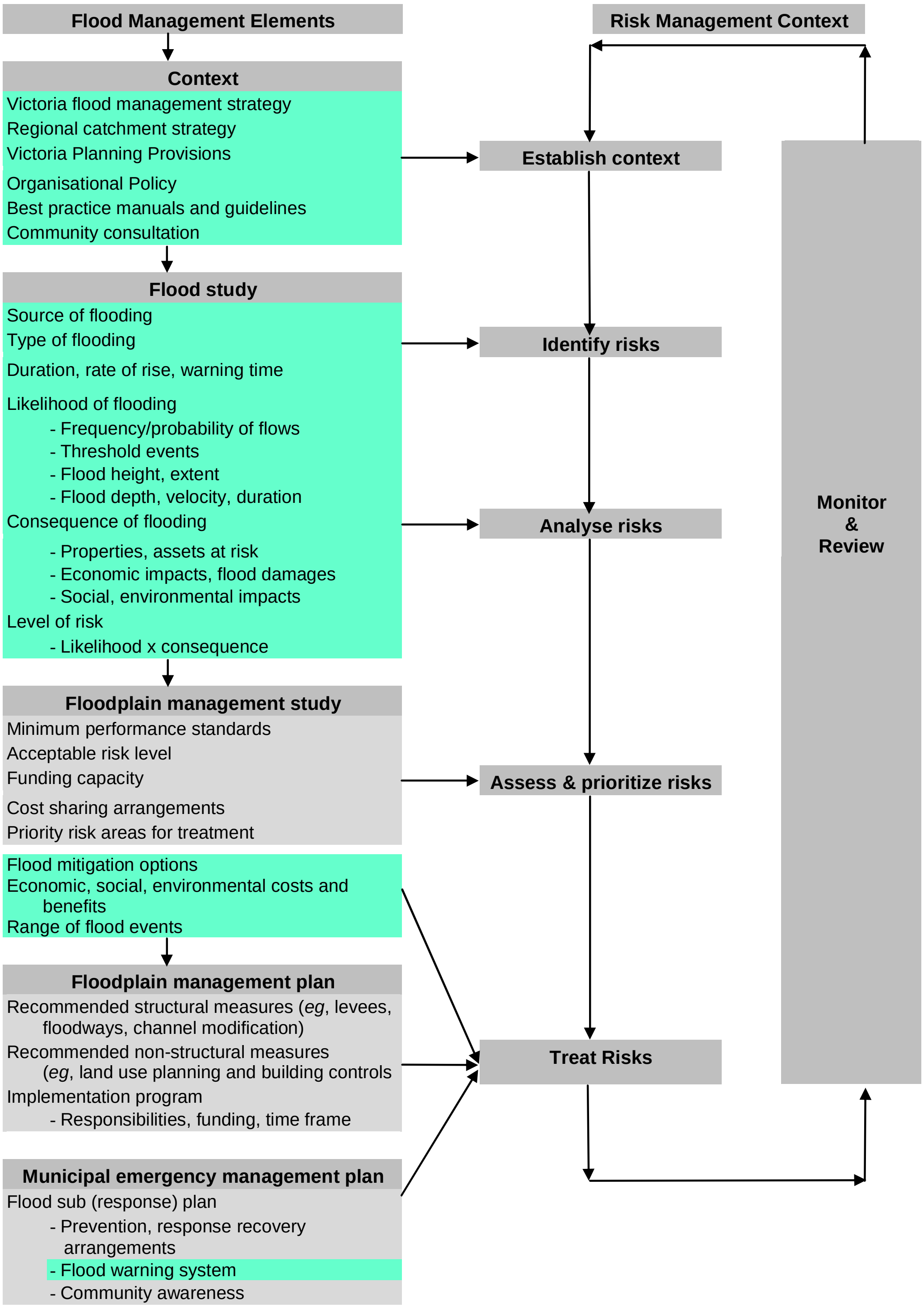

Figure 1-2 Flood Management in the Risk Management Context

1.4 Study Objectives

The aims of the investigation as specified in the study brief are as follows:

- Determination of flood levels, extents, velocities and depths for the Moyne River, Murray Brook and Reedy Creek within the study area for a range of flood events including the 1% AEP and PMF events
- Preparation of digital and hard copy floodplain maps for 1% AEP flood events showing both floodplain and floodway extents
- Assessment of flood damages
- A review of the Moyne Shire Planning Scheme's current Land Subject to Inundation Overlay for Port Fairy and recommendations for appropriate Planning Scheme amendments in the context of study outcomes
- Consideration and approximate costing of possible flood mitigation and/or flood risk reduction measures
- Delivery of all flood related data and outputs including fully attributed VFD compliant datasets in ArcGIS format.

1.5 Study Approach and Structure of Report

The study has been undertaken in partnership with the Glenelg Hopkins CMA, Moyne Shire Council and the Port Fairy community. The study program has consisted of a series of sub-tasks with corresponding sub-reports that have been reviewed and approved by a Technical Steering Committee (TSC) consisting of representatives from MSC, DSE, SES, BoM and GHCMA.

Due to the size of the component reports and the weight of technical data provided, the study reporting is delivered as a series of separate volumes. The processes and outcomes of the study have been collated in this Study Summary Report which is Volume 1. The technical details of each main component of the study are provided in separate report volumes. The components of the overall study report are listed below.

Volume 1 Study Summary Report

Volume 2 Survey Report - outlines the input data gathered for use in the study

Volume 3 Hydrology Report - details the hydrologic analysis

Volume 4 Hydraulics Report - details the hydraulic analysis

Volume 5 Risk Assessment Report - provides details of the flood risk study

Volume 6 Mapping Report - describes the study mapping and deliverables

2. BACKGROUND

2.1 Study Area

Port Fairy is located near the mouth of the Moyne River Estuary in south-west Victoria as shown in Figure 1-1. The river mouth is maintained as a navigable entrance to Bass Strait. The channel is dredged and protected by rock training walls, discharging to the sea just east of the township. The southern side of the channel is bounded by Griffiths Island, which is joined to the mainland via a causeway that partially blocks a southern outlet to the ocean known as the south-west passage.

Port Fairy itself is situated on low-lying ground with the Moyne River running along the east side of the town. A high sand dune (crest elevation approximately 5 to 15 m AHD) separates the river/estuary from the ocean.

To the north (upstream) of the town the estuary widens into a shallow open water body known as Belfast Lough that is some 4.5 km long and up to 600 m wide with an average depth (at mean sea level) of 0.6 m. The Moyne River flows into the estuary approximately 3 km upstream of the town. Other waterways that enter the estuary include Murray Brook at the northern end of Belfast Lough and Reedy Creek, which flows through the northern edge of Port Fairy township. The Moyne River catchment has a total area of approximately 758 km^2 with significant tributaries including Murray Brook (133 km^2), Nardoo Creek (75 km^2) and Back Creek (77 km^2).

The catchment is characterised by relatively gentle grades with a maximum elevation of approximately 250 m above sea level and an average slope of 0.003 or 3 m in 1000 m. Slope through the catchment does not vary greatly with the upper reaches showing only moderately higher slopes than the lower reaches, as can be seen in Figure 2-1 which shows an approximate long section of the main stream path.

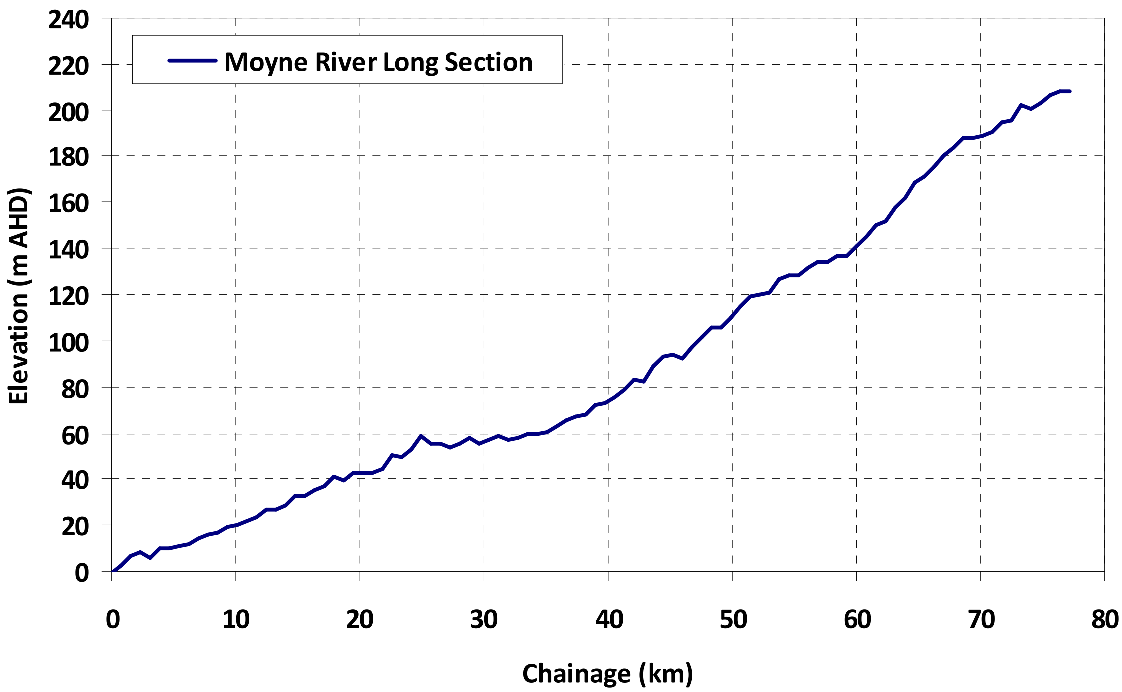

Figure 2-1 Moyne River , Approximate Catchment Slope

The catchment is also distinguished by significant floodplain storages in the form of wetlands and swamps. Whilst many low-lying areas have been drained, the efficiency of these drains in large flood events (say greater than 5% AEP) is expected to be low and hence significant active storage would be developed throughout the catchment. Figure 2-2 shows indicative wetland areas as highlighted by aerial mapping. This indicates the potential extent of flood storage and attenuation that could be active within the catchment.

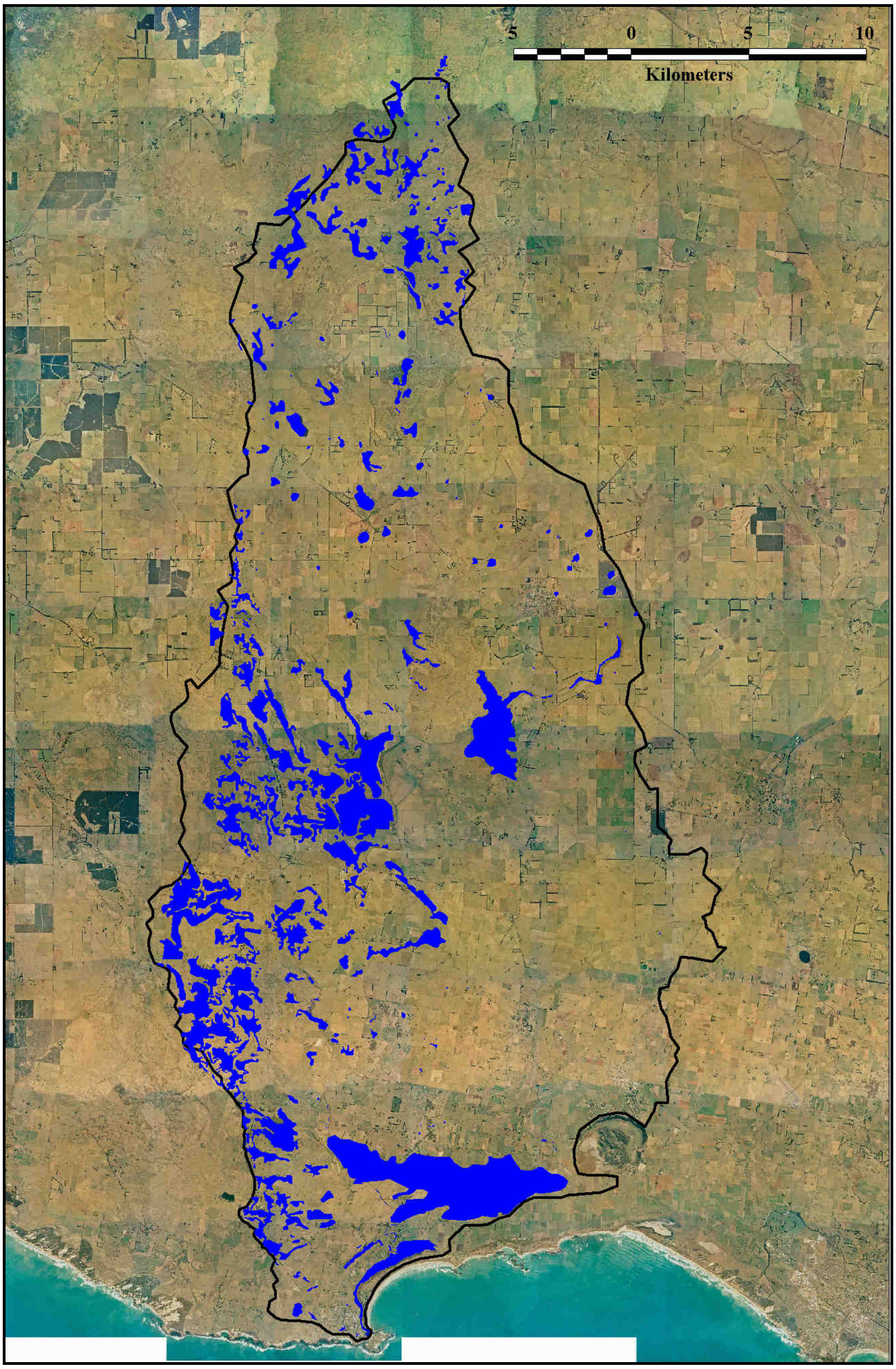

Figure 2-2 Moyne River Catchment - Wetland Areas

2.2 Floodplain Features

2.2.1 Key Physical, Hydrologic and Hydraulic Features

Through catchment inspection and review of available data, the following features were highlighted to potentially be of significant importance to the catchment:

- Storage volume within floodplain immediately to north and east of Port Fairy including Belfast Lough and the Murray Brook swamp/drainage area (Korongah Flats)..
- Wetland and drained swamp areas within the wider catchment
- The ocean outlet of the Moyne River and entrance to the estuary, including the South-West Passage
- Bridges on the Princes Highway at Rosebrook and on Reedy Creek
- The Gipps Street Bridge and abutments/approaches
- Physical description of both established and recent development within the floodplain (including the filling and piping of Reedy Creek downstream of the Princes Highway).
- The raising of Albert Road and Regent Street within the township and numerous rural roads, post 1946.
- Drainage systems both in the vicinity of the township and in the wider catchment
- Drainage and/or overland flow links between Moyne and Shaw rivers along the west boundary of the catchment.
- Height and stability of coastal dunes to the east of Belfast Lough around the golf course (and potential implications of sea-level rise on these)
- Numerous road embankments and culverts. These are located throughout the catchment and can play a significant role in determining catchment runoff. Figure 2-3 and Figure 2-4 are examples of the significance of one of these features, this embankment is over 3 m high at this location.

Figure 2-3 High Embankment, Resulting in Constriction Through Floodplain (Penshurst-Port Fairy Road at Murray Brook)

Figure 2-4 Bluestone Arch under Penshurst-Port Fairy Road at Murray Brook

2.3 Hydraulic Behaviour

The hydraulic behaviour of the floodplain in the vicinity of Port Fairy is dominated by two factors:

- Influence of the sea in terms of ocean levels and tides.
- Influence of catchment inflows from the Moyne River and tributaries.

The impact of both of these forcing mechanisms is investigated in the report. The analysis of sea levels is covered in Section 4, Volume 4 of the report. The magnitude of design flows into the Moyne River Estuary are covered in Section 5 of Volume 3 of the report. The combined influence of these factors are modelled and investigated in Volume 4 of the report.

Historically there has been one observed extreme flood (March 1946) and a number of minor floods in Port Fairy. The 1946 flood caused severe impacts in the Port Fairy district and is discussed in some detail in Section 6 of Volume 3 the report. Other significant events are reported to have occurred in 1870 and 1894.

Since the 1946 flood event there have been a number of minor floods in Port Fairy, however none of these events have resulted in significant flood damages to the township area. The main impact of moderate floods is potential to cut-off road access along Griffiths Street on the southern side of Belfast Lough.

There are no effective flood mitigation works protecting Port Fairy from flooding at present. Several low points along Regent Street have been raised in order to protect the central township from inundation from the north during extreme events. However there are no floodgates on the local stormwater pipe network draining this area and floodwater could backflow into the town this way. Hence this measure requires further work for it to be fully effective.

3. DATA GATHERING AND ANALYSIS

3.1 Overview

This section summarises the information utilised for the study including reference reports, documents and data, both from previous investigations available and that collected specifically for this study. Where required, analysis of this data has been performed and is documented. The details of the data gathered and analysed specifically for each component of the study is provided in the accompanying volumes.

3.2 Previous Studies

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

- 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.
- South Warrnambool Flood Study (Water Technology 2007) – This investigation involved hydrologic and hydraulic analysis of the Merri River catchment at Warrnambool. The Merri River is the next catchment east of the Moyne River with a similar overall catchment topography and area. As such it provides a useful catchment for correlation of behaviour with the Moyne River. In addition, this study involved extensive analysis of design sea levels along the South West Victorian Coast.
- Dennington Flood Study (Water Technology 2007) – This report provides a detailed hydrologic analysis of the 1946 flood event in the Merri River (the neighbouring catchment to the east of the Moyne River catchment).
- 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.
- Flood Data Transfer Project, Flood Mapping Report Moyne Shire (NRE 2000) – This report describes the interpretive flood mapping resulting from the state-wide FDTP program.
- Moyne River Flood Study - Port Fairy (GHD 2003) – This study includes hydrologic and hydraulic investigations of the Moyne River at Port Fairy.
- Review of Flood Studies, Part 1: Moyne River Flood Study Port Fairy (Erwin Weinmann, RJ Keller & Associates, 2007)
- Review of Flood Studies, Part 2: Merri River Warrnambool (Erwin Weinmann, RJ Keller & Associates, 2007)

3.3 Topographic Data

3.3.1 Overview

The following sub-sections describe the topographic data utilised in the study. This information provides the basis of the hydraulic modelling and mapping tasks and consists of:

- Aerial Survey – LIDAR
- Digital Aerial Photography
- Field Survey

3.3.2 Aerial Survey – LIDAR

LIDAR survey was conducted over the Port Fairy project area on the 15th and 23rd August 2007. A summary of the LIDAR capture is provided in Table 3.1 below (details of the LIDAR data are provided in Volume 2, Survey Report). A plot of the resultant terrain data is provided in Figure 3-1.

The LIDAR data was validated by the data provider against a total of 170 field test points, located on clear ground. In addition to these checks, the LIDAR information was independently verified by the study team using an additional 317 field survey points collected during the study (as described in Volume 2 Survey Report). This data verification produced a mean error in the LIDAR data of 0.08 m with a standard deviation of 0.1 m. This analysis suggests the accuracy of the LIDAR is within the specifications required and suitable for the purposes of the study.

Table 3-1 Summary of LIDAR Data

Parameter	Details
Flying Height	800 m
Swath Width	580 m
Area covered	100 km^2
Vertical Accuracy	+/- 100 mm
Output Format	1 m ASCII grid

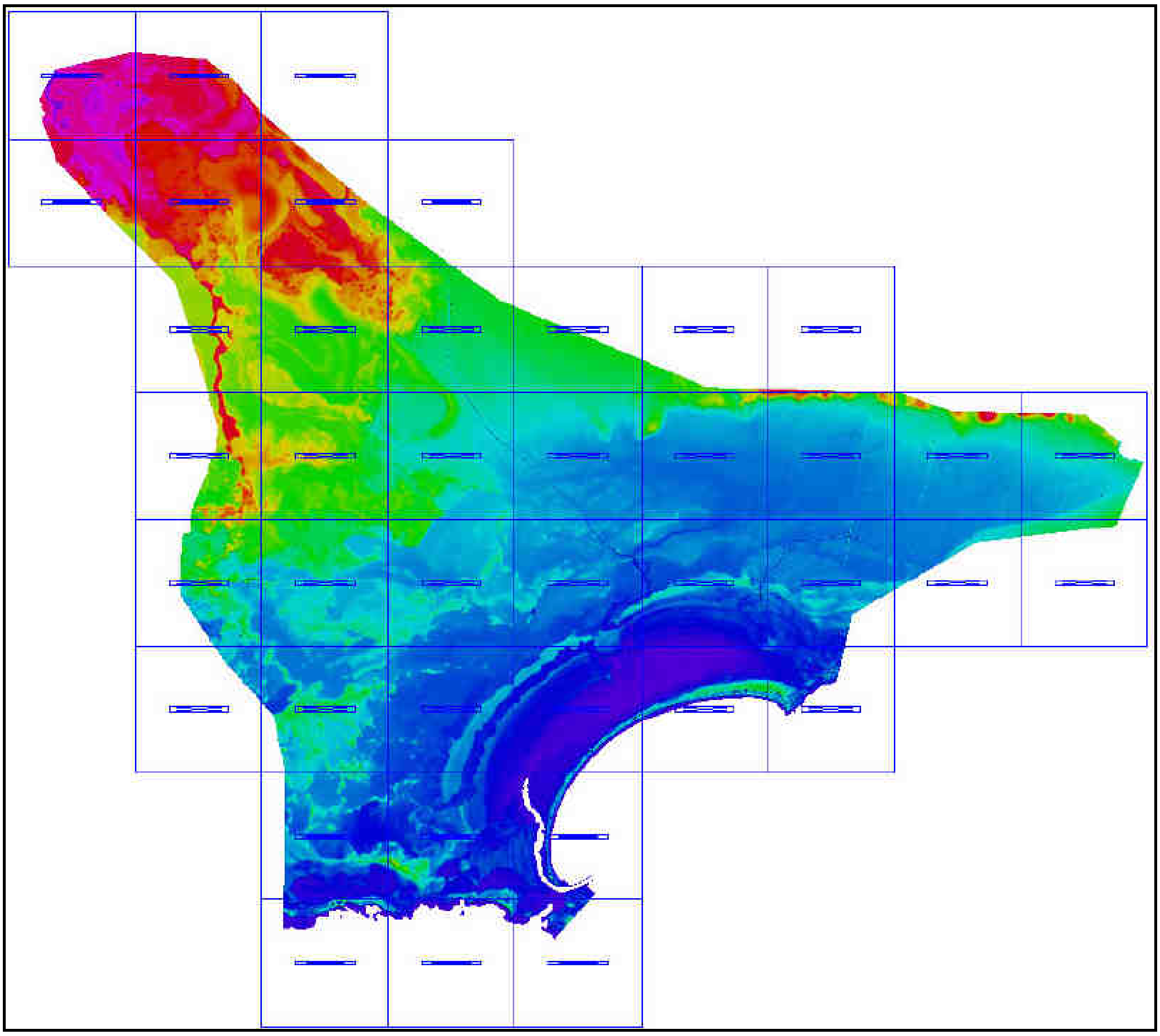

Figure 3-1 LIDAR Data Plot (AAM 2007)

3.4 Digital Aerial Photography

Two sources of digital aerial photography were utilised for the study. These were:

- Colour orthoimagery at 1:25,000 scale flown in February 2003. This data covers the whole Glenelg Hopkins region and was used to provide base imagery for the Moyne River catchment.
- Approximate orthoimagery of the LIDAR area, captured at the same time as the LIDAR in order to provide a "snap-shot" of conditions at the time the LIDAR was flown. This was specifically to interpret the LIDAR particularly with respect to areas of standing water. A plot of this imagery is shown in Figure 3-2.

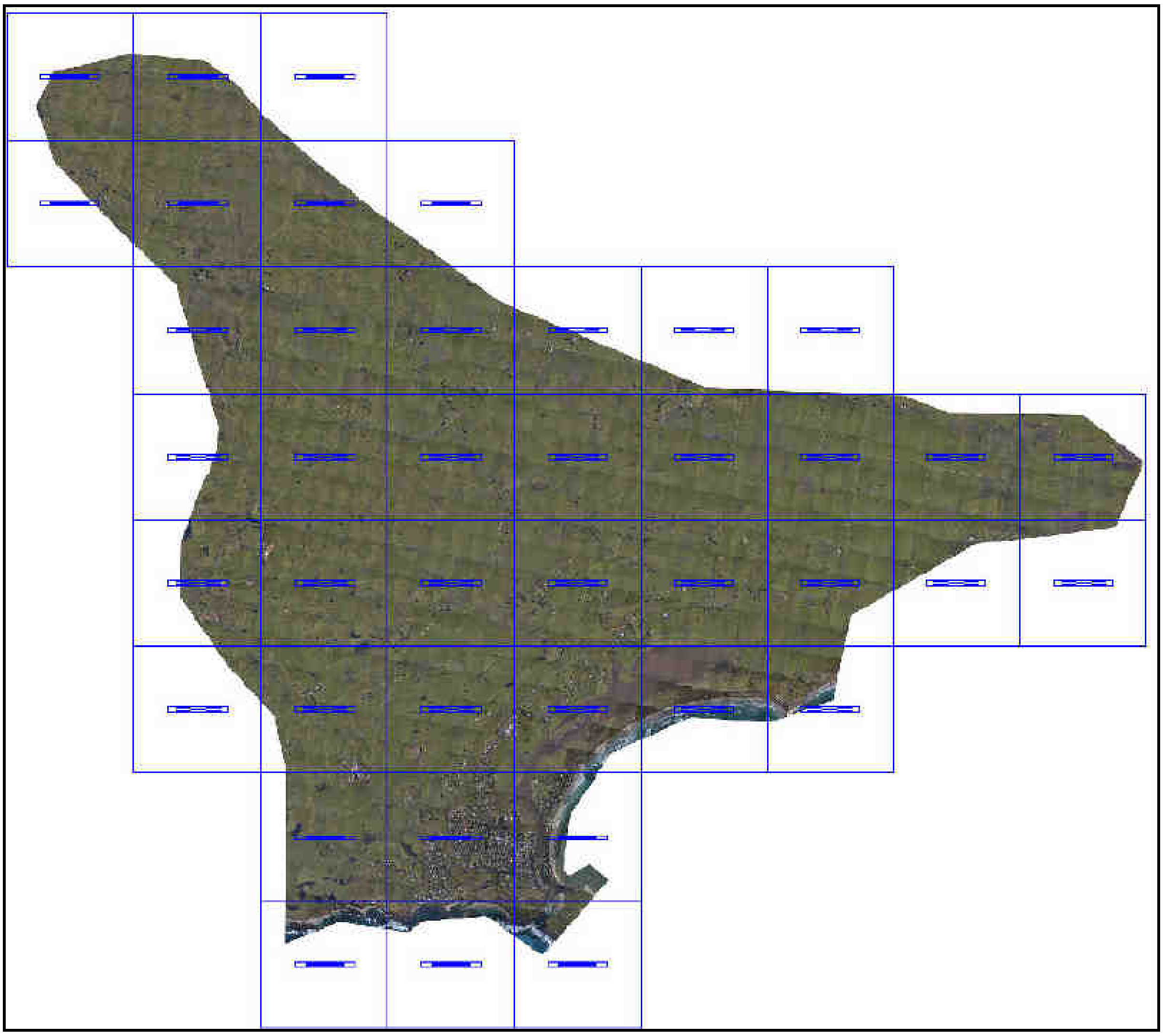

Figure 3-2 Orthoimage Plot (AAM 2007)

3.5 Field Survey

3.5.1 Introduction

Field survey was required to provide data additional to the LIDAR information and to complement this with local details where required. Field survey was undertaken by Alan H Simpson (licensed land surveyor, Warrnambool) primarily during September and October 2007 with the floor level survey being undertaken in March 2008. The survey was undertaken using total station traverse from known benchmarks and high-grade differential GPS in order to ensure the appropriate accuracy was achieved.

The various field survey components are described below. Plans of the field survey data including cross-sections and structures are provided in Volume 2 – Survey Report.

3.5.2 Cross Section Survey

Cross-section survey was gathered to define the details of channel geometry for waterways not well defined by the LIDAR or where there was significant waterway area below the waterline when the LIDAR was collected.

Cross-sections were collected from where the Moyne enters Belfast Lough (approximately 1 km south of Princes Highway) upstream to the study boundary, approximately 1 km north of the Toolong North Road Bridge. The locations of surveyed cross-sections are shown in Figure 3-3.

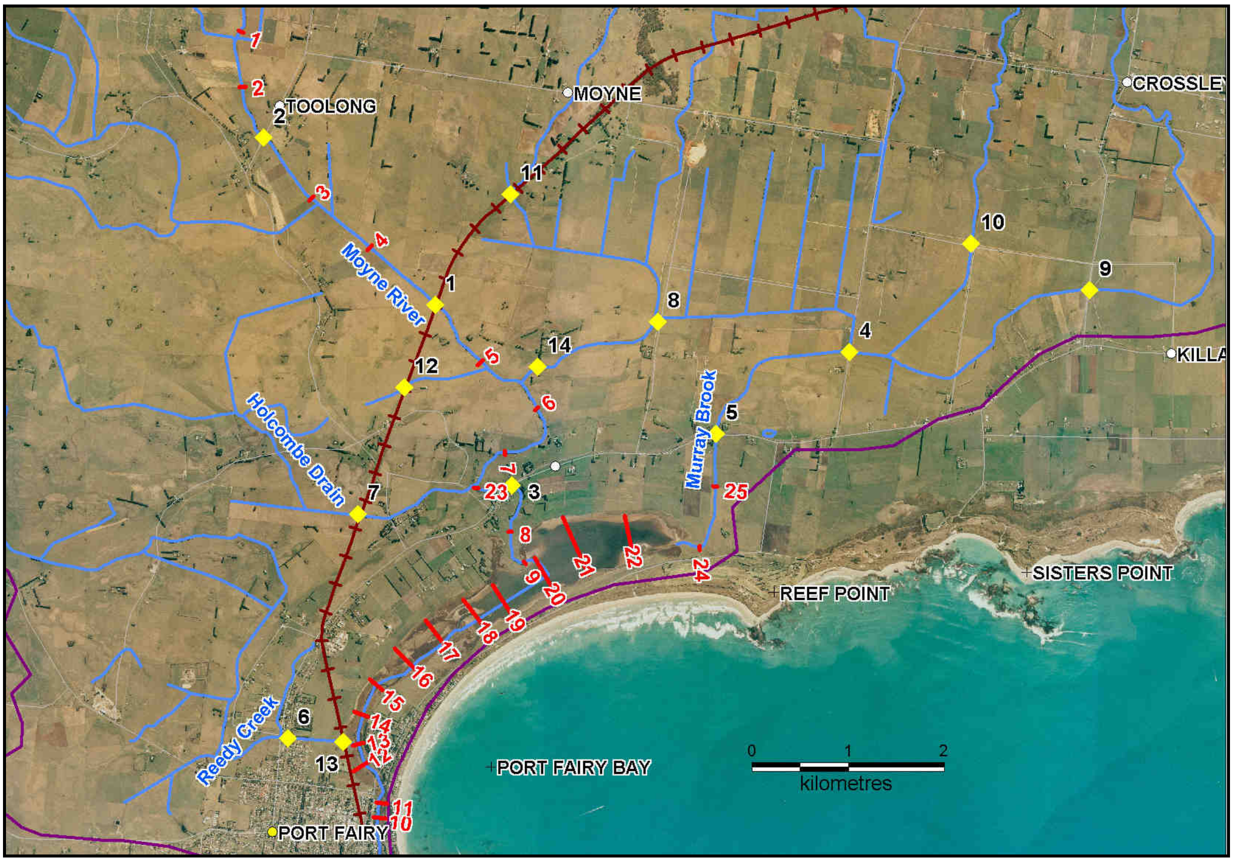

Figure 3-3 Locations of Field Surveyed Cross-sections and Structures

3.5.3 Hydraulic Control and Structure Survey

This component of the survey consisted of bridge and culvert hydraulic structures that significantly influence floodplain flow and storage.

A total of 15 hydraulic structures were surveyed with locations shown in Figure 3-3. Further to these major structures, 8 additional culverts were measured in the field. These structures were recorded in terms of their location and culvert dimensions (diameter).

3.5.4 Floor Level Survey

Floor levels are required for properties that are considered at risk of flooding for the calculation of flood damages and potential emergency management measures.

A significant number of property floor levels within Port Fairy were surveyed for the previous 2003 study. For the present investigation, the revised flood extents were checked against current aerial imagery to identify any new or missing buildings from the prior floor survey. These were then identified for survey and collected in the field. A total of 78 new floor levels were surveyed.

3.5.5 Flood Level Survey

Limited additional flood marks were identified during the initial consultation stages of the project. These were surveyed to a vertical accuracy of better than +/- 50 mm by CMA staff.

3.6 Bathymetric Survey

In order to develop a complete description of the dynamics of the Moyne River estuary, bathymetric data was compiled and included in the digital terrain model. This comprised data from the following sources:

- Depth-soundings of the Moyne River from the harbour entrance to Gipps Street Bridge, gathered from existing harbour plans.
- Cross-sections across the Moyne River and Belfast Lough from the foot bridge upstream.

The locations of newly surveyed cross-sections are shown in Figure 3-3. The bathymetric data from the previous survey was digitised in a GIS system from digital scans of the plan sheets.

3.7 Historical Survey Records

A number of historical survey records were available in hardcopy format from varying sources. These records generally required hand entry into spreadsheets or digitising into a GIS system for use in the digital terrain model or directly in the hydraulic model. Listing and plots of historic data plans are provided in Volume 2 – Survey Report.

3.8 Digital Terrain Model Construction

A digital terrain model (DTM) of the study area was developed from the available survey. This included all topographic data gathered as part of the aerial and terrestrial survey components of the study as well as historic plans covering parts of the river and port. GIS and terrain modelling software packages were used for this purpose.

The resulting study DTM is shown in Figure 3-4 as a 5 m grid. This terrain information is suitable for the study purposes of hydraulic model development and mapping of flood extents.

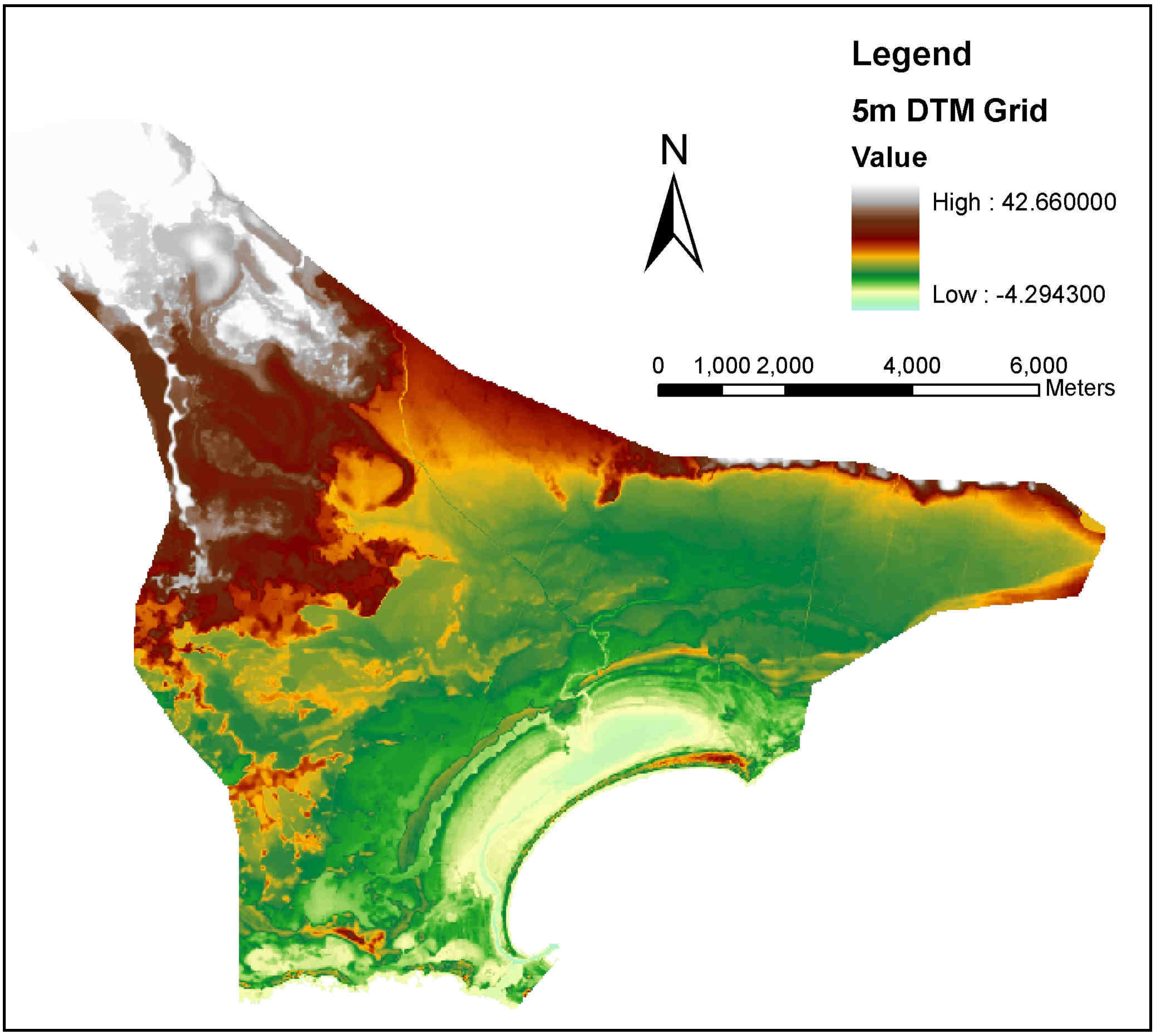

Figure 3-4 Port Fairy Digital Terrain Model

3.9 Hydrologic and Hydraulic Data

3.9.1 Rainfall Data

Rainfall data was used in the hydrologic model calibration. Historic rainfall information, consisting of data with 6 minute, 1 hour or daily record intervals, was gathered from the Bureau of Meteorology. Rainfall stations in and around the Moyne River catchment are shown in Figure 3-5. Further details on available rainfall information are provided in Volume 3 Hydrology Report.

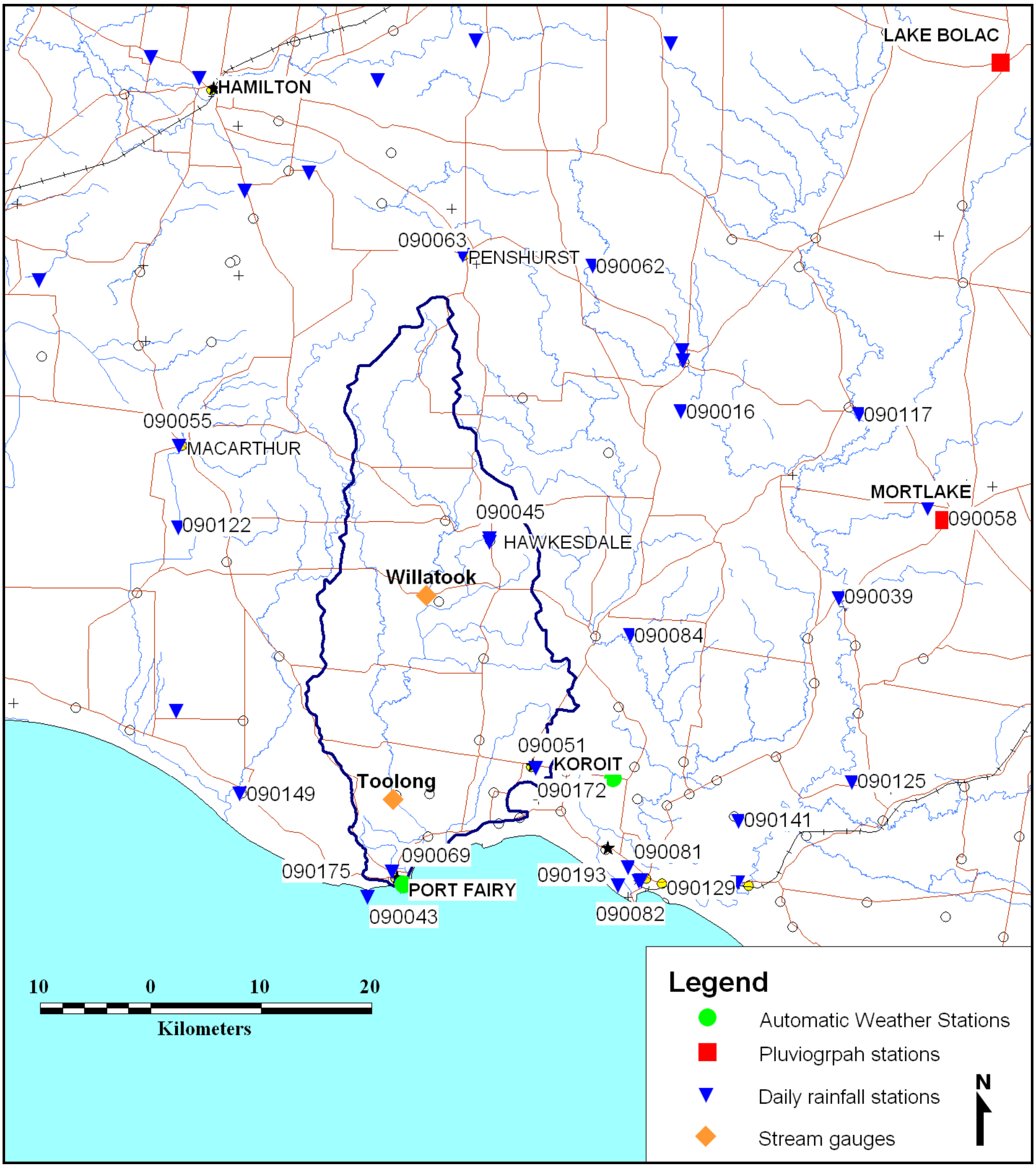

Figure 3-5 **Available Rainfall Stations**

3.9.2 Stream Gauge Data

Stream flow records are available at two gauge stations within the Moyne River catchment, at Toolong and Willatook as listed in Table 3-2 below. The Toolong Gauge is an active site whereas Willatook is inactive and was only operated for a period of approximately 10 years up to the mid 1980's. The 20 highest gauged flows are presented in Table 3-3. Further details on available gauge information are provided in Volume 3 Hydrology Report.

Table 3-2 Available Streamflow Gauge Stations

Station Name	Station No.	Status	Data Type	Period of Record
Toolong	237200	Active	Mean Daily Flow Instantaneous and Mean Daily Flow	1948-1972 1973-2007
Willatook	237208	Inactive	Instantaneous and Mean Daily Flow	1974-1985

Table 3-3 Highest 20 Gauged Floods at Toolong– Instantaneous Peak Flow

Rank	Month/Year	Peak (ML/d)	Peak (m^3/s)
1	Oct 1976	10,500	122
2	Aug 1978	10,300	119
3	Nov 1953	9,558	111
4	Aug 1951	9,403	109
5	Aug 1955	8,948	104
6	Aug 1975	8,600	100
7	Sep 1983	8,420	98
8	Sep 1960	8,215	95
9	Aug 1970	7,764	90
10	Aug 1966	7,613	88
11	Sep 1984	7,440	86
12	Aug 1958	7,374	85
13	Aug 1952	7,034	81
14	Jul 1977	6,960	81
15	Oct 1971	6,485	75
16	Sep 1979	6,310	73
17	Jul 1964	5,695	66
18	Aug 1981	5,030	58
19	Aug 2001	4,849	56
20	Sep 1996	4,650	54

Note: Pre-1974 mean daily flows have been scaled to provide instantaneous peak flow based on a mean-daily to instantaneous peak correlation.

A plot of the magnitude and timing of the annual flood peaks (based on mean daily flow) at Toolong from 1948 to 2006 is provided in Figure 3-6.

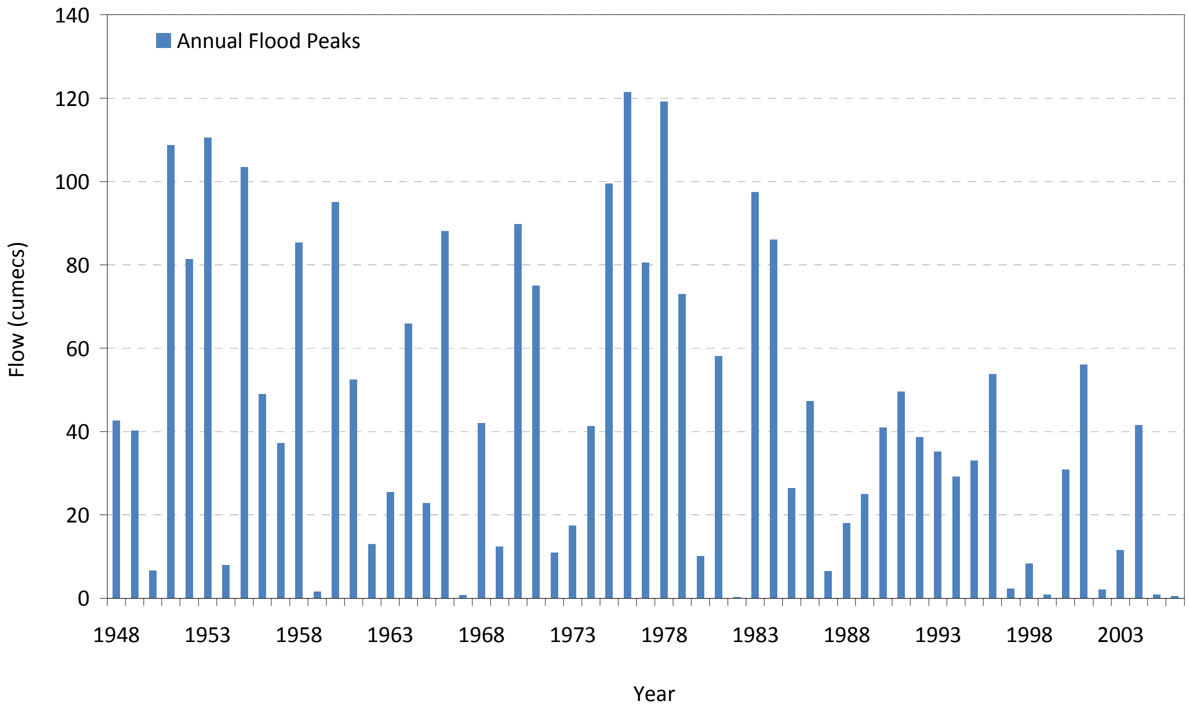

Figure 3-6 Annual Flood Peaks at Toolong (Instantaneous Peak Flow, Recorded or Derived)

3.9.3 Flood Data Transfer Project

Previous flood reporting and mapping associated with the Flood Data Transfer Project were provided by the Glenelg Hopkins CMA. This information provided background commentary on flooding in the Port Fairy area and interpretive flood mapping.

The present flood mapping layers are presented in Figure 3-7. This represents the status of knowledge in relation to flooding in Port Fairy prior to this study.

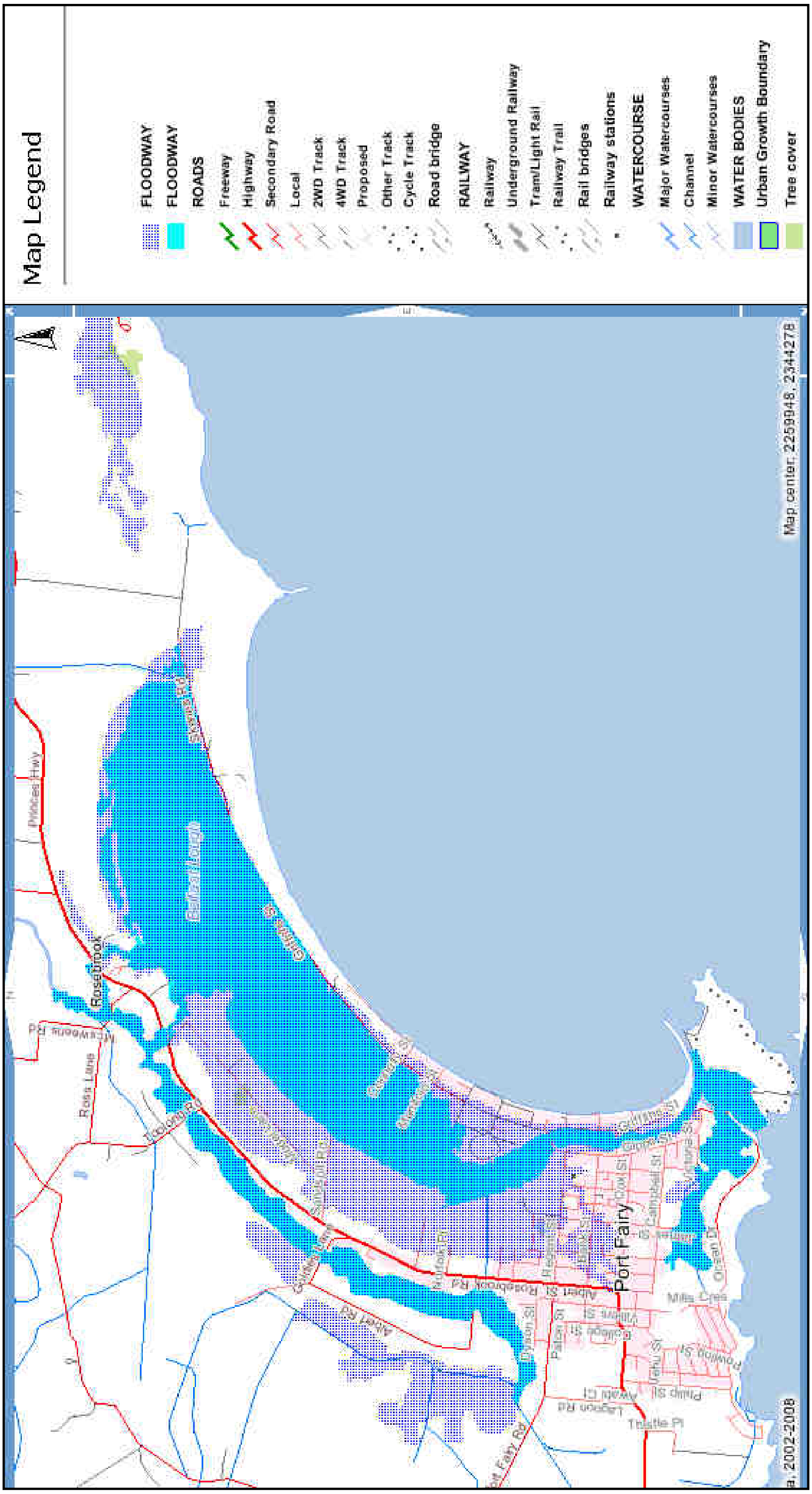

Figure 3-7 **Previous LSIO and Foodway Outline (from DSE, www.dse.vic.gov.au)**

3.10 Ocean Conditions

3.10.1 Available Data

In order to establish appropriate sea level conditions for flood assessments at Port Fairy, oceanographic data was collected. This includes data on tides and storm surge levels in Bass Strait and the Southern Ocean. Much of this data was gathered previously and described in the South Warrnambool Flood Study (Water Technology, 2007). The data utilised in this study (and described further in Volume 4 – Hydraulic Modelling Report) includes:

- Tidal Constituents for Portland and Port Fairy
- Sea levels at Portland Harbour
- Recent modelling results provided by CSIRO on storm surge along the west Victorian coast.
- Background information on climate change and sea level rise in particular

3.10.2 Storm Surge Analysis

A frequency analysis of 34 individual storm surge events identified in the Portland Harbour water level record was undertaken to determine the probability of occurrence of storm surge levels greater than 0.4 m.

The results of this analysis are shown below in Figure 3-8. The x axis identifies the probability of occurrence of a positive tidal residual (shown on the y axis). For example, the 1% AEP (1 in 100 year ARI) positive tidal residual is evaluated as 0.7 m.

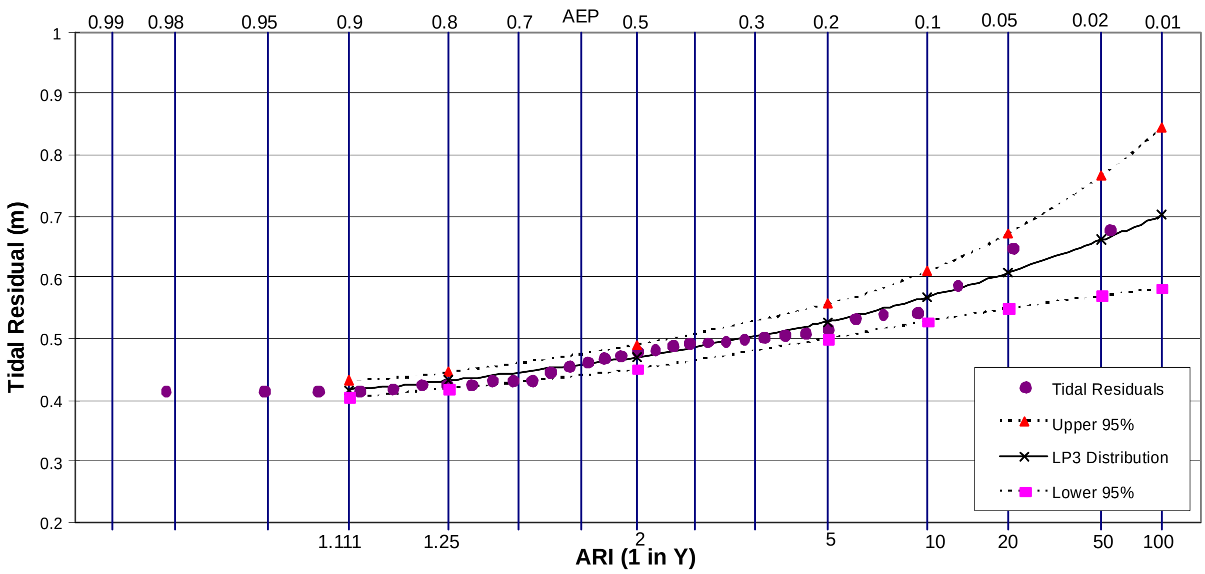

Figure 3-8 Probability of Occurrence of Storm Surge Levels at Portland

These results were combined with the tidal predictions to give a combined estimate of storm tide levels which were then compared with the results of detailed modelling of storm surges on the Victorian Coast by the CSIRO. These levels were found to be quite similar. The study has adopted the levels for Port Fairy provided by the CSIRO. The design 1% AEP sea level applicable to Port Fairy for planning purposes is determined to be 1.1 m AHD as shown in Table 3-4.

Table 3-4 Design Ocean Level Summary

Source	1% AEP Ocean Level (m AHD)	Ocean Level for Planning Purposes (Rounded) (m AHD)
Water Technology (2007)	1.07	1.1
CSIRO (McInnes, pers. communication 2008)	1.12	1.1

3.11 Other Information

Planning Scheme/Land Use

The existing planning scheme zones and overlays are available online from the DSE website. These were downloaded and used in interpretation of existing land-use and assessment of mitigation options.

4. COMMUNITY CONSULTATION

The community consultation components of the study are being managed by the Glenelg Hopkins CMA and Moyne Shire Council. The study team were involved in community information sessions at the commencement of the study in August 2007. This involved two full day sessions providing informal opportunities for members of the community to review plans, provide information and discuss flooding issues or concerns with the study team, CMA, Council and SES staff who were in attendance. General material on the flood study process was prepared in poster form for use during the sessions. An example of one of the posters is provided in Figure 4-1.

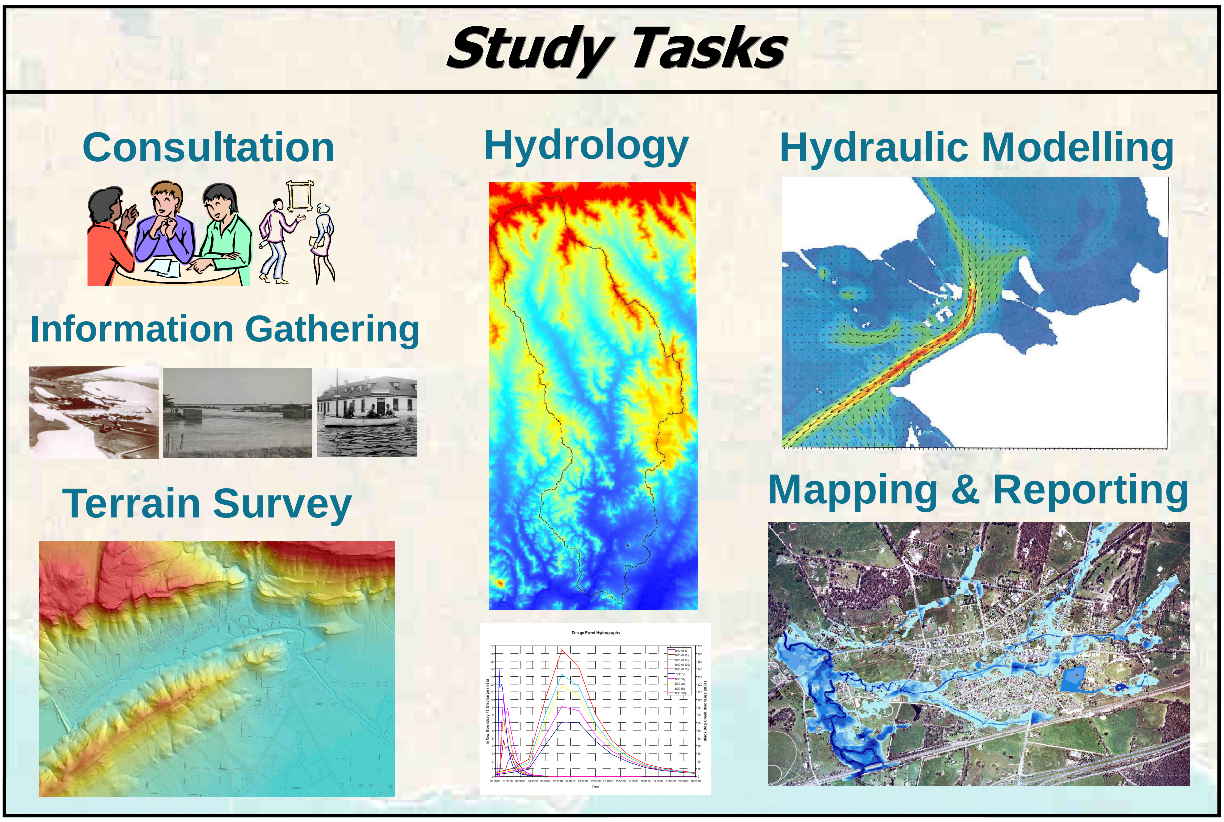

Figure 4-1 Example Poster from Community Information Session

5. HYDROLOGIC ANALYSIS

5.1 Overview

The hydrologic analysis developed design flood hydrographs for the 20%, 10%, 5%, 2%, 1% and 0.5% Annual Exceedence Probability (AEP) floods and the Probable Maximum Flood (PMF) at key inflow points to the study area. These flows are used as inputs to the hydraulic model which calculates flood inundation. Figure 5-1 shows the catchment locality and context with the study area. The main inflow points to the study area include:

- Moyne River at Toolong
- Murray Brook
- Reedy Creek
- Holcombe's Drain

In order to develop reliable design flood estimates, a number of hydrologic techniques have been employed. These include:

- Flood Frequency analysis of gauged flows at Toolong
- A calibrated RORB rainfall-runoff model
- Regional estimates based on local catchment studies
- Consideration of the 1946 flood event

By applying these different techniques, a range of estimates has been developed and then compared in light of the methodology and data underpinning each one. Through the adoption of this rigorous approach, a greater understanding of the sensitivities and characteristics of the catchment has been gained. Subsequently, greater confidence can be placed in the design flows adopted than would be the case if only a single methodology was employed.

5.2 Flood Frequency Analysis

An annual flood frequency analysis (FFA) was undertaken for the Toolong gauge on the Moyne River. This provides a statistical analysis of recorded flows in the Moyne catchment at Toolong which can be compared to outputs from other methods such as Rainfall Runoff modelling. Details of this analysis are presented in the Volume 3 report.

The initial FFA was found to result in a very flat curve above the 5% AEP event, which is considered unrealistic. In order to address this, a technique was used in which the 1946 flood estimate was included in the FFA by applying credible hypotheses of the magnitude and recurrence interval of this flood event. Upper and lower bound FFA curves were then generated that could be used in interpreting the likely magnitude of floods greater than the 5% AEP.

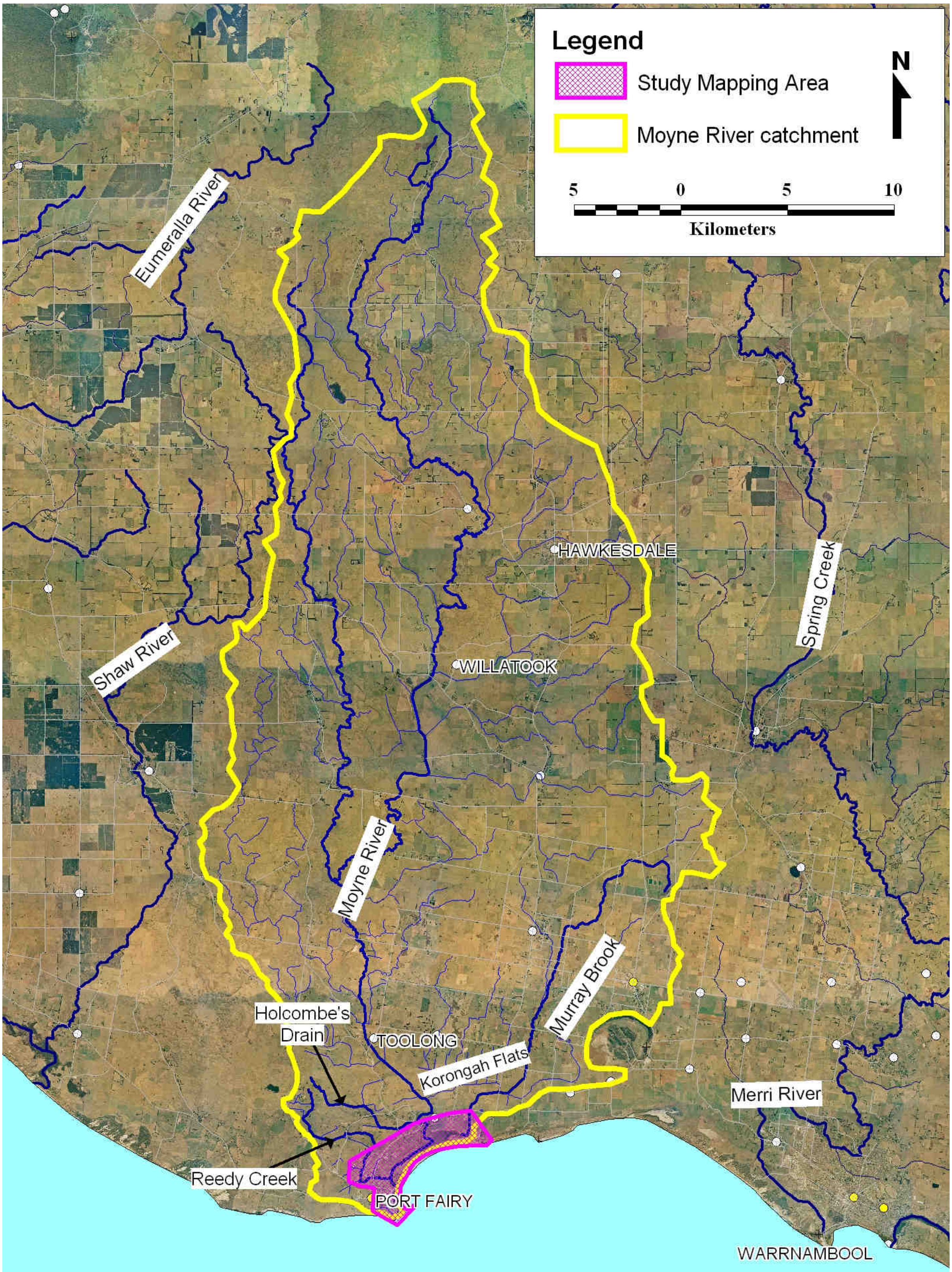

Figure 5-1 Moyne River Catchment Plan

The following guiding assumptions were made in order to generate nominal upper and lower bound frequency curves:

- A lower bound scenario, assuming that the 1946 flood peak was at least 40,000 ML/d and the largest event in the 1000 years before 1949
- An upper bound scenario, assuming that the 1946 flood peak was at least 50,000 ML/d and the largest event in the 500 years before 1949

The corresponding FFA curves are shown in Figure 5-2 along with the gauged data. This shows a spread of peak flows for the 1% AEP event between approximately 20,000 and 25,000 ML/day.

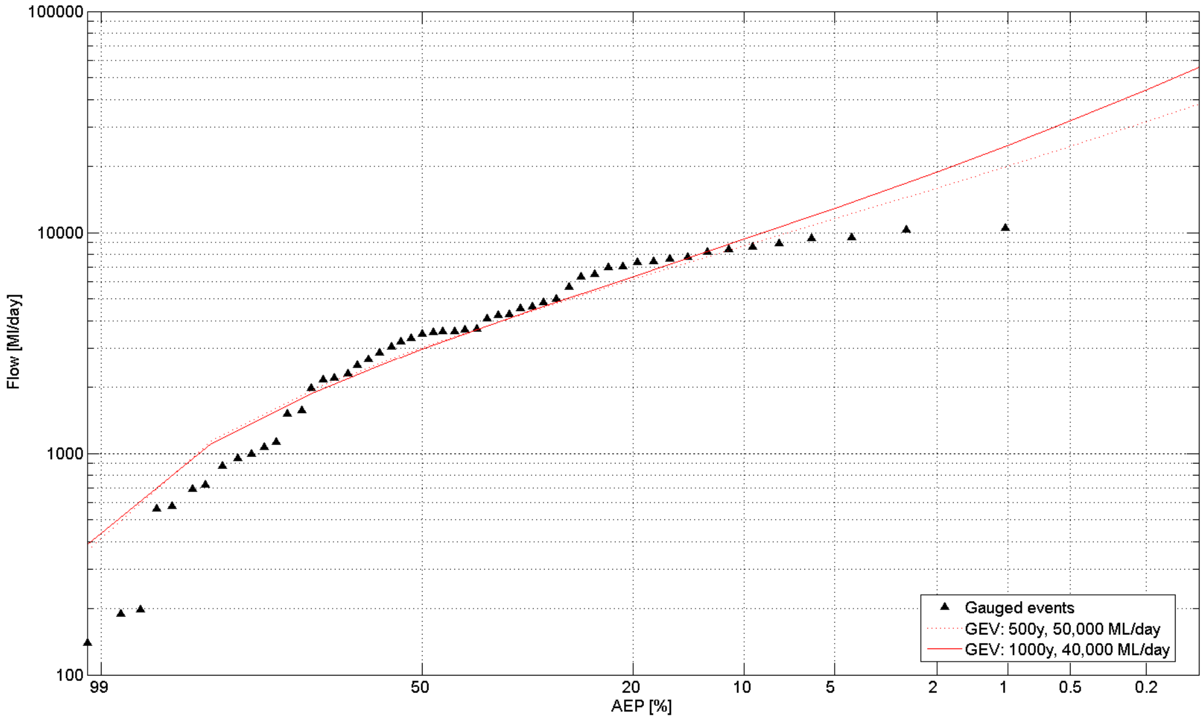

Figure 5-2 Upper and Lower Bound Flood Frequency Curves

A FFA was also undertaken for annual peak five-day-flood-volumes (5DV) in a similar manner to the annual peak flow series. The results of the 5DV FFA are presented in Figure 5-3. This shows a similar trend to the peak flow FFA with volumes flattening above the 5% AEP event.

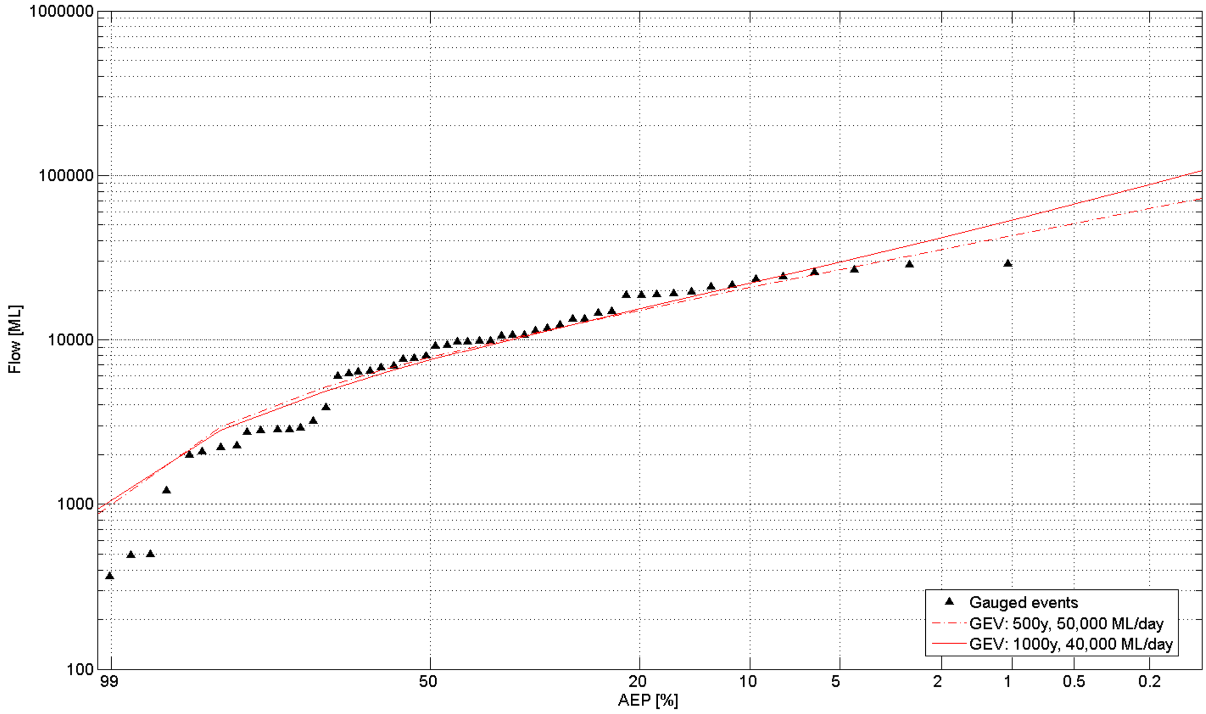

Figure 5-3 Modified Five Day Annual Flood Volume Frequency Results, Toolong

The role of the FFA in assisting design flood estimation in this study was to provide guidance on the expected flood peak and volume magnitudes of the design flood events. Considering the range of flow data available and the results of this analysis, it is considered that the conventional FFA should provide good estimates of design flow up to around the 5% AEP event. Beyond this range it was evident that the derived probability distributions, based on the gauged flows only, did not represent floods of greater magnitude well. Inclusion of the estimated 1946 flood event using plausible hypotheses provided upper and lower bound flood frequency curves that could be used in the interpretation of design flood magnitudes.

The derived FFA was used for the reconciliation (and scaling) of flows from the subsequent rainfall runoff modelling.

5.3 Rainfall Runoff Modelling

Due to the significant floodplain storage available upstream of Port Fairy, full design hydrographs were required as inputs to the hydraulic model. In order to develop design hydrographs a rainfall-runoff approach, using the RORB model, was chosen. For the purposes of the study, the total catchment was categorised into 3 main divisions, above Willatook, between Willatook and Toolong, and below Toolong. These divisions are based on the locations of the available stream flow gauges and are shown in Table 5-1 and Figure 5-4 below.

The RORB model parameters were determined through calibration of the modelled flood hydrographs to gauged stream flow records. Once calibrated, the RORB model was reconciled with the derived 5% AEP flow from the modified FFA. RORB was then applied to estimate design flood hydrographs using design rainfall and storm losses as inputs.

Table 5-1 RORB Model Structure Details

Catchment Division	Division Area (Accumulated Area) km^2	Number of Sub-catchments per Division (Total)
Moyne River at Willatook Gauge	272.2 (272.2) km^2	19
Moyne River at Toolong Gauge	299.7 (571.9) km^2	21 (40)
Moyne River at Port Fairy	186.6 (758.5) km^2	17 (57)

The RORB model was calibrated to 5 historic flood events as listed in Table 5-2 below. These include a number of large events and one smaller event.

Table 5-2 RORB Model Calibration Events

Event	Event Start & Finish Date	Willatook Gauge	Toolong Gauge	Rank of Peak Flow in Historical Record
		Recorded Peak (m^3/s)	Recorded Peak (m^3/s)	
1975	18th– 26th August	47.6	99.5	6
1976	13th– 21st October	65.4	121.5	1
1978	5th– 18th August	83.4	119.2	2
1983	2nd – 20th September	91.3	97.5	7
2001	26th -29th August	n/a	51.6	19

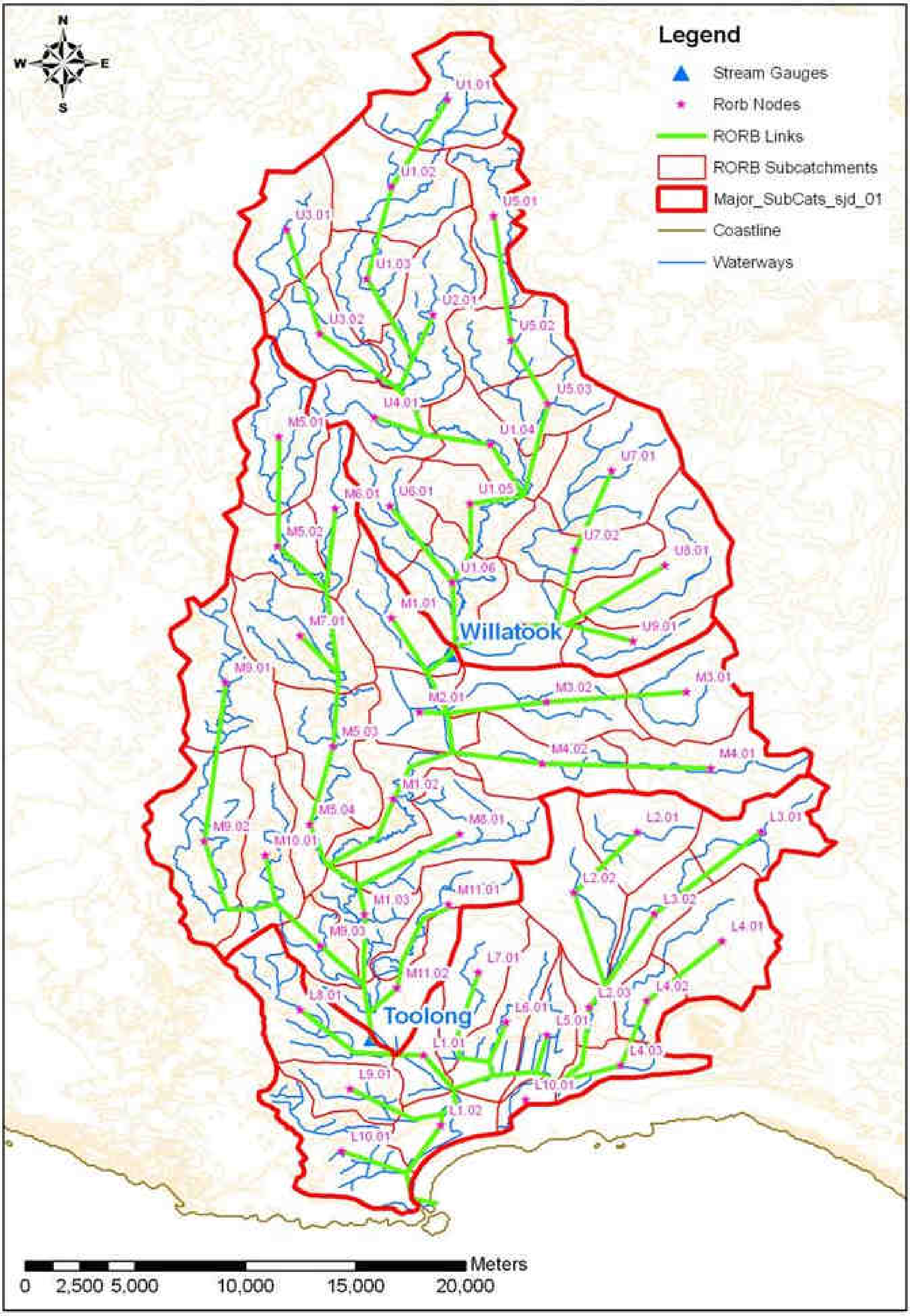

Figure 5-4 Moyne River RORB Model Structure – Catchment Subdivision

As more than one flow gauge was available for 4 of the 5 calibration events, it was decided to undertake an interstation calibration in which different parameters were used to fit the flows at each gauge. For each event the input RORB parameters were adjusted to provide the best fit to the observed hydrograph. The results of the RORB model calibration are provided in Table 5-3. A typical RORB model calibration plot is provided in Figure 5-5. Given the available data the RORB model calibration was considered to be satisfactory.

Table 5-3 RORB Model Calibration Events - Calibrated Interstation Model Parameters

Event	Willatook Kc Value	Toolong Kc Value	Murray Brook Kc Value	Moyne River at Toolong (237200)			
				Rainfall Loss Parameters		Peak Flow @ Toolong	
				IL (mm)	CL (mm/h)	Observed (m^3/s)	Modelled (m^3/s)
1975	32	48	30.9	15	0.06	99.5	102.6
1976	32	48	30.9	12	0.7	121.5	121.9
1978	32	48	30.9	6	0.02	119.2	123.9
1983	26	46	25.1	25	0.01	97.5	97.4
2001	65	65	65	10	5.00	51.6	56.8

The RORB design flows were reconciled against the modified annual flood frequency analysis (FFA) for flows and volumes at the Toolong gauge. This reconciliation focussed on the 5% AEP event as this was a magnitude at which the FFA both with and without the 1946 flood were quite similar.

Whilst the interstation RORB model results showed good agreement with the gauged data, it was found that the results were quite similar those derived with a single Kc. Further it was considered difficult to justify the use of a different Kc on the lower portion of the catchment (below Toolong) without any additional data. Hence the Single Kc RORB model setup was adopted for the study.

The reconciled RORB peak flows for events greater than 5% AEP were found to fall on or just below the lower bound estimates from the FFA. In order to be consistent with the FFA and the weight of evidence regarding the magnitude of the 1946 flood, it was decided to scale the RORB design hydrographs (for both peak flow and 5 day volume) to match the mid-point between the upper and lower bound values from the FFA.

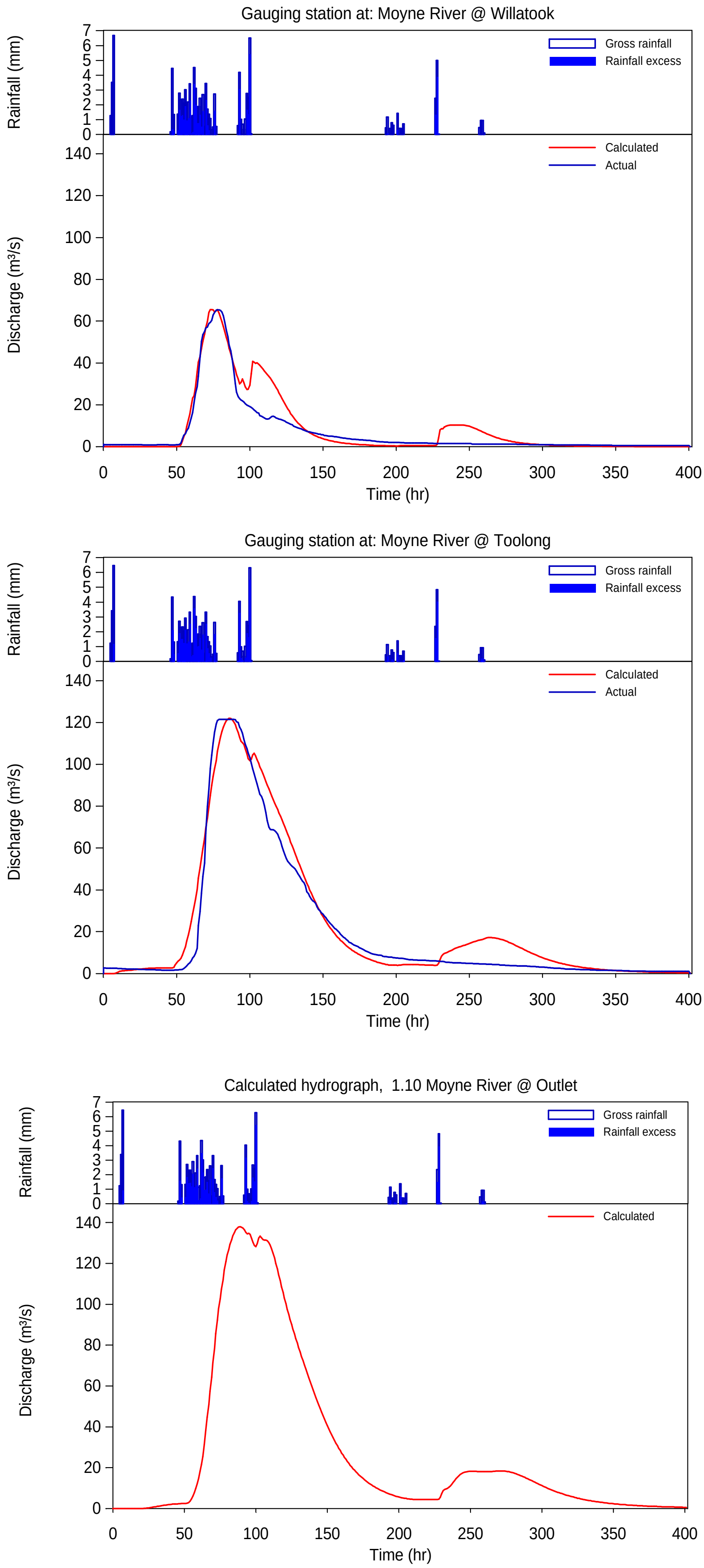

Figure 5-5 RORB Calibration – Moyne River August 1976 Event

5.4 Design Hydrographs

Design flood hydrographs were determined using the RORB model and then scaled to match the adopted design flow peaks at Toolong from the FFA. Hydrographs for the 20%, 10%, 5%, 2%, 1% and 0.5% Annual Exceedence Probability (AEP) events were generated. The hydrographs were extracted from the RORB model at the following inflow points to the study area:

- Moyne River at Toolong
- Murray Brook
- Reedy Creek
- Holcombe's Drain

These locations are illustrated in Figure 5-6 below with the peak flows listed in Table 5-4. This shows the main inputs to the study area are from the Moyne River at Toolong, 258 m^3/s and Murray Brook at Killarney, 92 m^3/s. Figure 5-7 shows the design flow hydrographs for all AEP's at Toolong whilst Figure 5-8 shows the 1% AEP design hydrographs at the study boundary inflow points.

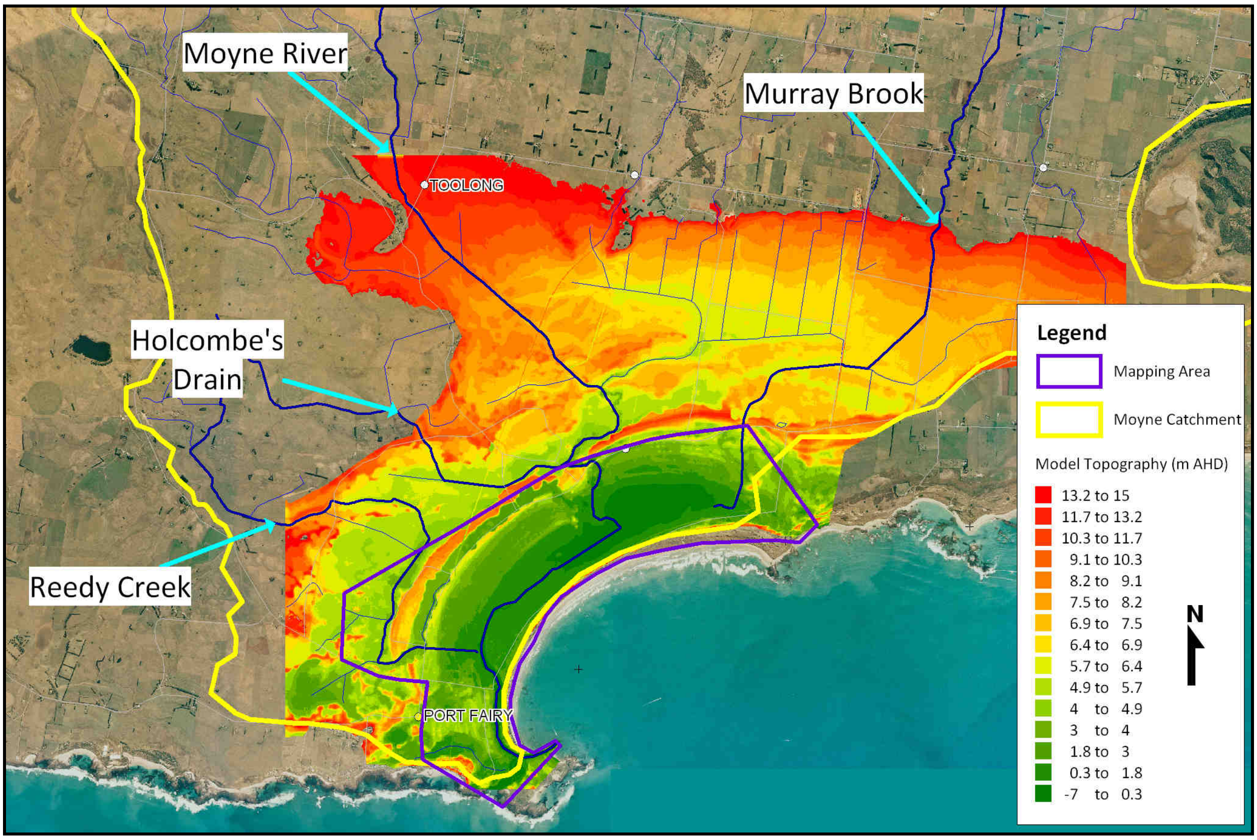

Figure 5-6 Port Fairy Hydraulic Model Inflow Locations

Table 5-4 Scaled Design Peak Flows for Hydraulic Model Boundaries

Location	Moyne Catchment Design Peak Flow ML/d (m^3/s)					
	20% AEP (5 yr ARI)	10% AEP (10 yr ARI)	5% AEP (20 yr ARI)	2% AEP (50 yr ARI)	1% AEP (100 yr ARI)	0.5% AEP (200 yr ARI)
Moyne River at Toolong	6,250 (72.3)	9,015 (104.3)	12,241 (141.7)	17,457 (202.1)	22,323 (258.4)	28,181 (326.2)
Murray Brook	2,431 (28.1)	3,483 (40.3)	4,594 (53.2)	6,337 (73.3)	7,951 (92.0)	9,853 (114.0)
Holcombe's Drain	360 (4.2)	497 (5.7)	626 (7.2)	823 (9.5)	994 (11.5)	1,195 (13.8)
Reedy Creek	1,016 (11.8)	1,383 (16.0)	1,729 (20.0)	2,232 (25.8)	2,626 (30.4)	3,087 (35.7)

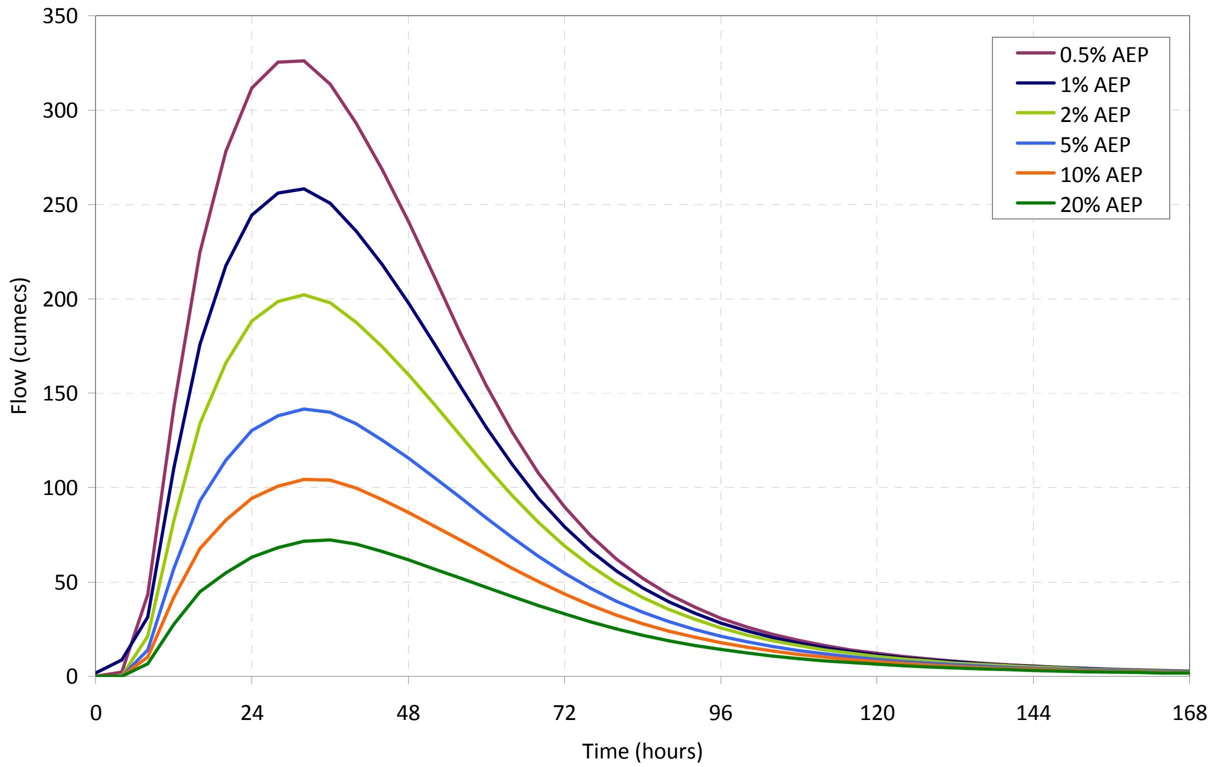

Figure 5-7 Design Hydrographs (Scaled RORB) at Toolong

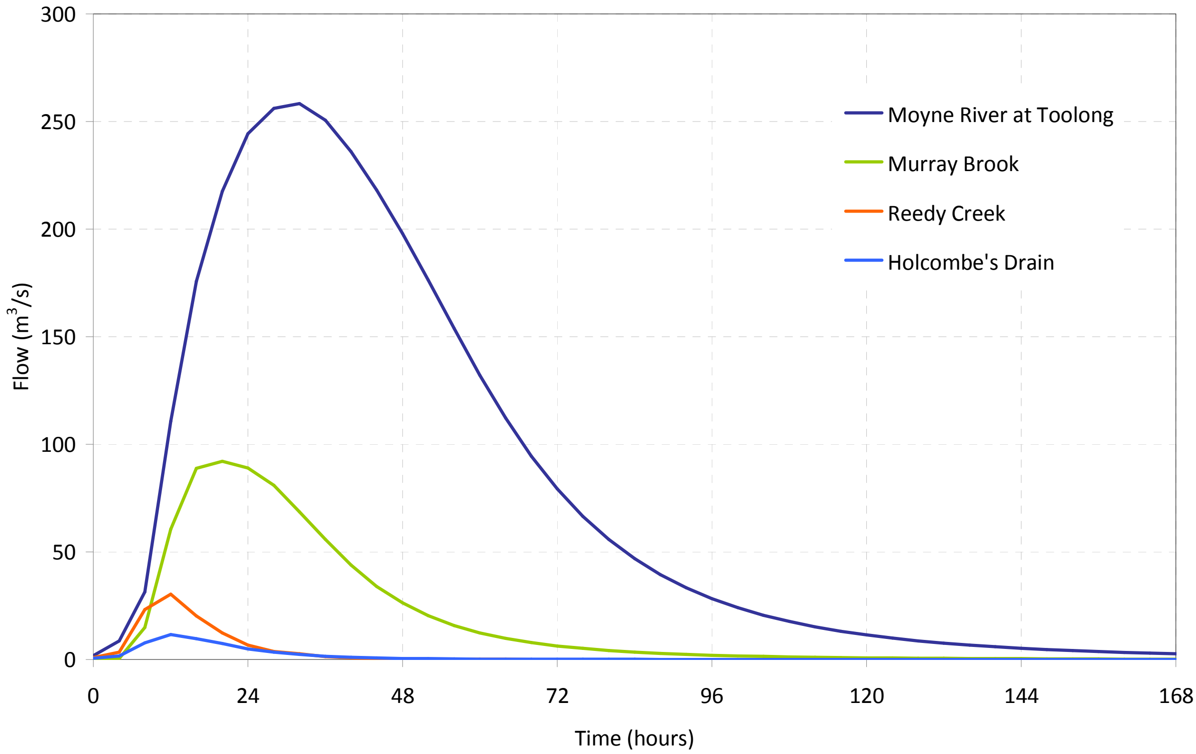

Figure 5-8 1% AEP Design Hydrographs (Scaled RORB) at Hydraulic Model Boundaries

5.5 Comparison with Regional Studies

In order to provide further comparison and verification of the estimated design events, the scaled RORB results were compared to design hydrology estimates from the neighbouring Merri River catchment, derived for the South Warrnambool Flood Study. This method predicted flow in the Moyne catchment based on the relative areas between the two catchments. This resulted in an estimated Moyne River 1% AEP design flow of 274 m^3/s at Toolong. This is within 5% of the adopted flow presented in Table 5-4 above and hence is considered consistent with the rest of the hydrologic analysis.

5.6 PMF Design Flood

The probable maximum flood (PMF) is the event caused by the greatest precipitation event that could be expected to occur in the specific catchment. Formal determination of the PMF involves the determination of the probable maximum precipitation (PMP) for the study catchment. Using standard procedures the PMP rainfall distribution was defined and run through the RORB model. The results are provided in Table 5-5 below. This highlights the extreme nature of the PMF with a peak estimated flow over 30 times the predicted 1% AEP flood.

Table 5-5 Moyne River Catchment - PMF Characteristics

Catchment Area (km^2)	Qp Peak Flow (m^3/s)	Event Volume (ML)	Tp Time to Peak (h)	Tr Recession Time (h)
Moyne River at Toolong – 572	7,500 *Approx*	7.44E+8 *Approx*	24	80

5.7 Review of 1946 Flood

The March 1946 event is the highest flood on record for the Moyne River. The weather system associated with this event (generally classified as an East Coast Low or Cut-off Low) caused widespread flooding in south-west Victoria with the highest rainfall totals (327 mm at Macarthur over 3 days) recorded in the area just to the west of the Moyne River catchment.

Due to the severity of this event and the significant impact it still has in the memory of Port Fairy residents it was required to be included in the hydraulic analysis. Hence the available data was used to perform a RORB model simulation of this event. Details of this analysis are provided in Volume 3. A range of parameters was used to test the sensitivity of estimated flows to assumptions. The resulting estimate of peak flow for the 1946 flood was 574 m^3/s. This is more than double the estimated 1% AEP flow and is consistent with other estimates of this event.

6. HYDRAULIC ANALYSIS

6.1 Overview

The hydraulic analysis determined historical and design flood levels, extents and velocities for the study area. These were determined for the 20, 10, 5, 2, 1 and 0.5% AEP floods and the probable maximum flood. The design flood levels and velocities were used to assist in determining the existing level of flood risk to Port Fairy.

A linked one and two-dimensional unsteady hydraulic model, MIKE FLOOD, was the principal tool for the hydraulic analysis. MIKE FLOOD is an advanced tool for floodplain modelling. The MIKE FLOOD model parameters were developed through calibration of modelled flood and hydrodynamic behaviour with observed flood and hydrodynamic behaviour in Port Fairy and the greater study area.

6.2 Model Development

The model consists of a two-dimensional grid describing the overall floodplain and one-dimensional elements that define localised flow through hydraulic structures. A plot of the model schematisation is provided in Figure 6-1.

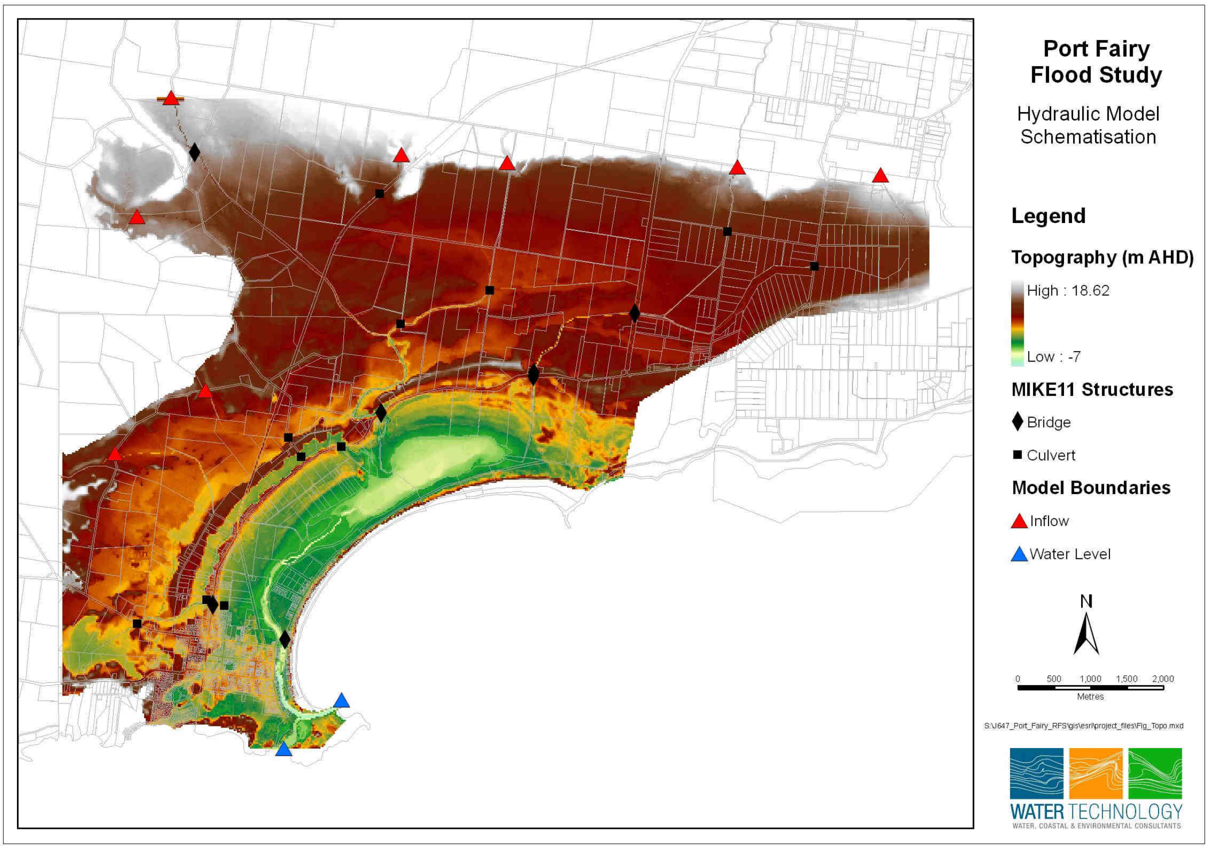

Figure 6-1 Hydraulic Model Schematisation

6.3 Calibration

The hydraulic model was calibrated in two ways as follows:

- Firstly, specific hydraulic characteristics of the model were tested. This included the ability to model estuary tidal flow, the ability of the two-dimensional model to represent in-bank flow in the Moyne River upstream of Rosebrook and the ability to model hydraulic losses through key bridge structures.
- Secondly the ability of the model to represent broad floodplain flow during historic flood events was tested.

The model was calibrated to the following three historic flood events:

- August 2001 – Peak Flow at Toolong (52 m^3/s), the most recent significant flow in the Moyne (largest gauged event since 1996 and second largest since 1984)
- August 1978 – Peak Flow at Toolong (119 m^3/s), equal highest gauged (instantaneous) flow at Toolong.
- March 1946 – Peak Flow at Toolong (est. ~ 550 m^3/s), largest flood in living memory and has best available flood information.

Apart from 1946, there was sparse detailed calibration data available, hence anecdotal evidence was used to verify model behaviour for the other two events. The model was found to perform satisfactorily over the range of calibration events. A typical calibration plot is provided in Figure 6-2 for the 1946 flood event.

In summary, the results of the hydraulic model calibration are considered to have demonstrated the following:

- Reasonably good agreement with the pattern and extent of historical inundation observed for floods ranging from approximately the 30% AEP up to approximately the 0.5% AEP flood.
- Satisfactory agreement with the small number of observed peak flood levels recorded from the 1946 flood.
- Good agreement with the location, relative magnitude and direction of flood flows observed throughout the study area.

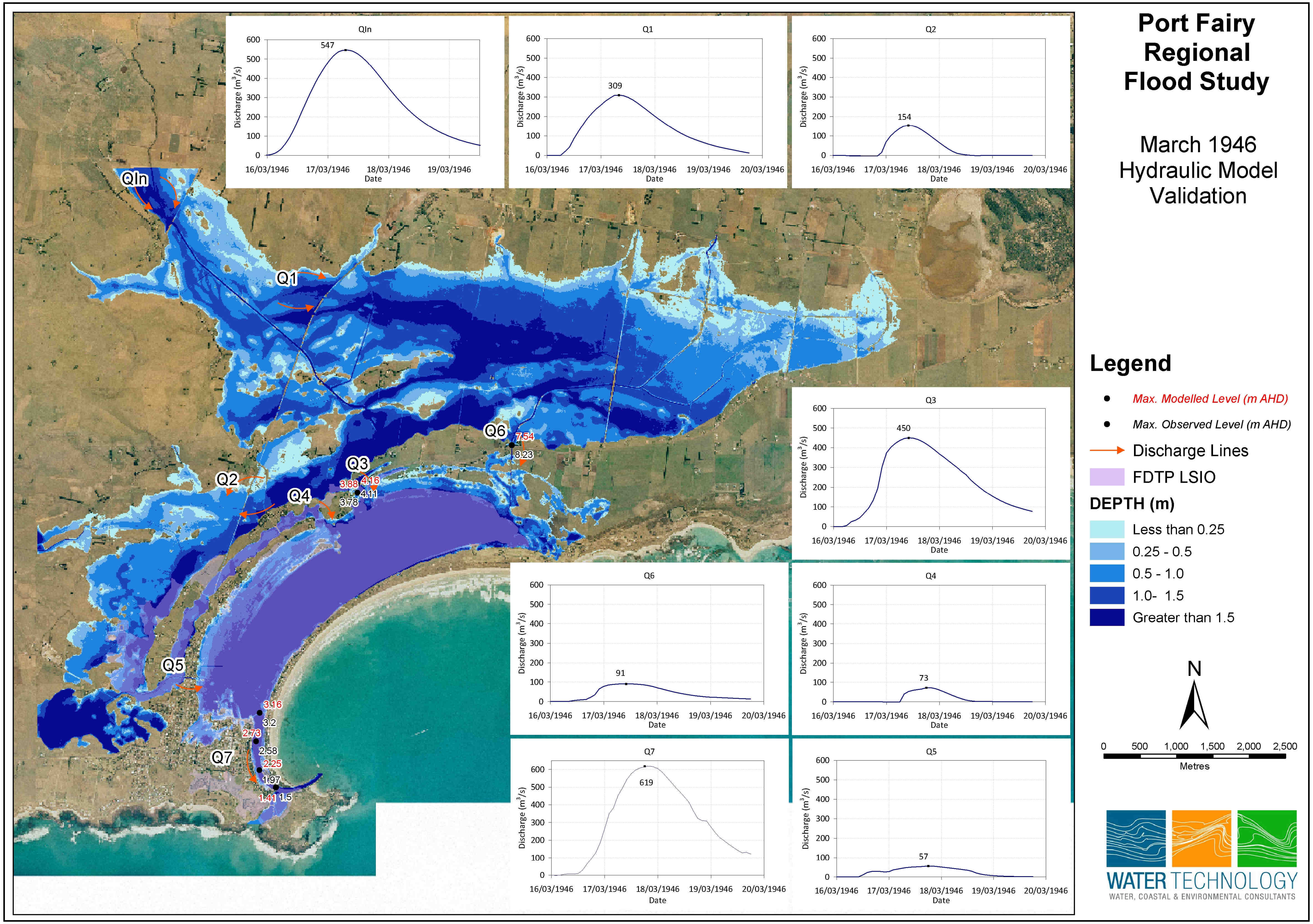

Figure 6-2 March 1946 Hydraulic Model Validation

6.4 Sensitivity Analysis

In the context of a risk-based flood study, the sensitivity of both hydrologic and hydraulic model results is critical to understanding the implications of the predicted or "best-estimate" flood results.

Based on previous hydraulic modelling experience, it was considered that for the present study the greatest sources of uncertainty likely to impact the determination of the existing flood risks to Port Fairy were the following:

- the uncertainty associated with the magnitude of the design flows (particularly the ungauged catchments)
- the adoption of an assumed ocean water level to undertake the design flood simulations.

For these reasons, the sensitivity of the modelled flood levels and extents for the 1% AEP design flood was tested in the hydraulic model with the following sensitivity scenarios:

Scenario 1

1% AEP design flows for the Moyne River and all sub-catchments scaled up by 20% (Peak flow and volume). This is considered to provide a conservative estimate of the magnitude of the overall uncertainty associated with the outputs of the hydrologic analysis.

Scenario 2

Ocean boundary water level condition increased to the 1% AEP storm surge level (tide + surge) of 1.1 m AHD. This is considered to provide an estimate of the relative impact of the adopted ocean water level conditions on modelled flood levels and extents given the uncertainties demonstrated in determining the joint probability of different flood flow magnitudes and storm surge levels.

The results of this analysis showed that the model results over most of the study area were not significantly sensitive to changes in water level boundary assumption (for existing conditions). The model results are more sensitive to changes in inflows, however given the significant increase in flows (+20%) the levels through most of the study area increased by around 300 to 400 mm. This range of increase is likely to be within allowable freeboard limits and hence provides a level of comfort with respect to the potential spread of flood risk based on the 1% AEP flood standard. A plot showing the results of the Scenario 1 case are shown in Figure 6-3

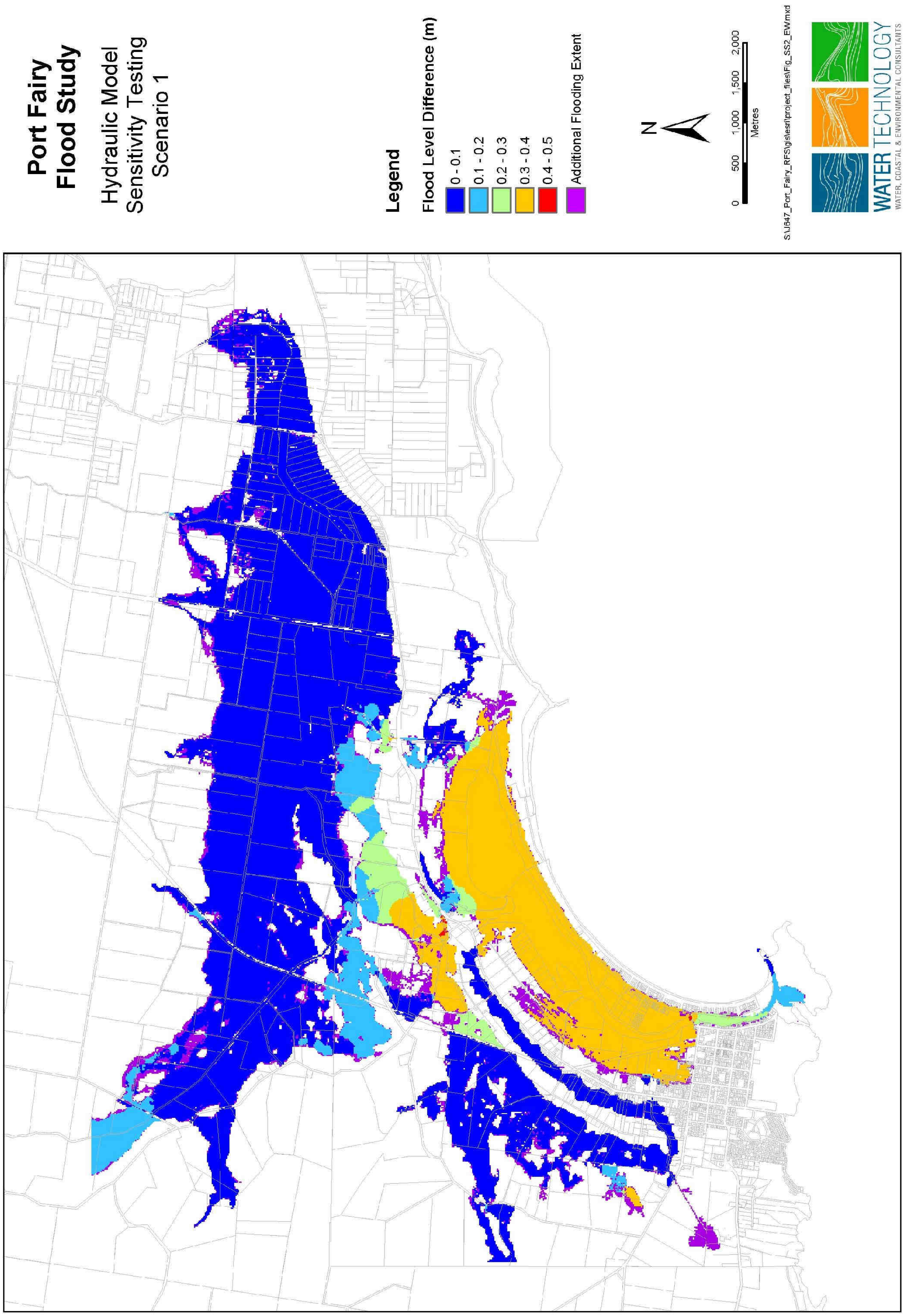

Figure 6-3 Impact of Sensitivity Scenario 1 on Predicted 1% AEP Flood Levels and Extents

6.5 Design Flood Modelling

The results of the hydrologic analysis were used to develop design boundary conditions for the calibrated hydraulic model to define flood impacts in Port Fairy. Model simulations were then undertaken for the range of design floods. Maximum design flood extent results from all the design simulations are presented in Figure 6-4. Figure 6-5 displays the predicted maximum extent and depth of inundation and peak velocity and direction for the 1% AEP design flood.

These results show that flooding around the township area is relatively well confined up to the 5% AEP. For floods greater than this there is some increase in flood extent to the north of the township around the Model Lane area.

The results show that for the wider study area, significant floodplain inundation is experienced for the 20% AEP (5 year ARI) and greater floods. This is due to the topography and waterway system north of the Princes Highway. As discussed in Volume 4 (Hydraulics Report) the Moyne River channel immediately downstream of Toolong has limited capacity and overbank flow occurs at a relatively low flow threshold. The historic path of the Moyne River passed to the east into the Korongah Flats area. Under low-flow conditions the Moyne River is contained within the artificial channel that flows south-east from Toolong. Once the channel capacity of the river is exceeded, overland flow passes east towards Korongah Flats, travelling in a wide arc and eventually returning to the Moyne upstream of Rosebrook. This area forms a large pool of floodwater that is approximately 1000 Ha in area and has a maximum storage volume of around 8,000 ML in a 1% AEP event. The average depth over the Korongah Flats is approximately 0.8 m in the 1% AEP event with maximum depths up to around 2 m in places on the floodplain.

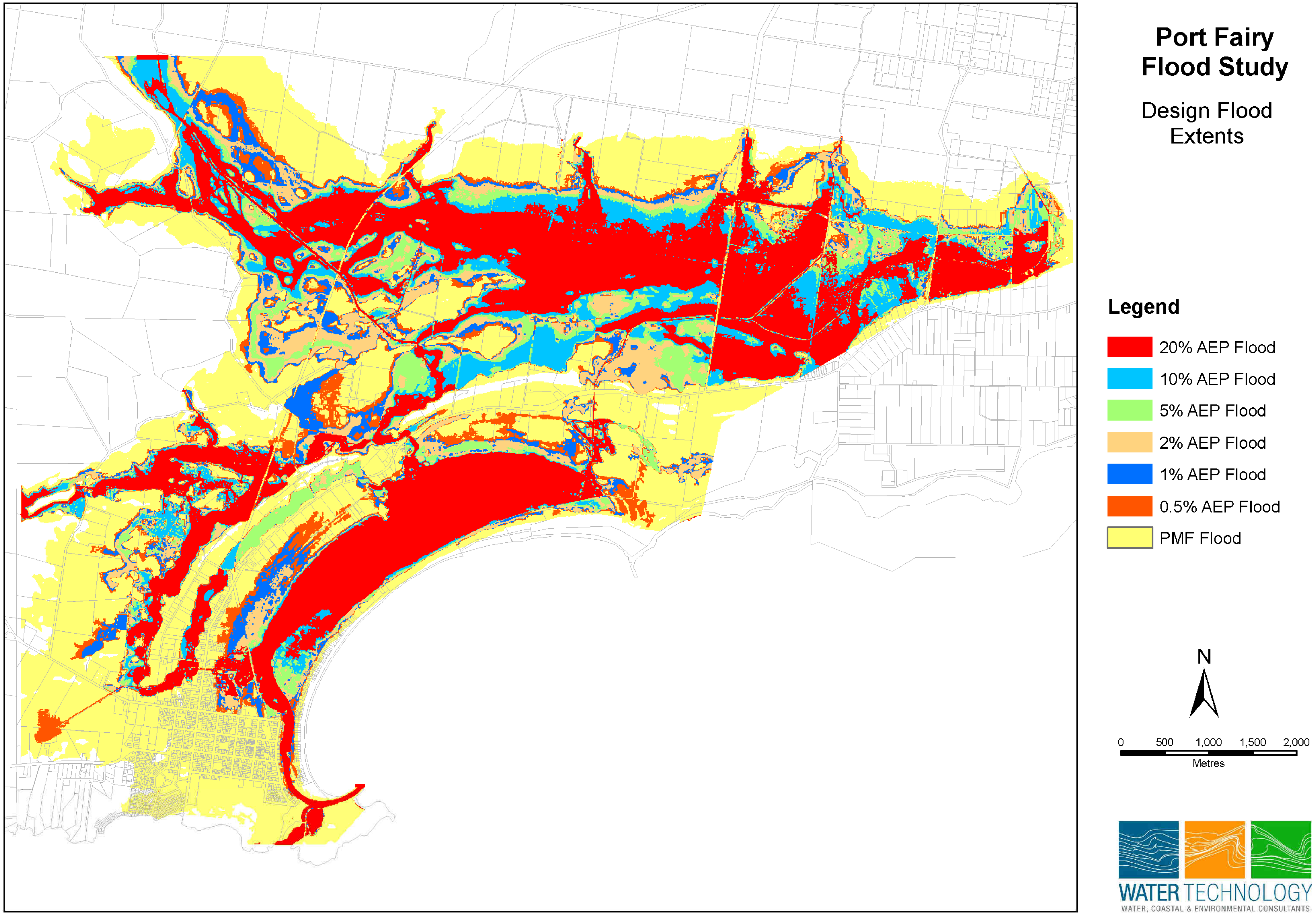

Figure 6-4 Maximum Design Flood Extents

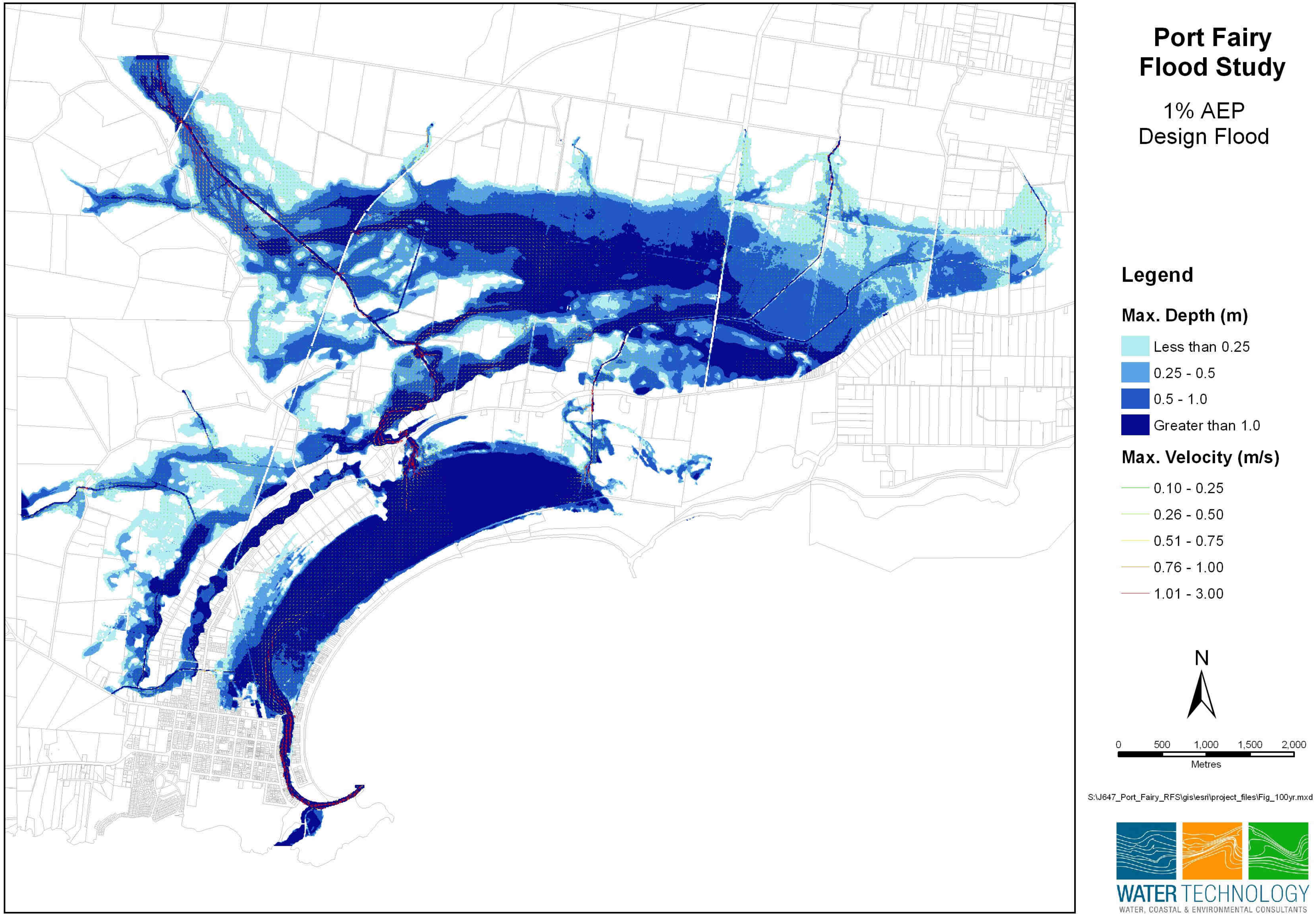

Figure 6-5 1% AEP Maximum Flood Depths & Velocities

7. RISK ASSESSMENT AND REDUCTION MEASURES

The risk assessment and mitigation measures assessment undertaken as part of the Port Fairy Regional Flood Study included the following components:

- Flood Damage Assessment – this quantifies the existing flood damage risks at Port Fairy.
- Flood Risk Mitigation Assessment – details the preliminary hydraulic analysis of potential flood mitigation measures for Port Fairy.
- Flood Warning and Response – reviews the feasibility for developing a formal flood warning system for the Port Fairy Township.
- Climate Change Risk Assessment – details the analysis of the sensitivity of the existing flood risks to various climate change and sea level rise predictions and assesses potential mitigation options.

7.1 Flood Damage Assessment

A flood damages assessment was undertaken for the study area under existing conditions. The flood assessment determined the monetary flood damages for design flood hydrographs as determined by the hydrologic and hydraulic analysis. The average annual damage (AAD) was also determined as part of the flood damage assessment. The damage analysis was undertaken using an ANUFLOOD type approach for property damage and elements of the RAM for assessment of other damages such as infrastructure.

Damages were calculated over a range of flood magnitudes from 10% to 0.5% AEP. A combination of existing and newly collected floor level survey was used in the property damage assessment. A summary of the resulting flood damage calculations is provided in Table 7-1 below. The 1% AEP or 1% AEP flood damage was calculated to be around $1.7 million and the AAD was calculated to be approximately $219,194 per year.

These are considered to be relatively modest damage totals and reflect that few properties and little infrastructure are threatened by flooding below a 5% AEP event under existing conditions.

ARI (years) / AEP	200yr 0.005	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1
Properties Flooded Above Floor	88	50	29	14	4
Properties Flooded Below Floor	135	141	121	100	39
Total Properties Flooded	**223**	**191**	**150**	**114**	**43**
Direct Potential External Damage Cost	$823,925	$225,705	$125,177	$53,782	$19,268
Direct Potential Residential Damage Cost	$2,142,761	$1,116,354	$578,850	$190,491	$67,046
Direct Potential Commercial Damage Cost	$179,544	$256,910	$138,044	$12,673	$0
Total Direct Potential Damage Cost	**$3,146,230**	**$1,598,969**	**$842,071**	**$256,946**	**$86,314**
Total Actual Damage Cost *(0.8*Potential)*	**$2,516,984**	**$1,279,175**	**$673,657**	**$205,557**	**$69,051**
Infrastructure Damage Cost	**$249,954**	**$191,838**	**$116,938**	**$29,635**	**$13,010**
Indirect Clean Up Cost	$430,712	$266,125	$174,506	$94,736	$41,085
Indirect Residential Relocation Cost	$53,260	$29,743	$17,292	$8,992	$2,767
Indirect Emergency Response Cost	$12,402	$8,268	$4,961	$3,307	$2,067
Total Indirect Cost	**$496,375**	**$304,135**	**$196,759**	**$107,035**	**$45,919**
Total Cost	**$3,263,312**	**$1,775,149**	**$987,353**	**$342,226**	**$127,980**

Table 7-1 Flood Damage Assessment Costs for Existing Conditions

7.2 Flood Risk Mitigation Assessment

Through consultation with the TSC, a list of 10 potential structural mitigation measures was initially reviewed and qualitatively assessed. From these, the three options considered most feasible were chosen for further hydraulic analysis. These were:

- Gipps Street Bridge – Augmentation of waterway capacity
- Whalers Drive Levee
- Osmonds Lane - Reedy Creek Culvert Removal

The results of this analysis are presented in detail in Volume 5. The major outcome of the analysis was that the Gipps Street Bridge augmentation provided minimal benefit whilst the other two options provided moderate localised benefits in terms of reduced flood impact and damages in the specific areas they sought to protect. The results for the Whalers Drive Levee, which had the most significant benefits, are shown in Table 7-2.

Table 7-2 Comparison of Properties Subject to Inundation Statistics for Whalers Drive Mitigation Option

Item	1% AEP Mitigation	1% AEP Existing
Flooded Above Floor	44	50
Property Inundated	98	141
Total Properties Subject to Inundation	142	191

7.3 Flood Warning and Response

Flood warning and associated response activities aim to reduce the growth in future flood damages by improving community awareness of flooding and emergency response in the event of a flood. The Bureau of Meteorology does not currently provide a flood warning service for Port Fairy or the Moyne River at Toolong.

A review of the hydrologic and hydraulic model results was undertaken in order to assess the potential flood warning time available at Port Fairy. This analysis determined that it may be reasonable to expect around 24 hours lead time between heavy rainfall in the Moyne catchment and a flood peak at Port Fairy.

The study team recommends that the GHCMA and council discuss with the BoM the possibility of and scope for developing a formal flood warning system for Port Fairy. This could, as a minimum, be based on the present gauge information at Toolong or through deployment of telemetered pluvio stations within the Moyne River catchment.

7.4 Climate Change Risk Assessment

As a low-lying coastal town, flanked by a significant river catchment, Port Fairy is susceptible to the future impacts of possible sea level rise and increased rainfall intensity as part of climate change. In order to assess the likely change in flood risk profile to the township and surrounds over the coming decades, a sensitivity analysis around the existing 1% AEP flood was undertaken.

A general background and discussion of possible climate change impacts is discussed in Volume 5.

Three scenarios that included a combination of sea level rise and increased rainfall intensity were simulated. The climate change scenarios have been assessed considering a 2100 planning horizon. These scenarios are outlined below:

1. Moderate Climate Change Impact Scenario

- 0.4 m mean sea level rise
- Additional 0.03 m storm surge
- Rainfall intensity increase of 30% in the 1% AEP flood hydrographs

2. Intermediate Climate Change Impact Scenario

- 0.8 m mean sea level rise
- Additional 0.07 m storm surge
- Rainfall intensity increase of 50% in the 1% AEP flood hydrographs

3. High Climate Change Impact Scenario

- 1.2 m mean sea level rise
- Additional 0.1 m storm surge
- Adopt estimated 1946 flood hydrographs

To give an impression of the rainfall based scenario inputs a plot of the applied hydrographs is shown in Figure 7-1. This shows that peak flood inflow for the Moyne River more than doubles for the intermediate climate change case.

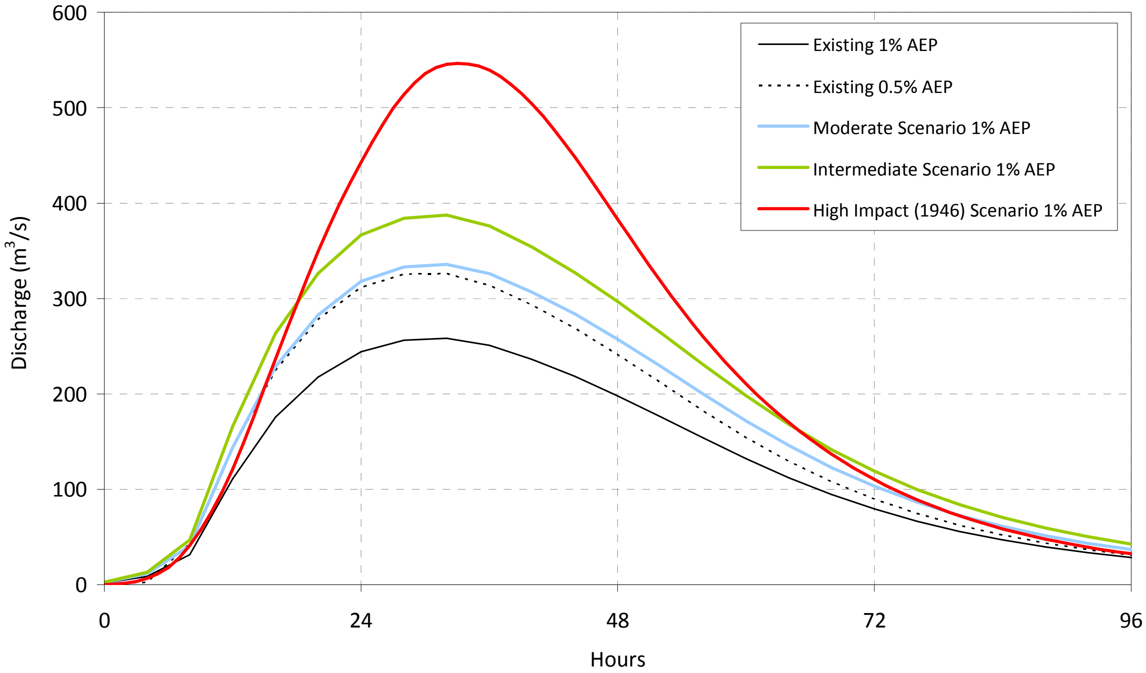

Figure 7-1 Comparison of Moyne River at Toolong Inflow Hydrographs under Existing Conditions and Climate Change Scenarios

The results of the climate change scenarios in terms of approximate impacts on flood damage are summarised in Table 7-3. This shows there is a significant increase in the number of properties that are predicted to be flood affected in each of the scenarios compared to existing conditions. Plots showing the impact of the scenarios are shown in Figure 7-2. Figure 7-3 shows the impact of sea level rise alone, without flooding or storm surge.

Table 7-3 Comparison of Properties Subject to Inundation Statistics for the Climate Change Impact Scenarios

Item	Moderate Impact Scenario	Intermediate Impact Scenario	High Impact Scenario	1% AEP Existing
Flooded Above Floor	114	143	211	50
Properties Inundated	110	86	20	141
Additional Dwellings at Risk of Inundation	50	74	286	-
Total Properties Subject to Inundation	274	303	517	191

* Note that floor level survey is not available for properties outside the existing flood extent, hence the climate change numbers above are likely to be underestimated.

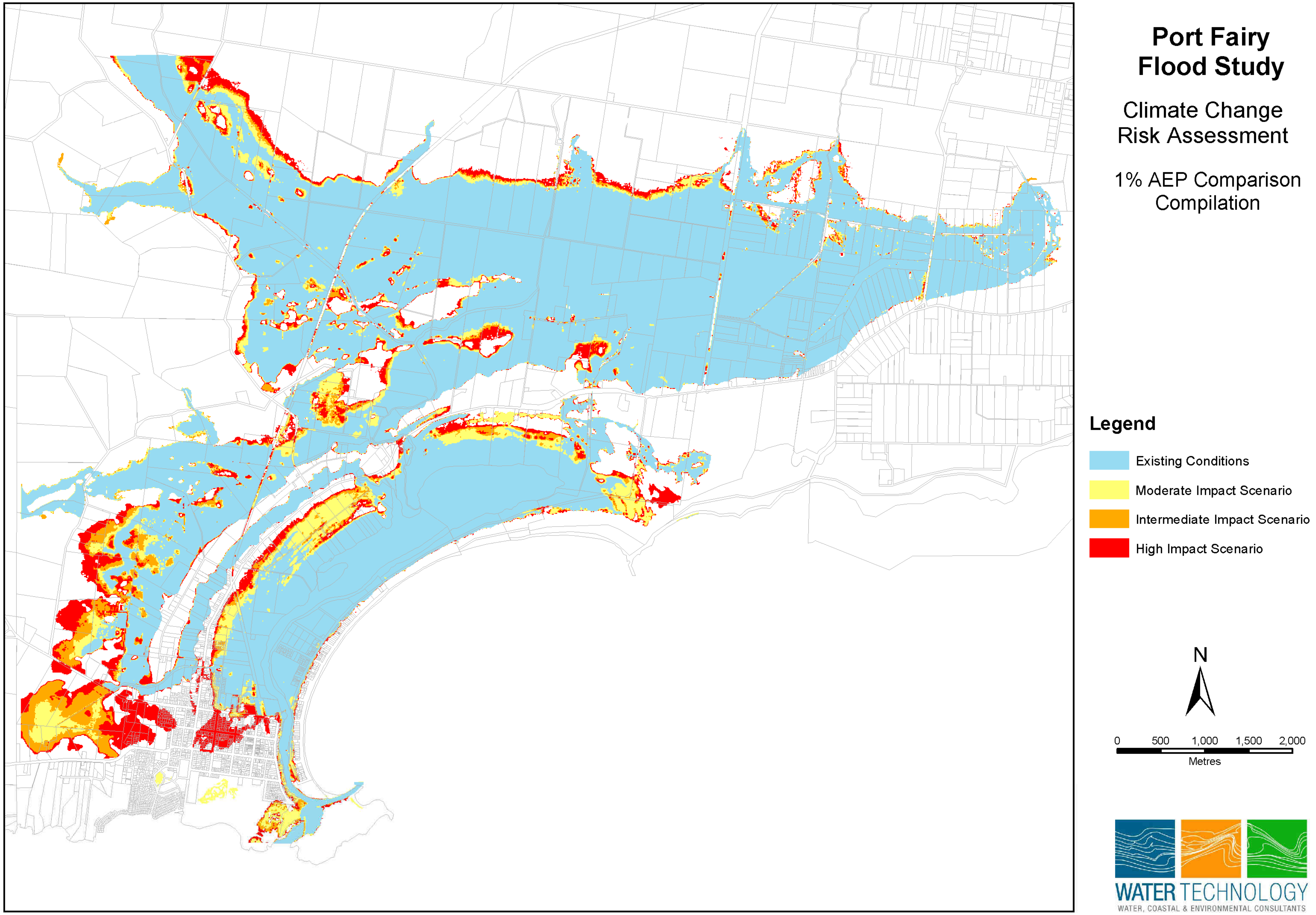

Figure 7-2 Comparison of Moderate, Intermediate and High Impact Climate Change Scenarios

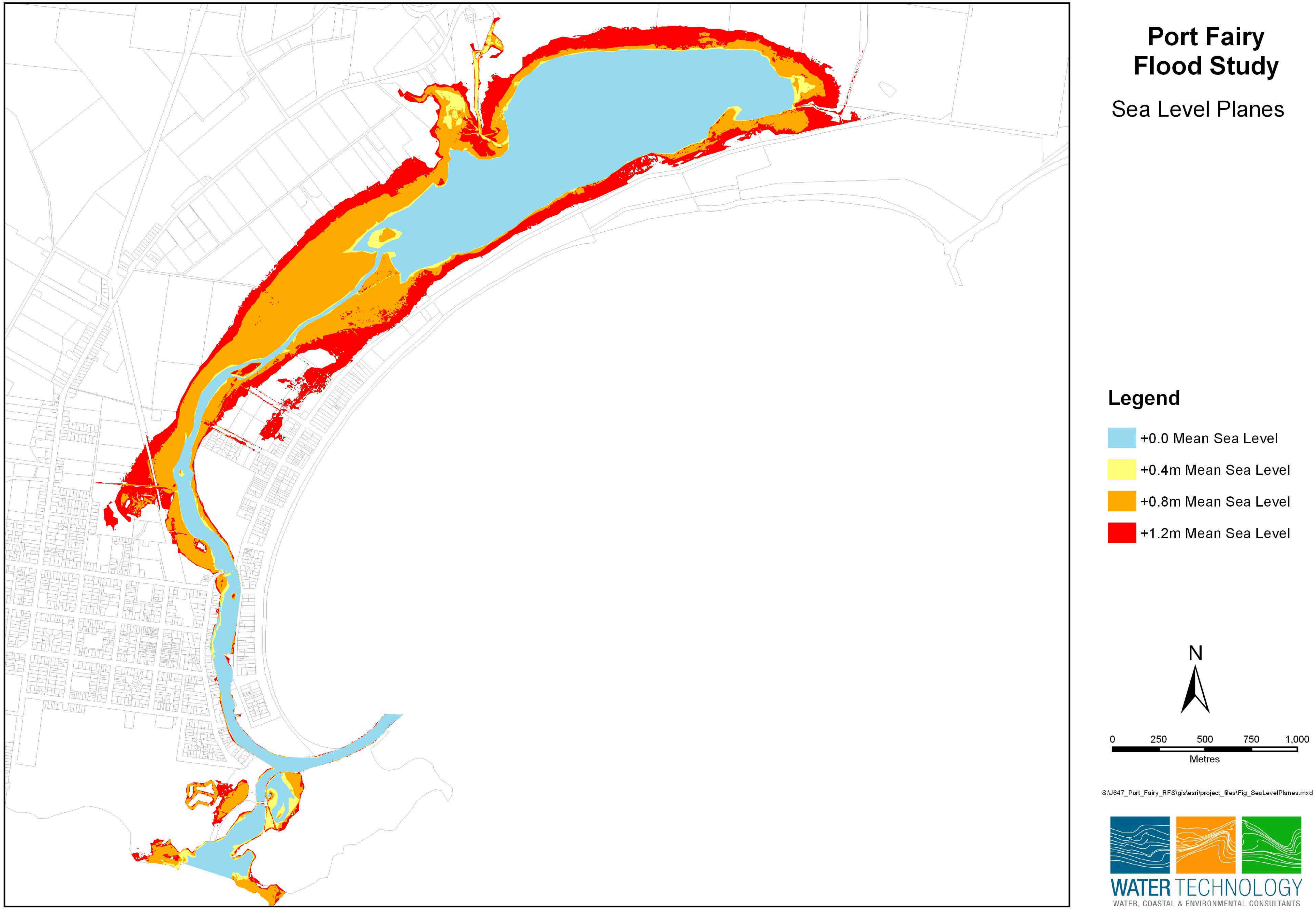

Figure 7-3 Sea Level Rise Plane Extents

7.5 Climate Change Flood Risk Mitigation Assessment

The feasibility of mitigation options to reduce flood risk and consequences at Port Fairy that result from predicted increases in flood risk associated with potential climate change scenarios was investigated.

Preliminary hydraulic analysis of structural mitigation options was undertaken for two potential climate change mitigation options as follows:

- Port Fairy Township Levee
- Murray Brook and Reedy Creek Flood Attenuation

The results of this analysis are provided in Volume 5 of the report. In summary it was found that the use of strategic levees has the potential to provide significant levels of protection to existing infrastructure under the modelled climate change scenarios. Levee works can be obtrusive within a local landscape and pose other logistical challenges depending on available space, etc. However a significant advantage of levees is that they can provide protection in both catchment and sea level flooding events.

The results of the mitigation simulations show that the construction of levees would not be expected to cause significant increases in flood levels for surrounding areas.

The flood attenuation option was found to be of significantly less benefit due to the size of the design hydrographs being considered. It is considered that more feasible options may be identified by looking further upstream into the catchment to identify areas where flood mitigation storages could be located. It is useful to note that storage higher in a catchment is generally more efficient at reducing flood peaks than near the catchment outlet.

8. DATASETS AND MAPPING

The flood mapping and datasets developed as part of the Port Fairy Regional Flood Study are described in Volume 6 of the report. This details the input data, methodology and outputs for the flood emergency response inundation and land use planning mapping including:

- Flood emergency response map formats
- Incremental flood inundation mapping
- Flood velocity mapping

8.1 Flood Emergency Response Maps

For each design flood, the peak flood elevation at the Toolong gauge was determined from the maximum modelled flood level at the location of the gauge. Table 8-1 displays the gauge heights at the Toolong gauge for which flood emergency response maps have been prepared.

Table 8-1 Flood Emergency Response Maps: Toolong Gauge Heights for Design Flood Events and Key Historical Events

Toolong Gauge Height[1]	Flood level at Toolong gauge (m AHD)	Design flood event AEP (%)	Design flood event ARI (years)
4.1	11.89	20%	5
4.4	12.18	10%	10
4.6	12.36	5%	20
4.9	12.62	2%	50
5.1	12.82	1%	100
5.2	13.00	0.5%	200
5.7	13.45	1946	Approx. 1000
4.5	12.29	1978	Approx. 15
3.7	11.51	2001	Approx. 3

1. Toolong gauge height determined by subtracting the gauge zero elevation in m AHD (7.77 m AHD) from the modelled flood level elevation in m AHD.

The flood emergency response maps have been produced on three A1 sheets, for each flood event, at 1:5,000. The map base is the cadastre as supplied in 2007 and is subject to change.

The following maps components were generated:

- Flood Extent and Flood Depth Zones
- Storm Tide Inundation Extent
- Flood Elevation Contours
- Flood Affected Properties
- Emergency Service Locations

8.2 Incremental Flood Inundation Maps

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

8.3 Flood Velocity Map

The hydraulic analysis provides a grid of flow speed and direction (velocity). For the 1% AEP design event, flow speeds were mapped using standard categories. The flow vectors were displayed on the map as arrows with the length of the arrow representing the flow speed.

8.4 Flood Mapping for Land Use Planning

For the purposes of future land use planning draft planning maps have been produced. At this stage these can be used as a guide, however they would be subject to change pending the outcomes of a full floodplain management plan and subsequent incorporation into the Moyne Shire Planning Scheme.

This mapping consists of:

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

The LSIO is generally adopted as the existing conditions 1% AEP flood extent. The Floodway area was defined in consultation with GHCMA and is guided by DSE guidelines for the delineation of floodways. A draft plan of proposed flood overlays is provided in Figure 8-1.

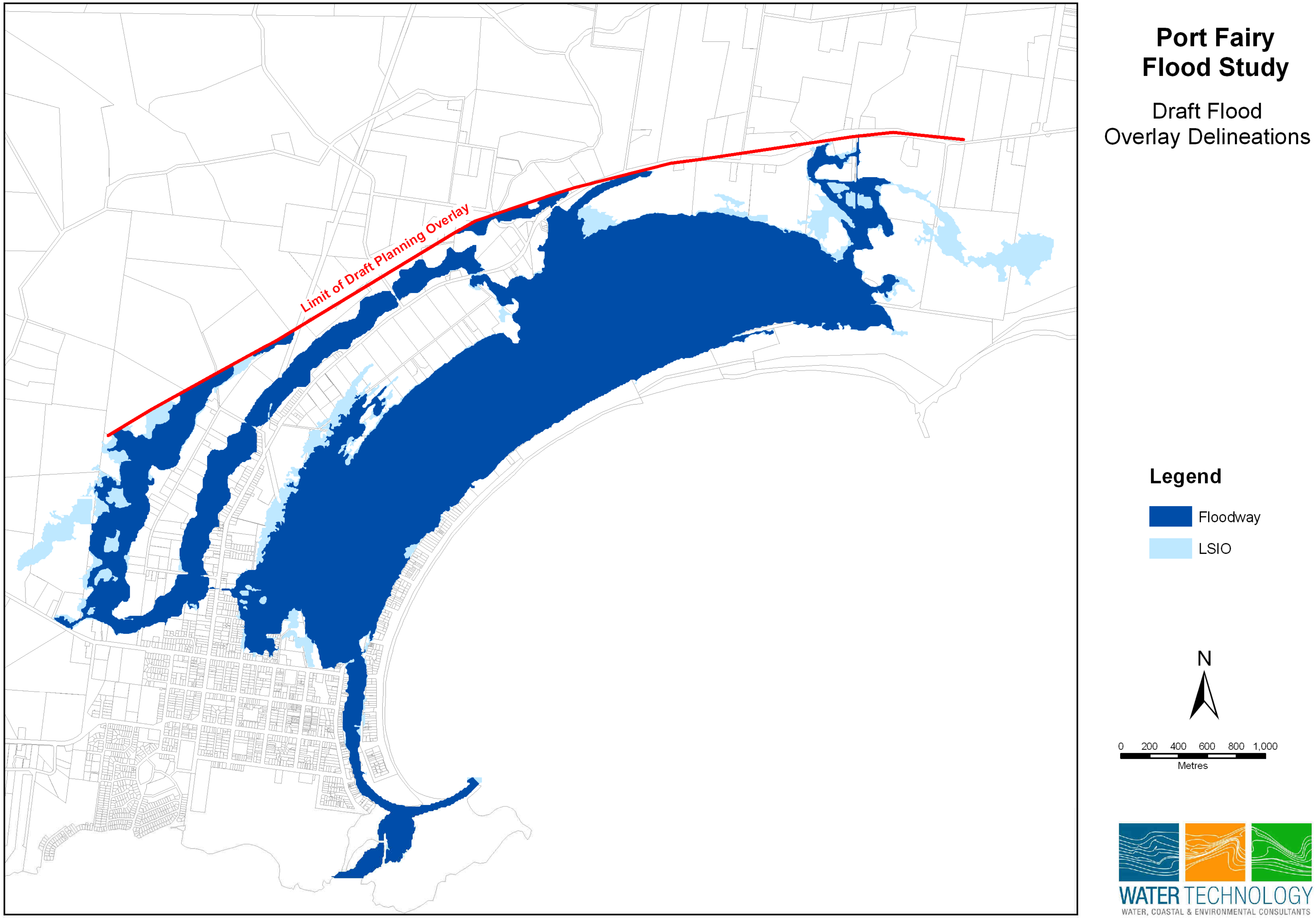

Figure 8-1 **Preliminary Planning Scheme Flood Overlay Delineations**

9. STUDY DELIVERABLES

The study deliverables provide a comprehensive set of data that support the study outcomes. The deliverables are supplied on a study DVD and consist of background data and outputs as listed below:

- Digital copies of study reports in MS Word and PDF formats.
- Study survey data (LIDAR, structures, cross-sections and floor levels)
- Other input data including rainfall and flow data
- A property database including flood information
- Digital copies of the maps (jpg and PDF format)
- GIS datasets for the model results (Mapinfo and ArcGIS format)
- The hydrologic and hydraulic model input files

There is a readme.txt file on the disk that describes the directory structure of the data contained on the disk.

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 Overview

The Port Fairy Regional Flood Study provides a comprehensive analysis and review of existing and future potential flood risk in the township and surrounding area. The study has involved:

- Collection and review of a range of data relevant to the investigation of flooding within the study area.
- A survey analysis to develop a detailed description of the study area topography as a basis for hydrologic/hydraulic analysis and mapping.
- A rigorous hydrologic analysis to develop robust design flood estimates for the study area.
- Development of a detailed hydraulic model that is capable of predicting flood impacts at Port Fairy under a range of conditions.
- Quantification of flood risk in terms of flood damages.
- Thorough sensitivity testing of the hydraulic results under both existing conditions and for a range of potential climate change scenarios.
- A preliminary examination of potential flood mitigation options for the township.

10.2 Key Outcomes

In undertaking this study a number of important aspects of flood risk relevant to Port Fairy have become apparent. These are summarised as follows.

Moyne River Catchment Hydrology – The hydrology of the Moyne River catchment is significantly influenced by the complex nature of its topography and geology. The catchment geology consists of areas of volcanic plains in the west and north and calcareous prior sea-bed forms in the south and east. Prior to land clearing and agricultural development these landforms contained numerous swamps and wetlands. It is believed that these areas would have provided significant storage and attenuation of flood peaks and that this effect has been reduced due to significant drainage works throughout the catchment over time. It is considered that uncertainties in catchment hydrology could be significantly reduced through:

- Collection of pluvio rainfall data through the catchment
- Gauging of main tributary inflows such as Murray Brook and Back Creek
- Collection of more detailed topographic data (such as LIDAR) for the catchment to define storage

Hydraulic Characteristics of the Moyne River at Port Fairy – The Moyne River at Port Fairy has a relatively confined outlet through the harbour area adjacent to the town. Upstream of this (north of the Gipps Street bridge) the floodplain opens out into a wide area that has a fairly flat water surface gradient. Due to the significant flow capacity of the outlet channel, flood impacts are relatively minor for floods up to the 5% AEP event. However, above this threshold (based on existing conditions) there is a significant increase in impacts (consequences) of flooding and hence risk. This is due to the relatively flat nature of the topography of the town and surrounding areas.

Climate Change Risk Profile - The implication of the above conclusion that flood impacts increase significantly beyond the 5% AEP is that Port Fairy is particularly susceptible to future changes in flooding due to climate change. This is because of the non-linear increase in flood damage with increased levels (as demonstrated in the flood damages section of the Volume 5 report) beyond the existing 5% AEP. A change in rainfall intensity alone has the potential to cause a significant shift in flood frequency. For the example of a 30% increase in rainfall intensity, a current 2% AEP event could translate to a 10% AEP flood which (based on existing flood damage calculations) would increase flood damages by a factor of 6.

Future Land Use Implications – Port Fairy is surrounded by relatively flat areas with restricted catchment outlets. Basalt and limestone ridges form barriers across the Moyne River, Murray Brook, Reedy Creek and Holcombe’s Drain catchments. Whilst inundation areas are significant under existing 1% AEP conditions, if more severe cases are considered such as a 1946 type event or various potential climate change scenarios these extents increase dramatically. Under NSW guidelines, the floodplain is defined as the extent of the PMF flood, which in the case of the Port Fairy region would inundate virtually the whole coastal plain. The implications of flood risk based on both present and future conditions will need to be carefully considered by council with respect of future development and expansion of Port fairy.

10.3 Recommendations

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 Moyne Shire and GHCMA continue to engage the community in the treatment of flood risks through the development of a full Floodplain Management Plan for Port Fairy that involves broad community involvement and consultation with stakeholders.
- The Moyne 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 Moyne Shire and GHCMA explore options for the development of a flood warning system for Port Fairy in conjunction with the BoM and SES.
- The Moyne Shire and GHCMA continue to monitor developments in the knowledge base for climate change impacts and adapt their response accordingly. This could involve a regular review of flood-related impacts based on revised inputs.

11. REFERENCES

Schiller, P., Forbes I.G.(1946), Report on the Western District Floods of March 1946, SR&WSC