Summary Report

Fitzroy River, Darlot Creek and Heywood Regional Floodplain Mapping Study

Department of Environment, Land, Water and Planning

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EXECUTIVE SUMMARY

This report details the input data, approach and outcomes for the Fitzroy River, Darlot Creek and Heywood Regional Flood Mapping study.

The study has been initiated by the Department of Environment Land Water and Planning (DELWP) in order to define the extent and characteristics of flooding in the Fitzroy River and Darlot Creek catchment so that future planning decisions may be soundly based and measures may be put in place to minimise risk to the community.

The study provides information on flood behaviour and flood intelligence across the Fitzroy River and Darlot Creek catchment. The study involved a rigorous technical analysis of the drivers for flooding, which provided confidence in the use of this information to guide emergency management and future floodplain management in the catchment.

Community consultation was undertaken at various stages of the study, primarily in order to gather data and accounts of flooding and to benchmark the outputs of the calibration and preliminary design event mapping. The flood information provided by residents was invaluable in the development of the study outcomes.

A hydrologic analysis of the Fitzroy River, Darlot Creek and their tributaries was undertaken to determine design flood hydrographs for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% annual exceedance probability (AEP) flood events in the Fitzroy River and Darlot Creek catchment as well as the probable maximum flood (PMF). A rigorous approach has been applied to test and validate the design flows by utilising a number of hydrologic approaches including Flood Frequency Analysis, the development of a detailed hydrologic (RORB) model, and iterative hydrologic-hydraulic analysis. The adopted design flood inflows for the study are listed in Table 1.

Table 1 Design peak flows at major waterways

AEP	Fitzroy River at US Extent		Darlot Creek at US Extent		Darlot Creek at DS of Lake Condah		Durations modelled
	Design Flow (m^3/s)	Critical Duration	Design Flow (m^3/s)	Critical Duration	Design Flow (m^3/s)	Critical Duration	
20%	7	72h	16	72h	8	72h	72h
10%	12	72h	34	72h	14	72h	72h
5%	20	72h	63	72h	22	72h	72h
2%	30	72h	110	72h	33	48h	72h, 48h
1%	37	72h	143	72h	44	48h	72h, 48h
0.5%	45	72h	180	72h	56	72h	72h
0.2%	59	72h	241	72h	79	72h	72h

To place the design peak flows in a historical context, the approximate AEP (and Average Recurrence Interval, ARI) of significant historical flood events are provided in Table 2. The March 1946 event is thought to be the largest event in living memory, but no gauge data was available at the time. The other calibration events in 2007, 2010 and 2013 were recorded as similar in scale to the final modelled 5% - 10% AEP events at the Heywood gauge.

4145_R04V02

Table 2 Fitzroy River, Approximate AEPs for significant historical flood events observed flood information

Event	Peak flow (m^3/s) and approximate AEP at Heywood		Available flood information	Use
	Peak Flow (m^3/s)	Approximate AEP in Final Hydraulics (%)		
November 2007	30 (57)*	>5%	Observed flood marks: **21** Gauged flows and levels	Calibration
October 2013	24 (38)*	5%	Gauged flows and levels	Calibration
September 2010	18 (31)*	10%	Gauged flows and levels	Calibration
March 1946	- (103)*	0.5%	Observed flood levels: 2	Validation

** Bracketed number represents final calibrated/validated peak flow in hydraulics, which differs from measured flow due to flow breakout around the gauge site discussed in Section 5.2.1.*

A digital elevation model (DEM) was developed from LiDAR survey. Using the DEM, a hydraulic model was established to simulate flood behaviour within the study area. Flood behaviour was assessed for flooding originating from tributaries as well as local catchment runoff within the floodplain. The hydraulic model was calibrated to three historic flood events (November 2007, October 2013 and September 2010) while the March 1946 event was used to further validate flood depths and extents across the floodplain. There was a significant amount of historic data available for the calibration events. This enabled a high level of model calibration to be achieved, lending confidence to the model performance.

A range of output data for all events have been produced. The model resolution of this study is suitable to inform land use planning and flood insurance pricing at a property scale. The timing of the flood peak and associated data is suitable to inform emergency response services. Key information on flooding throughout the catchment for each level of design event is presented in Table 4-3.

Sensitivity testing within Heywood, the major township which undergoes flooding in the catchment, suggests the railway bridge structure and embankments in Heywood present a major flow constriction. The capacity of the railway bridge opening will therefore impact the flood extents and depths through the town.

ACKNOWLEDGEMENTS

Numerous organisations and individuals have contributed both time and valuable information to the Fitzroy River, Darlot Creek and Heywood Regional Floodplain Mapping study. The study team acknowledges the contributions made by these groups and individuals, in particular:

- Rebecca Lett (Department of Environment Land Water and Planning & Project Manager)
- Graeme Jeffery and Ben Gaylard (Glenelg Hopkins CMA)
- Matt Berry and Billy Greenham (Glenelg Shire Council)
- Denis Rose (Gunditjmirring Traditional Owners Aboriginal Corporation)
- Ken Smith (VicSES)

The study team also wishes to thank all those stakeholders and members of the public who participated in the steering group and community information sessions and provided valuable records (including historic photos) and discussed their experiences and views on flooding in the Fitzroy River and Darlot Creek catchments.

GLOSSARY OF TERMS

Term	Definition
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 of extreme magnitude.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. A 10 year ARI flood is expected to be exceeded on average once every 10 years. A 100 year ARI flood is expected to be exceeded on average once every 100 years. The AEP is the ARI expressed as a percentage.
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 design flood is a probabilistic or statistical estimate, being generally based on some form of probability analysis of flood or rainfall data. An average recurrence interval or exceedance probability is attributed to the estimate.
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 elevated sea levels and/or waves overtopping coastline defences.
Flood frequency analysis	A statistical analysis of observed flood magnitudes to determine the probability of a given flood magnitude.
Flood hazard	Potential risk to life and limb caused by flooding. Flood hazard combines the flood depth and velocity.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Flood storages	Those parts of the floodplain that are important for the temporary storage, of floodwaters during the passage of a flood.
Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.

4145_R04V02

Term	Definition
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.
Intensity frequency duration (IFD) analysis	Statistical analysis of rainfall, describing the rainfall intensity (mm/hr), frequency (probability measured by the AEP), duration (hrs). This analysis is used to generate design rainfall estimates.
LiDAR	Spot land surface heights collected via aerial light detection and ranging (LiDAR) survey. The spot heights are converted to a gridded digital elevation model dataset for use in modelling and mapping.
MIKE FLOOD	A hydraulic modelling tool used in this study to simulate the flow of flood water through the floodplain. The model uses numerical equations to describe the water movement.
Peak flow	The maximum discharge occurring during a flood event.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Average Recurrence Interval.
Probable Maximum Flood	The flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area.
RORB	A hydrological modelling tool used in this study to calculate the runoff generated from historic and design rainfall events.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Topography	A surface which defines the ground level of a chosen area.

CONTENTS

4145_R04V02

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Overview

Water Technology was commissioned by the Department of Environment, Land, Water and Planning (DELWP) to undertake regional flood mapping for the Fitzroy River, Darlot Creek and Heywood. The project included detailed hydrological and hydraulic modelling of the Fitzroy River and Darlot Creek, with emphasis on detail through Heywood, and considering the downstream influences of the Portland Bay. Mapped outputs from the project will be used to satisfy a range of business requirements from planning, emergency response, to community awareness and for insurance purposes.

The study addressed the following aspects:

- Examine contributing factors to flood events within the Fitzroy River and Darlot Creek catchments including the main tributaries;
- Assess the sensitivity of flood mechanisms to a range of conditions, including channel roughness, pre-flood event catchment conditions, Portland Bay water levels, downstream berm condition, and structure blockage;
- Determine flood levels and extents for a range of flood modelling scenarios within the study area;
- Provide detailed flood intelligence outputs.

1.2 Study Catchment and Floodplain

The primary land use of the Fitzroy catchment is agriculture, accounting for approximately 75% of the land area (Mondon, et al, 2003). Apart from this agricultural land, a significant proportion of the catchment is forested. Within the study area are two main townships; Heywood and Tyrendarra.

Floodplains within the study area are of major cultural significance and parts of them are incorporated within the Budj Bim National Heritage Landscape, especially the area around Lake Condah and the Tyrendarra Indigenous Protected Area. The Fitzroy River and Darlot Creek catchments form part of the Gunditjmara nation, with the local clan known as the Kilger gundidj (Victorian Corporation for Aboriginal Languages, 2002). The local indigenous settlements were based on a system of trapping and smoking eels in the lake and wetland systems. Since European settlement, the landscape has been through a history of rural drainage and conversion of swamps to farmland. Lake Condah was drained in the 1950s and then partially reinstated in 2010 by the construction of a weir and regulator structure.

Where the Fitzroy River meets the ocean a sand bar seasonally closes the river mouth. The actual location of the entrance channel is variable over time as it can break out across the sand dune barrier (Barton & Sherwood, 2004). The effect of closure of the entrance is an increase in the extent of inundation across the estuary and to mitigate this, artificial openings of the estuary entrance do occur.

The Fitzroy River catchment has an area of 1,460 km^2 extending 57 km north westerly from Portland Bay to a maximum elevation of 170 m AHD in the Cobboboonee State Forrest. The catchment also has one major tributary in Darlot Creek, which extends 73 km upstream of its confluence with the Fitzroy River, to a maximum level of 440 m AHD at the summit of Mount Napier. A number of other minor streams feed into the River throughout its course. The Surrey River to the west and Eumeralla River to the east have clearly defined catchments and are unlikely to exchange flows with the Fitzroy River.

The main stream length of the Fitzroy River from the catchment divide to the mouth is 67 km with an equal area slope of 1.2 m/km. The main stream length of the Darlot Creek from the catchment divide to the confluence with the Fitzroy River is 95 km with an equal area slope of 1.4 m/km. Equal area slope is the averaged slope of a river, and if plotted as a straight line against the real topography will have an equal weighting of topographic error above and below the approximated line. It is commonly used in hydraulic and hydrological formulae. The catchment is relatively flat, except in the ranges around Mount Napier in the Upper Darlot Creek catchment area.

The Darlot Creek floodplain is dominated by swampy areas which have a history of artificial drainage for grazing land. The Condah swamp and Lake Condah were first drained in the 1890s, and the Condah Swamp Drainage Area was declared in 1948. In 2010, a weir and regulator was built in an attempt to reflood the lake and restore ecological and aboriginal heritage values to the area. The drainage and subsequent reflooding of the lake have had a profound impact on the hydrology of the system.

A consistent rainfall gradient exists over the catchment with average annual rainfall reaching 800 mm in the headwaters, while at the catchment centroid the average annual rainfall is around 700 mm. Some of the Upper Darlot Creek catchment reaches as low as 600 mm per year average rainfall.

1.3 Supporting Documents

A number of reports were prepared at each stage of the study. These reports were produced as separate standalone volumes, and a summary of each is provided in Table 1-1. In addition to these documents, flood intelligence outputs and GIS layers have been provided for each of the design flood events.

Table 1-1 Supporting documents

Report	Document Number	Title	Summary
1	R01	Preliminary Report	Review of flood related information for the study area, a review of available topographic and structure data (bridges and culvert information), and verification of topographic data.
2	R02	Hydrology Report	Hydrologic modelling and analysis report, summarising results of flood frequency analysis, RORB modelling, estimation of design event, and probable maximum flood hydrographs. This report has subsequently been superseded by R03, the combined hydrology and hydraulics report.
3	R03	Hydrology/Hydraulics Report	A combined hydrology and hydraulic modelling report providing details of hydrology and hydraulic model construction and calibration, sensitivity tests, and results of design event simulations.

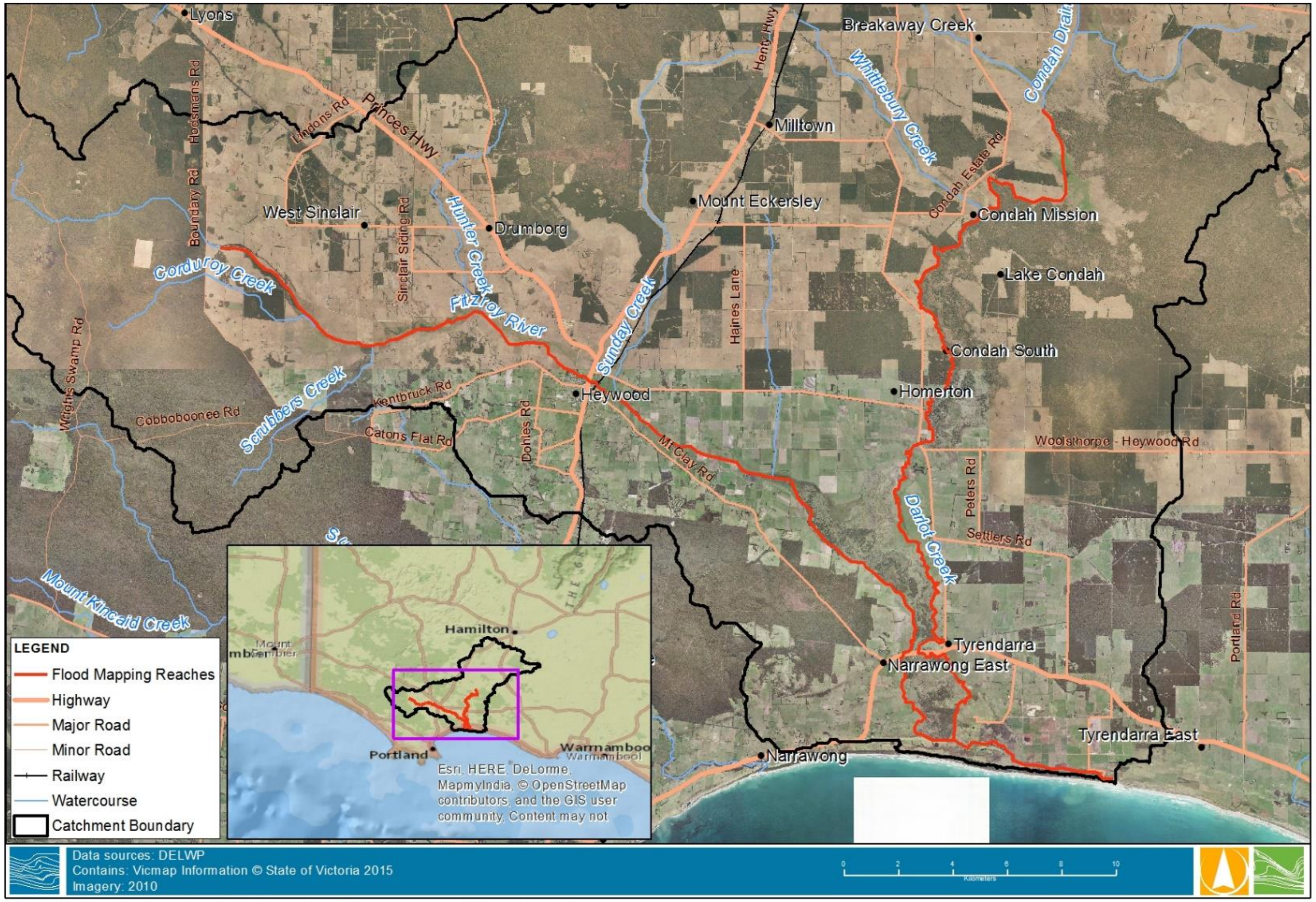

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Figure 1-1 Fitzroy River Study Area

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2 DATA REVIEW

On inception of the project a detailed review was undertaken of all available flood related information as well as topographic data, structure information, and hydrological data. Details of this review are provided in Report R01, while a short overview is provided herein.

2.1 Flood Related Studies

Due to relatively low levels of flooding recorded in the Fitzroy catchment in the past, there have been few flood related studies of the system. Early 20th century descriptions of the waterway, such as that by Schiller and Forbes (1946), suggest that extremely high rainfalls in the Fitzroy River catchment did not produce significant flood issues, and floodwaters dissipated relatively quickly. Darlot Creek was also described as causing little flood damage during major rainfall events.

Lake Condah (part of the Darlot Creek system) has been subject to hydrological regime modifications in the past. The lake was drained in 1908 as it was thought to exacerbate flooding (Gippel, et al, 2006). These drains were then variously upgraded and removed over the following years. In recent years the prevailing idea has been to restore Lake Condah to 'natural' conditions, as there would be major cultural and ecological benefits. To encourage this restoration Gippel, et al (2006), undertook a detailed analysis of the Condah Lake system. This analysis included a flood frequency analysis, development of a hydrological model, and a hydraulic analysis of the existing Condah system. From this study, a decision was made to attempt to return the hydrological regime of the Condah system more towards its original regime, by effectively blocking the Condah drain with a weir and re-flooding Lake Condah. This weir was built in 2010 and also has passing flow requirements so properties downstream of the weir still receive water from Darlot Creek.

In 2000, The Department of Natural Resources and Environment produced a series of '1% AEP' maps for the Shire of Glenelg, including the Fitzroy River and Darlot Creek for the Flood Data Transfer Project. Delineation of the '1% AEP' line was based on the 'Edge of High Ground' survey line from River survey, non-flood aerial photos and Rural land mapping which (based on alluvial soil deposits). This floodplain delineation was based on best available data, but is accepted that the base data has a low reliability, and the flood extent line is generally accurate to +/-100m.

A hydrologic and hydraulic investigation was previously undertaken on flooding in Heywood by Cardno (2008). The investigation utilised flood frequency analysis on the Fitroy River at Heywood gauge and a hydrologic RORB model to define inflows into a hydraulic model. The hydraulic model only considers the township of Heywood for its hydraulic outputs and the results of this present study update and supersede this previous analysis.

2.2 Historic Flood Information

Significant historic flood events have been compiled from available sources and are listed in Table 2-1. There is little available information regarding major flooding before gauging was implemented in the 1970s. The largest floods on record differ between the three gauges with a substantial record; the Fitzroy River at Heywood, Darlot Creek at Myamyn and Darlot Creek at Homerton gauges. At Homerton and Heywood, two of three largest floods were in October 1976 and September 1983. Large floods were also recorded in October 1975 and August 1978. At Myamyn there is a shorter gauge record, however the largest floods recorded (between 1987 and 2010) were September 2010, October 1992 and November 2007. There is very little evidence of historic (before flood gauge installation) flooding.

Table 2-1 Historic flood events

Event	Description	Data available
November 1906	Largest flood experienced at the time. Three inches of rain fell over 40 minutes. Water from the river reached the flood of the Presbyterian manse, and reached the floor of some houses.	Anecdotal newspaper report in *Portland Guardian*.
August 1939	Largest flood in 8-10 years, 235 points (83mm) of rain fell in two days. The Fitzroy River surged over its banks and was up to 300m wide in some places.	Anecdotal newspaper report in *Portland Guardian*.
March 1946	The south west of Victoria, including Heywood, receives its worst flood in living memory. Many rivers are in flood, including the Fitzroy River and Darlot Creek. High bridge over Darlot's Creek at Lake Condah was washed away.	Two flood mark at the railway bridge. Anecdotal reports in numerous newspapers.
August 1951	Flooding of some streets, the worst seen since 1946.	Anecdotal newspaper report in *Portland Guardian*.
November 1953	The worst flooding since 1946 in Condah swamp.	Anecdotal newspaper report in *The Age*.
October 1975	Largest recorded flood at Heywood.	Gauge records.
October 1976	Largest recorded flood at Homerton and third largest recorded flood at Heywood.	Gauge records.
August 1978	Second largest recorded flood at Homerton.	Gauge records.
September 1983	Second largest recorded flood at Heywood and third largest recorded flood at Homerton.	Gauge records.
November 2007	Only documented significant event in recent past.	Gauge records and numerous surveyed flood marks.

Historic flood data records as supplied by Glenelg Hopkins Catchment Management Authority is summarised in Figure 2-1.

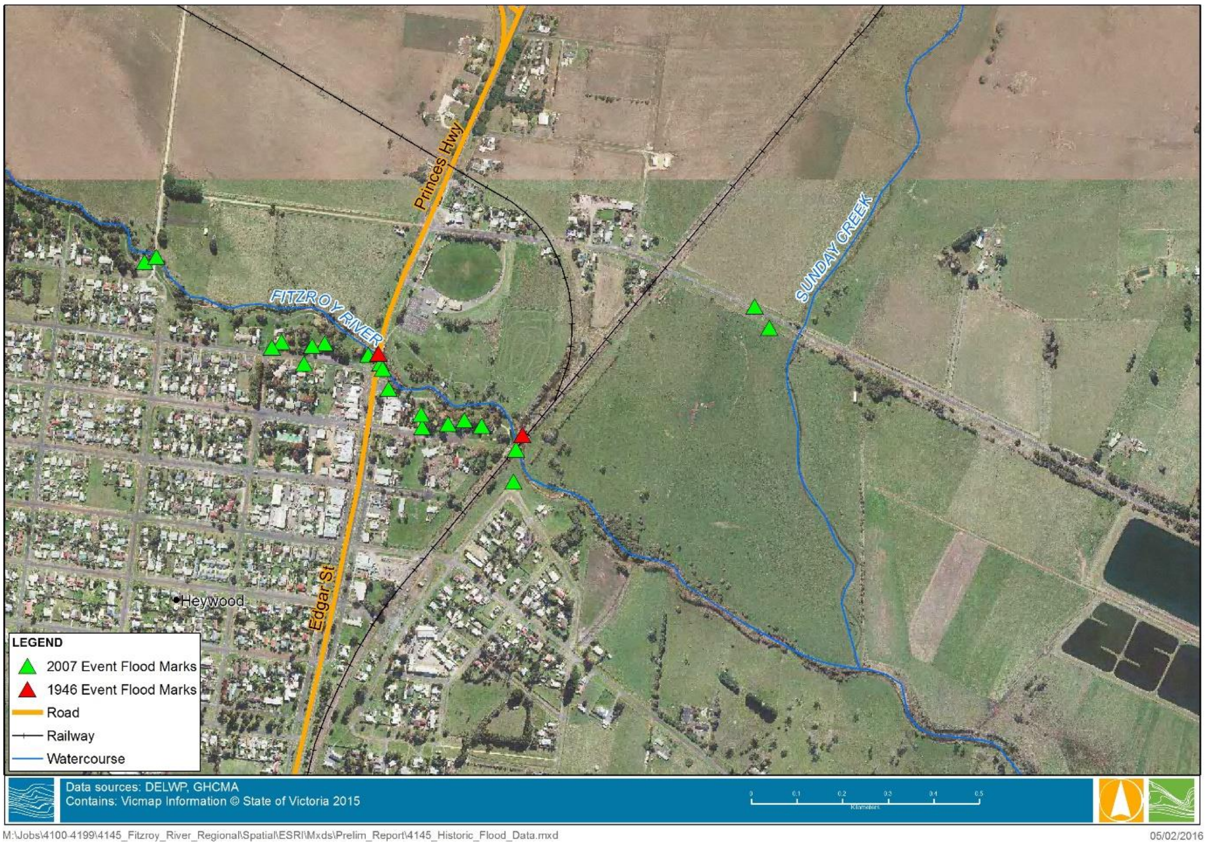

Figure 2-1 March 1946 and November 2007 flood information in VFD

2.3 Topographic Data

At the start of the project, it was recognised that Aerial LiDAR (Light Detection and Ranging) survey was available for the area from two different sources:

- 2009-10 Victorian State Wide Rivers LiDAR Project
- 2007-09 Vicmap Coastal LiDAR

Photogrammetric survey is available from one source:

- 2005 AEROmetrex Mt Eccles Lava Flow Photogrammetry

After beginning the project with these three data sources, two additional LiDAR datasets were made available for use in the flood study and were incorporated. This includes:

- 2011 Floodplains LiDAR (was not originally included in the original elevation dataset as it is not part of the VFD supplied by DELWP, but was made available mid-project by GHCMA).
- 2016 South West Towns Extension (a section of Heywood and downstream of Heywood thought to be critical to the floodplain modelling was flown and provided by DELWP in May 2016. This was flown specifically for this flood study as an extension to South West Towns LiDAR mapping that was underway in the area).

Key metadata for the three digital elevation models (DEMs) is given in Table 2-2, and their extents are shown in Figure 2-2. The Vicmap coastal LiDAR only covers the downstream section of the study area. The Rivers

LiDAR covers most of the study area but only for a 1-2km wide corridor along watercourses. The photogrammetry captures a large portion of Darlot Creek, especially around Lake Condah. The floodplains LiDAR captures a large section of Heywood and Darlot Creek. The 2016 South West towns LiDAR covers the remaining section of Heywood and downstream of Heywood. A coarse (20 m resolution) DEM is available from Vicmap for the whole study area for catchment delineation purposes.

Table 2-2 Key metadata for LiDAR datasets

Dataset	Source	Date of Capture	Vertical accuracy (1 sigma)	Resolution
2009-10 Rivers LiDAR	LiDAR	Nov 2009	0.20 m	1 m
2007-09 Coastal LiDAR	LiDAR	Apr 2007	0.10 m	1 m
2005 AEROmetrex Photogrammetry	Photogrammetry	Apr 2005	0.40 m	5 m
2011 Floodplains LiDAR	LiDAR	Sep 2011	0.10 m	1 m
2016 South West Towns Extension	LiDAR	May 2016	0.10 m	1 m

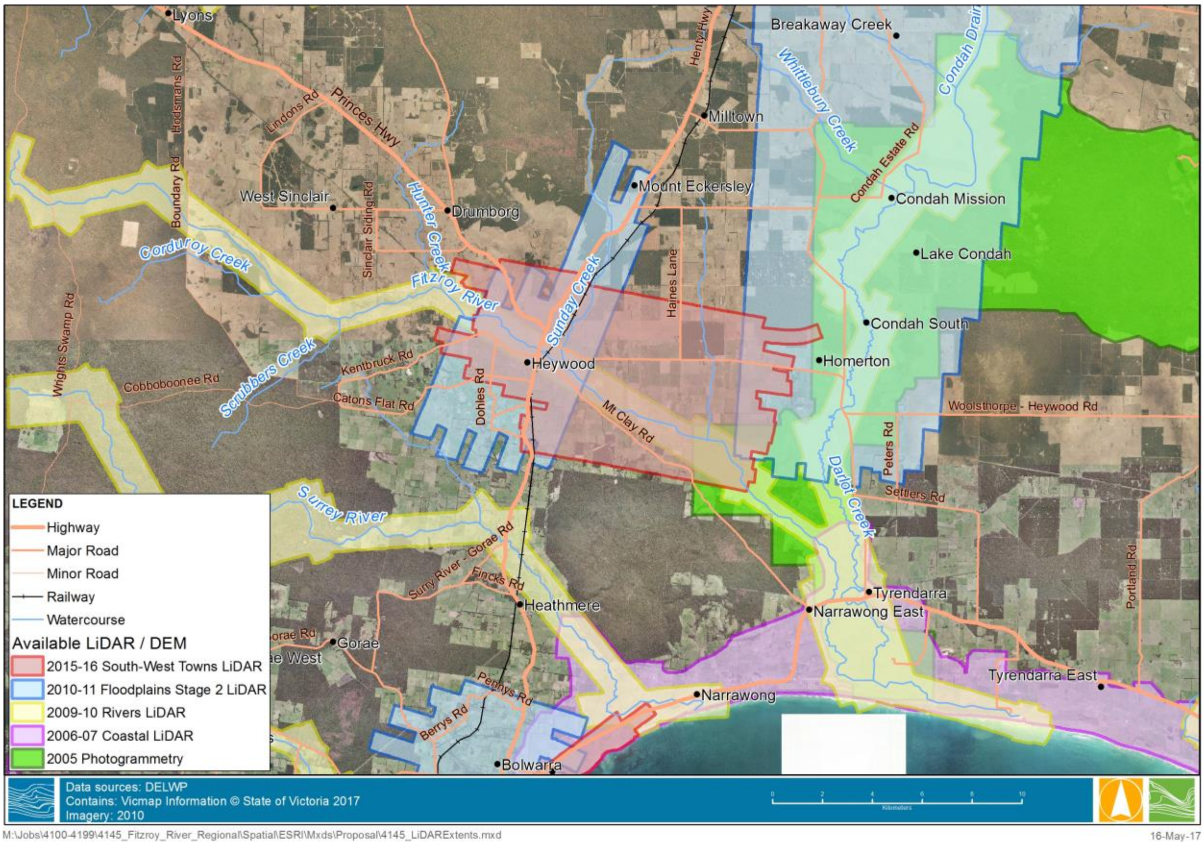

Figure 2-2 LiDAR and Photogrammetry Extents

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The final adopted DEM, with four primary LiDAR datasets, one photogrammetry dataset and coarse 20m DEM merged into a single DEM is shown in Figure 2-3 below.

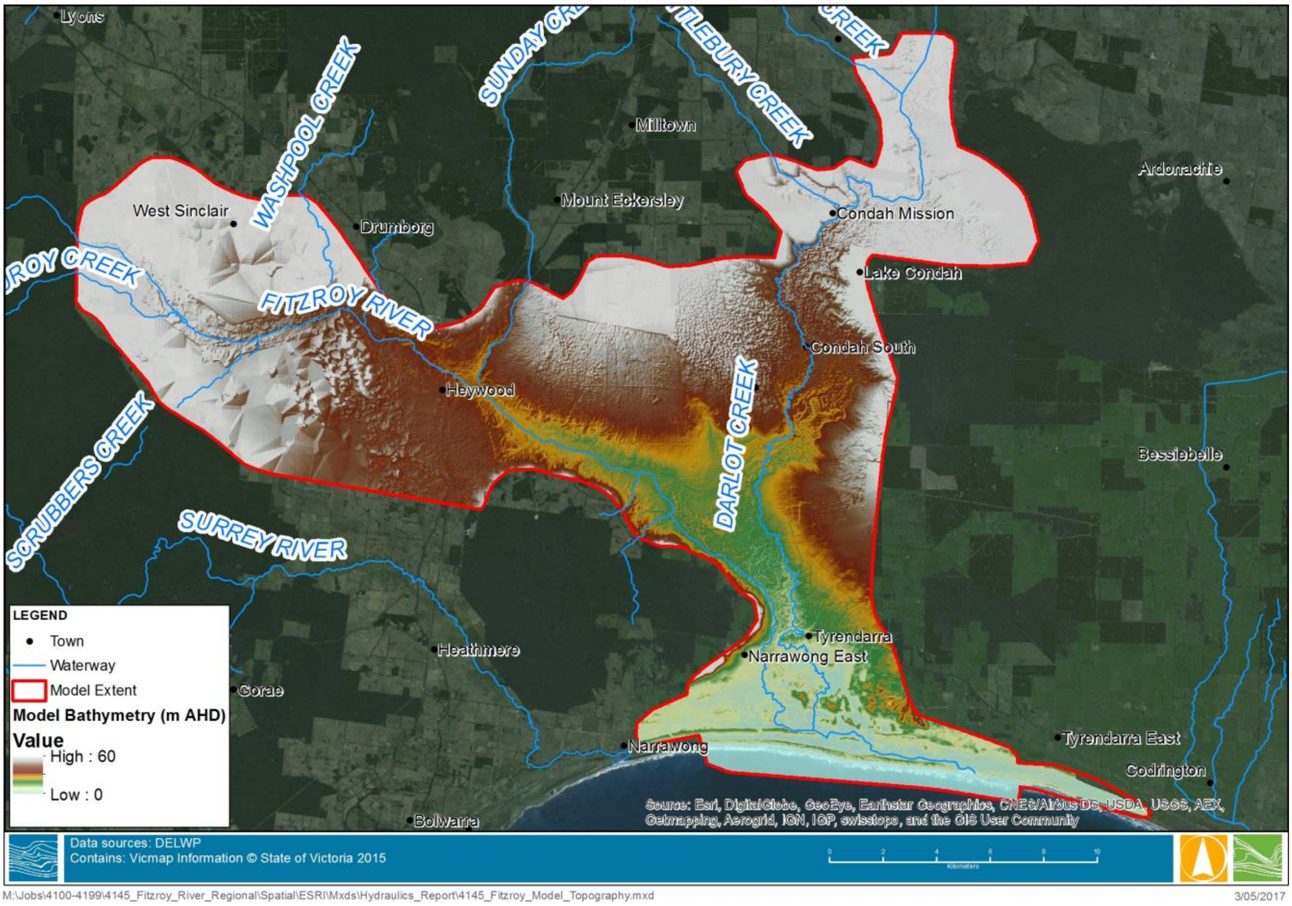

Figure 2-3 Adopted Model DEM

2.4 Structure Information

At the regional scale, hydraulic structures of interest are those that have the potential to impact the wider flood extent. These have been generally limited to bridges and weir crossings. The following structures are those that have been incorporated into the hydraulic model.

2.4.1 Road / Rail Crossings

The resolution of the model allows for key bridge and rail crossings of the waterways to be included. Data on these bridges has been provided by VicRoads, whilst railway track information has been accessed from VicTrack. Weir crossings for vehicles and large railway culverts were also measured and photographed during a site visit on the 02/12/15. Locations of key structures are shown in Figure 2-4 and details of the structures are listed in Table 2-3.

2.4.2 Channels

A number of open channels bisect the Darlot Creek floodplain, the most significant of which are located in the immediate vicinity of Lake Condah. Key channels in this area include Condah Drain and Louth Drain, and there are a number of unnamed drains that intersect these.

The channel banks of major channels which are known to impact on flooding have been sampled from the LiDAR and specifically incorporated into the hydraulic model.

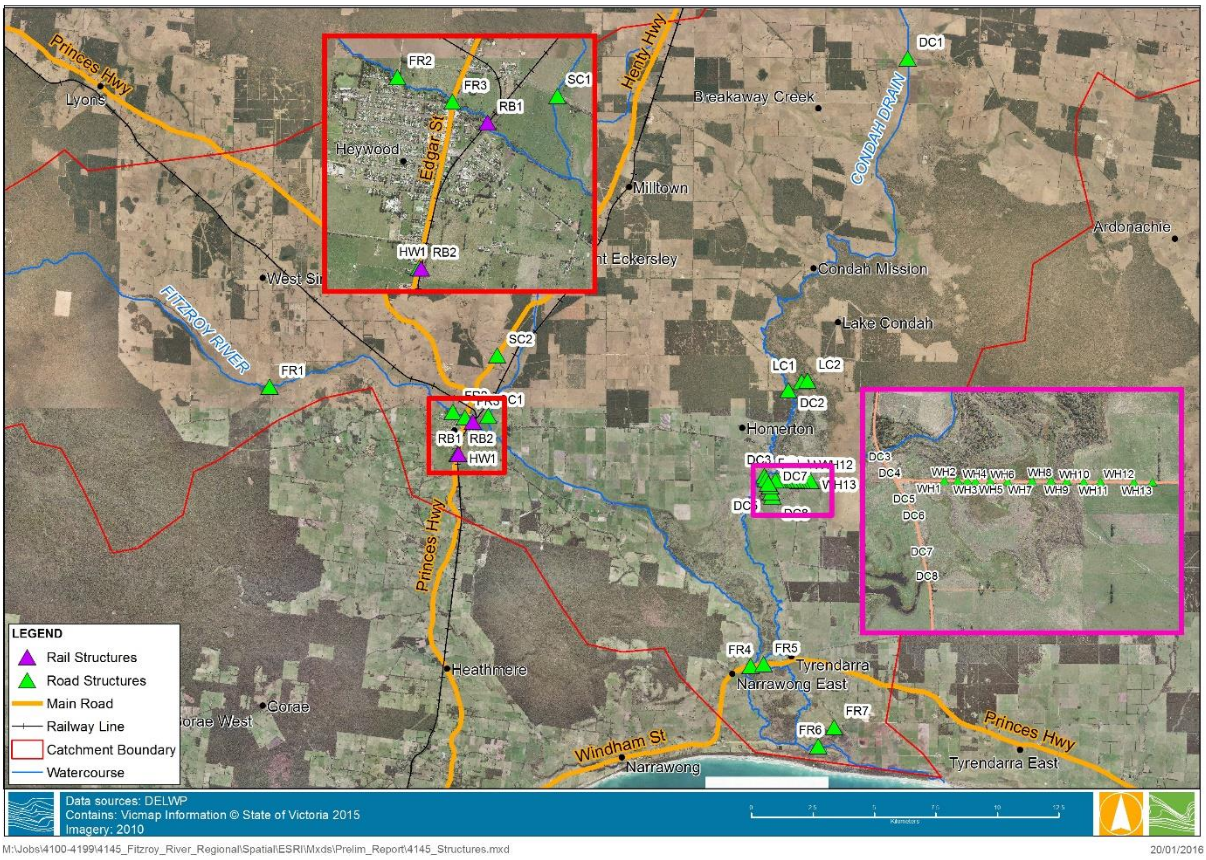

Figure 2-4 Key structures within study area

Table 2-3 Key details for surveyed bridges and culverts

Culvert ref.	Type	Description	Notes
RB1	Railway Bridge	Four-span rail bridge over Fitzroy River.	Structure data obtained from VicTrack.
RB2	Rail Opening	Two-span opening in railway embankment over unnamed Creek in Heywood.	Structure data obtained from VicTrack.
DC1	Road Bridge	Bridge over Condah Drain on Condah-Macarthur Rd. Named 'Reid's Bridge'.	Some structure details available from VicRoads.
DC2	Road Bridge	Small Bridge over Darlot Creek on Coustleys Rd	Unsurveyed
DC3	Road Bridge	Dual span road bridge over Darlot Creek on Ettrick-Tyrendarra Rd. Immediately downstream of Darlot Creek at Homerton gauge.	Some structure details available from VicRoads.
DC4	Road Culvert	Culvert under Ettrick-Tyrendarra Rd on Darlot Creek floodplain.	Unsurveyed.
DC5	Road Culvert	Culvert under Ettrick-Tyrendarra Rd on Darlot Creek floodplain.	Unsurveyed.

4145_R04V02

Culvert ref.	Type	Description	Notes
DC6	Road Culvert	Culvert under Ettrick-Tyrendarra Rd on Darlot Creek floodplain.	Unsurveyed.
DC7	Road Culvert	Culvert under Ettrick-Tyrendarra Rd on Darlot Creek floodplain.	Unsurveyed.
DC8	Road Culvert	Culvert under Ettrick-Tyrendarra Rd on Darlot Creek floodplain.	Unsurveyed.
FR1	Road Culvert	Culvert under Miltons Rd on the Fitzroy River.	Unsurveyed.
FR2	Road culvert	Culvert under Bond St in Heywood on the Fitzroy River.	Bond St is a low-level road crossing on the Fitzroy. Unsurveyed.
FR3	Road Bridge	Five-span road bridge over the Fitzroy River on Princes Hwy.	Some structure details available from VicRoads.
FR4	Road Bridge	Road bridge over the Fitzroy River on Princes Hwy.	Some structure details available from VicRoads.
FR5	Road Bridge	Road bridge over the Fitzroy River on Princes Hwy.	Some structure details available from VicRoads.
FR6	Road Bridge	Road bridge over the Fitzroy River on Tyrendarra School Rd.	Unsurveyed.
FR7	Road Culvert	Culvert in the Fitzroy River floodplain on Tyrendarra School Rd.	Unsurveyed.
HW1	Road Culvert	Culvert under Princes Hwy in Heywood.	Some structure details available from VicRoads.
LC1	Road Culvert	Culvert under Coustleys Rd in Lake Condah.	Unsurveyed.
LC2	Road Culvert	Culvert under Coustleys Rd in Lake Condah.	Unsurveyed.
SC1	Road Culvert	Culvert under Princes Hwy on a tributary to Sunday Creek.	Some structure details available from VicRoads.
SC2	Road Bridge	Bridge over Sunday Creek on Woolsthorpe-Heywood Rd.	Some structure details available from VicRoads.
WH1 – WH13	Road Culvert	Culvert under Woolsthorpe-Heywood Rd in the Darlot Creek floodplain.	Unsurveyed.

During the hydraulic model build and testing specific structures were explicitly included based on model resolution and impact of the structures to model results. The key structures that were explicitly included as openings in the topography were FR3, RB1, SC1, DC3, FR4, FR5 and FR6.

2.4.3 Levees

Constructed levees are not a key feature of the Fitzroy River, however they have been constructed in the Lake Condah area on Darlot Creek historically. These levees were incorporated into the model as standard topography, as no construction details are available and they are included in the DEM information.

Of significance is the new weir that has been constructed in the downstream section of Lake Condah, which causes a significant flow blockage to Darlot Creek and was constructed in 2010. The weir is designed so water backs up behind and forces water into Lake Condah. The weir includes a regulating structure which transmits passing flows to downstream of the weir. The levee height is 52.0m AHD, and for modelling purposes a passing flow of 30ML/day or natural (if flow is less than 30ML/day) has been adopted as this is the current operating passing flow.

Figure 2-5 Location of Condah Weir

2.5 Hydrological Data

2.5.1 Rainfall Data

The average annual rainfall varies throughout the catchment, reaching 800 mm in the forested Upper Fitzroy area, and as low as 600 mm near the flat upper headwaters of Darlot Creek. At the catchment centroid the average annual rainfall is approximately 700 mm, with Condah gauge (090028) averaging 699mm of rainfall/year.

Numerous daily rainfall sites are in operation in and around the catchment. All stations within the catchment and close to the catchment are listed in Table 2-4. Stations operating during the calibration events in 1946, 2007 and 2013 are identified with a * as they were used during hydrological calibration analysis.

Table 2-4 Daily rainfall stations around Fitzroy River catchment

Gauge No.	Location	Period	Years	Distance from catchment centroid (km)
090028	Condah*	1900 -1954	55	6.9
090047	Heywood Post Office*	1887 - 1971	85	15.1
090190	Branxholme Inverary Rd	2004 - 2006	3	15.1
090038	Tyrendarra (Ellangowan)*	1902 - 2008	107	15.6
090009	Branxholme*	1909 - 2004	95	17.8
090010	Branxholme (Bassett)*	1883 - Present	113	17.8
090048	Heywood (Forestry)*	1949 - 2013	64	17.8
090055	Macarthur (Post Office)*	1936 - Present	80	19.7
090124	Narrawong	1892 - 1919	20	20.9
090122	Macarthur (Glenhuntly)	1884 - 1945	62	21.5
090097	Grassdale	1954 - 2002	48	25.5
090156	Mouny Yandyke (Lyons)	1888 - 1893	6	27.7
090121	Crawford Lower	1932 - 1939	8	28.4
090002	Yambuk (Avalon)*	1920 – 1969	50	32.1
090103	Hamilton Research Station	1962 - 2000	38	33.3
090075	Tahara*	1937 - 2004	67	34.3
090150	Gorae	1905 - 1921	17	34.4
090169	Hamilton Godfrey	1980 - 1981	2	37.6
090044	Hamilton*	1869 - 1983	115	38.2
090057	Merino*	1886 - Present	124	38.6
090088	Yatchaw (Amaroo)*	1903 - Present	113	38.8
090056	Merino (Glenorchy Estate)*	1886 - 1946	61	40.5
090036	Drik Drik*	1907 - Present	109	41.1
090050	Mount Richmond*	1940 - Present	76	41.2
090149	Yambuk	1970 - 1987	18	41.5
090162	Portland Aero	1973 - 1982	10	41.9
090171	Portland (Cashmere Airport)*	1982 - Present	34	41.9
090070	Portland*	1857 - Present	154	42.8
090032	Dartmoor*	1884 - 1980	77	43.5
089014	Kanawalla*	1908 - 1952	45	45.5
090194	Dartmoor*	2009 - Present	7	46.0
090013	Cape Bridgewater*	1905 - Present	111	46.2
090024	Coleraine Hospital*	1898 - Present	118	46.7

Gauge No.	Location	Period	Years	Distance from catchment centroid (km)
090113	Coleraine (Wondo Dale)	1881 - 1917	37	47.0
090114	Coleraine (Mona Vale)	1903 - 1913	11	47.0
090063	Penshurst (Post Office)*	1882 - Present	134	47.7
090173	Hamilton Airport*	1983 - Present	33	48.3
090045	Hawkesdale (Post Office)*	1884 - Present	125	48.6
090046	Hawkesdale Shire Office*	1944 - 1995	52	48.6
089012	Dunkeld (Corea South)	1947 - 1986	40	48.9
090184	Cape Nelson Lighthouse*	1995 - Present	21	49.6

Pluviograph (sub-daily rainfall) stations around the Fitzroy River catchment that captured the 2007 or 2013 calibration events are listed in Table 2-5. There are no sub-daily gauges within the Fitzroy River catchment area. The 1946 event is not captured by pluviographs as it occurred before the installation of instantaneous rainfall gauging in the catchment. Whilst all gauges capture the 2013 event, the 2007 event occurred before installation of many of the gauges. The 2007 event was only captured at Casterton and Mount Gambier. Both of these gauges are in the far north western side of the catchment, so this gauge distribution is not ideal.

Table 2-5 Pluviograph stations around Fitzroy River catchment

Gauge No.	Location	Period	Years	Distance from catchment centroid
90171	Portland (Cashmore Airport)	2009 – 2016	6.8	41.5
90194	Dartmoor	2009 – 2016	6.4	45.9
90173	Hamilton Airport	2010 – 2016	5.7	48.6
90184	Cape Nelson Lighthouse	2010 – 2016	5.7	49.2
90175	Port Fairy AWS	2010 – 2016	5.7	57.2
90182	Casterton	2005 – 2016	6.8	61.9
90186	Warrnambool Airport Ndb	2010 – 2016	5.8	65.6
90176	Mortlake Racecourse	2010 – 2016	5.5	87.5
26021	Mount Gambier Aero	2003 – 2016	12.5	92.3
	Surrey River @ Heathmere	2006 - 2016		

2.5.2 Streamflow Data

Gauge Locations

Two streamflow gauges currently operate in the catchment, while historic data is also available for two other gauges (Table 2-6). The currently operating gauges, Fitzroy River at Heywood and Darlot Creek at Homerton Bridge gauges record streamflow at the two tributaries that are to be mapped – the Fitzroy River and Darlot Creek. The Fitzroy River at Heywood gauge catchment area of 234km^2 captures 17% of the Fitzroy catchment, and the Darlot Creek at Homerton captures another 56% of the catchment (760km^2), therefore approximately 73% of the catchment is captured by gauging stations. Of the two currently operating gauges, both of them recorded data during the 2007 and 2013 calibration events. The other gauges were not deemed suitable for use in calibration. The available streamflow gauge data is shown in Figure 2-7.

Table 2-6 Streamflow gauges in Fitzroy River and Darlot Creek catchment

Gauge No.	Location	Period	Years	Catchment Area (km^2)
237202	Fitzroy River @ Heywood	1968 — 2015	48	234
		1948 — 1968*	20	
237205	Darlot Creek @ Homerton Bridge	1969 — 2015	47	760
		1963 — 1969*	6	
237209	Darlot Creek @ Myamyn	1987 — 2010	24	600
237204	Darlot Creek @ Lake Condah Bridge	1961 — 1964*	4	607

* Instantaneous flows not recorded – mean daily flows only

2.5.3 Water Level Data

One historic water level gauge has operated in Lake Condah (Table 2-7). The Lake Condah water level gauge does not have recorded data during the calibration events.

Table 2-7 Water level gauges in Lake Condah

Gauge No.	Location	Period	Years
227600	Lake Condah @ Lake Condah	1988 - 1993	4

4145_R04V02

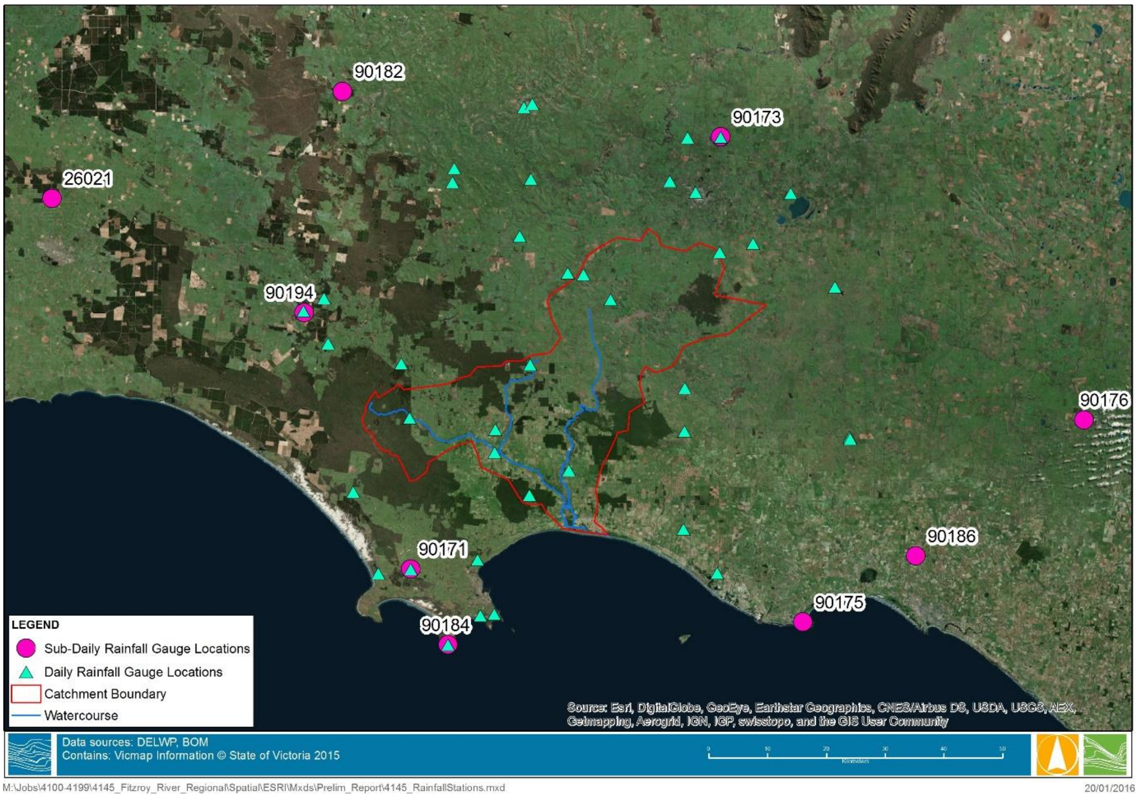

Figure 2-6 Rainfall stations in and around the Fitzroy River catchment

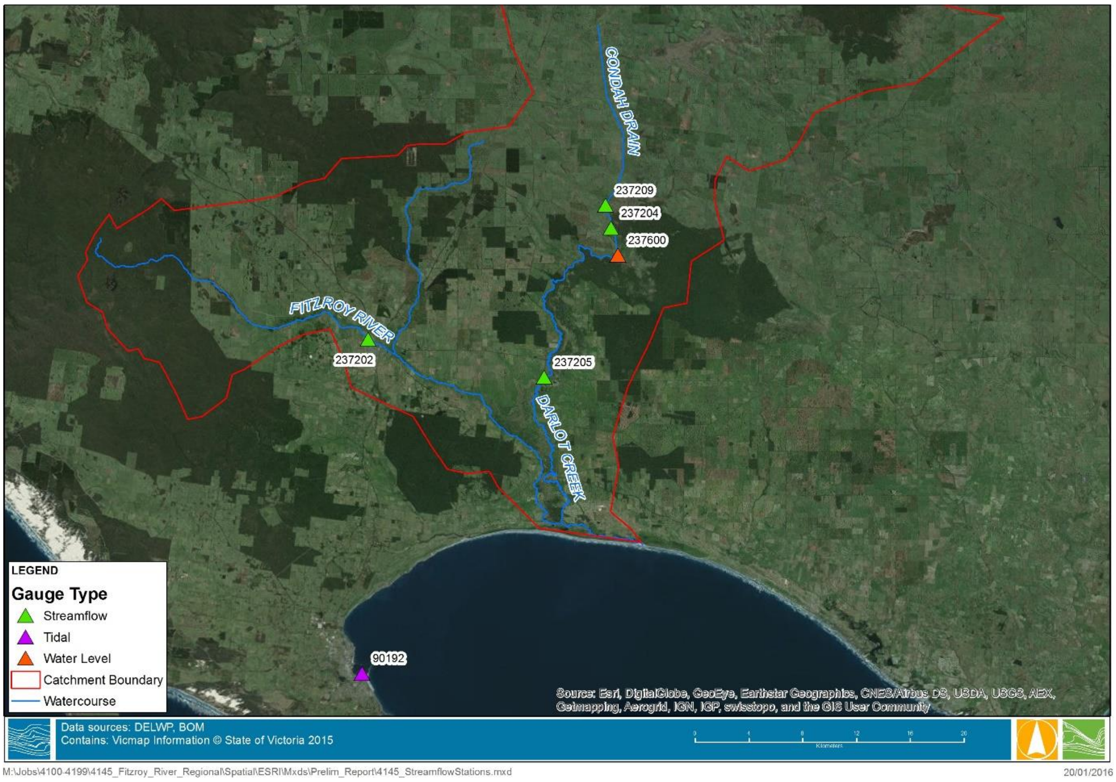

Figure 2-7 Streamflow and water level gauges in the Fitzroy River catchment

2.5.4 Tidal Gauge Data

A tidal gauge is available in Portland Bay (Table 2-8), with data available from 1991. The site is part of the Australian Baseline Sea Level Monitoring Project. The water level variation in November 2007 (corresponding to a flood event in the catchment) is shown in **Error! Reference source not found.**. Water levels relevant to calibration events (post 1991) have been extracted from the gauge information and used as boundary conditions in the hydraulic model.

Harmonic constituents for this port are available in the Royal Australian Navy's *Australian National Tide Tables*. These harmonic constituents allowed for generation of a synthetic water level data set for calibration events where no measured water level data is available.

Table 2-8 Tidal Gauges Data

Gauge No.	Location		Harmonic constituents				
			Z0	M2	S2	K1	O1
90192	Portland	Amplitude	0.65	0.129	0.134	0.177	0.129
		Phase	0	334.7	51.8	44.3	16.5

Estimates of extreme coastal water levels (storm tides) have been developed for the Victorian coastline by the CSIRO (2009) for difference planning and sea level rise scenarios. The storm tide levels for Portland are presented in Table 2-9 for Climate Change Scenario 2. This scenario combines the sea level rise (IPCC 2007 A1F1) with increased wind speeds of 19% by 2100.

Table 2-9 Storm Tide Levels Incorporating Mean Sea Level Rise Scenarios (CSIRO 2009)

(m AHD)	Existing	2030 High	2040 High*	2070 High	2100 High
Mean Sea Level Rise	-	0.15	0.20	0.47	0.82
Portland (10% AEP)	0.79	1.00	1.05	1.39	1.81
Portland (1% AEP)	1.01	1.22	1.27	1.61	2.11

* Interpolated value for this study

For the design flood event simulations, the existing 10% AEP storm tide levels were used as the downstream boundary conditions.

3 PROJECT CONSULTATION

3.1 Overview

An important element of the flood mapping study was the active engagement of residents in the study area. This engagement was developed over the course of the study through community consultation sessions and meetings with a Steering Committee. The aims of the community consultation were as follows:

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

3.2 Steering Committee

The floodplain mapping study was led by a Steering Committee consisting of representatives from Department of Environment Land Water and Planning (DELWP), Glenelg Hopkins Catchment Management Authority (GHCMA), Glenelg Shire Council (GSC), Victorian State Emergency Service (VicSES) and a member of the Gunditjmirring Traditional Owners Aboriginal Corporation.

The Steering Committee met on four occasions at key points throughout the study, to review and manage the development of the study.

3.3 Community Consultation

The main aim of the community engagement process was to provide information regarding the development of the study and to seek feedback, both verbally and through the use of online methods. All community meetings were supported by media releases to local papers and meeting notices.

The public consultation process was coordinated by DELWP. The following community meetings were held as part of the consultation process:

- Initial community meeting, 18th February 2016 in Heywood – The first public meeting was held to outline the objectives of the study to the community and to receive any flood information the community may be able to provide;
- Second community meeting, 27th September 2016 in Heywood– This meeting presented the results of the flood modelling. Community feedback was sought on the flood modelling results.
- Second community meeting, 9th May 2017 in Heywood – This meeting presented the final outputs to the community, and allowed residents to see and discuss how the outputs will affect them.

The community provided knowledge of a range of previous floods, however the lack of recent major flood meant that the 1% AEP is a much larger flood than most residents have experienced.

4145_R04V02

4 FLOOD BEHAVIOUR

4.1 Overview

Flooding in the Fitzroy River and Darlot Creek catchment can occur due to widespread and prolonged rainfall. Apart from numerous rural properties, the primary township affected by floodwater is Heywood.

The flood behaviour associated with catchment flooding mechanisms has been assessed using a range of industry standard approaches and tools:

- Hydrological analysis – this involves the analysis of the magnitude of previous flood events in the catchment, the development of a rainfall-runoff model for the entire Fitzroy River and Darlot Creek catchment, and the prediction of the likelihood of future flood events of a given magnitude,
- Hydraulic analysis – the physical understanding of what a given flood event may look like in the lower Fitzroy River and Darlot Creek catchment was assessed through a hydraulic analysis. A hydraulic model was used to predict the extent of flooding, flood depths and flow velocities for a range of possible future flood events.

The different flood mechanism and the results of the hydrologic and hydraulic analysis for the study area are discussed in the following sections. Further detailed information is also provided in Report 3.

4.2 Hydrology

4.2.1 Streamflow Gauging

Two streamflow gauges currently operate in the catchment, while historic data is also available for two other gauges (Table 2-6). The Fitzroy River at Heywood and Darlot Creek at Homerton gauges record streamflow at the two tributaries that have been mapped. The Fitzroy River at Heywood gauge catchment area of 234 km^2 captures 17% of the Fitzroy catchment, and the Darlot Creek at Homerton captures another 56% of the catchment (760 km^2), therefore approximately 73% of the catchment is captured by gauging stations.

It was initially thought that both gauges are located in suitable locations for model calibration, as they are generally downstream of most large tributaries and have a high quality gauging record. The Fitzroy River at Heywood gauge is also situated adjacent to the key township of Heywood, a critical location with respect to flood mapping. However, upon more detailed analysis, it was found that high flow gaugings at Fitzroy River at Heywood gauge was unreliable due to flow bypassing the gauge. A joint hydrologic-hydraulic calibration using the gauge water levels was therefore employed. A detailed analysis of each gauge was undertaken and is presented in the Section 2.3 of Report R03, the Joint Hydrology and Hydraulics report.

4.2.2 Flood Frequency Analysis

Flood frequency analysis (FFA) allows the estimation of peak flows of selected Annual Exceedance Probability (AEP) events based on a statistical analysis. FFA was undertaken for the Fitzroy River at Heywood and Darlot Creek at Homerton gauges in order to estimate the return periods of peak flow at the gauge for verification of the RORB model.

Hydrographs extracted from the hydrologic model at the Fitzroy River and Darlot Creek are used as direct inflows to the hydraulic model. It was intended to validate calibrated losses at these gauges with flood frequency analysis, however difficulties in calibrating the hydrologic and hydraulic models pointed to uncertainties in the rating curve at Heywood, and issues around the different hydrologic behaviour of the upper and lower Darlot Creek systems and the effect of Lake Condah, as discussed in Section 5.3 of Report R03, the Combined Hydrology and Hydraulics report. The FFA is also detailed in the Appendix of Report R02 and Section 3.5 of Report R02, the Hydrology Report, but was not used for the final design flood validation.

4.2.3 Hydrologic Modelling

A hydrological model of the catchment was developed for the purpose of extracting design flows to be used as boundary conditions in the Fitzroy River hydraulic model. The rainfall-runoff program, RORB (Version 6) was used for this study.

RORB is a non-linear rainfall runoff and streamflow routing model which is used for calculation of flow hydrographs in drainage and stream networks. The model requires catchments to be divided into subareas, connected by a series of conceptual reach storages. Design storm rainfall is input to the centroid of each subarea. Specified losses are then deducted, and the excess routed through the reach network.

The RORB model was at a resolution adequate to resolve the main drainage paths and sub-catchments, and to provide smooth hydrographs for the hydraulic model. 'Interstation areas' were introduced at Heywood and Homerton gauges, which allow for calibrated catchment routing parameters to be adopted for the upstream Fitzroy and Darlot Creek catchments, respectively. The areas downstream of the gauges initially adopted the upstream parameters.

As detailed in Report R03, the Joint Hydraulics and Hydrology Report, Lake Condah and other swampland in the upper Darlot Creek catchment provide significant flow storage capacity and retard the upstream flows. The result is that the upper Darlot Creek catchment responds differently to rainfall than the lower Darlot Creek catchment.

From a hydrologic modelling perspective, the system effectively requires two different flood hydrographs; one for the catchment upstream of Lake Condah and one for the catchment downstream of Lake Condah. The original hydrologic model was not able to replicate the effects of the upstream catchment storage using a single set of parameters, and it was therefore decided to split the hydrologic model into two; the first model consisting of the whole catchment, which provides inputs into upper Darlot Creek and the Fitzroy River catchment, and a second model focussing on a portion of the downstream catchment of Darlot Creek, between Lake Condah and the Homerton gauge.

After joint hydraulic-hydrologic calibration detailed in Report R03, the peak flow volumes shown in Table 4-1 were taken forward as design inflows in the hydraulic modelling.

Table 4-1 Recommended Design Peak Flows

AEP	Fitzroy River at US Extent		Darlot Creek at US Extent		Darlot Creek at DS of Lake Condah		Durations to be modelled
	Design Flow (m^3/s)	Critical Duration	Design Flow (m^3/s)	Critical Duration	Design Flow (m^3/s)	Critical Duration	
20%	7	72h	16	72h	8	72h	72h
10%	12	72h	34	72h	14	72h	72h
5%	20	72h	63	72h	22	72h	72h
2%	30	72h	110	72h	33	48h	72h, 48h
1%	37	72h	143	72h	44	48h	72h, 48h
0.5%	45	72h	180	72h	56	72h	72h
0.2%	59	72h	241	72h	79	72h	72h

4.2.4 Probable Maximum Flood

The Probable Maximum Flood (PMF) is the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area. The PMF was estimated through using the Probable Maximum Precipitation (PMP), then application of the PMP to the RORB model to generate PMF flood hydrographs.

The PMP rainfall totals, spatial and temporal patterns calculated using the regional GSAM method were input into the RORB model, with the calibrated routing parameters. An initial loss of 0 mm and a continuing loss of 1 mm/hr were adopted as recommended in Australian Rainfall and Runoff Book VI (1998). The resulting PMF peak flows are given in Table 4-2.

Table 4-2 PMF Peak Flow Estimates

AEP	Fitzroy River at Heywood		Fitzroy River at US Extent		Darlot Creek at US Extent		Darlot Creek at DS of Lake Condah	
	Design Flow (m^3/s)	Critical Duration	Design Flow (m^3/s)	Critical Duration	Design Flow (m^3/s)	Critical Duration	Design Flow (m^3/s)	Critical Duration
PMF	1483	24hr	382	24hr	3004	24hr	683	24hr

4.3 Hydraulics

4.3.1 Overview

This section discusses the application of the hydraulic model to simulate flood behaviour (extents, depth, velocities) for a range of flood magnitudes.

The hydrologic analysis, previously discussed, provided flood inflow hydrographs for the hydraulic model. These inflow hydrographs were routed through the calibrated hydraulic model. This enabled the modelling of flood depths, extents and velocities over a range of flood magnitudes. It also provided a tool for understanding the flood behaviour across the study area.

A detailed description of the hydraulic model setup, calibration, validation, sensitivity tests and design event simulation is provided in Report R03. This section summaries the general model development and key outcomes from the hydraulic modelling investigation.

4.3.2 Hydraulic Modelling

A two dimensional (2D) flexible mesh hydraulic model was developed for the study area using MIKE21FM GPU (Mike by DHI). MIKE21FM two-dimensional flexible mesh model systems is a 2D state-of-the-art tool for floodplain modelling which is run with a graphics processing unit (GPU). The GPU allows for greatly accelerated model runs, and represents a recent critical advancement in hydraulic modelling. Further details on the capabilities of the MIKE modelling system can be found at http://www.dhisoftware.com.

Adopting a flexible mesh modelling approach allowed the hydraulic model to incorporate greater detail in areas of importance, whilst maintaining computational efficiency through a larger element size in less sensitive regions of the modelled area. This allows features within the broader floodplain and the township areas (Heywood) to be resolved in varying detail in the same model whilst maintaining appropriate run times.

4145_R04V02

The model extent covered the full study area, as shown in Figure 2-3, and inflows were included from all tributaries (Darlot Creek, Fitzroy River), as well as runoff from Sunday Creek and the floodplain itself. Water levels in Portland Bay provided the downstream boundary of the model. Topography data was provided by LiDAR survey and photogrammetry.

The modelling process involved the following stages:

- Model setup and calibration,
- Validation and sensitivity tests,
- Design flood simulations,

The calibration, validation, and sensitivity assessments are an iterative investigative process and all outcomes from these stages inform the final design flood simulations.

4.3.3 Understanding Flood Behaviour

Table 4-3 describes the key flood characteristics in the Fitzroy River catchment for each design event. The key aspect to note is that properties in Heywood are inundated above floor level in the 2% AEP and larger flood events. There are also a number of key roadways that are inundated in 1% AEP events and larger.

It was assumed for all design events was that Lake Condah was already full when the deign events commenced. This condition was adopted based on sensitivity tests undertaken for the model calibration and verification, detailed in the combined Hydrology and Hydraulics Report (R04). If Lake Condah is assumed to be initially empty, the available storage in the lake significantly reduces the flood depths and extents along Darlot Creek downstream and therefore may underestimate the flood impacts.

Table 4-3 Summary of Flood Behaviour for Modelled Flood Events

Event	Flood Characteristics	Key roadways inundated
20% AEP	Sunday Creek is the first waterway to respond to flooding, and while it has overtopped its banks into adjacent land there is no significant roadways or key assets flooded. Sunday Creek starts receding 12 hours after flooding began. In the upper catchment area of the Fitzroy River (from upstream of Heywood to Boundary Rd), flooding peaks approximately 40 hours after flooding began. This floodplain area is typically at least 250m wide and is heavily vegetated floodplain. No major infrastructure or residential areas are affected in this area. The flood peak then continues towards Heywood, peaking at approximately 6 hours after the upper catchment. Upstream of Heywood, the flood becomes much more confined, restricted to an approximate 50m channel width, which continues into Heywood. Heywood is the critical location within the catchment for inundation, however for this event only parkland is inundated. Downstream of Heywood, at the start of the Fitzroy River - Darlot Creek swamp confluence area, the Fitzroy River splits into two major flow paths, with one flow path filling a large basin, whilst the other flow path continues towards the lower catchment. The lower catchment is typically characterised by inundation to low-lying swampland, and does not exhibit flooding of key infrastructure. In the upper Darlot catchment, Condah Swamp, Lake Condah and Whittlebury Creek storages inundate a large area of land. This is mostly swamp and farmland. The downstream Darlot Creek catchment typically inundates swamp and marshland, without affecting residential areas or key infrastructure.	Bond St

Event	Flood Characteristics	Key roadways inundated
10% AEP	Sunday Creek has overtopped its banks into adjacent land there is no significant roadways or key assets flooded. Sunday Creek starts receding 12 hours after flooding began. In the upper catchment area of the Fitzroy River (from upstream of Heywood to Boundary Rd), flooding peaks approximately 33 hours after flooding began. This floodplain area is typically at least 250m wide and is heavily vegetated floodplain. No major infrastructure or residential areas are affected in this area. The flood peak then continues towards Heywood, peaking at approximately 6 hours after the upper catchment. Approximately 1.5km upstream of Heywood, there is a channel break out to the north of the river, abutting the Mount Gambier railway line. This breakout reconnects with the main Fitzroy River upstream of the Princes Hwy bridge, after passing over Bond St and Owen St on the northern side of the river in Heywood. Heywood is the critical location within the catchment for inundation, however for this event only parkland and floodplain is inundated. Downstream of Heywood, at the start of the Fitzroy River - Darlot Creek swamp confluence area, the Fitzroy River splits into two major flow paths, with one flow path filling a large basin, whilst the other flow path continues towards the lower catchment. The lower catchment is typically characterised by inundation to low-lying swampland, and does not exhibit flooding of key infrastructure. In the upper Darlot catchment, Condah Swamp, Lake Condah and Whittlebury Creek storages inundate a large area of land. This is mostly swamp and farmland. The downstream Darlot Creek catchment typically inundates swamp and marshland, without affecting residential areas or key infrastructure. After the confluence of Darlot Creek and Fitzroy River, the far downstream end of the catchment exhibits flooding of swampland as per upstream. However, it appears two roads become inundated, Tyrendarra School Rd and Thompsons Rd.	Bond St Owen St Tyrendarra School Rd Thompsons Rd

Event	Flood Characteristics	Key roadways inundated
5% AEP	Sunday Creek has overtopped its banks into adjacent land, however there is no significant roadways or key assets flooded. Sunday Creek starts receding 11 hours after flooding began. In the upper catchment area of the Fitzroy River (from upstream of Heywood to Boundary Rd), flooding peaks approximately 28 hours after flooding began. This floodplain area is typically at least 250m wide and is heavily vegetated floodplain. No major infrastructure or residential areas are affected in this area. The flood peak then continues towards Heywood, peaking at approximately 4 hours after the upper catchment. Approximately 1.5km upstream of Heywood, there is a channel break out to the north of the river, abutting the Mount Gambier railway line. This breakout reconnects with the main Fitzroy River upstream of the Princes Hwy bridge, after passing over Bond St and Owen St on the northern side of the river in Heywood. Heywood is the critical location within the catchment for inundation. This event primarily inundates parkland and floodplain, however properties on the south side of the Fitzroy River at Heywood between Bond St and the Railway line become threatened by floodwater. Downstream of Heywood, at the start of the Fitzroy River - Darlot Creek swamp confluence area, the Fitzroy River splits into two major flow paths, with one flow path filling a large basin, whilst the other flow path continues towards the lower catchment. The lower catchment is typically characterised by inundation to low-lying swampland, and does not exhibit flooding of key infrastructure. In the upper Darlot catchment, Condah Swamp, Lake Condah and Whittlebury Creek storages inundate a large area of land. This is mostly swamp and farmland. The downstream Darlot Creek catchment typically inundates swamp and marshland, without affecting residential areas or key infrastructure. After the confluence of Darlot Creek and Fitzroy River, the far downstream end of the catchment exhibits flooding of swampland as per upstream. However, it appears two roads become inundated, Tyrendarra School Rd and Thompsons Rd.	Bond St Owen St Tyrendarra School Rd Thompsons Rd

Event	Flood Characteristics	Key roadways inundated
2% AEP	Sunday Creek has overtopped its banks into adjacent land, however there is no significant roadways or key assets flooded. Sunday Creek starts receding 11 hours after flooding began. In the upper catchment area of the Fitzroy River (from upstream of Heywood to Boundary Rd), flooding peaks approximately 24 hours after flooding began. This floodplain area is typically at least 250m wide and is heavily vegetated floodplain. No major infrastructure or residential areas are affected in this area. The flood peak then continues towards Heywood, peaking at approximately 3 hours after the upper catchment. Approximately 1.5km upstream of Heywood, there is a channel break out to the north of the river, abutting the Mount Gambier railway line. This breakout reconnects with the main Fitzroy River upstream of the Princes Hwy bridge, after passing over Bond St and Owen St on the northern side of the river in Heywood. Heywood is the critical location within the catchment for inundation. This event inundates numerous properties in Heywood, with sections Cameron St and Hunter St East inundated. Downstream of Heywood, at the start of the Fitzroy River - Darlot Creek swamp confluence area, the Fitzroy River splits into two major flow paths, with one flow path filling a large basin, whilst the other flow path continues towards the lower catchment. The lower catchment is typically characterised by inundation to low-lying swampland, and does not exhibit flooding of key infrastructure. In the upper Darlot catchment, Condah Swamp, Lake Condah and Whittlebury Creek storages inundate a large area of land. This is mostly swamp and farmland. The downstream Darlot Creek catchment typically inundates swamp and marshland, without affecting residential areas or key infrastructure. In this event, a section of Tyrendarra-Ettrick Rd is inundated downstream of Homerton. After the confluence of Darlot Creek and Fitzroy River, the far downstream end of the catchment exhibits flooding of swampland as per upstream. However, it appears two roads become inundated, Tyrendarra School Rd and Thompsons Rd.	Bond St Owen St Tyrendarra-Ettrick Rd at Darlot Creek Tyrendarra School Rd Thompsons Rd Cameron St Hunter St

Event	Flood Characteristics	Key roadways inundated
1% AEP	Sunday Creek is the first significant flooding. Sunday Creek does not flood any key infrastructure, apart from overtopping Woolsthorpe-Heywood Rd. Typically the flooding is restricted to farmland. Sunday Creek peaks after approximately 12 hours of flooding, then almost fully recedes 30 hours after flooding began. In the upper catchment area of the Fitzroy River (from upstream of Heywood to Boundary Rd), flooding peaks approximately 26 hours after flooding began. This floodplain area is approximately 500m wide and is typically heavily vegetated. No major infrastructure or residential areas are affected in this area. The flood peak then continues towards Heywood, peaking at approximately 2 hours after the upper catchment. Heywood is the critical location within the catchment for inundation, with numerous properties inundated to various levels in this event on the southern side of the River. Properties on Hunter St and Cameron St are the most inundated. The sporting fields on the north side of Heywood are also inundated. This event also causes inundation of the Princes Hwy in Heywood. Downstream of Heywood, at the start of the Fitzroy River - Darlot Creek swamp confluence area, the Fitzroy River splits into two major flow paths, with one flow path filling a large basin, whilst the other flow path continues towards the lower catchment. The lower catchment is typically characterised by inundation to low-lying swampland, and does not exhibit flooding of key infrastructure. In the Upper Darlot Catchment, Condah Swamp, Lake Condah and Whittlebury Creek storages inundate a large area of land. This is mostly swamp and farmland. The downstream Darlot Creek catchment typically inundates swamp and marshland, without affecting residential areas or key infrastructure. In this event, a section of Tyrendarra-Ettrick Rd is inundated downstream of Homerton. The downstream Darlot Creek catchment typically inundates swamp and marshland, without affecting residential areas or key infrastructure. In this event, a section of Tyrendarra-Ettrick Rd is inundated downstream of Homerton. After the confluence of Darlot Creek and Fitzroy River, the far downstream end of the catchment exhibits flooding of swampland as per upstream. Apart from two minor roads becoming inundated (Tyrendarra School Rd and Thompsons Rd) there is also inundation of the Princes Highway at Lovells Lane.	Bond St Owen St Woolsthorpe-Heywood Rd at Sunday Creek Princes Highway / Edgar St at Heywood Tyrendarra-Ettrick Rd at Darlot Creek Tyrendarra School Rd Thompsons Rd Princes Highway at Downstream end of Fitzroy River Hunter St Cameron St

Event	Flood Characteristics	Key roadways inundated
0.5% AEP	Sunday Creek is the first significant flooding. Sunday Creek does not flood any key infrastructure, apart from overtopping Woolsthorpe-Heywood Rd. Typically the flooding is restricted to farmland. Sunday Creek peaks after approximately 11 hours of flooding. In the upper catchment area of the Fitzroy River (from upstream of Heywood to Boundary Rd), flooding peaks approximately 25 hours after flooding began. This floodplain area is approximately 500m wide and is typically heavily vegetated. No major infrastructure or residential areas are affected in this area. The flood peak then continues towards Heywood, peaking at approximately 2 hours after the upper catchment. Heywood is the critical location within the catchment for inundation, with numerous properties inundated to various levels in this event on the southern side of the River. Properties on Hunter St, Cameron St and Scott St are the most inundated. The sporting fields on the north side of Heywood are also inundated. This event also causes inundation of the Princes Hwy in Heywood on both sides of the Fitzroy road crossing. Downstream of Heywood, at the start of the Fitzroy River - Darlot Creek swamp confluence area, the Fitzroy River splits into two major flow paths, with one flow path filling a large basin, whilst the other flow path continues towards the lower catchment. The lower catchment is typically characterised by inundation to low-lying swampland, and does not exhibit flooding of key infrastructure. In the upper Darlot catchment, Condah Swamp, Lake Condah and Whittlebury Creek storages inundate a large area of land. This is mostly swamp and farmland. The downstream Darlot Creek catchment typically inundates swamp and marshland, without affecting residential areas or key infrastructure. In this event, a section of Tyrendarra-Ettrick Rd is inundated downstream of Homerton. After the confluence of Darlot Creek and Fitzroy River, the far downstream end of the catchment exhibits flooding of swampland as per upstream. Apart from two minor roads becoming inundated (Tyrendarra School Rd and Thompsons Rd) there is also inundation of the Princes Highway at Lovells Lane.	Bond St Owen St Woolsthorpe-Heywood Rd at Sunday Creek Princes Highway / Edgar St at Heywood Tyrendarra-Ettrick Rd at Darlot Creek Tyrendarra School Rd Thompsons Rd Princes Highway at Downstream end of Fitzroy River Hunter St Cameron St Scott St

Event	Flood Characteristics	Key roadways inundated
0.2% AEP	Sunday Creek is the first significant flooding. Sunday Creek does not flood any key infrastructure, apart from overtopping Woolsthorpe-Heywood Rd. Typically the flooding is restricted to farmland. Sunday Creek peaks after approximately 11 hours of flooding. In the upper catchment area of the Fitzroy River (from upstream of Heywood to Boundary Rd), flooding peaks approximately 25 hours after flooding began. This floodplain area is approximately 500m wide and is typically heavily vegetated. No major infrastructure or residential areas are affected in this area. The flood peak then continues towards Heywood, peaking at approximately 2 hours after the upper catchment. Heywood is the critical location within the catchment for inundation, with numerous properties inundated to various levels in this event on the southern side of the River. Properties on Hunter St, Cameron St and Scott St are the most inundated. The sporting fields on the north side of Heywood are also inundated. This event also causes inundation of the Princes Hwy in Heywood on both sides of the Fitzroy road crossing. Downstream of Heywood, at the start of the Fitzroy River - Darlot Creek swamp confluence area, the Fitzroy River splits into two major flow paths, with one flow path filling a large basin, whilst the other flow path continues towards the lower catchment. The lower catchment is typically characterised by inundation to low-lying swampland, and does not exhibit flooding of key infrastructure. In the upper Darlot catchment, Condah Swamp, Lake Condah and Whittlebury Creek storages inundate a large area of land. This is mostly swamp and farmland. The downstream Darlot Creek catchment typically inundates swamp and marshland, without affecting residential areas or key infrastructure. In this event, a section of Tyrendarra-Ettrick Rd is inundated downstream of Homerton. The downstream Darlot Creek catchment typically inundates swamp and marshland, without affecting residential areas or key infrastructure. In this event, a section of Tyrendarra-Ettrick Rd is inundated downstream of Homerton. After the confluence of Darlot Creek and Fitzroy River, the far downstream end of the catchment exhibits flooding of swampland as per upstream. Apart from two minor roads becoming inundated (Tyrendarra School Rd and Thompsons Rd) there is also inundation of the Princes Highway at Lovells Lane.	Bond St Owen St Woolsthorpe-Heywood Rd at Sunday Creek Princes Highway / Edgar St at Heywood Tyrendarra-Ettrick Rd at Darlot Creek Tyrendarra School Rd Thompsons Rd Princes Highway at Downstream end of Fitzroy River Hunter St Cameron St Scott St

5 FLOOD BEHAVIOUR AND INTELLIGENCE OUTPUTS

5.1 Overview

The flood behaviour and intelligence outputs developed as part of the Fitzroy River, Darlot Creek and Heywood Regional Floodplain Mapping Study are described in this section.

5.2 Model Results Outputs

The model result data including grids and extents have been provided in specified Victorian Flood Database (VFD) format for each flood event. The following result components were generated:

- Flood level, flood depth, flood velocity and flood hazard grids
- Flood elevation contours
- Flood extent data
- Hydrographs at key locations

Details are provided of the study outputs for emergency response, and land use planning mapping including:

- Data sets: grids and shapefiles (ESRI/VFD format), Data tables (Excel csv/xlsx format).

5.3 Data Sets

The following datasets have been provided. All GIS files were provided in ESRI VFD format or Excel csv/xlsx format. A summary of the datasets is provided below and shown in Figure 5-1.

5.3.1 Grids

Gridded datasets of model results were provided for the following:

- Design events (20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF events) – maximum depth, hazard, velocity and water surface elevation.
- Calibration events (1946, 2007, 2010, and 2013 events) – maximum depth and water surface elevation.
- Model Topography

The hydraulic analysis provides regular grid of flood elevations across the hydraulic model study area. The flood extent was defined by converting the 2m flood elevations grid to an extent polygon. The extent is smoothed to remove the sharp edges of the grid cells for cartographic / presentation purposes.

Flood depths were classified for mapping using the following classifications:

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

4145_R04V02

5.3.2 Vector Data

ERSI shapefiles in VFD format were provided for the following:

- Peak flood extents
- Peak flood elevation contours
- Mapping limits

5.3.3 Data Tables

Data tables in excel CSV format were provided for the following:

- Stage height hydrographs at 50 points across the study area for 6 design events (20%, 10%, 5%, 2%, 1% and 0.5% AEP events).
- Water surface level profile along the Fitzroy River for 6 design events (20%, 10%, 5%, 2%, 1% and 0.5% AEP events). The long section profile location is shown in Figure 5-1.

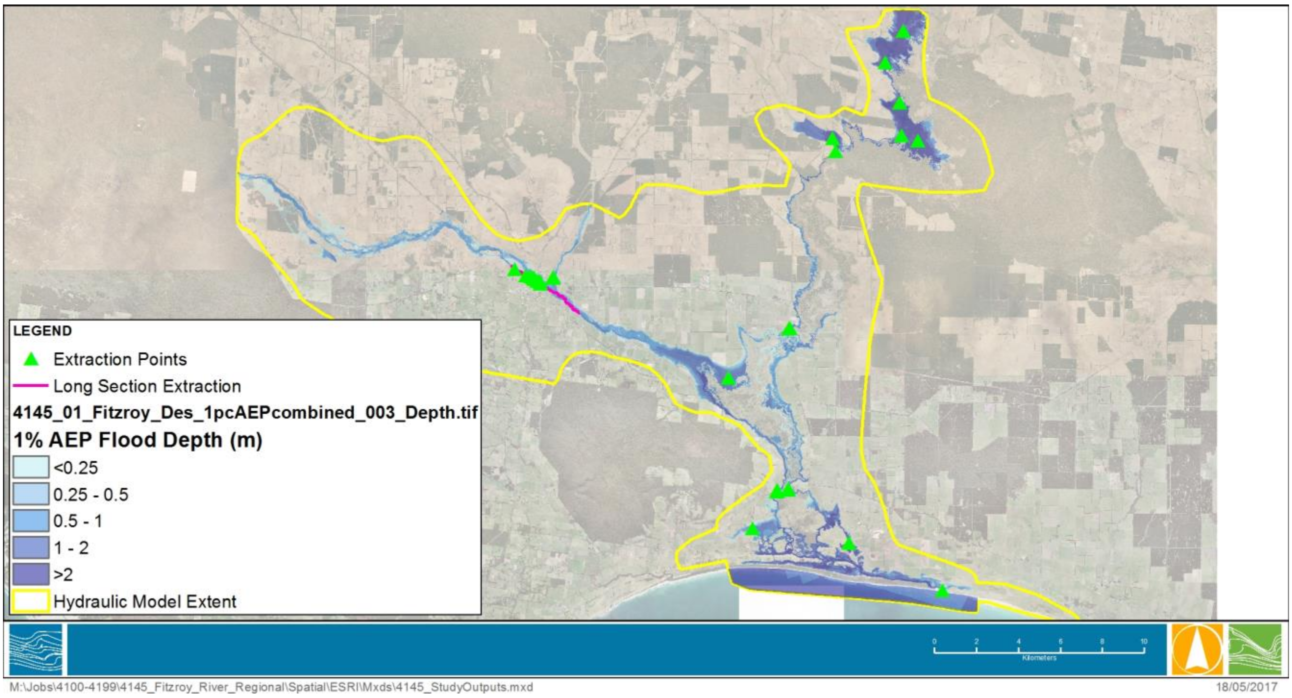

Figure 5-1 Long Section and Point Extraction Locations

5.3.4 Gauge Height Relationship

For each design flood event, the model results were interpreted to provide information on the relationship between the flood level at each of the gauges on the Fitzroy River and Darlot Creek and the equivalent design flood magnitude (in % AEP and ARI (years)). Table 5-1 and Table 5-2, results of the assessment.

Table 5-1 Fitzroy River at Heywood Gauge Heights for Design Flood Events

Gauge Height[1] (m)	Flood level at Gauge (m AHD)	Design Flood Event AEP (%)	Design Flood Event ARI (years)
1.95	25.77	20	5
2.25	26.07	10	10
2.44	26.26	5	20
2.61	26.43	2	50
2.70	26.52	1	100
2.78	26.60	0.5	200
2.90	26.72	0.2	500

Table 5-2 Darlot Creek at Homerton Gauge Heights for Design Flood Events

Gauge Height[2] (m)	Flood level at Gauge (m AHD)	Design Flood Event AEP (%)	Design Flood Event ARI (years)
1.72	22.09	20	5
1.90	22.27	10	10
2.12	22.49	5	20
2.37	22.74	2	50
2.51	22.88	1	100
2.72	23.09	0.5	200
3.01	23.38	0.2	500

5.4 Study Deliverables

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

- Digital copies of study reports in PDF format.
- Digital copies of the maps (PDF format)
- GIS datasets for the model results (ArcGIS VFD format and Excel csv format)
- Digital elevation models

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

4145_R04V02

[1] The Heywood gauge is located at Heywood on the Fitzroy River. Gauge zero is 23.82m AHD
[2] The Homerton gauge is located at Homerton on Darlot Creek. Gauge zero is 20.37m AHD

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Overview

The Fitzroy River, Darlot Creek and Heywood Regional Floodplain Mapping Study provides a comprehensive analysis and review of flood risk in the Fitzroy River catchment. The study has involved:

- Collection and review of a range of data relevant to the definition of flooding within the study area.
- A rigorous hydrologic analysis to develop robust design flood estimates for the study.
- Development of a detailed hydraulic model that is capable of predicting flood impacts across the entire floodplain under a range of conditions.
- Design and calibration model result outputs.

6.2 Key Outcomes

In undertaking this study, a number of important aspects of flood risk relevant to the Fitzroy River and Darlot Creek catchment have become apparent. These are summarised as follows.

Hydraulic Characteristics of the Fitzroy River – Overbank flows are common in the Fitzroy River catchment, however significant flooding does not occur in the key township of Heywood in floods less than a 1% AEP event. In the 2% AEP event and larger flood events. As the magnitude of a flood event increases the increase in flow results in an increase in depth and velocity and flood extent, especially on the northern side of town. There are also a number of key roadways at risk through the town and at the downstream end of the river

Hydraulic Characteristics of Darlot Creek – The Darlot Creek catchment exhibits two key types of flooding regimes, 'dry catchment events' and 'staged wet catchment events'. A dry catchment event is characterised by a relatively dry catchment pre-flood event. This means there is minimal baseflow leading up to the event, and Lake Condah and the Condah Swamp area upstream are not holding a significant volume of water. The catchment is then subject to a significant rainfall event, which may cause flooding in the Fitzroy River catchment, but is unlikely to cause flooding in the Darlot Creek catchment.

A staged wet catchment event is characterised by a relatively wet catchment pre-flood event. This type of event consists of a series of rainfall events. This results in the steady rise of the water levels in Lake Condah over a period of months. There may also be one final large rainfall event which results in the peak flow in Darlot Creek over the entire period. These types of flood events have flood peaks in the catchment which slowly increase following rainfall (approximately one week), then have steadily increasing peaks throughout the wet period each time it rains.

Flooding does not appear to be common along Darlot Creek due to the major storages upstream of Tyrendarra. These storages dominate flood levels in the catchment and are capable of retaining enough volume to effectively remove the flood peak of major flood events that come from upstream. For the design floods, a conservative methodology was used, assuming a staged wet catchment event concluding with a design event.

6.3 Learnings and Recommendations

6.3.1 Learnings

4145_R04V02

Based on the study process and outcomes the following learnings are noted for future Regional Flood Studies:

- Traditional techniques for streamflow gauging is difficult in high flow events when there are flow breakouts around the gauge. This behaviour occurs at the Fitzroy River at Heywood gauge. The use of the hydraulic model in conjunction with traditional streamflow gauging could better construct an extrapolated gauge rating curve suitable for estimating flows in events the break out of channel.

- In complex catchments without quality streamflow data, where there are major uncertainties in the hydrology, a joint hydrology-hydraulic calibration such as that adopted in this study can be highly beneficial.
- Sharing of major datasets between different Government agencies remains an issue, as evidenced by the different LiDAR datasets that were uncovered throughout the project. Improved sharing of this data is encouraged.

6.4 Recommendations

With regard to the study outcomes, the following recommendations are provided:

- Flood levels in Darlot Creek are sensitive to pre-event catchment conditions, especially Lake Condah levels. It is recommended that Condah Weir operating procedures and management are reviewed, taking into account environmental and cultural assets that the lake provides, along with the implications on water supply and flooding.
- Whilst the wider catchment is not affected by Fitzroy River outlet berm conditions, there is a noticeable impact in the downstream end of the model. Whilst management of the berm is currently regulated by GHCMA, it is recommended that an official management plan be designed and implemented.
- The Heywood gauge is currently significantly bypassed during flows greater than the 10% AEP, via a flowpath to the north of the main river and gauge. This severely impacts the quality of the output data from this site. Re-location of the site is recommended, with the railway crossing at Heywood appearing to be an appropriate site. It should be noted that DELWP has already commissioned high-flow gauging updates based on model results from this study.
- If flood class levels are to be introduced at the Fitzroy River at Heywood gauge, it would be recommended to introduce Minor Flood Class at 25.7 m AHD (1.88 m at gauge), Moderate Flood Class at 26.0 m AHD (2.18 m at gauge) and major flooding at 26.3 m AHD (2.48 at Gauge). These levels are based on the BOM guidelines, with the Minor Flood Class level starting to inundate the Heywood parkland areas, the Moderate Flood Class level beginning to inundate properties in Heywood above floor level and roadways, and the Major Flood Class Level causing extensive inundation of roadways and properties in the catchment.
- The GHCMA and Glenelg Shire Council adopt the determined design flood levels and proceed to incorporate them into planning scheme amendments.
- The GHCMA and Glenelg Shire Council continue to engage the community in the treatment of flood risks through regular flood awareness programs such as the VICSES FloodSafe program. This project has already lead to the commissioning of a Municipal Flood Emergency Plan (MFEP) outputs that will allow for a local flood guide for Heywood to be developed.
- Flood levels in Heywood are sensitive to the rail bridge opening, and potential increases in the bridge culvert capacity should be considered for flood mitigation.
- DELWP should incorporate the results of this study into the Victorian Flood Database and upload to FloodZoom.

7 REFERENCES

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