Goulburn River Constraints Management - Environmental Flow Inundation Modelling and Mapping

January 2016

DOCUMENT STATUS

Version	Doc type	Reviewed by	Approved by	Distributed to	Date issued
v01	Report	Ben Tate	Ben Tate	Geoff Earl, Guy Tierney	15/11/2015
v02	Report	Ben Tate	Ben Tate	Geoff Earl, Guy Tierney	15/12/2015
v04	Report	Ben Tate	Ben Tate	Geoff Earl, Guy Tierney	28/01/2016
V04	Final	Ben Tate	Ben Tate	Geoff Earl, Guy Tierney	28/01/2016

PROJECT DETAILS

Project Name	Goulburn River Environmental Flow Mapping Project
Client	Goulburn Broken Catchment Management Authority
Client Project Manager	Geoff Earl
Water Technology Project Manager	Lachlan Inglis
Report Authors	Lachlan Inglis
Job Number	3954-01
Report Number	R03
Document Name	Goulburn River Environmental Flow Mapping Project_R03_FINAL.docx

Cover Photo: Goulburn River near Alexandra, source: www.foresthillrotary.com

Quality ISO 9001 SAI GLOBAL
Environment ISO 14001 SAI GLOBAL
Health & Safety AS 4801 SAI GLOBAL

15 Business Park Drive
Notting Hill VIC 3168

Telephone (03) 8526 0800
Fax (03) 9558 9365

ACN No. 093 377 283
ABN No. 60 093 377 283

TABLE OF CONTENTS

1. Introduction 7

2. Task 1 – Data Collation 8

2.1 Streamflow Data 8
2.2 Permanent Gauges with Rating Curves 11
2.3 Temporary Gauging Data 11

3. Hydraulic Model Build 12

3.1 Grid Extent and Resolution 12
3.2 DEM Preparation 12
3.3 Channel Profile 14
3.3.1 Mid Goulburn Model 15
3.3.2 Lower Goulburn Model 16
3.3.3 Murray River 18
3.4 Roughness 19

4. Task 2 - Calibration 20

4.1 Mid Goulburn Model 20
4.1.1 November 2011 Release 21
4.2 Lower Goulburn Model 24

5. Task 3 – Environmental Flow Modelling 25

6. Task 4 - Goulburn Tributary Interactions 26

6.1 Acheron River 26
6.2 Yea River 32
6.3 Murray River 40

7. TASK 5 - Statistics 45

7.1 Total Area Inundated 48
7.2 Buildings 49
7.3 Dwellings Isolation 54
7.4 Bridges 56
7.5 Roads 58
7.6 Specialist Business 62
7.7 Public Land 62
7.8 Private Land 64
7.9 Land Use 66
7.10 Native Vegetation 75
7.11 Wetlands 76

8. Levee Profiles 78

9. References 81

LIST OF FIGURES

Figure 2-1 Streamflow Gauges located within the Goulburn River catchment 10
Figure 3-1 Mid Goulburn Hydraulic Model DEM 13
Figure 3-2 Lower Goulburn Hydraulic Model DEM 13
Figure 3-3 Starting Channel Depth below LiDAR Levels in the mid Goulburn Model 15
Figure 3-4 Model DEM verification upstream of Trawool 16
Figure 3-5 Model DEM verification downstream of Alexandra 16
Figure 3-6 Bathymetric Points and ISC 'Top of Bank' layers for the Lower Goulburn 17
Figure 3-7 Example Cross Section Upstream of McCoys Bridge 18
Figure 3-8 Example Cross Section at Loch Garry 18
Figure 4-1 Gauged Flows in the Goulburn Catchment between Lake Eildon and Trawool 22
Figure 4-2 Mid Goulburn Temporary Peak Level Indicators 23
Figure 6-1 Low Acheron Flow - Flood Extents 27
Figure 6-2 Low Acheron River Event - Difference Plot 27
Figure 6-3 Low Acheron River Event - Long Section Plot 28
Figure 6-4 High Acheron River Event - Flood Extents 29
Figure 6-5 High Acheron River Event - Difference Plot 29
Figure 6-6 High Acheron River Event - Long Section Plot 30
Figure 6-7 Acheron River Time Series Locations 30
Figure 6-8 Acheron River Time Series Downstream of Breakaway Rd, High Acheron Flows 31
Figure 6-9 Acheron River Time Series Upstream of Breakaway Rd, High Acheron Flows 31
Figure 6-10 Low Yea Flow - Flood Extent comparisons 33
Figure 6-11 Low Yea River Event - Difference Plot 33
Figure 6-12 Low Yea River Event - Long Section 34
Figure 6-13 High Yea Flow - Flood Extents 35
Figure 6-14 High Yea River Event - Difference Plot 35
Figure 6-15 High Yea River Event - Long Section 36
Figure 6-16 Yea River Time Series Locations 37
Figure 6-17 High Yea River Flow Comparison - Goulburn River Running Distance 360 37
Figure 6-18 High Yea River Flow Comparison - Yea River Location 12 38
Figure 6-19 Low Yea River Flow Comparison - Goulburn River Running Distance 360 38
Figure 6-20 Low Yea River Flow Comparison - Yea River Location 12 39
Figure 6-21 Murray/Goulburn River Interaction - Flood Model Extent 40
Figure 6-22 25,000 ML/d Goulburn River flow - High and Low Murray River Difference Plot 42
Figure 6-23 35,000 ML/d Goulburn River flow - High and Low Murray River Difference Plot 43
Figure 6-24 40,000 ML/d Goulburn River flow - High and Low Murray River Difference Plot 43
Figure 6-25 55,000 ML/d Goulburn River flow - High and Low Murray River Difference Plot 44
Figure 7-1 Goulburn Constraints - Statistics Reach Layout 46
Figure 7-2 Total Inundation Area 48
Figure 7-3 Total Buildings within Flood Extent 50
Figure 7-4 Houses within Flood Extent 50
Figure 7-5 House Sites Flooded above 300 mm 52
Figure 7-6 "Other" Buildings within the Flood Extent 53
Figure 7-7 Public Land Inundated 63
Figure 7-8 Private Land Inundated 65
Figure 7-9 Reach 1 - Land Use Type Inundated 67
Figure 7-10 Reach 2 - Land Use Type Inundated 68
Figure 7-11 Reach 3 - Land Use Type Inundated 69
Figure 7-12 Reach 4 - Land Use Type Inundated 70
Figure 7-13 Reach 5 - Land Use Type Inundated 71

Figure 7-14 Reach 6 - Land Use Type Inundated ... 72
Figure 7-15 Reach 7 - Land Use Type Inundated ... 73
Figure 7-16 Reach 8 - Land Use Type Inundated ... 74
Figure 7-17 Native Vegetation Inundated (ha) ... 75
Figure 7-18 Wetlands Inundated (ha) ... 76
Figure 7-19 Percentage of Wetland Inundated ... 77
Figure 8-1 Goulburn Levee Profile Section Layout ... 78
Figure 8-2 Goulburn Levee section 1 Example Longitudinal section ... 78

Figure A - 1 Bathymetry of Goulburn River at Yea ... 83
Figure A - 2 Example of the Lower Goulburn River Bathymetry ... 84
Figure A - 3 Lake Nagambie Bathymetry Extent ... 85
Figure A - 4 Lower Goulburn SRWSC Cross Section Locations ... 85
Figure A - 5 Location of Goulburn River Cross Sections at Seymour ... 86
Figure A - 6 Mid Goulburn Topographic Datasets ... 87
Figure A - 7 Lower Goulburn Topographic Datasets ... 88
Figure A - 8 LiDAR & Cross Section Comparison Locations ... 89
Figure A - 9 Cross Section 13 LiDAR comparison ... 91
Figure A - 10 Cross Section 14 LiDAR Comparison ... 91
Figure A - 11 Lower Goulburn Levee Crest Survey ... 92

LIST OF TABLES

Table 2-1 Mid Goulburn Streamflow Data Records obtained from DELWP (2015) ... 8
Table 2-2 Lower Goulburn Streamflow Data Records obtained from DELWP (2015) ... 9
Table 2-3 Ratings Curves used with Maximum Gauging’s ... 11
Table 3-1 Available LiDAR sets throughout the Goulburn River Study Area ... 12
Table 3-2 Manning's 'n' Roughness values ... 19
Table 4-1 mid Goulburn Steady State Calibration ... 20
Table 4-2 Mid Goulburn Model - Gauge Comparisons (Modelled Minus Rating Curve) ... 21
Table 4-3 Thiess Temporary Gauging Data ... 22
Table 4-4 Lower Model Gauge Comparisons (Modelled Minus Rating Curve) ... 24
Table 5-1 Goulburn River Modelled Environmental Flow Rates ... 25
Table 6-1 Acheron River Tributary Interaction ... 26
Table 6-2 Yea River Tributary Interaction ... 32
Table 6-3 Murray River Tributary Interaction ... 41
Table 6-4 Area of Inundation (NSW Only), hectares ... 41
Table 6-5 Area of Inundation (McCoys Bridge - Murray River), hectares ... 42
Table 7-1 Available Design Flows ... 45
Table 7-2 Total Inundation Area ... 48
Table 7-3 Total Buildings within Flood Extent ... 49
Table 7-4 House Sites Flooded Above 300 mm ... 51
Table 7-5 "Other" Buildings within the Flood Extent ... 53
Table 7-6 Dwellings Isolated "Access cut" by environmental watering event ... 54
Table 7-7 Number of Road Bridges Inundated ... 56
Table 7-8 Length of Road Bridges Inundated (metres) ... 57
Table 7-9 Length of Road Inundated - Reach 1 (metres) ... 58
Table 7-10 Length of Road Inundated - Reach 2 (metres) ... 58
Table 7-11 Length of Road Inundated Reach 3 (metres) ... 59
Table 7-12 Length of Road Inundated - Reach 4 Seymour to Goulburn Weir (metres) ... 59

Table 7-13 Length of Road Inundated - Reach 5 (metres) ... 60
Table 7-14 Length of Road Inundated - Reach 6 (metres) ... 60
Table 7-15 Length of Road Inundated - Reach 7 (metres) ... 61
Table 7-16 Length of Road Inundated - Reach 8 (metres) ... 61
Table 7-17 Specialist Businesses impacted in Reach 1 & 2 ... 62
Table 7-18 Specialist Businesses impacted in Reach 3-8 ... 62
Table 7-19 Public Land Inundated ... 63
Table 7-20 Private Land Inundated ... 64
Table 7-21 Reach 1 - Land Use Type Inundated ... 67
Table 7-22 Reach 2 - Land Use Type Inundated ... 68
Table 7-23 Reach 3 - Land Use Type Inundated ... 69
Table 7-24 Reach 4 - Land Use Type Inundated ... 70
Table 7-25 Reach 5 - Land Use Type Inundated ... 71
Table 7-26 Reach 6 - Land Use Type Inundated ... 72
Table 7-27 Reach 7 - Land Use Type Inundated ... 73
Table 7-28 Reach 8 - Land Use Type Inundated ... 74
Table 7-29 Native Vegetation Inundated (ha) ... 75
Table 7-30 Wetlands Inundated (ha) ... 77
Table 8-1 Length of Levee Overtopped (m) ... 79

Table A - 1 Available LiDAR sets throughout the Goulburn River study area ... 89
Table A - 2 LiDAR Comparison Statistics ... 90

1. INTRODUCTION

This report details all work undertaken for the Goulburn River Environmental Flow Mapping project commissioned by the Goulburn Broken Catchment Management Authority (GBCMA). The project provides improved flow mapping and technical analysis to assist GBCMA in preparation of the environmental flow business case for the Goulburn River, addressing constraints in environmental flow delivery.

The work required for the Goulburn River Environmental Flow Business Case includes:

1. Understanding of hydrologic processes, particularly around tributary inflows to the Goulburn River;
2. Asset mapping including, specialist businesses (fish farms, high value agriculture, sand and gravel mining, caravan parks), dwellings and general buildings, roads and bridges;
3. Project costs evaluation including structures, levee upgrades, and easements; and
4. Hydraulic modelling to determine the inundation footprint areas for a range of environmental flows, including an impact assessment around the tributary inflows and statistical inundation assessment of identified assets.

This report focuses primarily on item 4 of the Goulburn River Business case above.

This report details the hydraulic model calibration approach taken to enable the modelling of overbank environmental flows. The report covers the use of permanent streamflow gauging stations throughout the floodplain as well as temporary gauging stations installed in the upper reach of the mid Goulburn River during an environmental flow release in November 2011 to undertake hydraulic calibration. A series of potential design flowrates were modelled to produce maximum flood depth, velocity and water surface result grids throughout the study area. A range of statistics relating to physical constraints and benefits of the environmental water releases have been included in this report. The statistics were also provided to GBCMA in Microsoft Excel format along with the flood model extents and result grids in a GIS format.

2. TASK 1 – DATA COLLATION

A number of hydrological and hydraulic studies have been undertaken throughout the Goulburn River catchment. Information from previous studies was used to inform decisions and assumptions around the modelling techniques applied throughout this project. Of the previous studies on the Goulburn River, Water Technology has undertaken several flood modelling and mapping projects in the past 5 years. An environmental flow study was undertaken which modelled the Goulburn River from Eildon through to Echuca as 8 separate hydraulic models (Water Technology, 2010). In 2014, these models were used for the MDBA to test further flow scenarios (Water Technology, 2014). The 2014 report also identified the benefits of utilising new emerging GPU hydraulic modelling software to greatly improve modelling of the river system.

Other information used in the project includes rainfall and streamflow data available from the Bureau of Meteorology and the Department of Environment, Land, Water and Planning's Water Measurement Information System. The Victorian State Government VICMAP, LiDAR and aerial imagery was utilised within this project. The GBCMA also provided a range of GIS layers used in the statistical analysis of the constraints and opportunities associated with the environmental water flows.

2.1 Streamflow Data

A good series of streamflow gauges with a long streamflow record exist throughout the mid and lower Goulburn River, the active gauges in the area are listed in Table 2-1 and Table 2-2 respectively. A number of the streamflow gauges along the Goulburn River do not have rating curves developed due to a lack of gauging data, the water level data from these gauges is however still useful for calibration purposes.

Table 2-1 Mid Goulburn Streamflow Data Records obtained from DELWP (2015)

Station	River	Station name	Start date	Finish date	Max gauged height (m)	Max gauged flow (ML/d)	Date of maximum gauging
405203	Goulburn	Eildon	1953	N/A	5.47	152,900	24/09/1916
405201	Goulburn	Trawool	1925	N/A	6.496	57,700	20/09/1975
405202	Goulburn	Seymour	1967	N/A	7.031	82,000	18/09/1975
405259	Goulburn	Goulburn Weir HG	2005	N/A	124.325	-	26/10/2013
405209	Acheron	Taggerty	1961	N/A	3.241	25,379	05/09/2010
405217	Yea	Devlins Bridge	1975	N/A	4.297	21,191	11/06/1989

Table 2-2 Lower Goulburn Streamflow Data Records obtained from DELWP (2015)

Station	River	Station name	Start date	Finish date	Max gauged height (m)	Max gauged flow (ML/d)	Date of maximum gauging
405200	Goulburn	Murchison[1]	1881	N/A	10.571	410,680	19/09/1975
405270	Goulburn	Kialla West	1977	1985	10.699	59,300	26/07/1981
405204	Goulburn	Shepparton	1987	N/A	12.081	191,200	17/05/1974
405276	Goulburn	Loch Garry	1978	N/A	10.893	97,400	07/10/1993
405232	Goulburn	McCoy Bridge	1967	N/A	11.015	167,300	19/05/1974
405277	Goulburn	D/S Yambuna Drain Outfall	1978	1996	9.548	44,000	08/10/1993

[1] Murchison Flood Study (Water Technology, 2013) Indicates the current rating at Murchison significantly overestimates the discharge at higher flows.

Figure 2-1 Streamflow Gauges located within the Goulburn River catchment

2.2 Permanent Gauges with Rating Curves

Rating curves were used to undertake a preliminary model calibration over a range of steady state flows. The flow rates considered ranged between the lowest environmental flow of interest (7,000 ML/d at Eildon) and the largest (55,000 ML/d downstream of the Goulburn Weir). Rating tables exist at eight of the twelve streamflow gauges identified in Table 2-1 and Table 2-2. The mid Goulburn model used rating tables at three permanent gauging stations; Eildon, Trawool and Seymour, all of which had good rating curve data between the flow rates of 7,000 ML/d and 40,000 ML/d. The Lower Goulburn model used five rating curves at Murchison, Kialla West, Shepparton, Loch Garry and McCoys Bridge. Table 2-3 shows the maximum gauged flow at each of the twelve gauges located within the study area.

Individual gauging data was made available for all gauging's on the Goulburn River during 2010 and 2011. This data was used to help verify the rating curves at locations where they were used.

Table 2-3 Ratings Curves used with Maximum Gauging's

Station	Station name	Start date	Max gauged height (m)	Max gauged flow (ML/d)	Date of maximum gauging
405203	Eildon	1953	5.47	152,900	24/09/1916
405201	Trawool	1925	6.496	57,700	20/09/1975
405202	Seymour	1967	7.031	82,000	18/09/1975
405253	Goulburn Weir	1980	10.594	111,000	17/05/1974
405200	Murchison	1881	10.571	410,700	19/09/1975
405270	Kialla West	1977	10.699	59,300	26/07/1981
405204	Shepparton	1987	12.081	191,200	17/05/1974
405276	Loch Garry	1978	10.893	97,400	07/10/1993
405232	McCoy Bridge	1967	11.015	167,300	19/05/1974
405277	D/S Yambuna Drain Outfall	1978	9.548	44,000	08/10/1993
405209	Acheron River at Taggerty	1961	3.241	25,379	05/09/2010
405217	Yea River at Devlins Bridge	1975	4.297	21,191	11/06/1989

2.3 Temporary Gauging Data

Goulburn Broken CMA commissioned Thiess Services to undertake gauging during an environmental flow release from Lake Eildon at 10 locations between Eildon and Killingworth. This gauging data was able to provide peak water levels at the 10 locations with an Eildon release of 7,000 ML/d and 9,000 ML/d. These flow rates are around bankfull type flows in the mid Goulburn River, so the gauge information allowed calibration of this section of the mid Goulburn River model at the critical bankfull level at more locations than just the three permanent gauges.

3. HYDRAULIC MODEL BUILD

3.1 Grid Extent and Resolution

The mid Goulburn model extent covers 39,000 ha from the Lake Eildon through to the Goulburn Weir at Nagambie. This area has a defined floodplain which has a number of anabranches and oxbow wetlands throughout the floodplain. The lower Goulburn model covers a much larger area at 125,000 ha, from the Goulburn Weir through to the Murray River upstream of Echuca. The model also includes the Murray River from Barmah to Echuca to allow the impact of Goulburn and Murray River flow interactions to be assessed. A 10 metre grid resolution was used in the model, this allowed for the Goulburn River channel to be represented by a minimum of 3-5 cells wide.

3.2 DEM Preparation

A digital elevation model (DEM) was constructed for the hydraulic model using the available LiDAR, bathymetry and field survey from a number of sources. The available LiDAR datasets are shown in Table 3-1. These datasets were then combined, adjusting them to match each other and benchmarking them to available field survey throughout the catchment. A 1 m grid resolution DEM was constructed of the flood model from the available LiDAR. A final 10 m DEM used for both of the models was produced and is shown below in Figure 3-1 and Figure 3-2. More detail on the LiDAR and survey datasets used in the DEM preparation as well as the representation of the Goulburn channel can be found in the data review summary in Appendix A.

Table 3-1 Available LiDAR sets throughout the Goulburn River Study Area

LiDAR Set	Resolution	Date Flown	Vertical Accuracy
Floodplains Stage 1 (FP1)	1 m DEM	2010	± 0.10 m
Floodplains Stage 3 (FP3)	1 m DEM	2011	± 0.10 m
Index of Stream Condition (ISC)	1 m DEM	2010	± 0.20 m
Furgo Spatial Services (FSS)	1 m & 5 m DEM	2007	± 0.10 m
Think Spatial UAV	1 m DEM	2013	± 0.15 m
North East Towns	1 m DEM	2013	± 0.10 m
VicMap Elevation	20 m DEM	2008	NA
Geoscience Australia (GA)	1 second DEM	2009	NA
Murray River (MDBA)	1 m DEM	2001	± 0.15 m

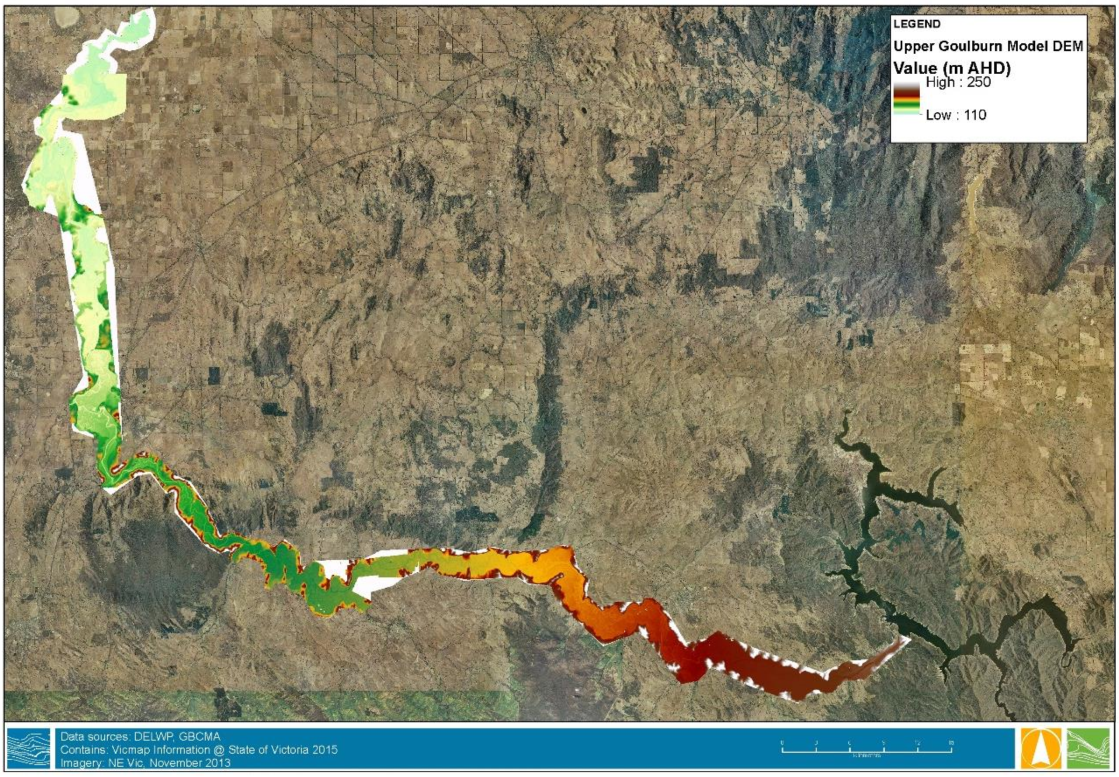

Figure 3-1 Mid Goulburn Hydraulic Model DEM

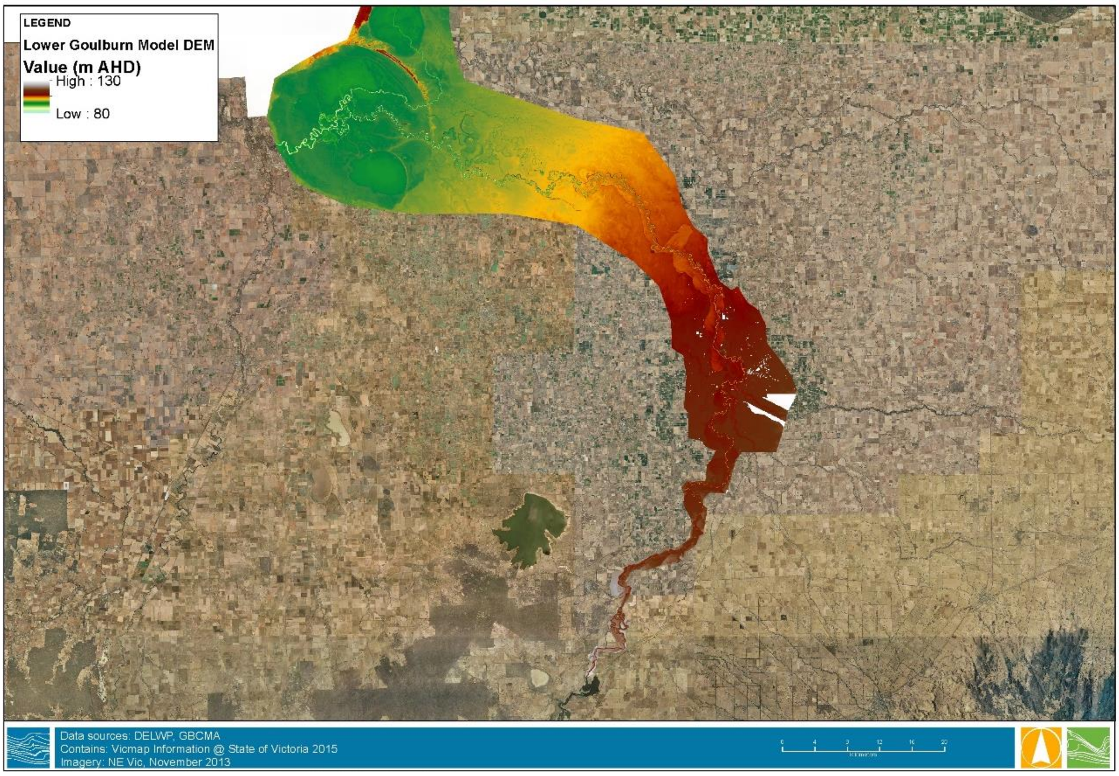

Figure 3-2 Lower Goulburn Hydraulic Model DEM

3.3 Channel Profile

The LiDAR datasets available for use do not provide an accurate representation of the channel profile of the Goulburn River and associated anabranches. This is a result of the LiDAR being flown when water is present within the channel, the LiDAR being unable to penetrate the water. To better represent the conveyance of the river channel the water level bathymetry was used where present including within Lake Nagambie and upstream of the Yea River. This bathymetry was added to the 2D terrain, supplementing the LiDAR data.

The channel profile of the Lower Goulburn River was represented using bathymetry along the centreline (or close to the centreline) of the river where available. The point data bathymetry was used to set the bed level along the channel using TUFLOW TIN lines and Z points which were then tinned back to the LiDAR level at the bank edge using ISC top of bank shape files. This method was not intended to accurately represent the channel profile 100%, however it provided a method that could be implemented relatively easily along the river and could be manipulated during model calibration. A number of surveyed cross sections throughout the lower Goulburn model were also used to compare against the model DEM during calibration. The above method was found to replicate the channel shape reasonably well upon comparison to available cross-section survey.

The majority of the mid Goulburn River has little channel profile information outside of the bathymetry data at Killingworth and Lake Nagambie. To represent the channel profile outside of these areas, a simplified channel lowering was undertaken using a similar method as used in the lower model. Given there was no bathymetry of the river available, a predetermined value as the depth from the water surface to the channel bed was estimated in three general areas shown in Figure 3-3 using available cross sections.

The average depths to the bed of the channel were used to set the initial channel profile in the mid Goulburn model, in an attempt to estimate the average depth to the channel bed. Upstream of the Yea River, the depth of the channel below the interpolated LiDAR surface/water level was set to 1 metre. Between the Yea River bathymetry and the field survey at Seymour, the channel was set to 1.5 metres below the LiDAR levels. Finally, between the survey at Seymour and the bathymetry at Lake Nagambie, the channel depth was set 2 metres below the LiDAR levels. This was further manipulated during the calibration phase of modelling and is described in Section 4.

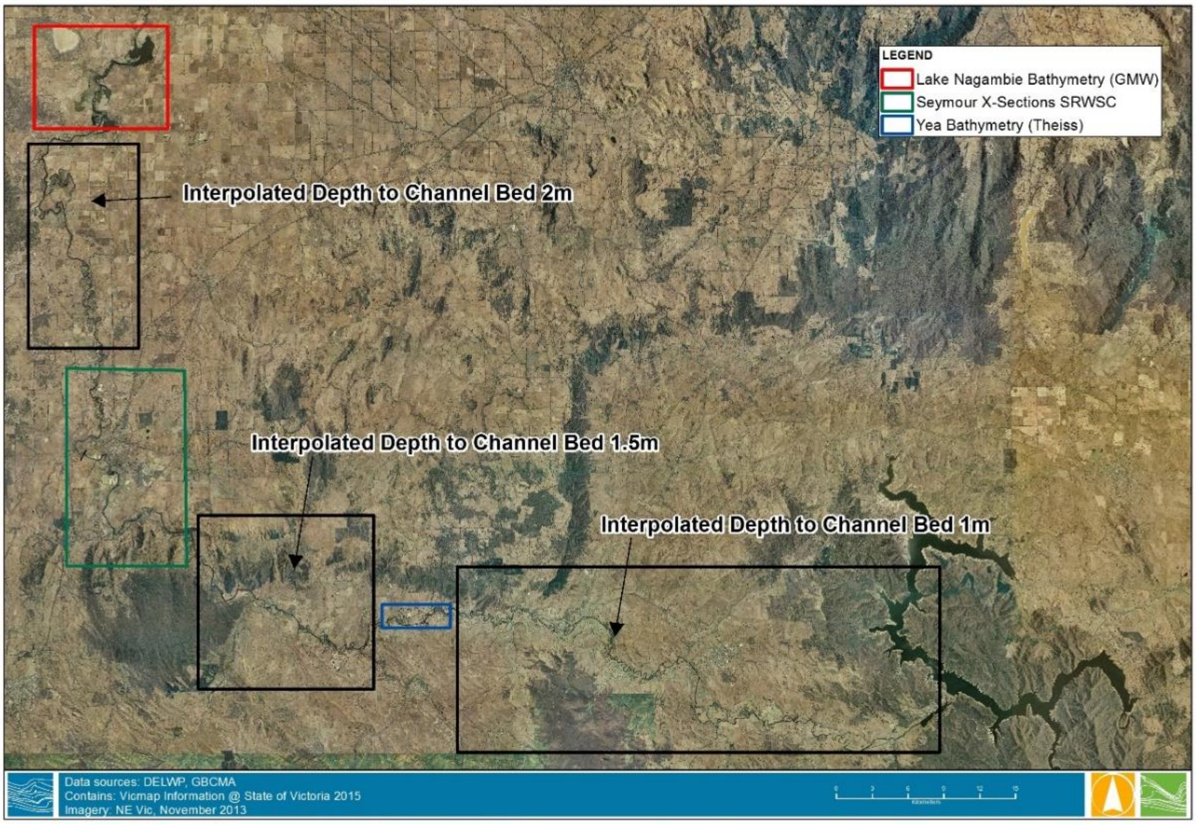

Figure 3-3 Starting Channel Depth below LiDAR Levels in the mid Goulburn Model

3.3.1 Mid Goulburn Model

The Furgo Spatial Services (FSS) LiDAR was used as the primary LiDAR dataset in the mid Goulburn River model as it covers the majority of the model area and generally extends wider on the floodplain than the Index of Stream Condition (ISC) Rivers LiDAR. Where required, the ISC Rivers LiDAR was used as the secondary LiDAR. Figure 3-4 and Figure 3-5 show where the LiDAR was lowered generally at the centreline of the channel and tinned back to the top of banks. These two plots show that while the model DEM doesn't line up exactly with the survey data, it does however give a good representation of the channel which can be adjusted based on calibration values.

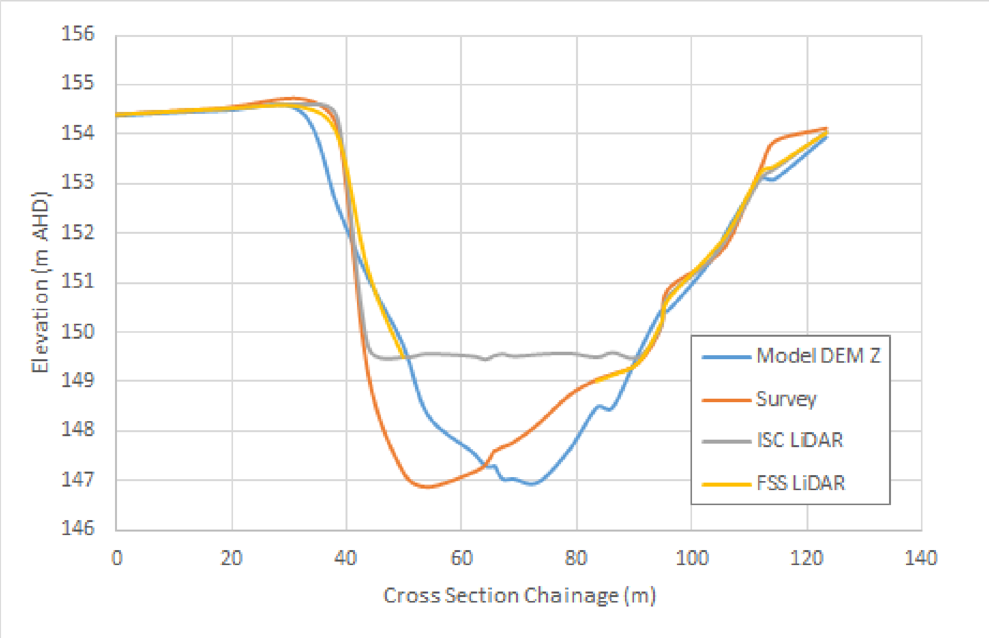

Figure 3-4 **Model DEM verification upstream of Trawool**

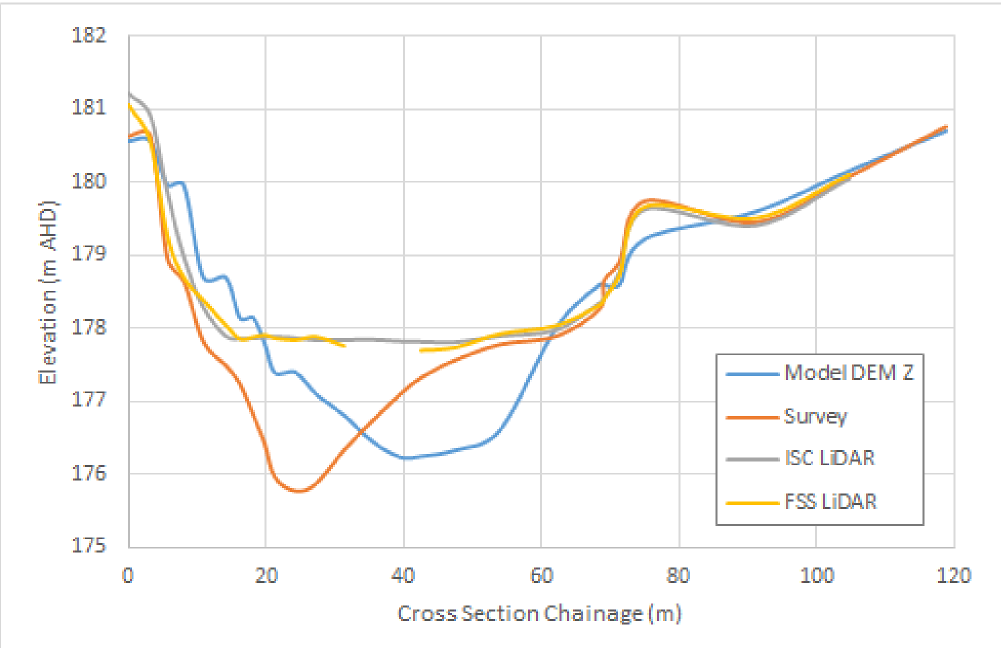

Figure 3-5 **Model DEM verification downstream of Alexandra**

3.3.2 Lower Goulburn Model

The lower Goulburn model calibration was undertaken in a similar manner to the mid Goulburn model. Bathymetric data from the Goulburn Weir through to the Murray River was available at regular intervals, an example of an area in the lower Goulburn model which shows the path of the boat while taking the points is shown in Figure 3-6. Over 400,000 bathymetric points were used in the lower Goulburn model. A similar method to the mid Goulburn channel profile was used. The bathymetric points were triangulated between each point and then back to the top of bank points (obtained from the LiDAR). The top of bank points were identified using the Victorian Index of Stream Condition shape files and then manually checked, these lines are also shown in Figure 3-6. Available cross sections throughout the lower model in a number of locations to check the channel profile was well represented in the final DEM used in the hydraulic model, two examples are shown in Figure 3-7 and Figure 3-8. These examples show that the method used to represent the channel profile within the 10 m grid gave a good representation and a starting point for calibration.

Figure 3-6 Bathymetric Points and ISC 'Top of Bank' layers for the Lower Goulburn

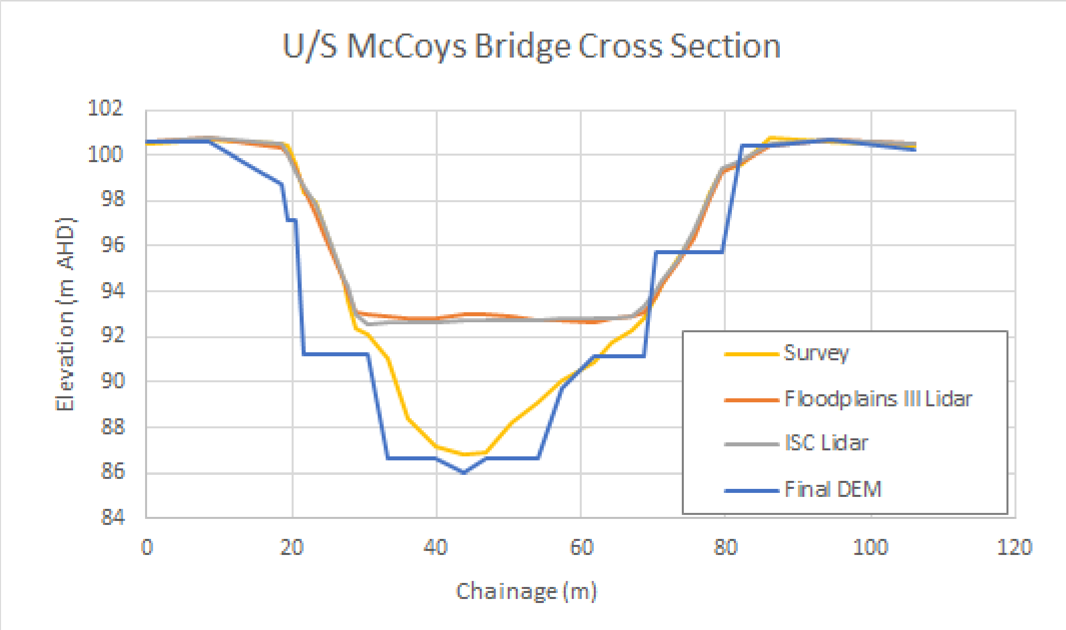

Figure 3-7 Example Cross Section Upstream of McCoys Bridge

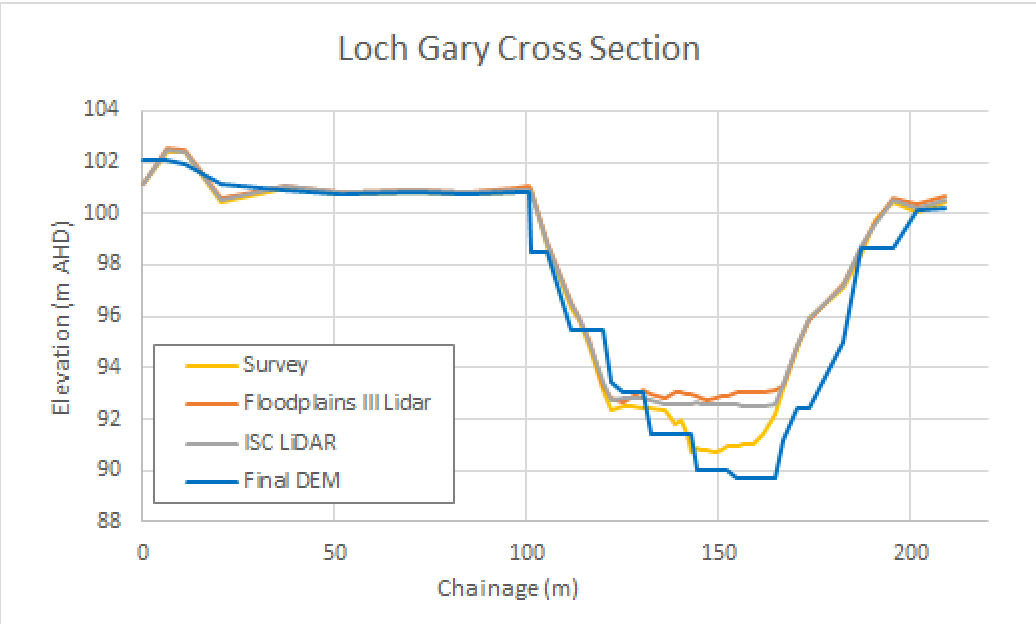

Figure 3-8 Example Cross Section at Loch Garry

3.3.3 Murray River

The Lower Goulburn model included around 45 km of the Murray River from Barmah to Echuca. ISC and floodplains LiDAR covered around half of this reach of the river. To cover the remaining area, LiDAR flown for the Murray Darling Basin Authority (MDBA) in 2001 was used. As the main objective of the study was to assess the constraints to environmental flow releases on the Goulburn River, depicting the channel profile within the Murray River was not a high priority. The available LiDAR was placed directly into the DEM without any modification to the channel, meaning the model's river bed was the river water surface when the LiDAR was captured. Using the metadata from MDBA LiDAR, it was found that the time over which the LIDAR was flown, the flow rate through this section of the channel was around 5,500 – 6,000 ML/d. Incorporation of the Murray River channel shape would improve the modelling of lower Goulburn floodplain inundation around the Goulburn/Murray confluence.

3.4 Roughness

The Manning's 'n' roughness parameter has important effects on flood velocities, flow paths, flood depths and extents. Manning's 'n' roughness values were derived from the latest planning scheme and aerial photography and refined during calibration.

For the 2D domain, simplified '*2d_mat'* TUFLOW files were produced based on the position within the floodplain as well as the likely vegetation based on high-resolution aerial photographs. The Manning's roughness values are specified in the .tmf TUFLOW model file. The final values used are listed below in Table 3-2. Manning's 'n' roughness coefficients used in the model were adopted from industry guidelines as a starting point and adjusted during calibration of the model.

Table 3-2 Manning's 'n' Roughness values

Material	Manning's n Roughness
Main Channel	0.03
Broader Floodplain (Low Vegetation/Grass)	0.04
Floodplain (Dense Vegetation/bushland)	0.05

4. TASK 2 - CALIBRATION

Steady state flows for both the mid and lower model calibration were run and compared to water levels from rating curves at permanent gauging stations. The mid Goulburn model was calibrated to steady flows of 7,000, 9,000 and 12,000 ML/d using three permanent gauges as well as ten temporary gauges located from Eildon to Molesworth. The lower Goulburn model used steady state flows released from the Goulburn Weir at Nagambie of 20,000 25,000 and 30,000 ML/d. The use of steady state calibration across the catchment allowed for the calibration of the model to a number of well-developed streamflow gauge rating curves, taking some of the uncertainty out of matching to an actual hydrograph when tributary flows vary in magnitude and timing along the Goulburn River.

4.1 Mid Goulburn Model

Initially the calibration of the three steady flows (7,000, 9,000 and 12,000 ML/d) showed that water levels modelled were in the order of 600-1200 mm too high at the Eildon and Trawool gauge. The Seymour gauge was also approximately 300 mm too high. This provided an initial indication that the capacity of the channel in the model was considerably less than the surveyed cross section data available. Using what survey data was available, the final model DEM was checked in several locations and confirmed that the cross sectional area of the channel within the model was significantly smaller. All channel centreline points which were estimated in Figure 3-3 where lowered an additional 1 metre from the original values used and the model was re-run. The second iteration of the three steady state flows showed a closer representation of gauged levels at the three permanent gauge locations as well as the ten temporary gauging locations. Levels were still 100-300 mm higher than the gauged level across nearly all of the locations. The Mannings 'n' roughness values were then adjusted from the original 0.04 within the channel to 0.03 to provide a slight reduction in flood levels. This impact also served as a sensitivity analysis of the roughness parameters within the model. The water levels across the entire mid model reduced on average 100-200 mm with flood levels at the three permanent gauges much closer to the gauged level as shown in Table 4-1. The Eildon and Seymour gauges were calibrated within +/- 150 mm, while the Trawool gauge was overestimating the flood levels by 150-300 mm at the three steady state flows.

Table 4-1 mid Goulburn Steady State Calibration

Gauge	7,000 ML/d Gauged	7,000 ML/d Modelled	Difference
Eildon	207.93	207.82	-0.11
Trawool	140.88	141.02	0.14
Seymour	132.39	132.30	-0.09
Gauge	**9,000 ML/d Gauged**	**9,000 ML/d Modelled**	**Difference**
Eildon	208.14	208.02	-0.12
Trawool	141.17	141.43	0.26
Seymour	132.61	132.63	0.02
Gauge	**12,000 ML/d Gauged**	**12,000 ML/d Modelled**	**Difference**
Eildon	208.54	208.41	-0.14
Trawool	141.65	142.94	0.29
Seymour	133.00	133.08	0.08

Given the rapid assessment approach taken, whereby entire reaches of the river were lowered by constant values from the water surface as well as the use of simplified roughness maps this was accepted as an appropriate calibration. Further refinement to the spatially varying roughness maps and a higher level of detail in the bathymetry could be used to reduce the difference in flood levels at the Trawool gauge for lower flows. However it was felt this was a localised discrepancy around the Trawool gauge and has little impact on results across the model reach and is likely to have little impact on the overall constraints analysis through the mid Goulburn model. The nature of floodplain in the reach where the main river channel is well incised and the floodplain in the immediate area does not contain built assets prone to regular flooding at the flow rates being assessed, the local discrepancy was considered acceptable for this study.

Table 4-2 Mid Goulburn Model - Gauge Comparisons (Modelled Minus Rating Curve)

Gauge	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d
Eildon	-0.11	-0.12	-0.14	-0.1	-0.07
Trawool	0.14	0.26	0.29	0.35	0.35
Seymour	-0.09	0.02	0.08	0.14	0.2
Gauge	**20,000 ML/d**	**25,000 ML/d**	**30,000 ML/d**	**35,000 ML/d**	**40,000 ML/d**
Eildon	-0.04	N/A	N/A	N/A	N/A
Trawool	0.34	0.3	-0.07	-0.12	-0.14
Seymour	0.21	0.19	0.1	0.03	-0.02

4.1.1 November 2011 Release

The modelling of calibration events in the mid Goulburn River has previously been identified as an issue due to the ungauged tributaries within the catchment. A previous study found that around 57% of the catchment between Eildon and Trawool was ungauged (Water Technology, 2010), and 65% of tributary catchment between Seymour and Murchison was ungauged. This study also identified that considerable additional inflows to the Goulburn River can be generated from these ungauged catchments. The development of a full hydrologic model to calibrate to gauges throughout the catchment was outside the scope of this project however staged environmental releases from the Lake Eildon provide the opportunity to calibrate the hydraulic model for flow events at Trawool and Seymour streamflow gauges where the impact of the ungauged catchments is lessened.

Between 16th November and 26th November, two staged flow releases of 7,000 and 9,000 ML/d were released from Lake Eildon. This November 2011 flow event between Lake Eildon and Trawool was dominated by flows released from Eildon, which accounted for approximately 74% of the total volume at Trawool. Other gauged tributary flows within this reach increased the total gauged volume to 94% of the total volume at Trawool. This allowed for the event to be calibrated within the hydraulic model providing confidence that the stream flow rates were almost wholly a result of the release from the Lake Eildon and the gauged tributary inflows.

The Goulburn Broken CMA commissioned Thiess services to install 10 water level indicators at locations on the Goulburn River between Lake Eildon and Killingworth as shown in Figure 4-2 (Water Technology, 2012). These gauges were monitored at Eildon flows of approximately 7,000 and 9,000 ML/d. The Thiess temporary gauging data results were used to calibrate the mid Goulburn model by running two steady state flows from the Lake Eildon of 7,000 ML/d and 9,000 ML/d. Of the ten gauging locations shown in Figure 4-2, the peak water level at 7,000 ML/d was replicated within +/- 200 mm at eight gauges, while peak water levels were within +/- 200 mm for nine gauges at the 9,000 ML/d flow rate. At gauge number 5 (Heritage listed Bridge upstream of the Acheron River), the model underestimated the flood level by 240 mm at the 7,000 ML/d flow rate. At gauge 8 (Berdue Homestead), the model overestimated the flood levels for both flow scenarios by 220 mm and 240 mm for the two flow rates. When assessing the calibration results at these ten temporary peak water level indicators, it was noted that the gauges were often separated by only 4-5 km of river running distance. Therefore the gauges with differences greater than 200 mm from gauged results appear to be localised discrepancies where the temporary gauges either immediately upstream or downstream appear to be well calibrated. Results of the Thiess temporary gauging data are shown in Table 4-3. This additional data was able to further validate the hydraulic model calibration process when combined with the permanent gauges at Eildon, Trawool and Seymour. It also provided further confidence in the ability of the model to replicate flows in the order of 7,000 – 12,000 ML/d in the mid Goulburn model between Eildon and Molesworth.

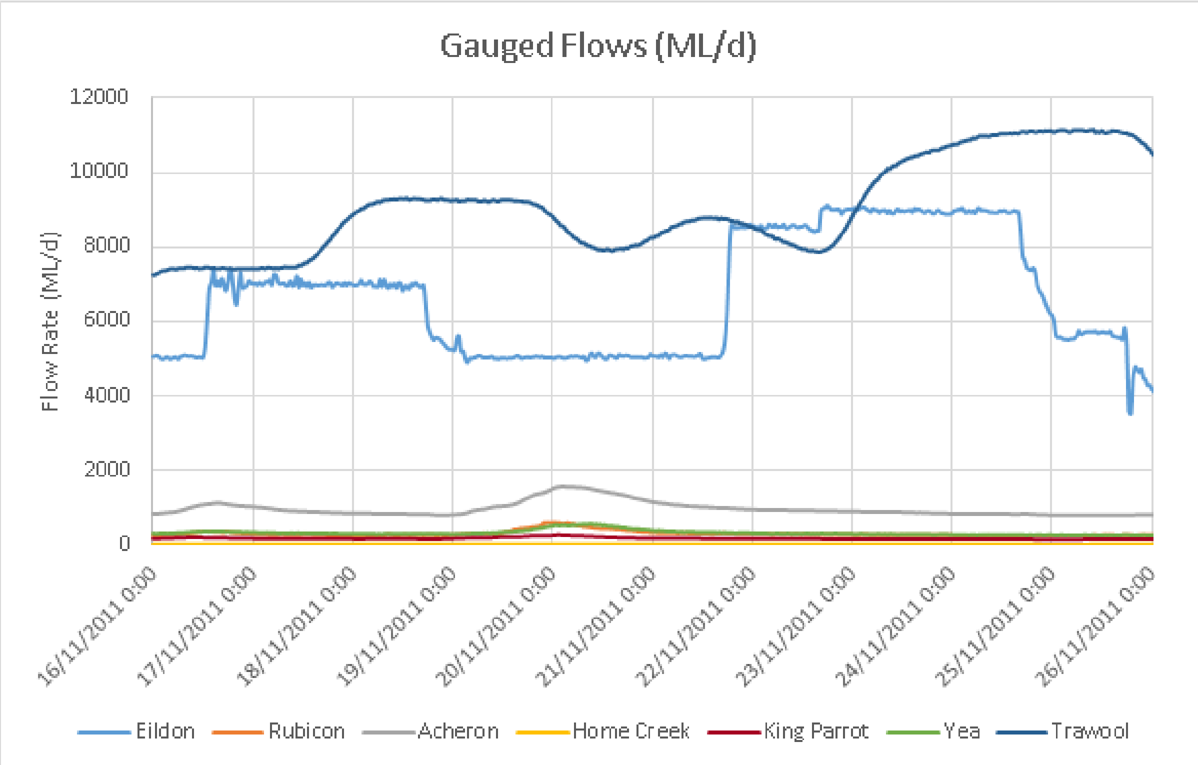

Figure 4-1 Gauged Flows in the Goulburn Catchment between Lake Eildon and Trawool

Table 4-3 Thiess Temporary Gauging Data

	7,000 ML/d			9,000 ML/d		
Gauge	**Gauged height (m AHD)**	**Modelled height (m AHD)**	**Difference (m)**	**Gauged height (m AHD)**	**Modelled height (m AHD)**	**Difference (m)**
1– Point Hill River Reserve	204.68	204.71	0.03	205.06	205.04	-0.02
2– Turn-off opposite Thoms Lane	202.28	202.21	-0.07	202.61	202.47	-0.14
3– Thornton Beach River Reserve	198.60	198.55	-0.05	198.84	198.82	-0.02
4– Gilmores Bridge	194.50	194.31	-0.19	194.71	194.54	-0.17
5– Heritage Listed Bridge	186.97	186.73	-0.24	187.15	187.00	-0.15

6– Private Property	183.37	183.27	-0.10	183.67	183.55	-0.12
7– Off-Stream Lagoon	179.11	179.15	0.04	179.42	179.48	0.07
8– Berdue Homestead	174.70	174.92	0.22	174.99	175.23	0.24
9 – End of Ridds Road	171.97	171.93	-0.04	172.30	172.25	-0.05
10–Molesworth Pedestrian Bridge	168.66	168.83	0.17	169.09	169.26	0.17

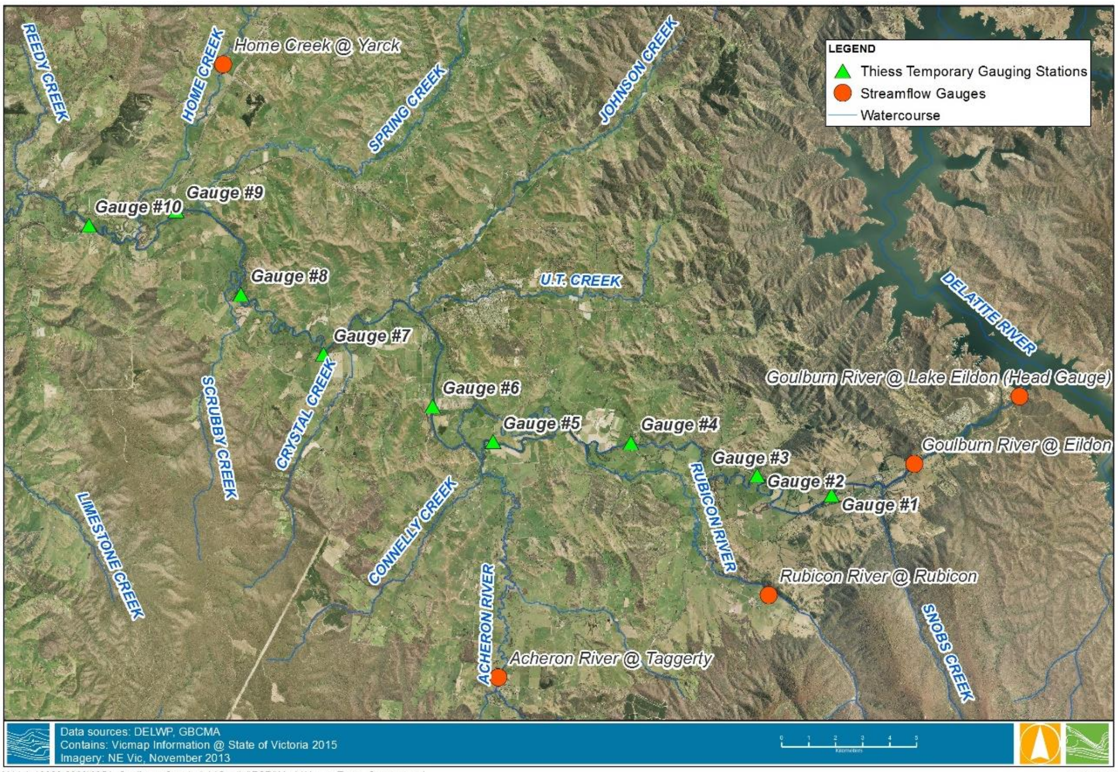

Figure 4-2 Mid Goulburn Temporary Peak Level Indicators

As well as the calibration to available streamflow gauging, the GBCMA conducted landholder consultation in the mid Goulburn. This was used to pick up further features affecting flow spilling onto the floodplain. Feedback from landholders in the area between Eildon and Molesworth generally agreed that the calibration modelling of 7,000 ML/d and 9,000 ML/d showed similar extents to what had been previously observed from flows of similar magnitude.

Between Seymour and Goulburn Weir there was no data to calibrate the model performance against. However, consultation by GBCMA with local landowners indicated that the model levels were higher than recent flood experience at much higher flows in the Mitchellstown, Tahbilk and Nagambie area. Unfortunately the modelling software does not adequately represent the flow behaviour in weir structures like Goulburn Weir, causing the weir tailwater to limit flow out of the model. Further, consultation indicated model levels are too low near Northwood. As a result, the model results in the Northwood (running distance 299 km) and Goulburn Weir were not used further in this study. Previous model results at flow rates of 30,000 ML/d and 40,000 ML/d produced by Water Technology in 2010 were used for the statistical analysis of the Goulburn River between Northwood and the Goulburn Weir.

Based on the levels observed at the temporary and permanent gauging locations combined with the community consultation, the GBCMA accepted the mid Goulburn model as being calibrated and sufficient for use in the environmental flow design mapping.

4.2 Lower Goulburn Model

The lower Goulburn Model was calibrated at Murchison, Shepparton and Loch Garry for flow rates of 25,000 ML/d, 30,000 ML/d and 35,000 ML/d. A good record of gauging's at flow rates in this magnitude exist at these three gauges. This allowed for good calibrations across these flow rates at the three sites, with Murchison at 30,000 ML/d which underestimated the water level being the exception.

At higher flows, the model at Loch Garry reasonably replicates the rating curve up to flows of 55,000 ML/d. At Shepparton the model tends to underestimate water levels as flow rates increase to 55,000 ML/d. This may be a result of the inability to include the Shepparton-Mooroopna Causeway structures in the TUFLOW GPU model. At Murchison the model replicates levels at 45,000 and 55,000 ML/d flows well but underestimates at 40,000 ML/d by 450 mm. When compared to the rating curve at McCoys Bridge, the model replicates the rating curve well for flows up to 35,000 to 40,000 ML/d, but then increasingly overestimates water levels as flows increase.

The gauges at Yambuna and Kialla West have limited gauging data across the higher flow rates assessed giving less certainty to the rating curves available. It was decided to only undertake a relaxed calibration approach at these locations and ensure that water levels were in the proximity of the expected values given the lack of reliable data. The model consistently overestimated the water level at Kialla West by around 600-800 mm, while at Yambuna it consistently underestimates the water level by 200-400 mm.

It was also noted that the Murray River reach within the lower Goulburn model had no data to calibrate to as the Barmah gauge was at the top of the model and the Echuca gauge was at the downstream end of the model.

Overall, the model gives a reasonable estimation of the total level of inundation, but is a less reliable predictor of inundation at some particular sites and flow rates. The GBCMA accepted the calibration for the lower model to be fit for purpose in mapping of the environmental flow design events.

Table 4-4 Lower Model Gauge Comparisons (Modelled Minus Rating Curve)

Gauge	Calibration Flow Rates (ML/d)					
	25,000	30,000	35,000	40,000	45,000	55,000
Murchison	0.03	-0.43	-0.16	-0.45	-0.03	-0.02
Kialla West	0.83	0.54	0.64	0.67	0.69	0.70
Shepparton	-0.02	-0.14	-0.17	-0.20	-0.28	-0.33
Loch Garry	0.08	-0.01	-0.09	-0.12	-0.15	-0.11
McCoys	-0.04	-0.13	-0.02	0.16	0.23	0.37
Yambuna	-0.31	-0.45	-0.46	-0.35	-0.31	-0.23

5. TASK 3 – ENVIRONMENTAL FLOW MODELLING

With both mid and lower Goulburn models calibrated, steady state flows were run through the models to determine what land was inundated at points along the river at different flow rates, listed in Table 5-1. This was achieved by having no tributary flows (except for a flow of roughly 11,000 ML/d in the Murray River at Barmah), and running a steady state flow from the upstream end of each model until water levels along the river reached equilibrium. This is not intended to be a water release strategy, but to provide a known flow at each point along the river to determine the inundation caused by that flow. This does not account for any backwater effects that could occur if less water came down the Goulburn River and more came from a particular tributary. The running of design flow scenarios for the mid Goulburn model (Eildon to Goulburn Weir) ranged from 7,000 ML/d through to 20,000 ML/d. Flows of 25,000 ML/d up to 40,000 ML/d were modelled from Killingworth to the Goulburn Weir. Results from previous modelling undertaken in 2010 by Water Technology were used for the area between Northwood and the Goulburn Weir but were limited to flow rates of 30,000 ML/d and 40,000 ML/d. Unfortunately the older modelling was of a much lower resolution and due to the 1D and 2D mapping not seamlessly mapping like the software allows now, the inundation mapping of the previous models is not very detailed.

The Lower Goulburn Model which ran from the Goulburn Weir through to the Murray River had six flow rates from 25,000 ML/d up to 55,000 ML/d. The lower model also included around 45 km of the Murray River from Barmah to Echuca. A constant flow rate of 5,000 ML/d used as the flow rate through the Murray. As mentioned previously, the channel profile in the Murray River was not altered from the LiDAR, therefore the water levels in the channel are higher than expected for the 5,000 ML/d flow rate. Using streamflow data at the Barmah gauge for the date taken from the LiDAR metadata, it was estimated that there was a flow of around 6,000 ML/d. Therefore it could be assumed that the water levels modelled in the Murray River system more accurately represented a flow rate of around 10,000 ML/d to 12,000 ML/d.

Table 5-1 Goulburn River Modelled Environmental Flow Rates

Eildon to Goulburn Weir	Killingworth, RD369.8 km to Northwood RD299 km	Northwood RD299 km to Goulburn Weir[1]	Goulburn Weir to Murray River
7,000 ML/d	25,000 ML/d		25,000 ML/d
9,000 ML/d	30,000 ML/d	30,000 ML/d	30,000 ML/d
12,500 ML/d	35,000 ML/d		35,000 ML/d
17,500 ML/d	40,000 ML/d	40,000 ML/d	40,000 ML/d
20,000 ML/d			45,000 ML/d
			55,000 ML/d

[1] Water Technology CPU Modelling Models D and E1 (2010)

6. TASK 4 - GOULBURN TRIBUTARY INTERACTIONS

Given environmental releases are proposed to be added to unregulated flows from the tributaries, a key question is the impact of increased Goulburn River flows on inundation in the tributaries when they have a significant flow. As a first step in understanding this issue, the interaction of the Acheron and Yea Rivers with the Goulburn River was modelled. The impact of Murray River flows on water levels in the Goulburn River was also assessed to help provide further information around the impact of high and low flow combinations of Murray and Goulburn Rivers on inundation in the Lower Goulburn floodplain.

6.1 Acheron River

In a separate model, the Goulburn River was modelled from around 6 km upstream and downstream of the confluence (using part of the mid Goulburn model), while the Acheron River was modelled from Taggerty to the Goulburn River confluence (a distance of 15 km). For the Acheron topography, ISC LiDAR was used plus Thalweg survey along the river. The THELWAG survey of the Acheron River was provided to Water Technology as points every 100-300 m along the waterway. In between these locations, the riverbed was interpolated every 5 metres. These points at or close to the centre of the waterway were produced to represent the channel profile of the Acheron River below the water surface shown in the LiDAR. This method replicated the Mid Goulburn Model in triangulating the THELWAG point to the top of bank points on both sides of the River obtained from the LiDAR. Initially the model resolution was kept at 10 m, however this did not provide an accurate representation of the Acheron River and a 5 m grid resolution was adopted.

The model was used to compare inundation under four scenarios (listed below in Table 6-1). The absolute levels of inundation were not important. Rather the modelling aimed to show a change in inundation between scenarios to understand the nature of interaction. The scenarios modelled assess the impact of a high Goulburn release, in this case 12,500 ML/d and a normal low flow of around 150 ML/d at the confluence of the Acheron and the Goulburn. In the Acheron, a normal winter/spring low flow of 800 ML/d was selected, along with the August 2005 flood flow hydrograph (a reasonable sized flood) measured at the Taggerty flow gauge.

Table 6-1 Acheron River Tributary Interaction

Scenario	Goulburn River (peak flow ML/d)	Acheron River (peak flow ML/d)
High Goulburn High Acheron	12,500	8,000
High Goulburn Low Acheron	12,500	800
Low Goulburn High Acheron	150	8,000
Low Goulburn Low Acheron	150	800

The impact of a high flow down the Goulburn River during a low flow event down the Acheron River was measured by assessing the flood extents of the Low Acheron/Low Goulburn against the Low Acheron/High Goulburn flow rate as shown in Figure 6-1. This showed an increase in flood extent along the Goulburn River and a small area to the south of Breakaway Road. Figure 6-2 shows the difference in maximum flood levels, with an increase of between 50- 100 cm up the Acheron River to the Breakaway Rd bridge. Flood levels are at least 50 cm higher under the High Goulburn River flow for approximately 800 m upstream of Breakaway Road. The difference in flood levels then decreases relatively quickly as the difference in levels decreases to less than 2 cm over the next 500 m. This corresponds to the increased slope of the Acheron River around this area. To assess how the water levels in the Acheron River are impacted on as a result of flow releases from Lake Eildon, The water levels for both 'low Acheron' flow events are plotted against the surveyed THELWAG of the Acheron (carried out in 2015). The change in flood levels in the Acheron floodplain are confined to the first 1300 metres upstream of the Goulburn River outfall as shown in Figure 6-3.

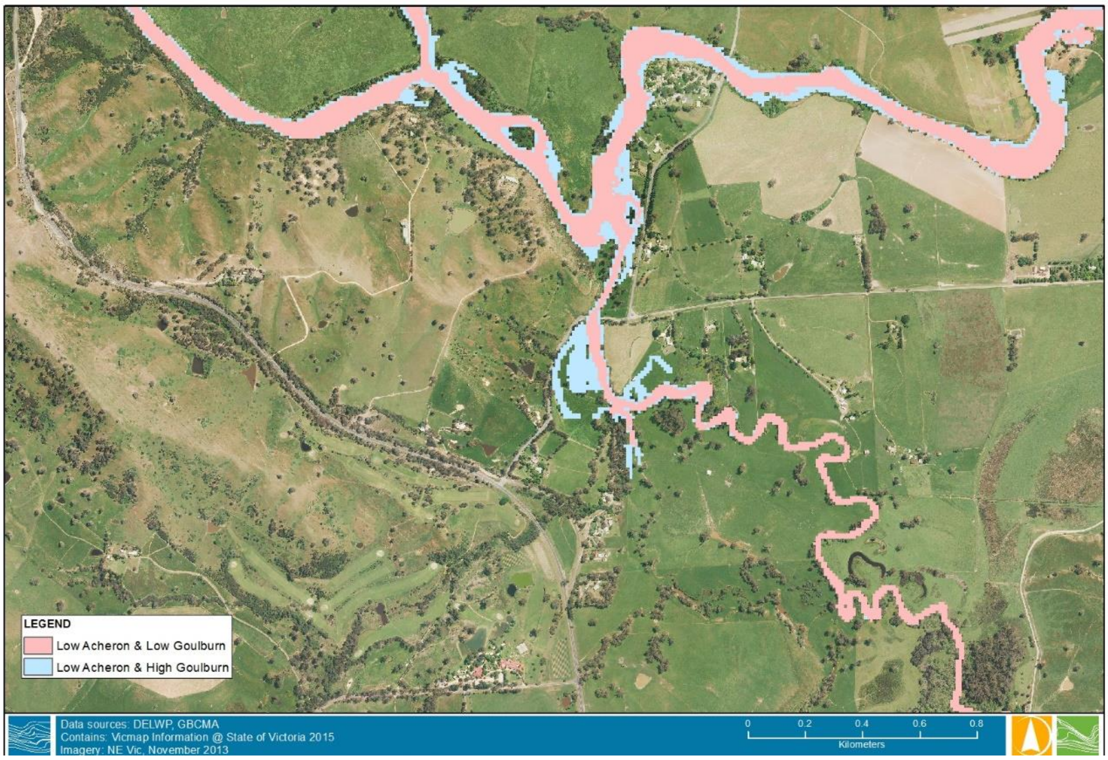

Figure 6-1 Low Acheron Flow - Flood Extents

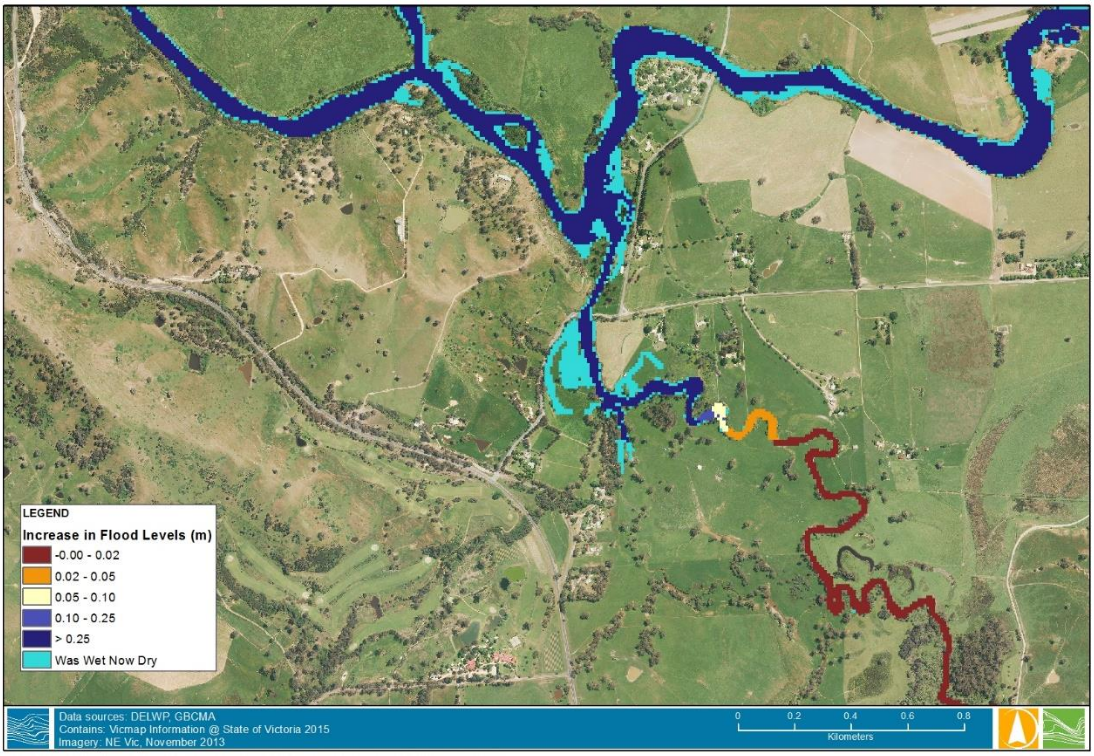

Figure 6-2 Low Acheron River Event - Difference Plot

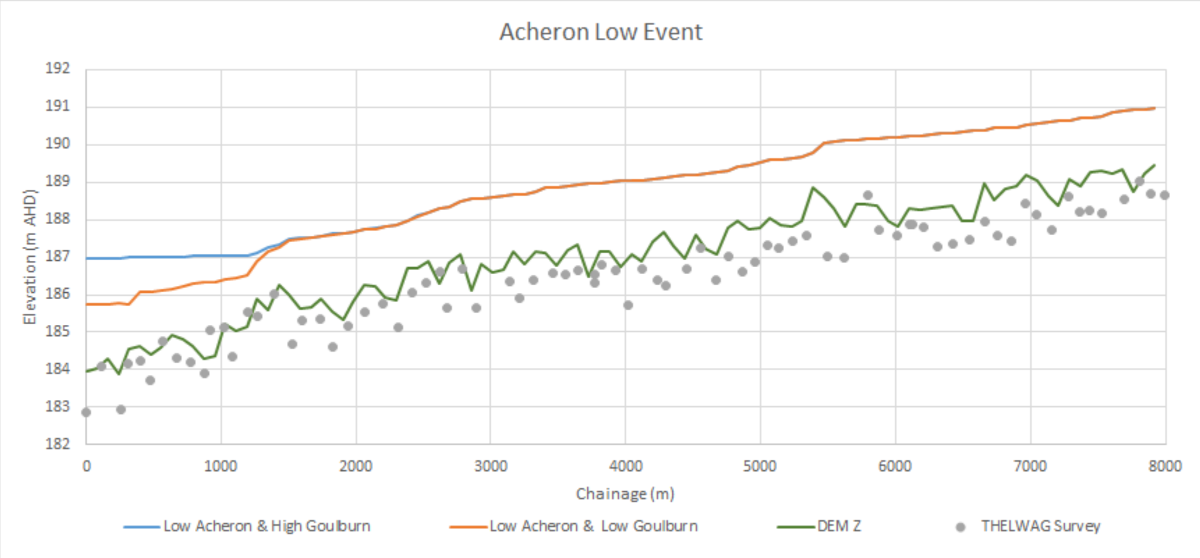

Figure 6-3 Low Acheron River Event - Long Section Plot

A high flow event for the Acheron River was modelled based on the August 2005 flow event which had a peak instantaneous flow rate of 8000 ML/d gauged at Taggerty. A low Goulburn River flow (150 ML/d) was compared against a high Goulburn flow (12,500 ML/d) from Lake Eildon. The flood extents shown in Figure 6-4 highlight the larger flood extent along the Goulburn River as the Goulburn flow at the confluence is now increased to 20,800 ML/d, while the extents are almost identical along the Acheron River through to the confluence with the Goulburn River. Figure 6-5 shows that the impact of increased Goulburn River flows extends for around 1300 m upstream of the Breakaway Road. The change in flood levels in the Acheron floodplain do not extend further upstream given the increased slope of the Acheron River. The increase in flood levels during the 'high Acheron' events is not as great as during 'low Acheron' events. The water levels for both 'high Acheron' flow events are plotted against the surveyed THELWAG of the Acheron (carried out in 2015). The difference in flood levels is shown in Figure 6-6, with the water levels having significant difference from chainage 0 – 400 m before with the impact decreasing between CH 400 – 1300 where there is almost no difference in peak flood levels. This shows that for the Goulburn River flow rates assessed the impact of the Goulburn does extended further than 1300-1500 upstream of the Breakaway Road or more than 2 km from the Goulburn outfall. Under higher Acheron River flow rates the potential for the Goulburn River flow impact extends wider across the floodplain but is not as great a difference when compared to low Acheron flows.

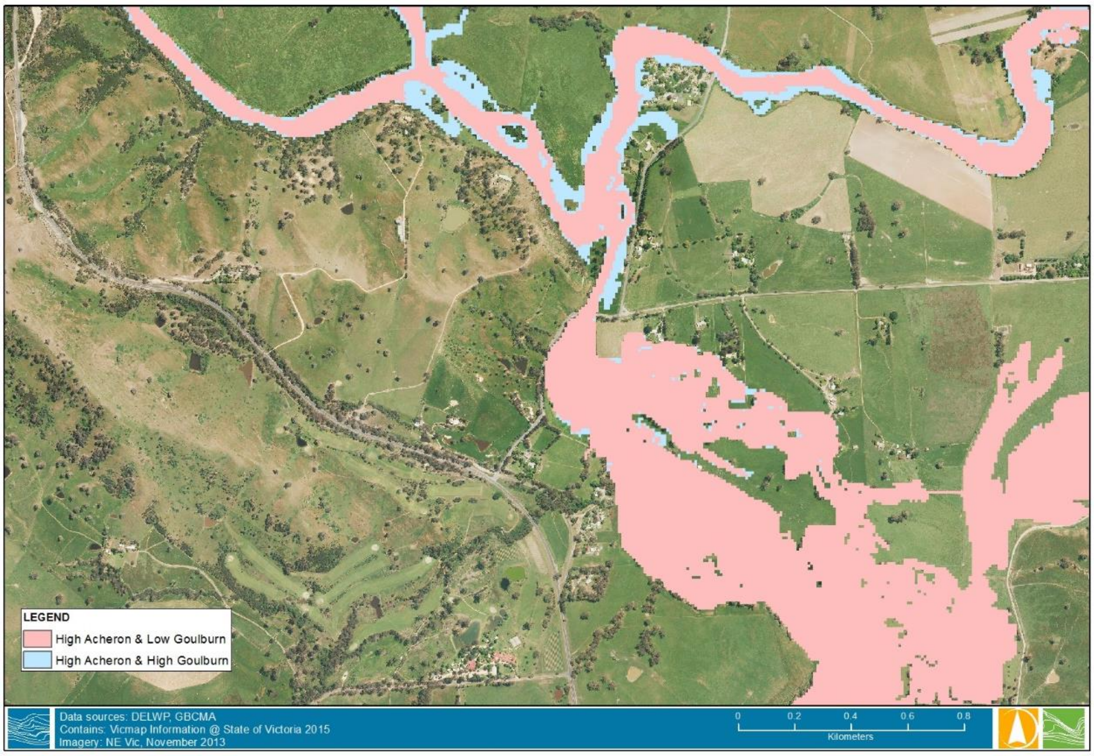

Figure 6-4 High Acheron River Event - Flood Extents

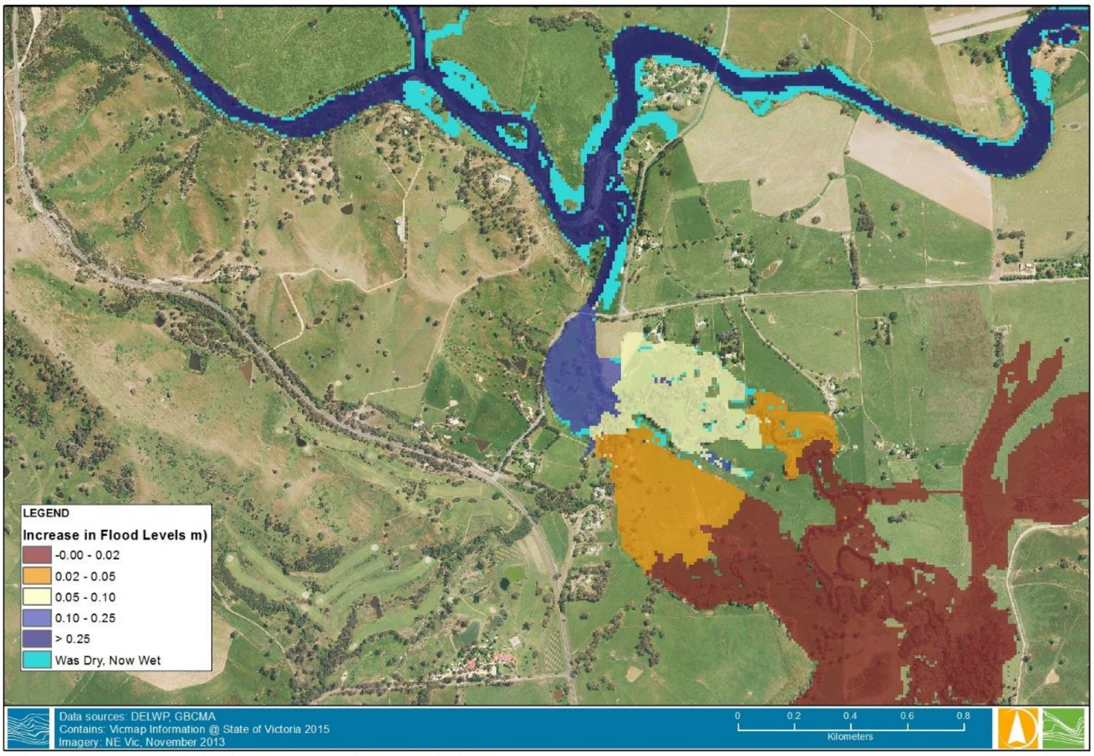

Figure 6-5 High Acheron River Event - Difference Plot

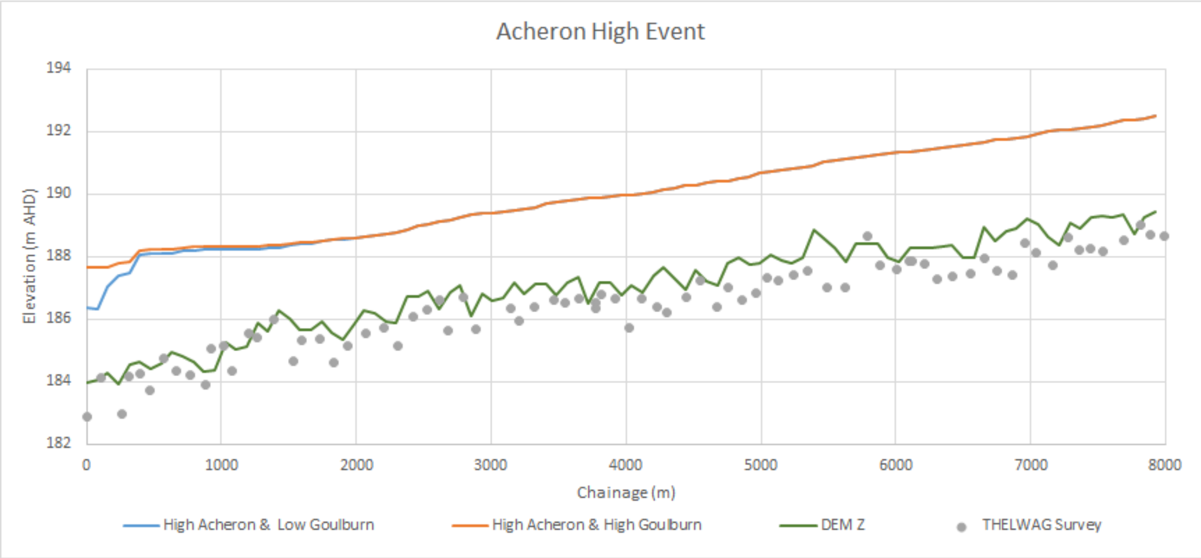

Figure 6-6 High Acheron River Event - Long Section Plot

Concerns over the ability of the Acheron River system to drain adequately during periods of high releases from Eildon have been raised. To assess the impact on how the Acheron flows drain away, several locations (shown in Figure 6-7), were selected to plot the water surface elevation during the event. Figure 6-8 and Figure 6-9 show the water surface elevation at two locations on the Acheron, (one either side of Breakaway Road). Upstream of Breakaway Road shows only a small difference in maximum water levels as well as almost no difference in the water levels as the water recedes from the peak, while downstream of Breakaway Road the impact of the Goulburn River is greater, with higher peak water levels and a slower time for water levels to recede.

Figure 6-7 Acheron River Time Series Locations

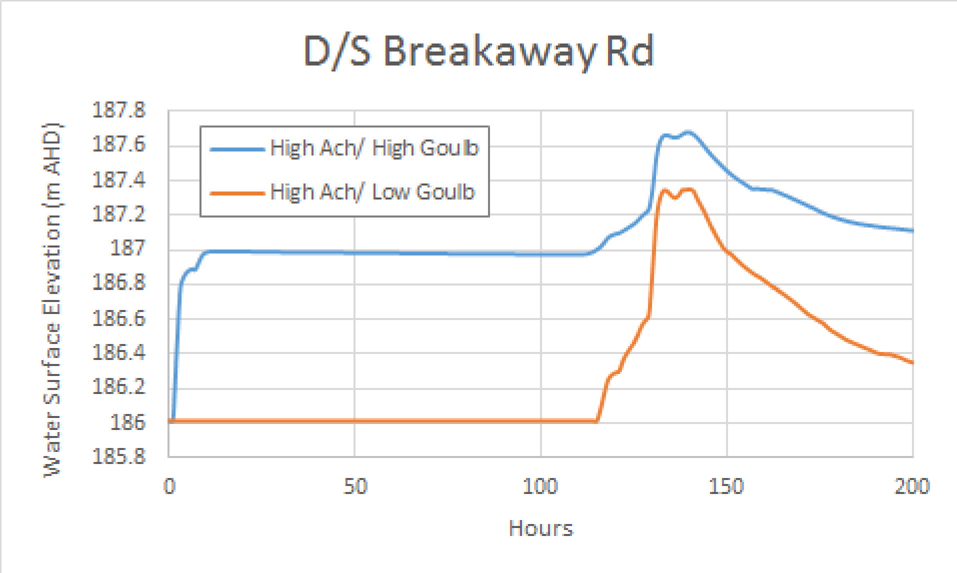

Figure 6-8 Acheron River Time Series Downstream of Breakaway Rd, High Acheron Flows

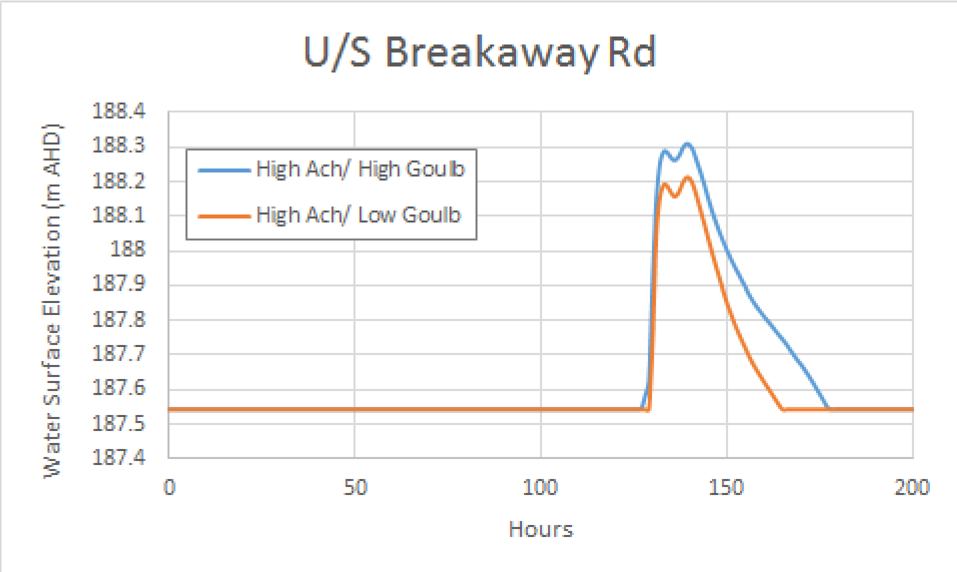

Figure 6-9 Acheron River Time Series Upstream of Breakaway Rd, High Acheron Flows

6.2 Yea River

Four scenarios involving the Yea/Goulburn interaction were modelled to show the impact of a high Goulburn River flow on the Yea River. The four scenarios modelled are listed below in Table 6-2. The Goulburn River was modelled from approximately 6 km upstream of the Yea River confluence through to around 10 km downstream, the Yea River was modelled from Murrindindi Road, approximately 8 km upstream of the Yea Township. The same model setup as used in the previous calibration and environmental flow modelling for the 'Mid Goulburn' was used. The Yea River model initially used a 10 m grid resolution however this was not representing the Yea River capacity and interaction with the Goulburn River to enough detail. A 5 m grid resolution was adopted, using the ISC LiDAR and to represent the channel capacity, surveyed THELWAG as the bottom of the channel profile which was triangulated back to the top of bank on both sides of the river.

Table 6-2 Yea River Tributary Interaction

Scenario	Goulburn River (peak flow ML/d)	Yea River (peak flow ML/d)
High Goulburn High Yea	12,500	10,400
High Goulburn Low Yea	12,500	250
Low Goulburn High Yea	1,000	10,400
Low Goulburn Low Yea	1,000	250

The figures below show the difference in flood extents, and maximum flood heights as well as two time series locations to show the comparison of flood levels across the different scenarios. Figure 6-10 shows a comparison of the flood extents around the Yea/Goulburn confluence. There is an increase in the flood extent along the main Goulburn River channel and an additional lagoon area just upstream of the confluence as a result of higher Goulburn flows. Figure 6-11 shows that during a low flow (approximate base flow) event down the Yea River, the impact of a high Goulburn River release extends around 700-800 m upstream of the Yea/Goulburn River confluence. The increased flow in the Goulburn River does not appear to adversely impact private land located on the Yea River during low Yea River flows. Figure 6-12 shows a comparison of the water levels upstream of the Goulburn confluence for the Low Yea events, this illustrates the impact of the Goulburn River flow being confined to the first 700-800 m of the Yea River. It also highlights the slope of the Yea River as it outfalls into the Goulburn River, the gradient of the slope appears to be the main factor which prevents the Goulburn water level from extending further upstream.

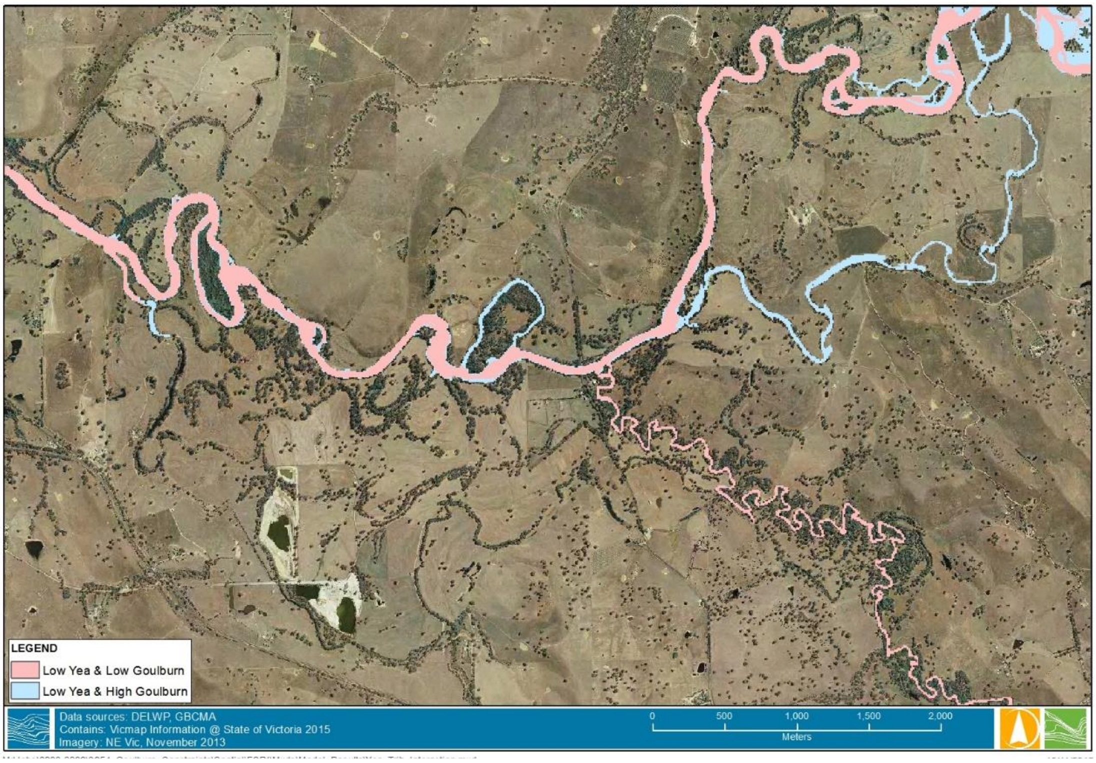

Figure 6-10 Low Yea Flow - Flood Extent comparisons

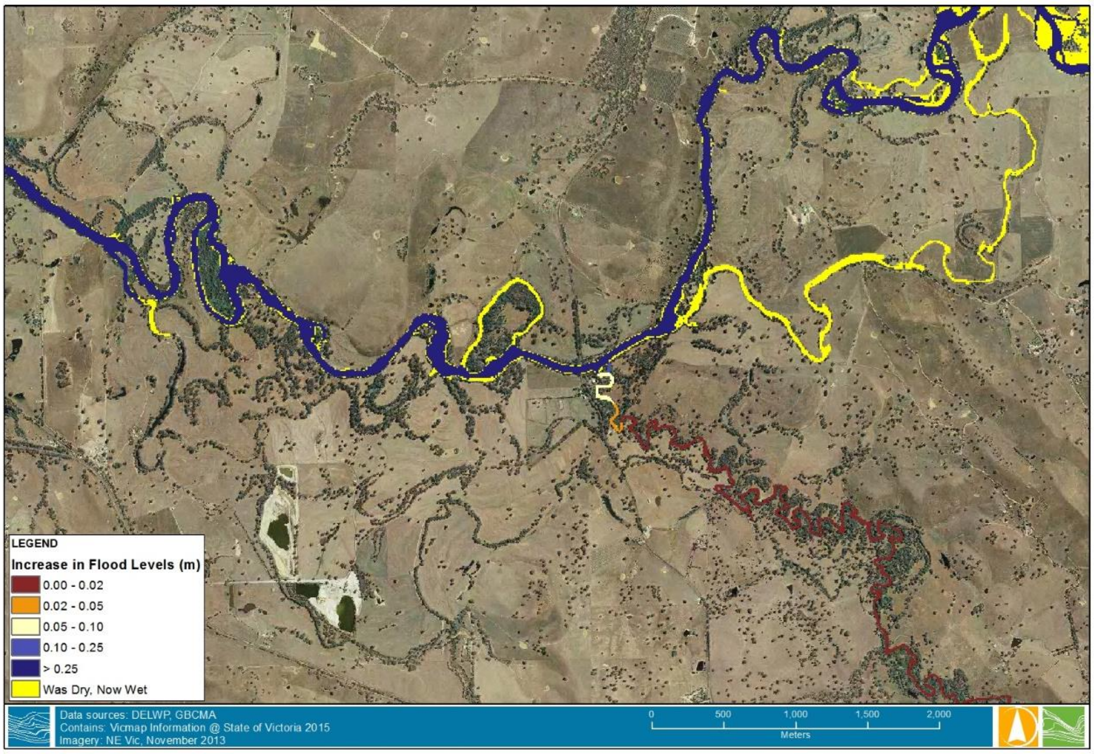

Figure 6-11 Low Yea River Event - Difference Plot

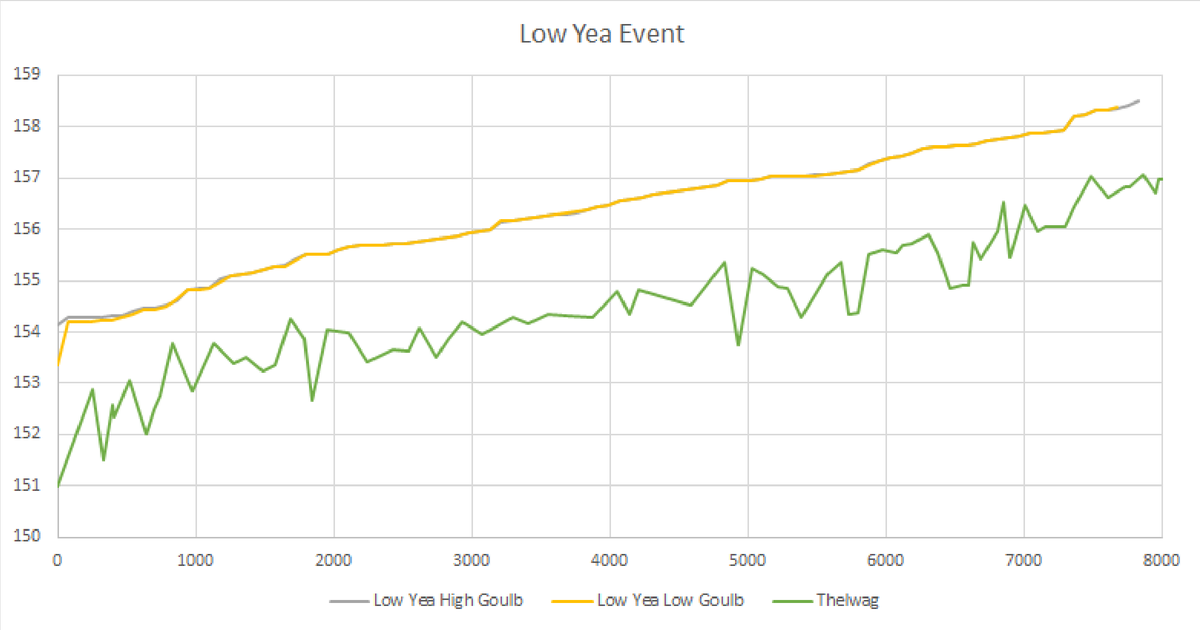

Figure 6-12 Low Yea River Event - Long Section

The high Yea River flow event used a peak flow rate of 10,600 ML/d based on the high flow recorded during October 2000. An instantaneous peak flow of around 5,300 ML/d was recorded at Devlin's Bridge. The catchment area upstream of Devlin's Bridge represents around 44% of the total Yea River catchment. To account for the catchment area downstream of the gauge, the flow recorded at Devlin's Bridge was then doubled (given the area upstream of Devlin's Bridge has a higher annual rainfall than the area below the streamflow gauge), to give a peak flow rate of 10,600 ML/d. Figure 6-13 shows the flood extents of the high Yea River flow scenarios while Figure 6-14 shows the difference in water levels between a "High Yea/High Goulburn" and a "High Yea/Low Goulburn". This shows the impact of the Goulburn River flow during a high Yea River event is limited to the Goulburn floodplain under the flow rates modelled. Figure 6-15 shows a long section comparison of the high Yea River water levels upstream of the Goulburn/Yea outfall. The influence of the Goulburn River on water levels in the Yea River extends only 200-300 m for the scenarios modelled, less than the influence during the low Yea River scenarios modelled. As mentioned previously, the slope of the Yea River increases just upstream of the Goulburn/Yea confluence restricting the impact of the Goulburn River water levels at the 'High Goulburn' flow rate (12,500 ML/d) modelled. At higher Goulburn River flow rates, the impact of the Goulburn River water levels are likely to extend further upstream and further out into the Yea River floodplain as the slope of the Yea River flattens out (between 2000-4000 m upstream of the confluence).

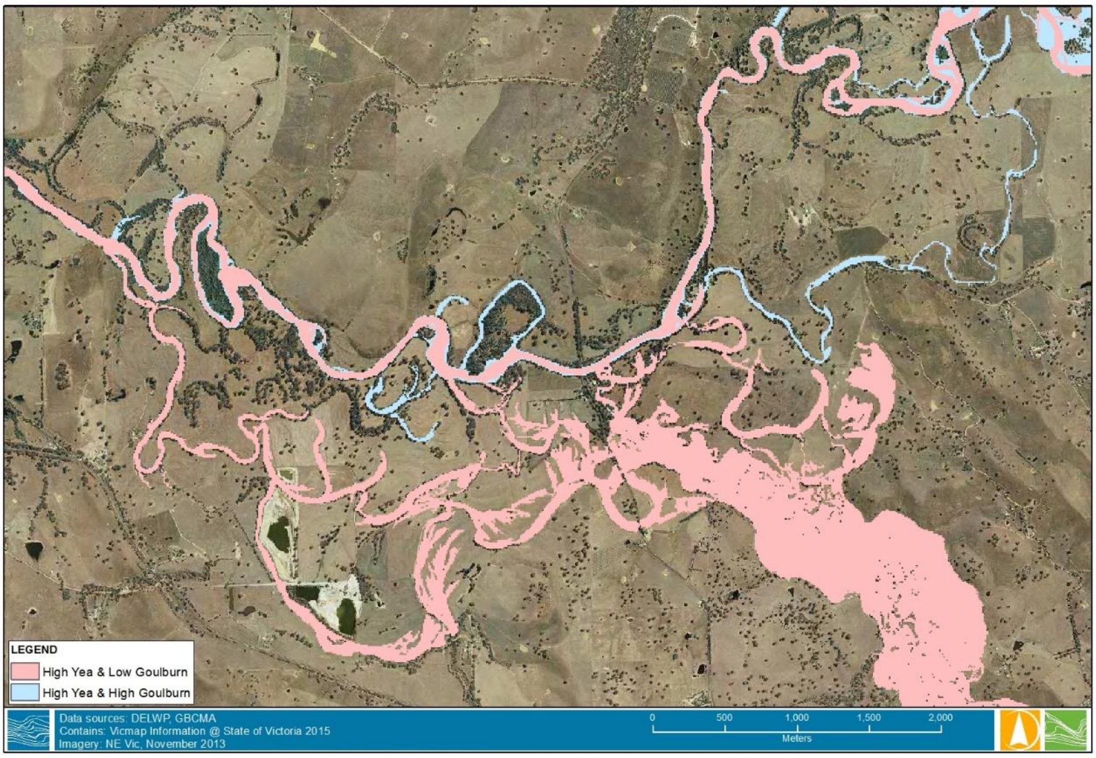

Figure 6-13 High Yea Flow - Flood Extents

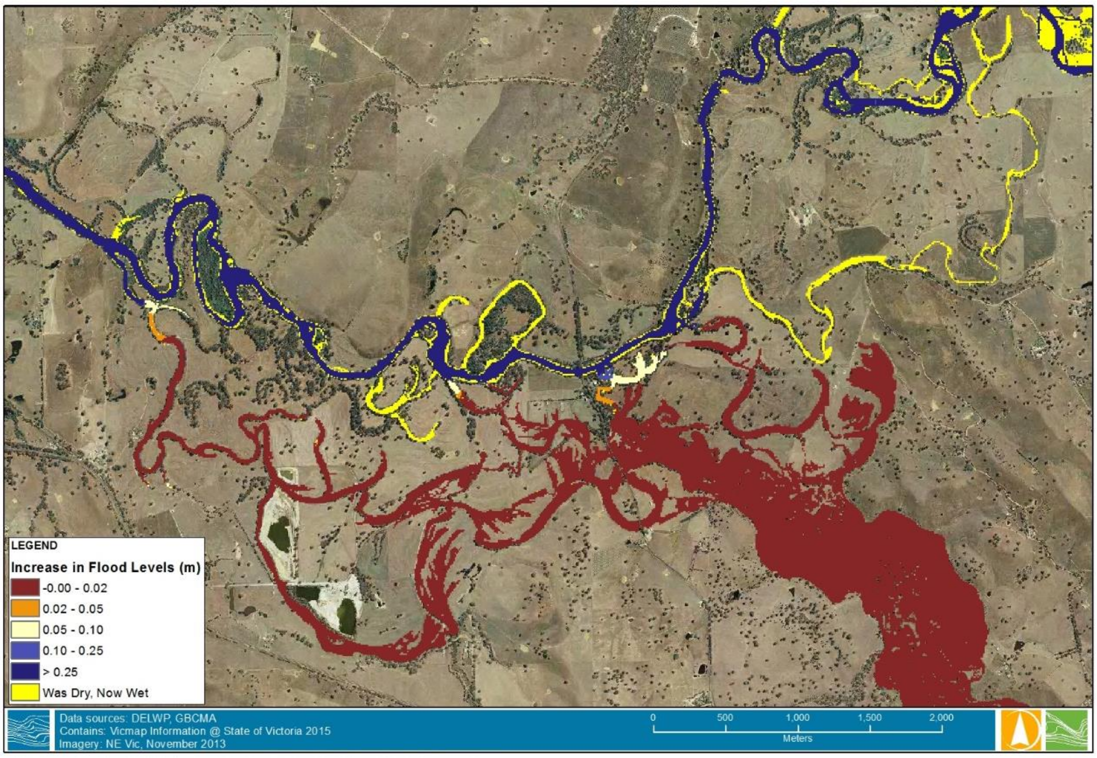

Figure 6-14 High Yea River Event - Difference Plot

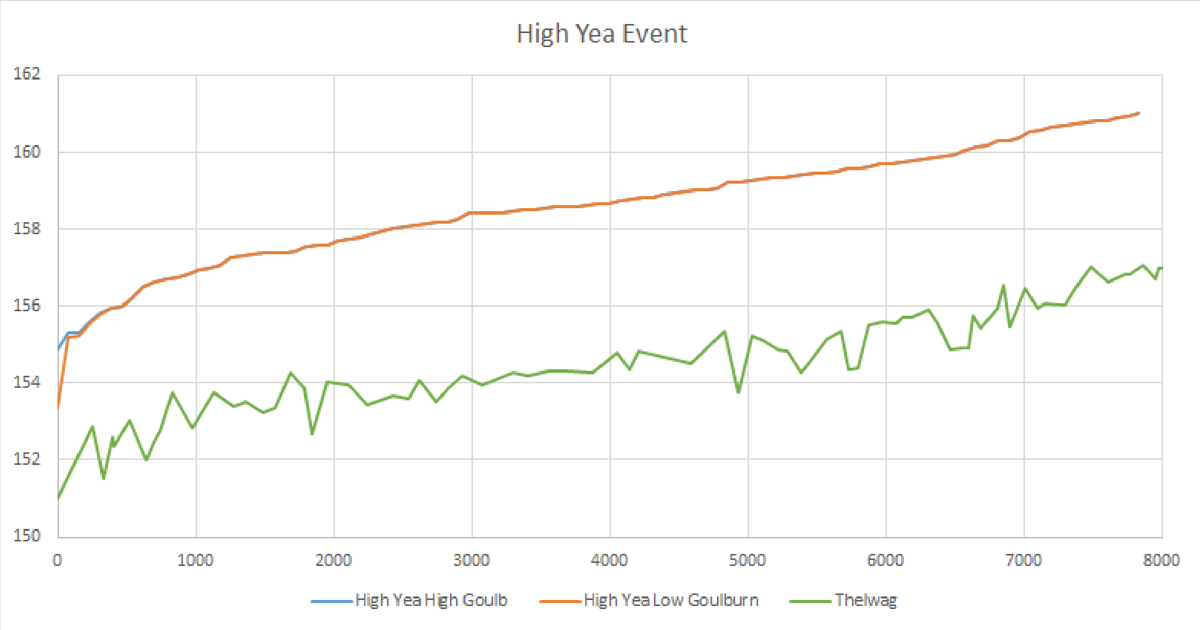

Figure 6-15 High Yea River Event - Long Section

A series of locations along the Goulburn River and Yea River (shown in Figure 6-16) were chosen to compare the difference in water levels during the high and low flow event scenarios. Figure 6-17 to Figure 6-20 show the water levels at two locations during both high and low flow scenarios. During high Yea River flows Figure 6-17 and Figure 6-18 show the influence of the Goulburn River on water levels in the Yea River do not extend upstream to the location of 'H Yea 12'. This matches well with difference plot in Figure 6-14 which showed the increase in water levels was limited to around the first 500 m upstream of the Yea/Goulburn River confluence. Figure 6-19 and Figure 6-20 show that the impact of High Goulburn flows on water levels in the Yea River during a low Yea flow periods are slightly higher compared to a high Yea River flow. A minor increase (2 cm) in water levels at the 'H Yea 12' location is shown Figure 6-20. This minor increase in peak water levels was also shown in Figure 6-11, where the increase in Yea River levels was shown to extend around 800 m upstream of the Yea/Goulburn confluence. The scenarios modelled show that the impact of a high Goulburn River flow on the Yea River is not significant and do not extend upstream more than around 1 km. Results showed that the impact of a high Goulburn flow is higher during a low Yea River flow compared to a High Yea River flow.

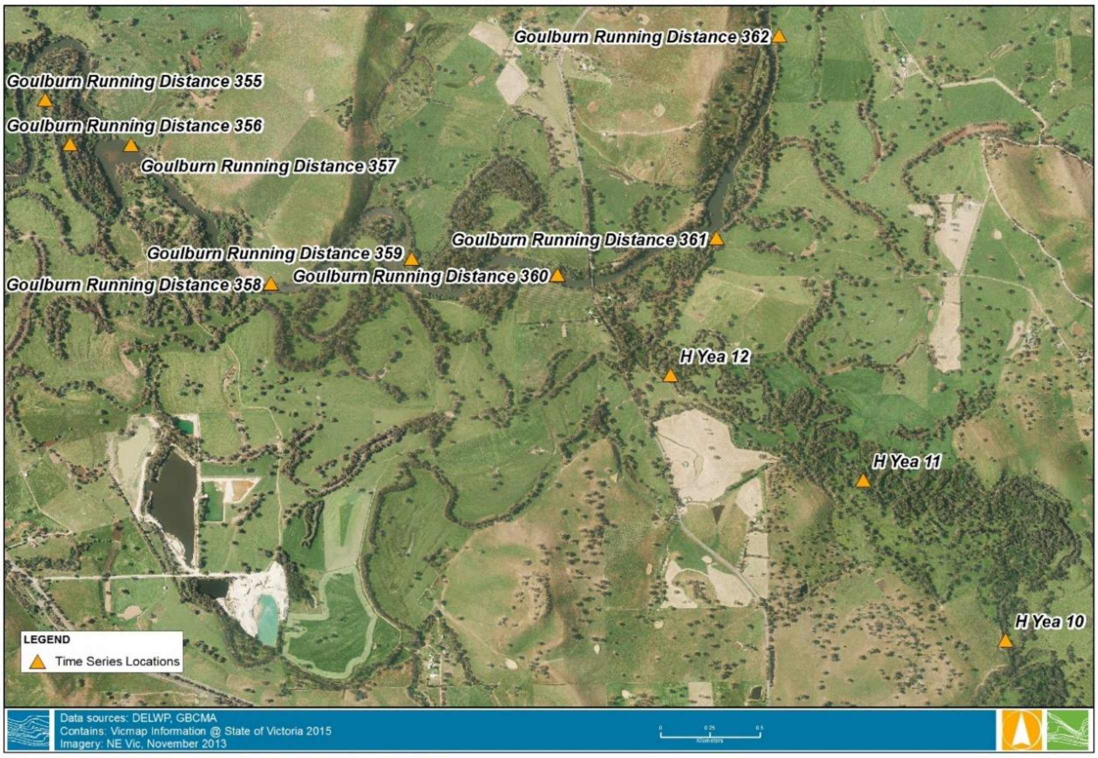

Figure 6-16 Yea River Time Series Locations

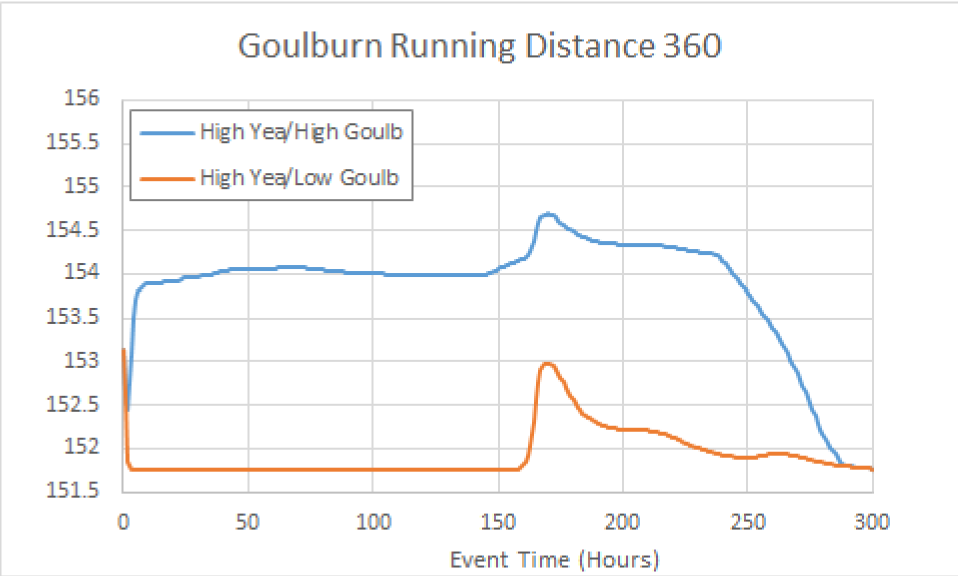

Figure 6-17 High Yea River Flow Comparison - Goulburn River Running Distance 360

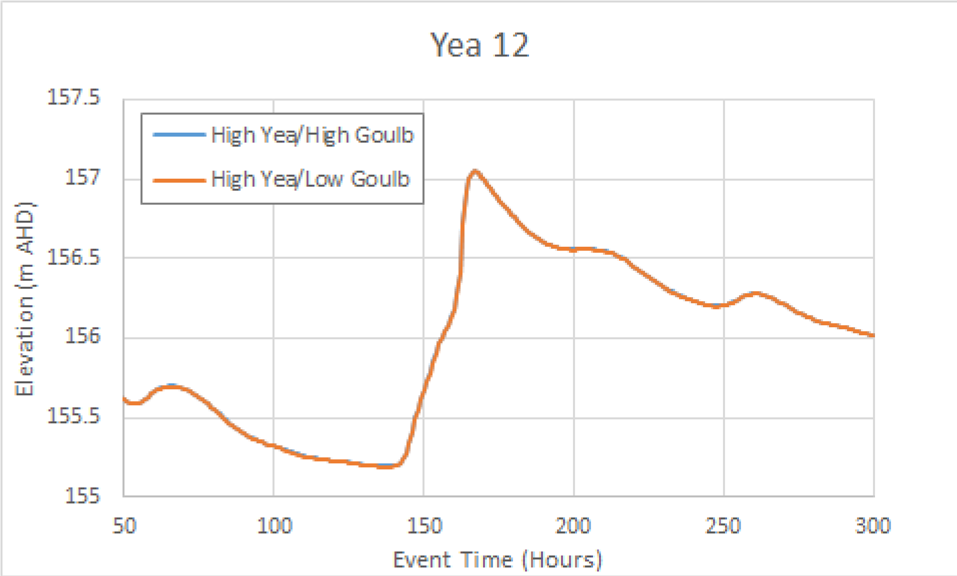

Figure 6-18 High Yea River Flow Comparison - Yea River Location 12

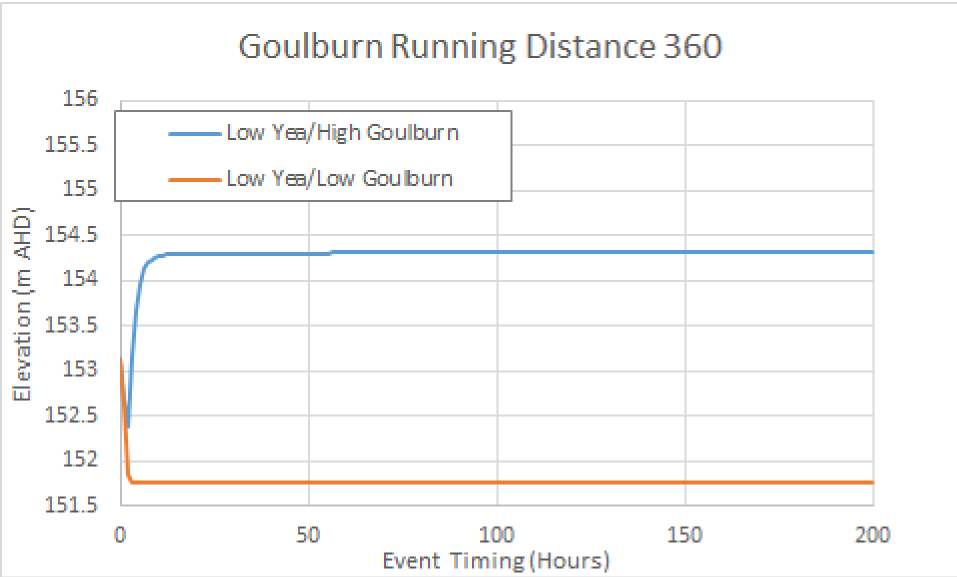

Figure 6-19 Low Yea River Flow Comparison - Goulburn River Running Distance 360

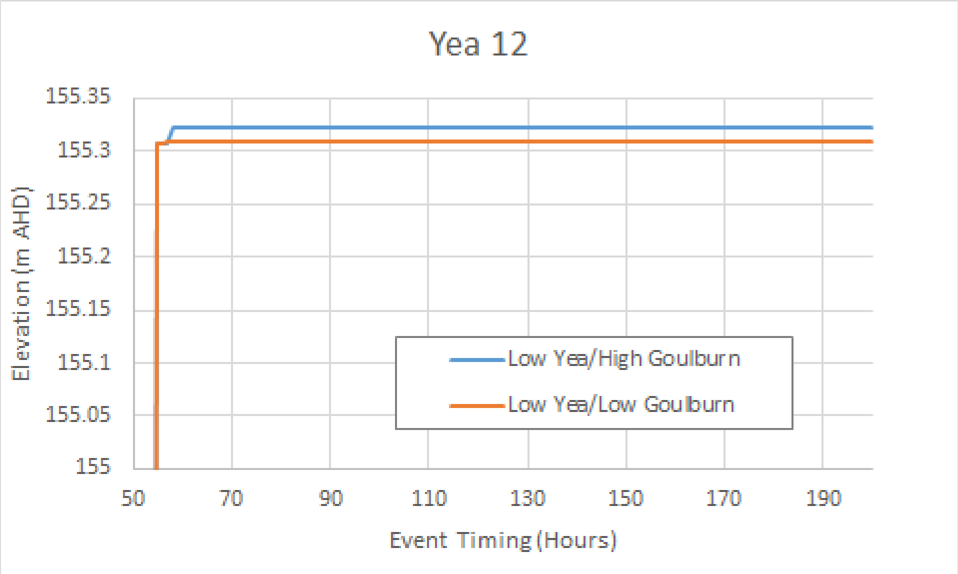

Figure 6-20 Low Yea River Flow Comparison - Yea River Location 12

6.3 Murray River

To investigate the impact on the flood extent of high Murray River flows associated with the Goulburn River flows, six scenarios involving the Murray/Goulburn Rivers interaction were modelled. The model was run along the Lower Goulburn floodplain from Loch Garry through to the Murray River using the same model as for Goulburn environmental flows. This also included around 45 km of the Murray River from the Barmah Township through to Echuca. The model consisted of a 10 m grid with the Goulburn River channel represented using bathymetry data to triangulate beneath the water surface shown in the LiDAR. As described earlier, the Murray River channel was placed into the model as shown in the LiDAR which over estimates flood levels in the Murray River floodplain.

A series of steady state Goulburn River flows from 25,000 ML/d up to 55,000 ML/d were placed in the model at Loch Garry while two Murray River scenarios (a high and low flow) were placed in the model at the Barmah Township. These flows were selected to assess the flood extent when combining Goulburn River flows with higher flows down the Murray River. The 'Barmah choke' is situated upstream of the Goulburn River junction and restricts the Murray River flows. Flows through the choke and past Barmah Township rarely exceed 26,000 ML/d (G.Earl, pers. com., 2015), therefore a high Murray flow rate of 22,000 ML/day was chosen. Given the model uses the river water level from the LiDAR as a bed level, 22,000 ML/day would be equivalent to an actual flow in excess of 30,000 ML/d (a very high flow where environmental releases are unlikely). The model extent is shown in Figure 6-21 and the six scenarios modelled are listed in Table 6-3.

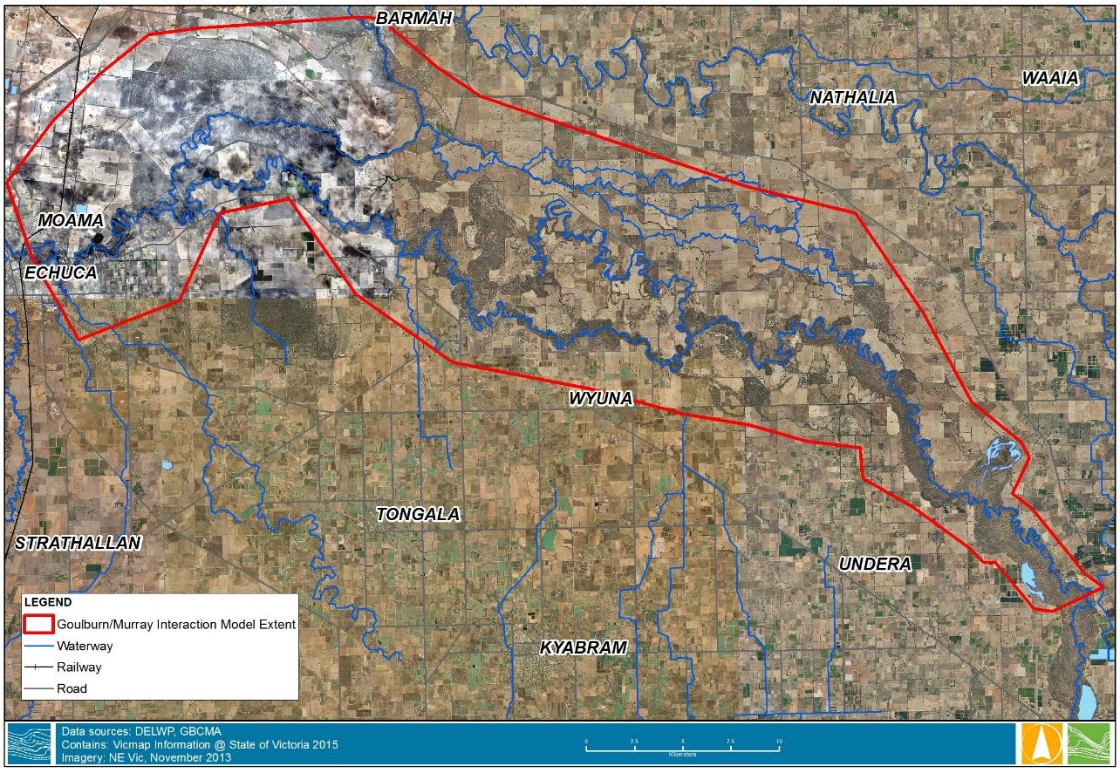

Figure 6-21 Murray/Goulburn River Interaction - Flood Model Extent

Table 6-3 Murray River Tributary Interaction

Scenario	Goulburn River (peak flow ML/d)	Murray River (peak flow ML/d)[1]
55,000 Goulburn High Murray	55,000	22,000
55,000 Goulburn Low Murray	55,000	5,000
40,000 Goulburn High Murray	40,000	22,000
40,000 Goulburn Low Murray	40,000	5,000
35,000 Goulburn High Murray	35,000	22,000
35,000 Goulburn Low Murray	35,000	5,000
25,000 Goulburn High Murray	25,000	22,000
25,000 Goulburn Low Murray	25,000	5,000

[1]Nominal flow, equivalent actual flow higher

The Goulburn River flow modelling undertaken as part of this project and outlined in section 5 utilised a nominal flow of 5,000 ML/d along the Murray River, with the inflow placed at Barmah Township. This flow scenario was considered a ‘low Murray River flow’ scenario with statistics being carried out based on the results. To assess the impact upon both benefits and constraints of combining the Goulburn environmental flow with a high Murray River flow, an assessment of land inundated between the scenarios was carried out. The additional land inundated throughout the lower area of the model with the higher flows along the Murray was assessed based purely on the flood extents. Several of the high flow extents were limited due to the model domain, with water glass walling up against a boundary.

The results showed there is a significant increase in the footprint of the flood extent through the combination of Goulburn River flows with High Murray River flows as show in Table 6-4 and Table 6-5 with the 55,000 ML/d Goulburn with low Murray flow combination having a similar total area of inundation to the 25,000 ML/d and high Murray combination.

Table 6-4 Area of Inundation (NSW Only), hectares

	Low Murray River Flow (5,000 ML/d)[1]	High Murray River Flow (22,000 ML/d)[1]	Increase in Flood Extent
25,000 ML/d	3,138	8,660	176%
35,000 ML/d	3,774	9,975	164%
40,000 ML/d	4,345	10,619	144%
55,000 ML/d	8,634	11,326	31%

[1]Nominal flow, equivalent actual flow higher

Table 6-5 Area of Inundation (McCoys Bridge - Murray River), hectares

	Low Murray River Flow (5,000 ML/d)[1]	High Murray River Flow (22,000 ML/d)[1]	Increase in Flood Extent
25,000 ML/d	3,602	6,608	83%
35,000 ML/d	5,003	8,614	72%
40,000 ML/d	6,033	9,370	51%
55,000 ML/d	6,697	11,377	70%

[1]Nominal flow, equivalent actual flow higher

Figure 6-22 through to Figure 6-25 show the increase in flood depth as well as the additional area of inundation between the low Murray River flow rates and high Murray River flow rates. While there are some differences, these figures demonstrate that Murray River and Goulburn River inundate some common areas around the Goulburn/Murray River junction, and the combination of flows is important to determining areas inundated.

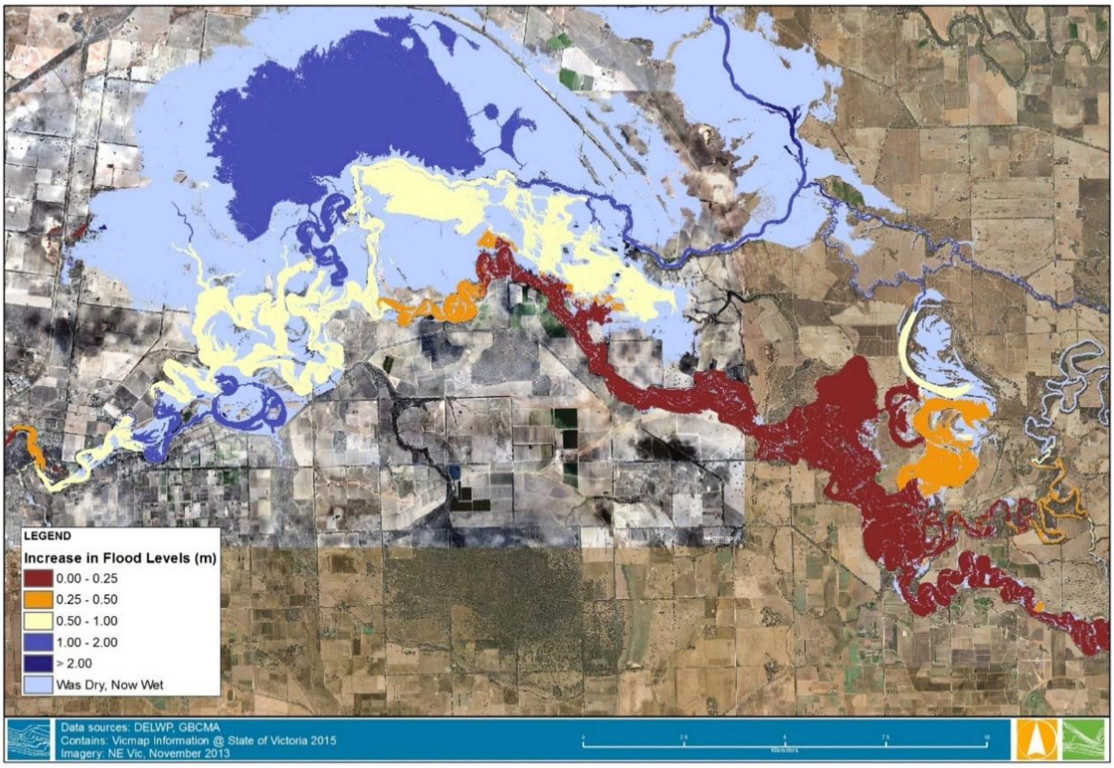

Figure 6-22 25,000 ML/d Goulburn River flow - High and Low Murray River Difference Plot

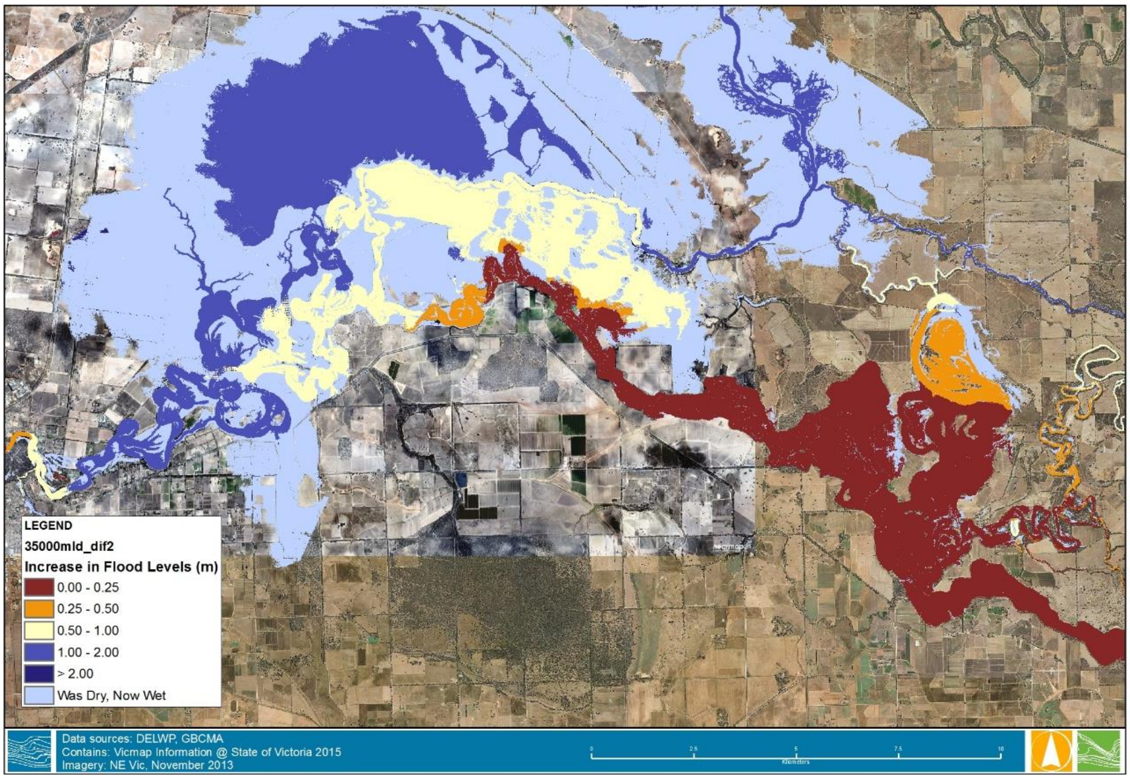

Figure 6-23 35,000 ML/d Goulburn River flow - High and Low Murray River Difference Plot

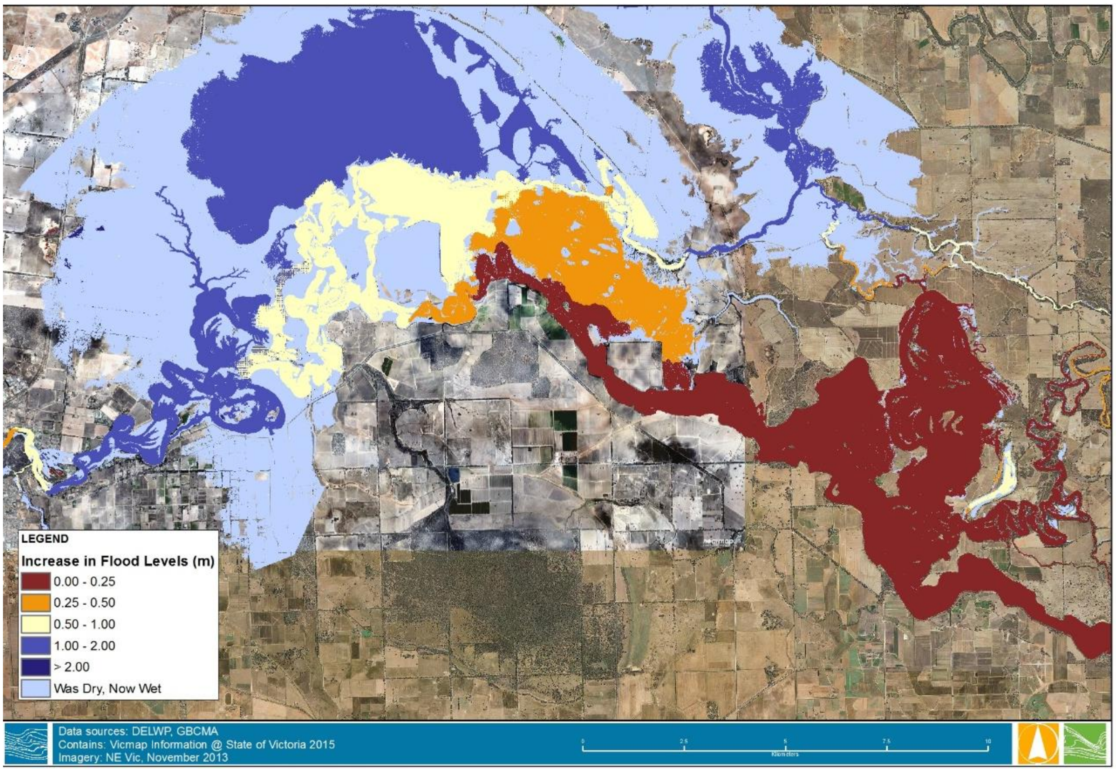

Figure 6-24 40,000 ML/d Goulburn River flow - High and Low Murray River Difference Plot

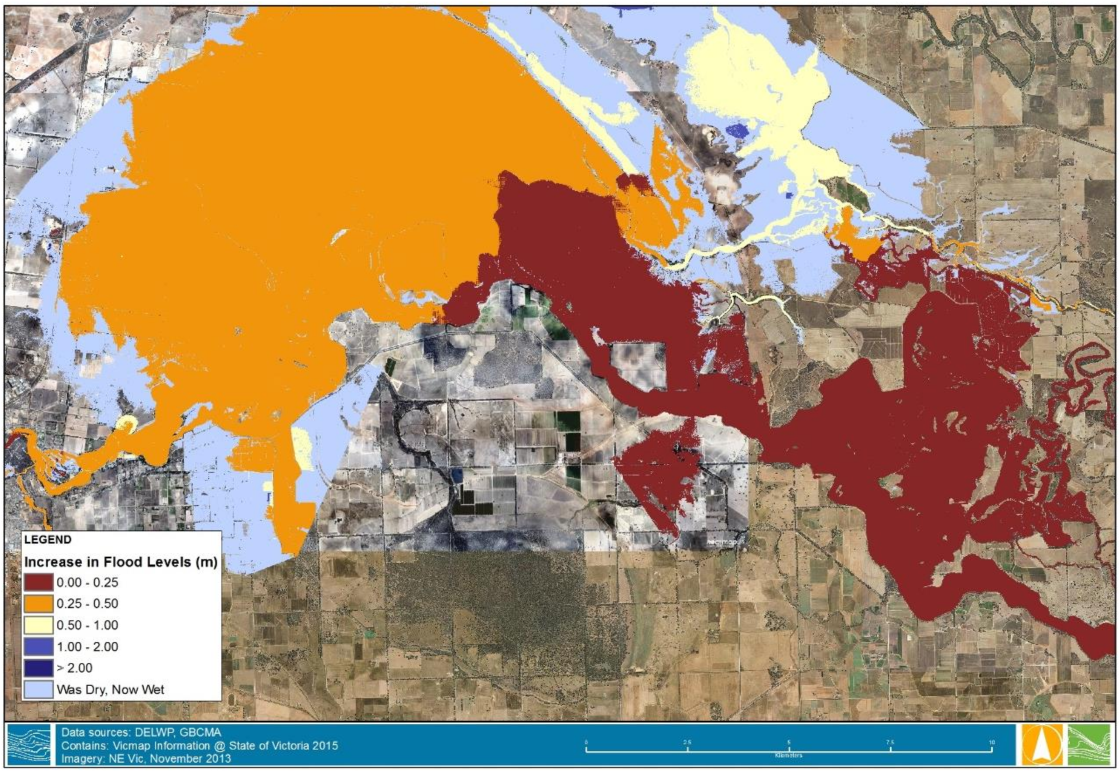

Figure 6-25 55,000 ML/d Goulburn River flow - High and Low Murray River Difference Plot

7. TASK 5 - STATISTICS

The design modelling described above was analysed and dissected using a number of statistical measures, similar to previous studies, but using much improved datasets. The statistics may therefore be slightly different to previous studies. The available design flows for which statistics were carried out are listed in Table 7-1.

Table 7-1 Available Design Flows

Eildon to Goulburn Weir	Killingworth, RD369.8 km to Northwood RD299 km	Northwood RD299 km to Goulburn Weir[2]	Goulburn Weir to Murray River
7,000 ML/d	25,000 ML/d		25,000 ML/d
9,000 ML/d	30,000 ML/d	30,000 ML/d	30,000 ML/d
12,500 ML/d	35,000 ML/d		35,000 ML/d
17,500 ML/d	40,000 ML/d	40,000 ML/d	40,000 ML/d
20,000 ML/d			45,000 ML/d
			55,000 ML/d

The statistics were calculated along a number of river reaches, namely:

1. Eildon to upstream of Acheron River;
2. Upstream of Acheron River to upstream of Yea River;
3. Upstream of Yea River to Seymour (river flow gauge);
4. Seymour to Goulburn Weir;
5. Goulburn Weir to upstream of Sevens Creek (say Kialla West);
6. Kialla West to McCoys Bridge;
7. McCoys Bridge to Murray River (Victoria only); and
8. Murray River (NSW only).

The numbers listed above are used throughout the document to identify the river reaches shown in Figure 7-1.

[2] Water Technology CPU Modelling Models D and E1 (2010)

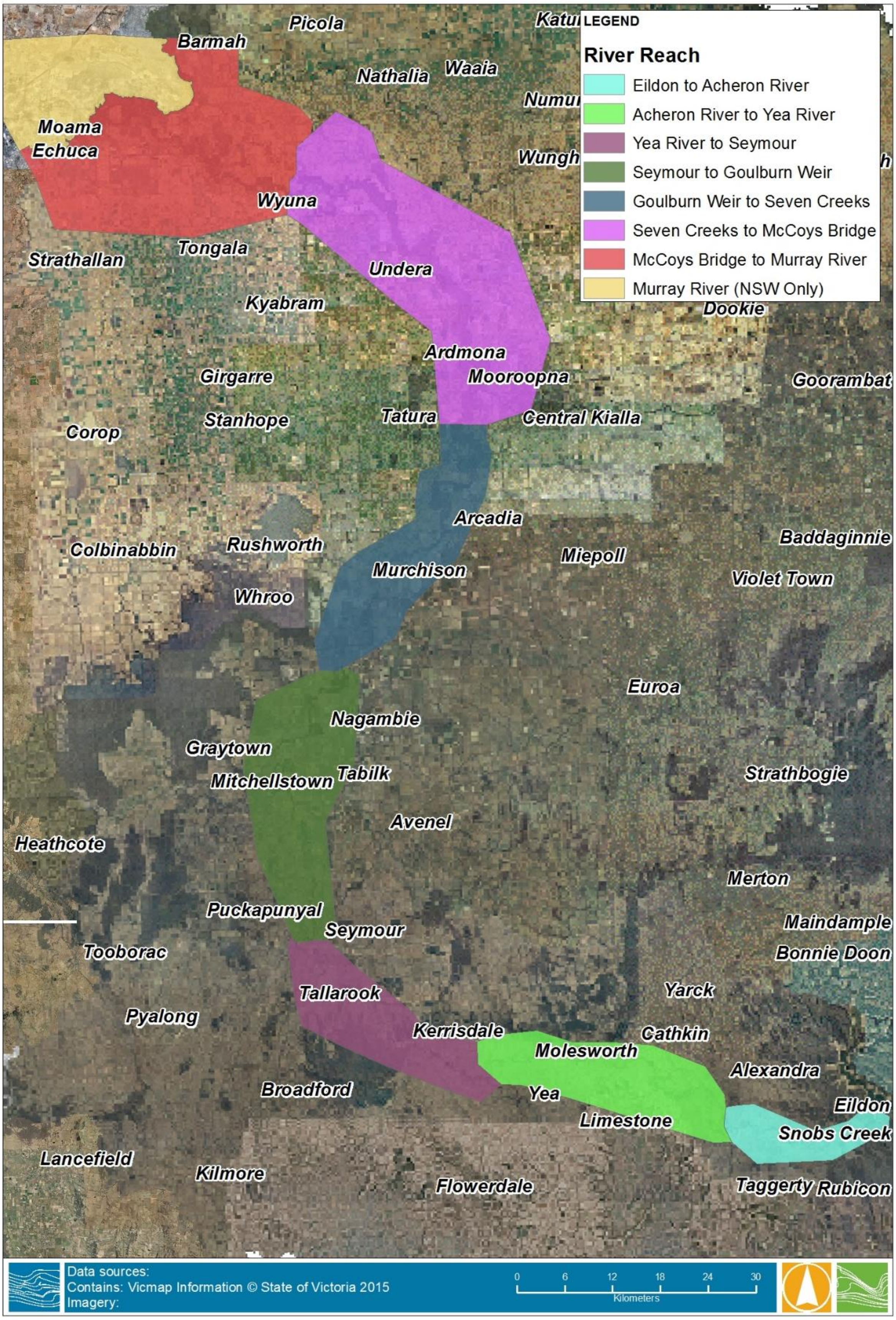

Figure 7-1 Goulburn Constraints - Statistics Reach Layout

The available design flows used for the above river reaches are as follows:

Reach	Flow Scenarios
1 - Eildon to upstream of Acheron River;	7000, 9000, 12500, 15000, 20000
2 - Upstream of Acheron River to upstream of Yea River;	7000, 9000, 12500, 15000, 20000
3 - Upstream of Yea River to Seymour (river flow gauge);	7000, 9000, 12500, 15000, 20000, 25000, 30000, 35000, 40000
4 - Seymour to Goulburn Weir;	7000[1], 9000[1], 12500[1], 15000[1], 20000[1], 25000[1], 30000[2], 35000[1], 40000[2]
5 - Goulburn Weir to upstream of Sevens Creek (say Kialla West);	25000, 30000, 35000, 40000, 45000, 55000
6 - Kialla West to McCoys Bridge;	25000, 30000, 35000, 40000, 45000, 55000
7 - McCoys Bridge to Murray River (Victoria only); and	25000, 30000, 35000, 40000, 45000, 55000
8 - Murray River (NSW only).	25000, 30000, 35000, 40000, 45000, 55000

[1] Model Results were only used up to Northwood

[2] Model Results were used to Northwood, from Northwood to Goulburn Weir 2010 Model Results were used.

7.1 Total Area Inundated

The total area inundated was calculated using the modelled maximum depth grids. These results, shown below in Figure 7-2 and Table 7-2 show an expected trend of increased area inundated associated with increased flow rates. It should be noted that Reach 4 has two outliers (30,000 ML/d & 40,000 ML/d) which included older and coarser 2010 modelling undertaken by Water Technology, while the remaining flow areas inundated were only calculated from Seymour to Northwood.

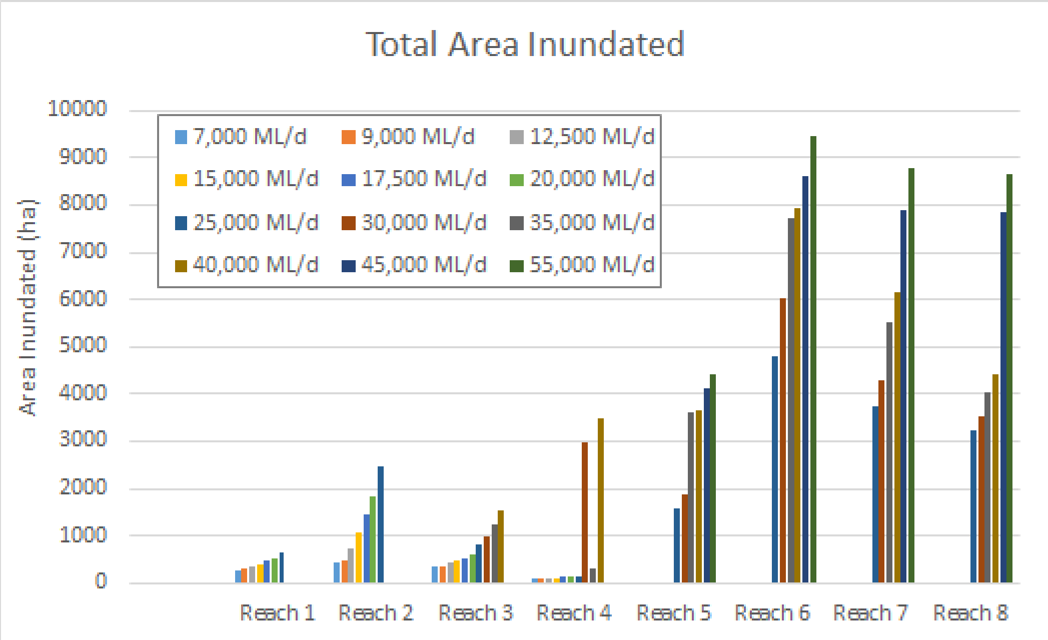

Figure 7-2 Total Inundation Area

Table 7-2 Total Inundation Area

	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d	20,000 ML/d
Reach 1	272	301	339	372	458	523
Reach 2	417	486	736	1055	1484	1875
Reach 3	342	370	414	464	523	606
Reach 4	90[1]	94[1]	102[1]	114[1]	124[1]	137[1]
Reach 5	N/A	N/A	N/A	N/A	N/A	N/A
Reach 6	N/A	N/A	N/A	N/A	N/A	N/A
Reach 7	N/A	N/A	N/A	N/A	N/A	N/A
Reach 8	N/A	N/A	N/A	N/A	N/A	N/A
	25,000 ML/d	**30,000 ML/d**	**35,000 ML/d**	**40,000 ML/d**	**45,000 ML/d**	**55,000 ML/d**
Reach 1	N/A	N/A	N/A	N/A	N/A	N/A
Reach 2	N/A	N/A	N/A	N/A	N/A	N/A
Reach 3	825	975	1,253	1,543	N/A	N/A
Reach 4	140[1]	2,958[2]	294[1]	3,650[2]	N/A	N/A
Reach 5	1,565	1,858	3,610	3,640	4,142	4,433
Reach 6	4,829	6,054	7,702	7,935	8,617	9,477
Reach 7	3,916	4,472	5,523	6,371	8,142	8,432
Reach 8	3,241	3,525	4,046	4,415	7,839	8,660

[1] Seymour to Northwood only

[2] Seymour to Goulburn Weir

7.2 Buildings

To assess buildings inundated throughout the study area, a buildings layer provided by GBCMA was clipped to the each flood extent. This was to identify the total number of buildings within each flood extent as listed in Table 7-3 and shown in Figure 7-3. The buildings identified were then split into building types, with the number of houses within the flood extent shown in Figure 7-4. The remaining houses identified as within the flood extent were then assessed for the depth of inundation based on the depth result grids. As no floor level survey was available a crude assumption was made to estimate the floor levels. It was assumed that the floor level was 300 mm above the natural surface at the location of the building. The houses identified as being flooded above 300 mm from the natural surface are listed below in Table 7-4.

Table 7-3 Total Buildings within Flood Extent

	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d	20,000 ML/d
Reach 1	0	0	0	0	1	2
Reach 2	0	0	2	2	5	6
Reach 3	0	0	0	0	0	0
Reach 4	0[1]	0[1]	0[1]	1[1]	2[1]	4[1]
Reach 5	N/A	N/A	N/A	N/A	N/A	N/A
Reach 6	N/A	N/A	N/A	N/A	N/A	N/A
Reach 7	N/A	N/A	N/A	N/A	N/A	N/A
Reach 8	N/A	N/A	N/A	N/A	N/A	N/A
	25,000 ML/d	**30,000 ML/d**	**35,000 ML/d**	**40,000 ML/d**	**45,000 ML/d**	**55,000 ML/d**
Reach 1	N/A	N/A	N/A	N/A	N/A	N/A
Reach 2	N/A	N/A	N/A	N/A	N/A	N/A
Reach 3	0[2]	0[2]	2[2]	3[2]	N/A	N/A
Reach 4	5[1]	10	10[1]	17	N/A	N/A
Reach 5	0	1	1	1	4	8
Reach 6	5	5	4	7	11	11
Reach 7	0	0	0	5	22	43
Reach 8	0	0	1	2	30	42

[1] Seymour to Northwood only

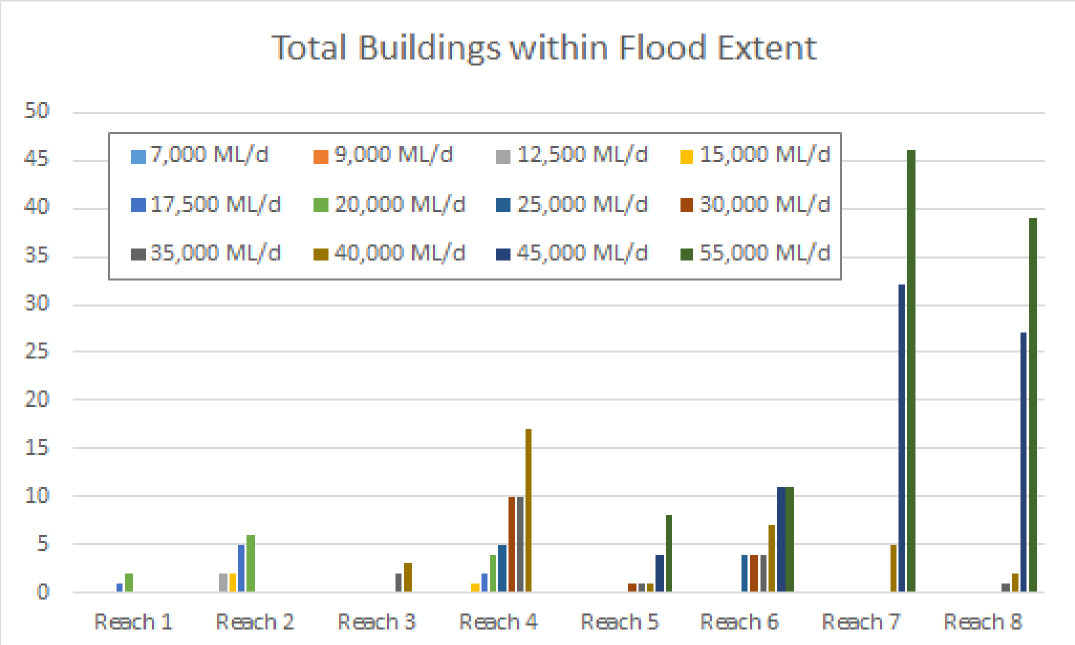

Figure 7-3 Total Buildings within Flood Extent

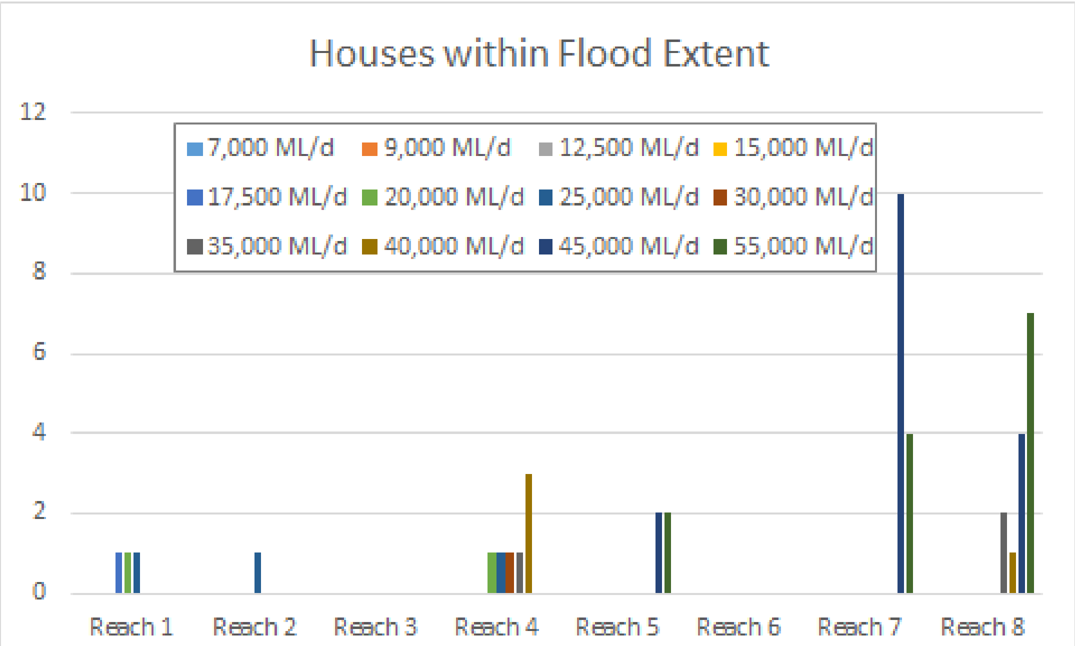

Figure 7-4 Houses within Flood Extent

Houses identified as flooded above 300 mm from the natural surface are shown in Table 7-4. There are very limited number of houses likely to be impacted, and it is likely that they are raised significantly higher than 300 mm from the floodplain, as these flows already occur routinely. It is recommended that the houses impacted be further investigated at a later stage of the project.

Table 7-4 House Sites Flooded Above 300 mm

	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d	20,000 ML/d
Reach 1	0	0	0	0	0	0
Reach 2	0	0	0	0	0	0
Reach 3	0	0	0	0	0	0
Reach 4	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]
Reach 5	N/A	N/A	N/A	N/A	N/A	N/A
Reach 6	N/A	N/A	N/A	N/A	N/A	N/A
Reach 7	N/A	N/A	N/A	N/A	N/A	N/A
Reach 8	N/A	N/A	N/A	N/A	N/A	N/A
	25,000 ML/d	**30,000 ML/d**	**35,000 ML/d**	**40,000 ML/d**	**45,000 ML/d**	**55,000 ML/d**
Reach 1	N/A	N/A	N/A	N/A	N/A	N/A
Reach 2	N/A	N/A	N/A	N/A	N/A	N/A
Reach 3	0	0	0	0	N/A	N/A
Reach 4	0[a]	0	0[a]	2[1,2]	N/A	N/A
Reach 5	0	0	0	0	0	2[3,4]
Reach 6	0	0	0	0	0	0
Reach 7	0	0	0	0	2[5,6]	3[5,6,7]
Reach 8	0	0	1[8]	1[8]	2[8,9]	3[8,9,10]

1 & 2 Punt Road, Michellstown
3 & 4 Bendigo – Murchison Rd*
5, 6 & 7 Deep Creek, Lower Picola
*Site visit revealed these dwellings are caravans

8 Christies Beach, NSW
9 Christies Beach, NSW
10 Christies Beach, NSW

[a] Seymour to Northwood only

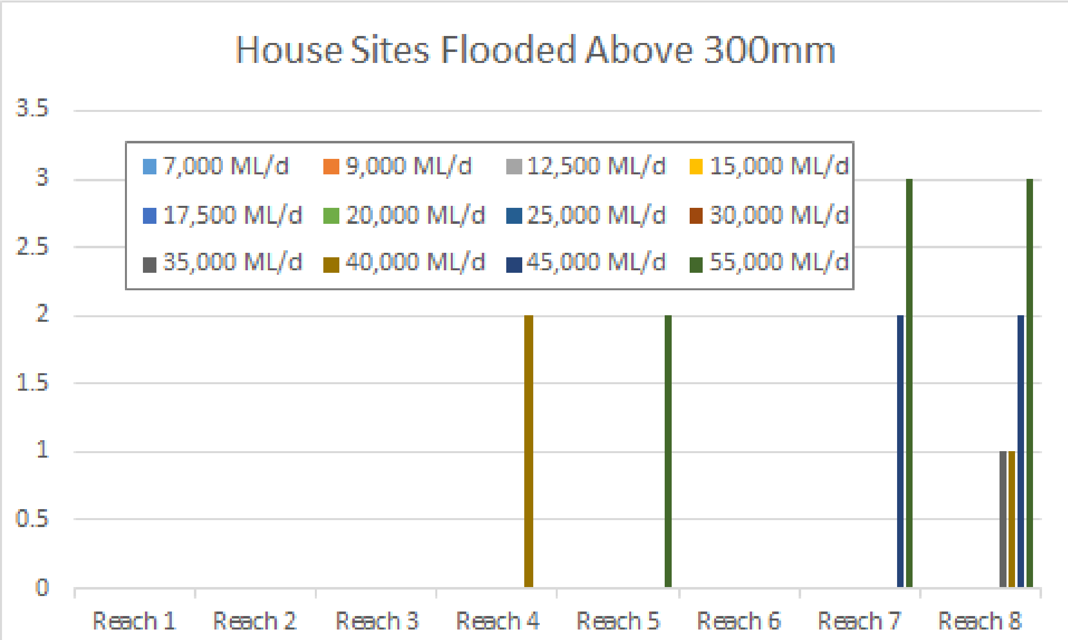

Figure 7-5 House Sites Flooded above 300 mm

The buildings not listed as house include a number of garages, machinery sheds, and hay sheds, dairies and other business related buildings. The number of "Other" buildings within the flood extent are shown in Table 7-5 and Figure 7-6

Table 7-5 "Other" Buildings within the Flood Extent

	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d	20,000 ML/d
Reach 1	0	0	0	0	0	1
Reach 2	0	0	2	2	5	6
Reach 3	0	0	0	0	0	0
Reach 4	0[1]	0[1]	0[1]	1[1]	2[1]	3[1]
Reach 5	N/A	N/A	N/A	N/A	N/A	N/A
Reach 6	N/A	N/A	N/A	N/A	N/A	N/A
Reach 7	N/A	N/A	N/A	N/A	N/A	N/A
Reach 8	N/A	N/A	N/A	N/A	N/A	N/A
	25,000 ML/d	**30,000 ML/d**	**35,000 ML/d**	**40,000 ML/d**	**45,000 ML/d**	**55,000 ML/d**
Reach 1	N/A	N/A	N/A	N/A	N/A	N/A
Reach 2	N/A	N/A	N/A	N/A	N/A	N/A
Reach 3	0	0	2	3	N/A	N/A
Reach 4	4[1]	9[2]	9[1]	14[2]	N/A	N/A
Reach 5	0	1	1	1	2	6
Reach 6	4	4	4	7	11	11
Reach 7	0	0	1	5	22	42
Reach 8	0	0	0	1	23	32

[1] Seymour to Northwood only

[2] Seymour to Goulburn Weir

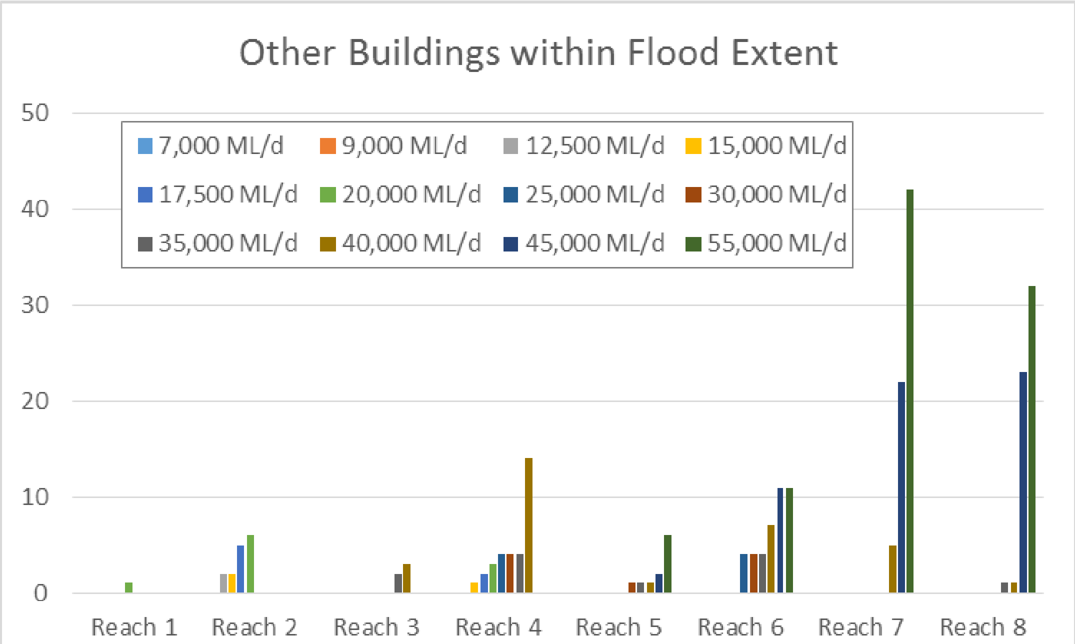

Figure 7-6 "Other" Buildings within the Flood Extent

7.3 Dwellings Isolation

An assessment of the dwellings which become isolated during flow events was carried out through manually inspecting dwellings sited on high land but which become isolated during a managed flow event. The assessment was primarily undertaken for the highest flow modelled in each reach i.e 20,000 ML/day in Reaches 1 and 2, 40,000 ML/day in Reaches 3 and 4, and 55,000 ML/day in Reaches 5 – 7.

Table 7-6 Dwellings Isolated "Access cut" by environmental watering event

Number of Dwelling Isolated	Description
Reach 1	
0	
Reach 2	
2	Accessway impacted along Baynes Road, Molesworth at 20,000 ML/d
1	Accessway impacted around Killingworth Road
Reach 3	
1	Accessway along Ghin Ghin Road may be impacted at 40,000 ML/d but okay at 30,000 ML/d
Reach 4	
3	Accessway impacted at 30,000 ML/d around Punt Road (near Tahbilk)
1	Accessway impacted to new dwelling located on west bank of Goulburn River (opposite Mangalore)
2-3	Accessway impacted from Johnsons Lane Northwood if Creek flows from high Goulburn River (local knowledge)
Nagambie Caravan Park	Accessway impacted along Loddings Lane
1	Accessway impacted u/s west
2	Accessway impacted u/s west
1	Accessway impacted near Watervale Road
Reach 5	
0	
Reach 6	
1	Accessway impacted along McFarlane Lane, Mooroopna
2	Accessway impacted along Watts Road Kialla
2	Accessway impacted at Low Road, Murchison East for 55,000 ML/d but approximately okay at 45,000 ML/d
Reach 7	
2	Accessway impacted along Stewarts Bridge Road
1	Accessway impacted around Madowla near Deep/Wallalla Creeks

Several	Accessway impacted along Woodbine Drive, Lower Picola on Deep Creek/Murray River
2	Accessway impacted along Yambuna Bridge
3	Accessways impacted around Hutchins Lane
2	Accessways impacted around Goddard and Rathbones Roads
2	Accessways impacted around Hutchisons Road
1	Accessway impacted around Loch Garry (from Hurricane Bend)

7.4 Bridges

To assess the number of bridges inundated during the environmental flow scenarios, all bridges identified within the flood extent were selected and manually allocated a bridge deck height based on the surrounding LiDAR. This was undertaken to account for locations (mainly bridges) where the LiDAR processing has removed the bridge deck from the LiDAR dataset. The bridges identified as being inundated are listed below in Table 7-7, and the total length of the bridges inundated was then calculated and shown in Table 7-8.

Table 7-7 Number of Road Bridges Inundated

	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d	20,000 ML/d
Reach 1	0	0	0	0	0	0
Reach 2	0	0	0	0	0	0
Reach 3	0	0	0	0	0	0
Reach 4	0	0	1[1]	1[1]	1[1]	1[1]
Reach 5	N/A	N/A	N/A	N/A	N/A	N/A
Reach 6	N/A	N/A	N/A	N/A	N/A	N/A
Reach 7	N/A	N/A	N/A	N/A	N/A	N/A
Reach 8	N/A	N/A	N/A	N/A	N/A	N/A
	25,000 ML/d	**30,000 ML/d**	**35,000 ML/d**	**40,000 ML/d**	**45,000 ML/d**	**55,000 ML/d**
Reach 1	N/A	N/A	N/A	N/A	N/A	N/A
Reach 2	N/A	N/A	N/A	N/A	N/A	N/A
Reach 3	0	0	0	0	N/A	N/A
Reach 4	1[1]	1[1]	1[1]	2[1,2]	N/A	N/A
Reach 5	0	0	0	0	1[3]	1[3]
Reach 6	1[4]	1[4]	2[4,5]	2[4,5]	2[4,5]	2[4,5]
Reach 7	0	0	1[6]	1[6]	1[6]	1[6]
Reach 8	0	0	0	0	0	0

Bridges impacted are listed below:

[1]: Mitchellstown Road, Mitchellstown
[2] O'Neils Rd, Tabilk
[3] Bridge Road, Arcadia
[4] Ferguson Track, Toolamba
[5] Raftery Road, Kialla
[6] Stewarts Bridge Rd, Lower Moira

Table 7-8 Length of Road Bridges Inundated (metres)

	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d	20,000 ML/d
Reach 1	0	0	0	0	0	0
Reach 2	0	0	0	0	0	0
Reach 3	0	0	0	0	0	0
Reach 4	0	0	34	34	34	34
Reach 5	N/A	N/A	N/A	N/A	N/A	N/A
Reach 6	N/A	N/A	N/A	N/A	N/A	N/A
Reach 7	N/A	N/A	N/A	N/A	N/A	N/A
Reach 8	N/A	N/A	N/A	N/A	N/A	N/A
	25,000 ML/d	**30,000 ML/d**	**35,000 ML/d**	**40,000 ML/d**	**45,000 ML/d**	**55,000 ML/d**
Reach 1	N/A	N/A	N/A	N/A	N/A	N/A
Reach 2	N/A	N/A	N/A	N/A	N/A	N/A
Reach 3	0	0	0	0	N/A	N/A
Reach 4	34	34	34	60	N/A	N/A
Reach 5	0	0	0	0	94	94
Reach 6	61	61	103	103	103	103
Reach 7	0	0	63	63	63	63
Reach 8	0	0	0	0	0	0

7.5 Roads

A 2015 VicMap roads layer with a number of definitions of road type was provided by GBCMA for analysis of the length and type of road inundated at a number of flow rates. The road types determined in the VicMap were assessed by the GBCMA before handing over to Water Technology. The roads layer was clipped to each flood extent, the total road distance within the flood extents were then calculated and sorted by road type. It should be noted that the flood extent may overlap roads which are only inundated by shallow flows and still trafficable.

Table 7-9 Length of Road Inundated - Reach 1 (metres)

Road Type	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d	20,000 ML/d
Freeway	0	0	0	0	0	0
Highway	0	0	0	0	0	0
Arterial	0	0	0	0	0	0
Sub-Arterial	0	0	0	0	0	10
Collector	0	0	0	0	0	0
Local	0	0	0	0	0	0
Two Wheel Drive	0	27	142	268	471	846
Four Wheel Drive	0	0	0	0	0	0
Walking Track	0	0	0	0	0	0
Bicycle Track	0	0	0	0	0	0

Roads Inundated: Taggerty-Thornton Road, Christies Road

Table 7-10 Length of Road Inundated - Reach 2 (metres)

Road Type	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500	20,000 ML/d
Freeway	0	0	0	0	0	0
Highway	0	0	0	0	0	0
Arterial	0	0	0	0	0	0
Sub-Arterial	0	0	0	0	0	0
Collector	0	0	0	0	0	0
Local	3	3	80	275	300	300
Two Wheel Drive	121	174	725	1,056	1,720	2,332
Four Wheel Drive	0	0	0	0	0	0
Walking Track	0	0	0	0	16	381
Bicycle Track	0	0	0	0	0	0

Roads Inundated:
Recreation Reserve Road, Molesworth

Great Victorian Rail Trail, Molesworth

Table 7-11 Length of Road Inundated Reach 3 (metres)

Road Type	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d
Freeway	0	0	0	0	0
Highway	0	0	0	0	0
Arterial	0	0	0	0	0
Sub-Arterial	0	0	0	0	0
Collector	0	0	0	0	0
Local	0	0	0	0	0
Two Wheel Drive	0	0	0	0	0
Four Wheel Drive	0	0	0	0	0
Walking Track	0	0	0	0	17
Bicycle Track	0	0	0	0	0
Road Type	**20,000 ML/d**	**25,000 ML/d**	**30,000 ML/d**	**35,000 ML/d**	**40,000 ML/d**
Freeway	0	0	0	0	0
Highway	0	0	0	0	0
Arterial	0	0	0	0	0
Sub-Arterial	0	0	0	0	51
Collector	0	0	0	0	0
Local	0	0	0	0	2
Two Wheel Drive	0	0	198	335	810
Four Wheel Drive	0	0	0	0	0
Walking Track	28	0	29	41	60
Bicycle Track	0	0	0	0	0

Roads Inundated: Great Victorian Rail Trail, Kerrisdale

Table 7-12 Length of Road Inundated - Reach 4 Seymour to Goulburn Weir (metres)

Road Type	7,000 ML/d[1]	9,000 ML/d[1]	12,500 ML/d[1]	15,000 ML/d[1]	17,500 ML/d[1]
Freeway	0	0	0	0	0
Highway	0	0	0	0	0
Arterial	0	0	0	0	0
Sub-Arterial	0	0	0	0	0
Collector	0	0	0	0	0
Local	0	0	0	0	0
Two Wheel Drive	100	489	1,687	2,074	2,529
Four Wheel Drive	0	0	0	0	0
Walking Track	0	0	0	0	0
Bicycle Track	0	0	0	0	0
Road Type	**20,000 ML/d[1]**	**25,000 ML/d[1]**	**30,000 ML/d**	**35,000 ML/d[1]**	**40,000 ML/d**
Freeway	0	0	0	0	0
Highway	0	0	0	0	0
Arterial	0	0	0	0	0
Sub-Arterial	0	0	39	0	156
Collector	0	0	0	0	0
Local	0	0	937	0	1,399
Two Wheel Drive	2,847	0	1,386	153	2,978
Four Wheel Drive	0	0	0	0	0
Walking Track	0	0	0	0	0
Bicycle Track	0	0	0	0	0

[1]Seymour to Northwood Only

Roads Inundated:

Mitchelstown Road, Mitchelstown
O'Neils Road, Tabilk
Manners Street, Seymour

Table 7-13 Length of Road Inundated - Reach 5 (metres)

Road Type	25,000 ML/d	30,000 ML/d	35,000 ML/d	40,000 ML/d	45,000 ML/d	55,000 ML/d
Freeway	0	0	0	0	0	0
Highway	0	0	0	0	0	0
Arterial	0	0	0	0	0	0
Sub-Arterial	0	0	0	0	0	0
Collector	0	0	0	0	0	0
Local	21	100	636	1,035	1,432	1,856
Two Wheel Drive	6,599	11,661	37,670	48,520	59,311	66,272
Four Wheel Drive	0	0	0	0	0	0
Walking Track	0	0	0	0	39	39
Bicycle Track	0	0	0	0	0	0

Roads Inundated:

Low Road, Murchison East
Mad Jacks Tack, Toolamba,
Lils Track, Toolamba
Darcys Track, Toolamba
Bridge Track, Toolamba

Table 7-14 Length of Road Inundated - Reach 6 (metres)

Road Type	25,000 ML/d	30,000 ML/d	35,000 ML/d	40,000 ML/d	45,000 ML/d	55,000 ML/d
Freeway	0	0	0	0	0	0
Highway	5	5	5	5	5	5
Arterial	0	0	0	0	0	0
Sub-Arterial	0	0	0	0	0	0
Collector	0	0	0	0	0	0
Local	3,431	4,548	5,483	7,173	8,540	9,640
Two Wheel Drive	90,016	131,201	157,774	190,078	199,749	208,448
Four Wheel Drive	872	904	968	1,264	1,330	1,403
Walking Track	91	168	191	273	385	448
Bicycle Track	2,082	2,572	3,149	3,996	4,401	4,777

Roads Inundated:

Coomboona Track, Coomboona
Munro Rd, St Germains
McFarlane Road, Mooroopna
Watt Road, Kialla
Raftery Road, Kialla
Riverview Drive, Kialla
Pyke Road, Mooroopna
Reedy Swamp Road, Shepparton
Tom Collins Drive, Shepparton

Table 7-15 Length of Road Inundated - Reach 7 (metres)

Road Type	25,000 ML/d	30,000 ML/d	35,000 ML/d	40,000 ML/d	45,000 ML/d	55,000 ML/d
Freeway	0	0	0	0	0	0
Highway	0	0	0	0	0	0
Arterial	0	0	0	0	0	0
Sub-Arterial	3,363	4,062	6,559	6,937	9,816	10,565
Collector	0	0	0	0	0	0
Local	703	937	1,417	1,763	6,465	8,692
Two Wheel Drive	43,995	55,699	75,961	81,566	94,677	96,626
Four Wheel Drive	6,490	10,415	13,235	14,806	17,106	17,291
Walking Track	0	0	0	0	0	0
Bicycle Track	0	0	0	0	0	0

Roads Inundated:

Yambuna Road, Kotupna
Stewarts Bridge Road, Lower Moira
Kotupna – Barmah Road, Kotupna
Hutchins Lane, Kotupna
Taylors Road, Kotupna
Wallala Drive, Lower Moira
Brooms Road, Kotupna
Hancocks Bridge Road, Kotupna

Table 7-16 Length of Road Inundated - Reach 8 (metres)

Road Type	25,000 ML/d	30,000 ML/d	35,000 ML/d	40,000 ML/d	45,000 ML/d	55,000 ML/d
Freeway	0	0	0	0	0	0
Highway	0	0	0	0	0	0
Arterial	0	0	0	0	0	0
Sub-Arterial	0	0	0	0	171	307
Collector	0	0	0	0	0	0
Local	6,615	6,791	7,389	7,389	9,695	9,838
Two Wheel Drive	5,444	6,907	16,284	16,437	29,838	30,643
Four Wheel Drive	34,339	36,568	42,366	42,366	65,160	65,469
Walking Track	0	0	0	0	0	0
Bicycle Track	0	0	0	0	0	0

Roads Inundated

Old Barmah Road, Moama

7.6 Specialist Business

An assessment of specialist businesses which may be adversely impacted during an environmental flow release was undertaken using a GIS layer of specialist businesses localities. The GIS layer was developed by ThinkSpatial by aerial photography interpretation, with boundaries of key assets mapped rather than total property boundaries. A variety of businesses have been included in this section, the business types include: vineyards, holiday/caravan parks, orchards, cherry farms, flower farms, green tea farms, sand and gravel extraction. The businesses impacted during flow releases are listed in Table 7-17 and Table 7-18 shown below. Individual business details have been listed in more detail in a separate document held with the GBCMA.

Table 7-17 Specialist Businesses impacted in Reach 1 & 2

Specialist Businesses Impacted – Flow Rate (ML/d)						
Reach	7,000	9,000	12,500	15,000	17,500	20,000
1 & 2	-	-	1	3	4	4

Table 7-18 Specialist Businesses impacted in Reach 3-8

Specialist Businesses Impacted – Flow Rate (ML/d)						
Reach	25,000	30,000	35,000	40,000	45,000	55,000
3 & 4	1	4	5	6	N/A	N/A
5, 6, 7 & 8	1	3	3	3	6	6

7.7 Public Land

The public land area inundated was calculated using the 2013 Bureau of Rural Sciences (BRS) Land Use layer and checked against the 2015 VicMap Crown Land Tenure layer for consistency. It should be noted that the crown land tenure layer does not cover the entire flood extent in reach 8, resulting in a discrepancy between the total flood extent and the sum of public and private land inundated as shown below.

Table 7-19 Public Land Inundated

	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d	20,000 ML/d
Reach 1	223	247	276	288	309	325
Reach 2	359	401	516	597	685	768
Reach 3	301	324	353	374	397	424
Reach 4	76	80	86	94	101	110
Reach 5	N/A	N/A	N/A	N/A	N/A	N/A
Reach 6	N/A	N/A	N/A	N/A	N/A	N/A
Reach 7	N/A	N/A	N/A	N/A	N/A	N/A
Reach 8	N/A	N/A	N/A	N/A	N/A	N/A
	25,000 ML/d	**30,000 ML/d**	**35,000 ML/d**	**40,000 ML/d**	**45,000 ML/d**	**55,000 ML/d**
Reach 1	N/A	N/A	N/A	N/A	N/A	N/A
Reach 2	N/A	N/A	N/A	N/A	N/A	N/A
Reach 3	460	493	558	606	N/A	N/A
Reach 4	121	812	156	957	N/A	N/A
Reach 5	1,054	1,282	2,212	2,222	2,380	2,471
Reach 6	4,388	5,452	6,624	6,714	6,921	7,047
Reach 7	2,686	3,017	3,406	3,889	3,939	4,042
Reach 8	128	156	168	169	199	206

[1] Reach 4 – Seymour to Northwood Only

[2] Reach 4 – Seymour to Goulburn Weir

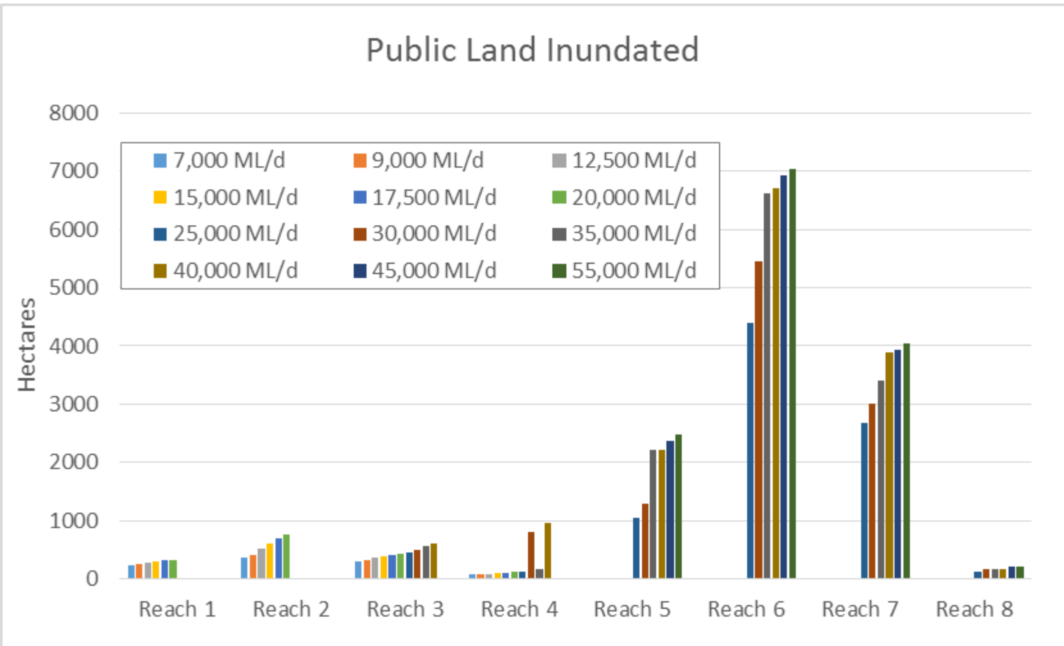

Figure 7-7 Public Land Inundated

7.8 Private Land

The Private land inundated was calculated using the 2013 BRS Land Use Layer and was checked for consistency against the 2015 VicMap Crown Land Tenure layer. It should be noted that neither land tenure layer extended all the way into reach 8, resulting in a discrepancy between the total flood extent and the sum of public and private land inundated as shown below.

Table 7-20 Private Land Inundated

	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d	20,000 ML/d
Reach 1	49	54	63	84	149	198
Reach 2	58	85	220	459	799	1,106
Reach 3	41	46	61	90	126	182
Reach 4	13[1]	14[1]	16[1]	20[1]	23[1]	27[1]
Reach 5	N/A	N/A	N/A	N/A	N/A	N/A
Reach 6	N/A	N/A	N/A	N/A	N/A	N/A
Reach 7	N/A	N/A	N/A	N/A	N/A	N/A
Reach 8	N/A	N/A	N/A	N/A	N/A	N/A
	25,000 ML/d	**30,000 ML/d**	**35,000 ML/d**	**40,000 ML/d**	**45,000 ML/d**	**55,000 ML/d**
Reach 1	N/A	N/A	N/A	N/A	N/A	N/A
Reach 2	N/A	N/A	N/A	N/A	N/A	N/A
Reach 3	327	482	694	937	N/A	N/A
Reach 4	28[1]	2,183[2]	137[1]	2,693[2]	N/A	N/A
Reach 5	511	576	1,377	1,418	1,763	1,962
Reach 6	441	601	1,096	1,220	1,697	2,430
Reach 7	1,229	1,456	1,980	2,482	3,780	4,390
Reach 8	54	55	63	63	69	73

[1] Reach 4 – Seymour to Northwood Only [2] Reach 4 – Seymour to Goulburn Weir

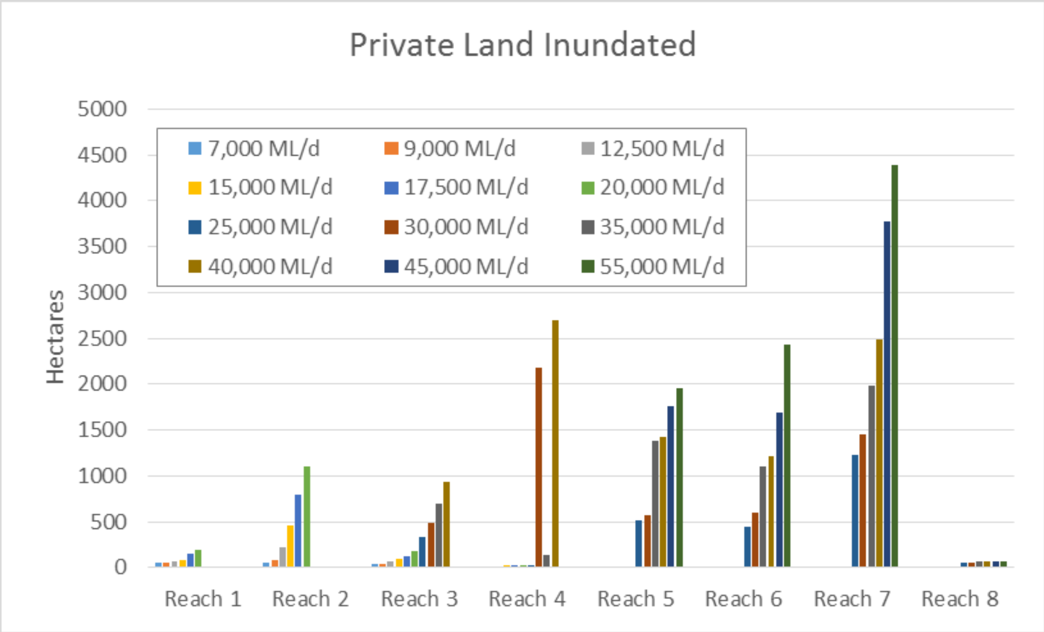

Figure 7-8 Private Land Inundated

7.9 Land Use

The following section assesses the area inundated by environmental watering by land use type. The land use layer used was developed by the federal department for agriculture in 2013. This layer classified land use into over 80 categories, which were then simplified into 9 categories shown below. A full list of land use types is shown in Appendix B.

- Dryland Pasture
- Dryland Broadacre
- Irrigated Pasture
- Other Fruit
- Forestry
- Grapes
- Vegetables
- Intensive Agriculture.

The remaining land use types classed into 'other' category include:
Manufacturing and industrial, Urban residential, Rural residential, Commercial services, Public services, Recreation and culture, Other minimal use, Natural feature protection, Strict nature reserves, Other conserved area, Managed resource protection, Remnant native cover, Residual native cover, Utilities, Roads, Defence, Railways, Quarries, Vegetables & herbs, Waste treatment and disposal, Irrigated vegetables & herbs, as well as the area taken up by surface water features: Water, Lake, Reservoir/dam, Water storage and treatment, Water storage - intensive use/farm dams, Surface water supply, River, Channel/aqueduct and Marsh/wetland.

In calculating the area inundated of these various agricultural businesses, it is assumed that the land use type was applied across the entire property parcel. This assessment therefore derives different results compared to the specialty businesses statistics described previously. Each reach has a table listing the area inundated within each category as well as two plots which graphically show the land types inundated (a second graph is shown for each reach without the 'Other' area included to give a better representation of the land types inundated.

Table 7-21 Reach 1 - Land Use Type Inundated

	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d	20,000 ML/d
Dryland Broadacre Crops (ha)	7	8	10	12	16	18
Dryland Pasture (ha)	22	24	27	38	73	93
Forestry (ha)	3	3	4	6	20	39
Grapes (ha)	0	0	0	0	0	0
Intensive agriculture (ha)	5	6	7	7	7	8
Irrigated pasture (ha)	9	10	11	17	19	24
Other Fruit (ha)	0	0	0	0	0	0
Vegetables (ha)	0	0	0	0	0	0
Other (ha)	226	251	279	293	322	342

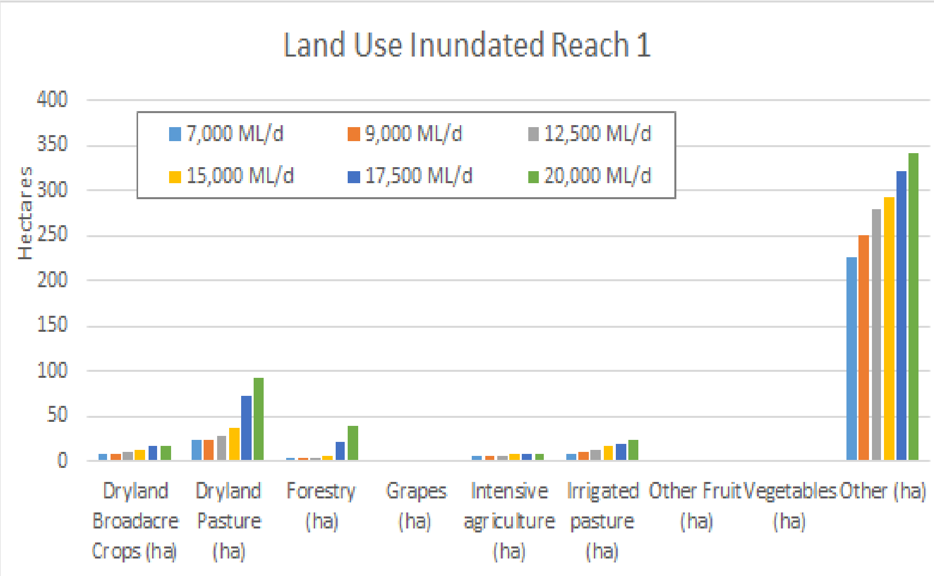

Figure 7-9 Reach 1 - Land Use Type Inundated

Table 7-22 Reach 2 - Land Use Type Inundated

	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d	20,000 ML/d
Dryland Broadacre Crops (ha)	3	7	20	31	56	82
Dryland Pasture (ha)	14	16	39	85	147	230
Forestry (ha)	20	31	74	183	331	461
Grapes (ha)	0	0	0	0	0	0
Intensive agriculture (ha)	0	0	0	0	0	0
Irrigated pasture (ha)	18	25	75	138	234	291
Other Fruit (ha)	0	0	0	0	0	0
Vegetables (ha)	0	0	0	0	0	0
Other (ha)	363	406	527	619	716	810

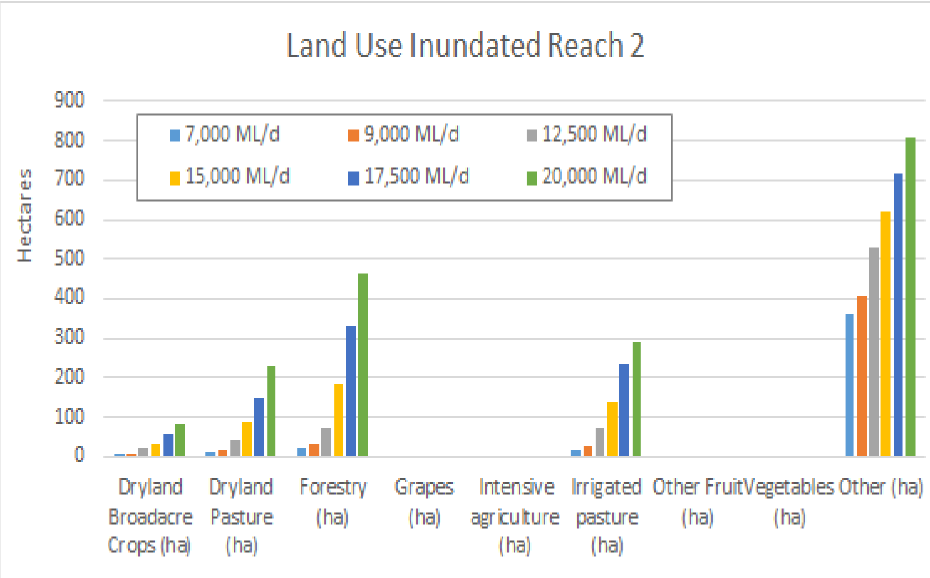

Figure 7-10 Reach 2 - Land Use Type Inundated

Table 7-23 Reach 3 - Land Use Type Inundated

	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d
Dryland Broadacre Crops (ha)	1	1	2	2	2
Dryland Pasture (ha)	6	6	9	18	25
Forestry (ha)	9	10	15	25	39
Grapes (ha)	0	0	0	0	0
Intensive agriculture (ha)	0	0	0	0	0
Irrigated pasture (ha)	17	19	24	31	39
Other Fruit (ha)	0	0	0	0	0
Vegetables (ha)	0	0	0	0	0
Other (ha)	309	333	364	388	417
	20,000 ML/d	25,000 ML/d	30,000 ML/d	35,000 ML/d	40,000 ML/d
Dryland Broadacre Crops (ha)	6	10	17	24	29
Dryland Pasture (ha)	41	97	130	228	335
Forestry (ha)	58	111	131	170	213
Grapes (ha)	1	1	1	1	2
Intensive agriculture (ha)	0	0	0	0	0
Irrigated pasture (ha)	51	93	126	168	230
Other Fruit (ha)	0	0	0	0	0
Vegetables (ha)	0	0	0	11	11
Other (ha)	449	521	570	661	734

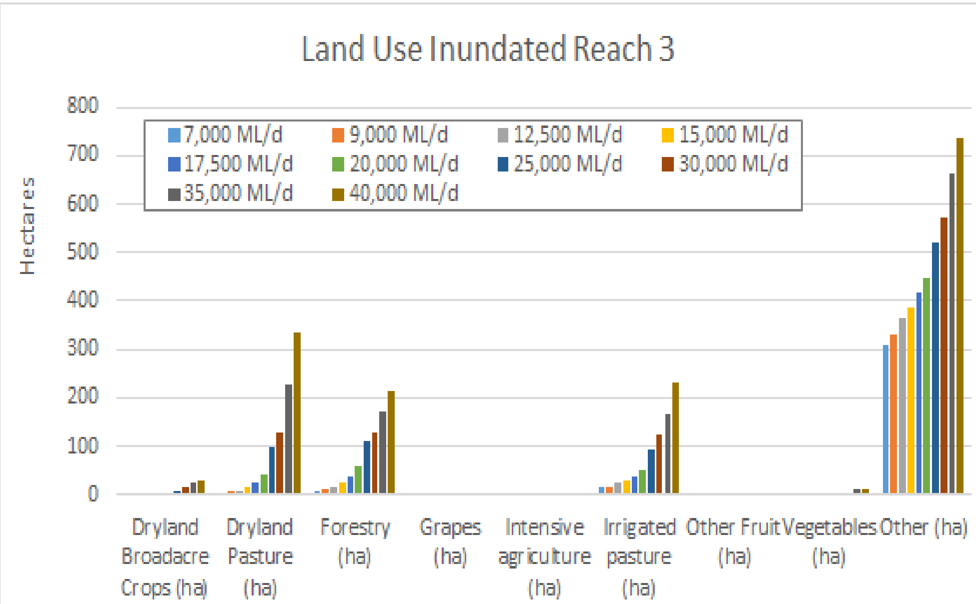

Figure 7-11 Reach 3 - Land Use Type Inundated

Note for Reach 4 results, the 30,000 ML/d and 40,000 ML/d flood extents include the area from Northwood through to the Goulburn Weir as previously mentioned.

Table 7-24 Reach 4 - Land Use Type Inundated

	7,000[1] ML/d	9,000[1] ML/d	12,500[1] ML/d	15,000[1] ML/d	17,500[1] ML/d
Dryland Broadacre Crops (ha)	0	0	0	2	2
Dryland Pasture (ha)	6	7	7	9	10
Forestry (ha)	0	0	0	0	0
Grapes (ha)	0	0	0	0	0
Intensive agriculture (ha)	0	0	0	0	0
Irrigated pasture (ha)	4	4	5	5	5
Other Fruit (ha)	0	0	0	0	0
Vegetables (ha)	0	0	0	0	0
Other (ha)	79	83	89	98	106
	20,000[1] ML/d	25,000[1] ML/d	30,000[2] ML/d	35,000[1] ML/d	40,000[2] ML/d
Dryland Broadacre Crops (ha)	2	2	60	4	81
Dryland Pasture (ha)	13	13	427	35	569
Forestry (ha)	0	0	33	0	39
Grapes (ha)	0	0	206	0	314
Intensive agriculture (ha)	0	0	0	0	0
Irrigated pasture (ha)	5	6	310	52	402
Other Fruit (ha)	0	0	0	0	0
Vegetables (ha)	0	0	0	0	0
Other (ha)	117	119	1957	201	2144

[1] Seymour to Northwood Only [2] Seymour to Goulburn Weir

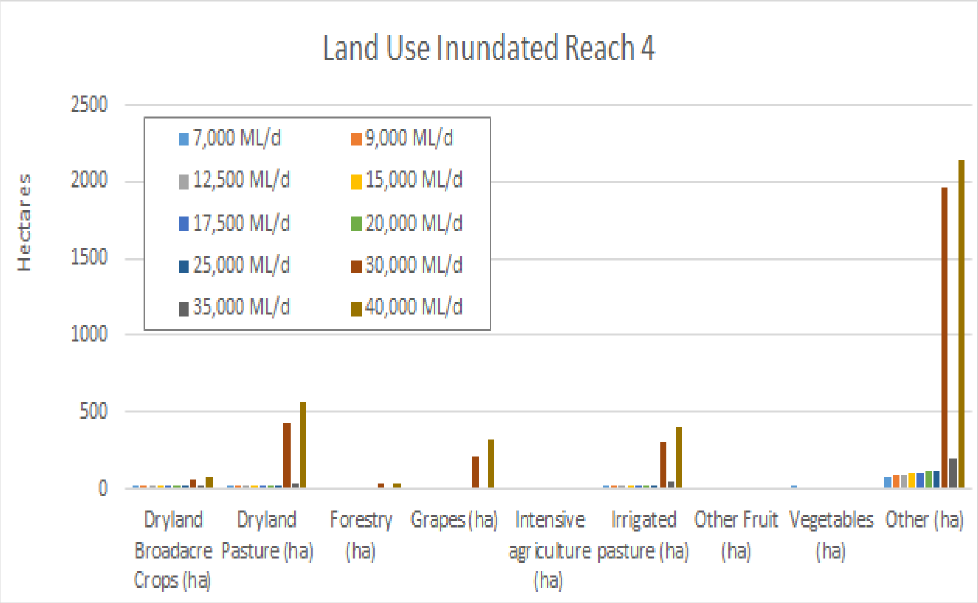

Figure 7-12 Reach 4 - Land Use Type Inundated

Table 7-25 Reach 5 - Land Use Type Inundated

	25,000 ML/d	30,000 ML/d	35,000 ML/d	40,000 ML/d	45,000 ML/d	55,000 ML/d
Dryland Broadacre Crops (ha)	33	36	112	130	172	193
Dryland Pasture (ha)	94	106	430	443	540	588
Forestry (ha)	136	146	306	317	363	393
Grapes (ha)	127	127	150	159	204	226
Intensive agriculture (ha)	8	10	21	23	29	33
Irrigated pasture (ha)	93	128	271	367	469	530
Other Fruit (ha)	0	0	0	0	0	0
Vegetables (ha)	0	0	0	0	0	0
Other (ha)	1074	1306	2192	2200	2365	2461

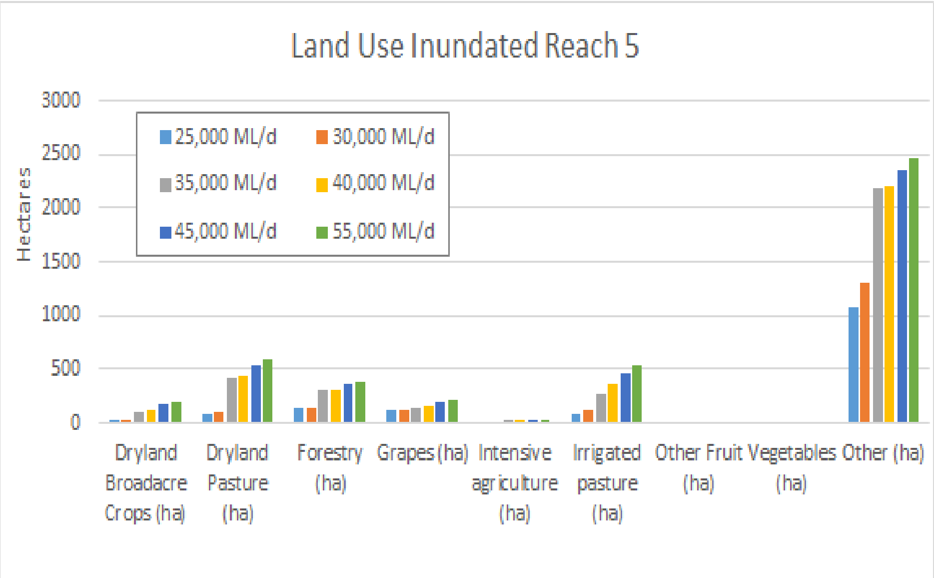

Figure 7-13 Reach 5 - Land Use Type Inundated

Table 7-26 Reach 6 - Land Use Type Inundated

	25,000 ML/d	30,000 ML/d	35,000 ML/d	40,000 ML/d	45,000 ML/d	55,000 ML/d
Dryland Broadacre Crops (ha)	51	73	123	166	473	837
Dryland Pasture (ha)	13	26	143	156	192	269
Forestry (ha)	37	59	110	138	186	295
Grapes (ha)	0	0	0	0	0	0
Intensive agriculture (ha)	2	7	15	16	16	16
Irrigated pasture (ha)	4643	5749	6530	253	319	437
Other Fruit (ha)	0	0	0	0	0	0
Vegetables (ha)	0	0	0	0	0	0
Other (ha)	4643	5749	6530	7206	7431	7551

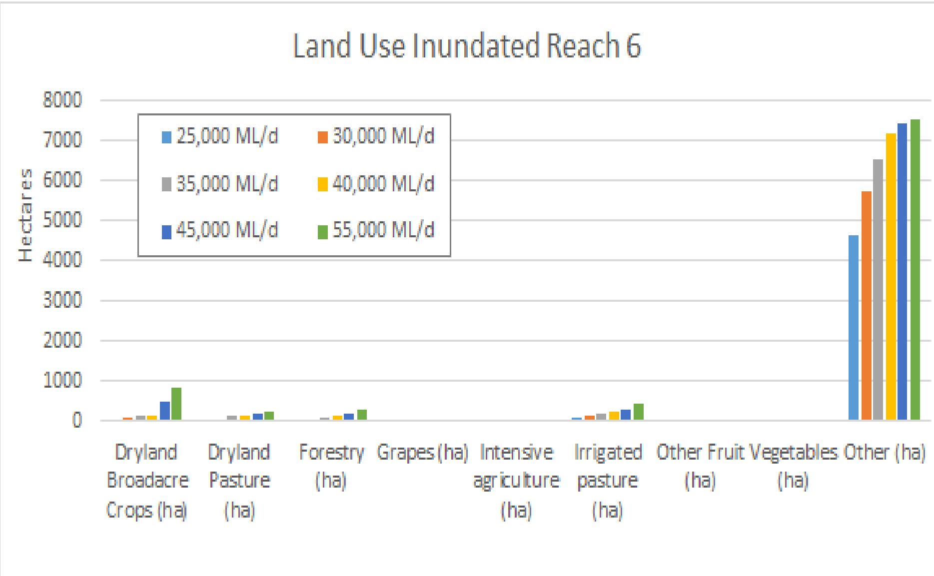

Figure 7-14 Reach 6 - Land Use Type Inundated

Table 7-27 Reach 7 - Land Use Type Inundated

	25,000 ML/d	30,000 ML/d	35,000 ML/d	40,000 ML/d	45,000 ML/d	55,000 ML/d
Dryland Broadacre Crops (ha)	19	22	33	38	114	252
Dryland Pasture (ha)	100	130	205	254	325	407
Forestry (ha)	430	499	732	734	923	1157
Grapes (ha)	0	0	0	0	45	46
Intensive agriculture (ha)	0	0	0	0	0	0
Irrigated pasture (ha)	237	281	859	684	1435	1817
Other Fruit (ha)	0	0	0	0	0	0
Vegetables (ha)	0	0	0	0	0	0
Other (ha)	2947	3329	4051	4219	4731	4966

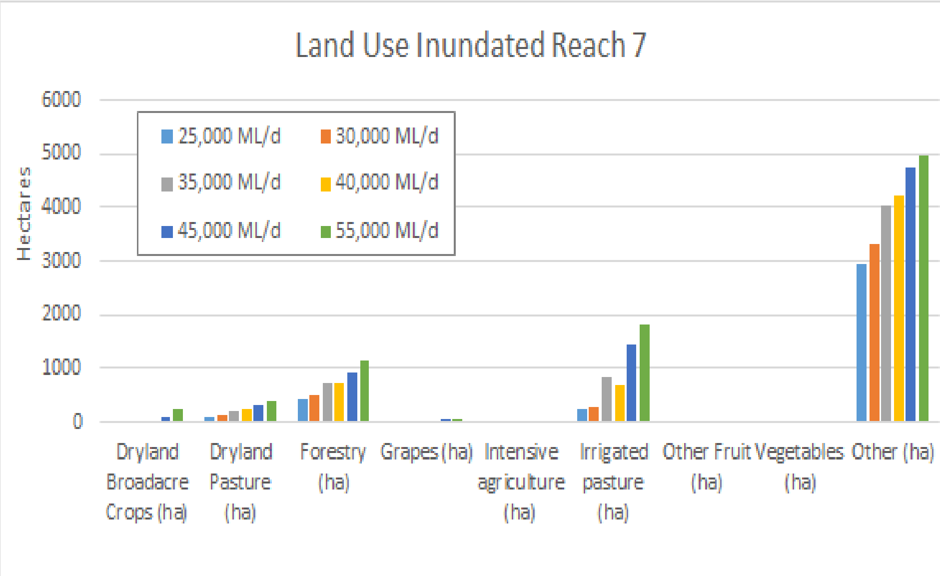

Figure 7-15 Reach 7 - Land Use Type Inundated

Table 7-28 Reach 8 - Land Use Type Inundated

	25,000 ML/d	30,000 ML/d	35,000 ML/d	40,000 ML/d	45,000 ML/d	55,000 ML/d
Dryland Broadacre Crops (ha)	0	0	0	0	0	0
Dryland Pasture (ha)	0	0	0	0	0	0
Forestry (ha)	41	62	62	65	79	82
Grapes (ha)	0	0	0	0	0	0
Intensive agriculture (ha)	0	0	0	0	0	0
Irrigated pasture (ha)	0	0	0	0	0	0
Other Fruit (ha)	0	0	0	0	0	0
Vegetables (ha)	0	0	0	0	0	0
Other (ha)	141	149	171	173	195	197

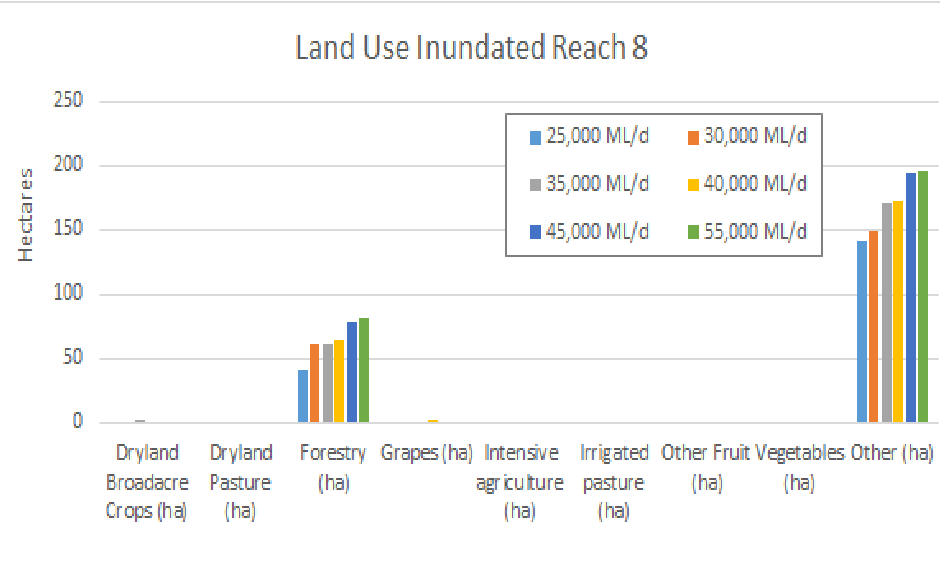

Figure 7-16 Reach 8 - Land Use Type Inundated

7.10 Native Vegetation

A spatial GIS layer produced in 2005 by the Department of Sustainability and Environment (DSE) categorised the landscape into native woody, native grassy and major native wetland cover together with probability ratings, ranging from "highly likely native vegetation cover" through to "unlikely to support native vegetation". The layer was produced using remote-sensing data, and is a combination of a number of spatial datasets such as tree cover, rainfall and temperature together with time series LANDSAT imagery and ground-truthed site data. The layer is designed for use at a large scale (1:25,000 to 1:100,000) and is not definitive at the site or property scale. (DSE, 2007). For this project, the area defined as Native Vegetation used the same methodology in previous studies (Water Technology 2010 & Water Technology, 2014), which selected only areas labelled "*Highly likely native vegetation – woody"* from the DSE native vegetation layer.

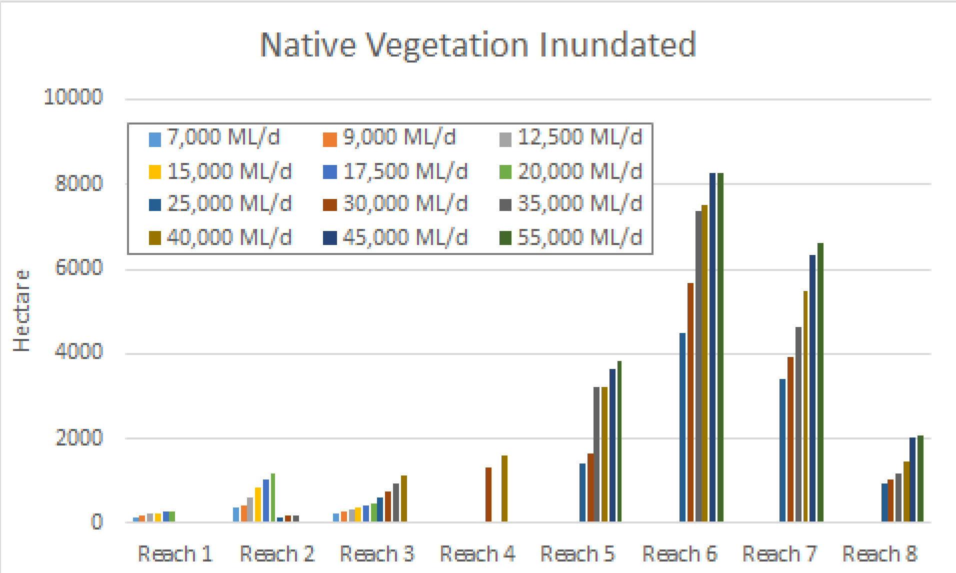

Figure 7-17 Native Vegetation Inundated (ha)

Table 7-29 Native Vegetation Inundated (ha)

	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d	20,000 ML/d
Reach 1	155	180	212	235	273	295
Reach 2	379	441	628	833	1,027	1,192
Reach 3	249	274	315	361	417	479
Reach 4	N/A	N/A	N/A	N/A	N/A	N/A
Reach 5	N/A	N/A	N/A	N/A	N/A	N/A
Reach 6	N/A	N/A	N/A	N/A	N/A	N/A
Reach 7	N/A	N/A	N/A	N/A	N/A	N/A
Reach 8	N/A	N/A	N/A	N/A	N/A	N/A
	25,000 ML/d	**30,000 ML/d**	**35,000 ML/d**	**40,000 ML/d**	**45,000 ML/d**	**55,000 ML/d**
Reach 1	N/A	N/A	N/A	N/A	N/A	N/A
Reach 2	136	177	198	N/A	N/A	N/A
Reach 3	625	746	938	1,133	N/A	N/A
Reach 4	N/A	1,331	N/A	1,621	N/A	N/A
Reach 5	1,396	1,657	3,200	3,202	3,633	3,827
Reach 6	4,481	5,691	7,359	7,517	8,280	8,280
Reach 7	3,402	3,912	4,632	5,466	6,319	6,601
Reach 8	959	1,040	1,186	1,464	2,015	2,098

7.11 Wetlands

In a previous study (Water Technology 2010) the wetland areas were defined by the drained inundated area from a 60,000 ML/d flow event. The lower Goulburn floodplain area (previously Reach H) which includes much of Reach 7 & 8 was not drained due to limitations around the previous model size and run time to drain the area of the 60,000 ML/d flow event. The wetland definition for the lower Goulburn River floodplain statistics uses the DELWP wetland layer "*wetland_1994*".

The wetland area has been clipped to the flood extents of each flow extent and the total area inundated is shown in Figure 7-18 and Table 7-30. Figure 7-19 shows the area inundated as a percentage of the total wetland area. The percentage of wetland inundated across each reach differs considerably, with reach 6 showing 86% of the wetland area inundated at 25,000 ML/d and only increasing to 93% at a flow rate of 55,000 ML/d. However Reach 5 has a considerable jump in wetland area inundated from 41% of total wetland at 30,000 ML/d up to 90% at 35,000 ML/d.

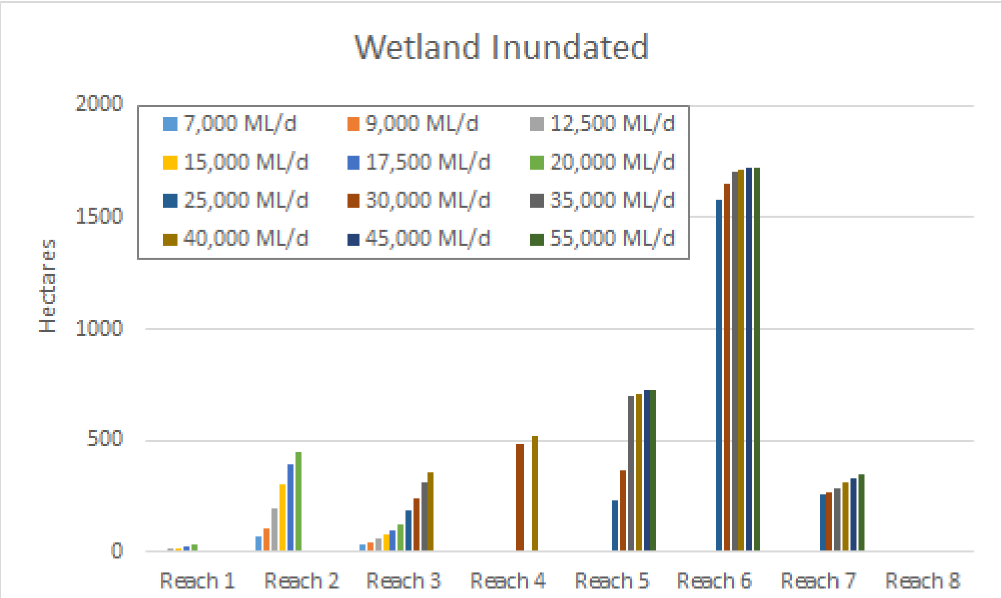

Figure 7-18 Wetlands Inundated (ha)

Table 7-30 Wetlands Inundated (ha)

	7,000 ML/d	9,000 ML/d	12,500 ML/d	15,000 ML/d	17,500 ML/d	20,000 ML/d
Reach 1	5	11	17	20	27	32
Reach 2	72	104	198	300	392	452
Reach 3	36	45	58	79	97	126
Reach 4	N/A	N/A	N/A	N/A	N/A	N/A
Reach 5	N/A	N/A	N/A	N/A	N/A	N/A
Reach 6	N/A	N/A	N/A	N/A	N/A	N/A
Reach 7	N/A	N/A	N/A	N/A	N/A	N/A
Reach 8	N/A	N/A	N/A	N/A	N/A	N/A
	25,000 ML/d	**30,000 ML/d**	**35,000 ML/d**	**40,000 ML/d**	**45,000 ML/d**	**55,000 ML/d**
Reach 1	N/A	N/A	N/A	N/A	N/A	N/A
Reach 2	N/A	N/A	N/A	N/A	N/A	N/A
Reach 3	191	245	310	359	N/A	N/A
Reach 4	N/A	479	N/A	522	N/A	N/A
Reach 5	236	371	696	709	729	730
Reach 6	1,583	1,657	1,706	1,714	1,720	1,720
Reach 7	256	272	287	312	335	345
Reach 8	N/A	N/A	N/A	N/A	N/A	N/A

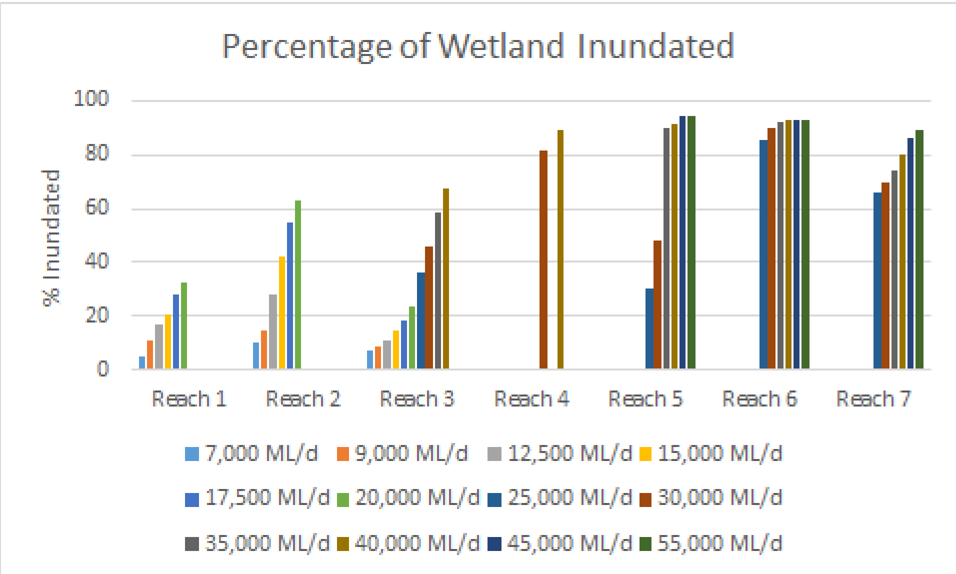

Figure 7-19 Percentage of Wetland Inundated

8. LEVEE PROFILES

The lower Goulburn floodplain has an extensive system of levees, described in detail in a previous levee audit project for the GBCMA (Water Technology, 2013), the 16 levee locations are shown in Figure 8-1. A longitudinal profile of each levee section was produced showing the levee crest and natural surface height compared with the water surface level for six flow rates between 25,000 ML/d and 55,000 ML/d. The levee heights were based on detailed survey points compiled during the levee audit. These survey points were intersected with the flood modelling results, interpolating the highest water surface level within a 25 m radius of the point. A longitudinal section for levee section 1 is shown below in Figure 8-2, the remaining sections were provided in Microsoft excel format to the GBCMA as part of the final deliverables.

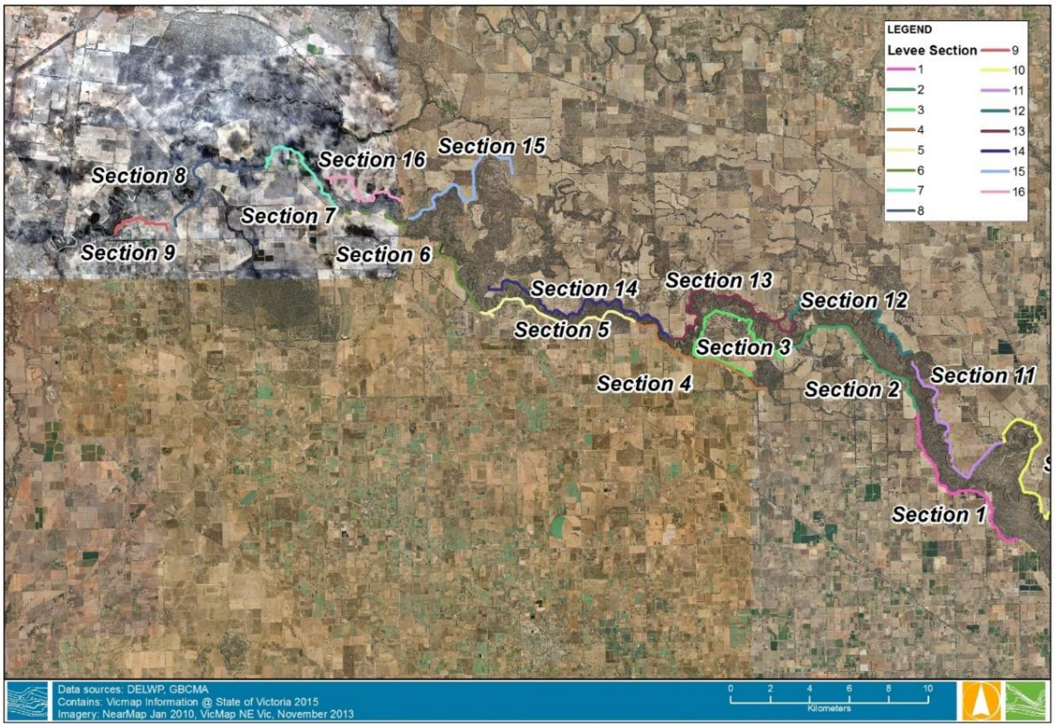

Figure 8-1 Goulburn Levee Profile Section Layout

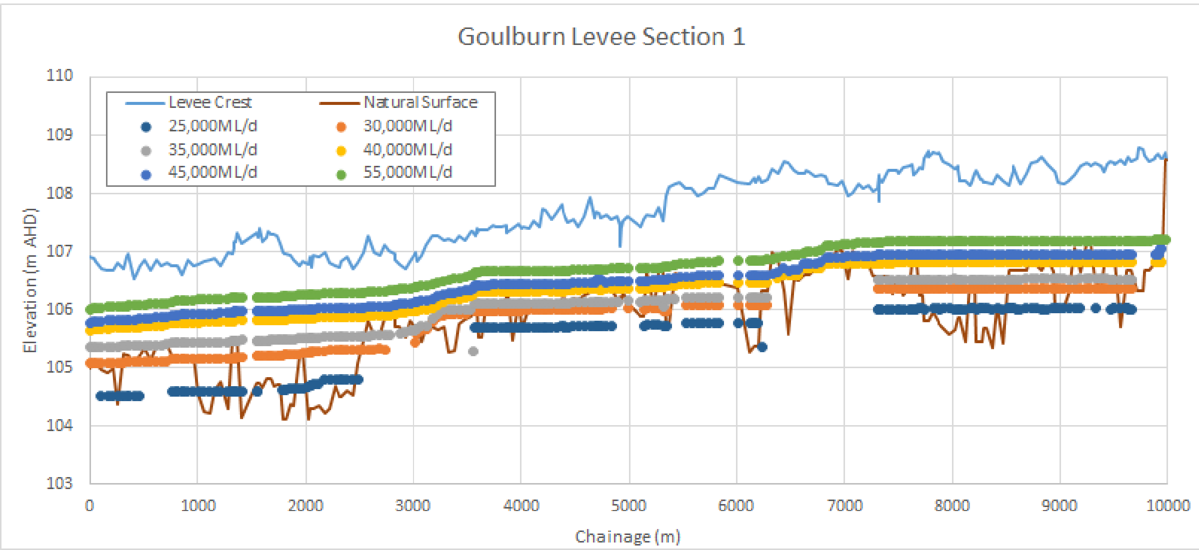

Figure 8-2 Goulburn Levee section 1 Example Longitudinal section

Results of the levee profile assessment using the environmental watering design flows are provided in Table 8-1 and show the length of levee overtopped for the Goulburn levee sections across all flow rates. The length of levee inundated at 40,000 ML/d (1,375 m) showed a good comparison when compared to the levee risk project undertaken in conjunction with this project (levee risk distance 1460 m). This minor discrepancy and a difference in the length of levee overtopped at 55,000 ML/d is a conservative approach compared to the levee risk project which used levee heights interpolated at 1 metre intervals along the entire length of the levee. The approach taken in this assessment utilised only surveyed levee points and calculated the length of levee overtopped between surveyed levee points only.

Table 8-1 Length of Levee Overtopped (m)

	25,000 ML/d	30,000 ML/d	35,000 ML/d	40,000 ML/d	45,000 ML/d	55,000 ML/d
Goulburn 01	0	0	0	0	0	0
Goulburn 02	0	0	0	0	0	0
Goulburn 03	0	0	0	1	1	788
Goulburn 04	0	0	0	0	0	44
Goulburn 05A	0	49	49	49	53	109
Goulburn 05B	0	0	0	0	0	0
Goulburn 06A	0	0	0	0	0	9
Goulburn 06B	0	0	47	47	47	47
Goulburn 07	0	0	38	38	38	38
Goulburn 08	0	0	0	0	0	0
Goulburn 09	42	42	42	42	42	42
Goulburn 10	0	0	0	0	0	0
Goulburn 11	0	0	0	0	0	0
Goulburn 12	0	0	0	29	29	264
Goulburn 13A	0	0	0	0	0	66
Goulburn 13B	0	0	262	262	310	456
Goulburn 14	93	93	93	215	348	2,836
Goulburn 15A	38	38	38	38	38	135
Goulburn 15B	0	0	0	4	378	463
Goulburn 16A	54	348	424	650	965	1,316
Goulburn 16B	0	0	0	0	0	14
Grand Total	227	569	992	1,375	2,248	6,627

Further assessment of the model results looked into the length of levees on private and public land which had water sitting up against them. This also provides a general indication of the amount of private land which may require levee upgrades into the future.

Length of Levee with water up against it	40,000 ML/d	55,000 ML/d
Total Length (m)	109,415	125,662
Public Land (m)	55,705	59,171
Private Land (m)	53,710	66,491
Area wet (10 m buffer radius)		
Public Area (ha)	116	122
Private Area (ha)	117	141

9. REFERENCES

DELWP (2015), Victorian Water Monitoring web portal, Department of Environment, Land, Water and Planning, accessed April 29, 2015.

DSE (2007), *Native Vegetation Information – Overview of native vegetation spatial datasets,* Department of Sustainability and Environment, Accessed from:

http://www.dse.vic.gov.au/__data/assets/pdf_file/0006/97323/NV_spatial_datasets.pdf

Water Technology (2010) Goulburn River Environmental Flow Hydraulic study: Report prepared for Goulburn Broken Catchment Management Authority

Water Technology (2012) Mid Goulburn River, Elevation Analysis: Report prepared for Goulburn Broken Catchment Management Authority

Water Technology (2013) Rural Levees Assessment: Report prepared for Goulburn Broken Catchment Management Authority

Water Technology (2014) Analysis of Goulburn River Constraints Modelling: Report prepared for Murray Darling Basin Authority

Water Technology (2015a) Goulburn River Constraints Analysis: Data Review Report prepared for Goulburn Broken Catchment Management Authority

APPENDIX A – Data Review Summary

A.1 Data Summary

A preliminary review of the available data focussed primarily on the available topographic data sets along the Goulburn River floodplain. The first task reviewed the recent TUFLOW GPU model topography to ensure that the best datasets were used and where required, are updated. A new LiDAR dataset has become available since the previous modelling and this has been considered for use in the lower floodplain below Shepparton. Rating curves and gauging plots at streamflow gauge locations along the Goulburn River are available from the DELWP water monitoring portal and were also reviewed.

A.2 Previous Studies

Water Technology has previously undertaken a large number of flood modelling and mapping and environmental studies on the Goulburn River. Several previous studies which have a direct relevance to this project include:

- Goulburn River Environmental Flow Hydraulics Study (Water Technology, 2008)
- Lower Goulburn River Hydraulic Modelling Analysis (Water Technology, 2011)
- Audit of Strategic Levees in the lower Goulburn Floodplain (Water Technology, 2013a)
- Shepparton Mooroopna Flood Mapping and Flood Intelligence Report (Water Technology, 2013b)
- Murchison Flood Mapping (Water Technology, 2014a)
- Goulburn River Constraints Analysis for Murray Darling Basin Authority (Water Technology, 2014b)
- Goulburn River GPU design modelling (Water Technology, 2014c)

Information from these studies has helped formed the base knowledge for available data, catchment hydrology and flow behaviour along the Goulburn River.

A.3 Topographic Data

Several topographic datasets have been identified from previous studies and will be used to create the hydraulic model Digital Elevation Model (DEM). For this project an additional LiDAR set through the lower Goulburn floodplain as well as several township areas in the mid Goulburn River reach are available. All available topographic datasets are shown in Figure A - 6 and Figure A - 7.

A.4 Field Survey

Field Survey forms an integral component of the hydraulic model DEM development, it is used to verify the accuracy of the LiDAR sets and fill missing gaps within the LiDAR sets. LiDAR does not penetrate water well, and this requires treatment in the models using a variety of approaches depending on available information. For instance the Nagambie weir pool will be updated using available bathymetry, however in areas with no survey information the bed level may be lowered using best estimates and judgement (previous work lowered the bed by 1.5 m in the reach upstream of Nagambie weir pool).

Bathymetric Data

Three bathymetric datasets have been identified in previous studies, these are outlined below.

Goulburn River upstream of Yea River

A bathymetric survey of the Goulburn River upstream of the Yea River was undertaken in 2007. This was provided to Water Technology in 2008 as a 2 m DEM for the Goulburn River Environmental Flow Hydraulics Study (Water Technology, 2008) and is shown in Figure A - 1. This DEM data will be used as the Goulburn River channel in the hydraulic model. It will also be compared against the mid Goulburn LiDAR sets to estimate the average depth of channel bed below the reflected water level shown in the LiDAR sets. The estimated depth below the LiDAR water surface will be used to assist in the calibration, this is covered in more detail in Section 3.2.

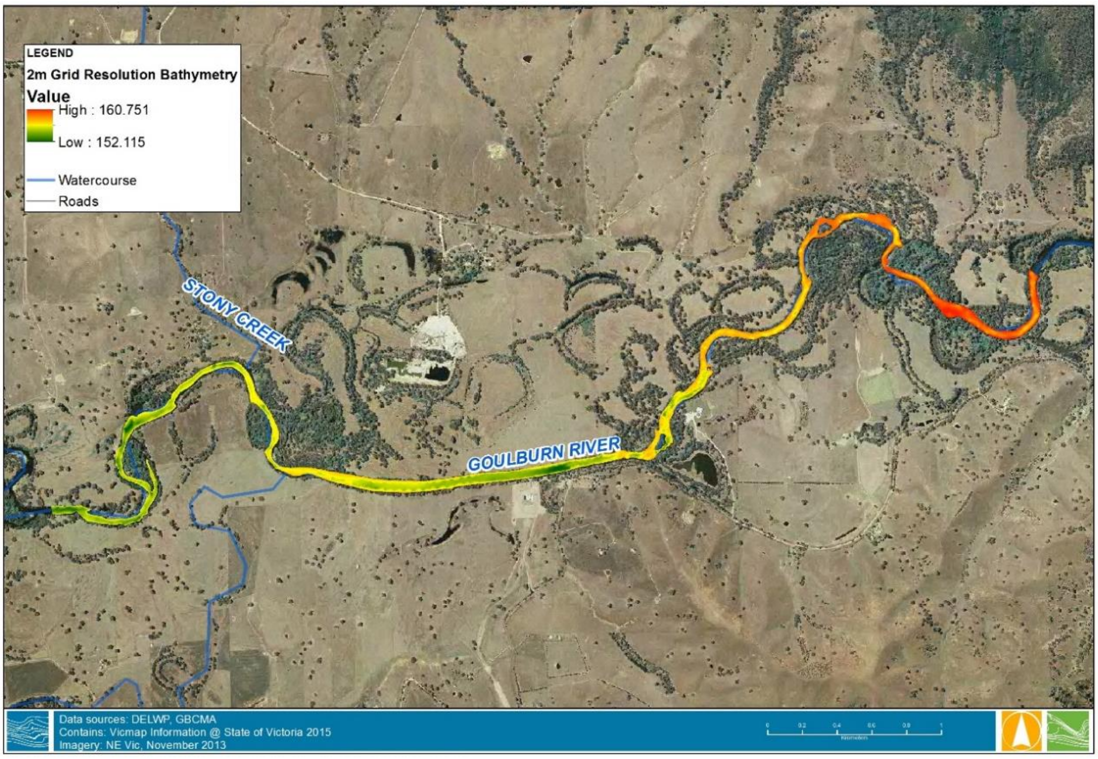

Figure A - 1 Bathymetry of Goulburn River at Yea

Lower Goulburn Bathymetry

A bathymetric survey was undertaken for the Goulburn River below Goulburn Weir through to the Murray River in 2007. This bathymetric survey consists of a continuous long section along the nominal river centreline, with additional bathymetric data captured at large pools. The water level at the time of the survey was also captured, this dataset provides a high level of detail regarding the channel profile. As LiDAR data does not penetrate the water surface, estimating the channel capacity was previously considered a major hurdle in calibrating hydraulic models to low flow scenarios. An example of the available bathymetry is shown in Figure A - 2, in this example, the additional points at the bend in the river as a result of the boat turning around will allow for higher definition of the channel for the hydraulic model. Further information on how these bathymetry points will be used to develop the DEM for the hydraulic model is discussed in Section 3.2. The bathymetry was validated to a number of on bank points, these points will be used to verify the LiDAR sets.

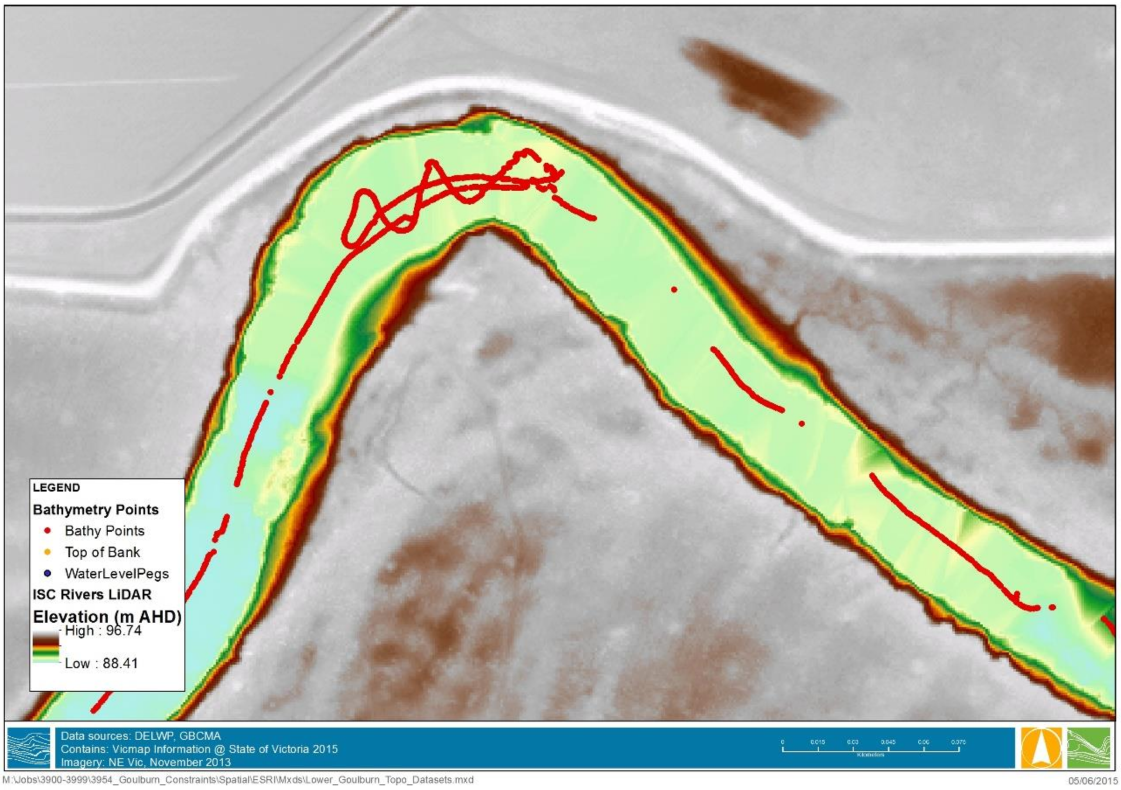

Figure A - 2 Example of the Lower Goulburn River Bathymetry

Lake Nagambie Bathymetry

Goulburn Murray Water commissioned SKM and Thiess services in 2006 to undertake a bathymetric survey of the weir pool at Lake Nagambie in order to determine an accurate DEM to allow for identifying volumetric capacity of the lake at different water levels. The bathymetry also allows for the identification of the original channel course which can be at depths of around 9-10 metres when at full supply level. The extent of the bathymetry is shown below in Figure A - 3.

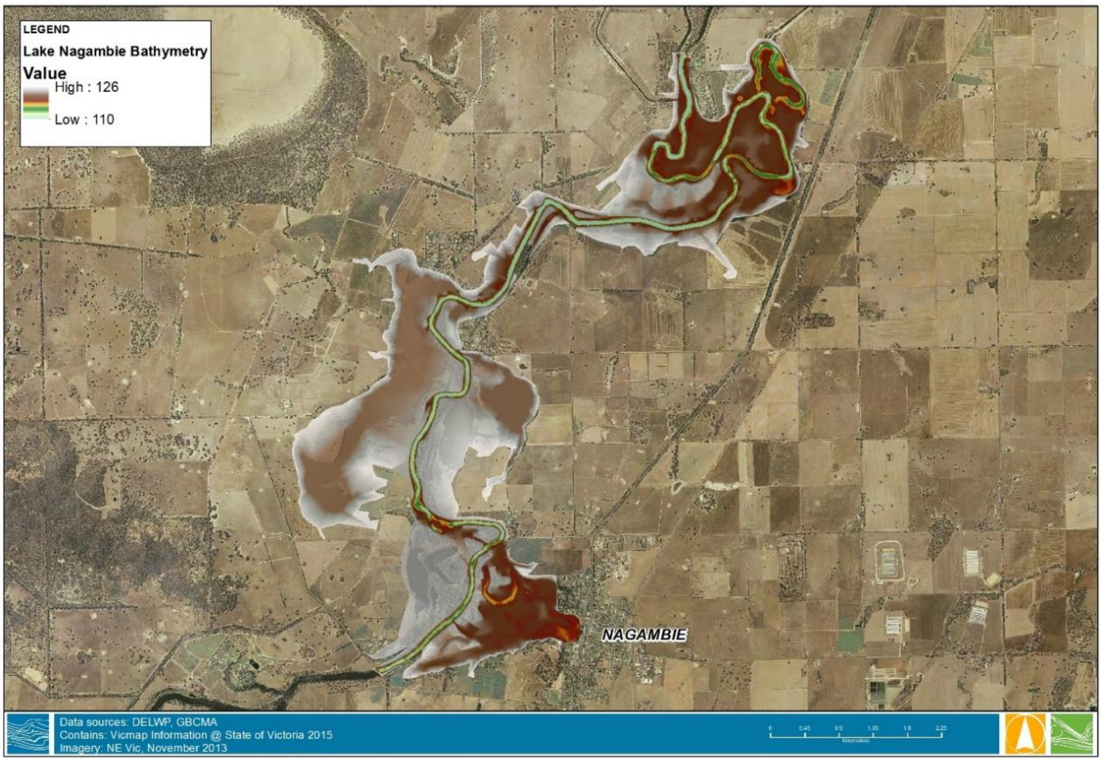

Figure A - 3 Lake Nagambie Bathymetry Extent

State Rivers and Water Supply Commission

A large number of field surveyed cross sections along the Goulburn River were undertaken by the State Rivers and Water Supply commission in the 1970s and 1980's. This included 58 cross sections around Shepparton (Ch 136.8-182.8 km) and 54 from Shepparton through to the Murray River (Ch 0-135.5 km), these are highlighted in green and pink respectively in Figure A - 4.

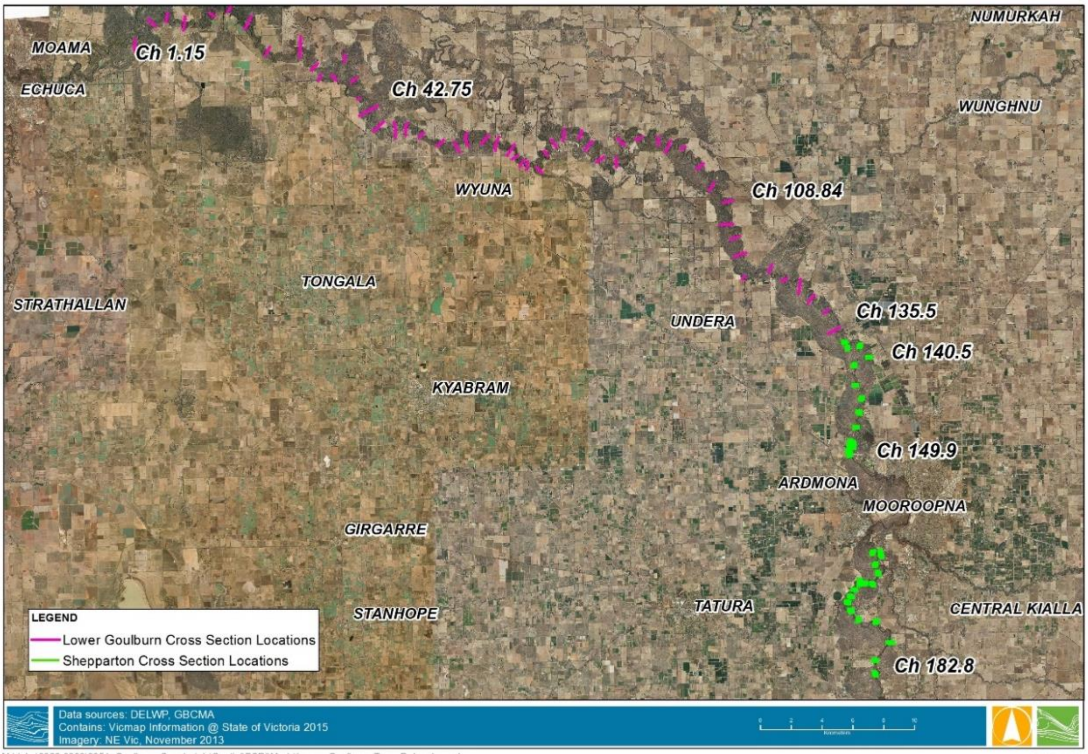

Figure A - 4 Lower Goulburn SRWSC Cross Section Locations

Figure A - 5 shows the location of nine cross sections covering around 8 km of the Goulburn River from 4 km upstream of Seymour through to upstream of the Hume Highway crossing.

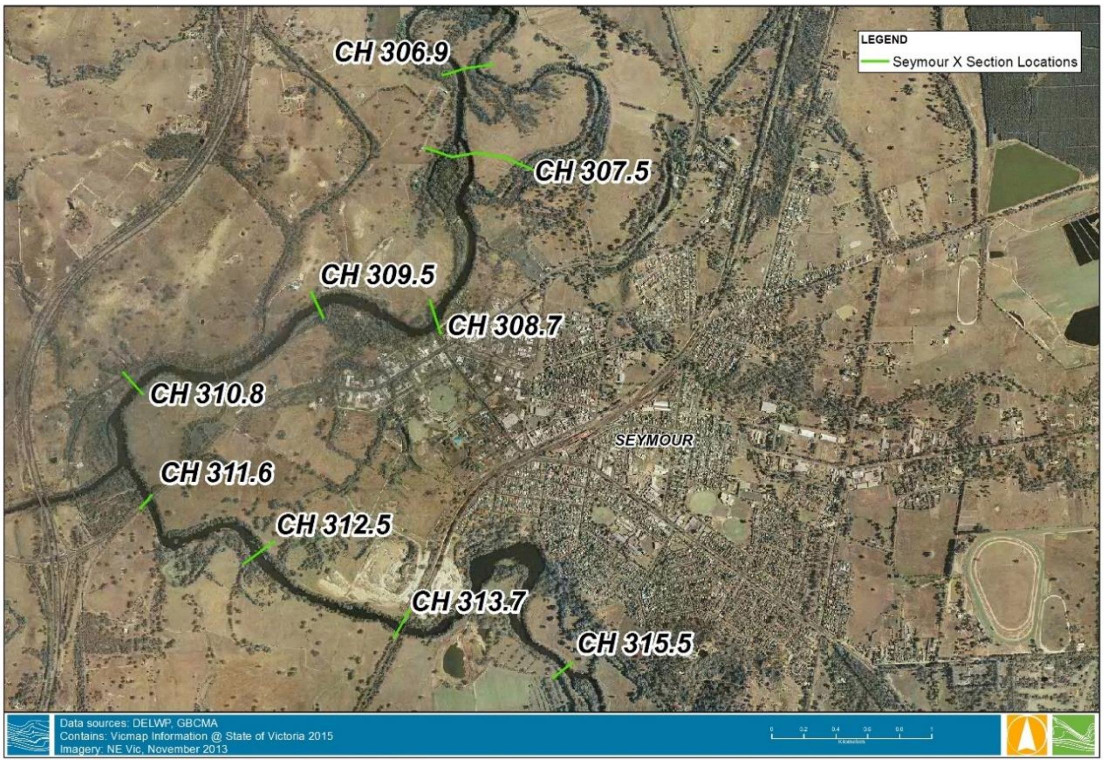

Figure A - 5 Location of Goulburn River Cross Sections at Seymour

Goulburn River Environmental Flow Study (Cottingham et al 2003)

Waterway cross sections were taken for 5 reaches. For three of the five reaches, the cross sections were geo-referenced to AMG. These sets consist of 16-18 cross sections at a separation of 200 m. The geo-referenced cross section sets are located at the following chainages: 276.27 km to 273.26 km (Site 1), 222.11 km to 219.11 km (Site 2) and 165.19 km to 162.17 km (Site 3).

Water Technology can not locate these cross-sections. If GBCMA have these and can easily locate them, it is requested that they be supplied.

A.5 LiDAR Data

A number of LiDAR datasets exist across the study area ranging from low resolution (20 m DEM) VicMap elevation data, through to high resolution 1 m LiDAR flown across the Goulburn River floodplain. Any LiDAR set used will be verified through available ground survey or comparison to other LiDAR datasets, and if required, can be adjusted to better represent the on ground survey values. All LiDAR datasets available are shown in Figure A - 6 and Figure A - 7 and listed in Table A - 1, this shows for the higher resolution data sets (1-5 m), a level of vertical accuracy was achieved suitable for the development of a DEM required for hydraulic modelling purposes. The floodplain LiDAR will form the basis for the development of the DEM used in the hydraulic model, this is further discussed in Section 3.2.

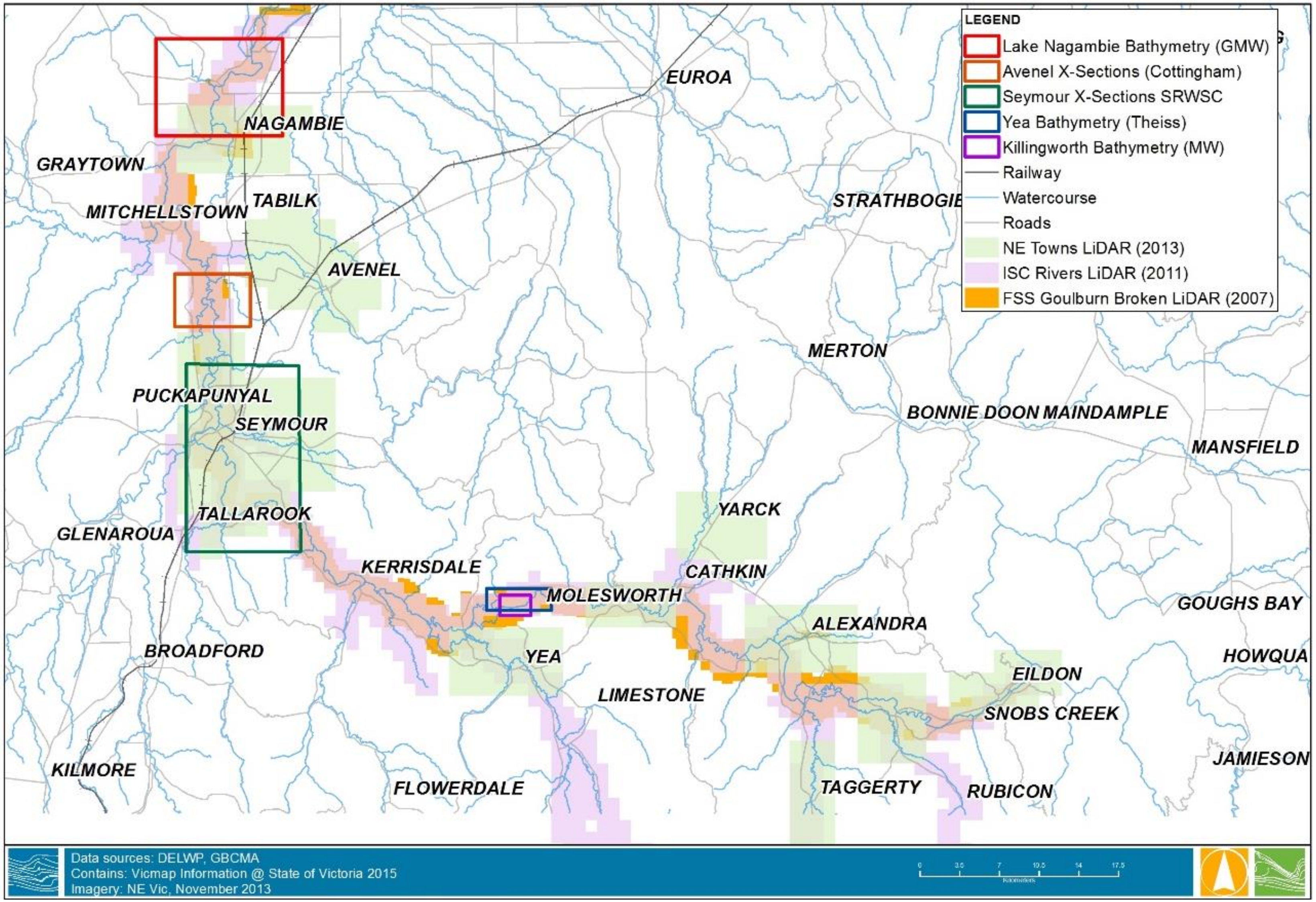

Figure A - 6 Mid Goulburn Topographic Datasets

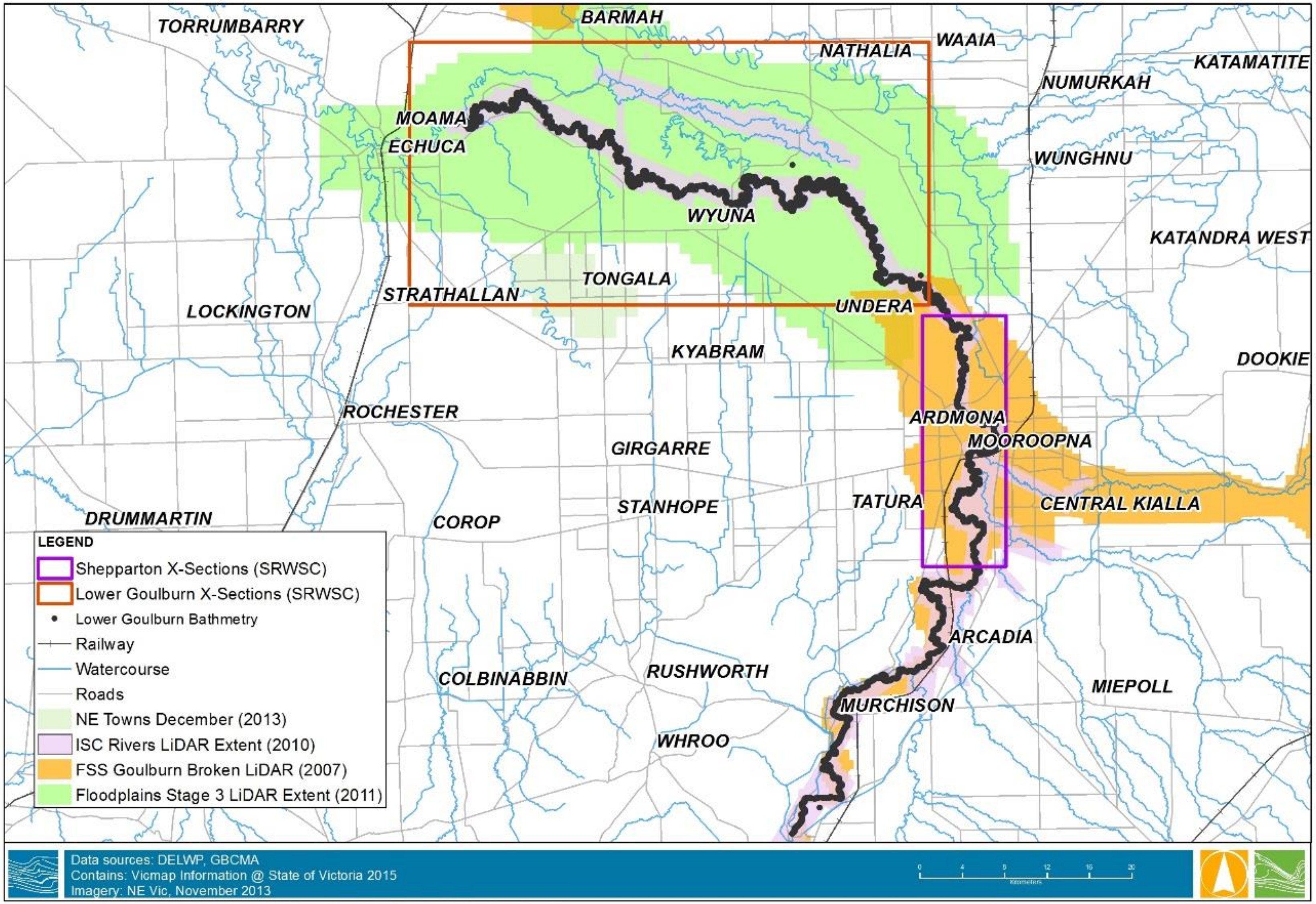

Figure A - 7 Lower Goulburn Topographic Datasets

Table A - 1 Available LiDAR sets throughout the Goulburn River study area

LiDAR Set	Resolution	Date Flown	Vertical Accuracy
Floodplains Stage 1 (FP1)	1 m DEM	2010	± 0.10 m
Floodplains Stage 3 (FP3)	1 m DEM	2011	± 0.10 m
Index of Stream Condition (ISC)	1 m DEM	2010	± 0.20 m
Furgo Spatial Services (FSS)	1 m & 5 m DEM	2007	± 0.10 m
Think Spatial UAV	1 m DEM	2013	± 0.15 m
North East Towns	1 m DEM	2013	± 0.10 m
VicMap Elevation	20 m DEM	2008	NA
Murray River (MDBA)	1 m DEM	2001	± 0.15 m
Geoscience Australia (GA)	1 second DEM	2009	NA

A combination of different LiDAR sets is to be used to develop the DEM for the hydraulic model. As the different LiDAR sets were flown across a number of years, a comparison of how well the LiDAR will mesh together is important to assess. A comparison of the LiDAR sets available was undertaken across the model study area. For the mid Goulburn area, comparison of the Index of Stream Conditions (ISC) and Fugro Spatial Services (FSS) LiDAR was undertaken at 14 separate cross sections as shown in Figure A - 8.

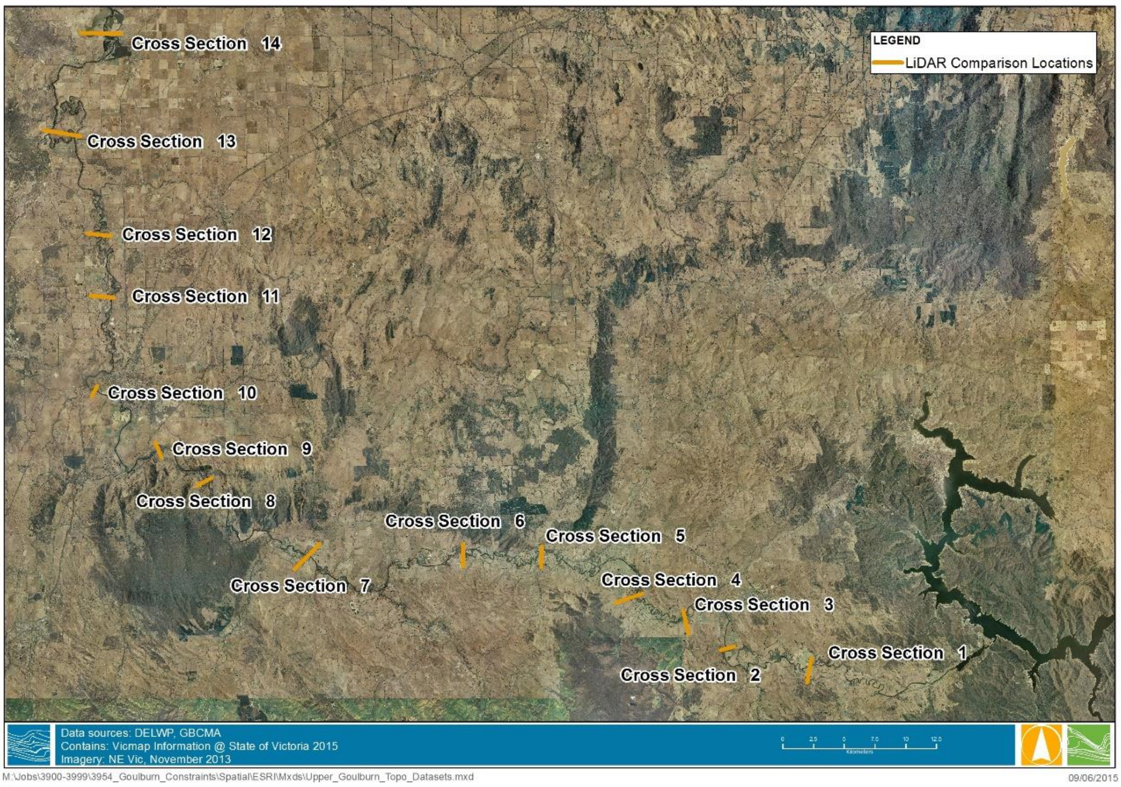

Figure A - 8 LiDAR & Cross Section Comparison Locations

Two cross section examples are shown below for cross section 13 (Figure A - 9) and cross section 14 (Figure A - 10), both of these show the LiDAR sets to have minimal difference in elevations at these cross sections. Figure A - 10 also shows that for cross section 14, NE Towns LiDAR and Bathymetry for Lake Nagambie is also available for comparison, the NE Towns LiDAR generally sat between the FSS and ISC datasets. A comparison of the 14 cross sections undertaken showed that generally the 2010 ISC Rivers LiDAR is on average 13 cm higher than the 2007 FSS LiDAR. These points also included water surface levels which are likely to show a difference depending on flow rate in the River at the time the LiDAR was flown. Comparison statistics of each cross section are shown in Table A - 2. Given the variability shown in the average difference in LiDAR sets across 14 cross sections all ranged from -0.196 m through to + 0.037 m with the exception of cross section 5. It is unlikely that a wholesale datum shift of either LiDAR set will result in significant benefit to the DEM development. This is covered further in section 3.2.

Table A - 2 LiDAR Comparison Statistics

Cross Section	FSS Points	ISC Points	Mean FSS Minus ISC Difference	SD	Min Difference	Max Difference
1	1,013	1,013	0.037	0.15	-0.95	1.39
2	556	573	0.017	0.31	-2.47	1.52
3	513	536	-0.031	0.29	-1.64	1.06
4	713	716	-0.011	0.10	-0.84	0.21
5	836	855	-0.367	0.72	-3.60	0.72
6	566	583	-0.141	0.38	-2.63	0.54
7	1067	1070	-0.140	0.12	-0.81	0.71
8	659	661	-0.154	0.18	-1.35	0.91
9	654	665	-0.060	0.17	-1.58	0.19
10	455	480	-0.183	0.07	-0.83	0.21
11	953	857	-0.120	0.08	-0.52	0.08
12	954	970	-0.162	0.11	-0.76	0.41
13	1284	1321	-0.196	0.07	-0.71	0.01
14	890	951	-0.125	0.10	-0.42	0.24
All Points	11,114	11,251	-0.132	0.28	-3.60	1.52

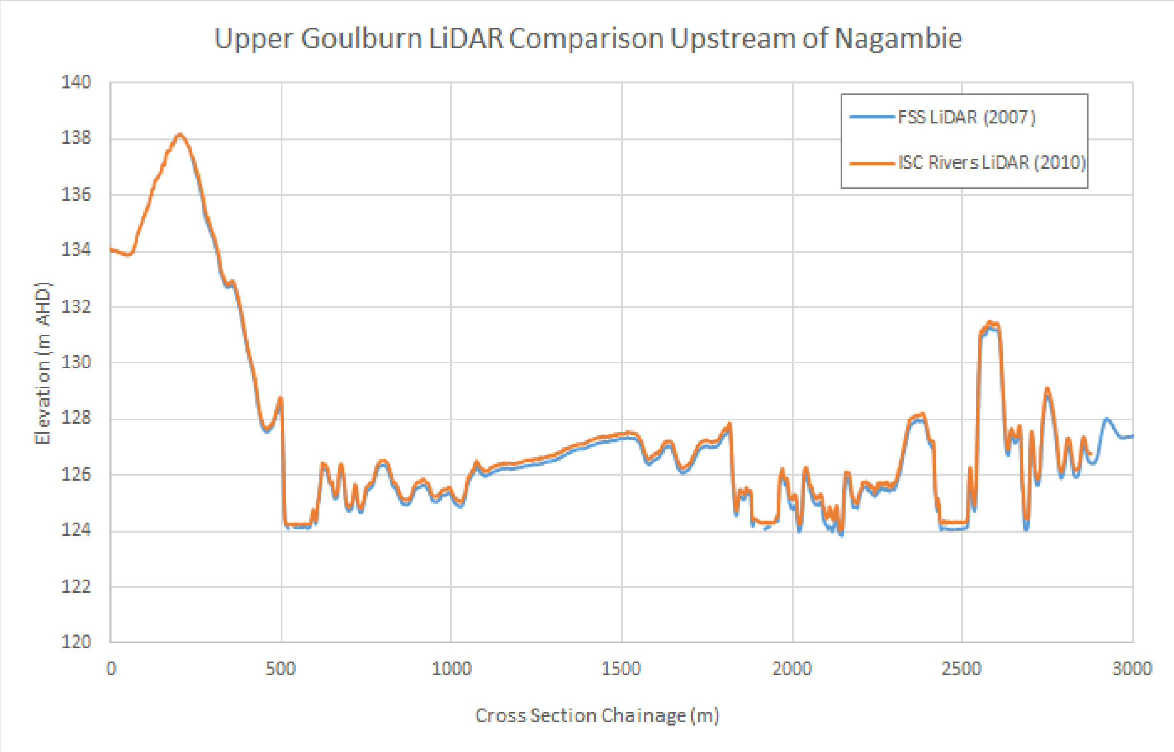

Figure A - 9 Cross Section 13 LiDAR comparison

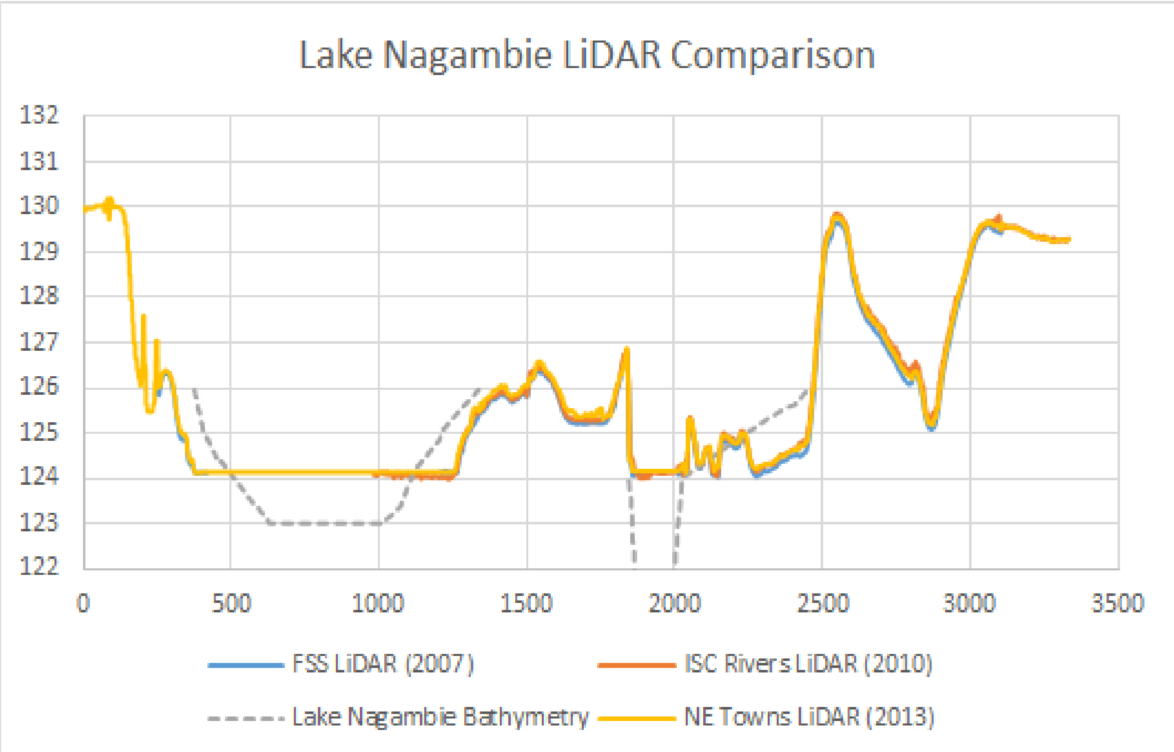

Figure A - 10 Cross Section 14 LiDAR Comparison

A.6 LiDAR Validation

The ISC Rivers LiDAR and the FSS LiDAR are given a vertical accuracy of +/- 100 mm which is considered suitable for use within a hydraulic model. Using available spot heights obtained from field survey outside of the river bank, the LiDAR accuracy can be validated. Currently the available field survey is generally limited to within the channel and due to varying water levels does not allow for adequate validation of the LiDAR. A number of points located on the bank have been obtained from SRWSC cross sections and general found to be within +/- 200 mm, however this survey is very old and floodplain conditions could have changed in that time.

Further verification of the LiDAR datasets in the lower Goulburn model was undertaken using field survey from a levee audit undertaken in 2012 and discussed in Water Technology (2013b). Over 4000 levee crest spot heights were available for assessment along the levee at locations shown in Figure A-11. When compared with the floodplains stage 3 LiDAR, the field survey was on average 3 cm higher than the field survey with a standard deviation of 0.18 m. This was considered to be an extra validation of the LiDAR across the lower Goulburn floodplain.

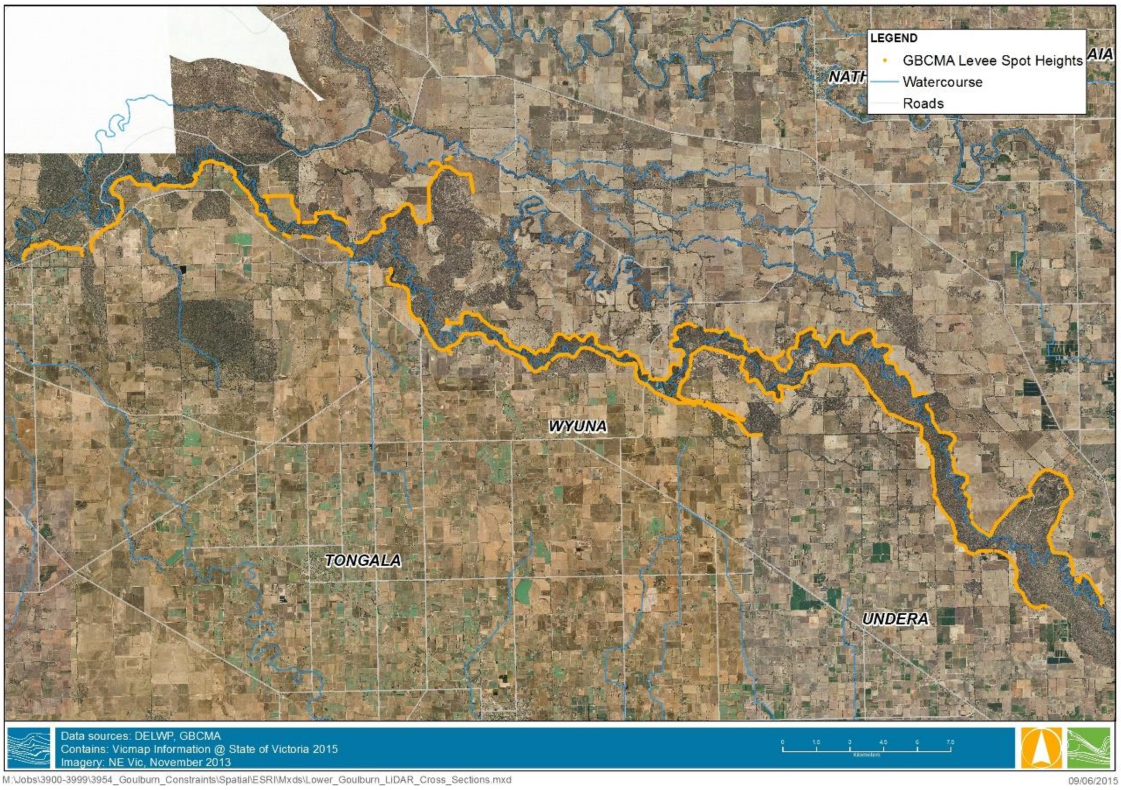

Figure A - 11 Lower Goulburn Levee Crest Survey

VEFMAP survey taken in 2011 throughout the lower Goulburn floodplain was also provided for validation of the LiDAR datasets.

APPENDIX B – BRS Land Use Layer

BRS Land Use Code	BRS Land Use	Land Use Assessment (GBCMA)
1.1.1	Strict nature reserves	Other
1.1.3	National Park	Other
1.1.4	Natural feature protection	Other
1.1.7	Other conserved area	Other
1.2.0	Managed resource protection	Other
1.2.2	Surface water supply	Other
1.3.0	Other minimal use	Other
1.3.1	Defence	Other
1.3.3	Remnant native cover	Other
1.3.3	Residual native cover	Other
2.1.0	Grazing natural vegetation	Dryland Pasture
2.1.0	Livestock grazing	Dryland Pasture
2.2.0	Production forestry	Forestry
3.1.1	Hardwood plantation	Forestry
3.1.2	Softwood plantation	Forestry
3.2.0	Grazing modified pastures	Dryland Pasture
3.3.0	Cropping	Dryland Broadacre Crops
3.3.0	Grazing modified pastures	Dryland Pasture
3.3.1	Cereals	Dryland Broadacre Crops
3.3.4	Oil seeds	Dryland Broadacre Crops
3.3.5	Sown grasses	Dryland Broadacre Crops
3.3.8	Pulses	Dryland Broadacre Crops
3.4.0	Perennial horticulture	Other
3.4.3	Hay & silage	Dryland Broadacre Crops
3.4.9	Grapes	Grapes
3.5.1	Tree fruits	Other Fruit
3.5.2	Oleaginous fruits	Other Fruit
3.5.4	Vine fruits	Grapes
3.5.7	Vegetables & herbs	Vegetables
4.1.1	Irrigated Hardwood Plantation	Forestry
4.1.2	Irrigated Softwood	Forestry
4.2.0	Irrigated modified pastures	Irrigated pasture
4.3.0	Irrigated cropping	Irrigated pasture
4.3.1	Irrigated Cereal	Irrigated pasture
4.3.2	Irrigated pasture legumes	Irrigated pasture
4.3.3	Irrigated hay & silage	Irrigated pasture
4.3.4	Irrigated sown grasses	Irrigated pasture
4.3.8	Irrigated pulses	Irrigated pasture
4.4.0	Irrigated horticulture	Intensive agriculture

4.4.1	Irrigated tree fruits	Other Fruit
4.4.3	Irrigated hay & silage	Irrigated pasture
4.4.4	Irrigated vine fruits	Grapes
4.4.7	Irrigated vegetables & herbs	Vegetables
4.4.8	Irrigated Legumes	Irrigated pasture
4.4.9	Irrigated Grapes	Grapes
4.5.4	Vegetables & herbs	Vegetables
5.1.0	Intensive Horticulture	Intensive agriculture
5.2.0	Intensive animal production	Intensive agriculture
5.2.4	Poultry	Intensive agriculture
5.2.5	Pigs	Intensive agriculture
5.2.6	Aquaculture	Intensive agriculture
5.2.7	Horse Stud	Other
5.3.0	Manufacturing and industrial	Other
5.3.1	Rural residential	Other
5.3.2	Food processing factory	Other
5.3.5	Abattoirs	Other
5.3.6	Oil Refinery	Other
5.3.7	Forestry	Forestry
5.4.0	Residential	Other
5.4.1	Urban residential	Other
5.4.2	Rural residential	Other
5.4.3	Rural residential	Other
5.5.1	Commercial services	Other
5.5.2	Public services	Other
5.5.3	Recreation and culture	Other
5.6.0	Utilities	Other
5.6.4	Utilities	Other
5.7.1	Airport	Other
5.7.2	Roads	Other
5.7.3	Railways	Other
5.7.5	Transport	Other
5.8.0	Mining- Extraction	Other
5.8.2	Quarries	Other
5.8.4	Mining- Extraction	Other
5.9.0	Waste treatment and disposal	Other
6.0.0	Water	Other
6.1.0	Lake	Other
6.2.0	Reservoir/dam	Other
6.2.1	Reservoir	Other
6.2.1	Water storage and treatment	Other
6.2.2	Water storage - intensive use/farm	Other
6.3.0	River	Other
6.4.1	Supply channel/aqueduct	Other
6.5.0	Marsh/wetland	Other