West Gippsland
Catchment Management Authority

WGCMA Floodplain Mapping Program

Floodplain mapping for Toongabbie Township

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Table of Contents

Document details ... i

Table of Contents ... ii

List of Figures ... iv

List of Tables ... v

List of Abbreviations ... vii

Glossary ... viii

1 Introduction ... 1

1.1 Purpose ... 1

1.2 Objectives ... 1

1.3 Catchment description and history ... 1

1.4 Flood history ... 0

1.5 Previous decision-related data ... 1

2 Hydrology ... 3

2.1 Description of hydrologic modelling approaches adopted ... 3

2.2 Available data ... 3

2.3 Initial hydrology estimates ... 4

2.4 RORB hydrologic model ... 6

2.5 Summary of Hydrology Results ... 12

3 Hydraulics ... 15

3.1 Description of hydraulic modelling approach adopted ... 15

3.2 Available data ... 15

3.3 Key hydraulic features ... 16

3.4 Catchment extent hydraulic model ... 17

3.5 Township extent hydraulic model – hydrograph flows ... 23

3.6 Township extent hydraulic model – Rain on grid ... 32

3.7 Summary of hydraulics results ... 41

4 Conclusion and Recommendations ... 42

4.1 Conclusion ... 42

4.2 Recommendations ... 42

References ... 43

Appendix A: Preliminary data collection ... 45

Appendix B: Hydrologic model input data ... 48

Appendix C: Output data from hydrologic model 60
Appendix D: Hydraulic model input data........ 63
Appendix E: Output data from hydraulic model 66
Appendix F: Flood extent maps........ 69
Appendix F1: Flood extent maps - Catchment Extent Hydraulic Model........ 69
Appendix F2: Flood extent maps - Township Extent Hydraulic Model – Hydrograph flows 70
Appendix F3: Flood extent maps - Township Extent Hydraulic Model – Rain on grid........ 71
Appendix G: Flood level maps 72
Appendix G1: Flood level maps – Catchment Extent Hydraulic Model........ 72
Appendix G2: Flood level maps – Township Extent Hydraulic Model – Hydrograph Flows 76
Appendix G3: Flood level maps – Township Extent Hydraulic Model – Rain on Grid........ 79
Appendix H: Flood depth maps........ 81
Appendix H1: Flood depth maps - Catchment Extent Hydraulic Model 81
Appendix H2: Flood depth maps - Township Extent Hydraulic Model – Hydrograph flows85
Appendix H3: Flood depth maps - Township Extent Hydraulic Model – Rain on grid 88
Appendix I: Flood flow velocity maps 90
Appendix I3: Flood flow velocity maps–Catchment Extent Model 90
Appendix I2: Flood flow velocity maps - Township Extent Hydraulic Model – Hydrograph Flows........ 94
Appendix I3: Flood flow velocity maps - Township Extent Hydraulic Model – Rain on grid 97

List of Figures

Figure 1 Toongabbie Catchment Area 2

Figure 2 – 1995 Flood Extent -Toongabbie Creek - South side of Township, showing Traralgon-Maffra Road covered by flood waters........ 0

Figure 3 Toongabbie entrance left 4th Nov 2007........ 0

Figure 4 December 2014 surveyed flood levels........ 1

Figure 5 - Existing flood overlays and land subject to inundation overlay for Toongabbie 2

Figure 6 RORB catchment area and sub-catchment delineation 7

Figure 7 Catchment outlet hydrographs 12

Figure 8 - Flow estimation for the range of storm events at the catchment outlet 14

Figure 9 Key hydraulic structures........ 17

Figure 10 Catchment extent and major waterways........ 18

Figure 11 Manning's n roughness map for the catchment extent model 20

Figure 12 The 100 year ARI flood extent for the catchment extent hydraulic model 23

Figure 13 Toongabbie Township study area 24

Figure 14 Detailed roughness map for the township area 26

Figure 15 The 100 year ARI flood extent for the Toongabbie Township using hydrograph inflows........ 30

Figure 16 1995 Flood Event - Looking North East from Traralgon side showing cemetery in foreground defined by the yellow circle 31

Figure 17 The 100 year ARI flood extent in the vicinity of the entrance to the Township, showing the Traralgon Maffra Road and the location of the cemetery defined by the yellow circle 32

Figure 18 Rain on grid model study area........ 33

Figure 19 Underground drainage network........ 35

Figure 20 100yr ARI flood extent using rain on grid modelling........ 38

Figure 21 A section of the underground drainage network, indicating storm water from two pits is likely to spill into the street 39

Figure 22 1995 Flood Event - Looking south over Toongabbie towards Toongabbie Creek , with Toongabbie store in bottom left and fire station in centre left of photo........ 40

Figure 23 Localised flooding for a 100 yr ARI flood event in the township........ 41

Figure 24 - 1995 Flood Event (Cemetery centre left)........ 45

Figure 25 - 1995 Flood Event - South edge of Toongabbie Township with cemetery in top right of photo........ 45

Figure 26 - 1995 Flood Event - Looking west from east side of town showing cemetery in top left of photo 45
Figure 27 - 1995 Flood Event - Looking north east from Traralgon side showing cemetery in foreground 45
Figure 28 - 1995 Flood Event - South side of Toongabbie Township showing the Traralgon Maffra Rd inundated with flood waters 45
Figure 29 - 1995 Flood Event - Looking south over Toongabbie towards Toongabbie Creek , with Toongabbie store in bottom left corner and fire station in centre left of photo 45
Figure 30 2007 Flood 46
Figure 31 4th Nov 2007 46
Figure 32 Toongabbie entrance left 4th Nov 2007 46
Figure 33 - Annual average rainfall bands across Victoria (BoM, 2015). 47
Figure 34 Zones for temporal patterns in Australia 47
Figure 35 RORB model graphical representation 48
Figure 36 Location of hydrographs obtained from RORB model 49
Figure 37 Plot of flow estimations for catchment 1 50
Figure 38 Plot of flow estimations for catchment 2 51
Figure 39 Plot of flow estimations for catchment 3 52
Figure 40 Plot of flow estimations for catchment 4 53
Figure 41 Plot of flow estimations down stream of Toongabie Creek 54
Figure 42 Plot of flow estimations down stream of Rosedale Creek 55
Figure 43 Plot of flow estimates at the confluence of Toongabie and Rosedale creek 56
Figure 44 Plot of catchment outlet flow estimations 57

List of Tables

Table 1 Flow Estimation Method Results for the Catchment Outlet 6
Table 2 Recommended kc values 8
Table 3 Loss estimates for Toongabbie 9
Table 4 RORB model parameter verification simulation 9
Table 5 Adopted parameters for the RORB model 10
Table 6 IFD Coefficients 10
Table 7 Design parameters used in the RORB model for the range of storm events 11
Table 8 RORB Design Run Flow Estimation at Catchment Outlet 12

Table 9 Comparison of the 100 year ARI flow estimation at different locations in the catchment 13

Table 10 Comparison of flow estimations at the catchment outlet 13

Table 11 Catchment extent 2D topography grid parameters 19

Table 12 Manning's n values adopted for the catchment extent model 19

Table 13 Boundary parameters for the catchment extent model 20

Table 14 Roughness coefficients adopted for hydraulic structures included in the catchment extent model 21

Table 15 Township topography grid parameters 25

Table 16 Manning's n roughness values for the township area 25

Table 17 Boundary condition parameters for the Township extent hydraulic model using hydrographs 26

Table 18 Roughness coefficients adopted for hydraulic structures included in the township extent model 27

Table 19 Sensitivity to changes in roughness coefficient values 28

Table 20 Sensitivity to varying degrees of blockages to hydraulic structures 29

Table 21 Township topography grid parameters for the rain on grid model 33

Table 22 Manning's n values adopted for the rain on grid model 34

Table 23 Total volume of rainfall for the different duration events 36

Table 24 Intensity Frequency Duration Table for Toongabbie 46

Table 25 Hydrograph 1 flow estimations 49

Table 26 Hydrograph 2 flow estimations 50

Table 27 Hydrograph 3 flow estimations 51

Table 28 Hydrograph 4 flow estimations 52

Table 29 Hydrograph 5 flow estimations 53

Table 30 Hydrograph 6 flow estimations 54

Table 31 Hydrograph 7 flow estimations 55

Table 32 Catchment outlet flow estimations 56

Table 33 RORB model sub area parameters 57

Table 34 RORB model reach parameters 58

Table 35 Critical Durations for Hydrograph Locations 60

Table 36 Burst Initial Loss corresponding to Duration 63

Table 37 Key Hydraulic Structure Data 63

Table 38 Discharge curves at key hydraulic structures for 100 year ARI flood event for catchment extent modelling 66

List of Abbreviations

AEP	Annual exceedance probability
AHD	Australian height datum
ARI	Average recurrence interval
ARR	Australian Rainfall and Runoff
BOM	Bureau of Meteorology
DEM	Digital elevation model
FFA	Flood frequency analysis
FO	Floodway overlay
GDA	Geographic datum of Australia
GIS	Geographic information system (specifically ArcGIS 10.2)
IFD	Intensity-frequency-duration (curve)
LiDAR	Light detection and ranging (specifically, data derived from this process)
LSIO	Land subject to inundation overlay
PMF	Probable maximum flood
ROG	Rain on grid
SES	State Emergency Service
VFD	Victorian Flood Database
WGCMA	West Gippsland Catchment Management Authority

Glossary

TERM	DESCRIPTION
Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datum's.
Average Recurrence Interval (ARI)	The average or expected value of the period between exceedances of a given discharge or event.
Catchment	The area draining to a site.
Direct Rainfall Method	Involves applying the rainfall directly onto the hydraulic model grid cells
Discharge	The rate of flow of water measured in terms of volume over time.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event
GDA94	The Geocentric Datum of Australia (GDA) is the new Australian coordinate system, replacing the Australian Geodetic Datum (AGD)
Geographical Information System (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
Hydraulics	The term given to the study of water flow in a river, channel or pipe.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Intensity Frequency Duration	Intensity Frequency Duration, method of determining design rainfalls according to procedures in Australian Rainfall and Runoff. This includes total rainfall for a given design (ARI) storm event and the pre-determined temporal pattern over which this rainfall is distributed.

TERM	DESCRIPTION
LIDAR	Light Detection and Ranging is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. The range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal.
Peak discharge	The maximum discharge occurring during a flood event.
Probable maximum flood	The flood calculated to be the maximum that is likely to occur.
RORB	A rainfall-runoff hydrological modelling program
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Sobek	A 1D/2D hydraulic modelling program
Topography	A surface which defines the ground level of a chosen area

1 Introduction

1.1 Purpose

The purpose of conducting floodplain mapping for the Toongabbie Township is to determine the nature and extent of flooding through the estimation of design flood flows, levels and velocities. The flood information produced by these investigations will be used by West Gippsland Catchment Management Authority (WGCMA) for statutory planning purposes, planning schemes and emergency management purposes.

1.2 Objectives

The objectives of the Toongabbie Township floodplain mapping project as set out by the WGCMA were as follows:

- Conduct a desktop study of the Toongabbie Township and catchment area
- Derive a RORB model for the Toongabbie Creek catchment area
- Calculate and tabulate expected design flow hydrographs for Toongabbie Creek for 2, 5, 10, 20, 50, and 100 year ARI flood events.
- Derive a 1D/2D hydraulic model of Toongabbie Creek catchment area and Township using Sobek
- Using the direct rainfall method, model localised rainfall effects
- Determine the 2, 5, 10, 20, 50, and 100 year ARI flood extents, depths and velocities
- Prepare maps corresponding to requirements for inclusion into the Victorian Flood Database

1.3 Catchment description and history

The Toongabbie catchment area is located in the Latrobe Basin in South Eastern Victoria, north of Traralgon and approximately 177 kilometres from Melbourne. It is an ungauged catchment covering approximately 45 square kilometres and contains two major waterways, Toongabbie Creek and Rosedale Creek which are tributaries of the Latrobe River.

The topography of the catchment area ranges in elevation from approximately 360 metres AHD to 15 metres AHD, with the upper portion of the catchment area consisting of forested areas, and the lower portion of the catchment area consisting predominately of farmland, before flowing into the Latrobe River, shown in Figure 1. The mean annual rainfall in the catchment lies between the range of 600 and 1000 mm per annum (BoM, 2015).

The catchment area also consists of the small rural town of Toongabbie, which is a low density residential area with an approximate population of 600 people. Toongabbie Creek and Rosedale creek traverse the township, resulting in 8 major hydraulic structures to be located in the town. The confluence of the two creeks is downstream of the township. The topography of the township area is relatively flat with limited definition of the floodplain, making it highly prone to flooding.

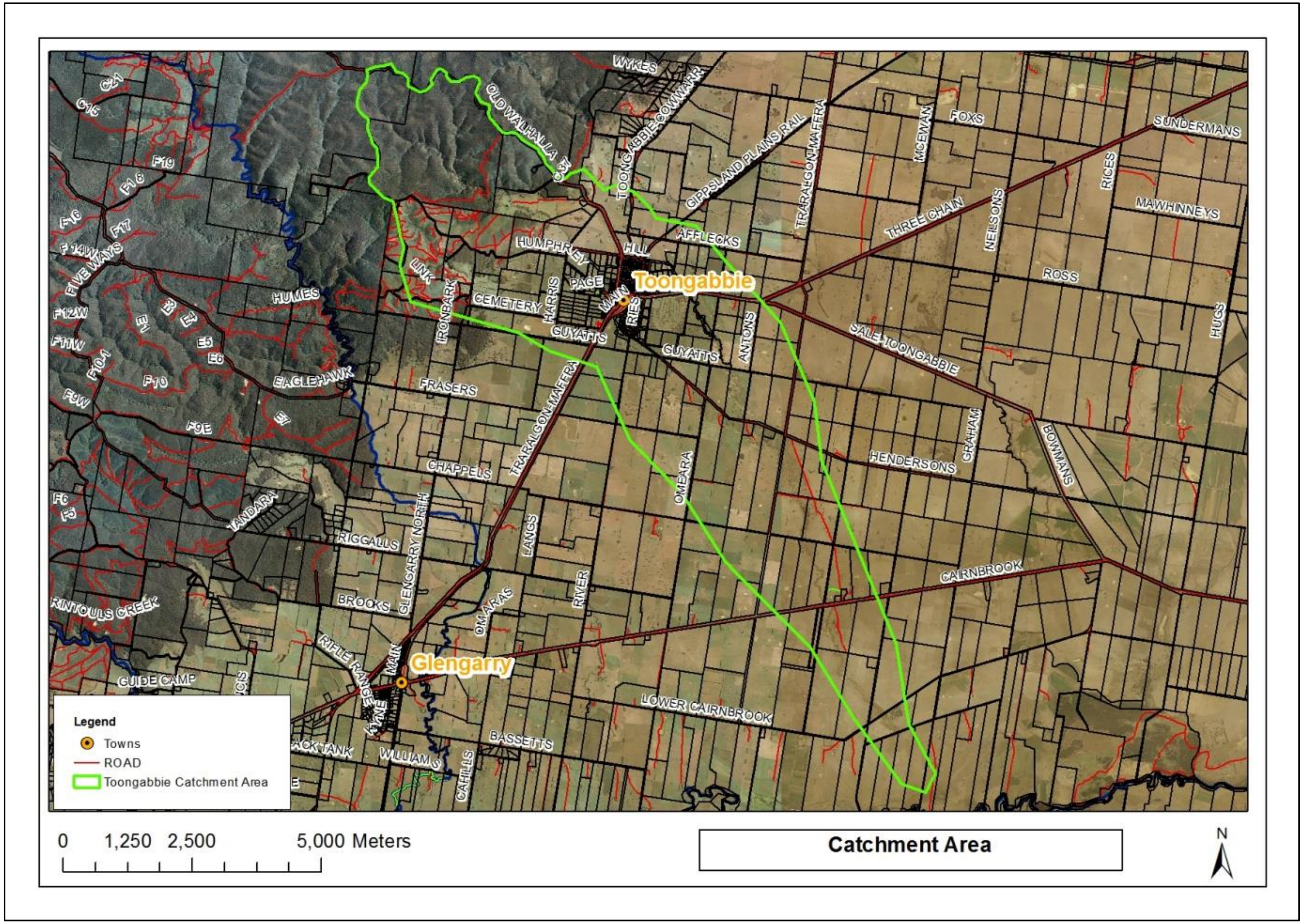

Figure 1 Toongabbie Catchment Area

1.4 Flood history

Flood information was recorded during recent flood events in the years of 1995, 2007 and 2014, however the size of these storm events is unknown. The information will be used to compare flood extent results obtained from the hydraulic model.

Refer to Appendix A for all available photography.

In 1995, aerial flood photography was captured by staff at WGCMA; the photography indicates it was quite extensive flooding with the main egress route to Traralgon, along the Traralgon – Maffra Road inundated by flood waters, shown in Figure 2.

In 2007, flood photography was captured by staff at WGCMA at ground level. Photos were taken at the Toongabbie township entrance, shown in Figure 3 and around local roads.

Surveyed flood extents were recorded in the flood event of December 2014, along the Main Road, Humphreys Road and River Road in the Toongabbie Township area, with locations shown in Figure 4.

Figure 2 – 1995 Flood Extent -Toongabbie Creek - South side of Township, showing Traralgon-Maffra Road covered by flood waters

Figure 3 Toongabbie entrance left 4th Nov 2007

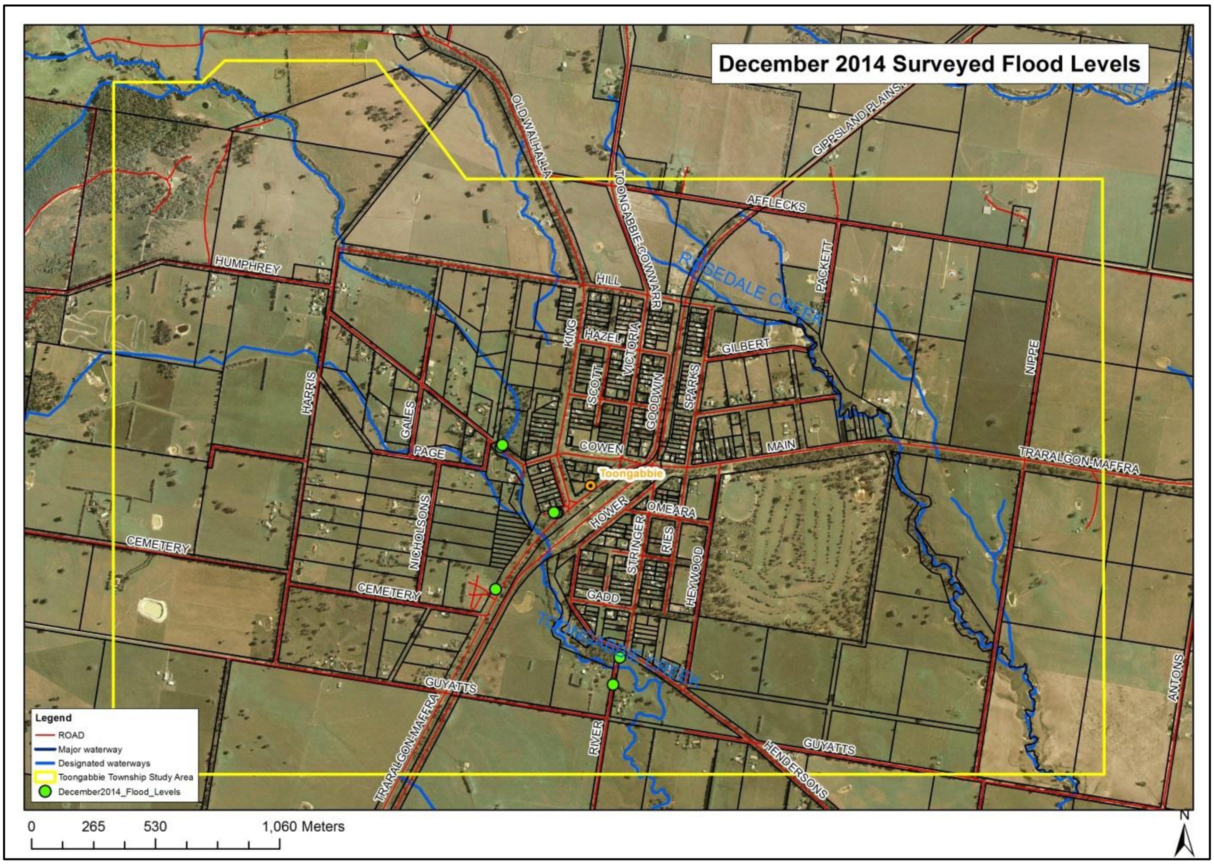

Figure 4 December 2014 surveyed flood levels

1.5 Previous decision-related data

The existing Land Subject to Inundation Overlay (LSIO) and Flood Overlay (FO) for Toongabbie Creek and Rosedale Creek which are included in the current planning scheme are shown in Figure 5.

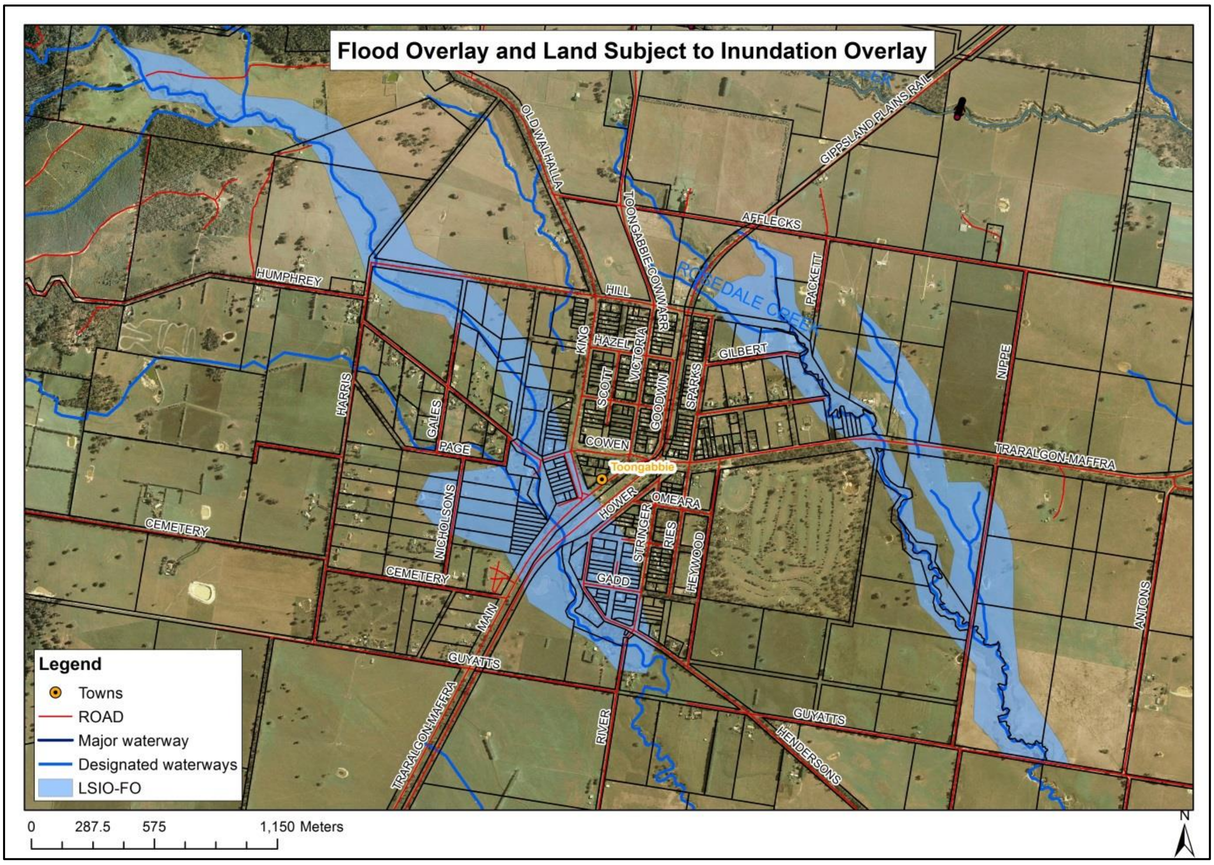

Figure 5 - Existing flood overlays and land subject to inundation overlay for Toongabbie

2 Hydrology

2.1 Description of hydrologic modelling approaches adopted

A hydrological analysis was undertaken in order to determine the peak design discharge volumes for the Toongabbie Creek catchment area. The storm events for which flood estimates were derived were:

- 100 year ARI flood
- 50 year ARI flood
- 20 year ARI flood
- 10 year ARI flood
- 5 year ARI flood
- 2 year ARI flood

The hydrological analysis of the Toongabbie Township catchment area consisted of a review of hydrological data, flow estimation calculation methods, and hydrological modelling using RORB. RORB is a non-linear rainfall-runoff routing model for calculating flow hydrographs in stream networks. The hydrologic model will convert rain falling over the catchment into flow in the channel for various storm events and scenarios. The Toongabbie catchment area is an ungauged system; therefore the parameters selected for the RORB model were based on design loss rates for Victoria published in Volume 1 of the Australian Rainfall and Runoff (ARR) guidelines, the Australian Rainfall and Runoff Project 6 Stage 2 Report and recommended parameters outlined in the RORB manual, and were verified against the flow estimation methods. The purpose of the hydrological model is to determine flows to be used as the inflows for the hydraulic model.

2.2 Available data

The available data utilised for determining the hydrology for the Toongabbie Township area was:

- Aerial photography
- Waterway and catchment mapping
- Australian Rainfall and Runoff – Volume 1: A guide to flood estimation
- ARR Project 6 Stage 2 Report – Loss Models for catchment Simulation – Rural Catchments
- Previous studies

Aerial Photography

Digital aerial photography used for this study was supplied by WGCMA and obtained in 2009. The aerial photography covers the whole West Gippsland Region and was used to provide base imagery for the Toongabbie Creek catchment area. Aerial photography was also used to identify designated waterway flow paths for sub-catchment breakdown.

Waterway and Catchment Mapping

The waterways layer obtained from VicMap data was used to identify designated waterways, the main flow paths, tributaries associated with the system and to determine boundary locations for the sub catchment delineation.

Australian Rainfall and Runoff – Volume 1: A guide to flood estimation

The ARR Volume 1, Book 2 was used for guidance in parameter selection for the RORB model due to the system being ungauged. The ARR suggest recommendations for initial loss and continuing loss parameters to be used for Victorian catchments south and east of the great dividing range, which are CL = 2.5 mm/hr and IL = 15 – 20 or 25 – 35mm/hr (Canterford, 1987 Edition).

ARR Project 6 Stage 2 Report

The ARR Project 6 Stage 2 Report – Loss Models for catchment Simulation – Rural Catchments, was used for estimating the initial loss and continuing loss parameters for the RORB model, using the loss method derived by Hill et al 1996.

Previous Studies

A previous hydrology analysis was undertaken on the Tyers River catchment area by WGCMA, which is west of the Toongabbie Township catchment area. Parameter selection for the Toongabbie RORB model was compared to the parameters adopted for the Tyers River model.

2.3 Initial hydrology estimates

Three different flow estimation methods were used for comparison with design flows obtained from the RORB hydrologic model. The flow estimation equations are outlined below:

Nikolaou and Von't Steen Regional Estimate

The Nikolaou and Von't Steen regional estimate, which is an empirical equation developed by Nikolaou and Roelvon't Steen, which estimates the flow for a 100 year ARI flood event based on the area of the catchment using equation 3.1. Where A is the area in square kilometres (Km^2) and Q_{100} is the 100 year ARI flow in metres cubed per second (m^3/s).

$$Q_{100} = 4.67 \times (A^{0.763}) \qquad \text{Eq. 4.1}$$

Rational Method

The Rational Method is recommended for catchments less than 400 hectares and is used to calculate design peak flow rates throughout the drainage network (Melbourne Water, 2015). The Rational method was used to estimate flows for a 2, 5, 10, 20, 50, and 100 year ARI flood event, using equation 3.2. Where C_Y is the runoff coefficient for the Y year ARI flood event, which will be determined using the Australian Rainfall and Runoff guidelines. $I_{tc,Y}$ is the rainfall intensity in mm per hour with a duration t_c and an ARI of Y years. The variable t_c is the time of concentration or duration used to select the appropriate rainfall intensity, which is calculated using the Adams equation (Eq. 3.3), which is used for Victorian and Eastern NSW catchments. The rainfall intensity will be determined using the Bureau of Meteorology Rainfall Intensity-Frequency-Duration (IFD) data system. The intensity will be determined using the old IFD data system which uses rainfall analysis published in 1987 and the new IFD data system which uses rainfall analysis published in 2013, enabling the comparison of results. Q_Y is the flow for the Y year ARI flood event.

$$Q_Y = 0.278 \times C_Y \times I_{tc,Y} \times A \qquad \text{Eq. 4.2}$$

$$t_c = 0.76 \times (\, A^{0.38} \,) \qquad \text{Eq. 4.3}$$

Zaman Flow Estimation Method

The Zaman flow estimation method, developed by Zaman, Haddad and Rahman (2013), uses equations 3.4 to 3.9 to determine the flow for the particular ARI flood event. The equations use the catchment area and Rainfall Intensity for the particular ARI flood event to determine the flow for 2, 5, 10, 20, 50 and 100 year ARI flood events.

$$\log_{(10)}(Q_2) = -3.055 + 1.186\log_{10}(\text{Area}) + 2.103\log_{10}(I_{tc\_2}) \qquad \text{Eq. 4.4}$$

$$\log_{(10)}(Q_5) = -2.847 + 1.182\log_{10}(\text{Area}) + 2.0891\log_{10}(I_{tc\_5}) \qquad \text{Eq. 4.5}$$

$$\log_{(10)}(Q_{10}) = -2.476 + 1.13\log_{10}(\text{Area}) + 1.932\log_{10}(I_{tc\_10}) \qquad \text{Eq. 4.6}$$

$$\log_{(10)}(Q_{20}) = -2.766 + 1.173\log_{10}(\text{Area}) + 2.108\log_{10}(I_{tc\_20}) \qquad \text{Eq. 4.7}$$

$$\log_{(10)}(Q_{50}) = -2.793 + 1.169\log_{10}(\text{Area}) + 2.132\log_{10}(I_{tc\_50}) \qquad \text{Eq. 4.8}$$

$$\log_{(10)}(Q_{100}) = -2.789 + 1.159\log_{10}(\text{Area}) + 2.135\log_{10}(I_{tc\_100}) \qquad \text{Eq. 4.9}$$

The results from the flow estimation techniques are outlined in Table 1.

		FLOW ESTIMATE TECHNIQUE			
Average Recurrence Interval (ARI) (Years)	**Runoff Coefficient (C_Y)**	**Nikolaou and von't Steen equation (m^3/s)**	**Rational method based on 1987 IFD (m^3/s)**	**Rational method based on 2013 IFD (m^3/s)**	**Zaman et. al. (2013) equations (m^3/s)**
2	0.098		10.49	8.85	7.42
5	0.117		17.42	14.98	22.54
10	0.130		23.04	20.23	41.25
20	0.143		30.70	26.41	59.53
50	0.156		41.97	35.35	95.39
100	0.169	85.42	53.14	44.14	130.48

Table 1 Flow Estimation Method Results for the Catchment Outlet

2.4 RORB hydrologic model

A hydrological model of the catchment was developed for the purpose of extracting flows to be used as boundary conditions in the two hydraulic models. The rainfall runoff program RORB was used for the hydrology analysis of the Toongabbie and Rosedale Creeks. RORB is a runoff-routing model developed by Laurenson and Mein in 1992, which calculates flood hydrographs from rainfall. The model requires the catchment to be divided into sub-catchments, which are connected by reach storages. Design rainfall is applied to the centroid of each sub-catchment and specified losses are then deducted with the excess rainfall routed through the reach network. Flow hydrographs are then produced at points of interest.

The following methodology was applied for the RORB modelling:

- The catchment area for the Rosedale Creek and Toongabbie Creek study area was delineated
- The catchment was divided into subareas based on the topography and points of interest
- The RORB model was constructed using appropriately selected parameters including reach type, slopes and subarea fraction impervious values
- Design loss parameters were investigated using a number of techniques, with final parameters adopted
- Design flood events for the 2, 5, 10, 20, 50, and 100 year ARI were run for multiply durations to determine the critical durations

The RORB model covers an area of approximately 45 square kilometres, with the downstream outlet located at the confluence of Rosedale Creek and the Latrobe River. Hydrographs were extracted at points of interest, the outflow of the RORB model and at the downstream end of each sub-area for verification of parameters selection with flow estimation methods. The hydrographs obtained from key points of interest were used as a flow input into the hydraulic model.

Sub-area and reach delineation

The RORB model was constructed by using the designated waterways mapping to construct the catchment boundaries. Sub-areas were delineated using guidelines set out in the RORB manual and to allow flows to be extracted at the points of interest. The RORB model was delineated into twenty-one sub-catchments. Figure 6 shows the catchment area and the sub-area delineation.

Nodes were placed at areas of interest, junctions of reaches and at the downstream end of each sub-area. Nodes were connected by reaches, representing the length, slope and reach type. RORB allows a choice of five different reach types to be selected (1=natural, 2=excavated and unlined, 3=lined channel or pipe, 4=drowned reach, 5=dummy reach). All reaches were set to natural reaches. Using natural reaches doesn’t allow the slope of the reaches to be set.

The fraction impervious value for all sub-areas was set to 0% to represent the undeveloped nature of the catchment, as it is an excepted practice to use zero except for in urban areas.

Appendix B shows the graphical representation of the RORB model and outlines sub catchment information.

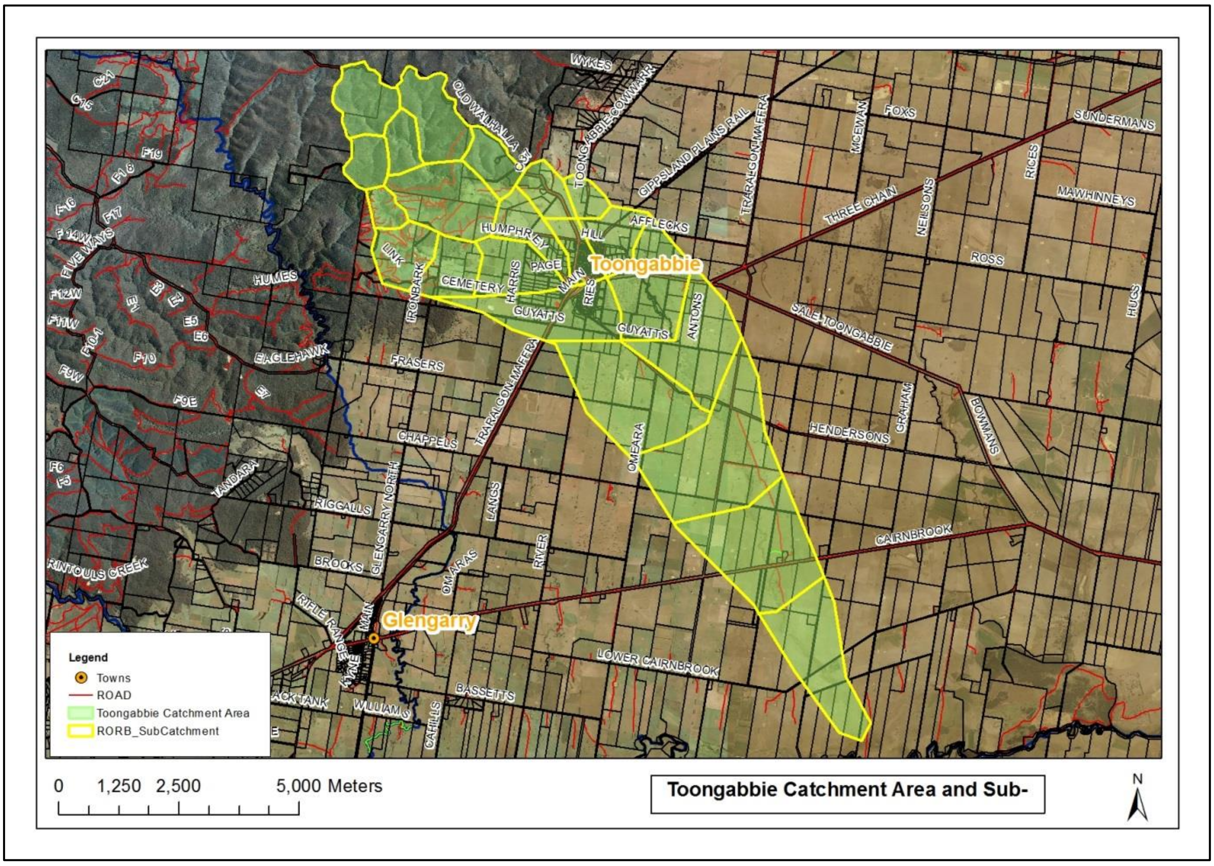

Figure 6 RORB catchment area and sub-catchment delineation

Parameters

The RORB model was run using the initial loss / continuing loss model, requiring storage and loss parameters m, kc, initial loss and continuing loss to be set to determine the peak flow for the series of ARI events.

Parameter selections for the RORB hydrologic model were determined by using the recommended parameters outlined in the Australian Rainfall and Runoff (ARR) guidelines and the RORB manual. The m parameter determines the degree of non-linearity of the catchments response to rainfall and the k_c parameter determines the storage available within the catchment. The parameter kc is the main parameter used to calibrate the model, a number of regional equations for the calculation of kc are recommended by ARR guidelines and the RORB manual, which are outlined in Table 2 and were used as a guide for the selection of this parameter. The default value of 0.8 for the m parameter was adopted.

Table 2 Recommended kc values

Source	Kc
Vic MAR>800mm – Eq 3.21 ARR87 (Book V)	14.27
Victoria data (Pearse et al 2002)	22.15
Default RORB	14.78

As the catchment is ungauged different methods of loss estimation were analysed to determine an estimated value for the catchment. Loss methods included recommendations in ARR87 and the design loss prediction equations developed by Hill et al (1998).

The ARR suggest recommendations for initial loss and continuing loss parameters to be used for Victorian catchments south and east of the great dividing range, which are CL = 2.5 mm/hr and IL = 15 – 20 or 25 – 35mm/hr (Canterford, 1987 Edition).

Hill et al (1998) losses are calculated by first calculating the storm initial loss using Equation 4.10, then the burst initial loss using Equation 4.11. The burst initial loss varies with storm duration. The continuing loss is estimated using Equation 4.12.

Storm Initial Loss

$$IL_s = -25.8\ BFI + 33.8 \qquad \text{Eq. 4.10}$$

Burst Initial Loss

$$IL_b = IL_s \left\{ 1 - \frac{1}{1 + 142\frac{\sqrt{duration}}{MAR}} \right\} \qquad N=75,\ r^2=0.43\ SE=18\% \qquad \text{Eq. 4.11}$$

Continuing Loss

$$CL = 7.97BFI + 0.00659PET - 6.00 \qquad \text{Eq. 4.12}$$

In the equations developed by Hill et al (1998) the following information is required:

- BFI is the base flow index, the volume of base flow divided by the total streamflow volume. It is a fixed value for a given catchment, and is only directly available for gauged catchments; however it appears to vary quite smoothly between gauge locations allowing reasonable estimates of BFI to be made for locations in Victoria. Using the plot of calculated base flow index values for sites in Victoria, taken from (Hill, et al, 1998) the estimated BFI for Toongabbie is 35%.
- MAR is the mean annual rainfall in mm. The MAR was derived from the Bureau of Meteorology climate maps, shown in Appendix A, and was determined to be 800mm (BoM, 2015).
- PET is the potential evapotranspiration. The PET was derived from the Bureau of Meteorology climate maps and was determined to be 1000mm (BoM, 2015).

Table 3 outlines the loss estimates analysed for the Toongabbie catchment area.

Table 3 Loss estimates for Toongabbie

Source	IL_s (mm)	IL_b (mm)	CL (mm/hr)
ARR(1987)	15-20 25-35	-	2.5
Hill et al (1998)	24.77	3.7 – 14.9 (for 1 -72 hour events)	3.38

Determining the most appropriate parameter selection involved running different simulation with a range of Kc and loss values shown in Table 4.

Table 4 RORB model parameter verification simulation

Run	Kc	IL (mm)	CL (mm/hr)	Description
	Single Set of Routing Parameters for the Whole Model			
1	14.27	15	2.5	Vic MAR>800mm – Eq 3.21 ARR87 (Book V) and ARR lowest initial loss and continuing loss
2	22.15	15	2.5	Victoria data (Pearse et al 2002) and ARR lowest initial loss and continuing loss
3	14.78	15	2.5	Default RORB and ARR lowest initial loss and continuing loss
4	14.27	35	2.5	Vic MAR>800mm – Eq 3.21 ARR87 (Book V) and ARR highest initial loss and continuing loss
5	22.15	35	2.5	Victoria data (Pearse et al 2002) and ARR highest initial loss and continuing loss
6	14.78	35	2.5	Default RORB and ARR highest initial loss and continuing loss
7	14.27	3.7 – 12.8	3.38	Vic MAR>800mm – Eq 3.21 ARR87 (Book V) and Hill et al (1996)
8	22.15	3.7 – 12.8	3.38	Victoria data (Pearse et al 2002) and Hill et al (1996)
9	14.78	24.77	3.38	Default RORB and Hill et al (1996)

The adopted parameters are outlined in Table 5, which were selected based on the following:

- Considering the results from this flood study are intended for use for planning purposes, the Kc parameter Vic MAR>800mm was adopted based on it giving a more conservative result.
- The loss parameters derived by Hill et al (1998) were adopted based on they are developed from more recent work and previous flood studies conducted by Water Tech in Victoria on gauged catchments, state that losses developed by Hill et al (1998) used in combination with the areal reduction factors from Siriwardena and Weinman (1996), produce peak flows that are more consistent with the results of flood frequency analysis.

Table 5 Adopted parameters for the RORB model

Source	Kc	IL_s (mm)	IL_b (mm)	CL (mm/hr)
Hill et al (1998) and VicMAR>800mm	14.27	24.77	3.7 – 14.9 (for 1 -72 hour events)	3.38

Design run

The RORB model design runs involved using design rainfall events for the centroid of the catchment and the parameters selected to estimate design flows. Design rainfall events were calculated using the Intensity Frequency Duration (IFD) analysis from AR&R (1987). The coefficients used are listed in Table 6, and were obtained from the Bureau of Meteorology (BoM) website for the catchment centroid.

Design rainfall specifications adopted for the design events were unfiltered temporal patterns with rainfall depths applied uniformly across the catchment. Areal reduction factors from Siriwardena and Weinmann were applied to the point design rainfall estimates. These areal reduction factors are recommended for use in Victoria (Hill, Graszkiewicz, Taylor, & Nathan, 2014).

Table 6 IFD Coefficients

IFD Coefficients	
2yr (50% AEP) 1hr rainfall intensity (mm/hr)	18.5
2yr (50% AEP) 12hr rainfall intensity (mm/hr)	3.79
2yr (50% AEP) 72hr rainfall intensity (mm/hr)	1.10
50yr (2% AEP) 1hr rainfall intensity (mm/hr)	46.48
50yr (2% AEP) 12hr rainfall intensity (mm/hr)	7.47
50yr (2% AEP) 72hr rainfall intensity (mm/hr)	2.21
Skew	0.35
F2	4.24
F50	15.18

Sensitivity analysis

The sensitivity of the RORB model to the kc parameter value was analysed. The results indicated that using the Pearse kc value which is higher, resulted in a smaller extent of flooding in the township area and at the downstream end of the catchment. Using the higher kc value also had a small decrease in the overall depth of flooding for the area. Considering it is an ungauged catchment with limited data and the potential use of the results will be for planning purposes, the Kc parameter Vic MAR>800mm with a value of 14.27 was adopted as it was the most conservative approach.

Assumptions

Assumptions made during the development of the RORB hydrologic model are as follows:

- As the catchment being analysed is relatively small, the spatial distribution of rainfall across the catchment is assumed to have a minor influence on the magnitude of the resultant peak floods. Therefore a uniform spatial pattern has been adopted for this catchment.
- The unfiltered temporal rainfall patterns were adopted directly from the RORB program, which use the ARR (1987) technique from Volume 2. Therefore any embedded bursts of higher rainfall in the design storm were not filtered out of the pattern.
- All reaches were modelled as natural reaches; therefore the slope of the reach was assumed to have negligible effect on the peak flows, due to the relatively flat catchment area and therefore not incorporated into the hydrology model.
- The fraction impervious value was zero for all areas

RORB results

Considering the purpose of the flood study is for planning purpose, the results obtained from the RORB model were based on selecting parameters that resulted in the most conservative flood extent. A range of durations were tested to determine the critical duration to achieve the peak flows for the series of ARI storm events, with results shown in Appendix C. The critical durations for the 5, 10, 20, 50 and 100 year ARI was determined to be 36 hours at the catchment outlet. The critical duration for the 2 year ARI was determined to be 12 hours.

The design parameters and the critical duration for the storm event are shown in Table 7.

Table 7 Design parameters used in the RORB model for the range of storm events

<table>
<tr><th>ARI (years)</th><th>K_c</th><th>m</th><th>Critical Duration (hrs)</th><th>IL (mm)</th><th>CL (mm/hr)</th></tr>
<tr><td>2</td><td rowspan="6">14.27</td><td rowspan="6">0.8</td><td>12</td><td>9.4</td><td rowspan="6">3.38</td></tr>
<tr><td>5</td><td>36</td><td>12.8</td></tr>
<tr><td>10</td><td>36</td><td>12.8</td></tr>
<tr><td>20</td><td>36</td><td>12.8</td></tr>
<tr><td>50</td><td>36</td><td>12.8</td></tr>
<tr><td>100</td><td>36</td><td>12.8</td></tr>
</table>

The peak flows obtained from the RORB design runs at the catchment outlet are outlined in Table 8 and hydrographs of the design flow estimates for 2, 5, 10, 20, 50 and 100 year ARI events for the catchment outlet are shown in Figure 7.

The peak flows and critical durations for the points of interest are summarised in Appendix C.

Table 8 RORB Design Run Flow Estimation at Catchment Outlet

Average Recurrence Interval (ARI) (Years)	Flow at outlet based on RORB design run model (m^3/s)
2	11.91
5	22.07
10	32.00
20	46.34
50	61.80
100	80.40

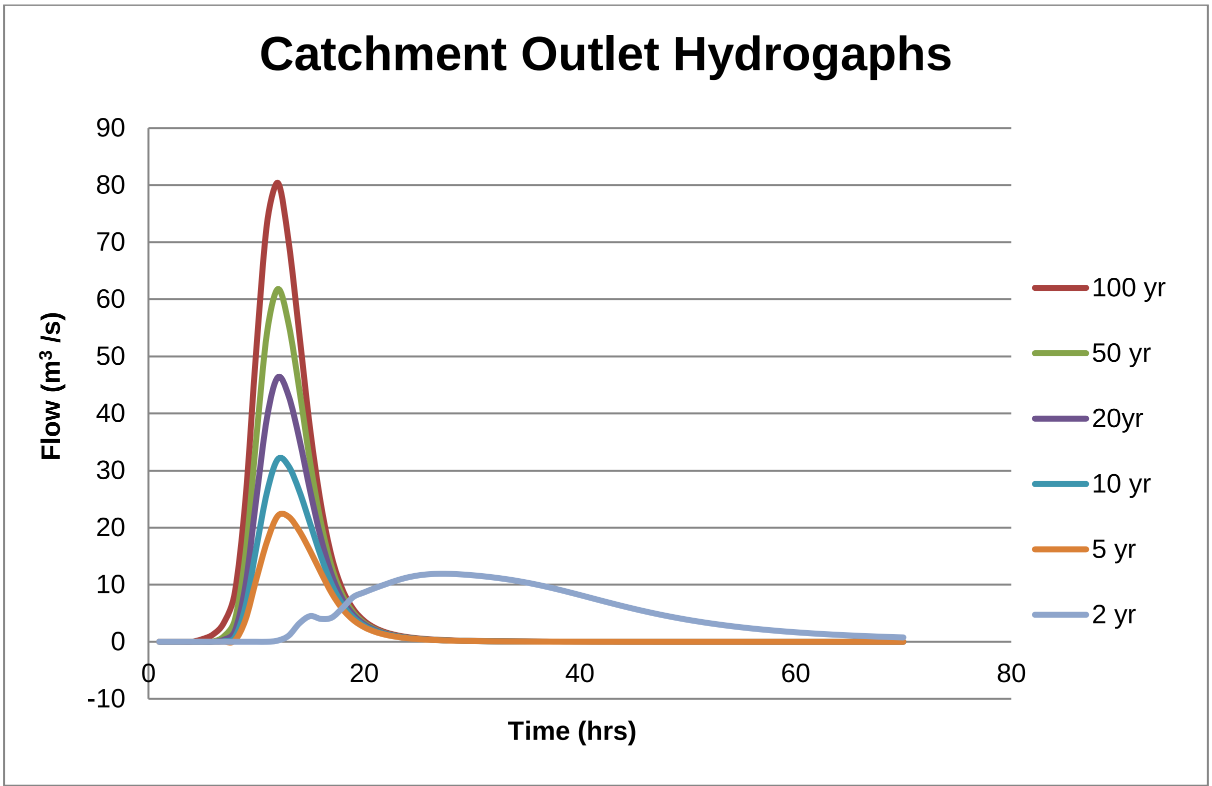

Figure 7 Catchment outlet hydrographs

2.5 Summary of Hydrology Results

The Toongabbie Township has no streamflow gauges on either the Toongabbie Creek or Rosedale Creek; therefore it was modelled as an ungauged system. As a result, to assess the reliability of the design flood estimates, they were compared to estimates obtained by other flow estimation methods. Table 9 compares the flow estimations for the 100 year ARI flood events at 8 locations in the catchment. The RORB results compare reasonably well to the Zaman method flows estimated for location 1 to 4 which are at the top of the catchment and consist of a smaller catchment areas. Locations 5 to 8 have a larger catchment area and compare reasonably well to the Regional equation. The results are as expected as the

Zaman method is suited to smaller catchment areas and the regional equation is suited to large rural catchment areas. A map identifying the different locations is shown in Appendix B.

The 100 year ARI flow estimated using the RORB model compares well to the Nikolaou and von't Steen equation, and lies in between flow estimates using the Rational method and the Zaman method, shown in Table 10 and Figure 8. However, considering location 1 to 4 are the main inflow locations for the hydraulic model, the results indicate that peak flows are likely to be overestimated rather than under estimated, resulting in a more conservative flood extent being produced.

Table 9 Comparison of the 100 year ARI flow estimation at different locations in the catchment

	100 year ARI Flows (m^3/s)				
Location	**RORB**	**1987 Rational**	**2013 Rational**	**Zaman**	**Regional**
1	24.41	9.02	7.32	34.36	12.57
2	42.59	16.57	16.48	54.54	24.16
3	12.33	3.23	3.12	15.6	4.2
4	9.04	3.23	2.33	17.3	3.86
5	55.72	29.95	27.48	86.26	45.34
6	26.05	10.73	9.16	38.86	15.24
7	68.25	42.05	35.98	111.24	65.48
8	80.40	53.14	44.14	130.48	85.42

Table 10 Comparison of flow estimations at the catchment outlet

Average Recurrence Interval (ARI) (years)	Nikolaou and von't Steen equation (m^3/s)	Rational method based on 1987 IFD (m^3/s)	Rational method based on 2013 IFD (m^3/s)	Zaman et. al. (2013) equations (m^3/s)	Flow at outlet based on RORB design run model (m^3/s)
2		10.49	8.85	7.42	11.91
5		17.42	14.98	22.54	22.07
10		23.04	20.23	41.25	32.00
20		30.70	26.41	59.53	46.34
50		41.97	35.35	95.39	61.80
100	85.42	53.14	44.14	130.48	80.40

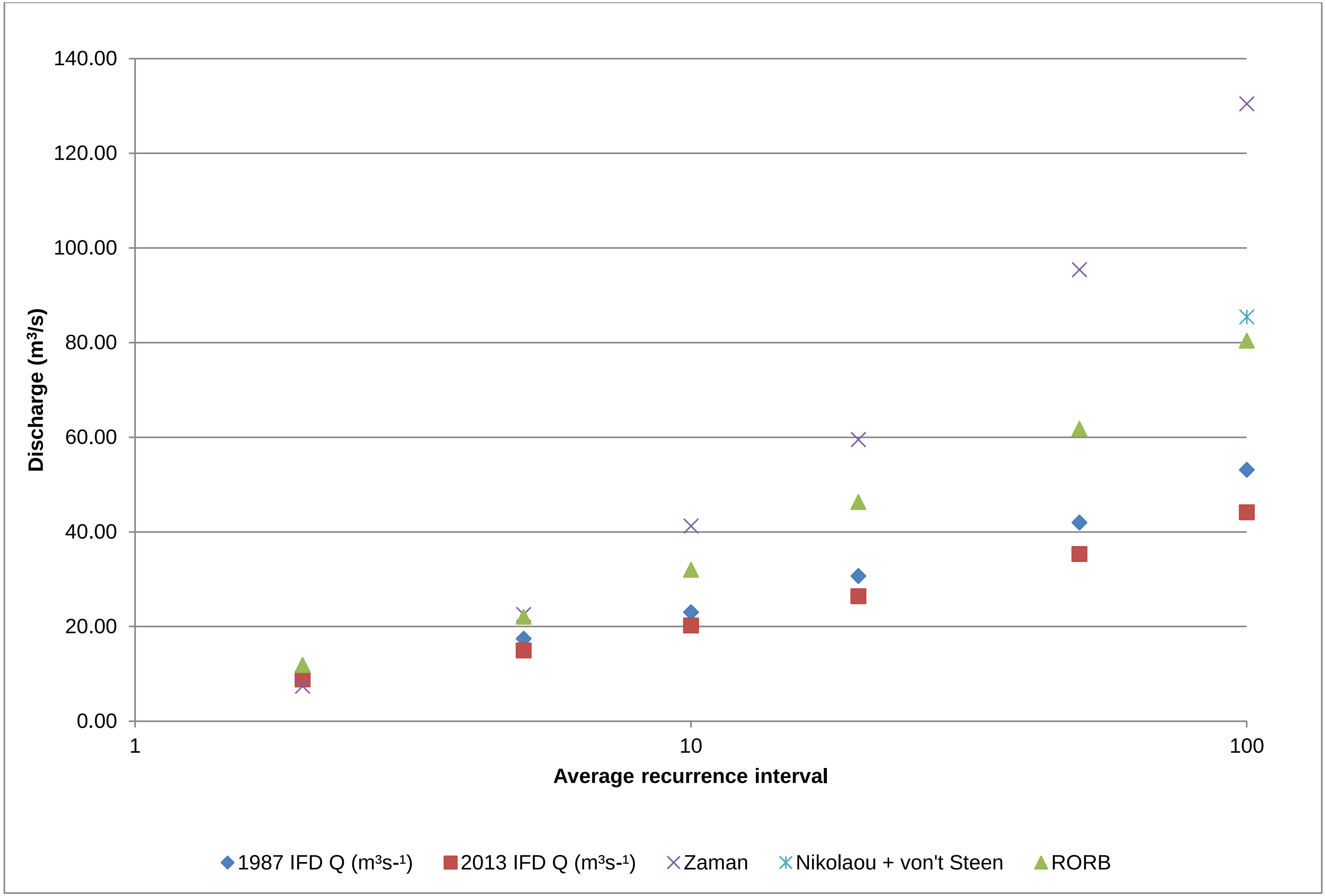

Figure 8 - Flow estimation for the range of storm events at the catchment outlet

3 Hydraulics

3.1 Description of hydraulic modelling approach adopted

Three different hydraulic models were constructed which included a catchment extent model, a Toongabbie Township extent model using hydrograph flows and a Toongabbie Township extent model using rain on grid modelling approach.

A combined 1D-2D hydraulic model was adopted and constructed for all three models, consisting of:

- A two dimensional (2D) hydraulic model of the study area
- A one dimensional hydraulic model of key hydraulic structures

The hydraulic modelling computer program Sobek, was used to investigate the flood flow characteristics for the Toongabbie catchment area and in the vicinity of the Toongabbie Township for the design 2, 5, 10, 20, 50 and 100 year ARI flow conditions. Sobek is a 1D/2D program developed by WL/Delft 1D/2D in the Netherlands, which is widely used in Australia and internationally. The combined 1D/2D approach allows accurate representation of the key hydraulic structures and overland flow paths.

3.2 Available data

The available data utilised for the hydraulic model of Toongabbie Township was:

- Aerial photography
- Waterway and catchment mapping
- Terrain data
- Field Survey data
- Underground Drainage data
- Rainfall Intensity data

Aerial Photography

Digital aerial photography used for this study was supplied by WGCMA and obtained in 2009. The aerial photography covers the whole West Gippsland Region and was used to provide base imagery for the Toongabbie Township study area.

Waterway and Catchment mapping

The waterways layer obtained from VicMap data was used to identify designated waterways, the main flow paths, tributaries associated with the system and to determine boundary locations and potential breakout points.

Terrain Data

Terrain data was obtained from LiDAR dataset supplied by the West Gippsland Catchment Management Authority. LiDAR surveying was conducted over the floodplain area in the vicinity of Toongabbie in April, 2011, by Fugro Spatial Solutions Pty Ltd. The results obtain identified the AHD vertical spatial accuracy is within the target specification, with 83.8% of the points analysed falling within +/-0.10 metres.

A full Metadata report for the LiDAR data sets used is documented in (Furgo Spatial Solution Pty Ltd, 2010).

Field Surveying Data

Field surveying was required to provide additional data to the LiDAR information at the location of key one-dimensional elements. Surveying was conducted during July 2015 using Leica surveying equipment and validated using benchmarks to ensure the appropriate accuracy was achieved.

The component of the survey consisted of bridge and culvert hydraulic structures that were assumed to have a significant influence on the floodplain flow and storage.

Underground Drainage data

The current stormwater drainage system for Toongabbie incorporates an underground drainage network, which includes drainage pits and a pipe network. Information on the network was obtained from Latrobe City Council, with the layout of the network shown in Figure.

Rainfall Data

Rainfall data was required for determining the design temporal rainfall patterns for the direct rainfall method (Rain on Grid). The Intensity-Frequency-Duration was determined using the Bureau of Meteorology IFD program. The temporal rainfall pattern was calculated using the distribution outlined in ARR (1987) Volume 2.

3.3 Key hydraulic features

There are several key hydraulic structures within the Toongabbie Township, which contribute to the nature and extent of flood waters in flood events ranging from small frequent events through to large flood events. The major hydraulic features were surveyed and include bridges and culverts at the following locations:

- Traralgon Maffra Road – Bridge
- Rail Trail (over Toongabbie Creek) – Bridge
- Humphrey Road – Box Culverts
- Page Road - Culvert
- Harris Road - Culvert
- Afflecks Road – Box Culvert
- Main Road – Culvert x2

- Rail Trail (over Rosedale Creek) - Bridge

These key hydraulic features were assessed during a site visit in July 2015, with the locations shown in Figure 9. Details and imagery of the structures are shown in Appendix D.

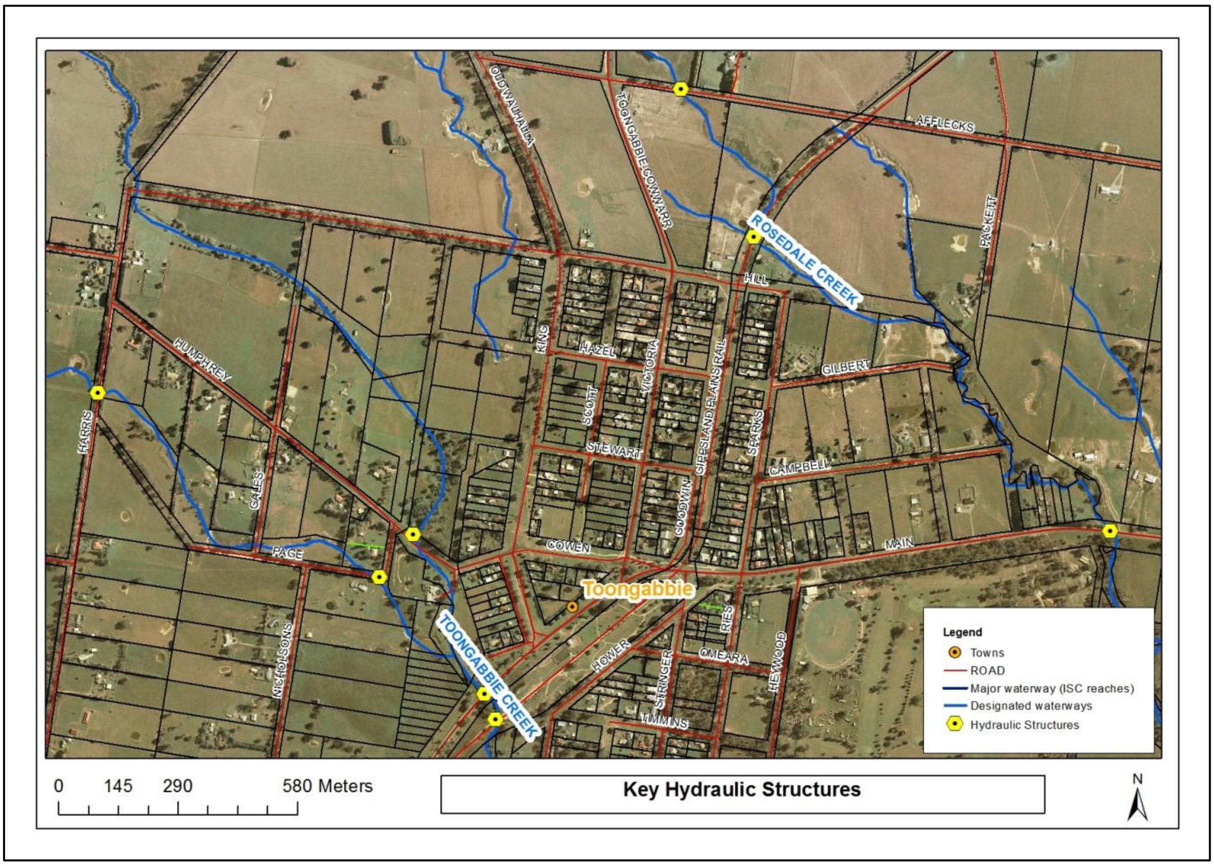

Figure 9 Key hydraulic structures

3.4 Catchment extent hydraulic model

Model Extent

The catchment extent hydraulic model was developed using a 2-dimensional component to model the terrain in the study area and a 1-dimensional component to represent the hydraulic structures. The 1D/2D model consisted of four main inputs, which were:

- Topography data
- Roughness coefficient
- Boundary conditions
- Hydraulic structures

The catchment extent hydraulic model aimed to determine the main flow paths for the whole catchment area. The study area extended from the forested area in the north to the confluence at the Latrobe River in the south, which covers approximately 55 square kilometres, shown in Figure 10. This study area included Toongabbie Creek and Rosedale Creek and their associated tributaries.

Fells Creek runs North East of the Toongabbie catchment area and is in close proximity to the Rosedale and Toongabbie Creek's. A preliminary 2D hydraulic model of Fells Creek was constructed to determine if the flood extent interacted with the Toongabbie Creek catchment. Flows were determined using the rational method, with the estimated 100 year ARI rational flow doubled and put through the model. The results indicated that it was not likely that the flood extent from Fells Creek would interact with the flood extent from the Toongabbie Creek and Rosedale Creek; therefore it was not included in the Toongabbie catchment extent hydraulic model.

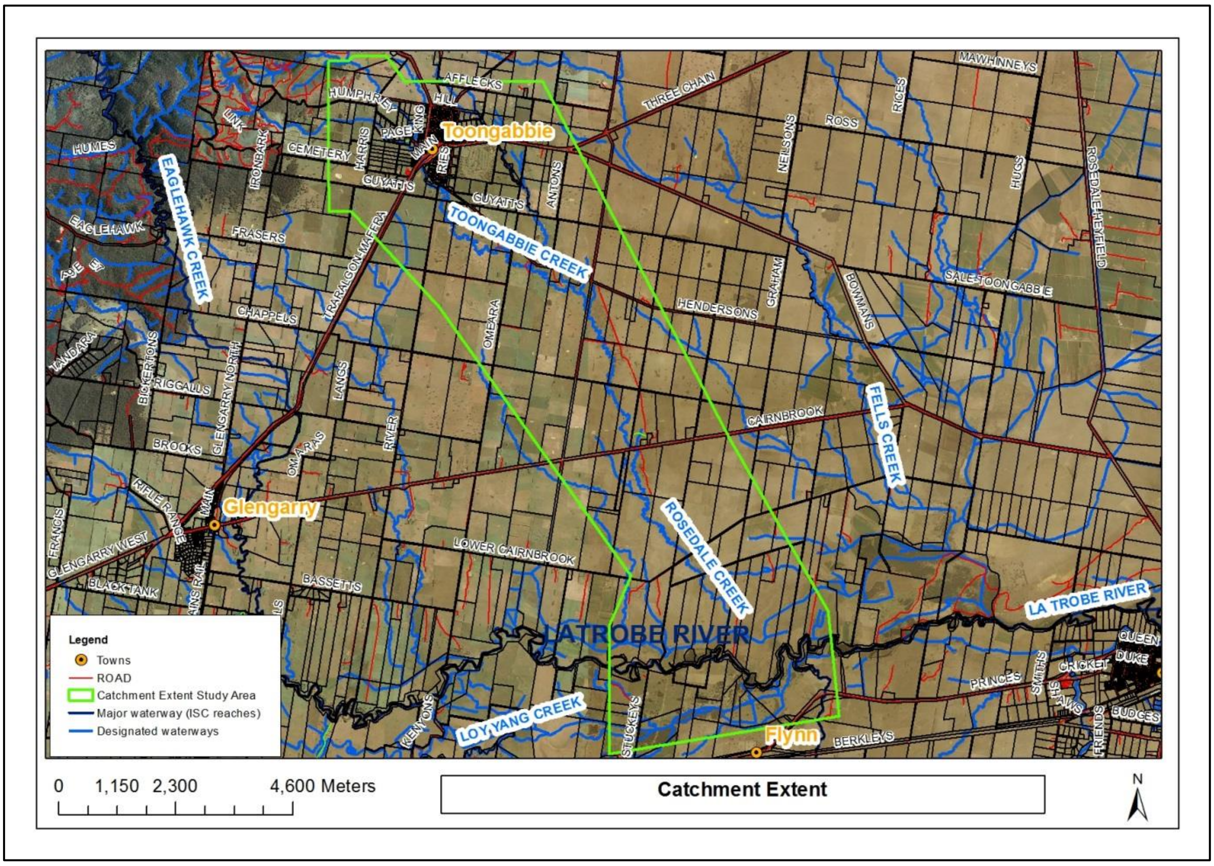

Figure 10 Catchment extent and major waterways

Topography Data

The major component of the two-dimensional component of the model is the grid that describes the topography of the area. The topography of the study area was obtained from LiDAR data. The LiDAR data was resampled into a digital elevation model (DEM), which is constructed as a square grid of elevations. A 20 metre grid size was adopted for this model and input into the Sobek program as an asci file. Using a 20 metre grid size resulted in the upper portion of the catchment not having a defined channel, resulting in water spreading across the entire upper section of the study area. Therefore manipulation of the grid was required to allow water to flow along the path of the main channels. The grid was aligned in a north-south orientation, using a GDA 1994 MGA Zone 55 coordinate projection. Parameters of the 2D topography grid are outlined in Table 11.

Table 11 Catchment extent 2D topography grid parameters

TOPOGRAPHY GRID PARAMETERS	
Parameters	**Value**
Grid Cells Size	20 metre x 20 metre
Grid Cells (x direction)	504 columns
Grid Cells (y direction)	688 rows
Total Grid Cells	346,752
Spatial Reference	GDA 1994 Transverse Mercator

Roughness Coefficient

A detailed roughness map was constructed based on the different land usage in the area. The catchment roughness values were used to represent the overland flow resistance associated with the different land use types and different vegetation types. Roughness values were assigned to each grid cell of the 2D topography grid, which resulted in a 20 metre by 20 metre roughness grid. The roughness values were defined as Manning's n Roughness values with adopted values shown in Table 12. The detailed roughness map is shown in Figure 11.

Table 12 Manning's n values adopted for the catchment extent model

MANNING'S n ROUGHNESS COEFFICIENTS FOR LAND USAGE	
Location	**Value**
Residential – Rural (lower density)- when building footprints and remainder of parcel are modelled together with one roughness value	0.15
Roads / pavement / carparks	0.03
Rail Trail	0.12
Waterway (minimal vegetation)	0.04
Farm/Grassed Areas/Parks	0.04
Moderate vegetation	0.08
Dense vegetation	0.1

Roughness values taken from (Chow, 2014) and (Melbourne Water, 2012(a))

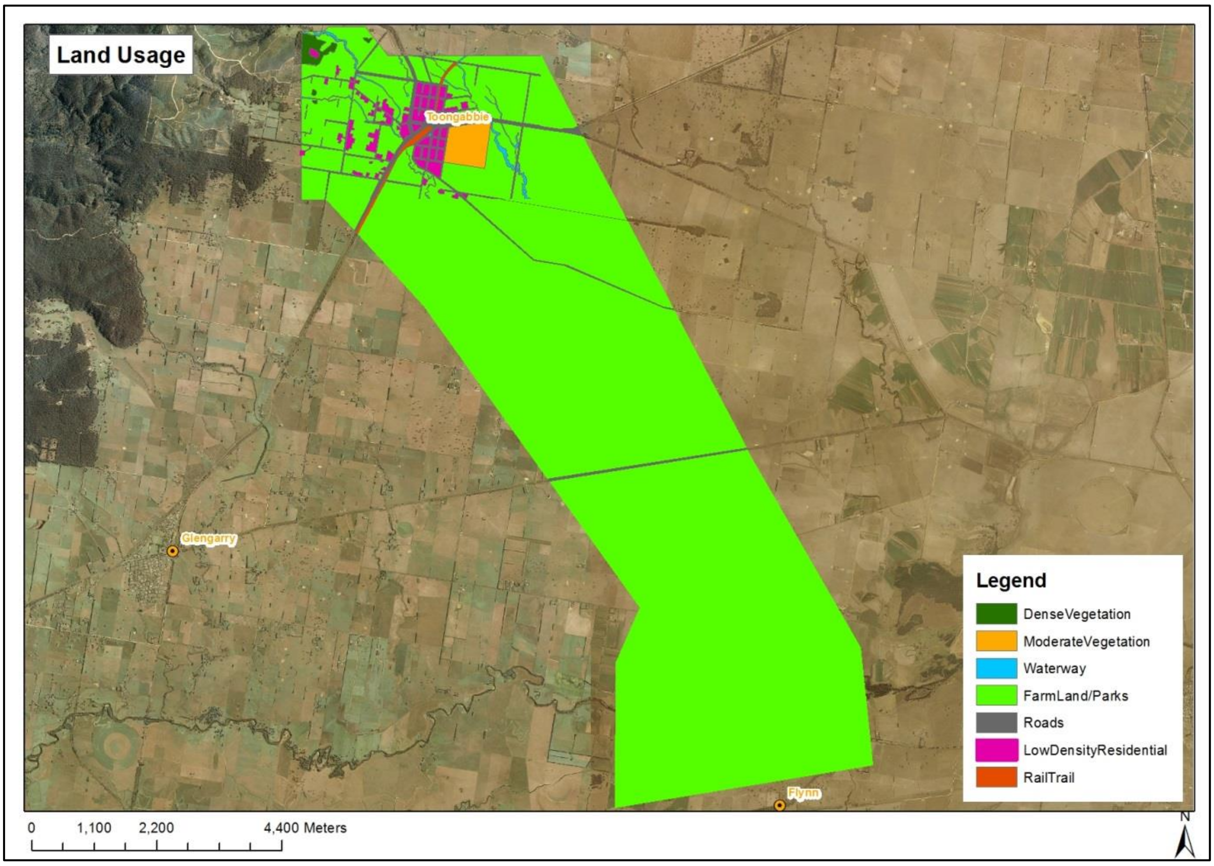

Figure 11 Manning's n roughness map for the catchment extent model

Boundary Conditions

Boundary conditions for the catchment extent map included 7 inflow boundaries and one outflow boundary. Four inflow boundaries are located at the top of the model and represent flow from the catchment area above the hydraulic study area. There is also 2 inflows located downstream of the township area, in the form of point inflows, these inflows aim to represent the contribution of overland flow from the surrounding farm land.

The downstream inflow boundary is set as a steady flow line boundary representing the Latrobe River 10 year ARI flood level. The outflow boundary of the model is set as a steady water level determined by the topography of the area to prevent back flow of water into the model and to allow the flow to smoothly exit the model to reduce run times.

Boundary condition parameters are outlined in Table 13.

Table 13 Boundary parameters for the catchment extent model

BOUNDARIES		
Location	**Node Type**	**Settings**
Inflow 1	2D Line Boundary	Hydrograph
Inflow 2	2D Line Boundary	Hydrograph
Inflow 3	2D Line Boundary	Hydrograph
Inflow 4	2D Line Boundary	Hydrograph
Inflow 5	2D Point Inflow	Hydrograph
Inflow 6	2D Point Inflow	Hydrograph

Inflow 7	2D Line Boundary	Water Level – Steady – 10yr ARI surface water level obtained from the Latrobe River
Outflows	2D Line Boundary	Ground Surface Water Level – Steady – Obtained from topography data

Hydraulic Structures

Key hydraulic structures located in the township that were identified as potentially having an impact on flood behaviour were included in the model, which included 3 bridges and 5 culverts at the following locations:

- Traralgon Maffra Road – Bridge
- Rail Trail (over Toongabbie Creek) – Bridge
- Humphrey Road – Box Culverts
- Page Road - Culvert
- Harris Road - Culvert
- Afflecks Road – Box Culvert
- Main Road – Culvert x2
- Rail Trail (over Rosedale Creek) - Bridge

Inputting bridge and culvert structures into the model involved constructing short 1D channels at the point of the structures, which also involved placing cross-section data on the channel. Cross-sections were placed upstream of the hydraulic structure to define the channel, with cross sectional data extracted from LiDAR information. Information on the dimensions of the structures were obtained from site visits and surveying. To ensure a smooth flow of water into the hydraulic structure, manipulation of the 2D topography grid was required at the inflow and outflow location.

Details and imagery of the hydraulic structures are shown in Appendix D.

Roughness values for hydraulic structures are shown in Table 14.

Table 14 Roughness coefficients adopted for hydraulic structures included in the catchment extent model

ROUGHNESS COEFFICIENTS FOR HYDRAULIC STRUCTURES	
Location	**Value**
Bridge Structure	0.010
Culverts	0.015

Roughness values taken from (Chow, 2014) and (Melbourne Water, 2012(a))

Model Settings

The adopted simulation time for the model was 6 days and 20 hours which was determined from the hydrographs produced from the RORB model. A 10 second time-step was used with GIS outputs at 1 hour intervals consisting of the average depth, water surface elevation and velocity produced. GIS data files were also produced for the maximum depth, water surface elevation and velocity that occurs throughout the simulation.

The 1D-2D connection setting used for the modelling of the catchment extent was ‘no embankments’. In this case the interaction of water flow between the 1D components and the 2D grid is that water enters the 2D grid as soon as the channel water level reaches the terrain level in the 2D grid. This setting was based on the fact that only data from one cross-section was used for inputting hydraulic structures and it would be unlikely that the embankment height would remain constant upstream and downstream of the structure. Therefore using this setting, overtopping of the channel banks is dependent on the 2D topography data.

Assumptions

Assumptions made during the development of the catchment extent hydraulic model using hydrograph inflows are as follows:

- Using a 20 metre by 20 metre grid cell will allow an acceptable level accuracy for the topography of the area to define the main break out points and to identify appropriate boundary locations for the Township hydraulic model
- No embankments were assumed, allowing flood waters from the 1D components to interact with the 2D floodplain when the water level reaches the elevation of the 2D grid
- The system is assumed completely dry before the storm events
- Outflow boundaries were set to the Latrobe River’s 10 year ARI flood level
- Only the tributaries of Toongabbie Creek and Rosedale Creek have an effect on flood waters in the Toongabbie catchment

Sensitivity analysis

The sensitivity analysis undertaken on the catchment extent model was conducted during the hydrological parameter selection analysis. This involved analysing the impact that changes to the inflow volumes have on the hydraulic model. The results indicated that changes to the flow affect the break outs and flood extent in the northern section of the township and immediately north of the Latrobe River. However, the changes to the flood extent were minimal, indicating that the model had little sensitivity to minor changes to peak flows. This could partially be due to the large grid size.

Results

The results obtained from the catchment extent hydraulic model determined flood behaviour within the catchment during the 2, 5, 10, 20, 50 and 100 year ARI flood events. The 2-dimensional overland flow results are recorded as depths (metres), surface water elevation (metres AHD), and velocities (m/s) for every grid cell at regular time intervals.

The flood extent during a 100 year ARI storm event is shown in Figure 12, which identifies the main break out points occur within the Township area of the catchment. Also minor breakouts occur in the downstream section of the catchment area near the confluence with the Latrobe River, which is likely to be part of the Latrobe River floodplain area. Variation in the extent of flooding was very minimal between the different ARI flood events, shown in Appendix F1. This could partially due to the 20 metre grid cell size, as the accuracy of the terrain data is reduced significantly.

Results of mapping of flood extents for all ARI flood events for the catchment extent model are shown in Appendix F1.

Results of flood surface water levels, depths and velocities for all ARI flood events for the catchment extent model are shown in Appendix G1, Appendix H1 and Appendix I1 respectively.

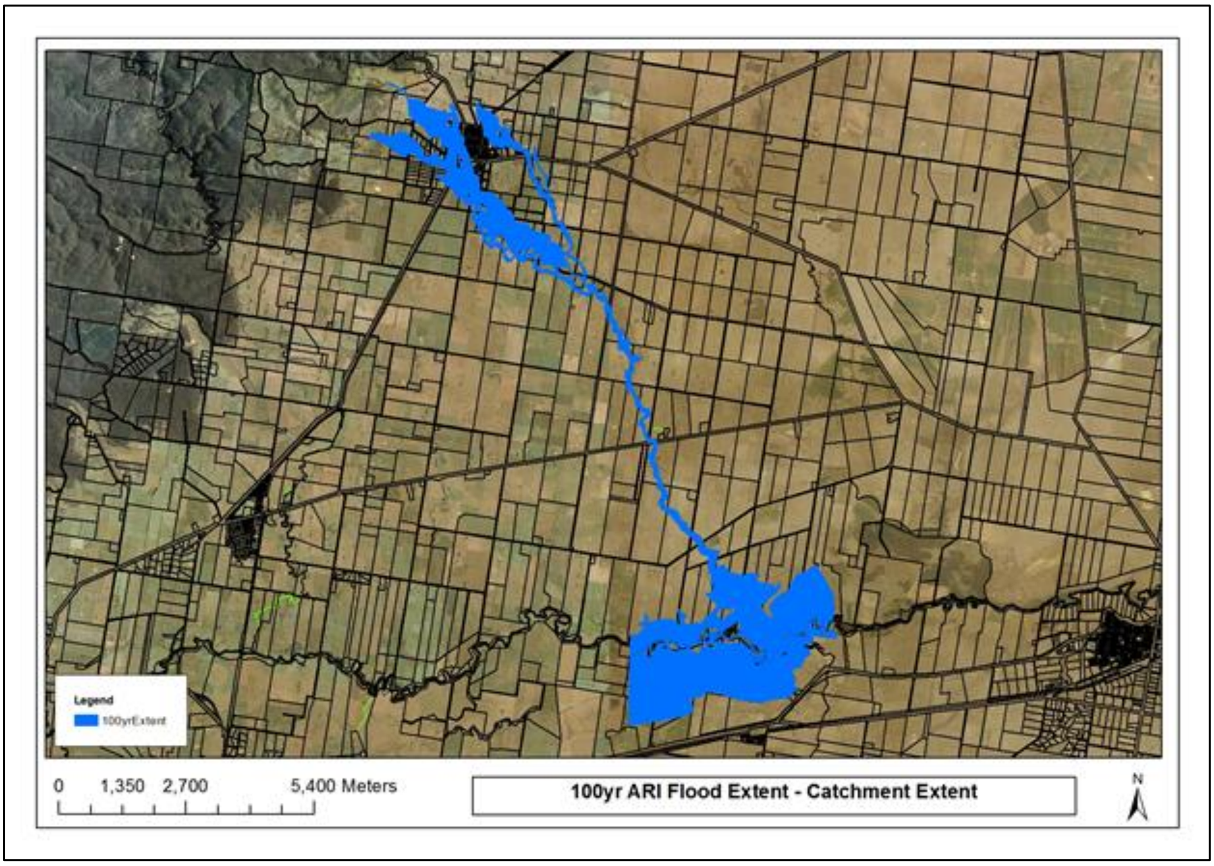

Figure 12 The 100 year ARI flood extent for the catchment extent hydraulic model

3.5 Township extent hydraulic model – hydrograph flows

Model Extent

The Toongabbie Township extent hydraulic model was developed using a 2-dimensional component to model the terrain in the study area and a 1-dimensional component to represent the hydraulic structures. The 1D/2D model consisted of four main inputs, which were:

- Topography data
- Roughness coefficient
- Boundary conditions
- Hydraulic structures

The Township extent hydraulic model using hydrograph inflows aimed to determine the main flow paths through the township and flood extents from riverine flooding. The study area covers approximately 12 square kilometres and is traversed by the Toongabbie Creek and Rosedale Creek, shown in Figure 13. The hydraulic modelling for the Toongabbie Township aimed to include flooding from the Toongabbie Creek and Rosedale Creek which will impact the residential area of Toongabbie.

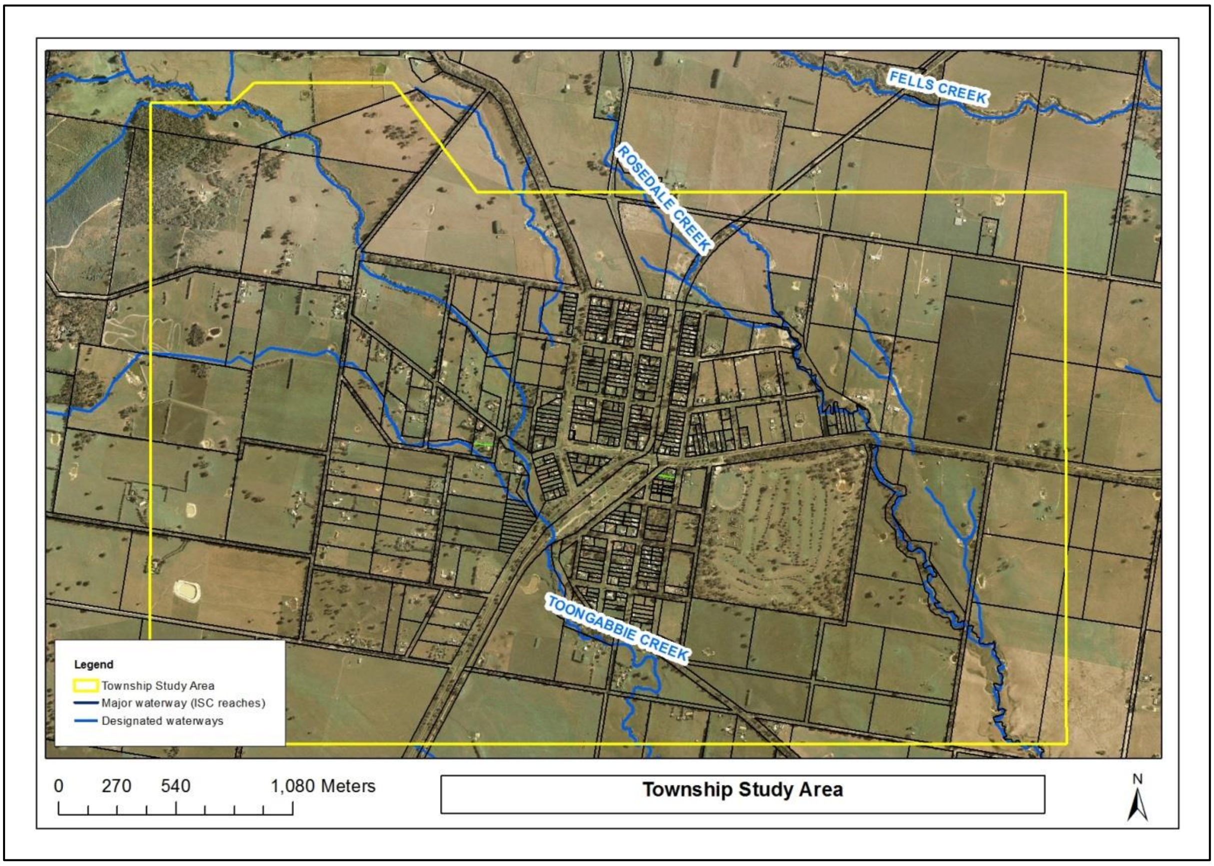

Figure 13 Toongabbie Township study area

Topography Data

The main two-dimensional component of the model is the grid that describes the topography of the area. The topography of the study area was obtained from LiDAR data. The LiDAR data was resampled into a digital elevation model (DEM), which is constructed as a square grid of elevations. A 10 metre grid size was adopted for this model and input into the Sobek program as an asci file. The grid was aligned in a north-south orientation, using a GDA 1994

MGA Zone 55 coordinate projection. Parameters of the Township 2D topography grid are outlined in Table 15.

Table 15 Township topography grid parameters

TOPOGRAPHY GRID PARAMETERS	
Parameters	**Value**
Grid Cells Size	10 metre x 10 metre
Grid Cells (x direction)	423 columns
Grid Cells (y direction)	305 rows
Total Grid Cells	134,865
Spatial Reference	GDA 1994 Transverse Mercator

Roughness Coefficient

A detailed roughness map was constructed based on the different land usage in the area. The township roughness values were used to represent the overland flow resistance associated with the different land use types and different vegetation types. Roughness values were assigned to each grid cell of the 2D topography grid, which resulted in a 10 metre by 10 metre roughness grid. A high, medium and low roughness value was chosen for each land usage type to be used for sensitivity analysis. The roughness values were defined as Manning's n Roughness values with adopted values shown in Table 16.The detailed roughness map is shown in Figure 14.

Table 16 Manning's n roughness values for the township area

MANNING'S n ROUGHNESS COEFFICIENTS FOR LAND USAGE			
Location	**Value**		
	Low	**Mid**	**High**
Residential – Rural (lower density)- when building footprints and remainder of parcel are modelled together with one roughness value	0.1	0.15	0.2
Roads / pavement / carparks	0.018	0.03	0.04
Rail Trail	0.05	0.12	0.2
Waterway (minimal vegetation)	0.03	0.04	0.05
Farm/Grassed Areas/Parks	0.03	0.04	0.05
Moderate vegetation	0.045	0.08	0.11
Dense vegetation	0.08	0.1	0.12

Roughness values taken from (Chow, 2014) and (Melbourne Water, 2012(a))

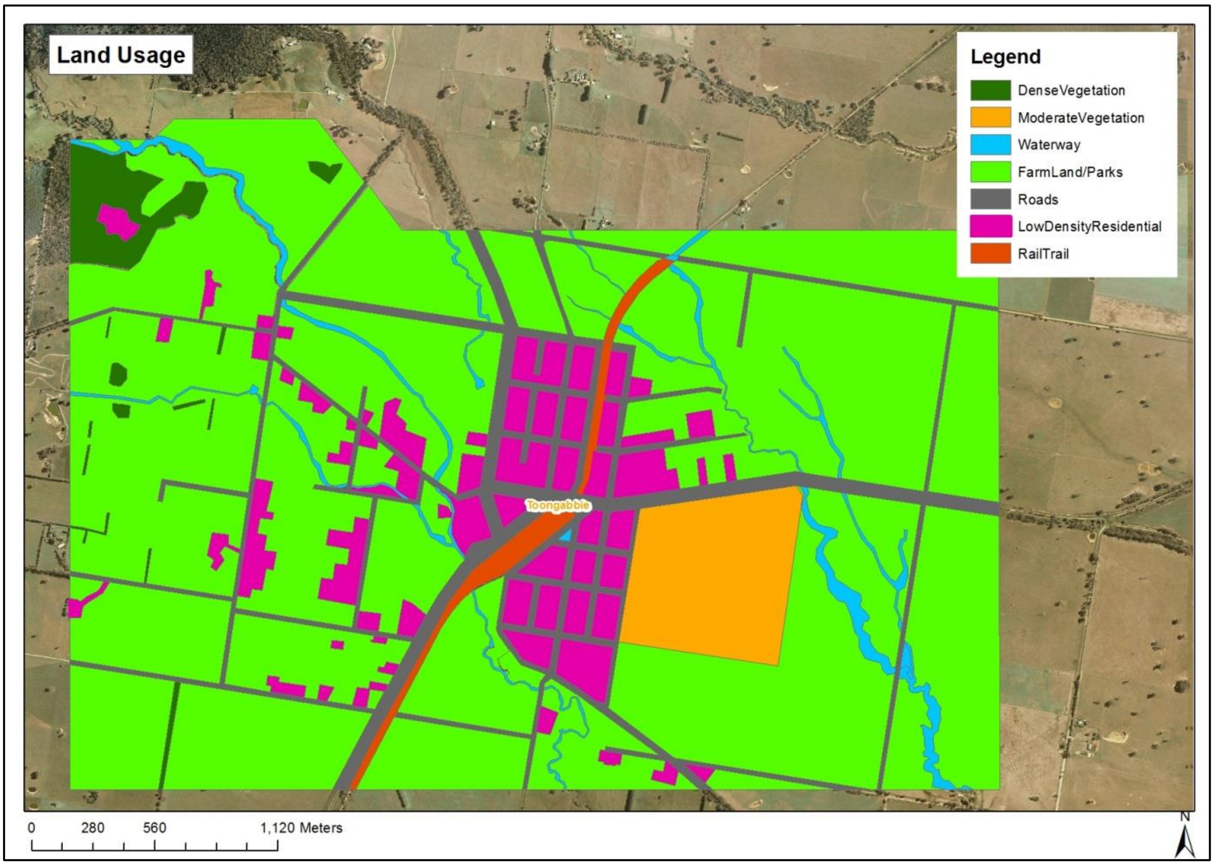

Figure 14 Detailed roughness map for the township area

Boundary Conditions

The Township hydraulic model consisted of 4 inflow boundaries to represent the contribution of water flowing into the study area from the above catchment area.

The inflows are in the form of streamflow hydrographs determined from the RORB hydrological model. The outflow boundary was set as a constant water level which was determined from the topography of the area. The water level relating to the topography of that area was chosen to reduce the back flow of water into the model. All boundaries were input as 2-dimensional line boundaries to allow the initial flow of water to be spread over more than one grid cell. Boundary condition parameters are outlined in Table 17.

Table 17 Boundary condition parameters for the Township extent hydraulic model using hydrographs

BOUNDARIES		
Location	**Node Type**	**Settings**
Inflow 1	2D Line Boundary	Hydrograph
Inflow 2	2D Line Boundary	Hydrograph
Inflow 3	2D Line Boundary	Hydrograph
Inflow 4	2D Line Boundary	Hydrograph
Outflows	2D Line Boundary	Ground Surface Water Level – Steady

Hydraulic Structures

Key hydraulic structures located in the township that were identified as potentially having an impact on flood behaviour were included in the model, which included 3 bridges and 5 culverts at the following locations:

- Traralgon Maffra Road – Bridge
- Rail Trail (over Toongabbie Creek) – Bridge
- Humphrey Road – Box Culverts
- Page Road - Culvert
- Harris Road - Culvert
- Afflecks Road – Box Culvert
- Main Road – Culvert x2
- Rail Trail (over Rosedale Creek) - Bridge

Inputting bridge and culvert structures into the model involved constructing short 1D channels at the point of the structures, which also involved placing cross-section data on the channel. Cross-sections were placed upstream of the hydraulic structure to define the channel, with cross sectional data extracted from LiDAR information. Information on the dimensions of the structures were obtained from site visits and surveying. To ensure a smooth flow of water into the hydraulic structure, manipulation of the 2D topography grid was required at the inflow and outflow location.

Details and imagery of the hydraulic structures are shown in Appendix D.

Roughness values for hydraulic structures are shown in Table 18.

Table 18 Roughness coefficients adopted for hydraulic structures included in the township extent model

ROUGHNESS COEFFICIENTS FOR HYDRAULIC STRUCTURES	
Location	**Value**
Bridge Structure	0.010
Culverts	0.015

Roughness values taken from (Chow, 2014) and (Melbourne Water, 2012(a))

Model Settings

The adopted simulation time for the model was 6 days and 20 hours which was determined from the hydrographs produced from the RORB model. A 10 second time-step was used with GIS outputs at 1 hour intervals consisting of the average depth, water surface elevation and velocity produced. GIS data files were also produced for the maximum depth, water surface elevation and velocity that occurs throughout the simulation.

The 1D-2D connection setting used for the modelling of the catchment extent was ‘no embankments’. In this case the interaction of water flow between the 1D components and the 2D grid is that water enters the 2D grid as soon as the channel water level reaches the terrain level in the 2D grid. This setting was based on the fact that only data from one cross-section was used for inputting hydraulic structures and it would be unlikely that the embankment height would remain constant upstream and downstream of the structure.

Therefore using this setting, overtopping of the channel banks is dependent on the 2D topography data.

Assumptions

Assumptions made during the development of the Township hydraulic model using hydrograph inflows are as follows:

- The 8 hydraulic structures included in the model are the key structures in the study area that will potentially impact the flooding behaviour.
- The 10 metre resolution of the topography grid will allow identification of roads and any table drains in the area
- The underground drainage network will not affect the riverine flood extent due to the location of the pits and pipe network
- The system is completely dry before the flood events occur

Sensitivity analysis

The sensitivity analysis aims to examine the impact that changes to the roughness parameters and the hydraulic structures have on the hydraulic model. The sensitivity was undertaken on the 100 year ARI design event for the township model.

Sensitivity to 2-Dimensional Roughness Parameters

The selected roughness parameters can have a noticeable effect on the flow behaviour and flooding depths present within the model. The sensitivity analysis was undertaken to see if the roughness parameters selected for the 2D topography grid impacted the extent, depth and velocity of flooding on the floodplain. Roughness parameters were selected based on the characteristics and land usage for the area; with the recommended roughness ranges obtained from (Chow, 2014) and (Melbourne Water, 2012(a)), which are outlined in Table 16. The 100 year ARI design event was then analysed using the low, medium and high values. Results are outlined in Table 19, which shows that the change in the roughness had the greatest effect on the velocity of the flood waters.

Table 19 Sensitivity to changes in roughness coefficient values

RESULTS FROM USING LOW, MEDIUM AND HIGH RANGE OF MANNING' N VALUE						
Value	**Depth (m AHD)**	**Difference between low and high values (m AHD)**	**Surface water Elevation (m AHD)**	**Difference between low and high values (m AHD)**	**Velocity (m/s)**	**Difference between low and high values (m/s)**
Low	0 – 5.421	0.0986	52.3 – 101.135	0.263	0 – 5.4486	2.1918
Mid	0 – 5.466		52.3 – 101.254		0 – 3.6189	

High	0 – 5.5196		52.3 – 101.371		0 – 3.2568	

Sensitivity to Varying Degrees of Hydraulic Structure Blockages

Toongabbie is a rural area with grazed paddocks which limits the availability of debris within the catchment. The ability for debris to become mobilised has an effect on the amount of debris that can be transported to a structure (Weeks, 2014). Considering Toongabbie is a relatively flat catchment, the likely mobility of debris is considered low. Therefore the low availability and mobility of debris indicates the complete blockage of hydraulic structures would be unlikely. Sensitivity analysis was undertaken on the hydraulic structures by modelling the structures fully opened, with a 20% blockage, a 50% blockage and a 100% blockage, with results shown in Table 20. The results indicate that blockages to hydraulic structures can alter the velocity of flood waters, however the overall depth and surface water elevation is unlikely to be effected.

Table 20 Sensitivity to varying degrees of blockages to hydraulic structures

RESULTS FROM APPLYING VARYING DEGREES OF BLOCKAGES TO HYDRAULIC STRUCTURES						
Degree of Blockage to Hydraulic Structure	**Depth (m AHD)**	**Difference between low and high values (m AHD)**	**Surface water Elevation (m AHD)**	**Difference between low and high values (m AHD)**	**Velocity (m/s)**	**Difference between low and high values (m/s)**
Fully Opened	0 – 5.466	0	52.3 – 101.254	0	0 – 3.6189	0.0176
20% Blockage	0 – 5.466		52.3 – 101.254		0 – 3.6171	
50% Blockage	0 – 5.466		52.3 – 101.254		0 – 3.6211	
100% Blockages	0 – 5.466		52.3 – 101.254		0 – 3.6347	

Results

The results obtained from the Toongabbie Township extent hydraulic model using hydrograph determined riverine based flood behaviour within the Township during the 2, 5, 10, 20, 50 and 100 year ARI flood events. The 2-dimensional overland flow results are recorded as depths (metres), surface water elevation (metres AHD), and velocities (m/s) for every grid cell at regular time intervals. Results of mapping of flood extents for all ARI flood events for the township model are shown in Appendix F2. Results of flood surface water levels, depths and velocities for all ARI flood events for the township model are shown in Appendix G2, Appendix H2 and Appendix I2 respectively.

The flood extent during a 100 year ARI storm event is shown in Figure 15, which identifies the break out points occurring within the Township area. The 100 year ARI flooding extent covers approximately 20% of the study area and indicates the main egress route to Traralgon, on the Traralgon-Maffra Road is likely to be inundated by flood waters during a

100 year ARI flood event.

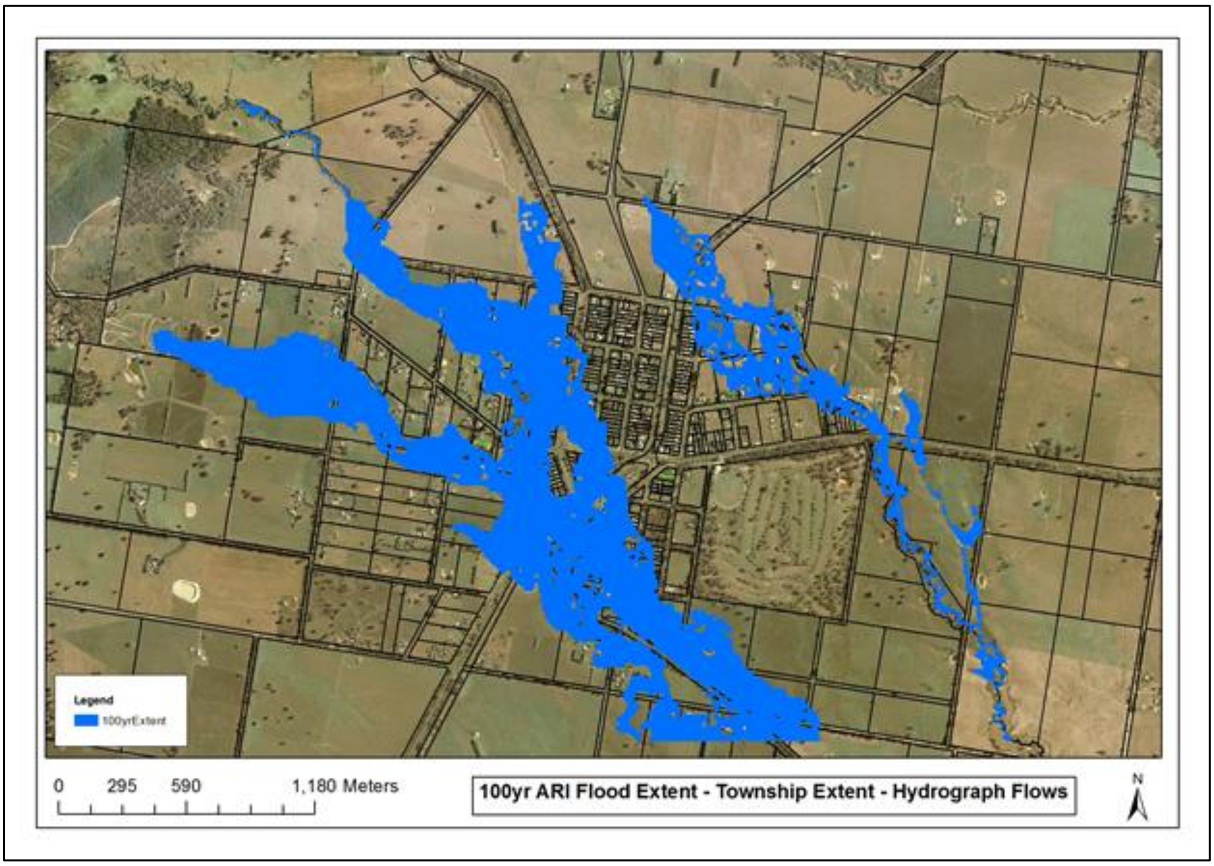

Figure 15 The 100 year ARI flood extent for the Toongabbie Township using hydrograph inflows

The flood extent produced from the hydraulic model was compared to aerial flood photograph taken during the 1995 flood event. The photo shown in Figure 12 identifies the Toongabbie cemetery by the yellow star, with the Traralgon Maffra Road running North through the township. Although the size of the 1995 flood event is unknown, the flood extent either side of the road compares reasonably well to the flood extent produced by the hydraulic model using a 100 year ARI flood event, shown in Figure 17. Figure 17 also defines the location of the cemetery with the yellow star, with the Traralgon Maffra Road running to the North-East.

The results of the flood extents produced for the different ARI flood events indicate that there is very little difference between flood extents for the 10 year ARI to the 100 year ARI flood event, shown in Appendix F2. Therefore, the reasonable comparison of flood extents produced by the hydraulic model with the flood photography allows a degree of confidence that the hydrological and hydraulic modelling technique adopted is producing reasonable results, considering it is an ungauged system.

Figure 16 1995 Flood Event - Looking North East from Traralgon side showing cemetery in foreground defined by the yellow circle

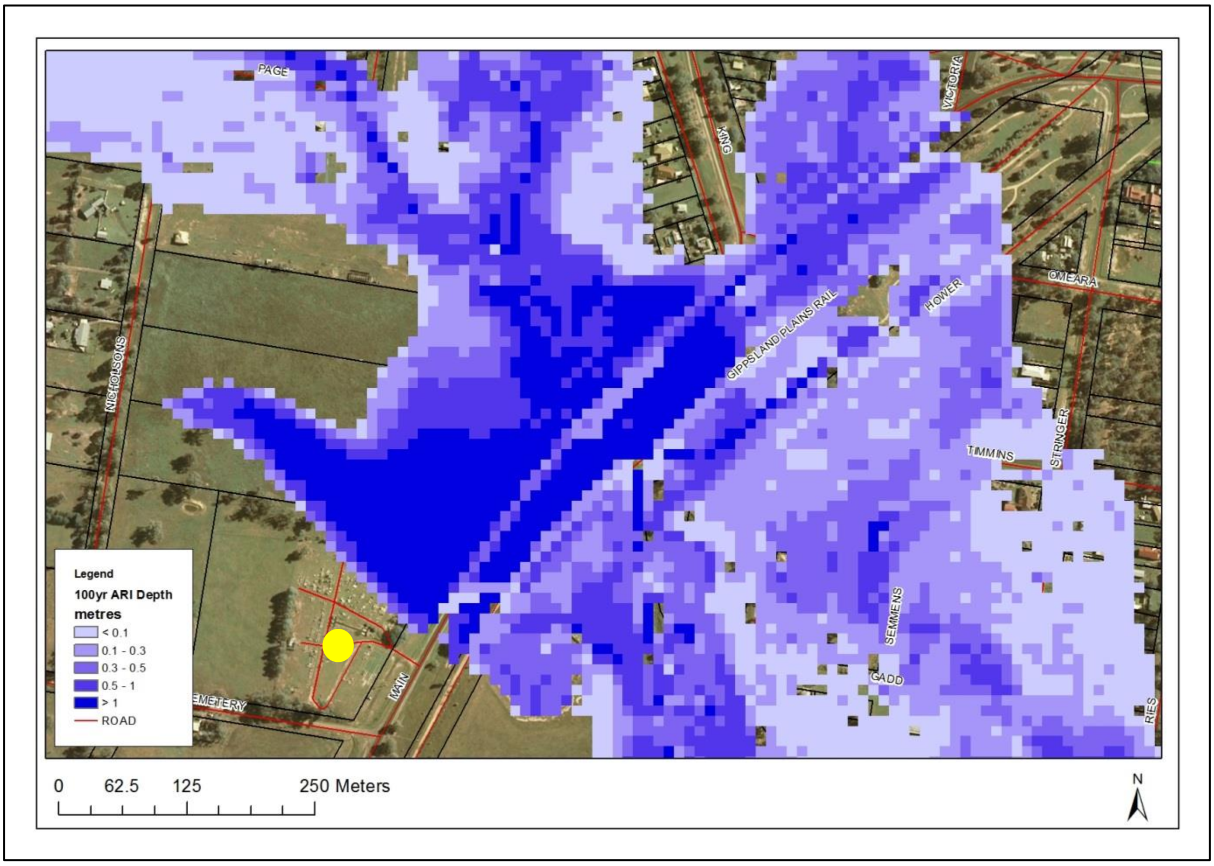

Figure 17 The 100 year ARI flood extent in the vicinity of the entrance to the Township, showing the Traralgon Maffra Road and the location of the cemetery defined by the yellow circle

3.6 Township extent hydraulic model – Rain on grid

Overview

The Township extent model using the direct rainfall method, also known as rain on grid, aims to model flooding in the study area that is not influenced by the designated waterways and tributaries. Rain on grid modelling is an integrated hydrological and hydraulic modelling method that involves directly applying rainfall on the catchment to generate runoff which is then routed downstream across the 2D topography grid.

The focus of this model was to determine the localised flood extents, depths, levels and velocities caused by rainfall during 10, 20, 50, and 100 year ARI storm events.

The rain on grid model was developed using a 2-dimensional component to model the terrain in the study area and a 1-dimensional component to represent the hydraulic structures. The 1D/2D model consisted of four main inputs, which were:

- Topography data
- Roughness coefficient
- Hydraulic structures

- Rainfall Patterns

The study area covers approximately 12 square kilometres, shown in Figure 18.

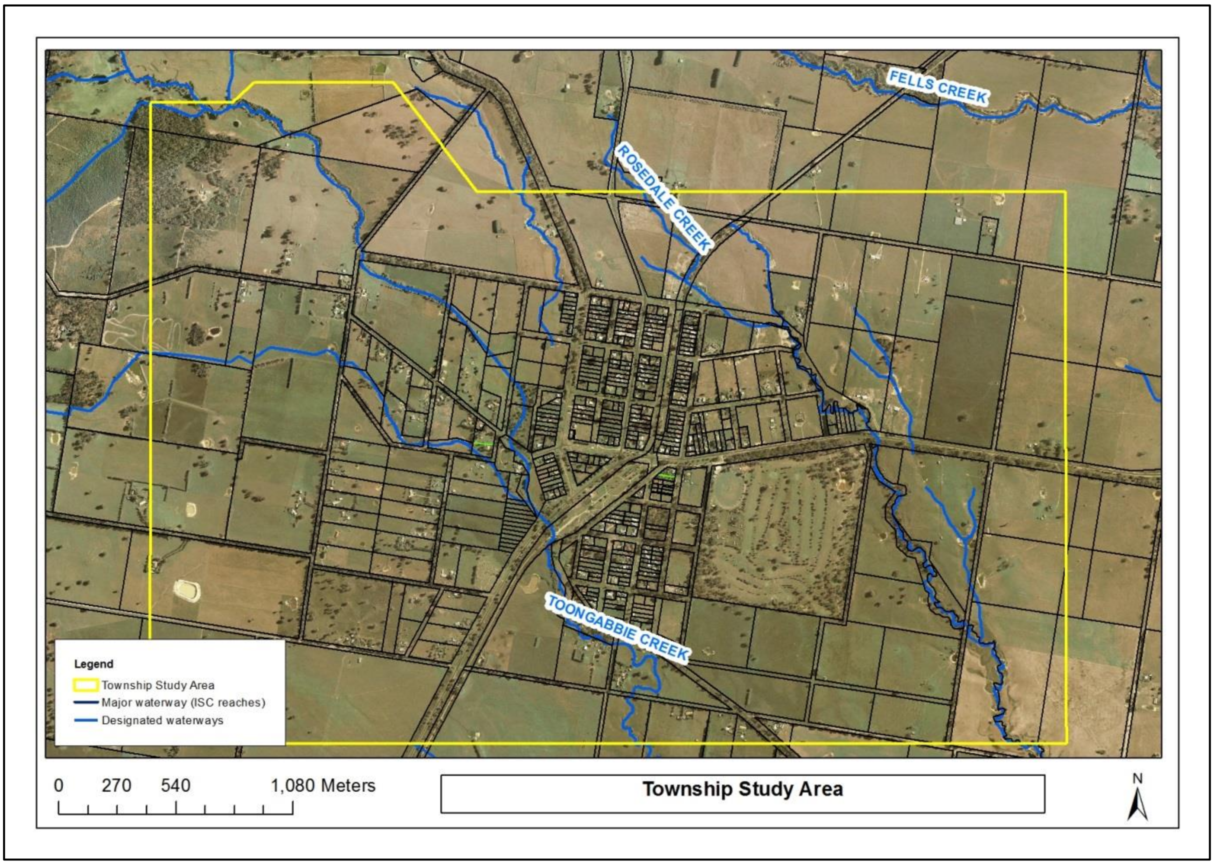

Figure 18 Rain on grid model study area

Topography Data

The two-dimensional component of the rain on grid model is the grid that describes the topography of the area. The topography of the study area was obtained from LiDAR data. The LiDAR data was resampled into a digital elevation model (DEM), which is constructed as a square grid of elevations. A 5 metre grid size was adopted for this model and input into the Sobek program as an asci file. The grid was aligned in a north-south orientation, using a GDA 1994 MGA Zone 55 coordinate projection. Parameters of the Township 2D topography grid are outlined in Table 21.

Table 21 Township topography grid parameters for the rain on grid model

TOPOGRAPHY GRID PARAMETERS	
Parameters	**Value**
Grid Cells Size	5 metre x 5 metre
Grid Cells (x direction)	847 columns
Grid Cells (y direction)	609 rows
Total Grid Cells	515823
Spatial Reference	GDA 1994 Transverse Mercator

Roughness Coefficient

The township roughness values were used to represent the overland flow resistance associated with the different land use types and different vegetation types. Roughness values were assigned to each grid cell of the 2D topography grid, which resulted in a 5 metre by 5 metre roughness grid. The roughness values were defined as Manning's n Roughness values with adopted values shown in Table 22.

The detailed roughness map utilised in the Township extent model using hydrograph flows, shown in Figure 14 was also used for this model.

Table 22 Manning's n values adopted for the rain on grid model

MANNING'S n ROUGHNESS COEFFICIENTS FOR LAND USAGE	
Location	**Value**
Residential – Rural (lower density)- when building footprints and remainder of parcel are modelled together with one roughness value	0.15
Roads / pavement / carparks	0.03
Rail Trail	0.12
Waterway (minimal vegetation)	0.04
Farm/Grassed Areas/Parks	0.04
Moderate vegetation	0.08
Dense vegetation	0.1

Roughness values taken from (Chow, 2014) and (Melbourne Water, 2012(a))

Hydraulic Structures

The hydraulic structures incorporating into the rain on grid model included:

- 3 Bridges
- 5 Culverts
- Underground drainage network consisting of pits and pipes

Bridge and culvert locations and data utilised for the Township extent model using hydrograph inflows, outlined in section 3.5, were also incorporated into this model.

Information on the underground drainage network for Toongabbie was provided by Latrobe City Council. The data included the location, pipe diameters, pit depths and the pit type (side entry or junction pit). A review of the data indicated modifications were needed to ensure the pit and pipe network incorporated into the hydraulic model was functioning as expected. This involved using judgement to ensure the slope of the network was running downhill towards the outflow, as expected.

The street elevation of the pit was also lowered to 0.1 metres below the 2D cells connected to the pit to ensure surface water and runoff enters the pits and pipes. The dimensions for the surface area of the pit were based on the average pit size of 900mm by 600mm.

Pits were modelled as either side entry pits which allow the water to interact with 2D topography grid, or junction pits which didn't allow any interaction between the 2D grid and underground drainage network. Selection of pit types was determined from the information provided by the Latrobe City Council.

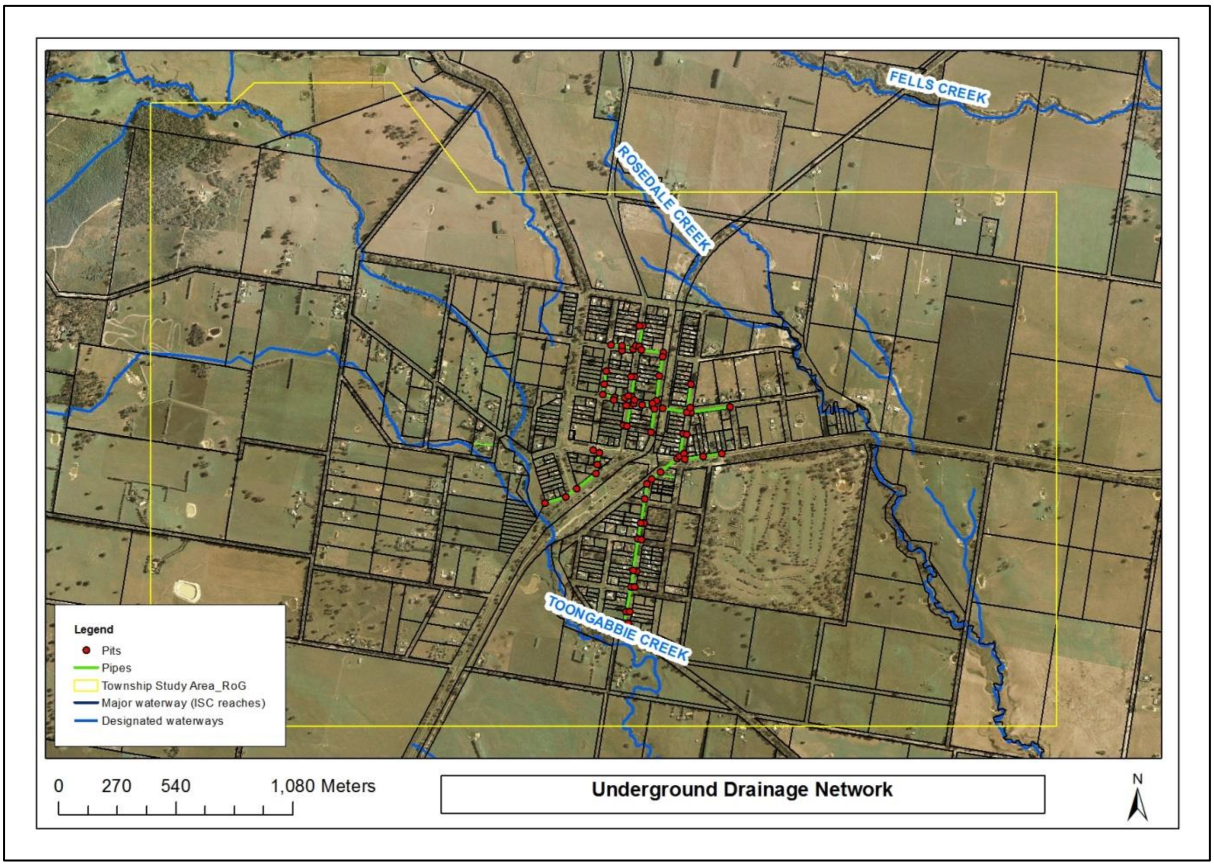

Figure 19 Underground drainage network

Rainfall Events

The estimation of design rainfall patterns are required for rain on grid modelling. The temporal rainfall pattern selected for creating a design rainfall event can have a large effect on estimates of peak flow rates and flood hydrographs.

The ARR technique was adopted for calculating the temporal pattern of design rainfall for this study, which determines the distribution of rainfall over a given duration. For durations greater than 1 hour temporal patterns depend on the zone. The temporal pattern also depends on whether the ARI of the design storm is greater than 30 years, or less than 30 years (Ladson, 2008).

Toongabbie is located in Zone 1, and the Intensity Frequency Duration was determined at the centre of the study area using the Bureau of Meteorology IFD program. Using the ARR(1987) technique from Volume 2, the temporal rainfall patterns were determined for durations of 20, 25, 30, and 45 minutes and 1 hour rainfall events.

The temporal rainfall patterns were then broken down into 1 minute intervals, with the total volume of rainfall for the different durations outlined in Table 23.

Table 23 Total volume of rainfall for the different duration events

Total Volume of Rainfall (mm)				
Duration	**10 year ARI**	**20 year ARI**	**50 year ARI**	**100 year ARI**
20 minutes	20.0	25.0	32.0	38.33
25 minutes	22.08	27.5	35.83	42.5
30 minutes	24.1	30.0	38.5	46
45 minutes	28.65	35.55	45.75	54.75
1 hour	32.1	39.8	51.0	61.0

The initial and continuing loss values adopted for the RORB hydrology model were adopted for the rain on grid model. Which were an initial loss of 12.8mm and a continuing loss of 3.38mm/hr. Initial and continuing losses were deducted from the rainfall pattern before the rainfall was applied to the hydraulic model. The continuing loss was calculated as 0.56mm/minute and was held constant throughout the duration of the storm event.

The range of rainfall durations was applied to the hydraulic model, with peak flow depths, levels and velocities obtained for each duration. These were then used to produce a maximum plot depth, levels and velocities; which were the result of the maximum value from all durations for each grid cell.

Filtering of Results

Rain on Grid hydraulic modelling results in rain falling on every active grid cell within the model, therefore producing flood model results at every cell. Filtering of the results is required to remove any inactive shallow ponding in the model. The Toongabbie Township model results were filtered using the criteria required by Melbourne Water, which are:

1. Minimum Depth Threshold – any flooded cells with depths less than 0.02 metres were removed
2. Velocity x Depth Criteria - any flooded cells where both the depth is less than 0.10 metres and the Velocity x Depth is less than 0.008, were removed

All cells considered as flooded after the removal of cells using the two criteria's are then combined into a flood extent that connects neighbouring cells, with any disconnected flooded areas that are less than 2000 square metres removed.

The purpose of removing small areas of ponding is to remove puddles in backyards that have an insignificant depth. The value of 2000 square metres was determined from the average size of a residential blocks being between 1500 and 2000 square metres. Also the depth of water in these small areas of ponding was less than 0.20 metres; therefore it would have insignificant effect on planning and development in the area.

Model Settings

The adopted simulation time for the model was 1 hour and 30 minutes which was determined based on the rainfall duration and having appropriate run times. A 5 second time-step was used with GIS outputs at 1 minute intervals consisting of the average depth, water surface elevation and velocity produced. GIS data files were also produced for the maximum depth, water surface elevation and velocity that occurs throughout the simulation.

The 1D-2D connection setting used for the modelling of the catchment extent was ‘no embankments’. In this case the interaction of water flow between the 1D components and the 2D grid is that water enters the 2D grid as soon as the channel water level reaches the terrain level in the 2D grid. This setting was based on the fact that only data from one cross-section was used for inputting hydraulic structures and it would be unlikely that the embankment height would remain constant upstream and downstream of the structure. Therefore using this setting, overtopping of the channel banks is dependent on the 2D topography data.

Assumptions

Assumptions made during the development of the Township hydraulic model using rain on grid are as follows:

- Rainfall was applied as a uniform spatial pattern across the topography grid
- The topography of the area has minimal changes in elevation over 5 square metres
- The duration of rainfall events in Toongabbie is likely to be relatively short and range between 20 minutes and 1 hour
- The rainfall is likely to reach its peak depth within one and a half hours of all rainfall events for all durations
- The initial loss and continuing loss values adopted from the RORB model are appropriate to be used for a rain on grid model
- The continuing loss remains constant during the rainfall event
- It is assumed the study area is dry before the rainfall event occurs.

Sensitivity analysis

Sensitivity analysis was applied to the rain on grid model by modelling the effects of the ground being wet before a rainfall event. Considering the losses are subtracted from the rainfall before it is applied to the model, to simulate the ground surface being wet a reduced infiltration was assumed. This was modelled by applying a 10% reduction in the continuing loss constantly over the duration of the rainfall event. The reduction in continuing loss resulted in a significant increase in areas likely to be affected by localised flooding. The results indicate that the model is very sensitive to changes in the rainfall and the loss applied to the model, therefore further work is required to determine the most appropriate losses to be used for this type of modelling.

Results

The results obtained from the Toongabbie Township extent hydraulic model using the rain on grid method determined localised flood behaviour within the Township during the 10, 20, 50 and 100 year ARI flood events. The 2-dimensional overland flow results are recorded as depths (metres), surface water elevation (metres AHD), and velocities (m/s) for every grid cell at regular time intervals. Results of mapping of flood extents for all ARI flood events for the rain on grid model are shown in Appendix F3. Results of flood surface water levels, depths and velocities for all ARI flood events for the rain on grid model are shown in Appendix G3, Appendix H3 and Appendix I3 respectively.

The flood extent during a 100 year ARI rainfall event is shown in Figure 20, which identifies areas likely to be effected by localised flooding in large rainfall events in the Township area. Review of the underground drainage network also showed that a number of pits would become completely full and back fill onto the streets during a 100 year rainfall event. This is shown in Figure 21, with the green line in the schematisation representing the street level and the blue line representing the water level, the vertical lines represent the pits.

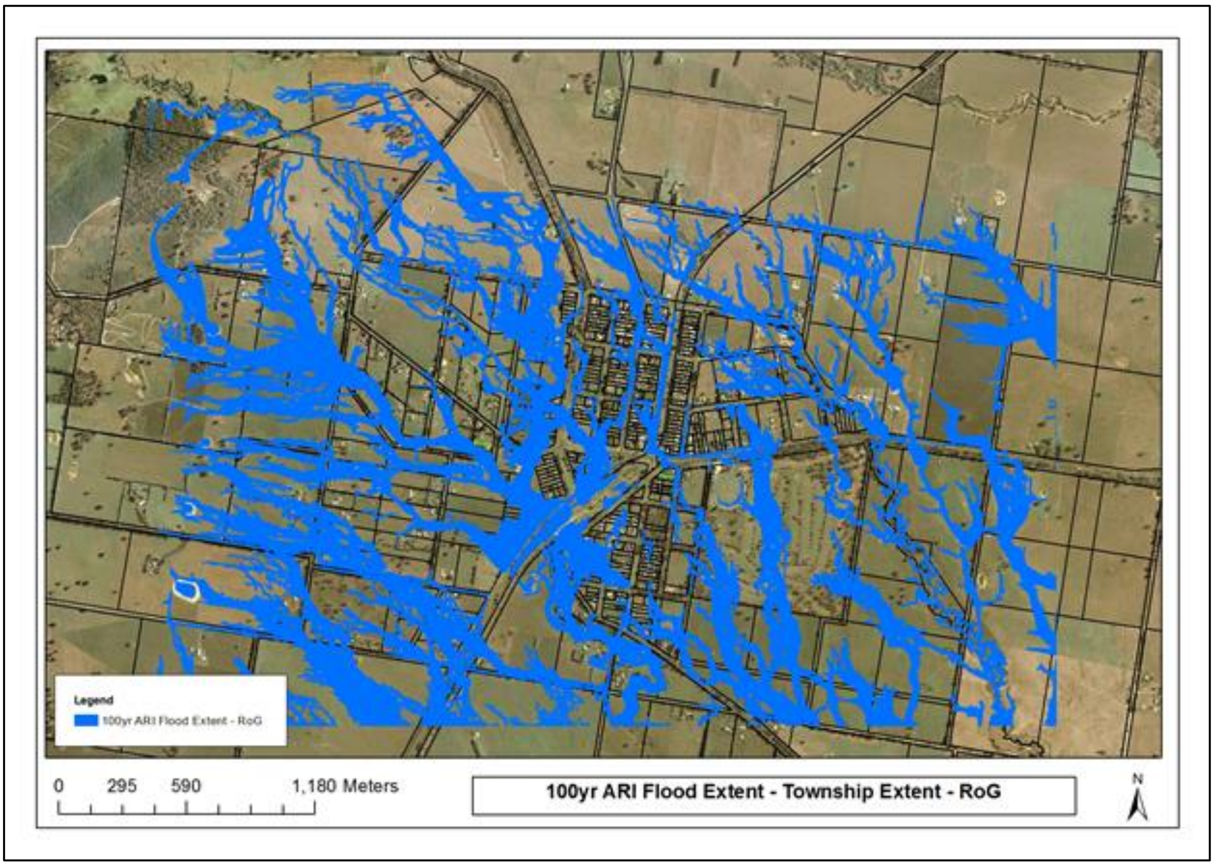

Figure 20 100yr ARI flood extent using rain on grid modelling

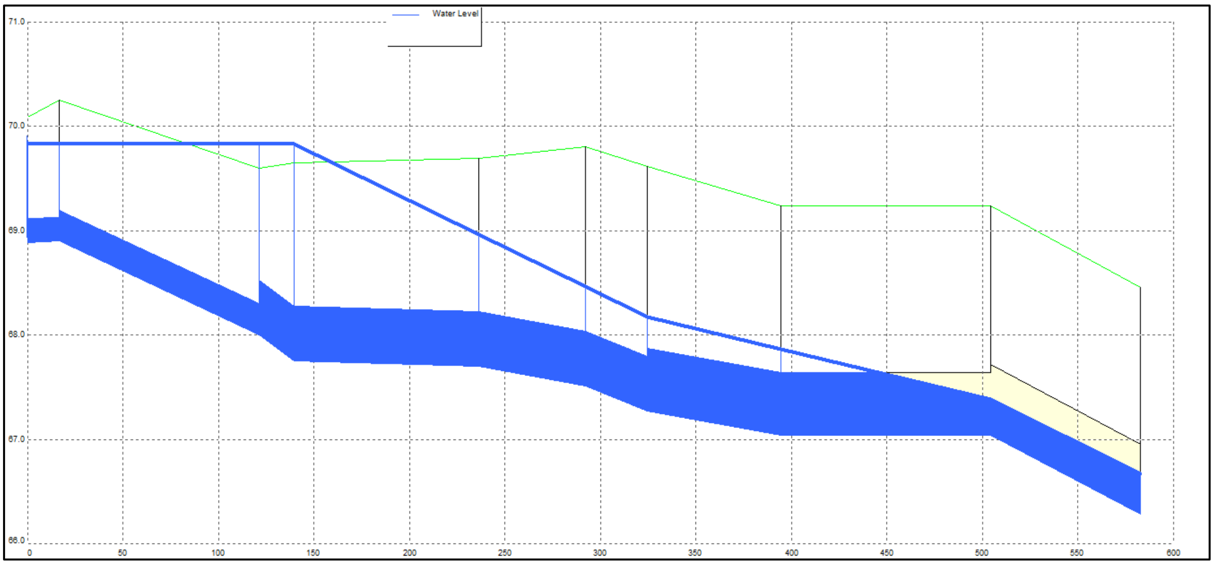

Figure 21 A section of the underground drainage network, indicating storm water from two pits is likely to spill into the street

The flood extent produced from the rain on grid hydraulic model was compared to aerial flood photograph taken during the 1995 flood event. The photo shown in identifies localised flooding in the town area, comparing the extent of localised flooding with the 100 year ARI model output shown in Figure 23 shows the extent produced by the hydraulic model is larger however the size of the 1995 flood event is unknown. The yellow circle on both Figures identifies localised flooding occurring around the perimeter of the cricket oval. The red circle on both Figures identifies localised flooding on vacant land.

Figure 22 1995 Flood Event - Looking south over Toongabbie towards Toongabbie Creek , with Toongabbie store in bottom left and fire station in centre left of photo

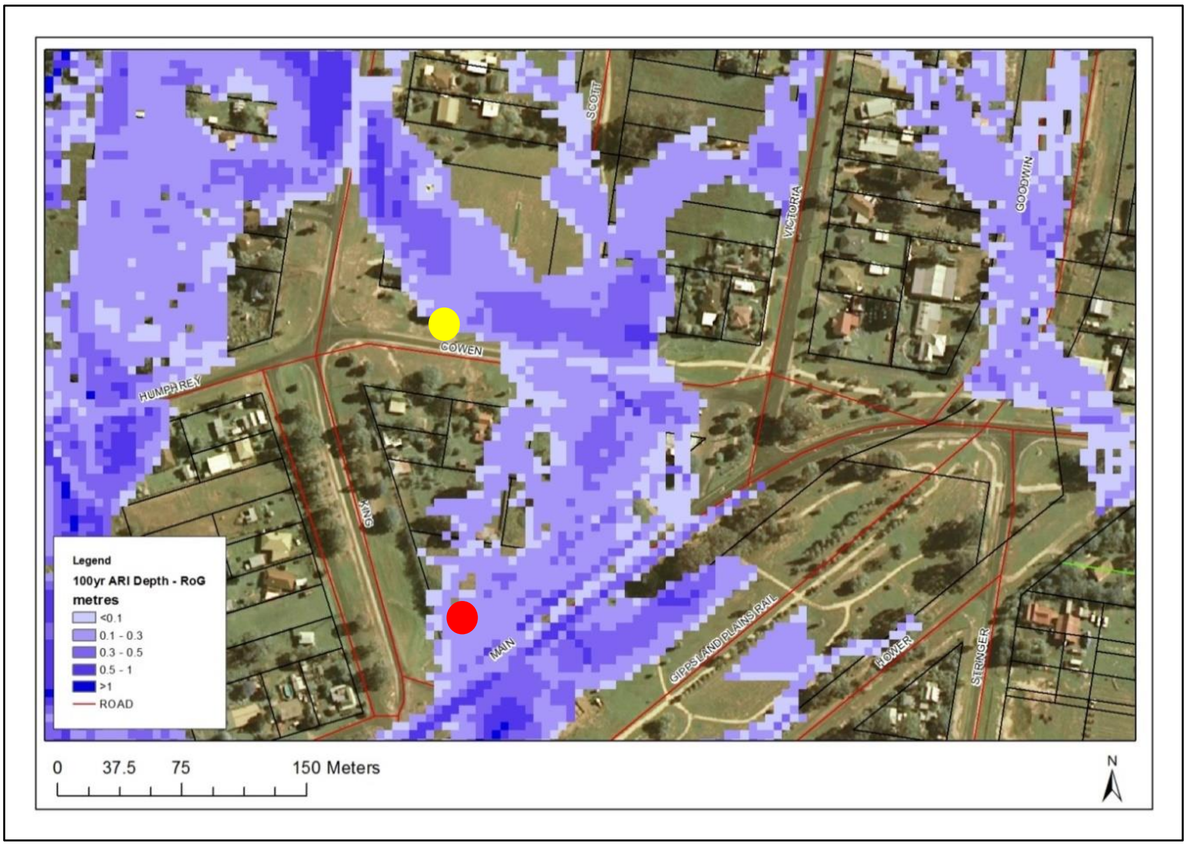

Figure 23 Localised flooding for a 100 yr ARI flood event in the township

3.7 Summary of hydraulics results

The hydraulic modelling of the Toongabbie catchment extent and the Township extent indicate that the Toongabbie Township is highly prone to localised flooding and riverine based flooding from the Toongabbie Creek and the Rosedale Creek, with all results shown in Appendix F to Appendix I.

Using the two different modelling approaches for the Township extent model, hydrograph inflows and rain on grid, identified that they both have disadvantages and advantages and parameter selection is a key to the accuracy and reliability of both models.

The main advantages to rain on grid modelling are:

- It allows the ability to provide flood extents for the whole study area where as the traditional approach only shows flood extents starting at a point where a flow hydrograph can be generated
- It can minimise hydrological and hydraulic assumptions as all routing is completed in the hydraulic model. This allows flows to be based on the topography of the area
- Models are relatively quick to set up

The major disadvantages of using rain on grid modelling are:

- It can increase simulation run times which can be due to the higher resolution grid size
- There is little guidance and previous work on parameter selections

4 Conclusion and Recommendations

4.1 Conclusion

The Toongabbie catchment area and township floodplain mapping provides an analysis and review of existing and future potential flood risks in the Township.

The resulting flood extent for the Township obtained from this study identifies a larger number of residential housing blocks are likely to be inundated by flood waters in comparison to the current Flood Overlays and Land Subject to Inundation Overlays applied to the area.

Key outcomes from the study identify that the main area of flooding in the catchment occurs in the Toongabbie Township. Also, the township is likely to be subjected to flooding to some degree in all magnitude ARI flood events, with the main egress route to Traralgon along the Traralgon-Maffra Road likely to be inundated by flood waters in large flood events.

This study has identified the need for appropriate floodplain management in the Toongabbie Township to ensure appropriate planning and development occurs due to the high risk of flooding.

4.2 Recommendations

Following this initial investigation into floodplain mapping of the Toongabbie catchment area and township it is recommended that:

- A higher degree of sensitivity analysis is undertaken on parameters used in hydraulic model
- The implementation of bridge structures in the hydraulic model needs further investigated to ensure accurate representation and to improve on the smoothness between the interaction of the 2D topography grid and the inflow and outflow from the hydraulic structures. As smoothness of the interaction between the 2D and 1D components was achieved by adjusting the inverts of bridges and culverts so they correspond with the 2D grid, as the survey data and LiDAR did not correspond.
- Analyses of the flood extent, depth and velocity when the system is wet by applying rainfall to the grid before the design storms are simulated
- Further investigation into parameter selection for the rain on grid modelling
- Investigation into the likelihood of a given rainfall event occurring at the same time as a given riverine flood event

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Appendix A: Preliminary data collection

Flood Photography in the Toongabbie Area

Figure 24 - 1995 Flood Event (Cemetery centre left)

Figure 25 - 1995 Flood Event - South edge of Toongabbie Township with cemetery in top right of photo

Figure 26 - 1995 Flood Event - Looking west from east side of town showing cemetery in top left of photo

Figure 27 - 1995 Flood Event - Looking north east from Traralgon side showing cemetery in foreground

Figure 28 - 1995 Flood Event - South side of Toongabbie Township showing the Traralgon Maffra Rd inundated with flood waters

Figure 29 - 1995 Flood Event - Looking south over Toongabbie towards Toongabbie Creek , with Toongabbie store in bottom left corner and fire station in centre left of photo

Figure 30 2007 Flood

Figure 31 4th Nov 2007

Figure 32 Toongabbie entrance left 4th Nov 2007

Table 24 Intensity Frequency Duration Table for Toongabbie

DURATION	1 Year	2 years	5 years	10 years	20 years	50 years	100 years
5Mins	44.7	61.2	90	111	138	180	215
6Mins	41.8	57.2	84	103	129	167	200
10Mins	34	46.5	68	83.6	104	135	161
20Mins	24.5	33.5	48.9	60.1	74.8	96.7	116
30Mins	19.8	27	39.4	48.3	60.1	77.6	92.7
1Hr	13.3	18.1	26.2	31.9	39.5	50.7	60.3
2Hrs	8.83	11.9	16.8	20.2	24.7	31.2	36.8
3Hrs	6.92	9.24	12.8	15.2	18.4	23.1	27
6Hrs	4.55	5.99	8	9.35	11.1	13.7	15.8
12Hrs	2.98	3.89	5.06	5.83	6.87	8.33	9.51
24Hrs	1.91	2.49	3.24	3.73	4.39	5.32	6.06
48Hrs	1.18	1.55	2.04	2.37	2.81	3.43	3.94
72Hrs	0.871	1.14	1.51	1.75	2.08	2.54	2.91

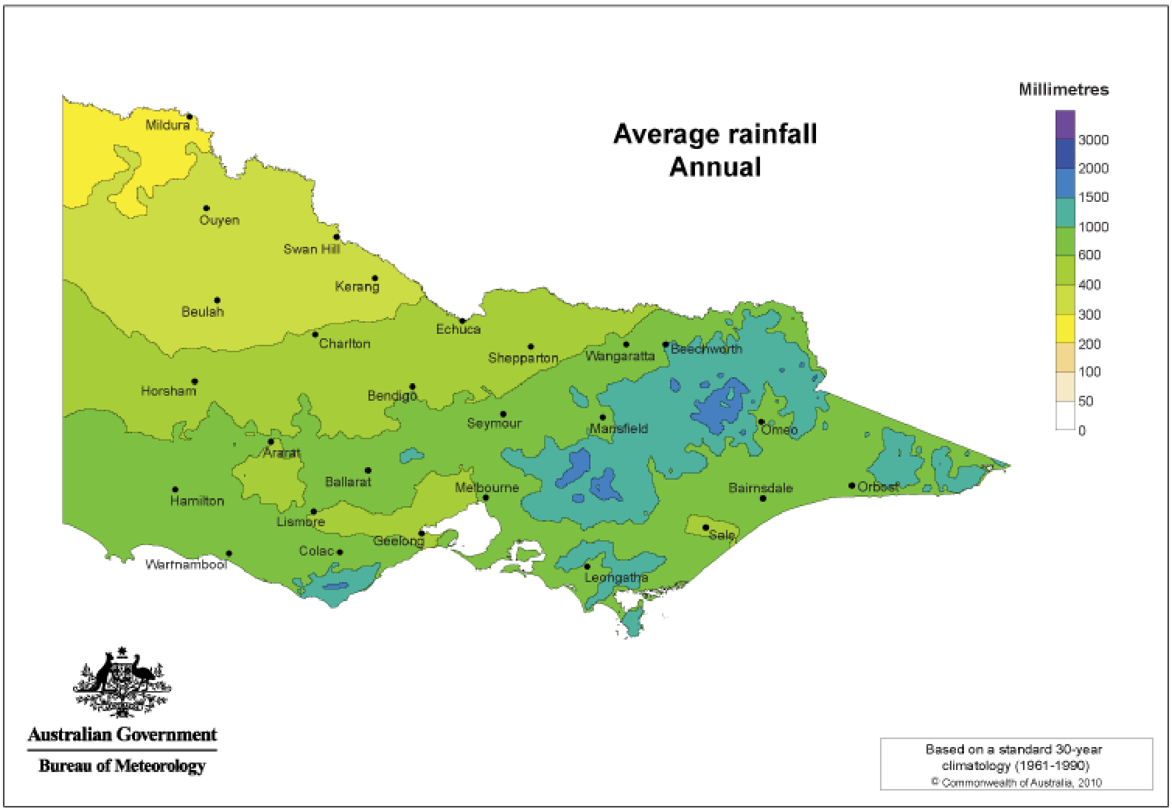

Figure 33 - Annual average rainfall bands across Victoria (BoM, 2015).

Figure 34 Zones for temporal patterns in Australia

Appendix B: Hydrologic model input data

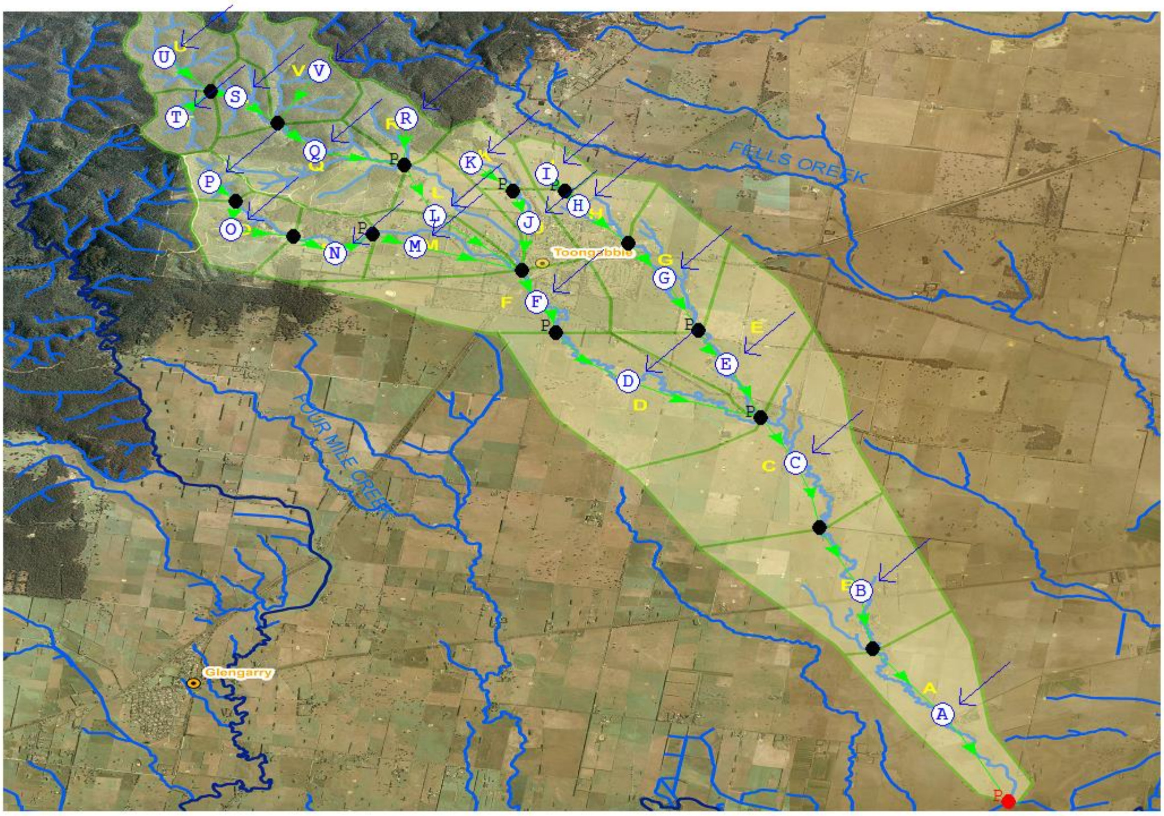

Figure 35 RORB model graphical representation

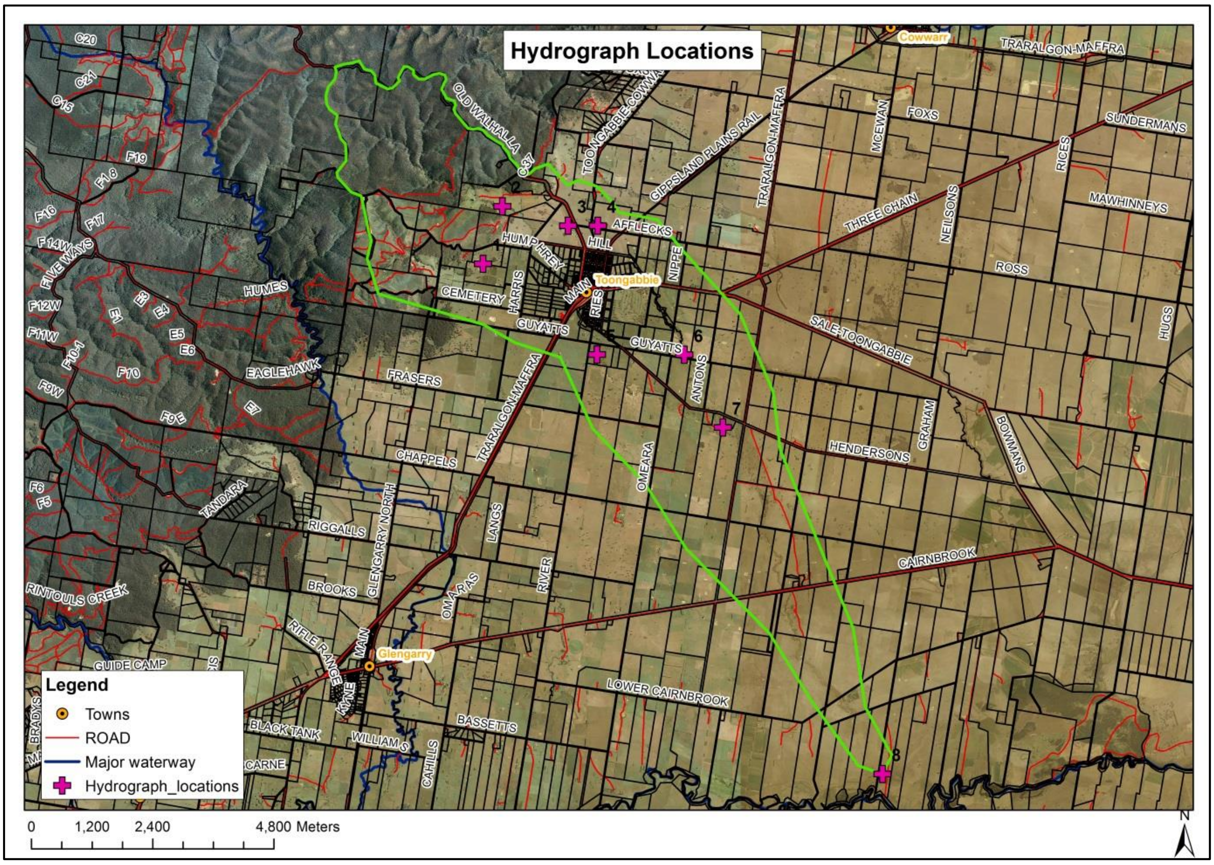

Figure 36 Location of hydrographs obtained from RORB model

Table 25 Hydrograph 1 flow estimations

Location 1 Flow estimates						
ARI (Y)	CY	1987 IFD Q (m^{3}s^{-1})	2013 IFD Q (m^{3}s^{-1})	RORB	Zaman	Nikolaou + von't Steen
2	0.098	1.60	1.36	4.76	1.43	
5	0.117	2.75	2.38	7.46	4.67	
10	0.130	3.72	3.26	9.33	9.11	
20	0.143	5.04	4.30	12.62	13.82	
50	0.156	7.03	5.82	18.46	23.75	
100	0.169	9.02	7.32	24.41	34.36	12.57

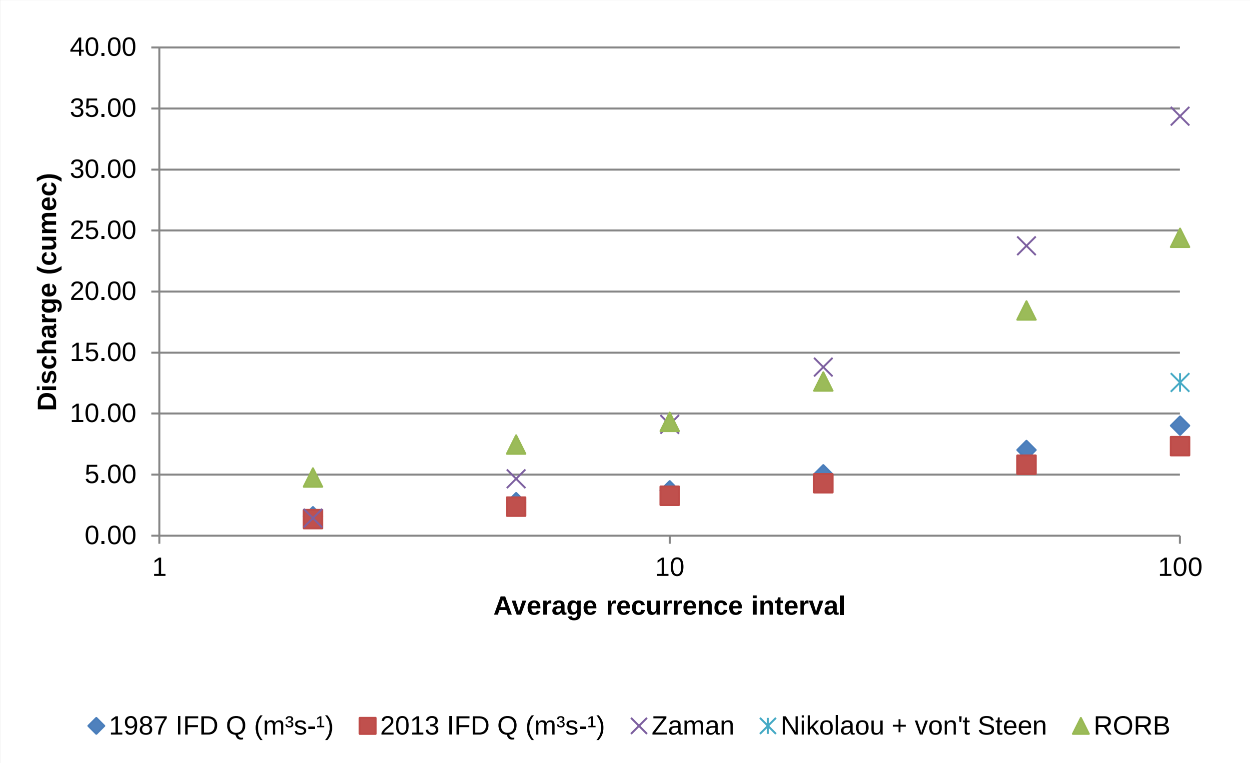

Figure 37 Plot of flow estimations for catchment 1

Table 26 Hydrograph 2 flow estimations

Location 2 Flow estimates						
ARI (Y)	CY	1987 IFD Q (m^3s^{-1})	2013 IFD Q (m^3s^{-1})	RORB	Zaman	Nikolaou + von't Steen
2	0.098	3.06	3.11	8.65	2.54	
5	0.117	5.20	5.35	14.21	8.08	
10	0.130	6.96	7.32	19.00	15.40	
20	0.143	9.38	9.67	25.02	22.97	
50	0.156	12.98	13.08	32.37	38.47	
100	0.169	16.57	16.48	42.59	54.54	24.16

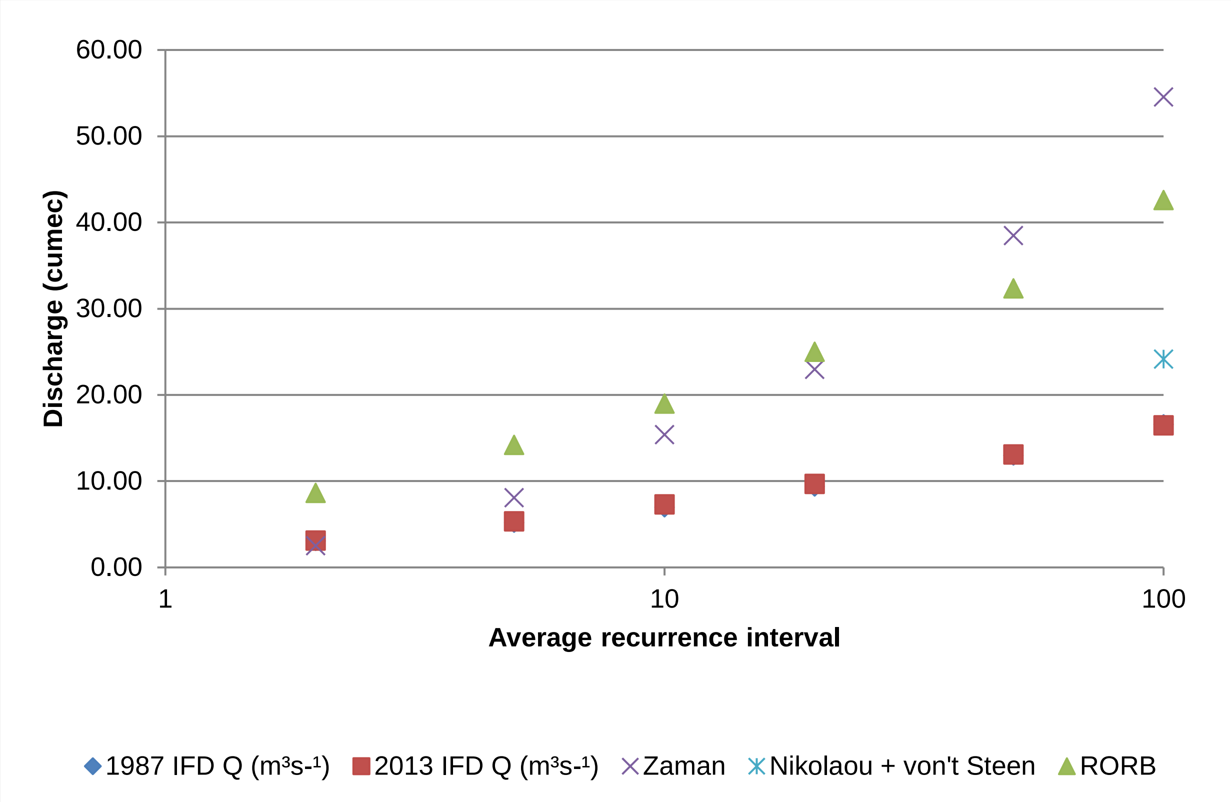

Figure 38 Plot of flow estimations for catchment 2

Table 27 Hydrograph 3 flow estimations

Catchment 3 Flow Estimations						
ARI (Y)	CY	1987 IFD Q (m^3s^{-1})	2013 IFD Q (m^3s^{-1})	RORB	Zaman	Nikolaou + von't Steen
2	0.098	0.55	0.57	2.04	0.56	
5	0.117	0.96	1.00	3.04	1.89	
10	0.130	1.30	1.38	4.00	3.81	
20	0.143	1.78	1.82	6.63	5.91	
50	0.156	2.50	2.48	9.45	10.49	
100	0.169	3.23	3.12	12.33	15.60	4.20

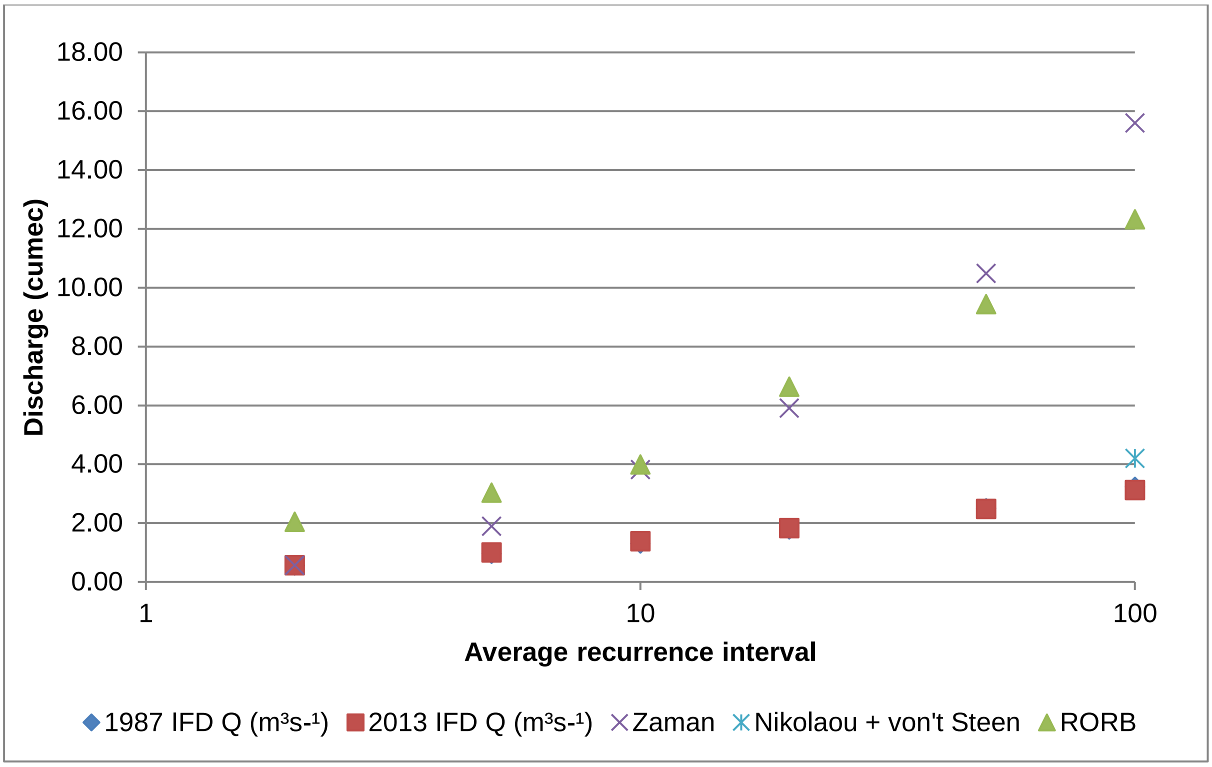

Figure 39 Plot of flow estimations for catchment 3

Table 28 Hydrograph 4 flow estimations

Location 4 Flow Estimation						
ARI (Y)	CY	1987 IFD Q (m^3s^{-1})	2013 IFD Q (m^3s^{-1})	RORB	Zaman	Nikolaou + von't Steen
2	0.098	0.55	0.42	1.15	0.61	
5	0.117	0.96	0.74	1.99	2.08	
10	0.130	1.30	1.02	3.05	4.14	
20	0.143	1.78	1.36	4.96	6.51	
50	0.156	2.50	1.84	6.92	11.60	
100	0.169	3.23	2.33	9.04	17.30	3.86

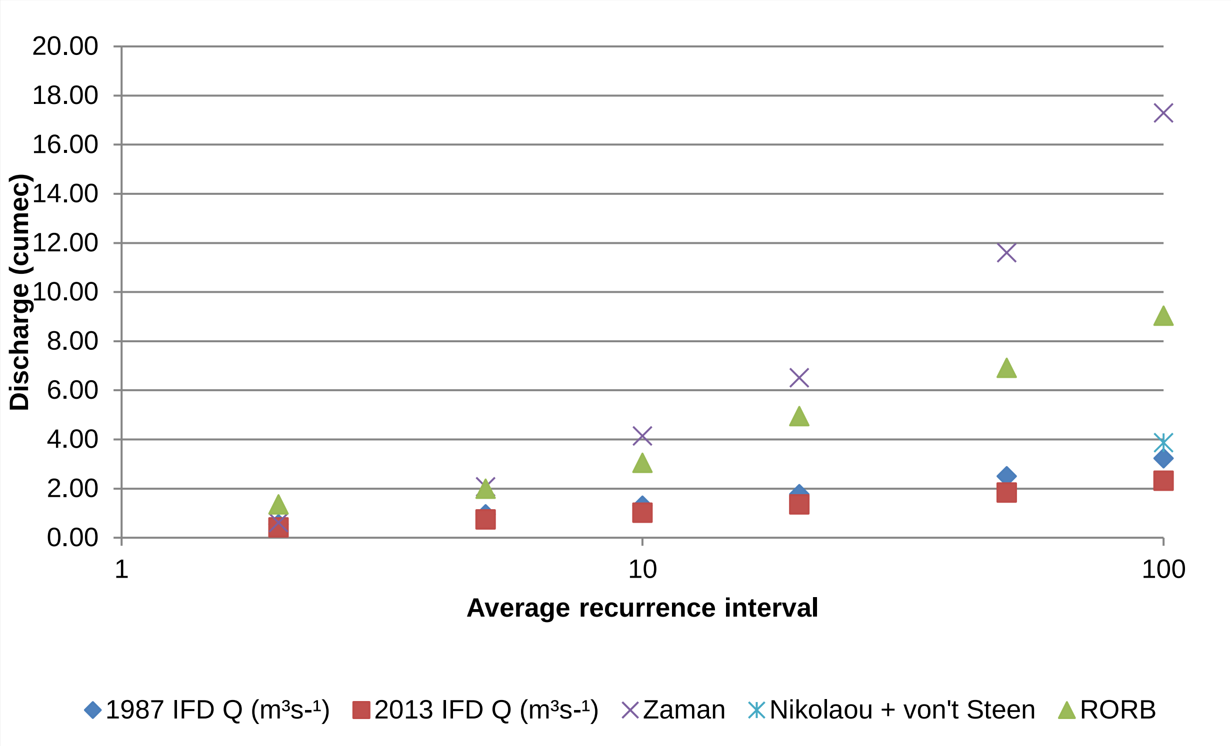

Figure 40 Plot of flow estimations for catchment 4

Table 29 Hydrograph 5 flow estimations

Location 5 - D/S Toongabbie Creek						
ARI (Y)	CY	1987 IFD Q (m^3s^{-1})	2013 IFD Q (m^3s^{-1})	RORB	Zaman	Nikolaou + von't Steen
2	0.098	5.77	5.18	10.46	4.52	
5	0.117	9.65	8.93	17.55	13.95	
10	0.130	12.83	12.21	23.41	25.91	
20	0.143	17.18	16.12	32.45	38.04	
50	0.156	23.59	21.82	43.72	62.11	
100	0.169	29.95	27.48	55.72	86.26	45.34

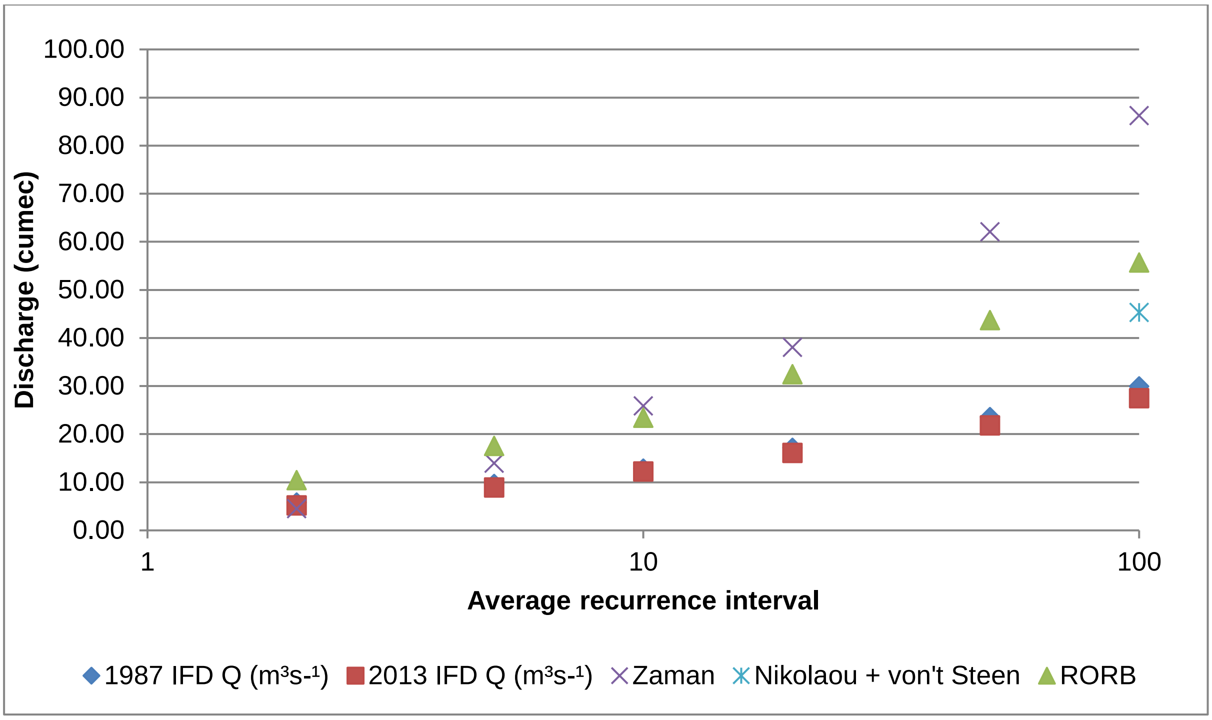

Figure 41 Plot of flow estimations down stream of Toongabie Creek

Table 30 Hydrograph 6 flow estimations

Location 6 - D/S Rosedale Creek						
ARI (Y)	CY	1987 IFD Q (m^3s^{-1})	2013 IFD Q (m^3s^{-1})	RORB	Zaman	Nikolaou + von't Steen
2	0.098	1.92	1.72	5.31	1.65	
5	0.117	3.29	2.99	8.58	5.37	
10	0.130	4.43	4.09	11.17	10.46	
20	0.143	6.01	5.39	14.48	15.78	
50	0.156	8.37	7.30	20.02	26.98	
100	0.169	10.73	9.16	26.05	38.86	15.24

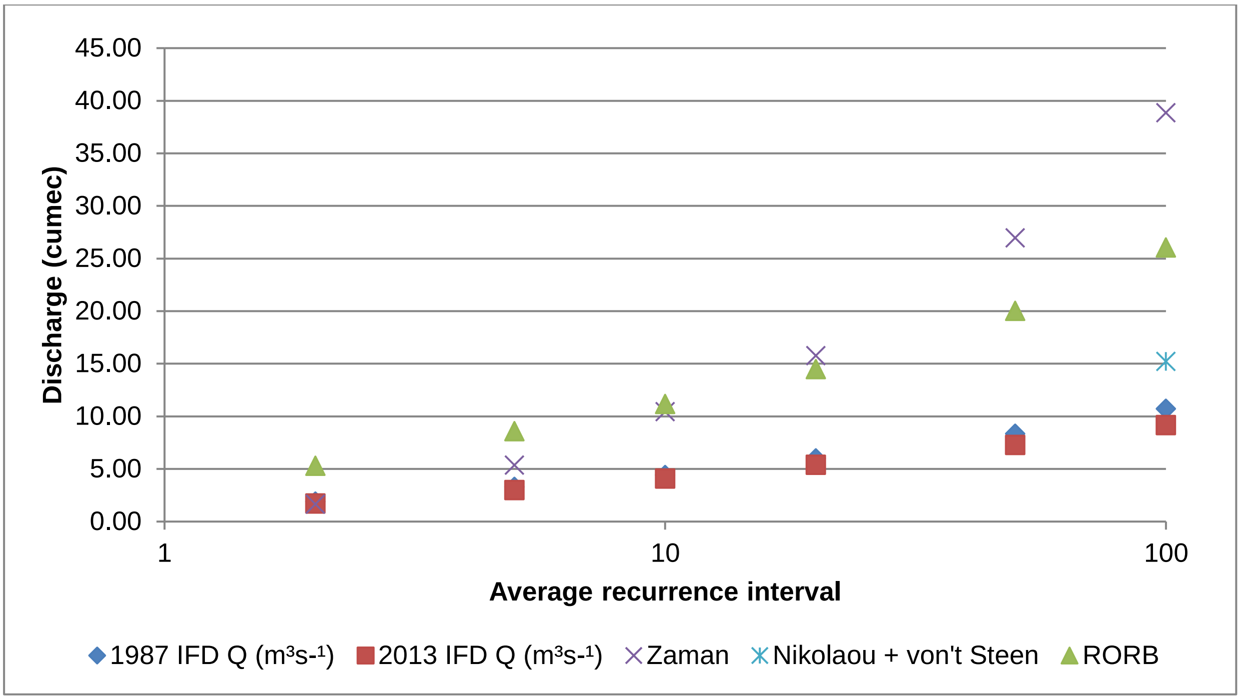

Figure 42 Plot of flow estimations down stream of Rosedale Creek

Table 31 Hydrograph 7 flow estimations

Location 7 - Confluence of Toongabbie Creek and Rosedale Creek						
ARI (Y)	CY	1987 IFD Q (m^3s^{-1})	2013 IFD Q (m^3s^{-1})	RORB	Zaman	Nikolaou + von't Steen
2	0.098	8.27	7.13	12.09	6.19	
5	0.117	13.74	12.11	20.78	18.85	
10	0.130	18.19	16.38	28.76	34.57	
20	0.143	24.28	21.46	40.78	50.26	
50	0.156	33.21	28.73	53.81	81.01	
100	0.169	42.05	35.98	68.25	111.24	65.48

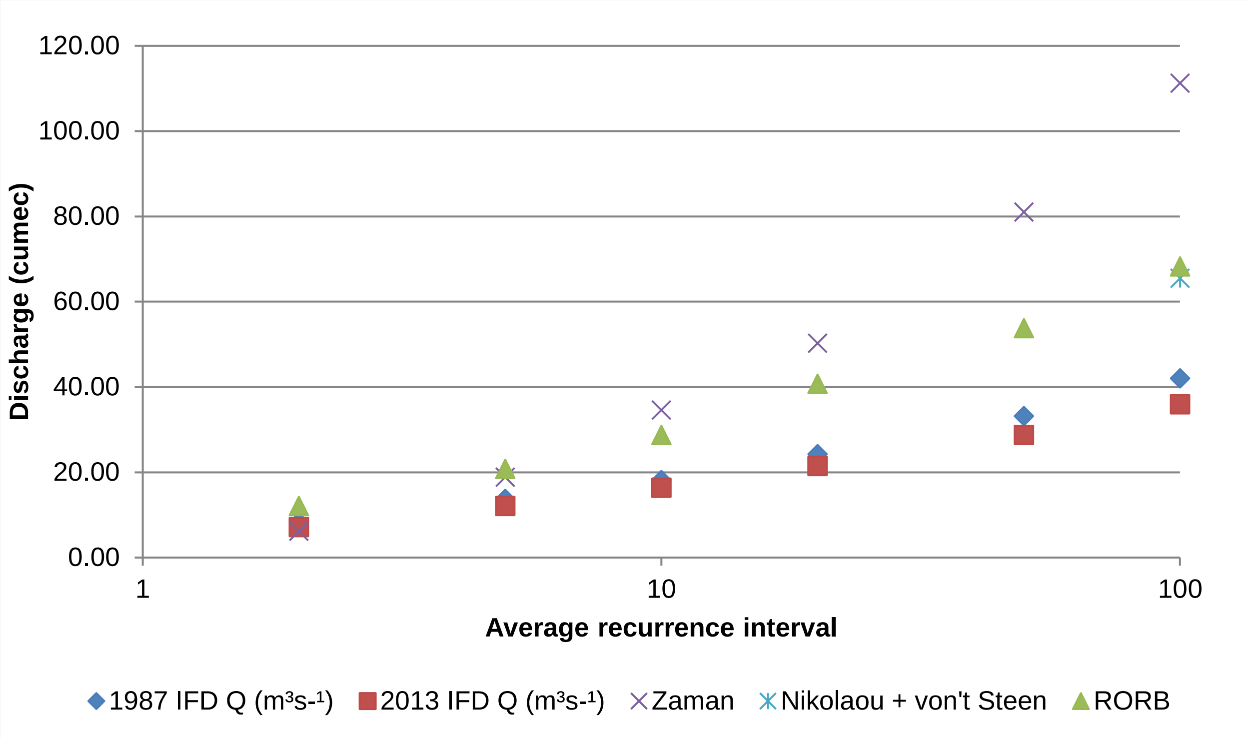

Figure 43 Plot of flow estimates at the confluence of Toongabie and Rosedale creek

Table 32 Catchment outlet flow estimations

Location 8 - Catchment Outlet Flow Estimations						
ARI (Y)	CY	1987 IFD Q (m^3s^{-1})	2013 IFD Q (m^3s^{-1})	RORB	Zaman	Nikolaou + von't Steen
2	0.098	10.49	8.85	11.91	7.42	
5	0.117	17.42	14.98	22.07	22.54	
10	0.130	23.04	20.23	32.00	41.25	
20	0.143	30.70	26.41	46.34	59.53	
50	0.156	41.97	35.35	61.80	95.39	
100	0.169	53.14	44.14	80.40	130.48	85.42

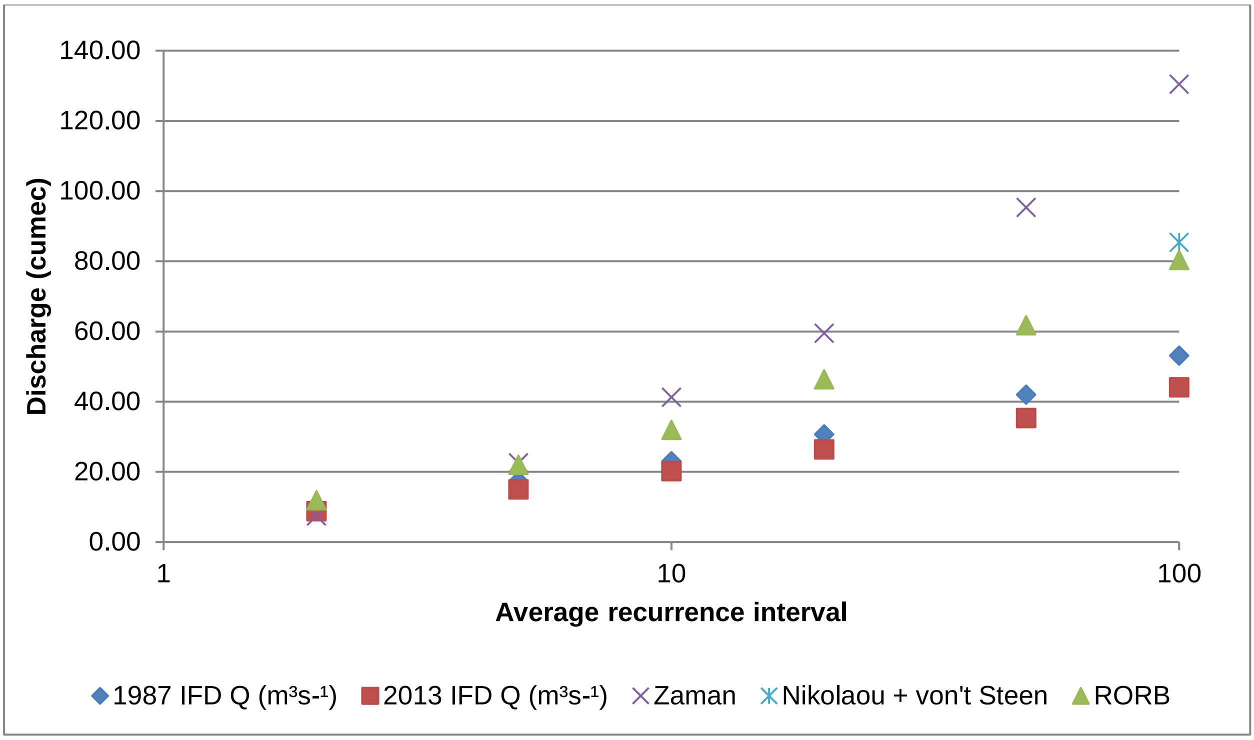

Figure 44 Plot of catchment outlet flow estimations

Toongabbie RORB Model Parameters

Main Stream length (Toongabbie Creek) = 27.232km

21 Sub-catchments

Table 33 RORB model sub area parameters

Sub-Area	Area (km²)	Fraction Impervious
A	3.268	0.000
B	4.466	0.000
C	5.534	0.000
D	4.407	0.000
E	3.062	0.000
F	2.891	0.000
G	2.844	0.000
H	1.278	0.000
I	0.573	0.000
J	0.855	0.000
K	0.926	0.000
L	1.293	0.000
M	1.666	0.000
N	1.323	0.000
O	1.404	0.000
P	0.523	0.000
Q	2.746	0.000

R	1.026	0.000
S	0.782	0.000

Table 34 RORB model reach parameters

Reach Number	Reach Type	Length (km)	Slope (%)
1	1. Natural	2.293	0.000
2	1. Natural	2.349	0.000
3	1. Natural	2.203	0.000
4	1. Natural	1.382	0.000
5	1. Natural	3.432	0.000
6	1. Natural	0.287	0.000
7	1. Natural	2.949	0.000
8	1. Natural	2.438	0.000
9	1. Natural	2.161	0.000
10	1. Natural	0.270	0.000
11	1. Natural	2.949	0.000
12	1. Natural	2.438	0.000
13	1. Natural	1.857	0.000
14	1. Natural	0.520	0.000
15	1. Natural	0.837	0.000
16	1. Natural	0.762	0.000
17	1. Natural	0.483	0.000
18	1. Natural	0.917	0.000
19	1. Natural	0.917	0.000
20	1. Natural	0.679	0.000
21	1. Natural	1.396	0.000
22	1. Natural	1.280	0.000
23	1. Natural	1.260	0.000
24	1. Natural	0.931	0.000
25	1. Natural	1.020	0.000
26	1. Natural	0.332	0.000
27	1. Natural	0.545	0.000
28	1. Natural	0.471	0.000
29	1. Natural	0.504	0.000
30	1. Natural	1.337	0.000
31	1. Natural	1.028	0.000
32	1. Natural	0.907	0.000
33	1. Natural	1.089	0.000
34	1. Natural	0.549	0.000
35	1. Natural	0.598	0.000
36	1. Natural	1.050	0.000
37	1. Natural	1.089	0.000

Total Area of catchment: 45.113km^2

Time of concentration (Adams equation): 3.23 hrs

	Location	Area (km^2)	Tc (Adams Equation) hrs	Coordinates
1	Catchment 1	3.66	1.24	463695.96 E 5788059.18 N 38.050 S 146.575 E
2	Catchment 2	8.62	1.72	463814.34 E 5790150.53 N 38.025 S 146.60 E
3	Catchment 3	0.87	0.72	466293.71 E 5789433.68 N 38.050 S 146.625 E
4	Catchment 4	0.78	0.69	467082.9 E 5789269.27 N 38.050 S 146.625 E
5	D/S Township on Toongabbie creek	19.67	2.36	464791.32 E 5789063.07 N 38.050 S 146.6 E
6	D/S Township on Rosedale creek	4.712	1.37	467923.99 E 5787877.73 N 38.050 S 146.625 E
7	Confluence of Toongabbie Creek and Rosedale Creek	31.841	2.83	466272.99 E 5788089.4 N 38.050 S 146.625 E
8	Catchment Outlet	45.113	3.23	467381.52 E 5784892.19 N 38.075 S 146.625 E

Appendix C: Output data from hydrologic model

RORBWin Batch Run Summary

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Program version 6.15 (last updated 30th March 2010)

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Rainfall location: Toongabbie

Temporal pattern : AR&R87 Volume 2 for zone 1 (unfiltered)

Spatial pattern : Uniform

Areal Red. Fact. : Based on Siriwardena and Weinmann formulation

Loss factors : Constant with ARI

Parameters: kc = 14.27 m = 0.80

Loss parameters Initial loss (mm) Cont. loss (mm/h)

12.80 3.38

Table 35 Critical Durations for Hydrograph Locations

Critical Duration and flows for the different ARI storm events and locations												
Run	Dur	ARI	Rain (mm)	Peak1 (m^3/s)	Peak2 (m^3/s)	Peak3 (m^3/s)	Peak4 (m^3/s)	Peak5 (m^3/s)	Peak6 (m^3/s)	Peak7 (m^3/s)	Peak8 (m^3/s)	Peak9 – Catchment Outlet (m^3/s)
1	30m	2y	13.5	0.3108	0.7839	0.2921	0.4062	0.228	0.389	0.7468	0.5537	0.3597
2	45m	2y	16.11	1.1083	2.4782	0.8629	1.4958	0.6414	1.2842	2.5222	1.8188	1.3324
3	1h	2y	18.13	1.6324	3.2835	1.1011	2.2048	0.821	1.786	3.5748	2.4848	2.037
4	1.5h	2y	21.3	2.3196	4.0803	1.1869	3.2849	0.8634	2.3952	4.9668	3.5868	3.1227
5	2h	2y	23.79	2.8289	4.7508	1.3873	4.187	0.9757	2.9413	6.1048	4.5782	4.0019
6	3h	2y	27.72	2.7831	4.7697	1.2862	4.816	0.8743	2.9709	6.5487	5.2996	4.9139
7	4.5h	2y	32.27	2.8801	5.4163	1.5313	5.9228	1.0504	3.2401	7.3518	6.5965	6.1445
8	6h	2y	35.95	3.6834	6.4417	1.5765	6.9839	1.0924	3.9774	8.5269	7.8257	7.2964
9	9h	2y	41.89	4.762	8.6451	2.0424	9.1318	1.3625	5.3146	11.8949	10.2103	9.5028
10	12h	2y	46.71	4.2796	7.7149	1.668	10.455	1.1479	4.7022	12.0852	12.4382	11.9114
11	18h	2y	54	2.5029	5.2408	0.8297	8.3592	0.545	2.8213	9.5274	10.3462	9.7922
12	24h	2y	59.71	3.691	7.3899	1.1905	8.5501	0.7361	4.3401	10.0316	9.7546	9.5013
13	30h	2y	64.37	2.1807	4.8734	0.634	6.8707	0.4296	2.7868	9.8213	9.7051	9.4859
14	36h	2y	68.27	2.7624	6.0881	0.7875	8.1195	0.476	3.4639	9.3713	10.5899	10.2029

15	48h	2y	74.4	2.4	5.3387	0.8996	8.0184	0.5854	2.9239	10.1146	9.9944	9.8105
16	30m	5y	19.66	0.9043	2.1986	0.7947	1.22	0.6057	1.1122	2.1507	1.5807	1.0742
17	45m	5y	23.38	2.4371	5.174	1.7307	3.297	1.2801	2.7444	5.4688	3.8676	3.1664
18	1h	5y	26.27	3.5022	6.5107	2.1026	4.7976	1.5336	3.6916	7.5351	5.2393	4.7109
19	1.5h	5y	30.32	4.5952	7.7604	2.1626	6.9253	1.5767	4.775	9.9738	7.5765	6.8991
20	2h	5y	33.44	5.2503	8.8323	2.3785	8.3836	1.7017	5.5041	11.5118	9.205	8.382
21	3h	5y	38.28	5.0411	9.1879	2.1592	9.8177	1.4422	5.5681	12.5678	10.8739	10.1045
22	4.5h	5y	43.76	4.8596	9.65	2.3848	11.5418	1.6198	5.669	13.1347	13.0229	12.2047
23	6h	5y	48.13	5.8773	10.428	2.3885	13.1725	1.6434	6.413	14.1855	15.1354	14.1542
24	9h	5y	55.08	7.4638	14.2114	3.0364	16.1813	1.9944	8.5843	19.753	18.1705	17.0083
25	12h	5y	60.64	6.5673	12.1056	2.5036	17.5488	1.6979	7.3491	20.7789	21.5345	20.7156
26	18h	5y	70.36	3.9543	8.9664	1.2723	15.1047	0.828	4.6429	18.0516	19.3528	18.38
27	24h	5y	78.01	5.9762	12.7589	1.8182	15.3466	1.1195	7.332	18.0092	18.32	18.7886
28	30h	5y	84.28	3.9055	9.0044	1.1512	13.706	0.773	5.0792	19.9849	21.099	20.4321
29	36h	5y	89.55	4.6978	10.9591	1.2836	16.7884	0.7901	6.1166	20.0343	22.8099	22.0709
30	48h	5y	97.87	4.2644	9.617	1.5312	15.1816	0.9884	5.3821	20.6385	21.1398	20.6499
31	30m	10y	24.09	2.7892	6.0282	2.1227	3.7663	1.6028	3.2372	6.396	4.5512	3.6913
32	45m	10y	28.62	5.0881	9.917	3.1676	6.8829	2.2915	5.5273	11.0782	7.6908	6.8937
33	1h	10y	32.11	6.7326	11.8968	3.7189	9.4359	2.711	6.9669	14.3667	10.313	9.5141
34	1.5h	10y	36.7	7.5819	12.7556	3.7097	12.0966	2.7882	7.9306	16.8149	13.2534	12.2654
35	2h	10y	40.19	8.3282	14.1086	3.9971	14.2841	3.049	8.87	18.8725	15.7315	14.5677
36	3h	10y	45.54	7.6494	14.3048	3.0118	16.1616	1.9598	8.5028	19.7285	18.0122	16.7814
37	4.5h	10y	51.53	7.1697	14.488	3.5674	18.2501	2.6091	8.3409	19.8894	20.8011	19.5633
38	6h	10y	56.27	8.5049	15.2267	3.5534	20.115	2.4062	9.393	20.9766	23.4826	21.9828
39	9h	10y	63.75	9.332	18.9957	3.6959	23.1975	2.4091	11.1661	27.3884	26.6573	25.0995
40	12h	10y	69.68	8.219	15.6642	3.059	23.2518	2.0569	9.3988	27.8934	28.9514	27.9195
41	18h	10y	81.03	5.289	11.729	1.6403	20.7758	1.1364	6.142	25.8475	27.5756	26.5065
42	24h	10y	89.97	7.4564	16.3481	2.227	20.5278	1.3689	9.3044	23.5315	25.5398	25.9951
43	30h	10y	97.32	5.0222	11.8585	1.5183	18.6523	1.0126	6.6324	27.7794	29.8862	28.7112
44	36h	10y	103.5	5.9153	14.2936	1.605	23.4075	1.0078	7.8821	28.5255	32.2442	31.9964
45	48h	10y	113.32	5.5083	12.5402	1.9475	20.8773	1.2522	7.0035	28.7612	29.9803	29.1452
46	30m	20y	29.94	6.0074	12.2928	4.0765	8.148	2.9446	6.6994	13.4301	9.3007	8.2093
47	45m	20y	35.52	9.2653	16.9735	5.1699	12.6883	3.7397	9.8541	19.9434	13.8612	12.8212
48	1h	20y	39.82	11.1073	19.2737	5.9866	16.0463	4.323	11.489	23.8503	17.5357	16.2343
49	1.5h	20y	45.14	12.0571	20.0849	6.2142	19.9985	4.7649	12.572	26.972	21.9585	20.3534
50	2h	20y	49.13	12.6242	21.6379	6.6348	22.9404	4.9555	13.5628	29.3465	25.3318	23.5281
51	3h	20y	55.18	11.3529	21.3432	4.3164	25.3537	3.0985	12.5485	29.7613	28.4488	26.5818
52	4.5h	20y	61.89	10.6557	20.6469	5.3788	27.131	3.8859	11.7846	28.6785	31.2736	29.4697
53	6h	20y	67.16	11.7118	21.2854	4.9374	29.3664	3.3071	13.0934	30.5247	34.4667	32.3959
54	9h	20y	75.42	11.858	25.0214	4.5824	32.4457	2.9685	14.4847	37.5474	38.1422	36.1619
55	12h	20y	81.93	10.4462	20.6566	3.8108	31.1515	2.5443	12.2289	38.515	39.913	38.67
56	18h	20y	95.45	6.9661	15.3536	2.1814	28.1925	1.4955	8.2178	36.3998	38.8245	37.9568
57	24h	20y	106.12	9.4471	21.2499	2.7773	27.8269	1.7098	11.9885	31.6829	36.2071	36.6348
58	30h	20y	114.91	6.5011	15.7147	1.9968	25.391	1.3203	8.7186	39.1557	42.6279	41.3781

59	36h	20y	122.32	7.5363	18.7414	2.0432	32.4003	1.2934	10.2341	40.7756	45.6911	46.3391
60	48h	20y	134.11	7.2178	16.4768	2.5084	28.6341	1.6054	9.2066	40.3031	43.2067	42.5447
61	30m	50y	38.63	11.5463	22.4628	7.1796	15.6399	5.0928	12.5948	25.4203	17.3599	15.7897
62	45m	50y	45.77	15.6827	27.7732	8.075	21.9723	5.7089	16.545	33.7768	24.0274	22.2237
63	1h	50y	51.26	18.2369	30.7207	9.1169	27.341	6.5988	18.8709	39.7401	29.9305	27.7015
64	1.5h	50y	57.52	18.2892	30.902	9.2403	32.3834	6.9219	19.3446	42.3969	35.6701	33.0887
65	2h	50y	62.16	18.4562	32.3676	9.4466	35.8944	6.9107	20.0242	43.9313	39.8132	37.0416
66	3h	50y	69.1	16.0651	31.0318	6.3288	38.8147	4.5006	17.8591	43.5967	43.9394	41.2398
67	4.5h	50y	76.72	15.1305	29.2595	7.1376	41.1514	5.0129	16.4333	43.8256	48.4082	45.8999
68	6h	50y	82.64	14.9902	28.4653	6.0397	42.0498	3.9613	17.2405	46.0578	50.6212	48.1059
69	9h	50y	91.86	14.5546	31.4764	5.4139	43.7178	3.4871	17.9783	49.2058	53.0326	50.7953
70	12h	50y	99.06	12.7625	26.849	4.5309	41.6476	2.9957	15.5275	54.4008	56.6937	55.2743
71	18h	50y	115.66	8.6988	19.1976	2.6983	37.3308	1.7927	10.8576	51.0864	55.5827	55.111
72	24h	50y	128.79	11.2094	26.0506	3.2721	36.5422	2.0116	14.5261	43.0496	50.5582	51.1511
73	30h	50y	139.63	7.8578	19.4158	2.4359	32.7751	1.5992	10.6913	51.5938	56.7843	56.9389
74	36h	50y	148.78	8.9729	22.7695	2.4436	41.1151	1.5502	12.3613	53.8053	60.323	61.7959
75	48h	50y	163.4	8.7901	20.0767	3.0062	35.9042	1.9163	11.2334	51.5941	57.1061	56.7461
76	30m	100y	46.08	16.4723	31.1504	9.6022	22.3505	6.7371	17.6461	35.8627	24.3843	22.5681
77	45m	100y	54.54	21.7296	37.7183	10.7353	30.9479	7.4429	22.8524	46.9785	33.8588	31.3245
78	1h	100y	61.03	24.4131	40.9751	12.0757	37.4588	8.6029	25.3459	53.6178	41.029	37.9797
79	1.5h	100y	68.02	24.0707	40.8158	12.2532	43.6528	9.037	25.5147	56.0806	48.1593	44.7006
80	2h	100y	73.14	24.1735	42.5906	12.3254	48.1985	8.8575	26.0533	58.0303	53.6148	49.9391
81	3h	100y	80.73	20.5729	39.526	8.1246	51.1793	5.6624	22.881	56.385	58.3438	54.8984
82	4.5h	100y	88.99	19.6568	36.8712	8.9359	53.4861	6.1728	20.9277	57.5447	63.4884	60.4134
83	6h	100y	95.38	18.4297	36.3878	7.2484	53.9931	4.6771	21.7216	60.9478	66.2327	63.2625
84	9h	100y	105.27	17.4467	38.159	6.3723	55.718	4.0901	21.5978	63.4528	69.3973	66.8244
85	12h	100y	112.96	15.1593	32.4597	5.3383	50.8946	3.5169	18.6626	68.0065	71.181	69.4142
86	18h	100y	132.08	10.4631	23.5183	3.2384	46.2882	2.1348	13.2933	64.156	70.7175	70.3133
87	24h	100y	147.23	13.3156	31.4624	3.8579	45.6235	2.386	17.4406	54.0801	64.6241	65.8405
88	30h	100y	159.76	9.429	23.5123	2.9459	40.7701	1.9286	12.9122	64.4821	72.0295	73.6338
89	36h	100y	170.35	10.7117	27.4301	2.9119	50.4514	1.8546	14.8539	68.2519	78.9886	80.3972
90	48h	100y	187.3	10.6691	24.384	3.6071	44.2855	2.293	13.6499	64.105	72.667	72.6602

Appendix D: Hydraulic model input data

Table 36 Burst Initial Loss corresponding to Duration

Hill et al Loss Values	
Critical Duration (hrs)	Burst Initial Loss
1	3.7
1.5	4.4
2	5
3	5.8
4.5	6.8
6	7.5
9	8.6
12	9.4
24	11.5
30	12.2
36	12.8
48	13.7
72	14.9

Table 37 Key Hydraulic Structure Data

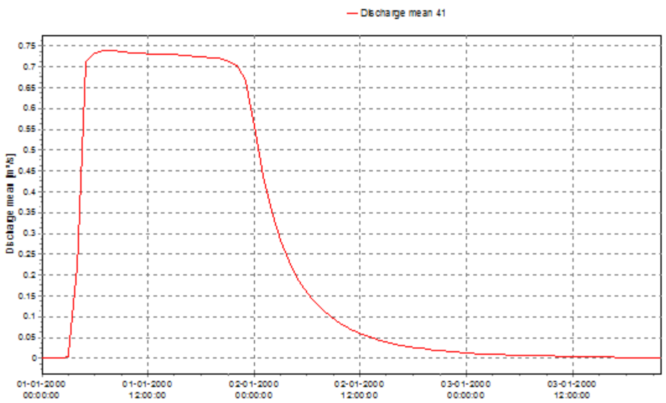
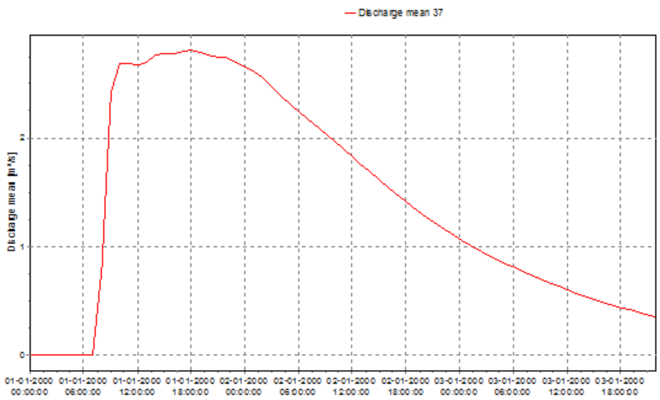
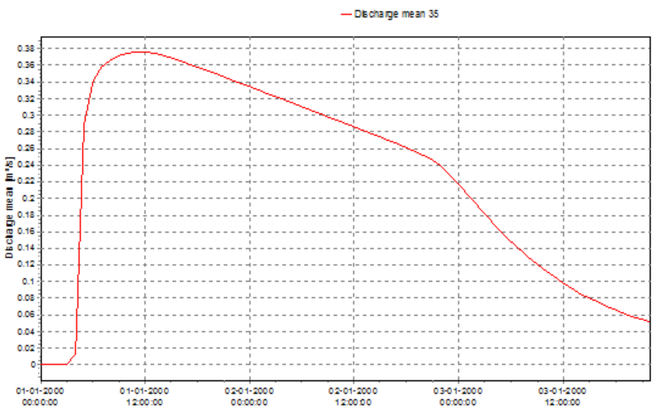
KEY HYDRAULIC STRUCTURE DATA			
Crossing Location	**Structure Details**	**Road Surface Level (m AHD)**	**Image**
Afflecks Road – Rosedale Creek	Box Culvert 1.0m (W) x 0.5m (H) x 7.0m (L)	78.086m AHD	
Humphreys Road – Toongabbie Creek	Box Culverts – x10 1.0m (W) x 0.6m (H) x 9.0m (L)	71.219m AHD	

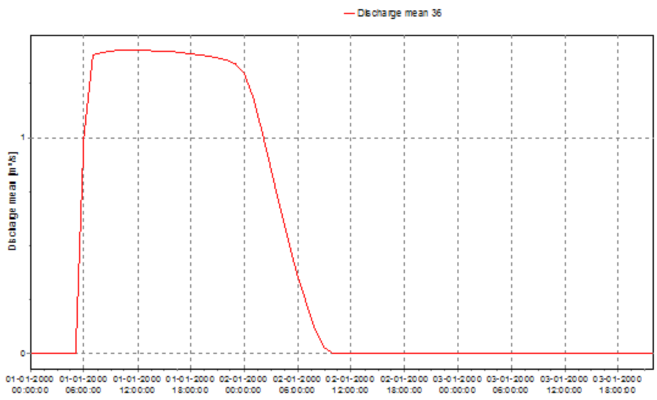
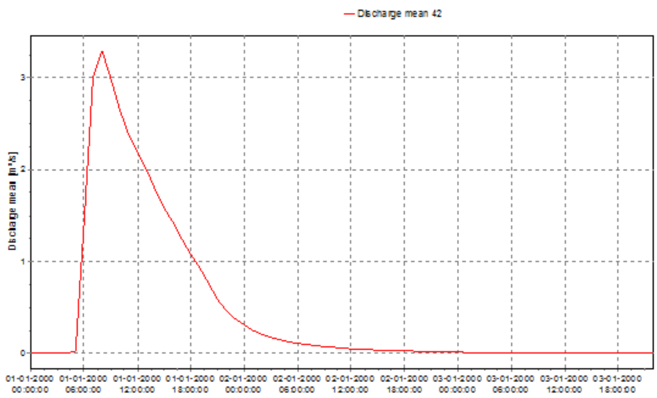
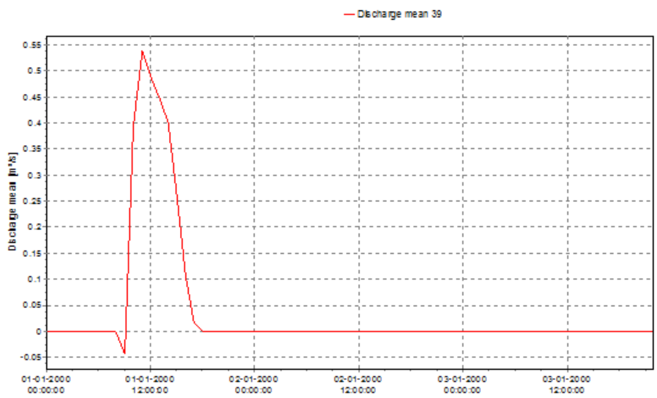
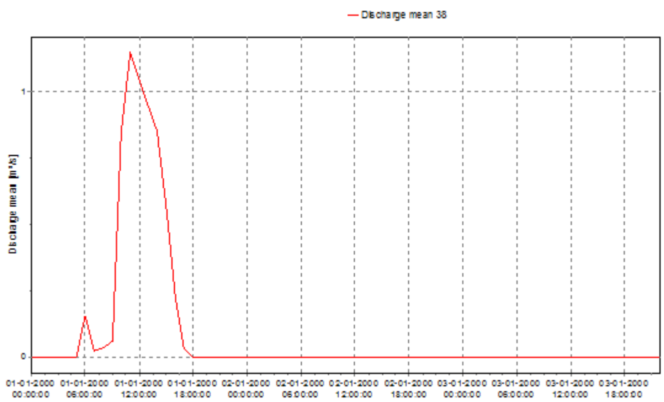
Harris Road – Tributary of Toongabbie Creek	Culvert 300mm Diameter Length 7.0m	80.68m AHD	
Pages Road – Tributary of Toongabbie Creek	Culvert 1.0m Diameter Length 9.0m	70.914m AHD	
Rail Trail – Tributary of Rosedale Creek	Bridge – 3.0m width Span 5.0m	75.208m AHD	
Rail Trail – Toongabbie Creek	Bridge – 3.0m width Span 14.7m	68.78m AHD	
Traralgon Maffra Road – Toongabbie Creek	Bridge – 9.0m width Span 12m Pile width of 600mm	69.585m AHD	

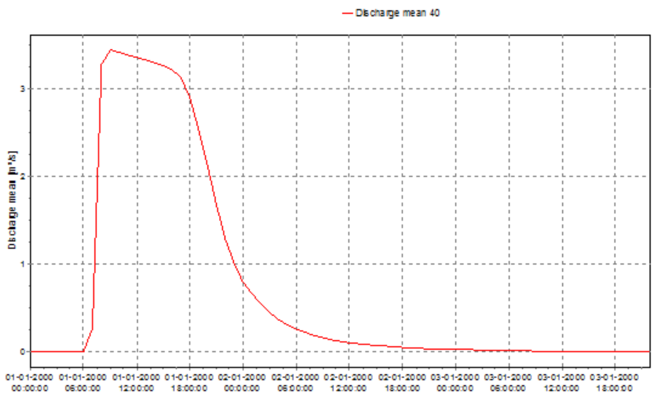
Main Road – Rosedale Creek	Culvert x2 – 1000mm Diameter Length 12m	66.14m AHD	

Appendix E: Output data from hydraulic model

Table 38 Discharge curves at key hydraulic structures for 100 year ARI flood event for catchment extent modelling

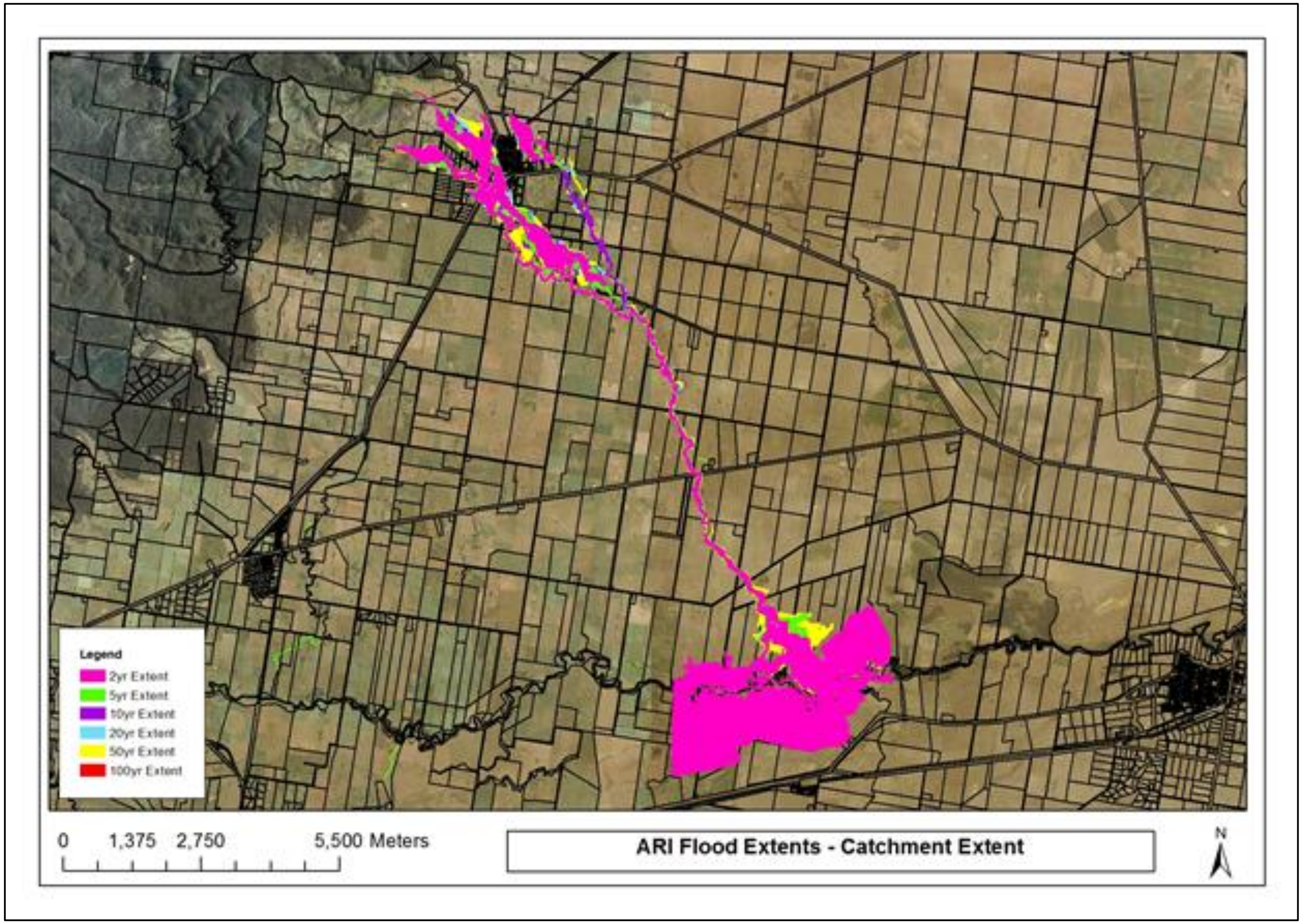
DISCHARGE CURVES AT KEY HYDRAULIC STRUCTURES	
Crossing Location	**Discharge Curve from Sobek**
Afflecks Road – Rosedale Creek	
Humphreys Road – Toongabbie Creek	
Harris Road – Tributary of Toongabbie Creek	

Pages Road – Tributary of Toongabbie Creek	
Rail Trail – Tributary of Rosedale Creek	
Rail Trail – Toongabbie Creek	
Traralgon Maffra Road – Toongabbie Creek	

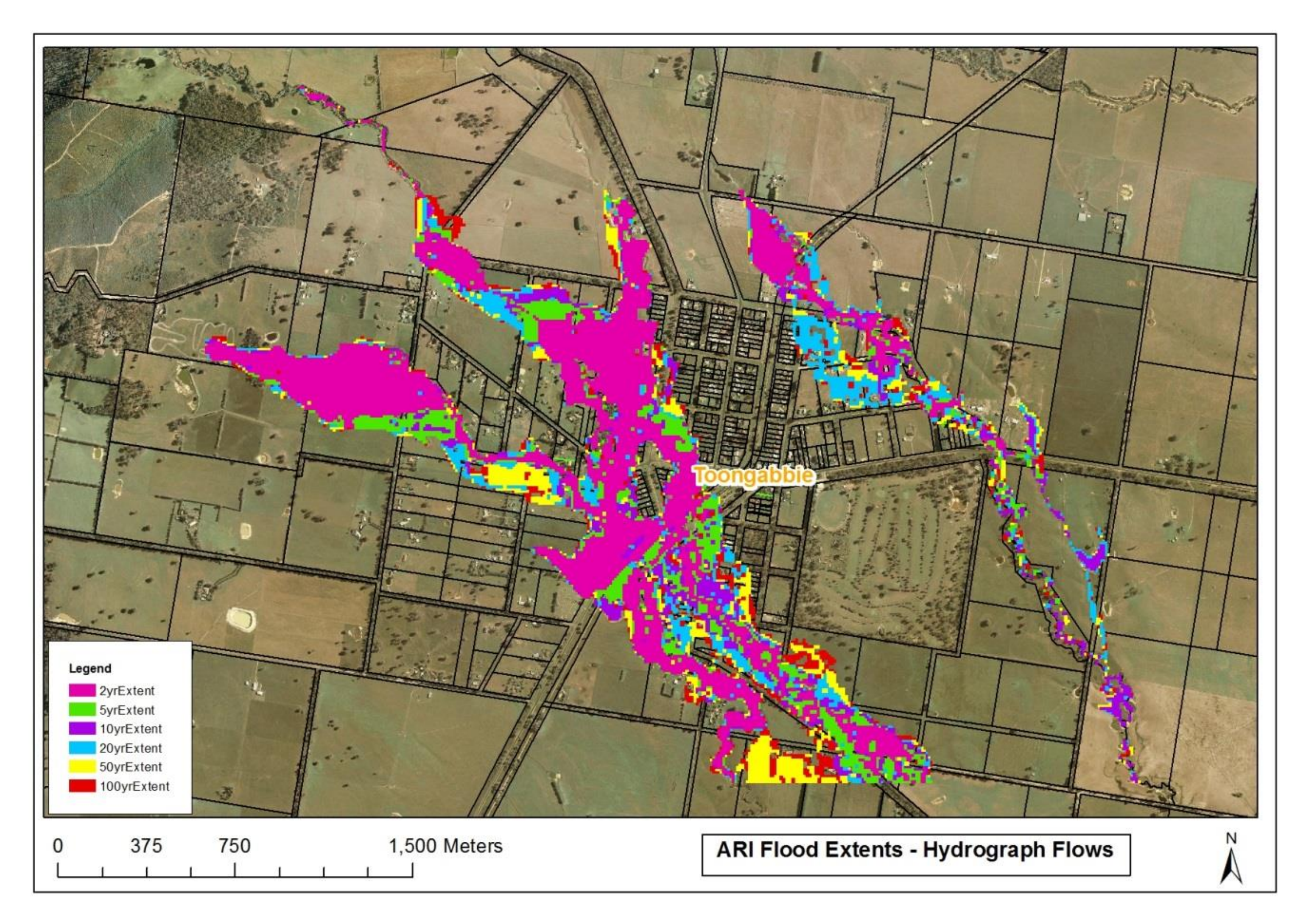
Main Road – Rosedale Creek	

Appendix F: Flood extent maps

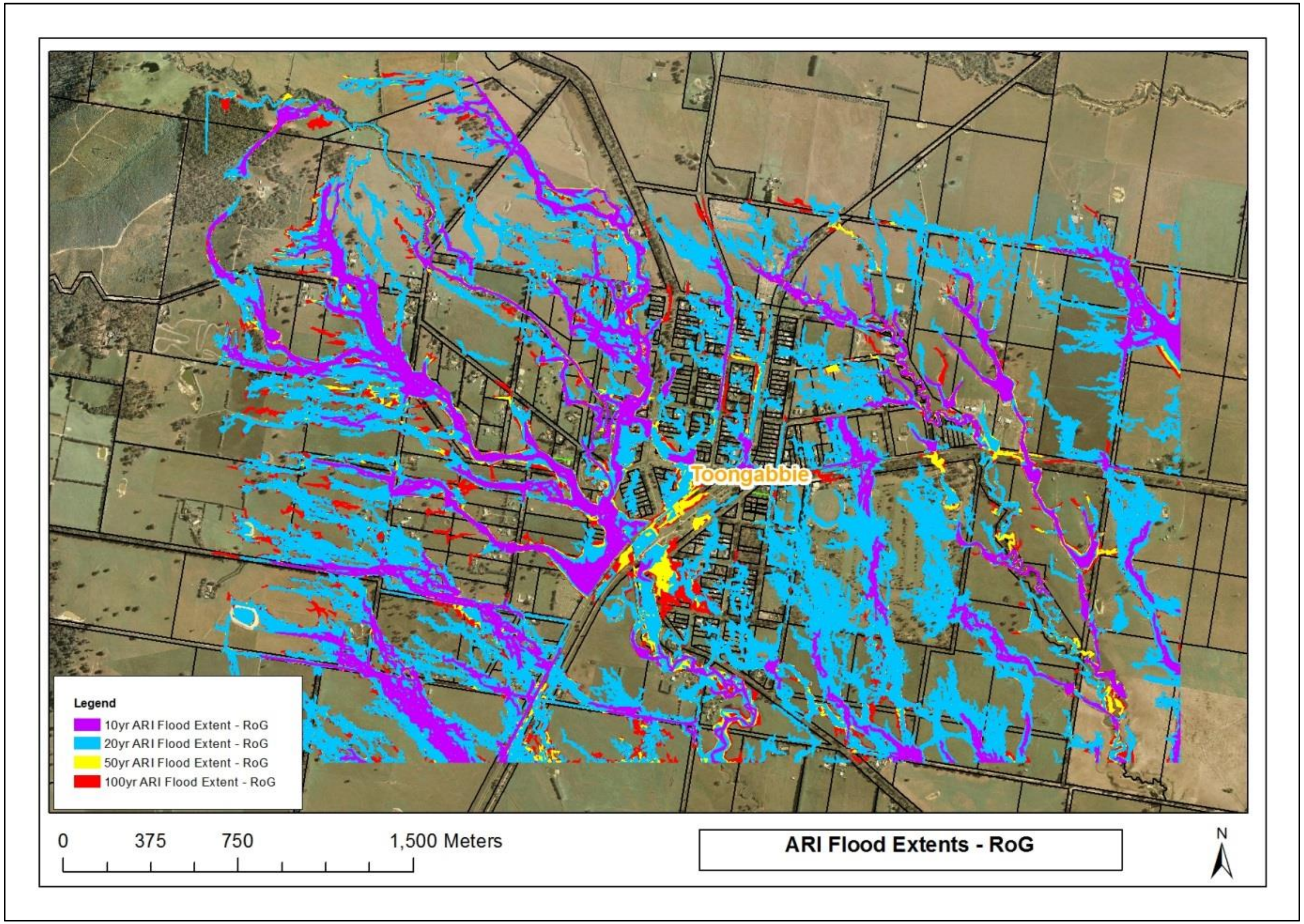
Appendix F1: Flood extent maps - Catchment Extent Hydraulic Model



Appendix F2: Flood extent maps - Township Extent Hydraulic Model – Hydrograph flows

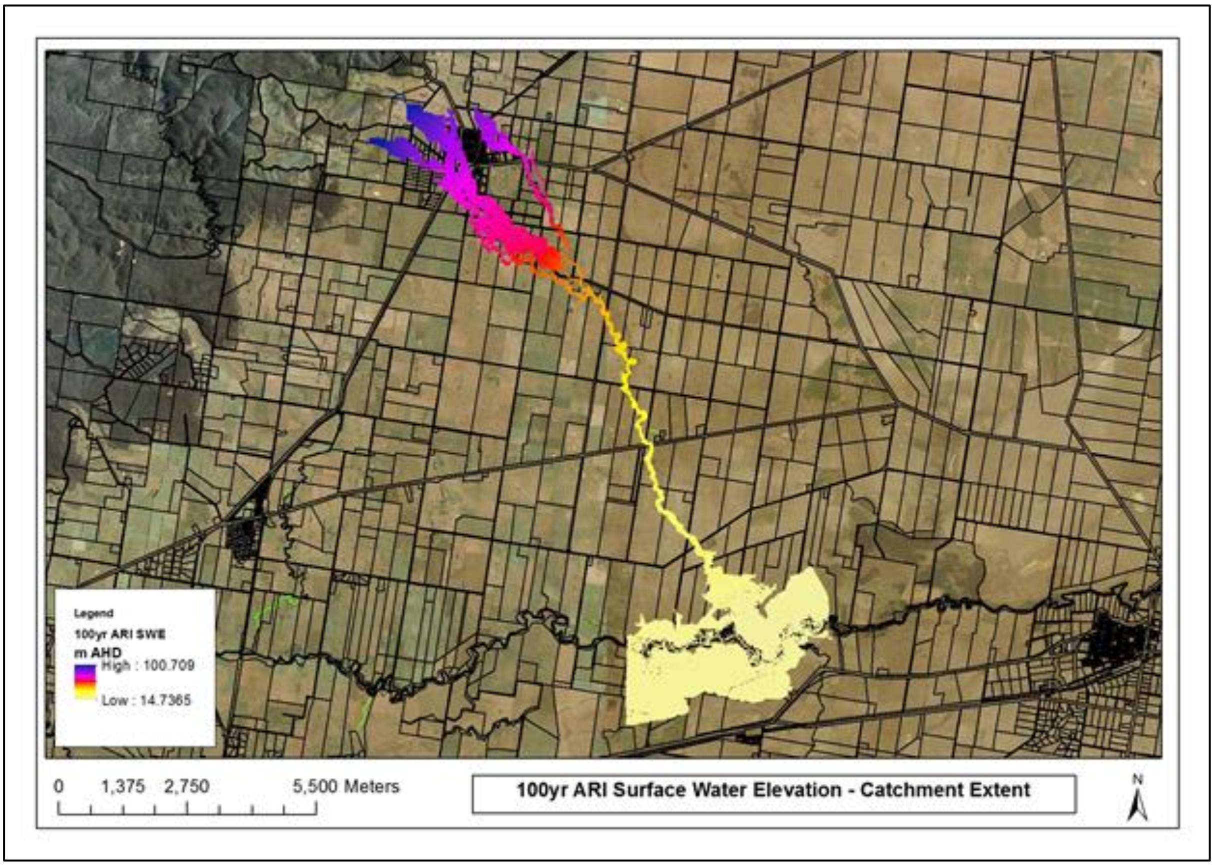


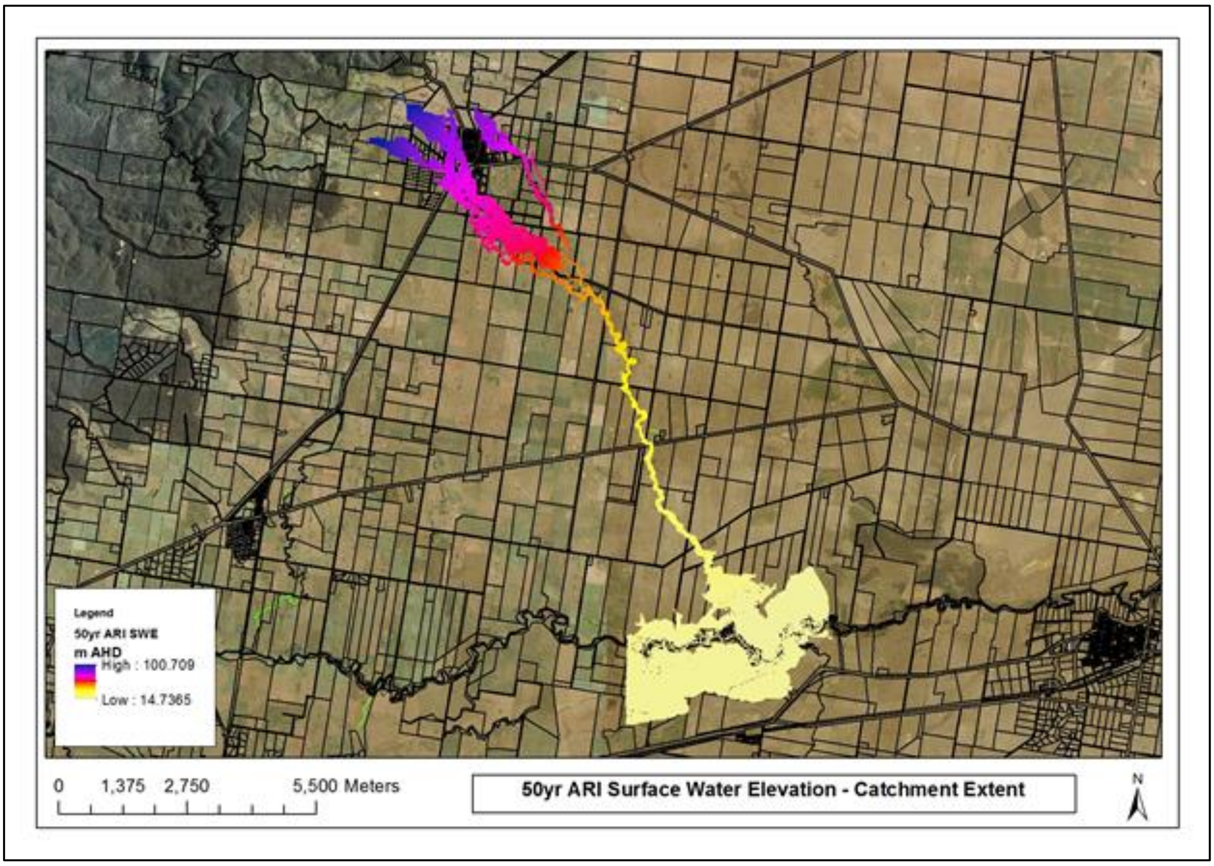
Appendix F3: Flood extent maps - Township Extent Hydraulic Model – Rain on grid

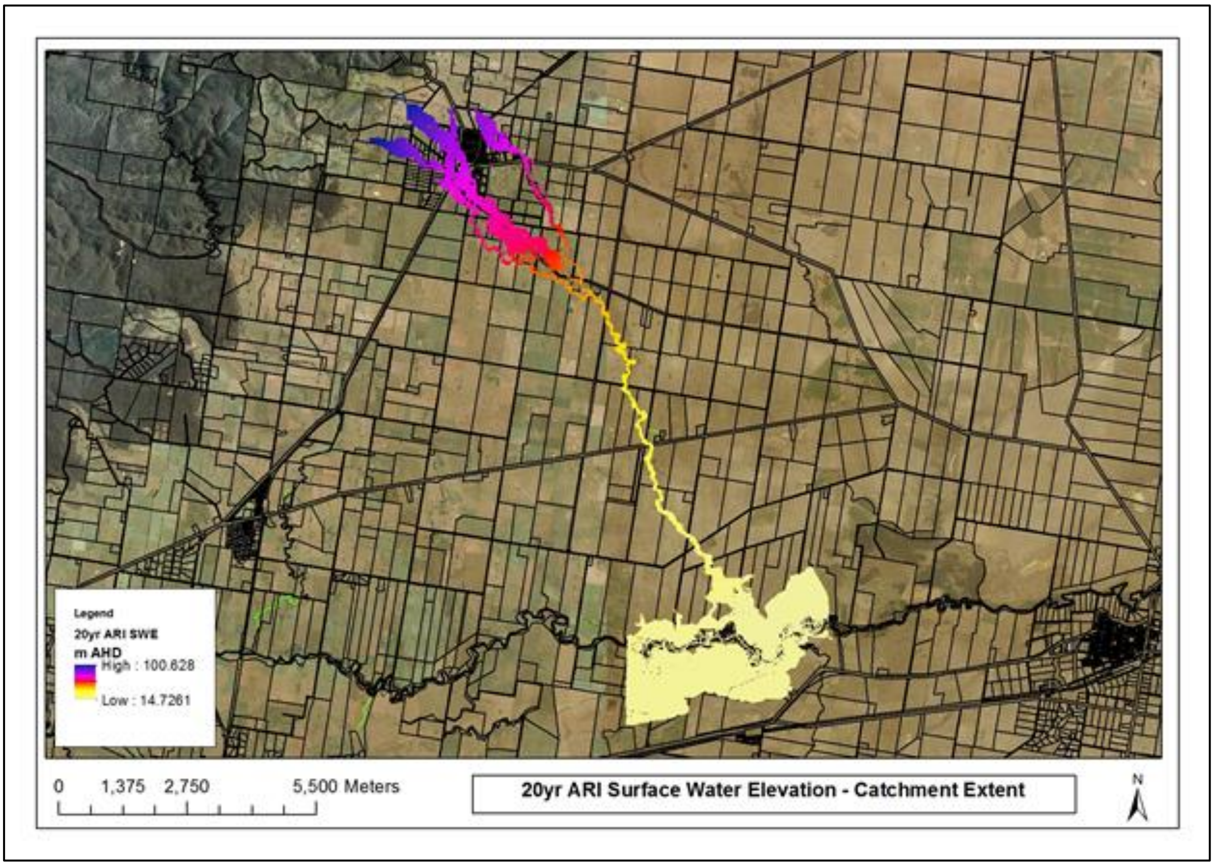


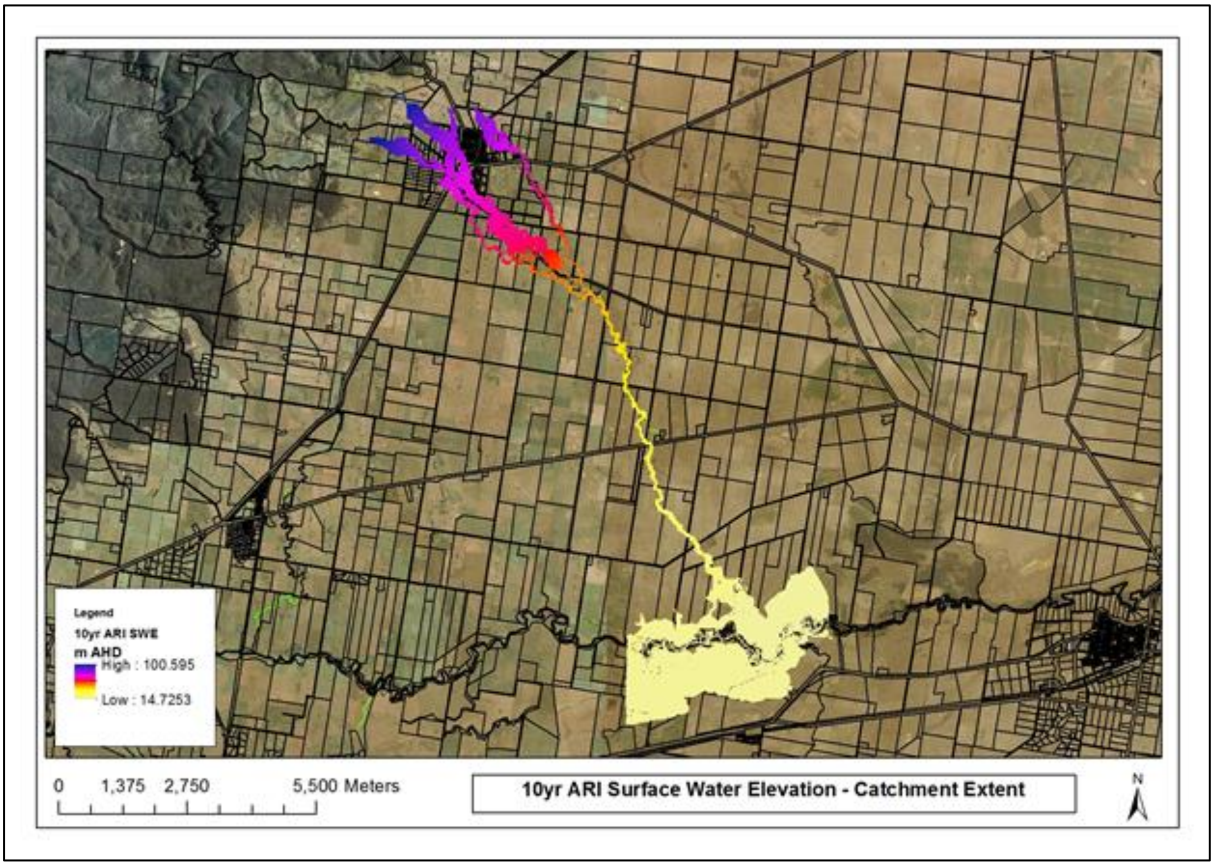
Appendix G: Flood level maps

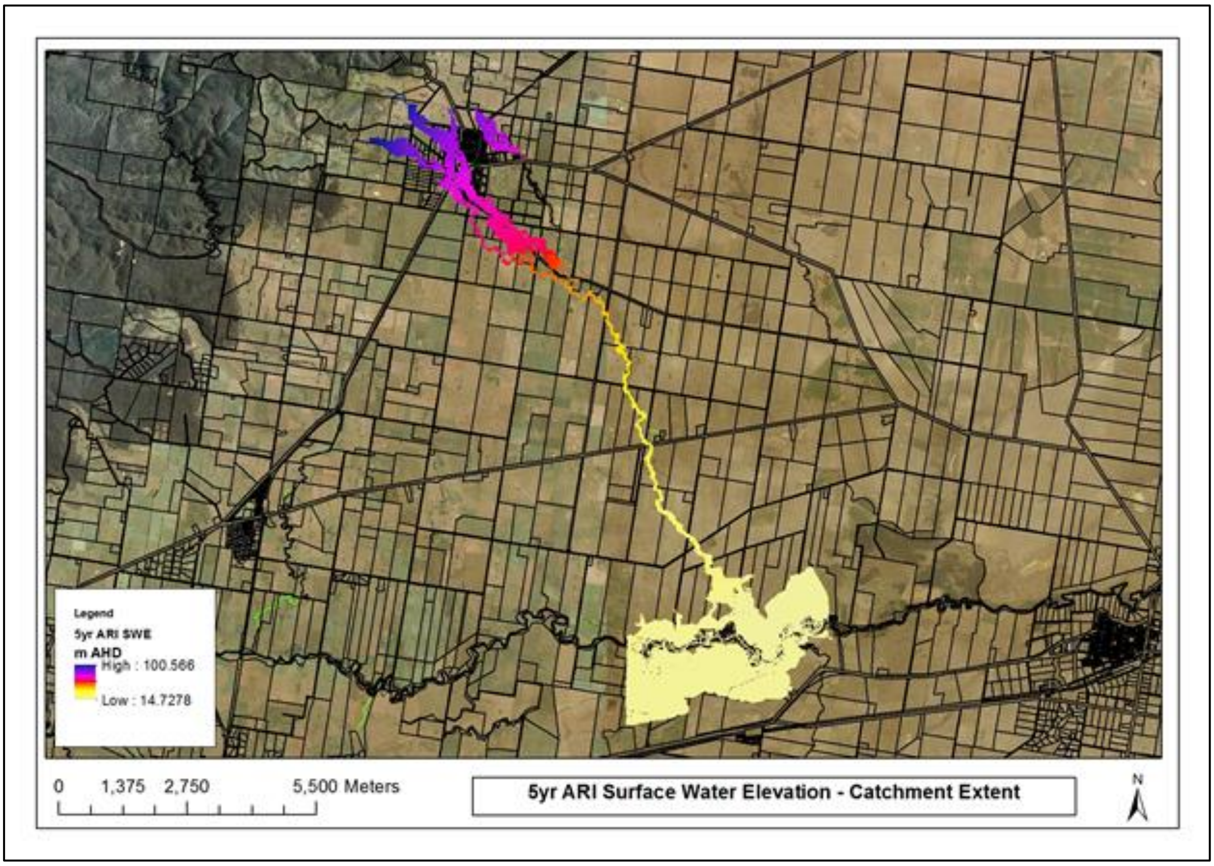
Appendix G1: Flood level maps – Catchment Extent Hydraulic Model

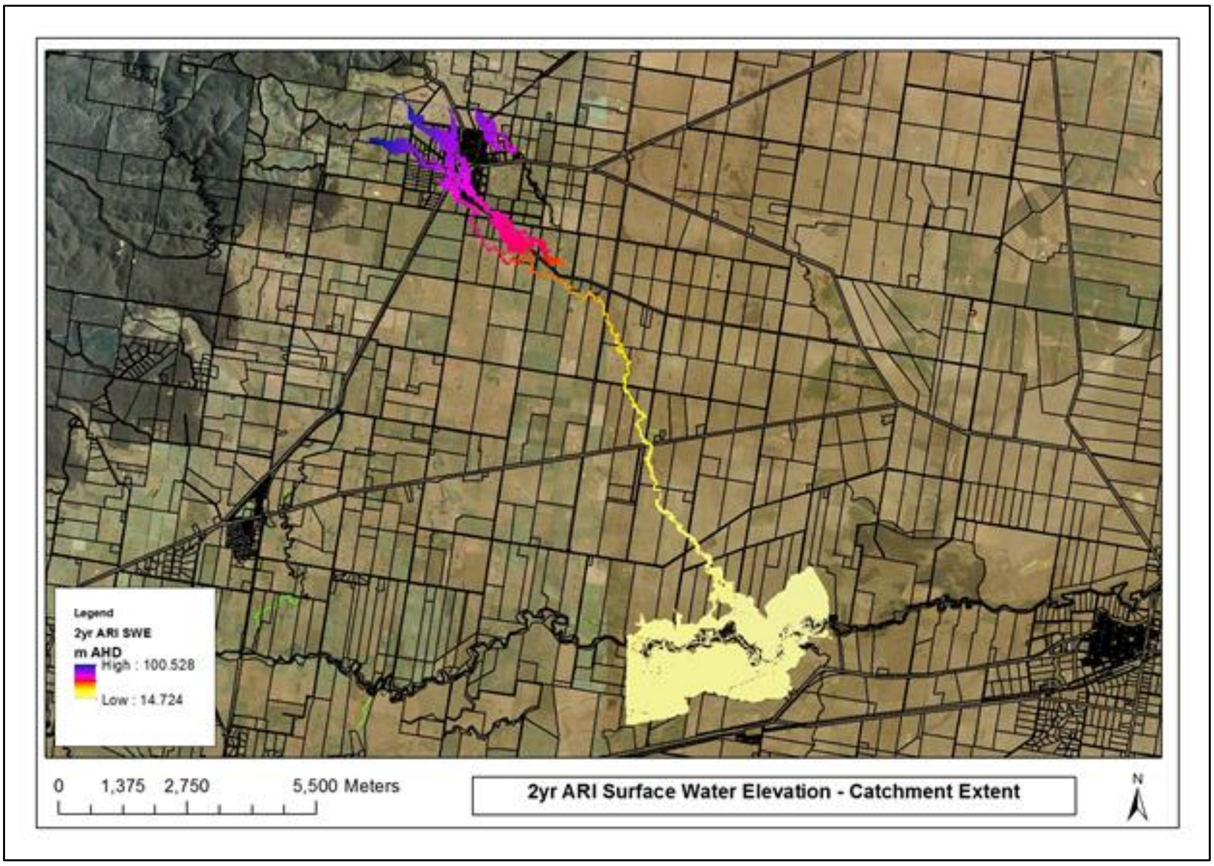

Legend
100yr ARI SWE
m AHD
High : 100.709
Low : 14.7365
0 1,375 2,750 5,500 Meters
100yr ARI Surface Water Elevation - Catchment Extent
N


Legend
50yr ARI SWE
m AHD
High : 100.709
Low : 14.7365
0 1,375 2,750 5,500 Meters
50yr ARI Surface Water Elevation - Catchment Extent
N

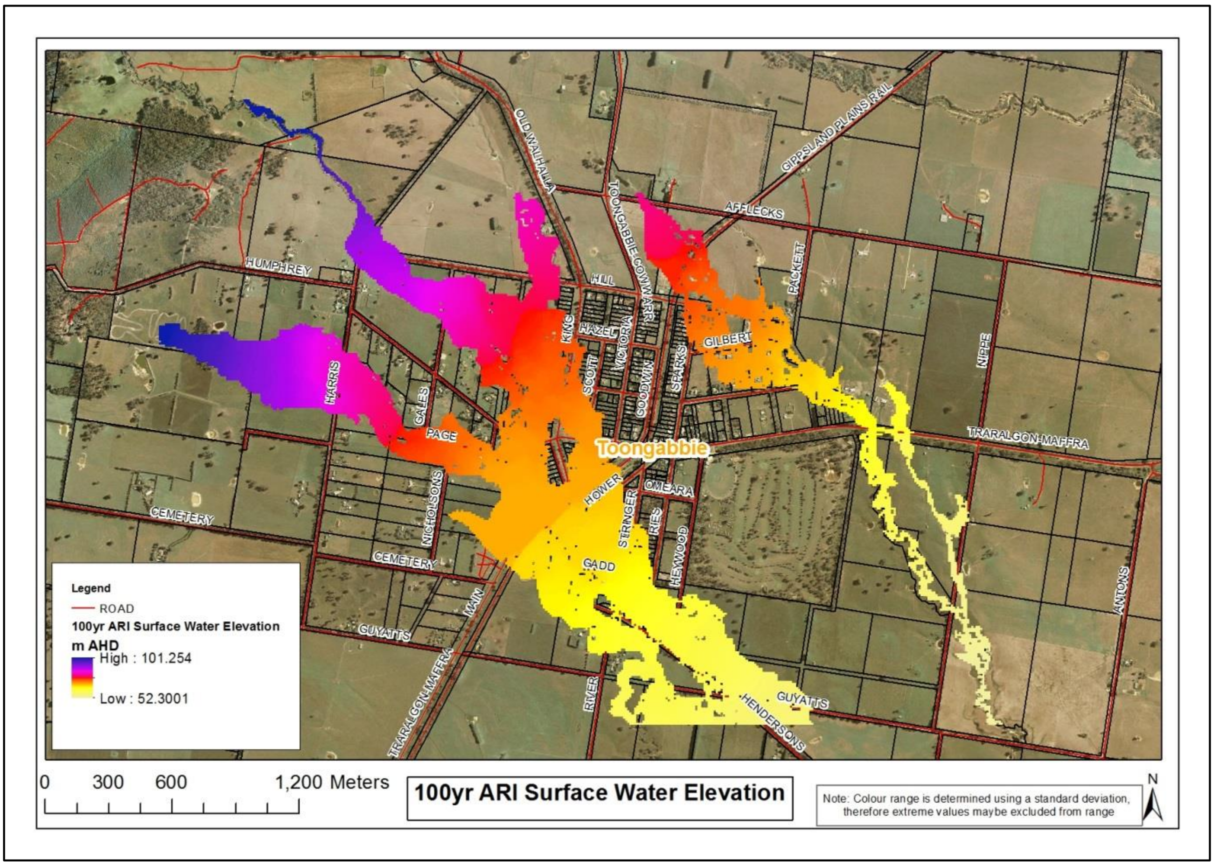

Legend
20yr ARI SWE
m AHD
High : 100.628
Low : 14.7261
0 1,375 2,750 5,500 Meters
20yr ARI Surface Water Elevation - Catchment Extent
N

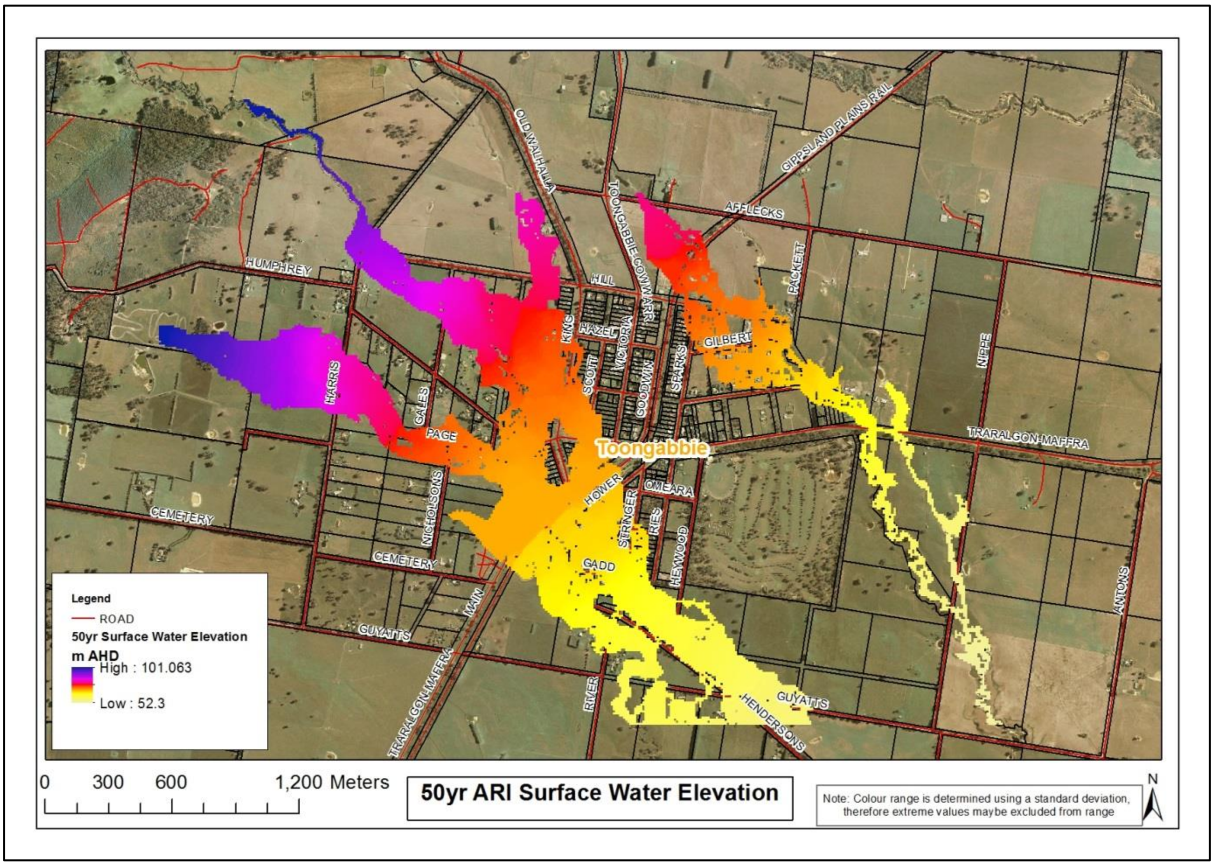

Legend
10yr ARI SWE
m AHD
High : 100.595
Low : 14.7253
0 1,375 2,750 5,500 Meters
10yr ARI Surface Water Elevation - Catchment Extent
N

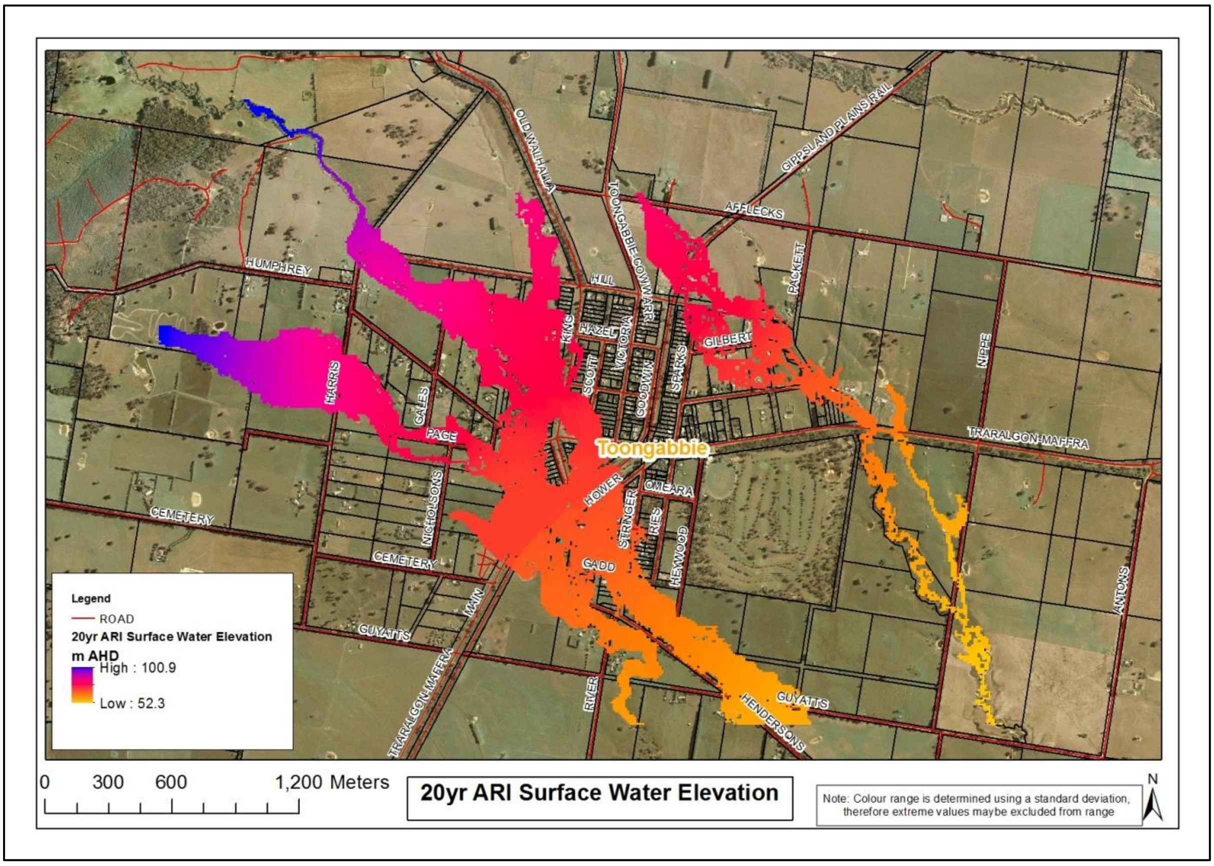

Legend
5yr ARI SWE
m AHD
High : 100.566
Low : 14.7278
0 1,375 2,750 5,500 Meters
5yr ARI Surface Water Elevation - Catchment Extent
N

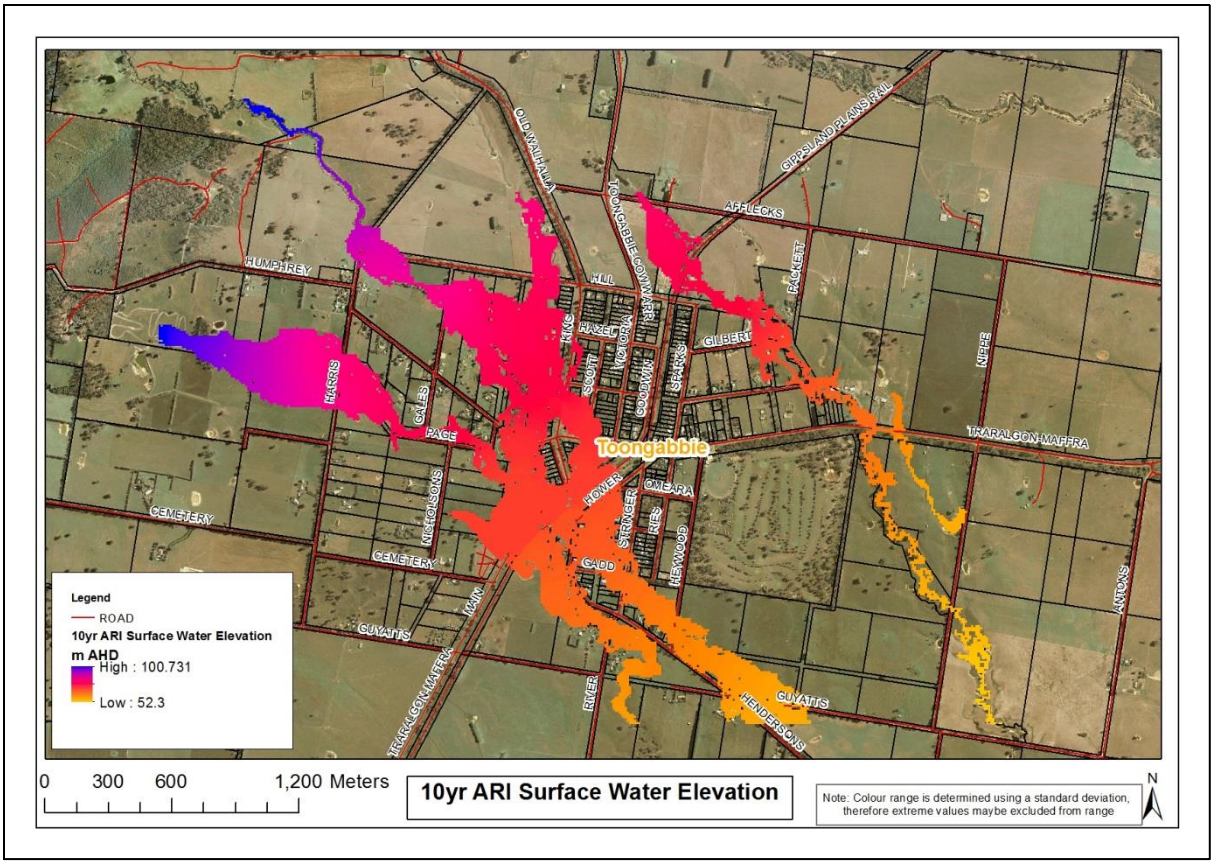

Legend
2yr ARI SWE
m AHD
High : 100.528
Low : 14.724
0 1,375 2,750 5,500 Meters
2yr ARI Surface Water Elevation - Catchment Extent
N

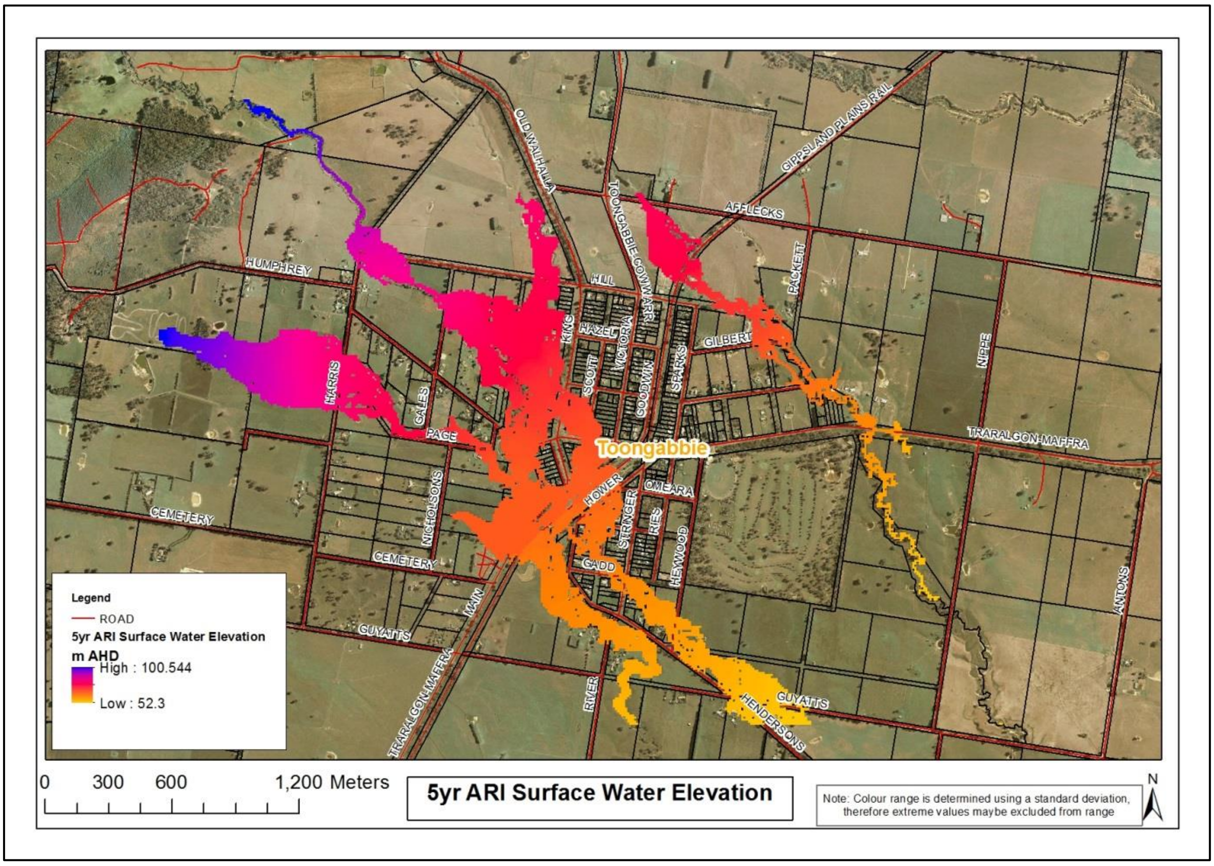
Appendix G2: Flood level maps – Township Extent Hydraulic Model – Hydrograph Flows

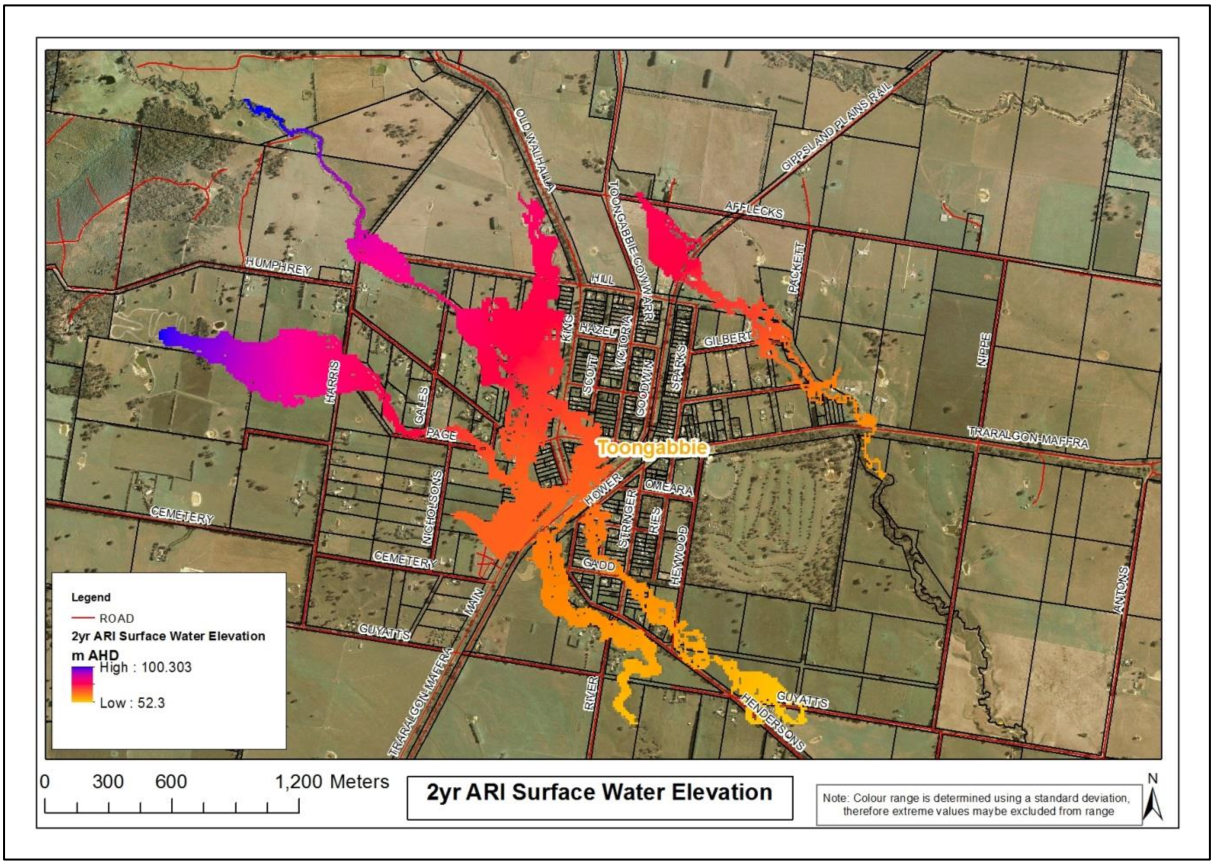




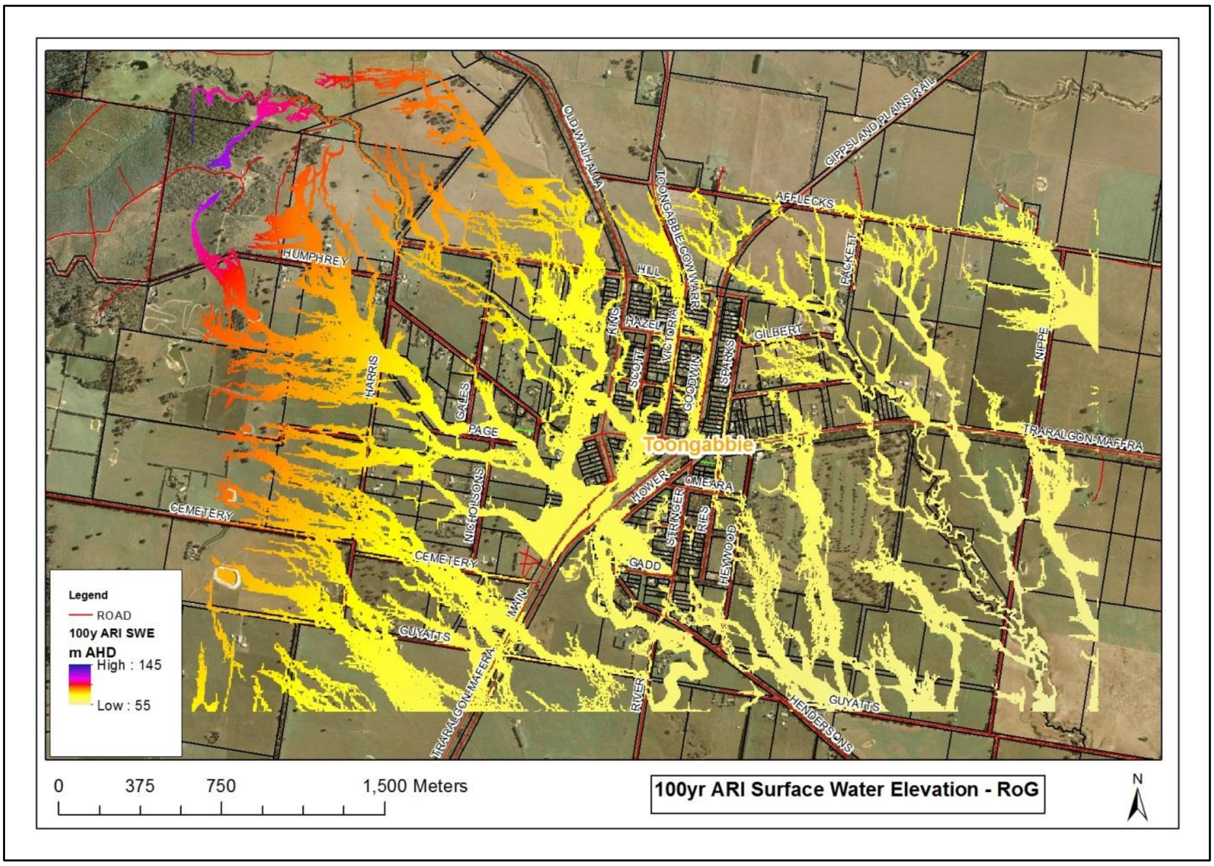

OLD WALHALLA
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
HUMPHREY
HILL
HAZEL
KING
SCOTT
VICTORIA
GOODWIN
SPARKS
GILBERT
BACKETT
NIPPE
HARRIS
GILES
PAGE
TRARALGON-MAFFRA
Toongabbie
HOWER
OMEARA
NICHOLSONS
CEMETERY
STRINGER
RIES
HEYWOOD
GADD
MAIN
ANTONS
GUYATTS
RIVER
HENDERSONS
Legend
ROAD
20yr ARI Surface Water Elevation
m AHD
High : 100.9
Low : 52.3
0
300
600
1,200 Meters
20yr ARI Surface Water Elevation
Note: Colour range is determined using a standard deviation, therefore extreme values maybe excluded from range
N

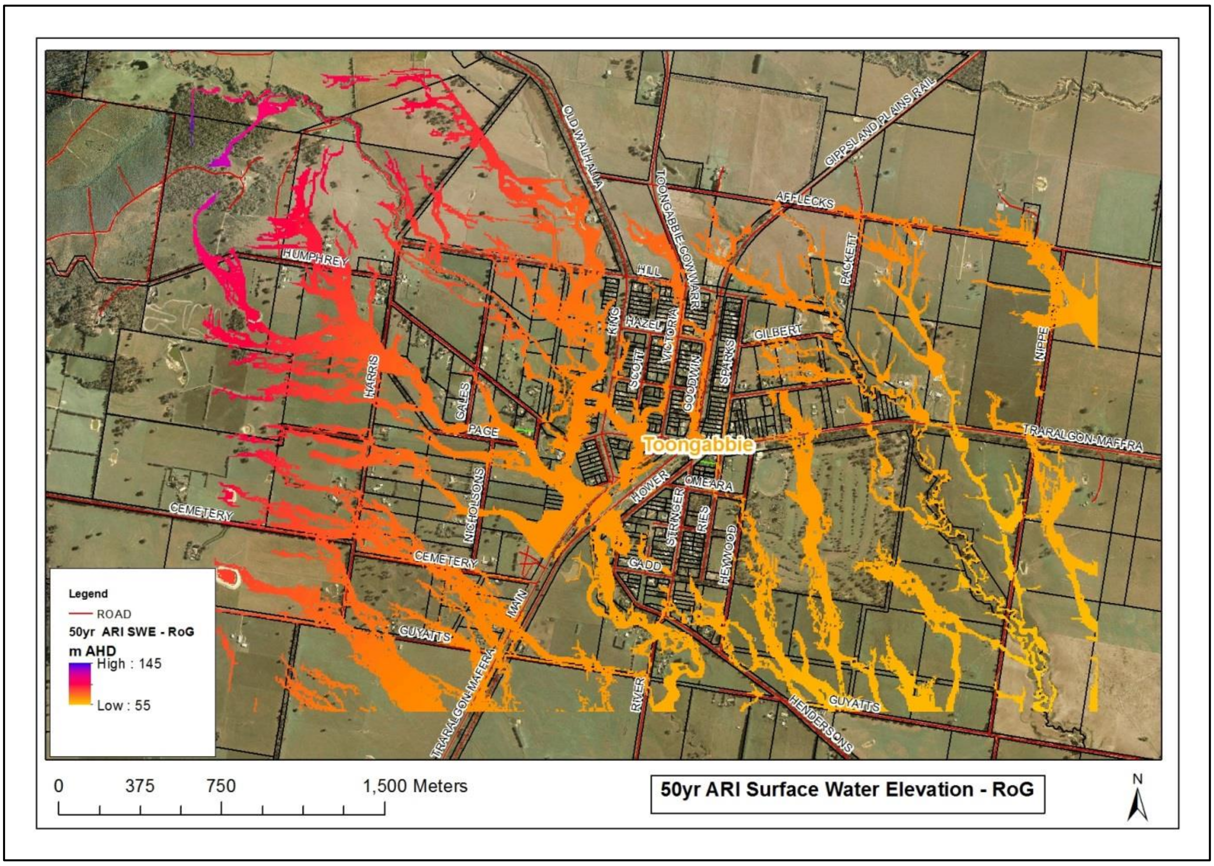

OLD WALHALLA
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
HUMPHREY
HILL
HAZEL
KING
SCOTT
VICTORIA
GOODWIN
SPARKS
GILBERT
BACKETT
NIPPE
HARRIS
GILES
PAGE
TRARALGON-MAFFRA
Toongabbie
HOWER
OMEARA
NICHOLSONS
CEMETERY
STRINGER
RIES
HEYWOOD
GADD
MAIN
ANTONS
GUYATTS
RIVER
HENDERSONS
Legend
ROAD
10yr ARI Surface Water Elevation
m AHD
High : 100.731
Low : 52.3
0
300
600
1,200 Meters
10yr ARI Surface Water Elevation
Note: Colour range is determined using a standard deviation, therefore extreme values maybe excluded from range
N

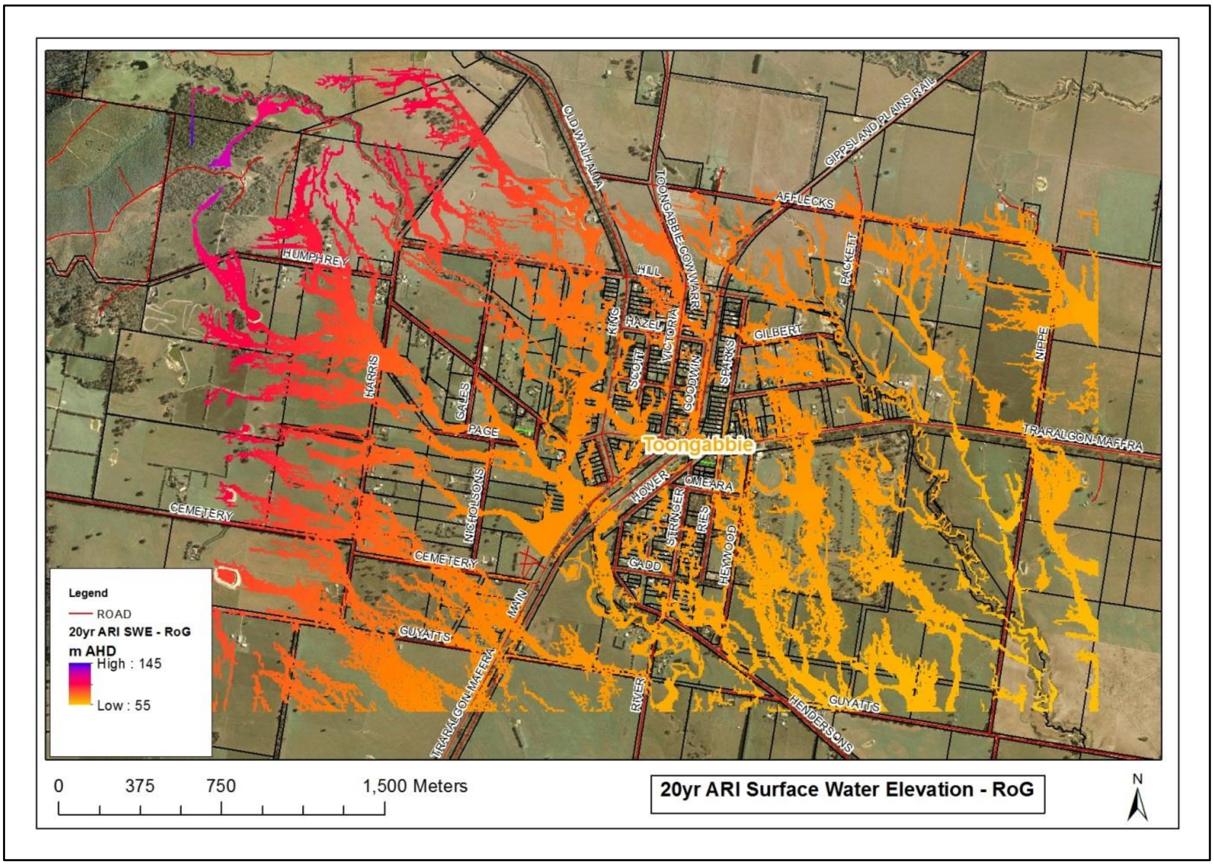

OLD WALHALLA
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
HUMPHREY
HILL
KING
HAZEL
SCOTT
VICTORIA
GOODWIN
SPARKS
GILBERT
PACKETT
NIPPE
HARRIS
GALES
PAGE
Toongabbie
TRARALGON-MAFFRA
NICHOLSONS
HOWER
OMEARA
STRINGER
RIES
HEYWOOD
CEMETERY
GADD
MAIN
GUYATTS
RIVER
HENDERSONS
ANTONS
Legend
ROAD
5yr ARI Surface Water Elevation
m AHD
High : 100.544
Low : 52.3
0 300 600 1,200 Meters
5yr ARI Surface Water Elevation
Note: Colour range is determined using a standard deviation, therefore extreme values maybe excluded from range
N

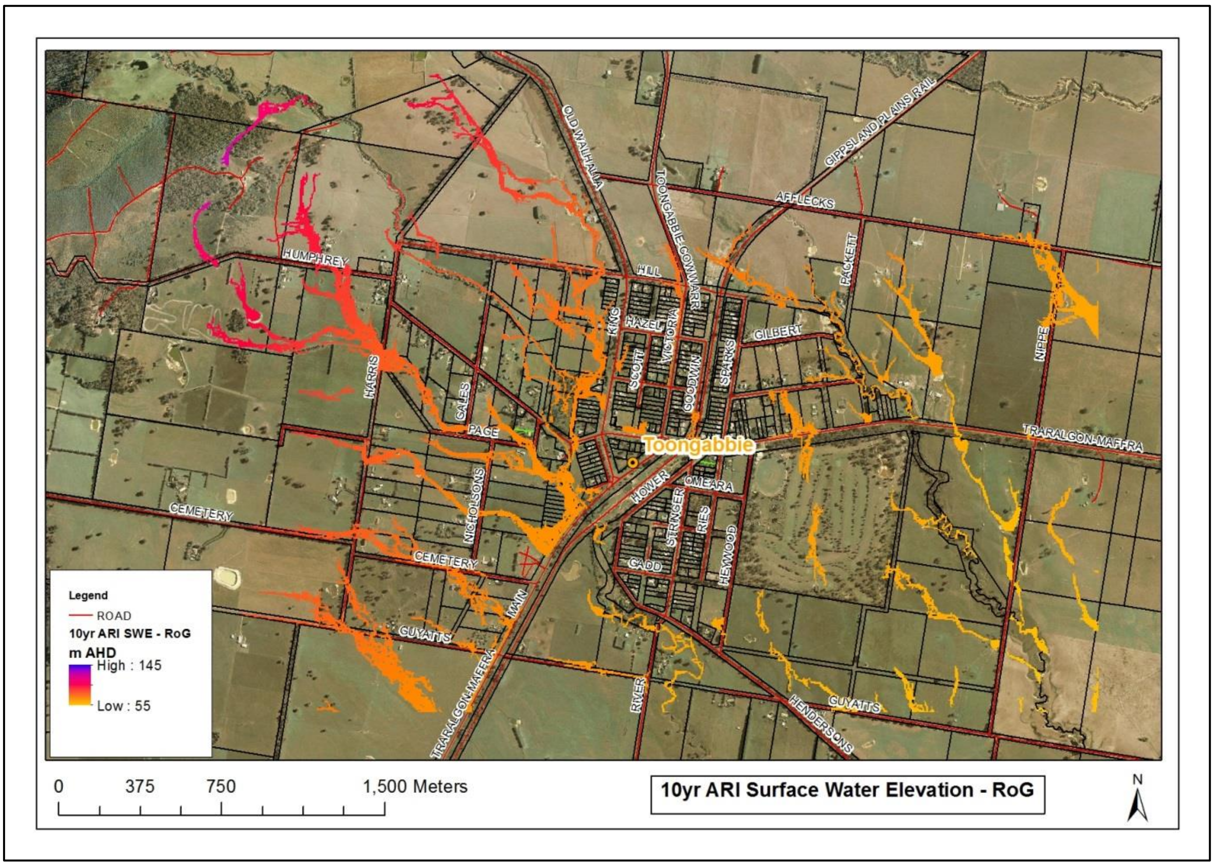

OLD WALHALLA
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
HUMPHREY
HILL
KING
HAZEL
SCOTT
VICTORIA
GOODWIN
SPARKS
GILBERT
PACKETT
NIPPE
HARRIS
GALES
PAGE
Toongabbie
TRARALGON-MAFFRA
NICHOLSONS
HOWER
OMEARA
STRINGER
RIES
HEYWOOD
CEMETERY
GADD
MAIN
GUYATTS
RIVER
HENDERSONS
ANTONS
Legend
ROAD
2yr ARI Surface Water Elevation
m AHD
High : 100.303
Low : 52.3
0 300 600 1,200 Meters
2yr ARI Surface Water Elevation
Note: Colour range is determined using a standard deviation, therefore extreme values maybe excluded from range
N

Appendix G3: Flood level maps – Township Extent Hydraulic Model – Rain on Grid



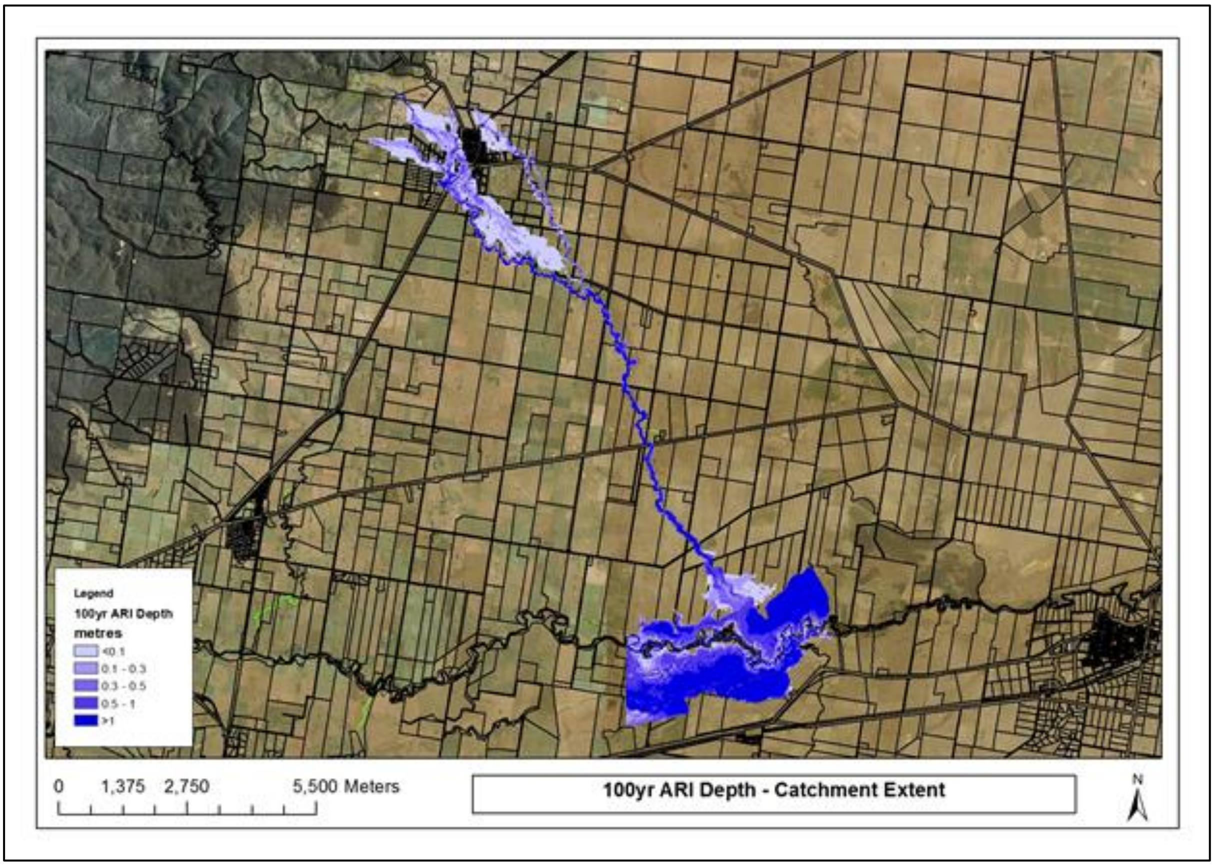


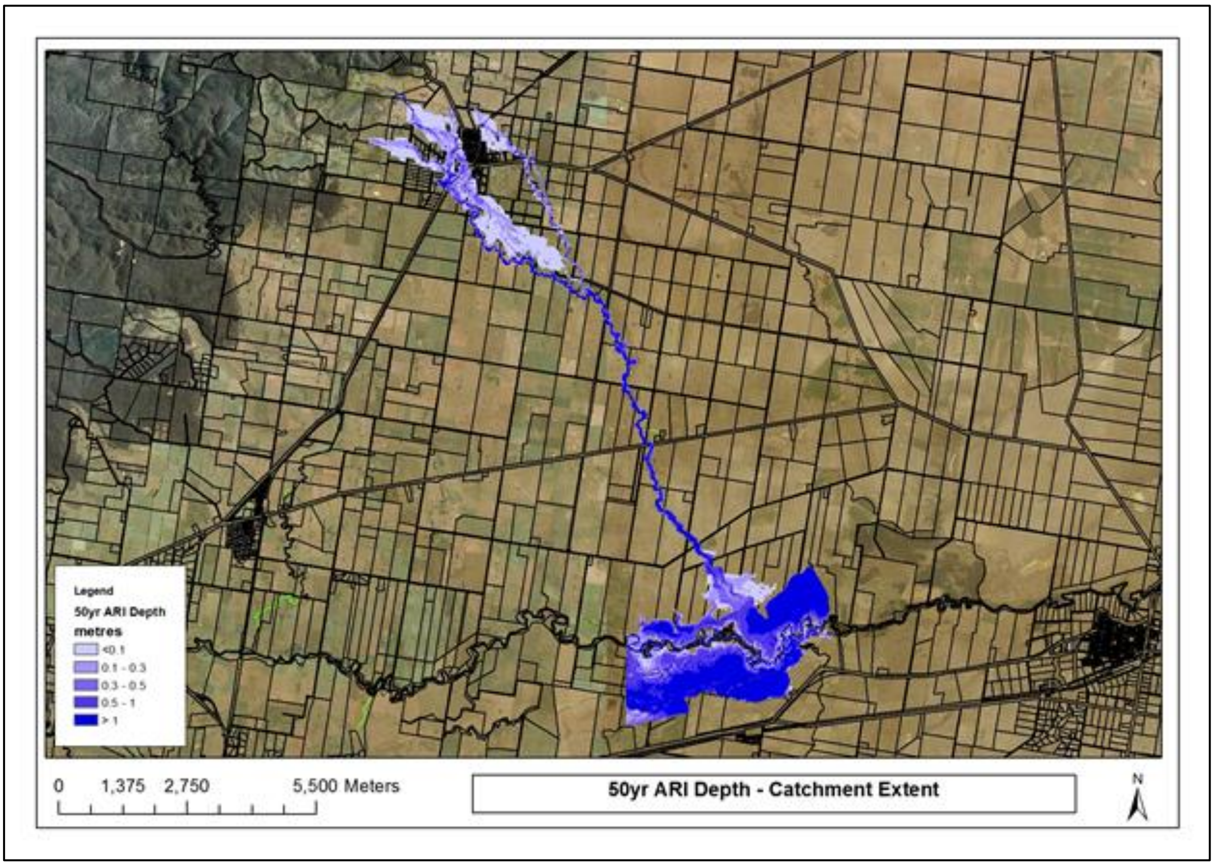

Legend
ROAD
20yr ARI SWE - RoG
m AHD
High : 145
Low : 55
0 375 750 1,500 Meters
20yr ARI Surface Water Elevation - RoG
N
Toongabbie
HUMPHREY
HARRIS
GALES
PAGE
NICHOLSONS
CEMETERY
GUYATTS
MAIN
TRARALGON-MAFFRA
RIVER
HENDERSONS
OLD WALHALLA
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
RACKETT
GILBERT
NIPPE
HILL
KING
HAZEL
SCOTT
VICTORIA
GOODWIN
SPARKS
HOWER
O'MEARA
STRINGER
RES
HEYWOOD
GADD

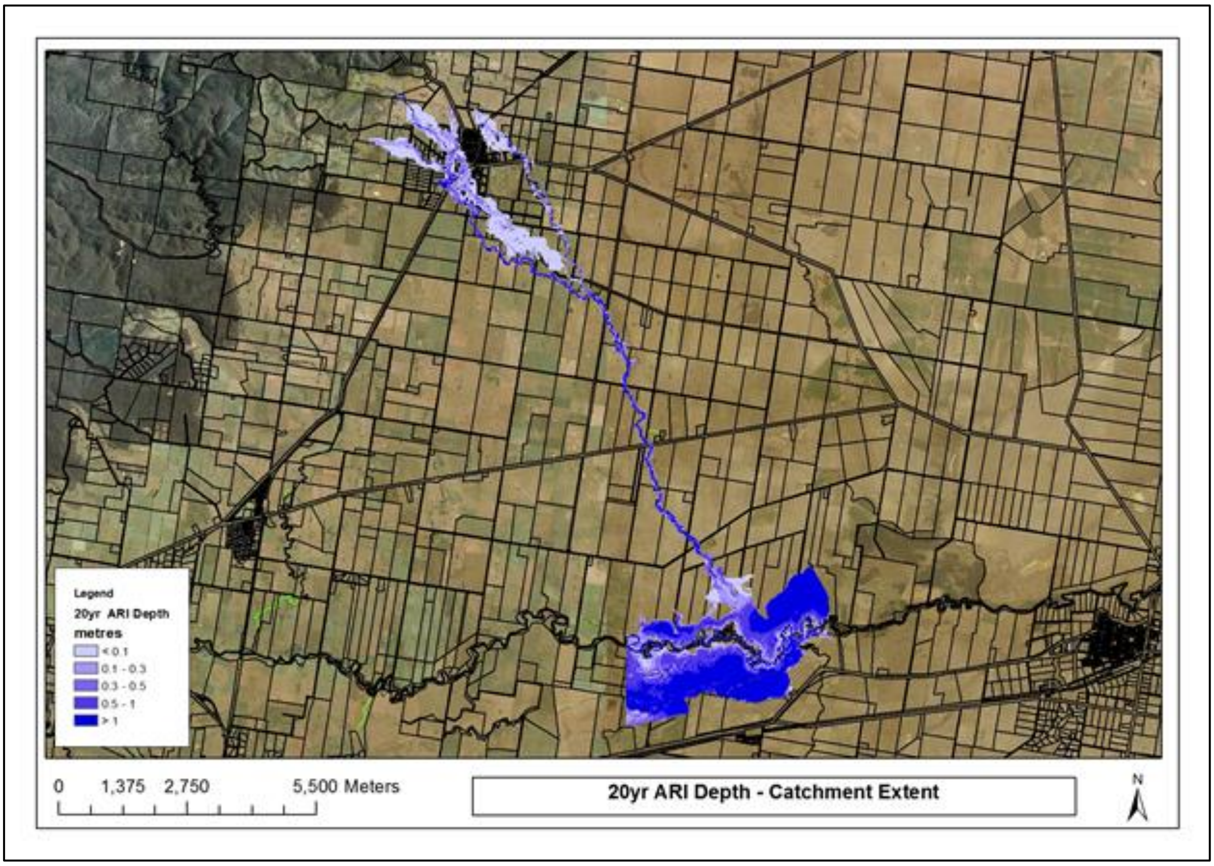

Legend
ROAD
10yr ARI SWE - RoG
m AHD
High : 145
Low : 55
0 375 750 1,500 Meters
10yr ARI Surface Water Elevation - RoG
N
Toongabbie
HUMPHREY
HARRIS
GALES
PAGE
NICHOLSONS
CEMETERY
GUYATTS
MAIN
TRARALGON-MAFFRA
RIVER
HENDERSONS
OLD WALHALLA
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
RACKETT
GILBERT
NIPPE
HILL
KING
HAZEL
SCOTT
VICTORIA
GOODWIN
SPARKS
HOWER
O'MEARA
STRINGER
RES
HEYWOOD
GADD

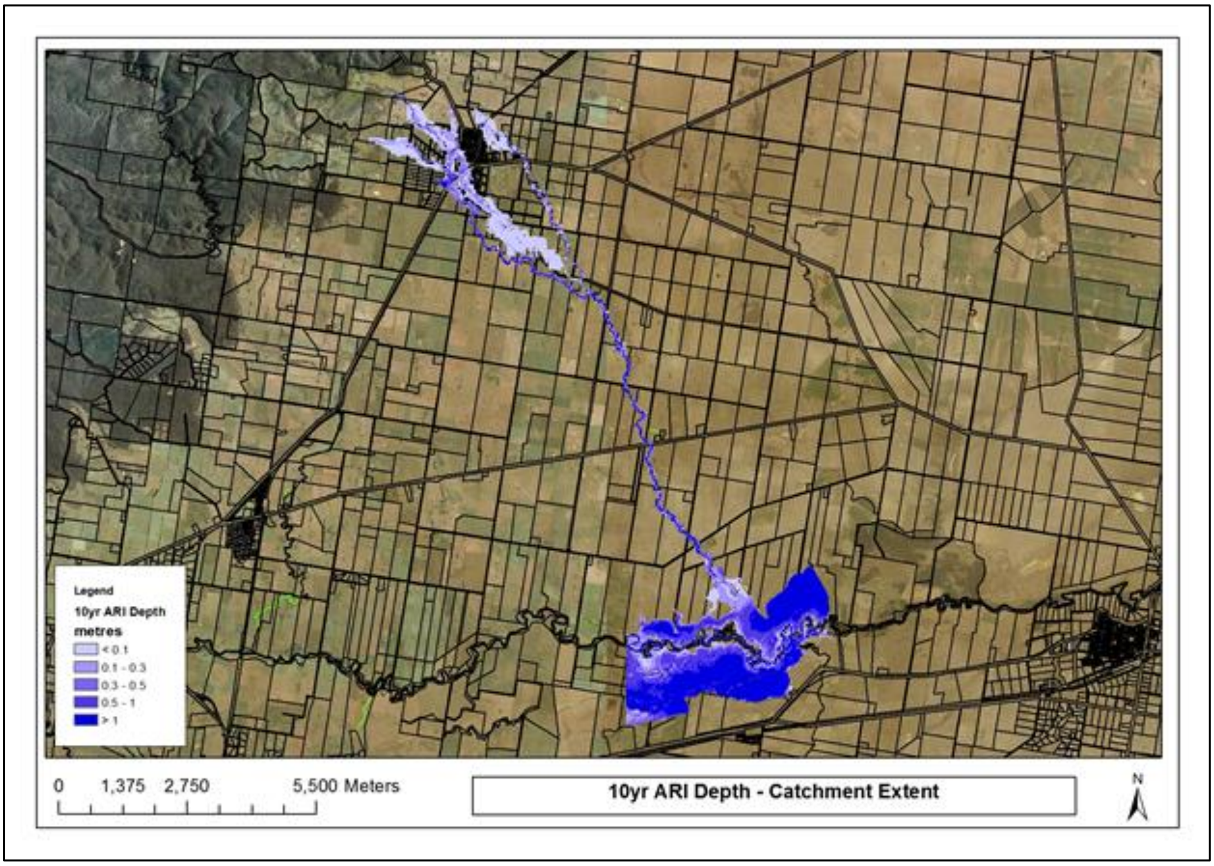
Appendix H: Flood depth maps

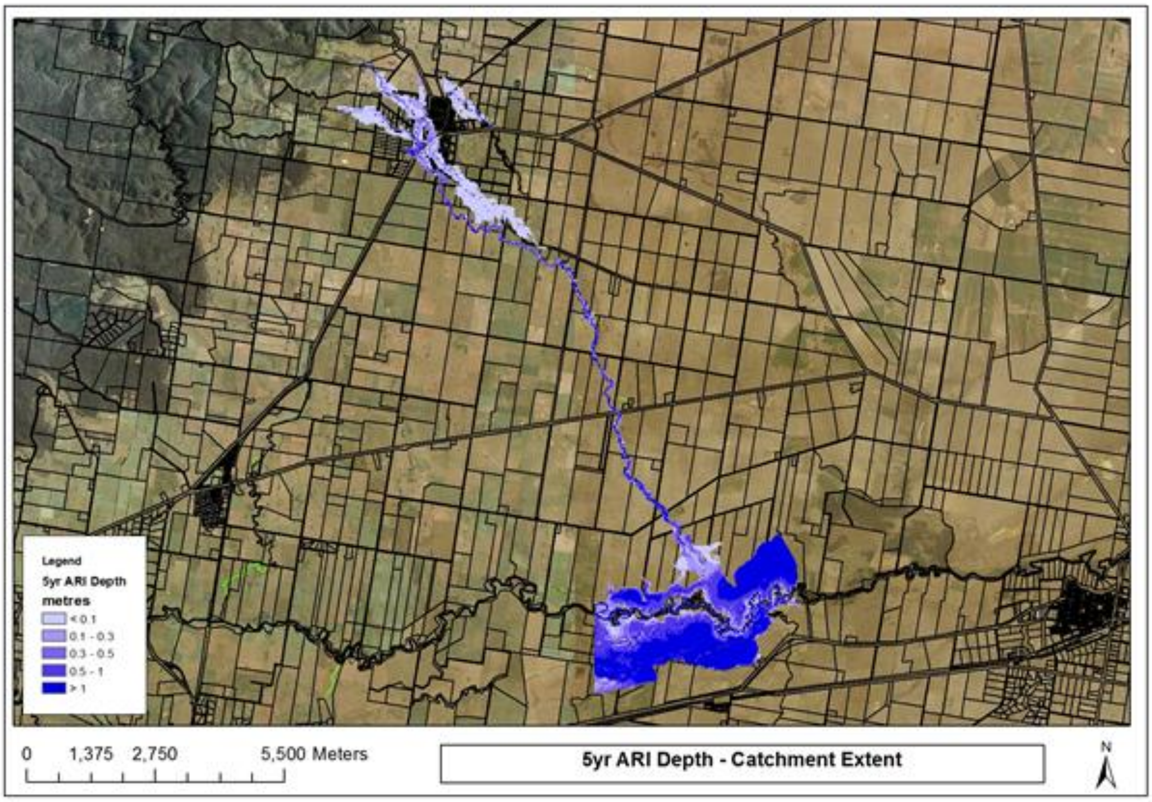
Appendix H1: Flood depth maps - Catchment Extent Hydraulic Model

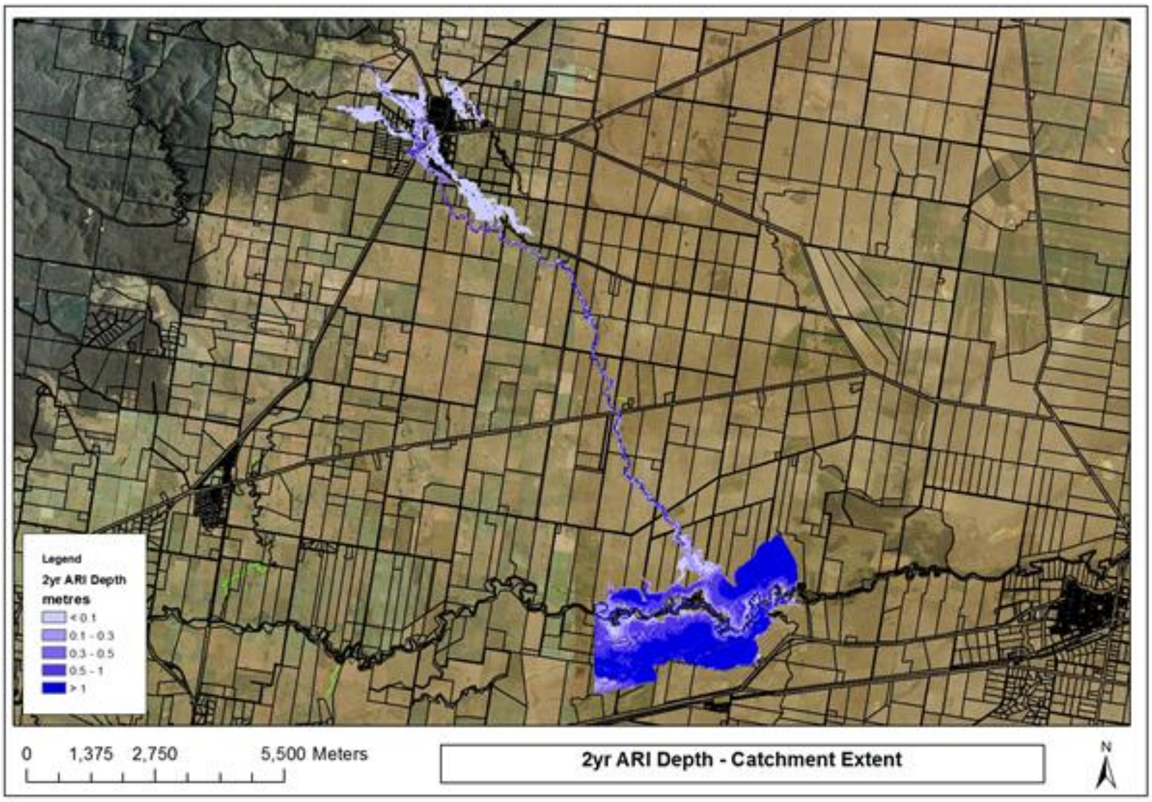

Legend
100yr ARI Depth
metres
<0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
>1
0 1,375 2,750 5,500 Meters
100yr ARI Depth - Catchment Extent
N


Legend
50yr ARI Depth
metres
<0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
> 1
0 1,375 2,750 5,500 Meters
50yr ARI Depth - Catchment Extent
N

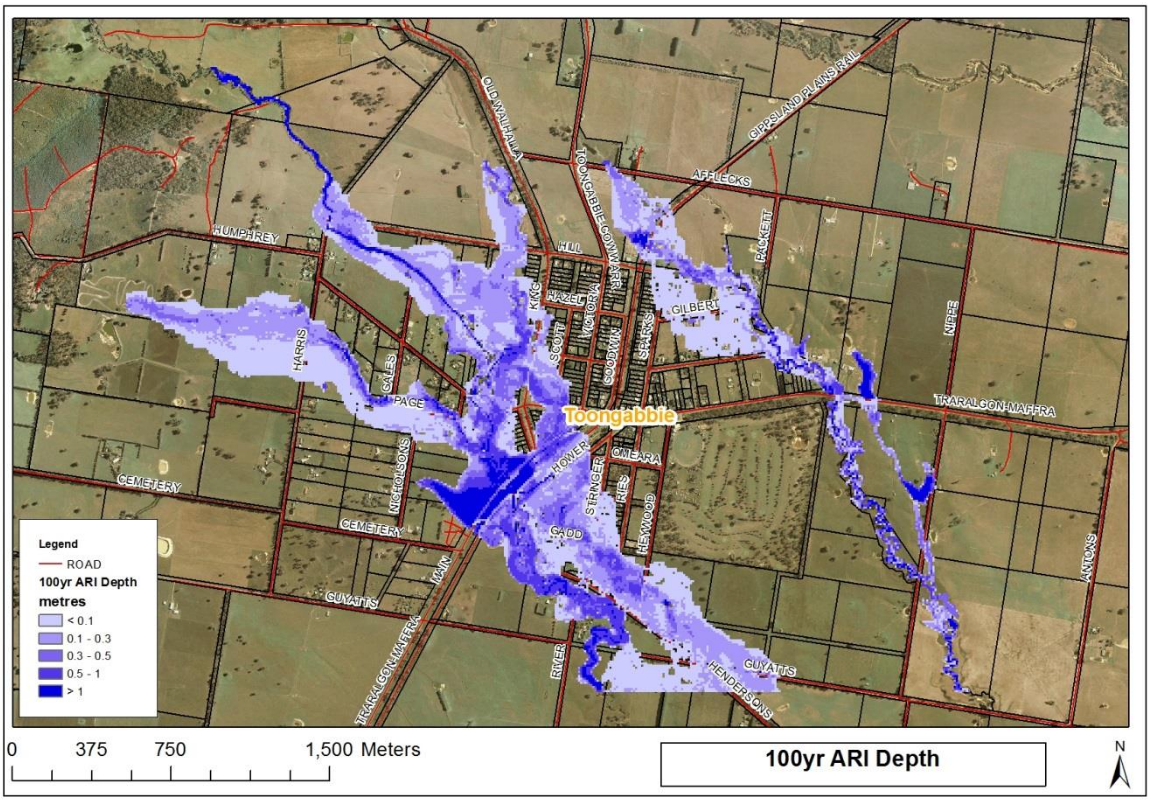

Legend
20yr ARI Depth
metres
< 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
> 1
0 1,375 2,750 5,500 Meters
20yr ARI Depth - Catchment Extent
N

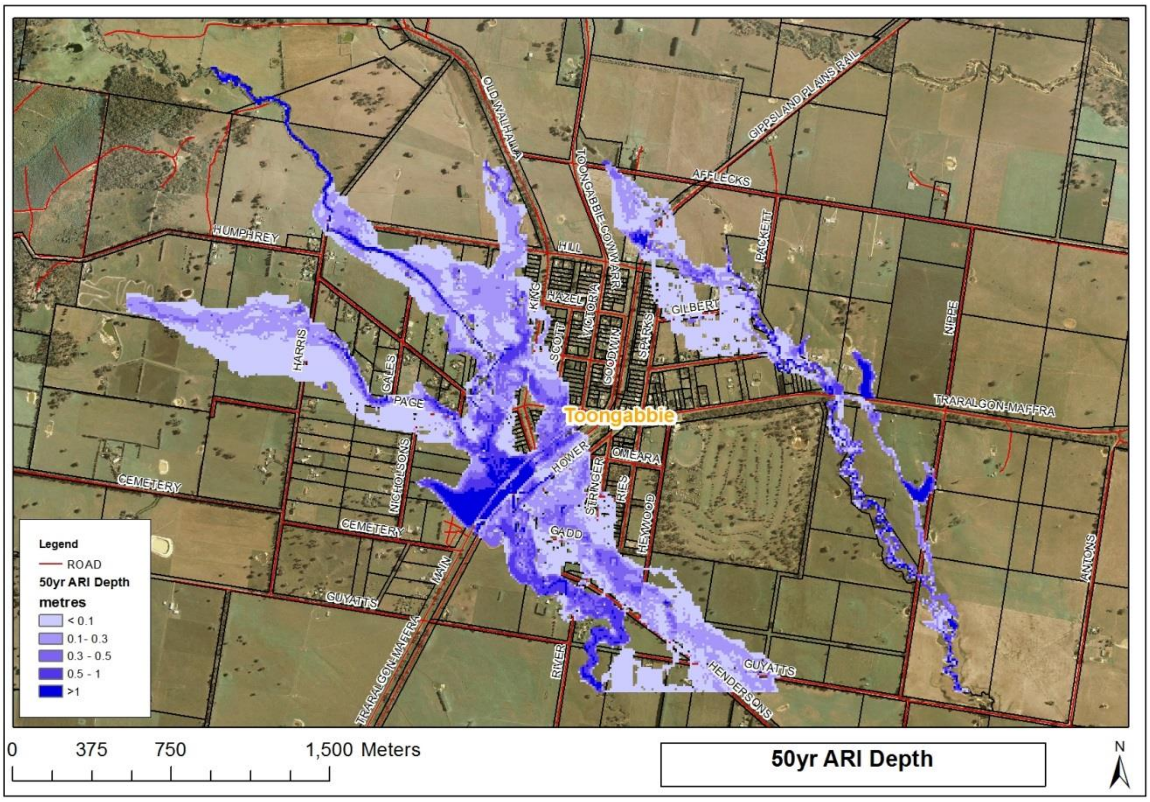

Legend
10yr ARI Depth
metres
< 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
> 1
0 1,375 2,750 5,500 Meters
10yr ARI Depth - Catchment Extent
N

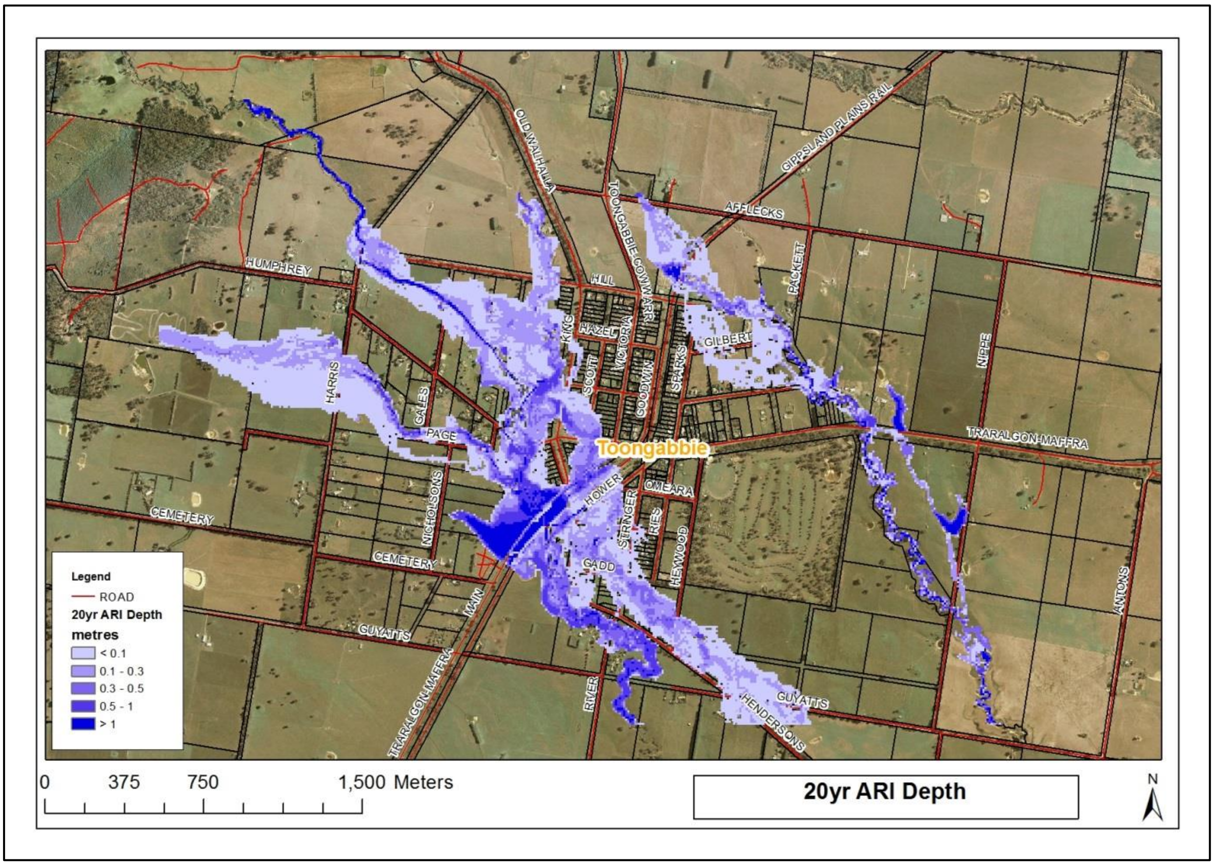

Legend
5yr ARI Depth
metres
< 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
> 1
0 1,375 2,750 5,500 Meters
5yr ARI Depth - Catchment Extent
N


Legend
2yr ARI Depth
metres
< 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
> 1
0 1,375 2,750 5,500 Meters
2yr ARI Depth - Catchment Extent
N

Appendix H2: Flood depth maps - Township Extent Hydraulic Model – Hydrograph flows



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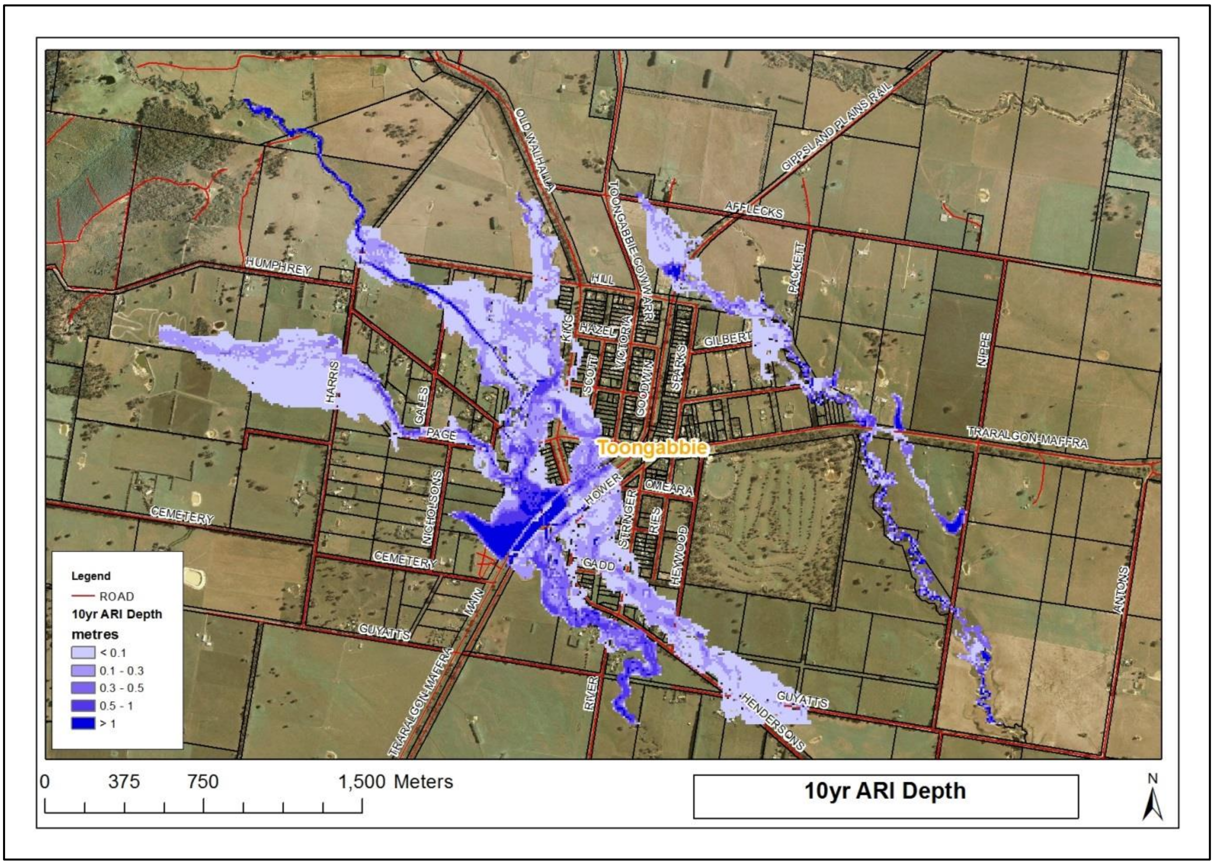
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
HUMPHREY
HILL
PACKETT
KING
HAZEL
VICTORIA
GILBERT
SCOTT
GOODWIN
SPARKS
HARRIS
GALES
NIPPE
PAGE
Toongabbie
TRARALGON-MAFFRA
NICHOLSONS
HOWER
OMEARA
CEMETERY
STRINGER
RIES
CEMETERY
HEYWOOD
GADD
MAIN
ANTONS
GUYATTS
TRARALGON-MAFFRA
RIVER
GUYATTS
HENDERSONS
Legend
ROAD
20yr ARI Depth
metres
< 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
> 1
0
375
750
1,500 Meters
20yr ARI Depth
N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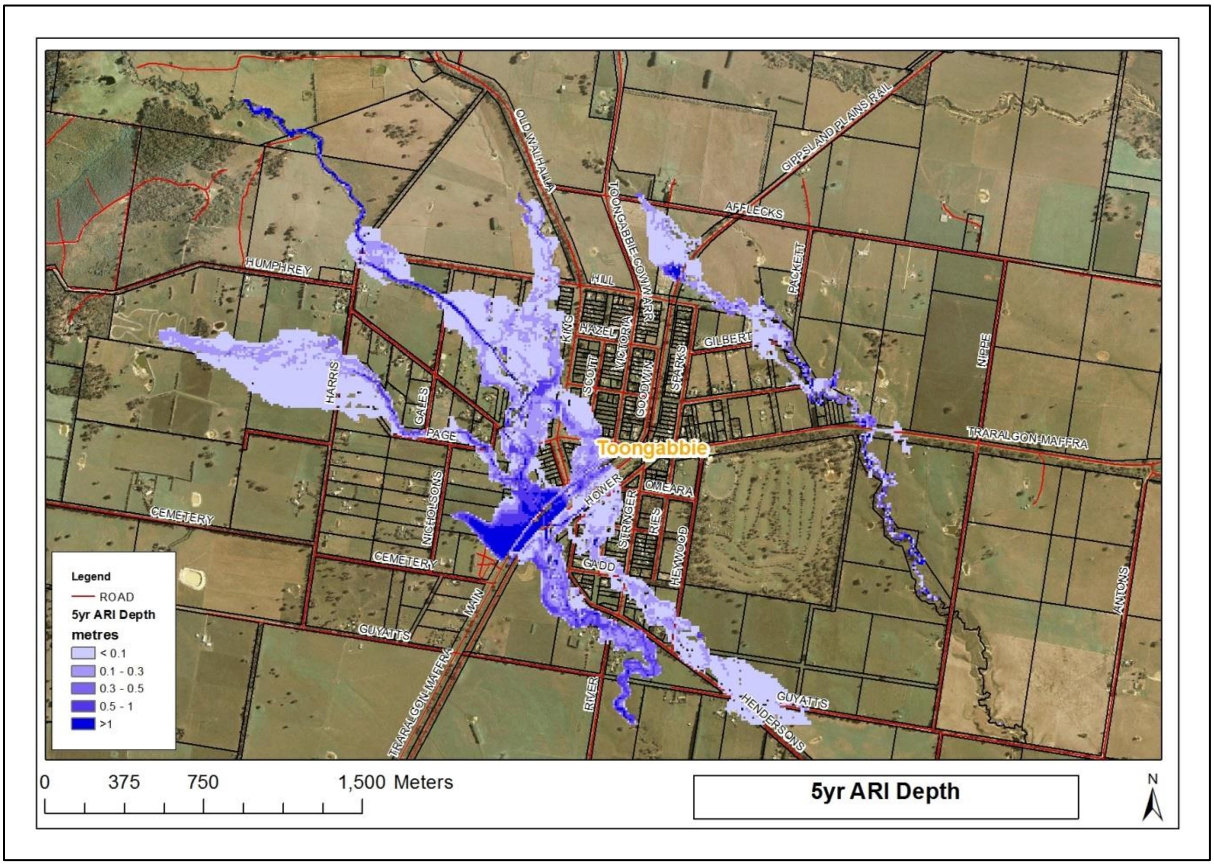
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
HUMPHREY
HILL
PACKETT
KING
HAZEL
VICTORIA
GILBERT
SCOTT
GOODWIN
SPARKS
HARRIS
GALES
NIPPE
PAGE
Toongabbie
TRARALGON-MAFFRA
NICHOLSONS
HOWER
OMEARA
CEMETERY
STRINGER
RIES
CEMETERY
HEYWOOD
GADD
MAIN
ANTONS
GUYATTS
TRARALGON-MAFFRA
RIVER
GUYATTS
HENDERSONS
Legend
ROAD
10yr ARI Depth
metres
< 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
> 1
0
375
750
1,500 Meters
10yr ARI Depth
N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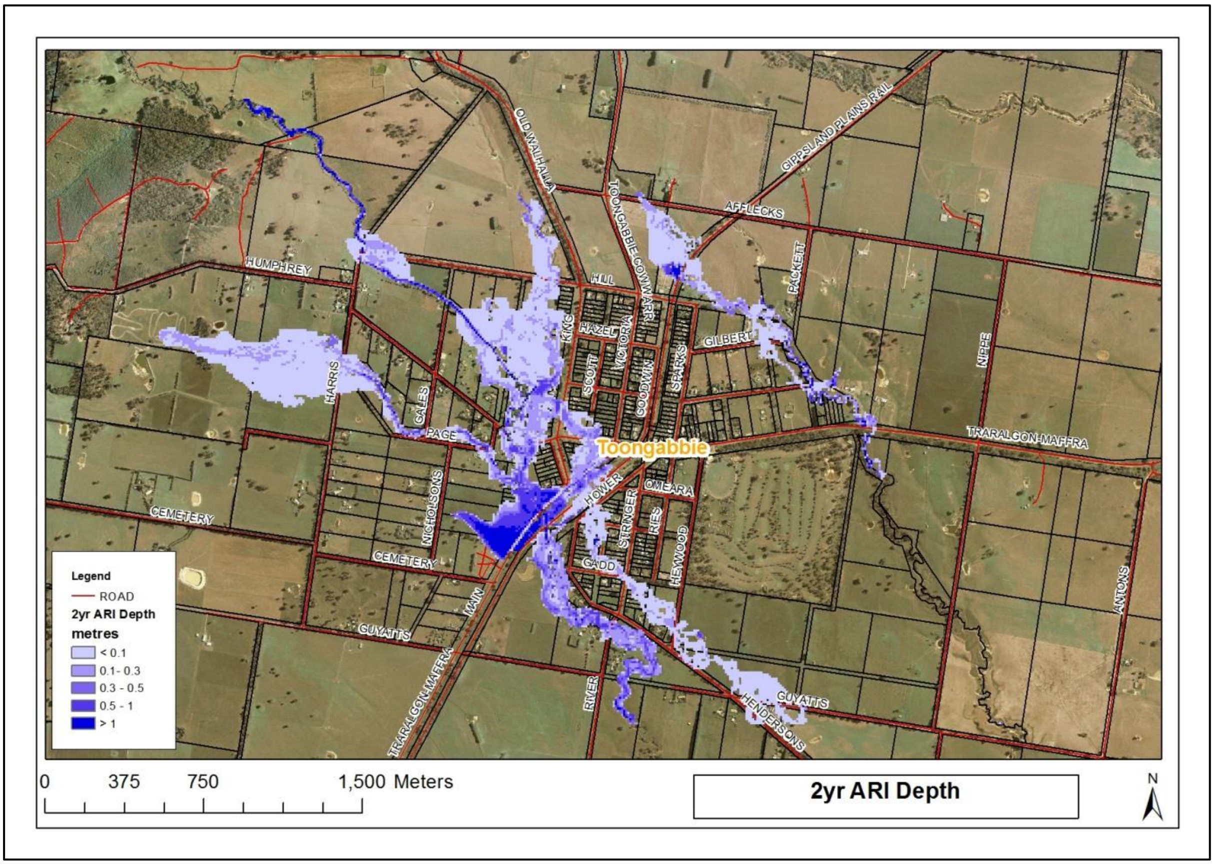
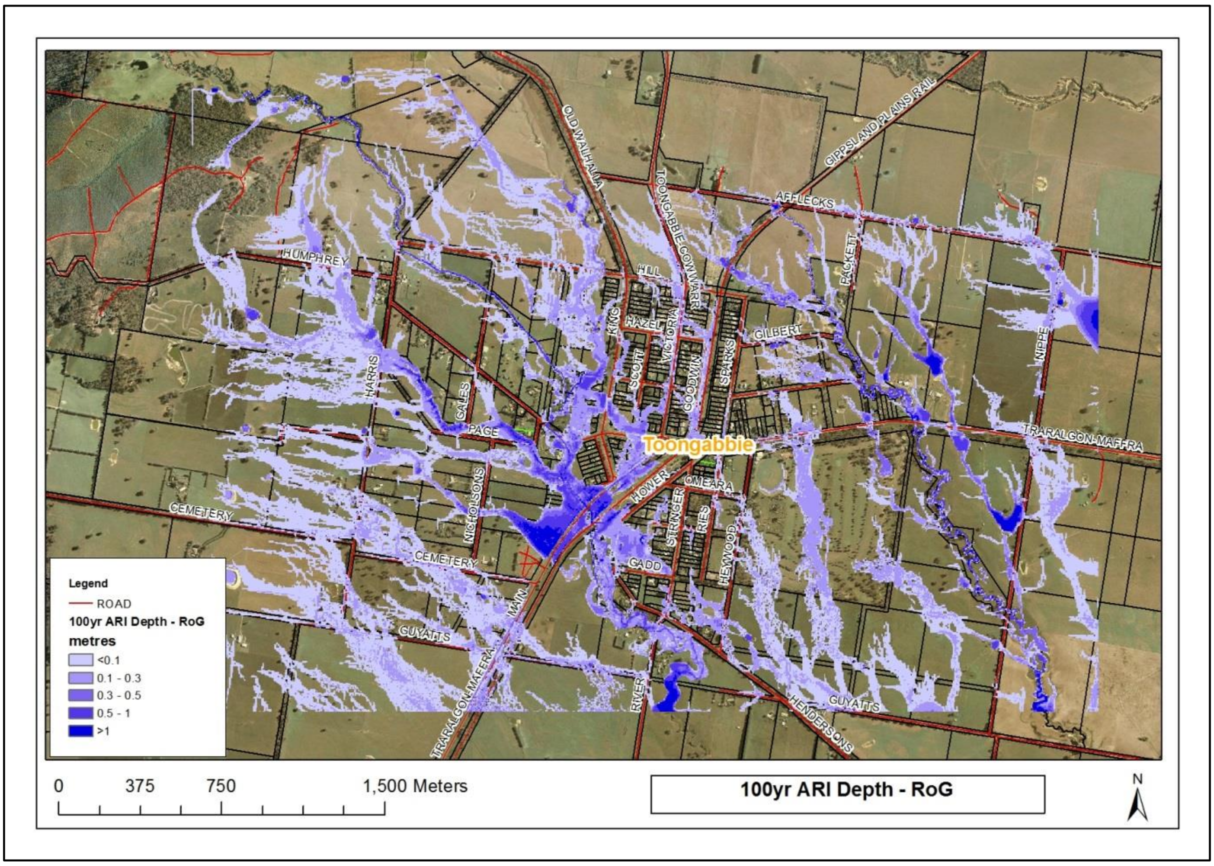
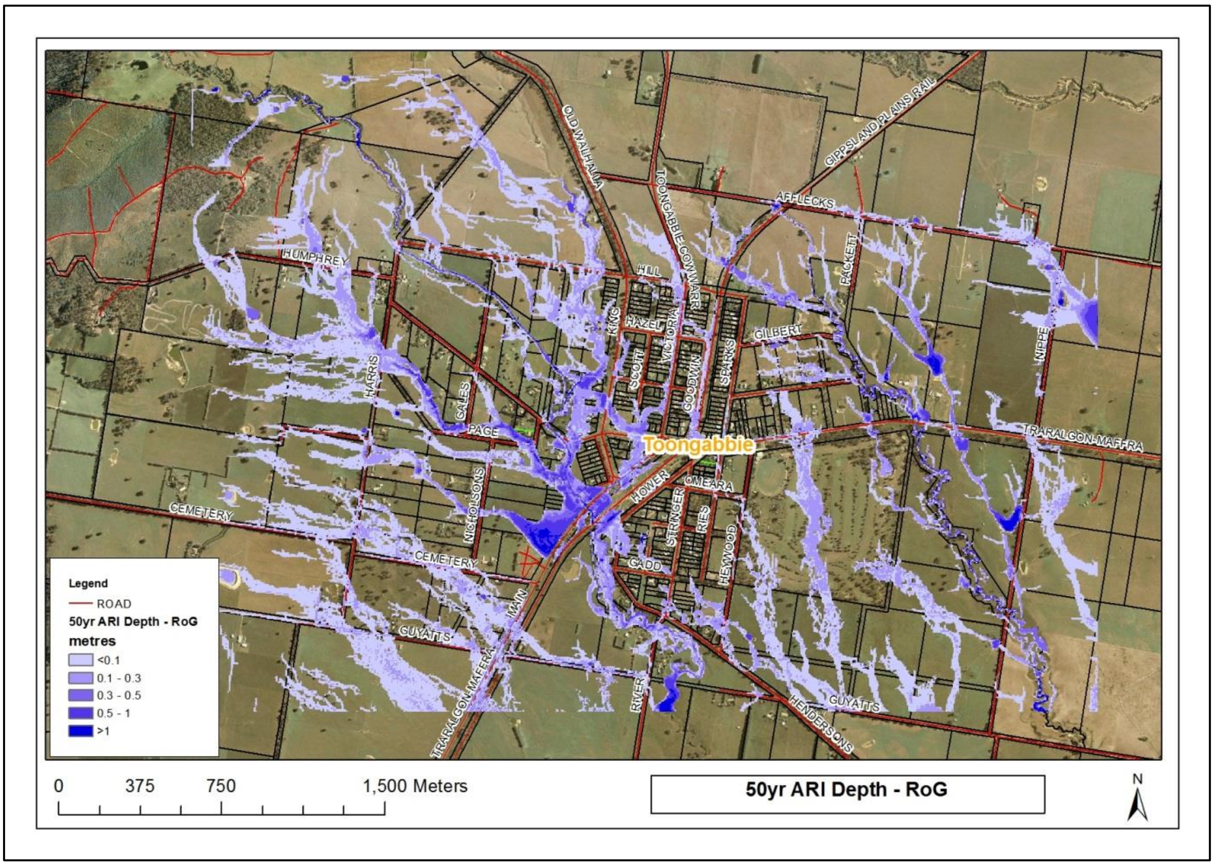
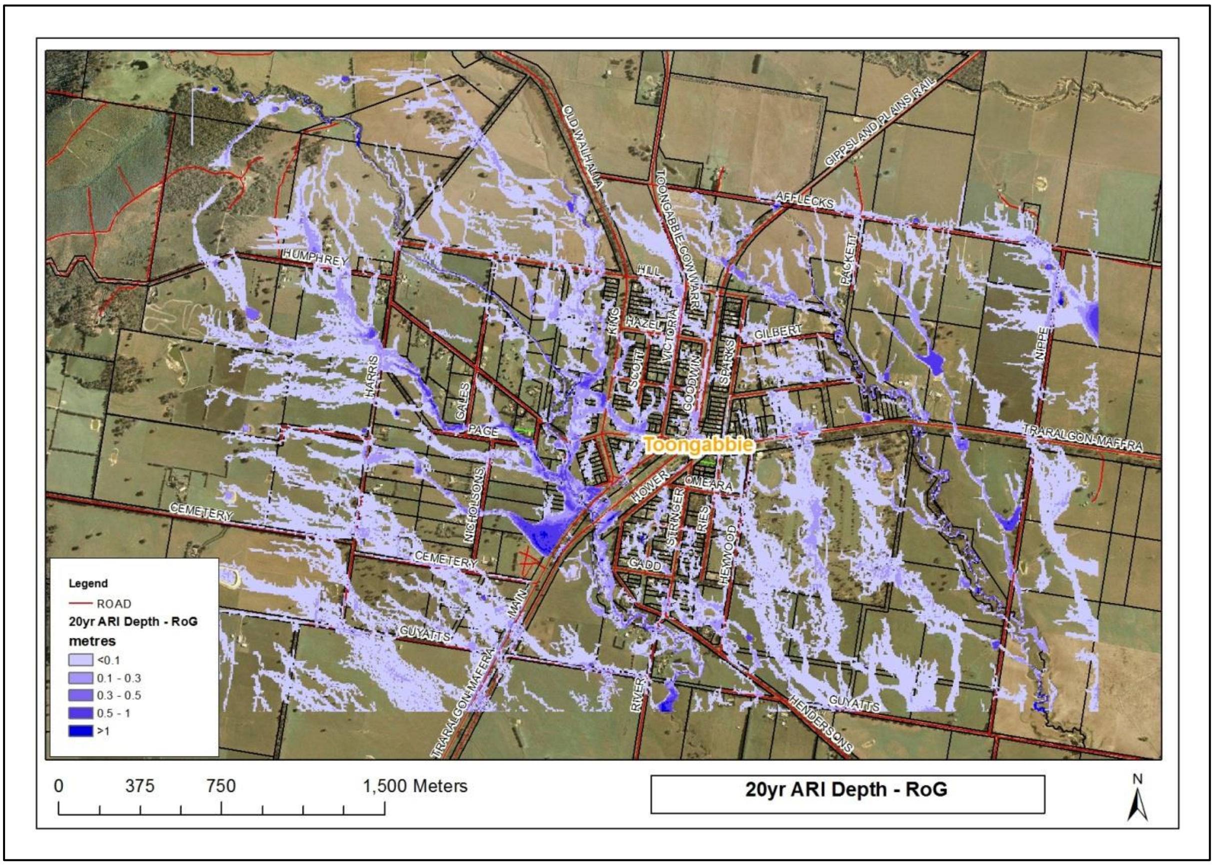
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
HUMPHREY
HILL
KING
HAZEL
VICTORIA
GOODWIN
SPARKS
SCOTT
GILBERT
PACKETT
NIPPE
HARRIS
GALES
PAGE
TRARALGON-MAFFRA
Toongabbie
NICHOLSONS
HOWER
OMEARA
STRINGER
RIES
HEYWOOD
CEMETERY
GADD
GUYATTS
MAIN
RIVER
HENDERSONS
ANTONS
Legend
ROAD
5yr ARI Depth
metres
< 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
>1
0 375 750 1,500 Meters
5yr ARI Depth
N


OLD WALHALLA
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
HUMPHREY
HILL
KING
HAZEL
VICTORIA
GOODWIN
SPARKS
SCOTT
GILBERT
PACKETT
NIPPE
HARRIS
GALES
PAGE
TRARALGON-MAFFRA
Toongabbie
NICHOLSONS
HOWER
OMEARA
STRINGER
RIES
HEYWOOD
CEMETERY
GADD
GUYATTS
MAIN
RIVER
HENDERSONS
ANTONS
Legend
ROAD
2yr ARI Depth
metres
< 0.1
0.1- 0.3
0.3 - 0.5
0.5 - 1
> 1
0 375 750 1,500 Meters
2yr ARI Depth
N

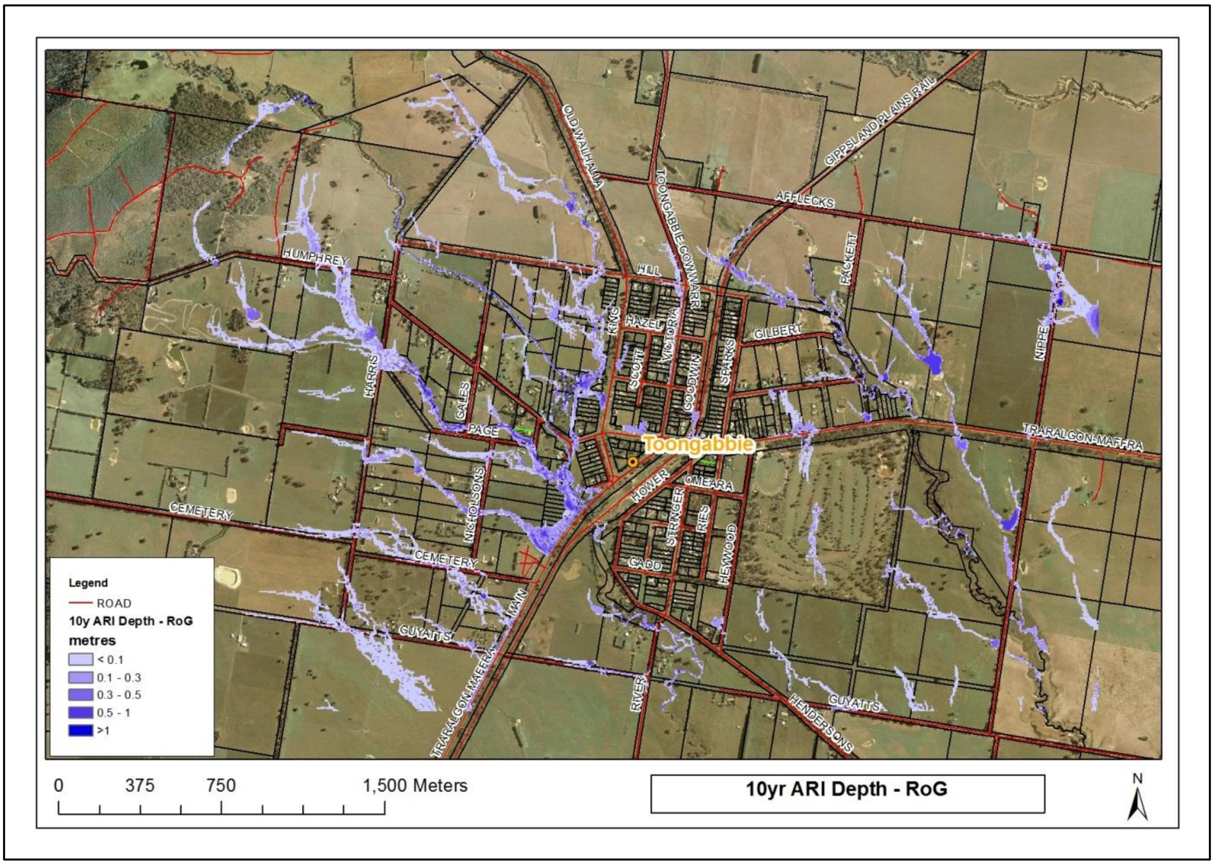
Appendix H3: Flood depth maps - Township Extent Hydraulic Model – Rain on grid







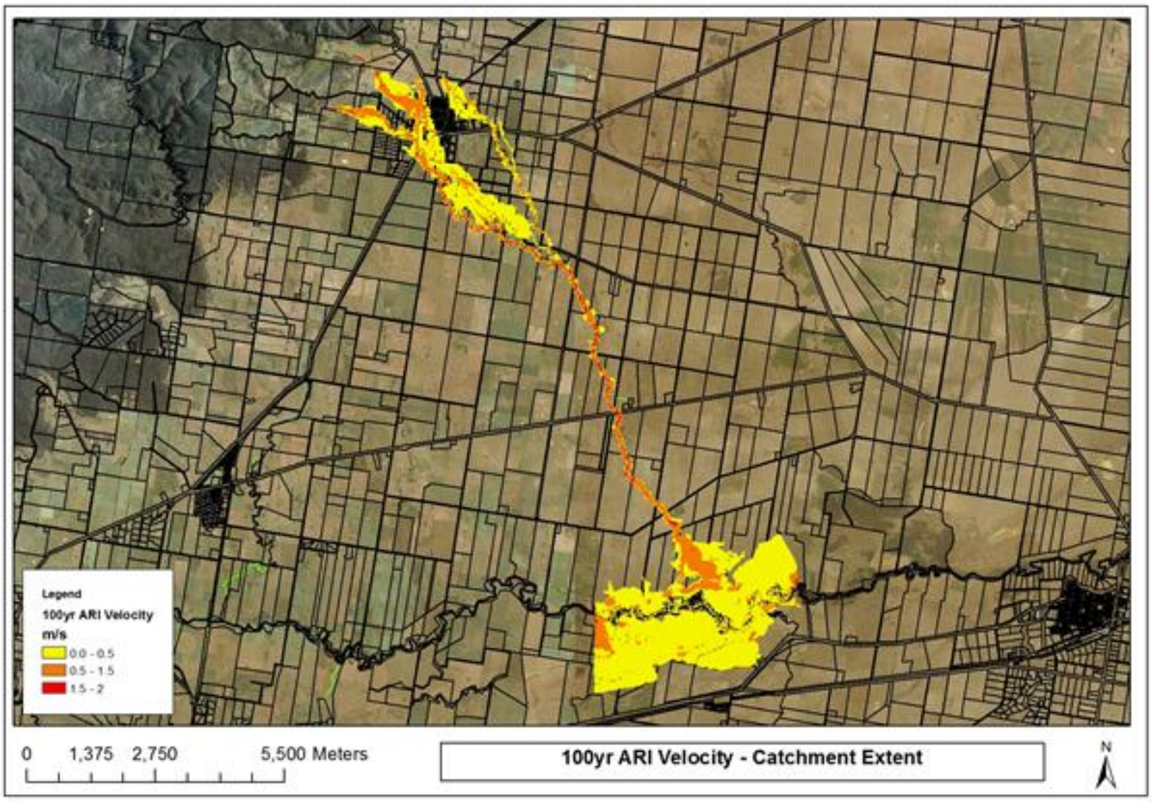
OLD WALHALLA
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
HUMPHREY
HILL
KING
HAZEL
SCOTT
VICTORIA
GOODWIN
SPARKS
GILBERT
RACKETT
NIPPE
HARRIS
GALES
PAGE
Toongabbie
TRARALGON-MAFFRA
NICHOLSONS
HOWER
O'MEARA
STRINGER
RES
HEYWOOD
CEMETERY
GADD
MAIN
GUYATTS
RIVER
HENDERSONS
Legend
ROAD
20yr ARI Depth - RoG
metres
<0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
>1
0 375 750 1,500 Meters
20yr ARI Depth - RoG
N

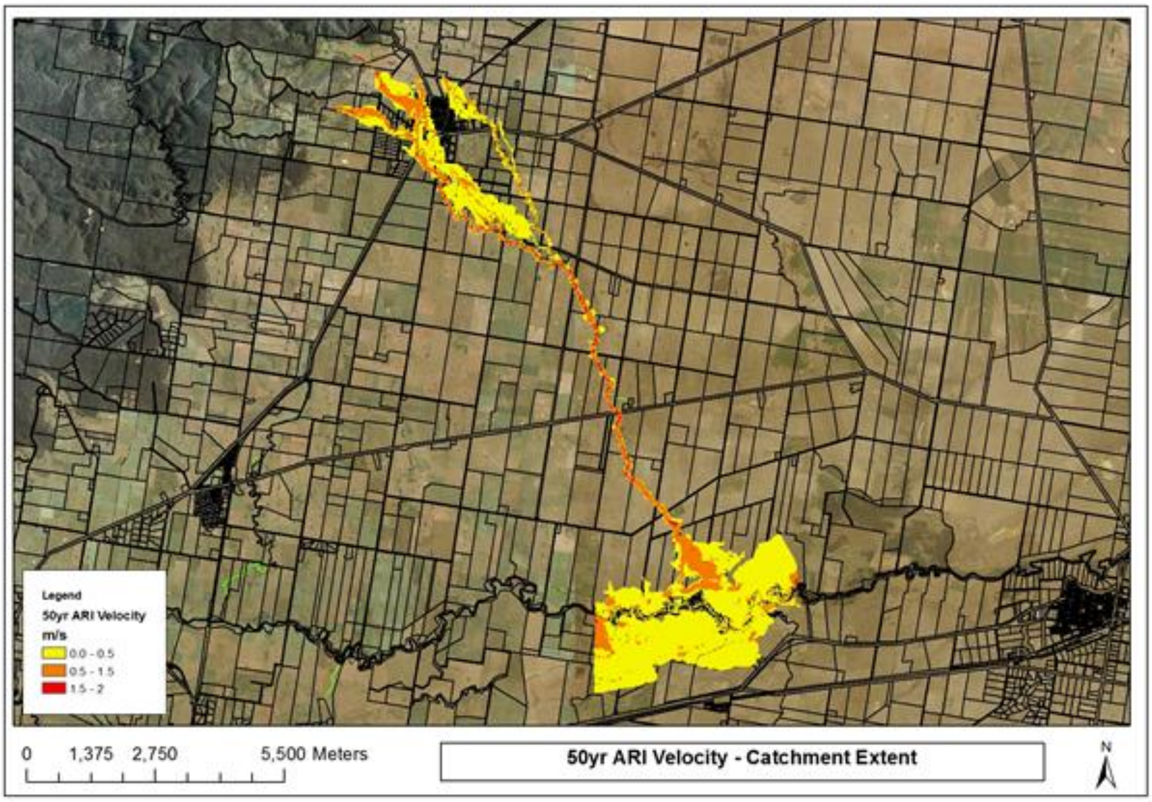


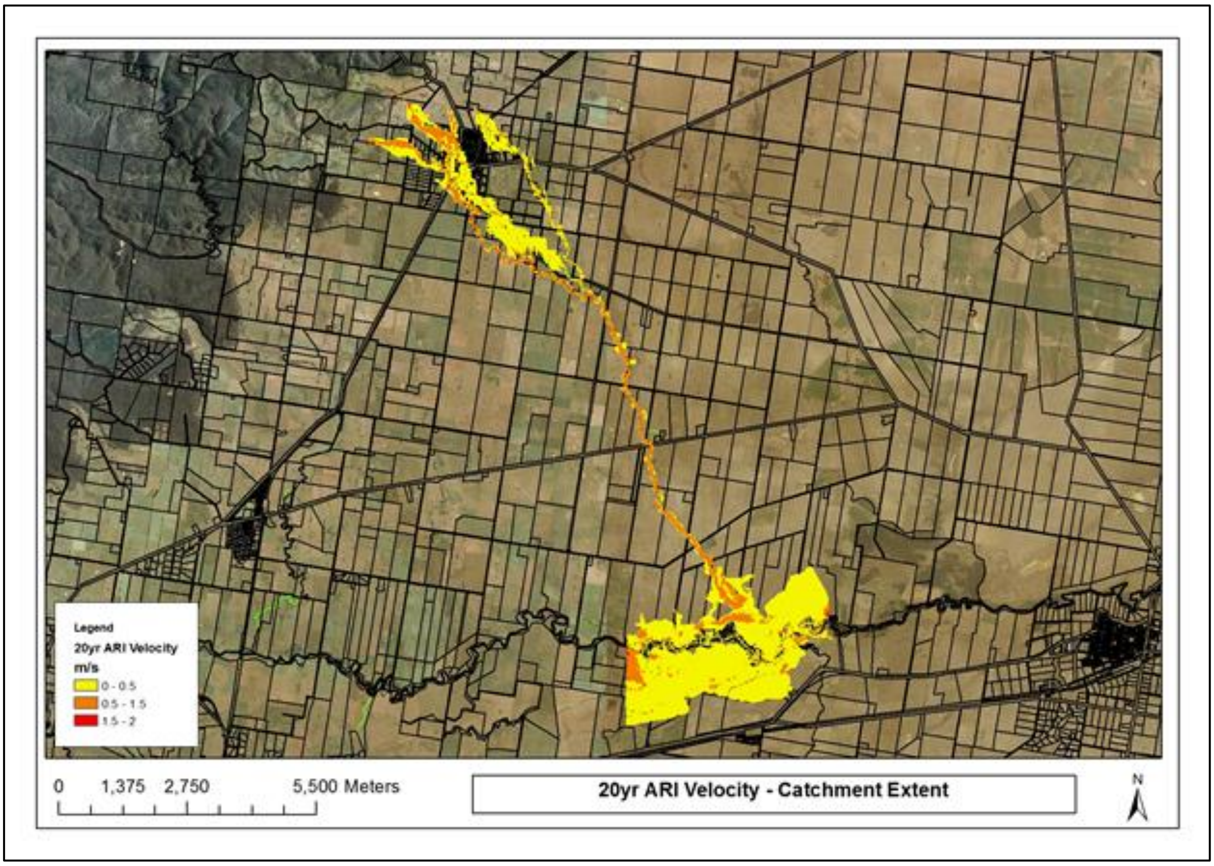
OLD WALHALLA
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
HUMPHREY
HILL
KING
HAZEL
SCOTT
VICTORIA
GOODWIN
SPARKS
GILBERT
RACKETT
NIPPE
HARRIS
GALES
PAGE
Toongabbie
TRARALGON-MAFFRA
NICHOLSONS
HOWER
O'MEARA
STRINGER
RES
HEYWOOD
CEMETERY
GADD
MAIN
GUYATTS
RIVER
HENDERSONS
Legend
ROAD
10y ARI Depth - RoG
metres
< 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
>1
0 375 750 1,500 Meters
10yr ARI Depth - RoG
N

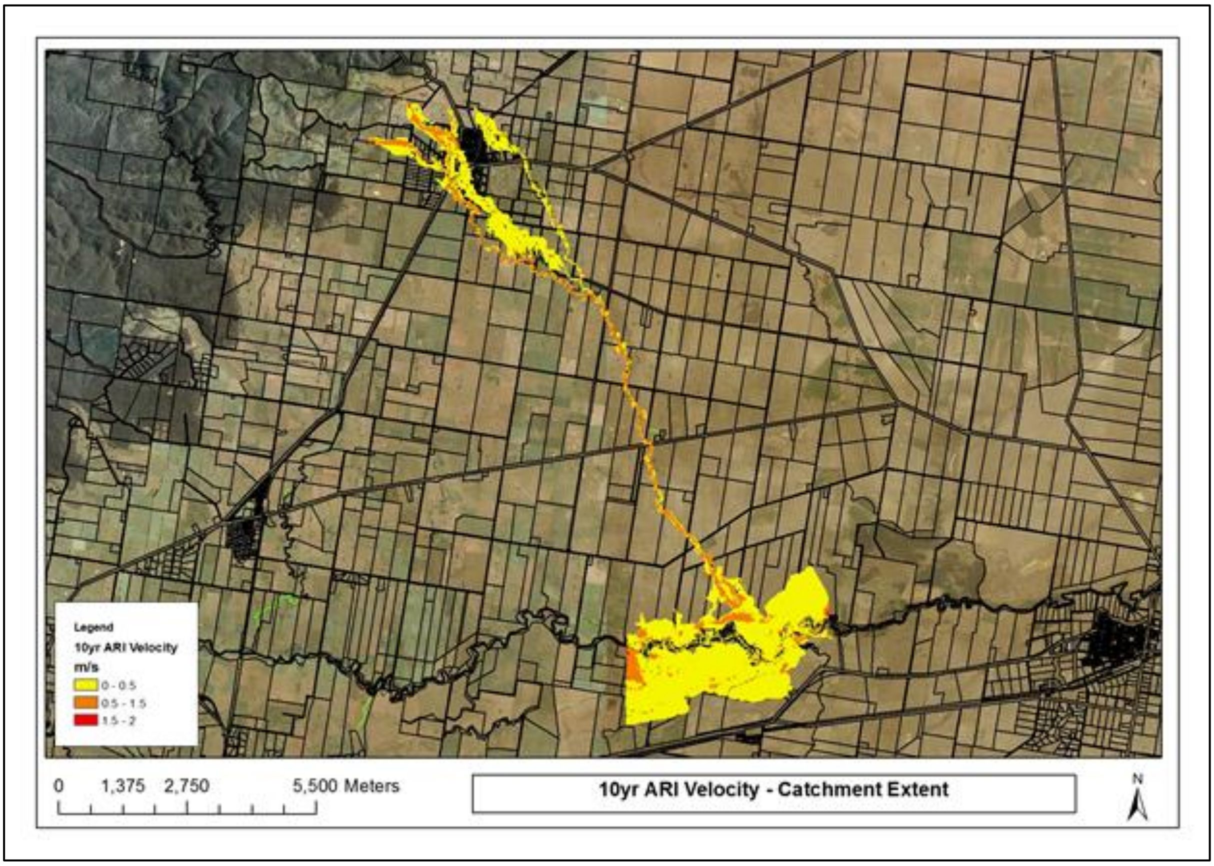
Appendix I: Flood flow velocity maps

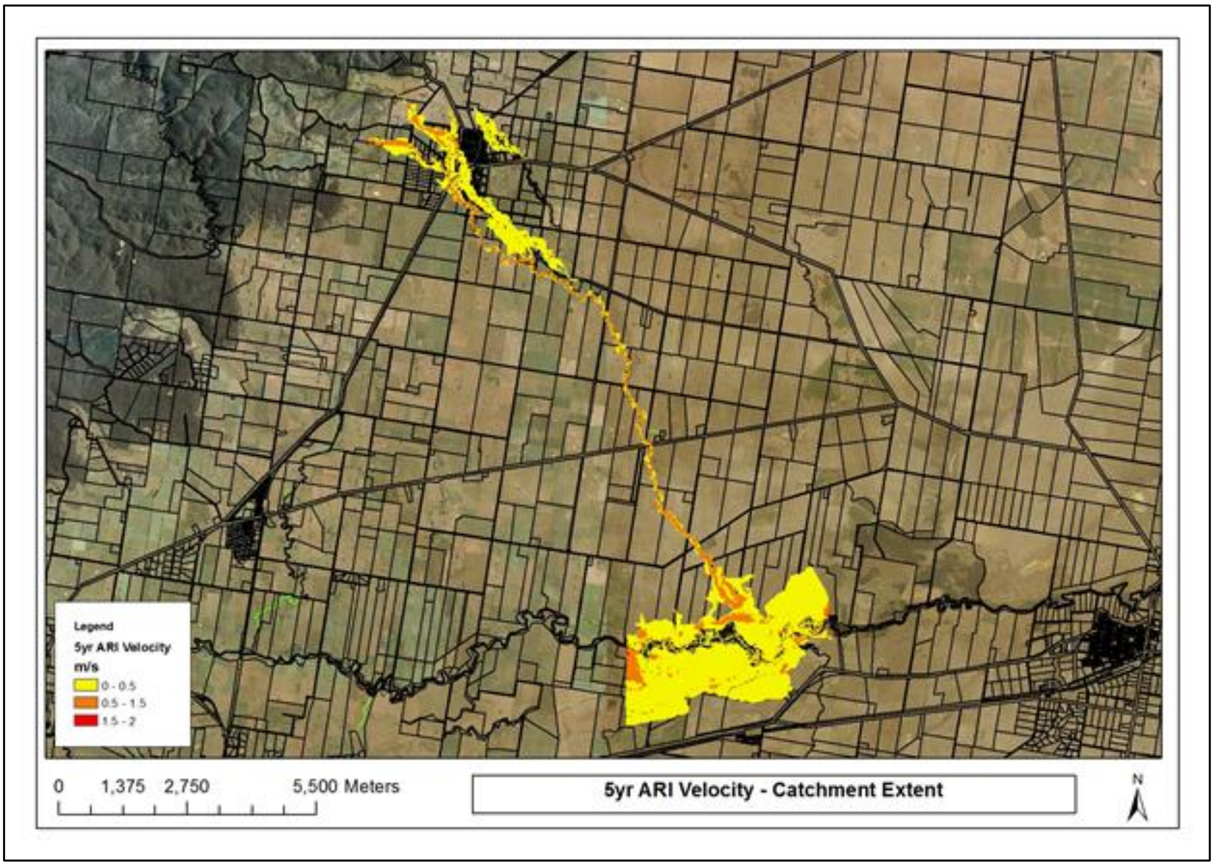
Appendix I3: Flood flow velocity maps–Catchment Extent Model

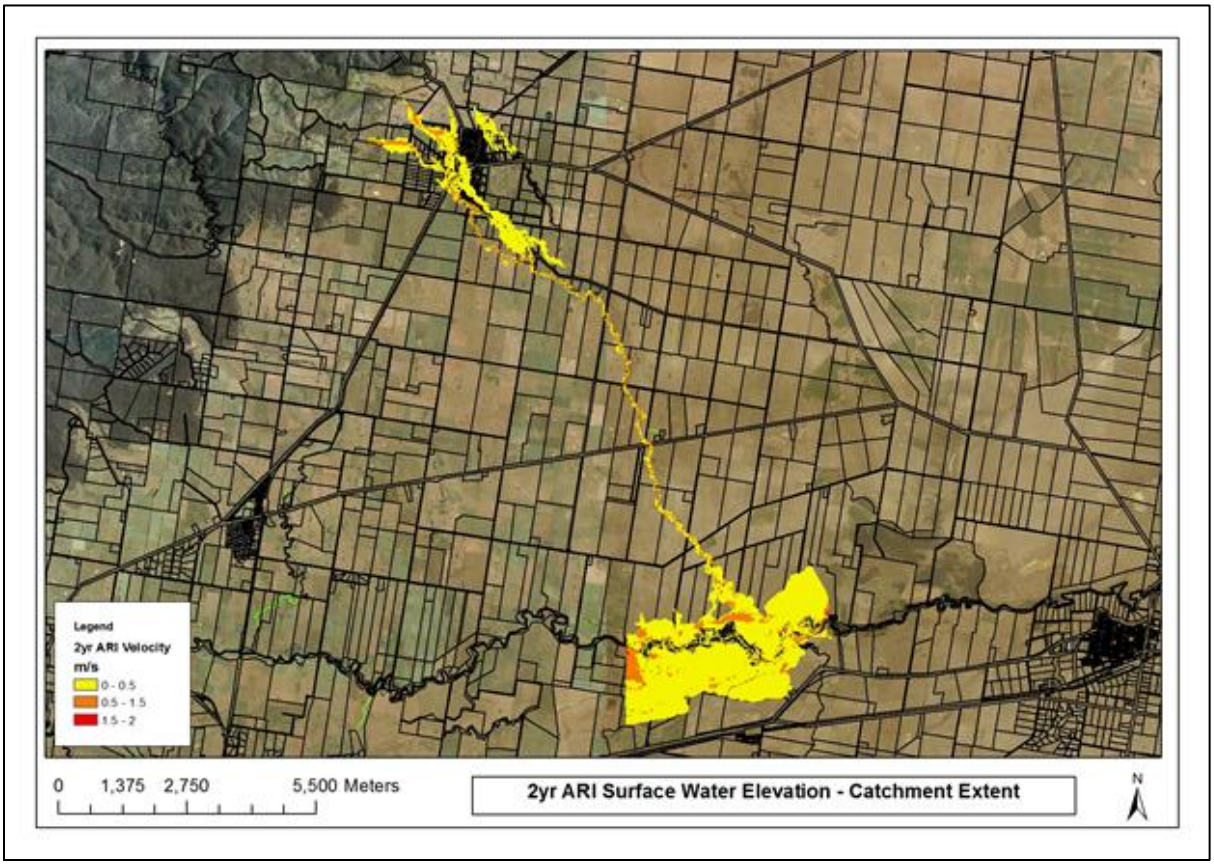

Legend
100yr ARI Velocity
m/s
0.0 - 0.5
0.5 - 1.5
1.5 - 2
0 1,375 2,750 5,500 Meters
100yr ARI Velocity - Catchment Extent
N


Legend
50yr ARI Velocity
m/s
0.0 - 0.5
0.5 - 1.5
1.5 - 2
0 1,375 2,750 5,500 Meters
50yr ARI Velocity - Catchment Extent
N

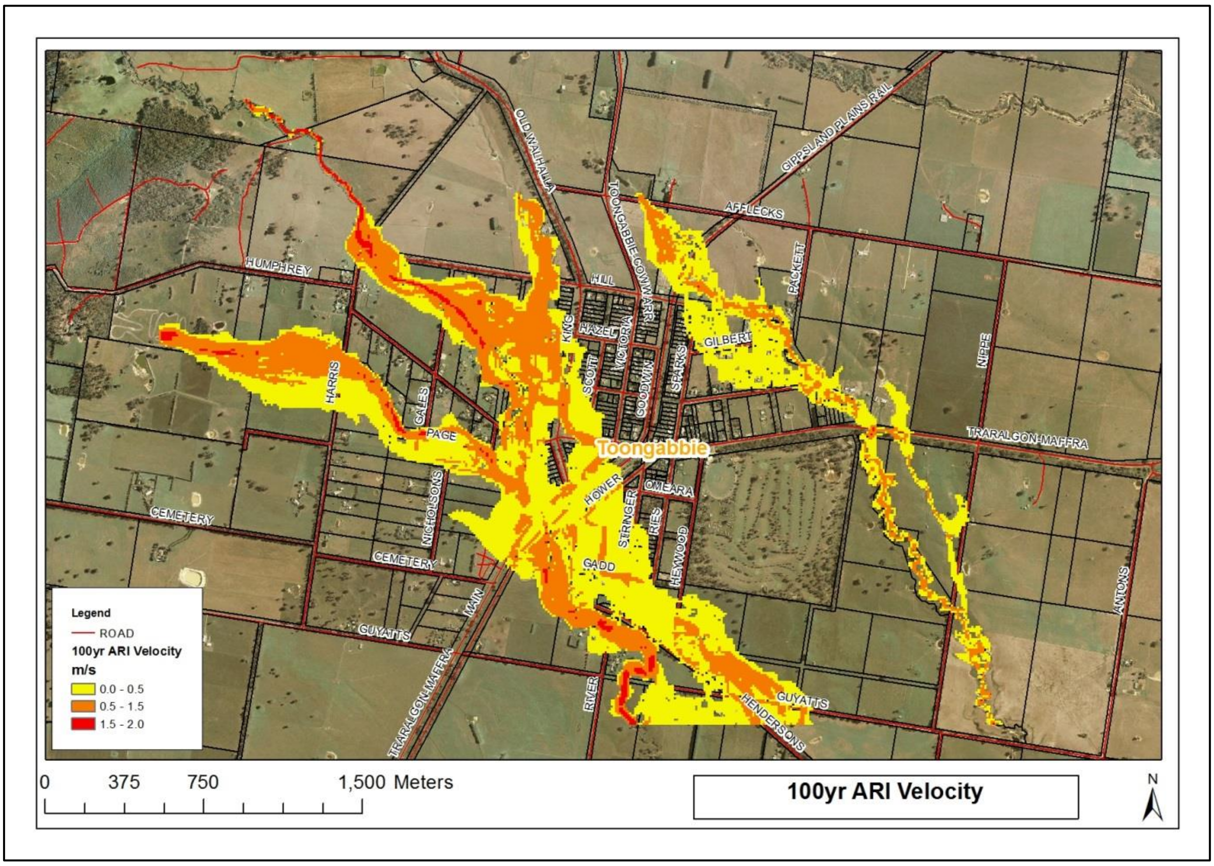

Legend
20yr ARI Velocity
m/s
0 - 0.5
0.5 - 1.5
1.5 - 2
0 1,375 2,750 5,500 Meters
20yr ARI Velocity - Catchment Extent
N

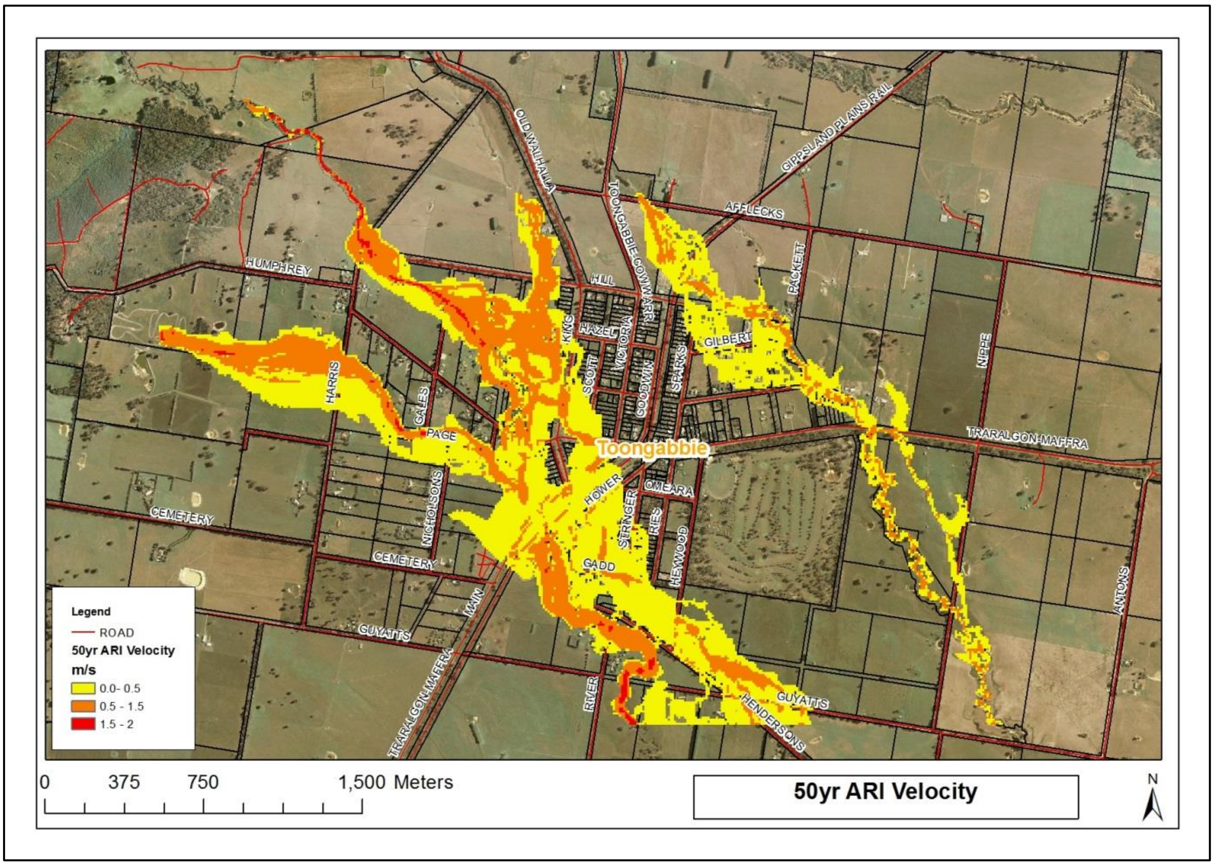

Legend
10yr ARI Velocity
m/s
0 - 0.5
0.5 - 1.5
1.5 - 2
0 1,375 2,750 5,500 Meters
10yr ARI Velocity - Catchment Extent
N

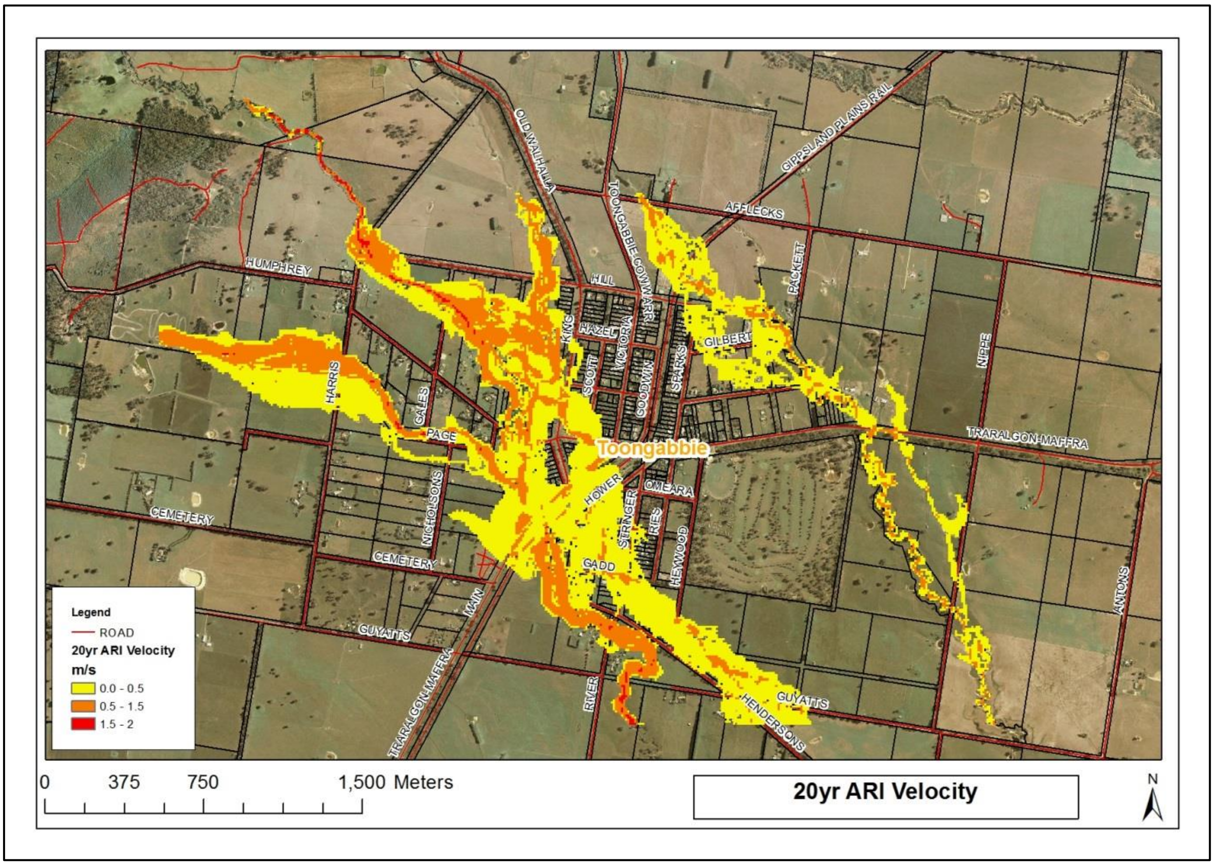

Legend
5yr ARI Velocity
m/s
0 - 0.5
0.5 - 1.5
1.5 - 2
0
1,375
2,750
5,500 Meters
5yr ARI Velocity - Catchment Extent
N

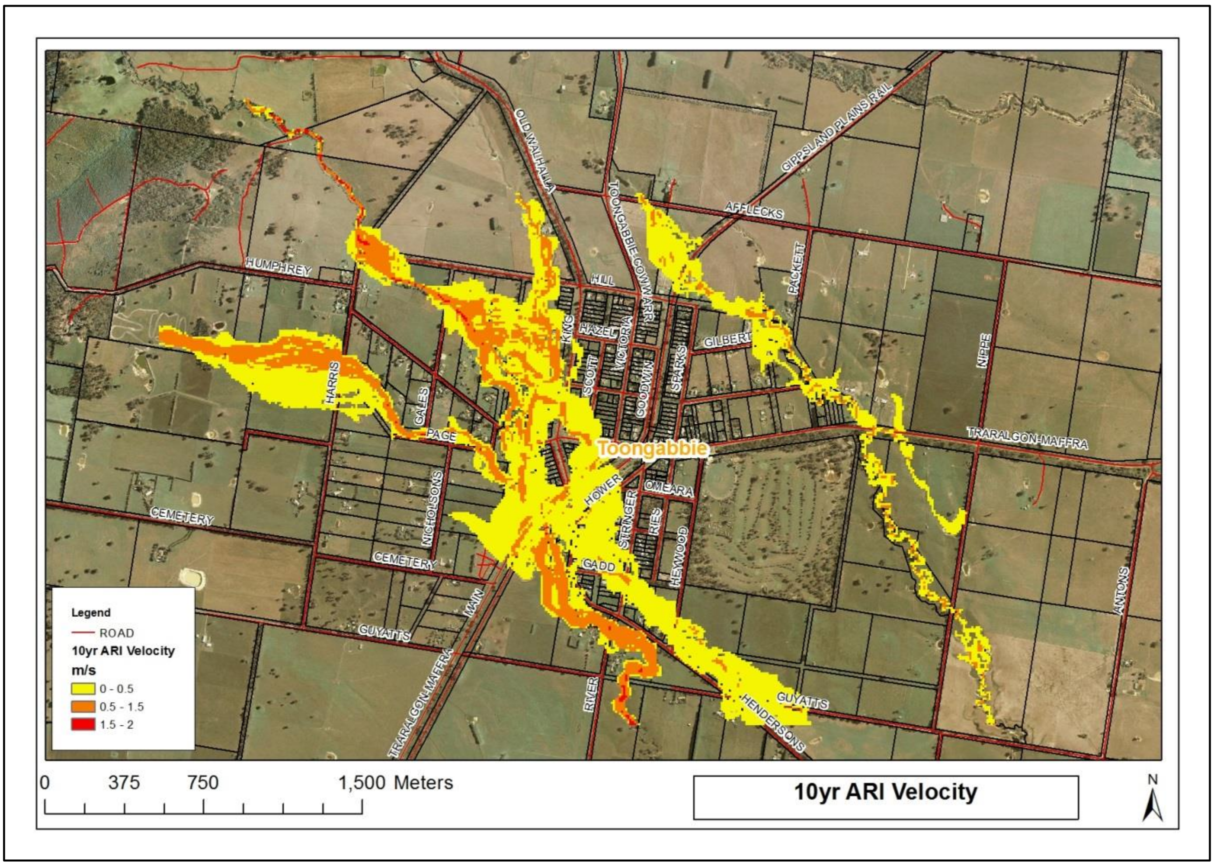

Legend
2yr ARI Velocity
m/s
0 - 0.5
0.5 - 1.5
1.5 - 2
0
1,375
2,750
5,500 Meters
2yr ARI Surface Water Elevation - Catchment Extent
N

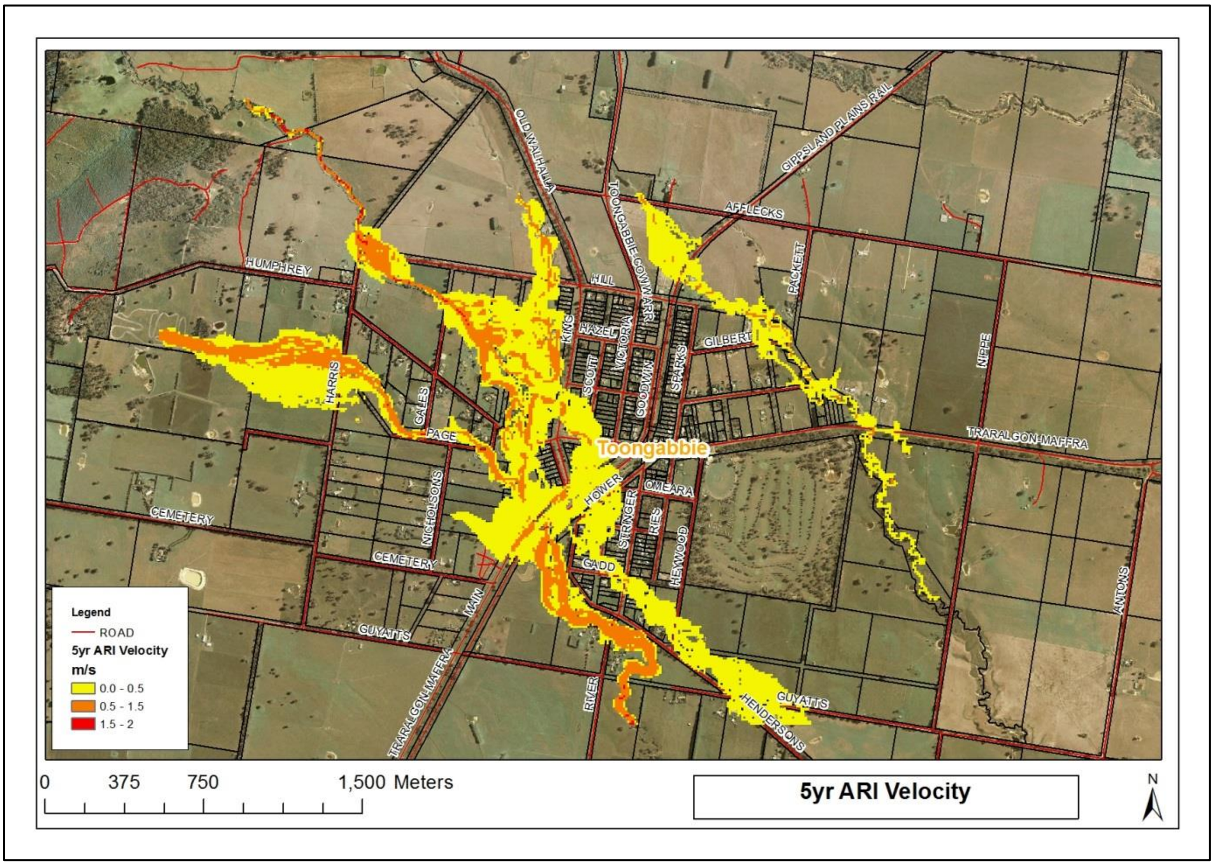
Appendix I2: Flood flow velocity maps - Township Extent Hydraulic Model – Hydrograph Flows

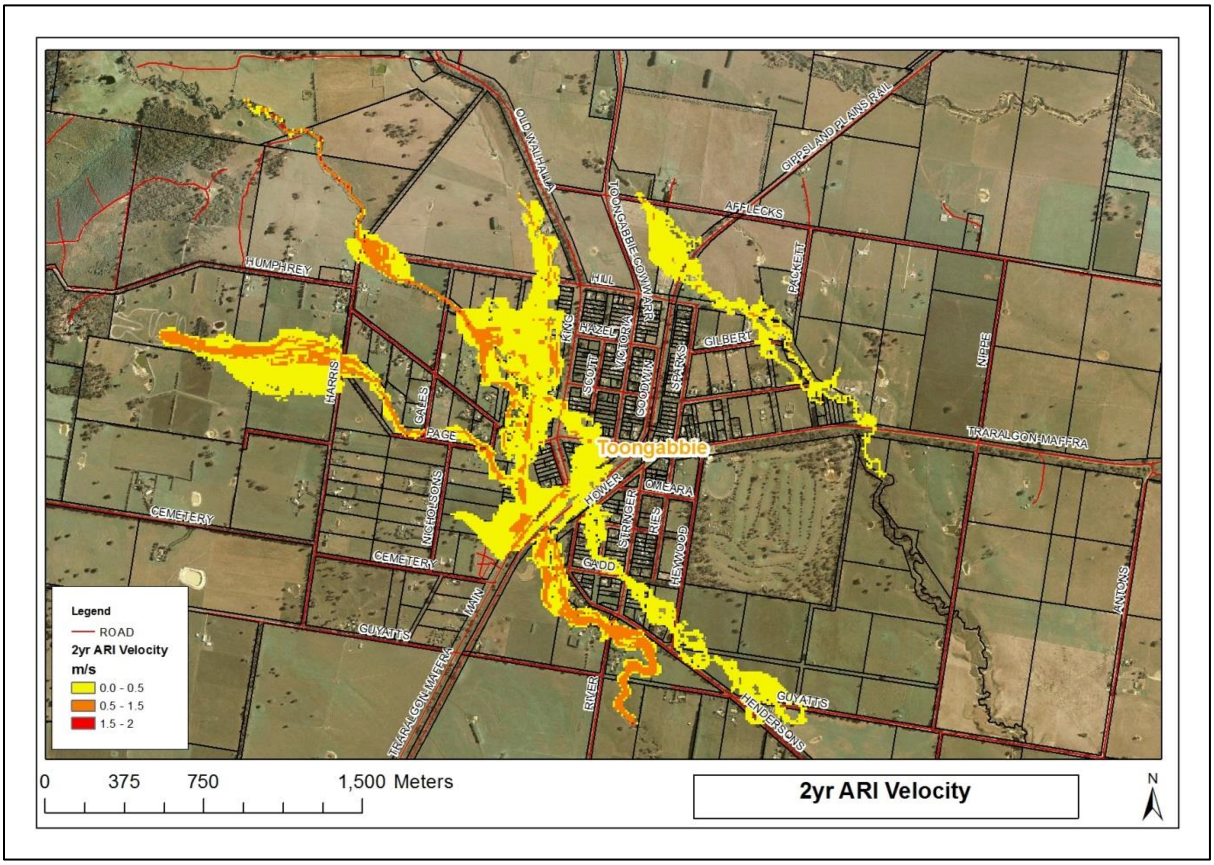




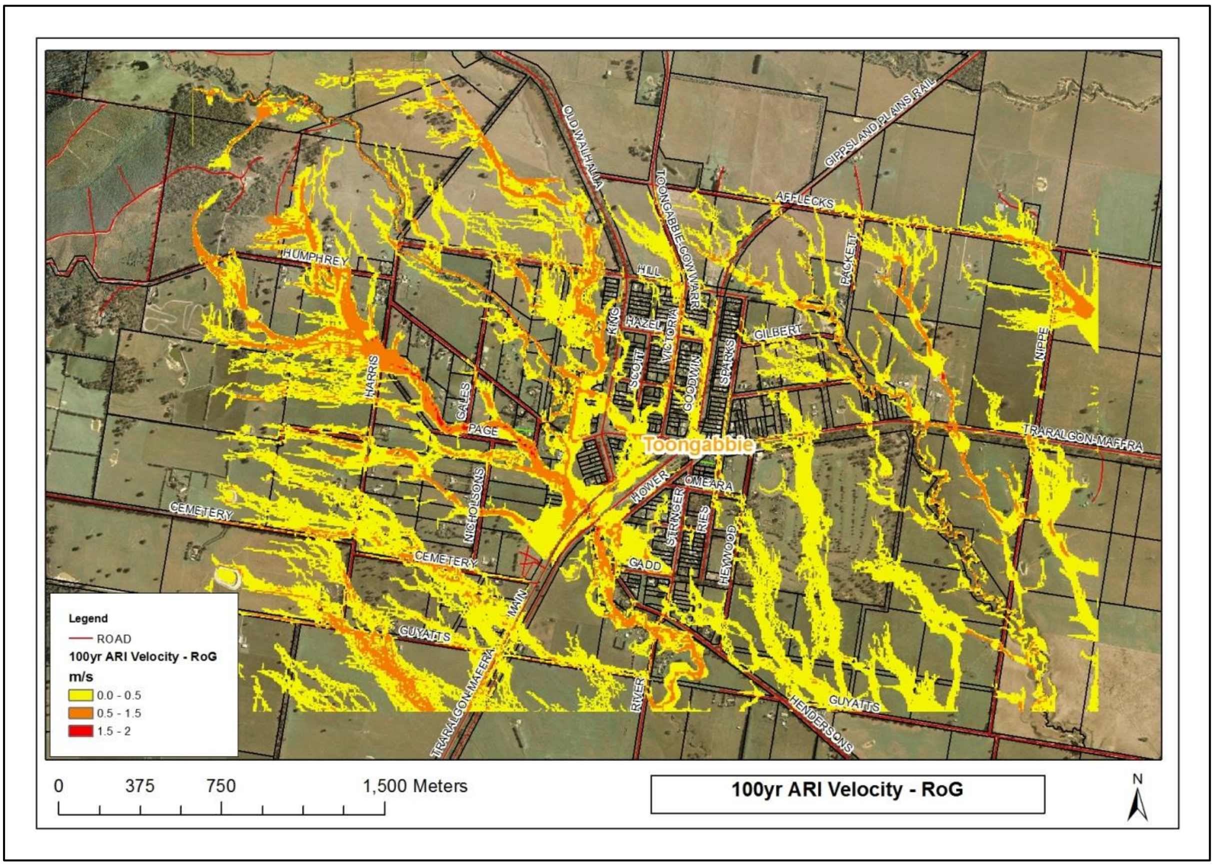

OLD WALHALLA
GIPPSLAND PLAINS RAIL
TOONGABBIE-COWWARR
AFFLECKS
HUMPHREY
HILL
BACKETT
KING
HAZEL
VICTORIA
GILBERT
HARRIS
GALES
SCOTT
GOODWIN
SPARKS
NIPPE
TRARALGON-MAFFRA
PAGE
Toongabbie
HOWER
OMEARA
NICHOLSONS
STRINGER
RIES
HEYWOOD
CEMETERY
CEMETERY
GADD
ANTONS
Legend
ROAD
20yr ARI Velocity
m/s
0.0 - 0.5
0.5 - 1.5
1.5 - 2
GUYATTS
MAIN
TRARALGON-MAFFRA
RIVER
GUYATTS
HENDERSONS
0
375
750
1,500 Meters
20yr ARI Velocity
N

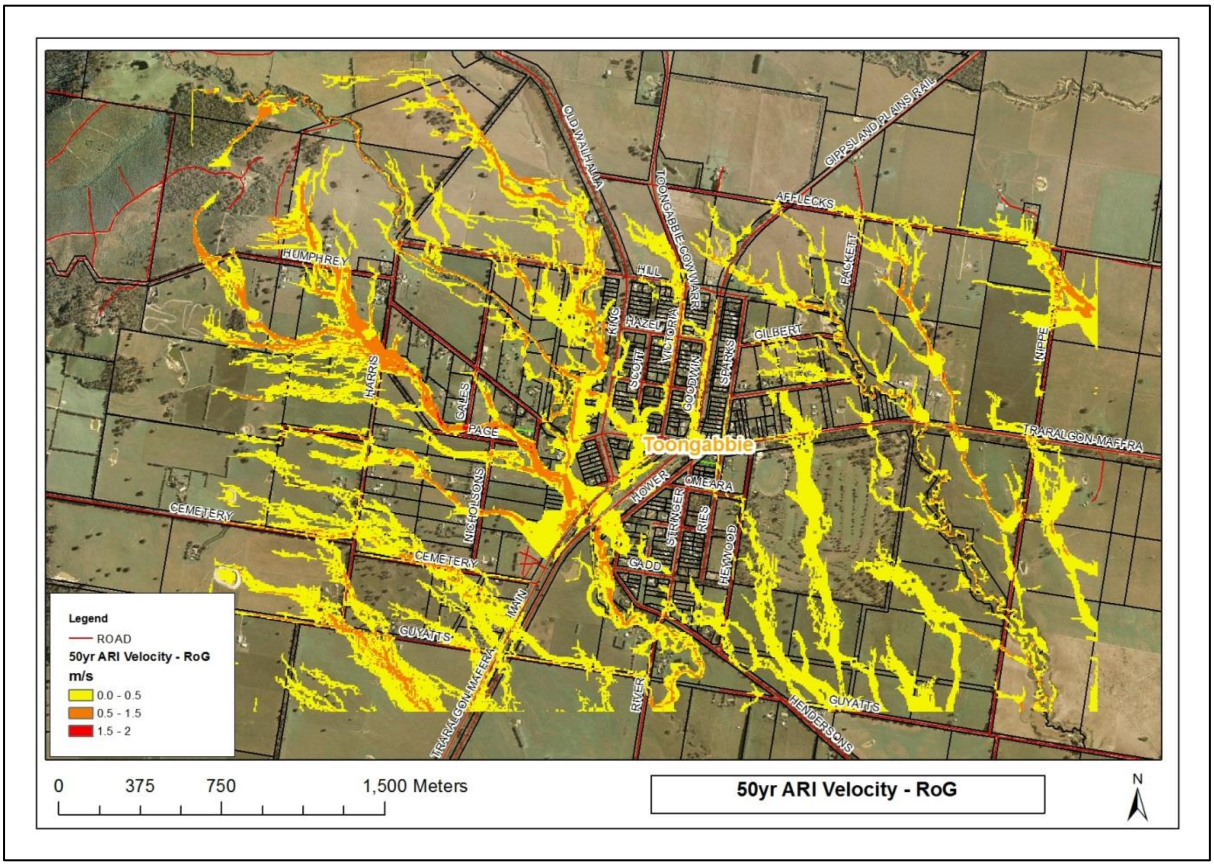

OLD WALHALLA
GIPPSLAND PLAINS RAIL
TOONGABBIE-COWWARR
AFFLECKS
HUMPHREY
HILL
BACKETT
KING
HAZEL
VICTORIA
GILBERT
HARRIS
GALES
SCOTT
GOODWIN
SPARKS
NIPPE
TRARALGON-MAFFRA
PAGE
Toongabbie
HOWER
OMEARA
NICHOLSONS
STRINGER
RIES
HEYWOOD
CEMETERY
CEMETERY
GADD
ANTONS
Legend
ROAD
10yr ARI Velocity
m/s
0 - 0.5
0.5 - 1.5
1.5 - 2
GUYATTS
MAIN
TRARALGON-MAFFRA
RIVER
GUYATTS
HENDERSONS
0
375
750
1,500 Meters
10yr ARI Velocity
N

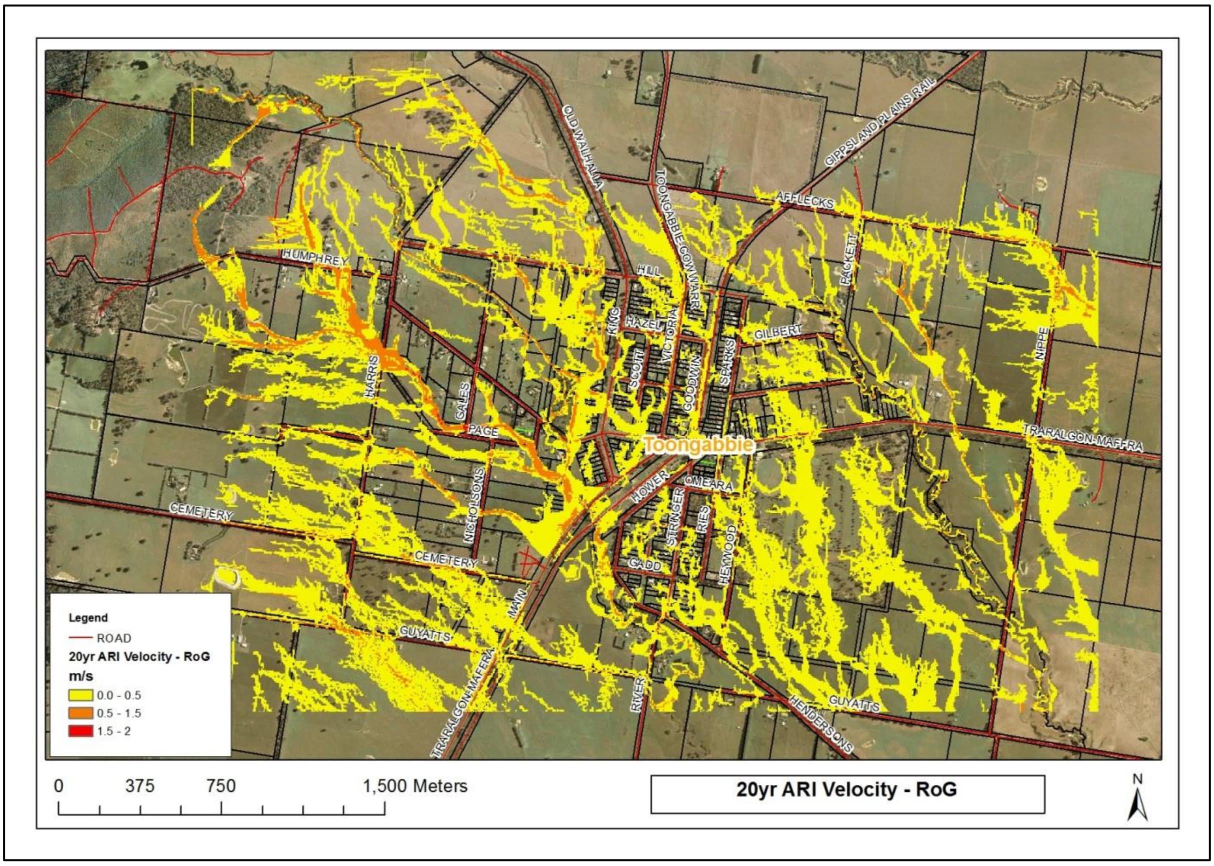

OLD WALHALLA
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
HUMPHREY
HILL
KING
HAZEL
VICTORIA
SCOTT
GOODWIN
SPARKS
GILBERT
PACKETT
NIPPE
HARRIS
GALES
PAGE
Toongabbie
TRARALGON-MAFFRA
NICHOLSONS
HOWER
STRINGER
OMEARA
RIES
HEYWOOD
CEMETERY
GADD
MAIN
GUYATTS
RIVER
HENDERSONS
ANTONS
Legend
ROAD
5yr ARI Velocity
m/s
0.0 - 0.5
0.5 - 1.5
1.5 - 2
0
375
750
1,500 Meters
5yr ARI Velocity
N

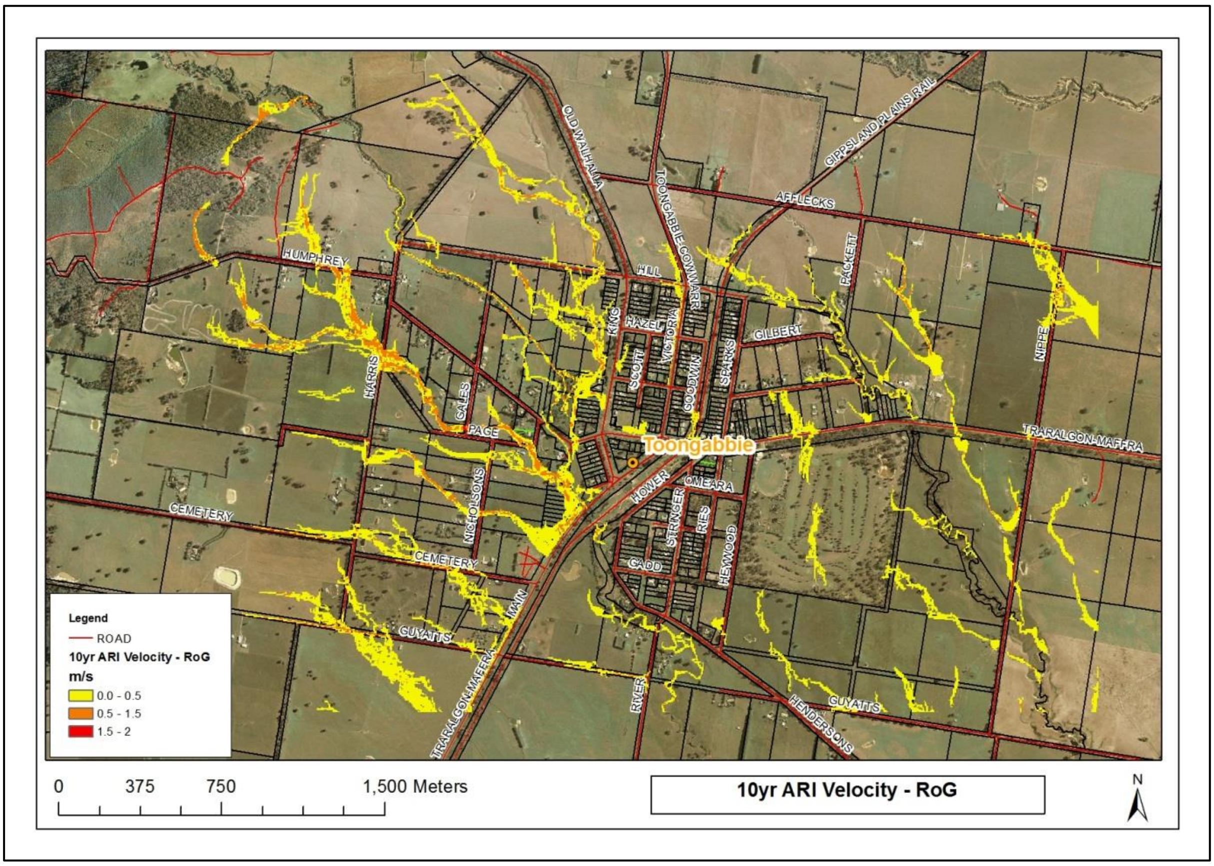

OLD WALHALLA
TOONGABBIE-COWWARR
GIPPSLAND PLAINS RAIL
AFFLECKS
HUMPHREY
HILL
KING
HAZEL
VICTORIA
SCOTT
GOODWIN
SPARKS
GILBERT
PACKETT
NIPPE
HARRIS
GALES
PAGE
Toongabbie
TRARALGON-MAFFRA
NICHOLSONS
HOWER
STRINGER
OMEARA
RIES
HEYWOOD
CEMETERY
GADD
MAIN
GUYATTS
RIVER
HENDERSONS
ANTONS
Legend
ROAD
2yr ARI Velocity
m/s
0.0 - 0.5
0.5 - 1.5
1.5 - 2
0
375
750
1,500 Meters
2yr ARI Velocity
N

Appendix I3: Flood flow velocity maps - Township Extent Hydraulic Model – Rain on grid






Legend
ROAD
20yr ARI Velocity - RoG
m/s
0.0 - 0.5
0.5 - 1.5
1.5 - 2
0 375 750 1,500 Meters
20yr ARI Velocity - RoG
N
Toongabbie
HUMPHREY
HARRIS
GALES
PAGE
NICHOLSONS
CEMETERY
GUYATTS
MAIN
TRARALGON-MAFFRA
OLD WALHALLA
TOONGABBIE-COWWARR
AFFLECKS
GIPPSLAND PLAINS RAIL
RACKETT
NIPPE
GILBERT
HILL
KING
HAZEL
SCOTT
VICTORIA
GOODWIN
SPARKS
HOWER
O'MEARA
STRINGER
RES
HEYWOOD
GADD
RIVER
HENDERSONS


Legend
ROAD
10yr ARI Velocity - RoG
m/s
0.0 - 0.5
0.5 - 1.5
1.5 - 2
0 375 750 1,500 Meters
10yr ARI Velocity - RoG
N
Toongabbie
HUMPHREY
HARRIS
GALES
PAGE
NICHOLSONS
CEMETERY
GUYATTS
MAIN
TRARALGON-MAFFRA
OLD WALHALLA
TOONGABBIE-COWWARR
AFFLECKS
GIPPSLAND PLAINS RAIL
RACKETT
NIPPE
GILBERT
HILL
KING
HAZEL
SCOTT
VICTORIA
GOODWIN
SPARKS
HOWER
O'MEARA
STRINGER
RES
HEYWOOD
GADD
RIVER
HENDERSONS