West Gippsland
Catchment Management Authority

WGCMA Floodplain Mapping Program

Floodplain mapping for Tyers River

December 2015

Document Details

Project name	Floodplain mapping for Tyers River
Priority system / township	Tyers River
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Document status	Work Started
Version no.	6
Date last modified	15/12/2015
Hydrology software	RORBWin 6.15
Hydraulics software	Sobek SBKRural 2.14.001
Hydraulics dimensionality	1D2D

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List of Abbreviations

ARI	Average recurrence interval
ARR	Australian Rainfall and Runoff
AHD	Australian height datum
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
ROG	Rain on grid
WGCMA	West Gippsland Catchment Management Authority

Glossary

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 datums.
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.
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.
Hyetograph	A graph that shows rainfall or rainfall intensity changes over time.
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.
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

Floodplain modelling is conducted to determine the nature and extent of flooding through the estimation of design flood flows, levels and velocities to be used by the West Gippsland Catchment Management Authority (WGCMA) for statutory planning purposes. This project will include detailed hydrological and hydraulic modelling of the Tyers River, for which there was no flood extent data available, aside from what was obtained in the Latrobe River Flood Study (2015).

1.2 Objectives

The objectives of the Tyers River floodplain mapping project as set out by the WGCMA are:

- Produce a RORB hydrologic model for the whole of the Tyers River catchment area, using the elevation contours and reaches to determine sub catchments locations.
- Calculate and tabulate expected design flow hydrographs for Tyers River for 50, 20, 10, 5, 2, and 1% AEP flood events, calibrated against flood frequency analysis, historic events and regional and rational methods.
- Produce a 1D/2D hydraulic model using Sobek with RORB hydrographs and LiDAR elevation data for 1D cross sections and 2D grids.
- Undertake hydraulic analysis to determine the 50, 20, 10, 5, 2, and 100 year Average Recurrence Interval (ARI) flood extents, depths and velocities and prepare maps

1.3 Catchment description and history

The Tyers catchment is located in the Latrobe basin covering an area of approximately 328km^2. The Tyers River is 86 km long, running south from Mt Baw Baw to the Latrobe River between Yallourn North, Tyers and Maryvale with a catchment slope of 17.2m/km. Flows in the Tyers River are confined by steep banks, thus breakouts are only expected to occur in the downstream portion of the catchment.

The Moondarra reservoir was constructed in 1961 and will affect the outcome downstream floods. It would also make any downstream flow records prior to construction irrelevant for flood frequency analysis as they would have been recorded under significantly different conditions to those experienced now. As a simplification, the reservoir was assumed full for the hydrologic analysis, as major flooding is likely to only occur when it is full.

The Tyers River has six discharge gauges. These are Tyers Junction, Morgans Mill, Browns, Gould, Boola and Pump House Of these gauges only Morgans Mill and Browns have data for large events where hourly rain gauge data exists. The others were either not operating when these events occurred, or their capacities were exceeded during these events. A number of rain gauges located in and around the Tyers catchment are available from DELWP and the Bureau of Meteorology (BoM). BoM Climate Data only offers daily rainfalls so they cannot be used to produce RORB hyetographs (which need to be in hourly intervals or smaller), but these gauges may be useful in determining total rainfall distribution of storm events.

The townships and localities of Caringal, Erica, Amor, Rawson, Jacob’s Creek, Moondarra, Yallourn North and Tyers are all located fully or partially within the Tyers River catchment and some contain a small number of dwellings. The majority of these dwellings are upstream of the floodplain area and are elevated well above the river. Only a few in Tyers and Yallourn North are likely to be affected by flooding. All of the land currently subject to inundation is zoned for farming or special use. This zoning means that while the results are less likely to affect the construction of new dwellings, only replacement dwellings would be allowed in locations subject to flooding of 0.3m or deeper.

1.4 Flood history

Historic data is available from various rainfall and flow gauges in and around the catchment. This data shows that the largest event occurred in 1978, with other large floods in 1976, 2005 and 2007. There are no historic heights of known ARI or flood photography available. Historic heights of 40.2 and 39.8m and unknown ARI were recorded approximately 1.75km upstream of the outflow in 1900 and 1923 respectively. As these were recorded before the construction of Moondarra Reservoir they are unlikely to be relevant today, even if the ARI was known.

1.5 Previous decision-related data

1% AEP flood extent data is currently only available in the Victorian Flood Database (VFD) on the Tyers River downstream of Brown Coal Mine Road, shown in Figure 1. This section is also covered by the Latrobe River Flood Study (2015), which extends upstream of Brown Coal Mine Road on the west overbank. The extent downstream of Brown Coal Mine Road is noticeably smaller than in the VFD, with a large area between Christensons Road and the Latrobe River escarpment that is shown to be not subject to inundation. The Light Detection and Ranging (LiDAR) indicates that this area is elevated above its surroundings, suggesting that the Latrobe extent is more accurate. Depth maps are available from the Latrobe River Flood Study (2015) that could be used to set the outflow boundary heights. Flooding from the Latrobe River would be expected to be much deeper than the Tyers River, so the 10 year Latrobe depth would be more appropriate for setting a boundary height for the Tyers hydraulic model.

The LiDAR data sets available for this flood study are Latrobe Northeast, Macalister Irrigation District (MID) and Latrobe and Reach 26-16 and 26-17.The Reach 26 LiDAR datasets are likely to be less accurate than MID and Latrobe than Latrobe Northeast due to the tall, dense vegetation.

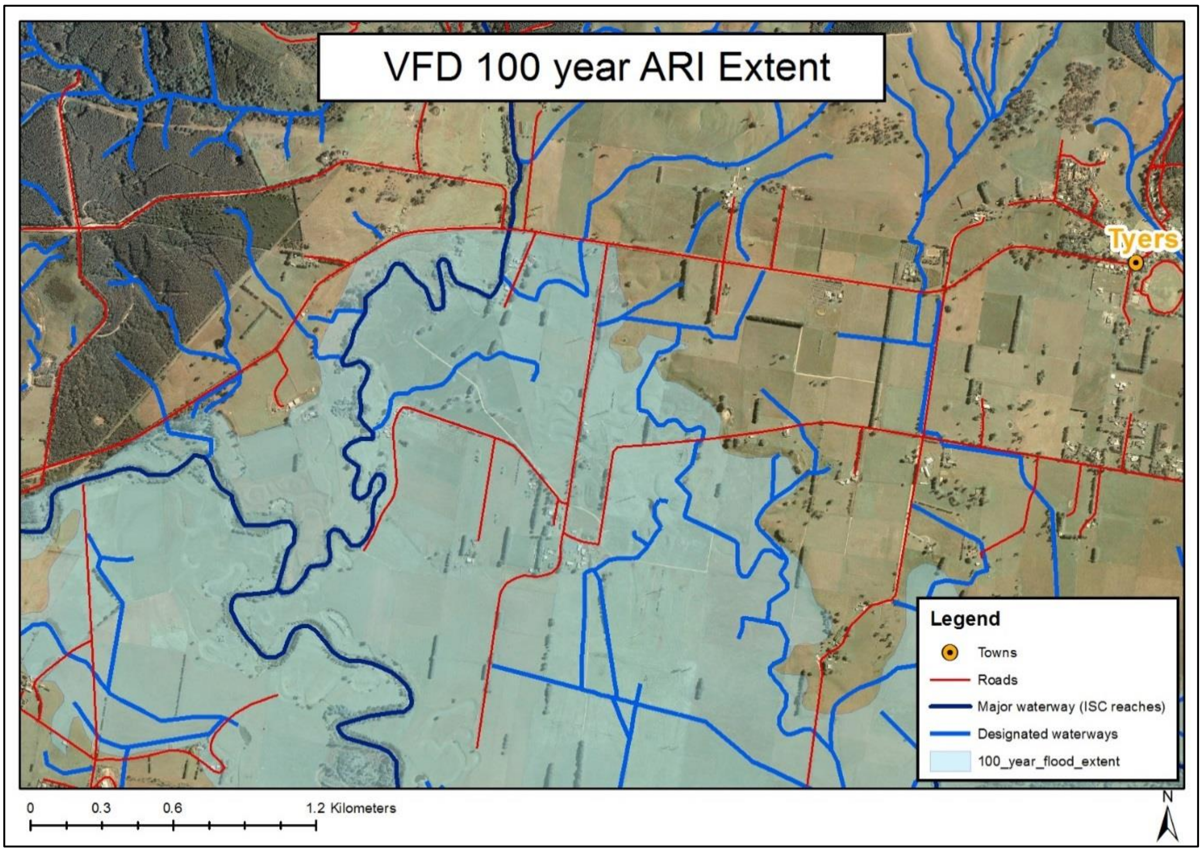

Figure 1 The Current Victorian Flood Database 1% AEP flood extent

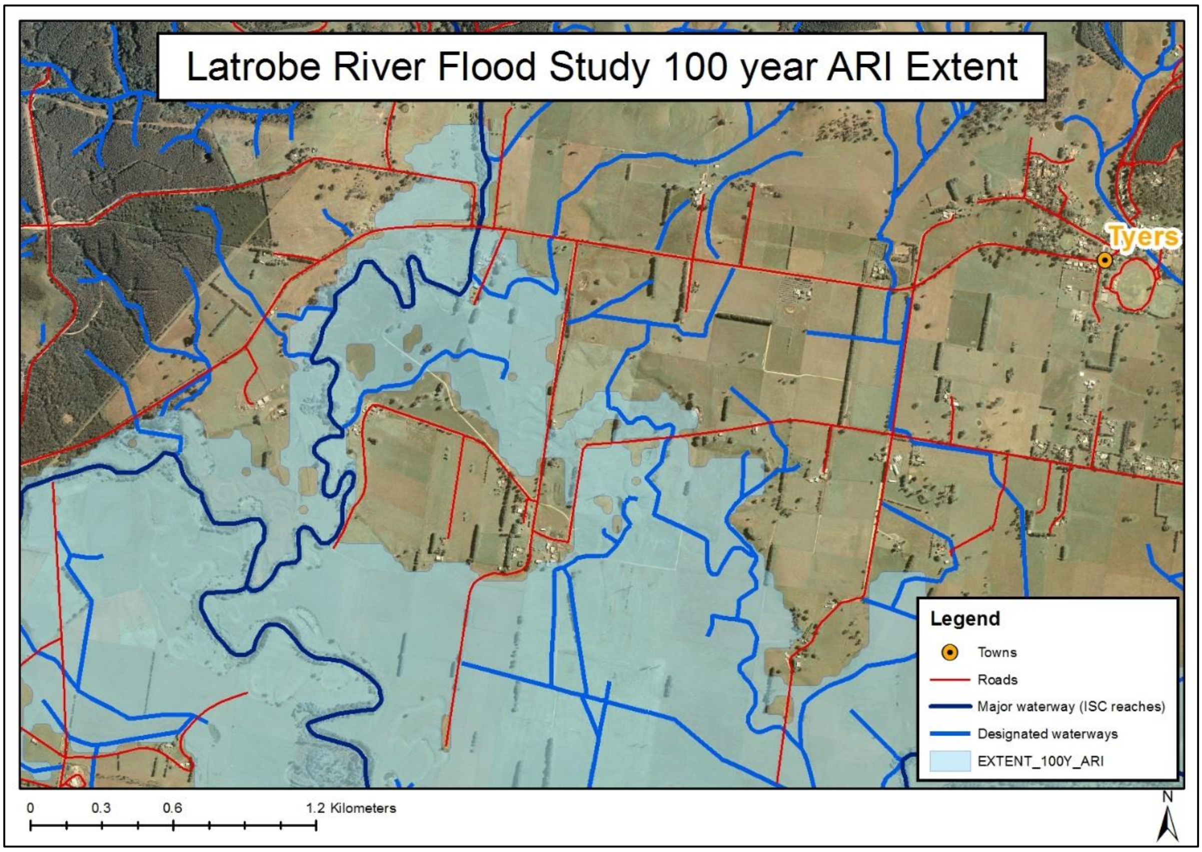

Figure 2 Latrobe River Flood Study (2015) Extent

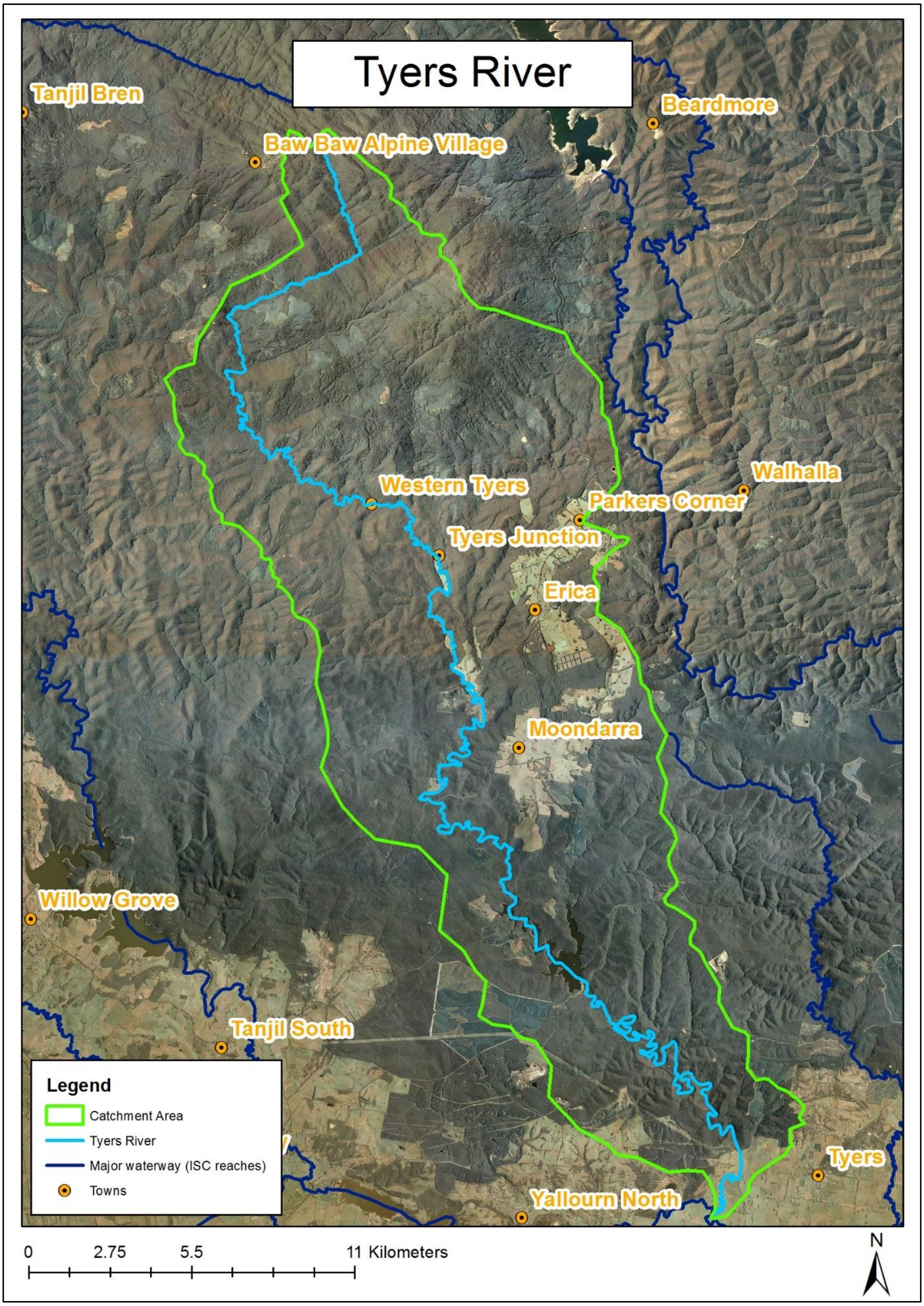

Figure 3 Catchment map

2 Hydrology

2.1 Description of hydrologic modelling approaches adopted

The hydrological analysis for Tyers River consisted of regional and rational flow estimation, flood frequency analysis and a RORB model. The RORB design parameters for initial and continuing loss were set according to ARR book two (1998) and validated using the rational method and flood frequency analysis results.

2.2 Available data

Available data for hydrology consisted of

- Aerial photography
- Waterway and catchment mapping
- Flow and rainfall gauge data
- Elevation contours
- Intensity Frequency Duration (IFD) tables

Aerial photography was available from the tile mosaics GIS layer. It was used for the RORB background.

The LiDAR came from four different sources, and was only available for the floodplain and along the main channel at a width of approximately 1.6 kilometres. Because of the restricted LiDAR extent, the elevation contours, spaced every 10 metres, were relied on to delineate the subcatchments and the reach slopes for most of the catchment. The LiDAR was used for the flatter lower catchment where the elevation contours are spaced too far apart

BoM 1987 and 2013 IFD tables were used for initial flow estimation, and the 1987 IFD table was used for the RORB model. The 1987 IFD table was chosen over the 2013 IFD table because it was considered more accurate at the time of reporting.

Historic rainfall gauge data was available from six gauges on the Tyers River. Only two of the available flow gauges (Browns and Morgans Mill) could be used for the RORB FIT run. Browns was the only gauge with sufficient data for flood frequency analysis. The closest rain gauges to the catchment with hourly data were used in the RORB FIT run, and all gauges were used to determine the rainfall distribution. More detailed information on the gauges can be found in section 2.3.

2.3 Streamflow and rainfall gauge review

Gauge 226006 Tyers River at Boola

Boola only has 6 full years of data and one of those, 1959, predates the construction of the Moondarra Reservoir, however it does have data for the June 1978 flood, the largest flood recorded in the Tyers catchment. The lack of rainfall data and short operation period prevents Boola from being used for flood frequency analysis and the RORB FIT run, but a print node was still placed at Boola in the design run.

Gauge 226007 Tyers River at Browns

Browns, located north of the Moondarra Reservoir as shown in Figure 4, has the largest amount of data available, and is the only discharge gauge with enough data to perform a flood frequency analysis. The largest event recorded at Browns was the June 1978 flood with a flow of 20,351ML/day recorded. Because there was no hourly rainfall data available, the second largest event in February 2005, which recorded a flow of 12,522 ML/day, was used to write the RORB calibration storm file.

Gauge 226008 Tyers River at Morgan's Mill

Morgan's Mill is towards the upstream end of Tyers River, as shown in Figure 4. It operated from 1961-67 and was reopened in 2005. While it did not have enough data for flood frequency analysis it does have hourly data for the February 2005 event and was used in the RORB storm file.

Gauge 226223 Tyers River at Tyers Junction

The Tyers Junction gauge at the north of the catchment has been operating since 2001. Although it has been active every year since then its rating table was exceeded in February 2005 and in other large events, making it unusable for both RORB calibration and flood frequency analysis.

Other Gauges: Gould and Pump House

The two remaining gauges have only operated for very short periods of time in which no major floods occurred. Gould only has two years of data, 1953-54, before the Moondarra Reservoir was built, and Pump house only has 6 years.

Rain Gauges

The following rain gauges, marked in yellow in Figure 4, were used to generate the rainfall distribution in the ArcMap GIS program. The Tanjil at Tanjil South, Tyers West Branch downstream of South Face Road and Traralgon EPA gauges were also used for the RORB FIT run storm file as these were the closest gauges to the catchment with hourly data.

- Macalister River at Licola
- Tanjil at Tanjil South
- Traralgon EPA
- Thomson River at Murderers Hill
- Thomson River u/s Cowwarr Weir
- Tyers River West Branch d/s of South Face Road
- Erica
- Erica (Philips Bridge)
- Willow Grove
- Willow Grove (Blue Rock Reservoir)
- Mt Baw Baw

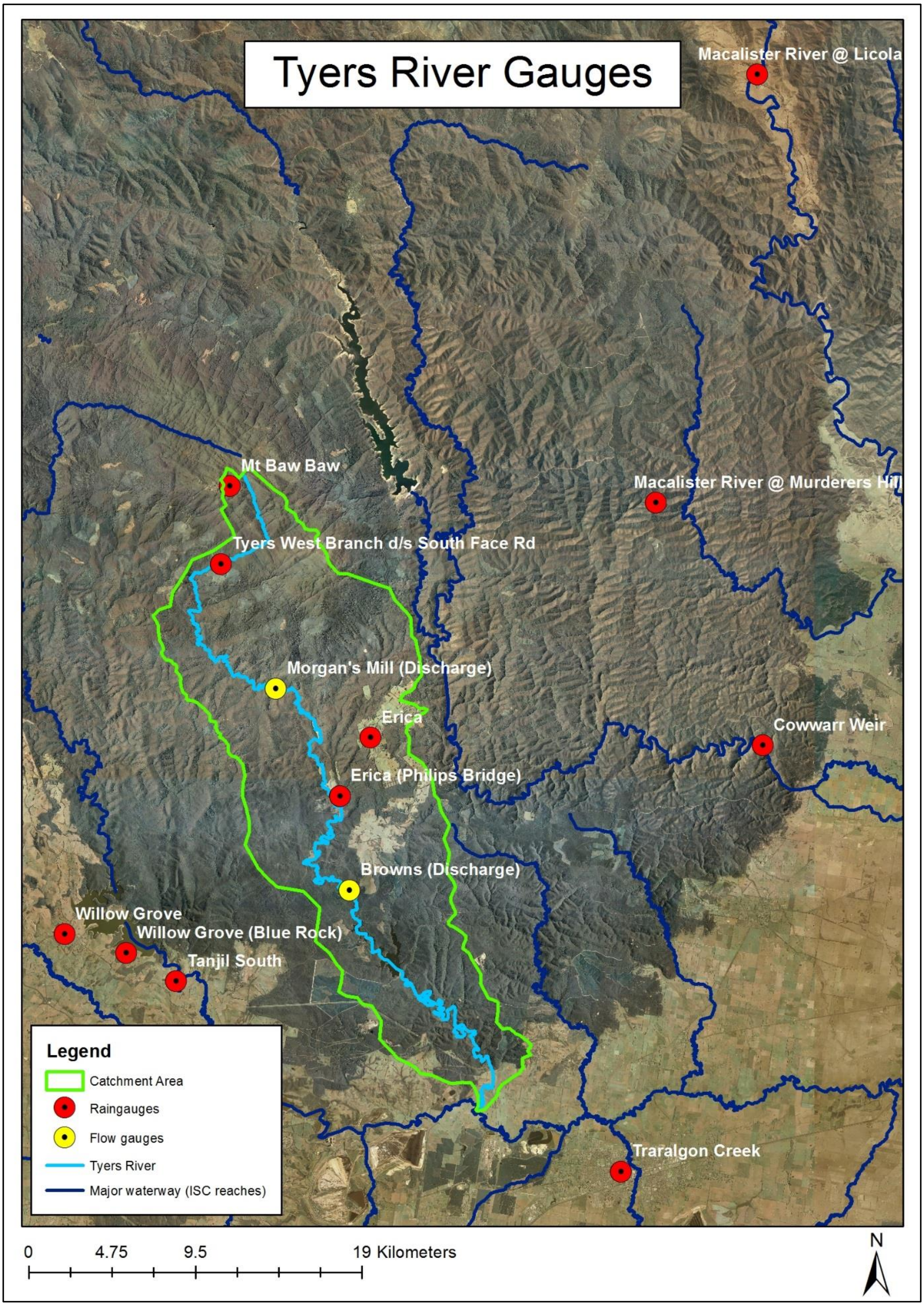

Figure 4 Gauge locations

2.4 Initial hydrologic estimates

Regional and rational methods were used to estimate design flows for 50, 20, 10, 5, 2 and 1% AEP floods. The results of these calculations were the only calibration data available for the RORB model.

Nikolaou and von't Steen Regional Equation

The Nikolaou and von't Steen regional equation is an empirical method for calculating the 1% AEP flow from catchment area only.

Adams Formula

Adams Formula for Victorian and Eastern NSW catchments was used to calculate the time of concentration, tc, that is entered into the 1987 and 2013 BOM IFD programs to calculate the intensity for the Zaman Regional method and probabilistic rational methods.

Probabilistic Rational Method

The rational method was used to determine flows for 50, 20, 10, 5, 2 and 1% AEP floods based on both 1987 and 2013 IFD intensities. It is determined using catchment area A, and the runoff coefficient C_Y (Eq. 2.1-3) and intensity I_{tc_Y} for the Y year ARI. The runoff coefficient was calculated with the C_{10} runoff coefficient from Figure 5.3b Australian Rainfall and Runoff Volume 2, and the frequency factor, F, from Table 1.4 in ARR Book IV section 1. Because two different methods are used there are two sets of results. Engineers Australia recommends using the 1987 IFD for rational method calculations as other inputs for design flood estimation are yet to be developed for the 2013 IFD. The 2013 IFD intensities can still be used with the 1987 inputs for sensitivity analysis. The 1987 IFD intensities for the catchment outlet and Browns are displayed in Appendix A, Table 11 and Table 12 respectively.

Zaman Regional Method

The Zaman et al (2013) regional flow estimation method was used to determine flows for 2-1% AEP events. The equations in the Zaman method, shown below, use catchment area and rainfall intensity for a given ARI flood event to determine flows for 50, 20, 10, 5, 2 and 1% AEP floods.

Table 1 Zaman Regional Equations

ARI	Equation	R^2	SEE
2	$\log_{10}(Q_2) = -3.055 + 1.186l \log_{10}(area) + 2.103\log_{10}(I_{tc\_2})$	0.780	0.21
5	$\log_{10}(Q_5) = -2.847 + 1.182 \log_{10}(area) + 2.0891\log_{10}(I_{tc\_5})$	0.805	0.22
10	$\log_{10}(Q_{10}) = -2.476 + 1.13 \log_{10}(area) + 1.932\log_{10}(I_{tc\_10})$	0.764	0.23
20	$\log_{10}(Q_{10}) = -2.476 + 1.13 \log_{10}(area) + 1.932\log_{10}(I_{tc\_10})$	0.763	0.21
50	$\log_{10}(Q_{20}) = -2.766 + 1.173 \log_{10}(area) + 2.108\log_{10}(I_{tc\_20})$	0.722	0.22
100	$\log_{10}(Q_{100}) = -2.789 + 1.159\log_{10}(area) + 2.135\log_{10}(I_{tc\_100})$	0.684	0.25

Where SEE is the standard error of estimate, R^2 is the coefficient of determination and I_{tc_n} is the intensity for a given time of concentration and the nth ARI.

Initial hydraulic estimates were completed at the catchment outlet and at the Browns flow gauge station. The location of Browns is shown in Figure 4. The results are shown in Table 2 and Table 3. There is a large degree of variation between the probabilistic rational method and the Zaman (2013) regional method, particularly for floods above 10% AEP. The Nikolaou and von't Steen regional equation only applies to 1% AEP floods and produced flows between the rational and Zaman (2013) regional methods. The probabilistic rational method has been shown by Rijal and Rahman (2005) to have an average error of 61 to 80 percent in 75 percent of south east Australian test catchments (Ladson, 2008). Because of the large errors associated with these methods, flood frequency analysis was used as the primary means of RORB model calibration.

Table 2 Summary of initial hydrologic estimates at the catchment outlet

		Flow estimate technique			
Average Recurrence Interval (ARI)	Runoff Coefficient (C_Y)	Nikolaou and von't Steen equation	Rational method based on 1987 IFD	Rational method based on 2013 IFD	Zaman et. al. (2013) equations
years		m³/s	m³/s	m³/s	m³/s
2	0.113		65.72	56.94	42.14
5	0.135		104.12	94.33	115.74
10	0.150		134.17	126.93	191.64
20	0.165		174.85	165.49	269.34
50	0.180		232.64	222.14	436.21
100	0.195	388.38	289.23	278.73	515.91

Table 3 Summary of initial hydrologic estimates at Browns

		Flow estimate technique			
Average Recurrence Interval (ARI)	Runoff Coefficient (C_Y)	Nikolaou and von't Steen equation	Rational method based on 1987 IFD	Rational method based on 2013 IFD	Zaman et. al. (2013) equations
years		m³/s	m³/s	m³/s	m³/s
2	0.113		47.12	42.15	32.41
5	0.135		72.38	69.53	83.42
10	0.150		96.23	93.12	147.76
20	0.165		125.49	121.19	209.00
50	0.180		167.09	161.93	312.98
100	0.195	269.98	207.65	202.60	404.89

2.5 Flood frequency analysis

The TUFLOW FLIKE flood frequency analysis (FFA) was used with log-normal, gumbel, gumbel-log, exponential and exponential log probability distributions with Bayesian fitting parameters. The log normal produced the best fit with the historical data.

FLIKE FFA using a log Pearson III distribution and Bayesian fitting parameters showed that the largest flood recorded, the 1978 flood, was a 1 in 75 year flood, while the February 2005 flood was a 1 in 28 year. A 1% AEP flood in the Tyers catchment will produce a flow of 248m^3/s at Browns. The quantile estimation using log Pearson III method showed that the June 1978 flood was a 1 in 78 and the February 2005 was a 1 in 29 year. Intensities for each year of data are shown in Appendix B, Table 21 (quantile estimation) and Table 22 (FLIKE). The results for both methods were similar up to a 10% AEP before the Bayesian started to become noticeably higher. The quantile estimation method also had a higher standard deviation at all ARIs. Graphs and tables of all FFA distributions can be found in Appendix B. Intensities for each year from 1963 as calculated by quantile distribution and FLIKE are also shown in Appendix B, Table 21 and Table 22 respectively.

Table 4 Design flows at Browns based on flood frequency analysis

Average Recurrence Interval (ARI)	Flow based FLIKE flood frequency analysis	Flow based quantile distribution flood frequency analysis
years	m^3/s	m^3/s
2	42.20	46.7633727
5	84.95	81.7687308
10	116.18	110.235334
20	150.92	141.487031
50	203.26	188.014405
100	248.39	227.798379

2.6 RORB hydrologic model

The RORB runoff routing program was developed by Laurenson and Mein in 1975. The RORB model subtracts initial and continuing losses from design or historic rainfall hyetographs to determine surface runoff, which is routed through a network of reaches, nodes and storages to produce flood hydrographs between 1 and 1% AEP at selected nodes.

The RORB model requires data on catchment area, reach length and type and fraction impervious. Slope can also be entered, but not for natural reaches. RORB also requires an IFD table. ARR IFD tables for every capital city are included in the RORB program, and user defined IFDs can also be used. The parameters required are initial and continuing losses, m, and Kc. The dimensionless exponent m is a measure of the catchment's non linearity and Kc .is a dimensionless empirical coefficient. The m is set by RORB to 0.8 and Kc can be calculated by RORB using one of the formulas contained within the program. There are six

Kc equations that could be applied to The Tyers River: Australia wide (Yu), Australia wide (Dyer), Vic MAR>800mm, Vic MAR<800mm, Pearse Victorian Data and RORB default. These equations are listed in Appendix B, Table 16. Values for initial were chosen according to the recommendations in ARR Book Two and continuing loss from ARR Book Two and ARR Revision Project Six.

The hydrograph tables for the completed 20, 10, 5, 2 and 1% AEP RORB models were saved in spreadsheets and used as inflows for the corresponding hydraulic models.

Sub-area and reach delineation

The subcatchments were delineated using ArcMap by drawing a polygon shapefile around the catchment and splitting off tributary subcatchments. This left a long, narrow subcatchment around The Tyers River that was divided based on topography into subcatchments so that no subcatchment contained more than one third of the main channel. The subcatchment areas can be found in Appendix B, Table 15.

Tributary reaches were delineated by tracing the designated waterways to the subcatchment centroid, and segments of the main channel were traced through the entire length of each subcatchment and split at the centroid. The reaches were then split at points where print nodes were required in order to produce hydrographs. The slope of every reach was then calculated, and any reach with a slope greater than five percent was modelled as an excavated unlined reach because RORB does not allow slope to be specified on a natural reach.

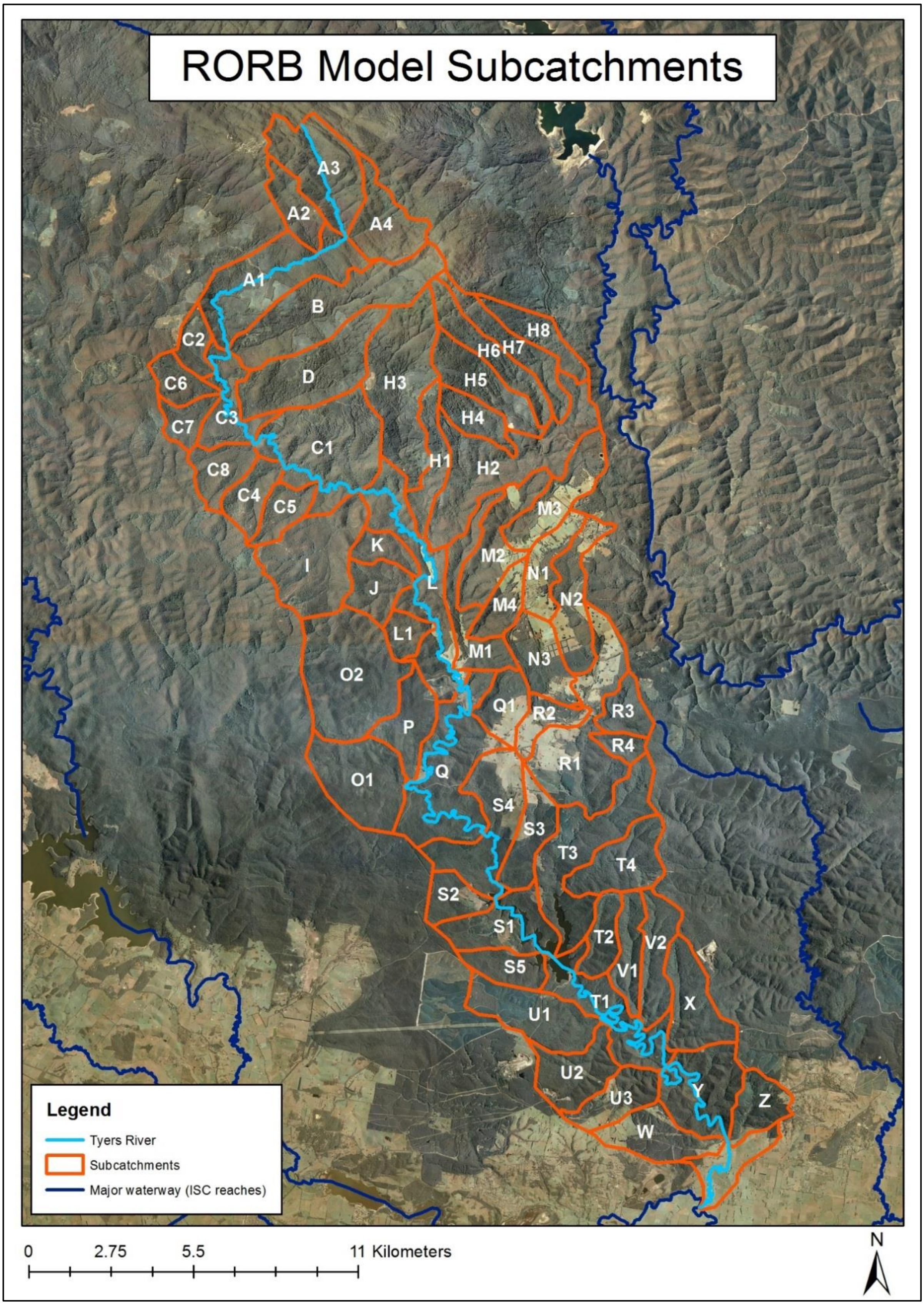

Figure 5 RORB subcatchments

Parameters

The following parameters were used in the RORB design run. Initial and continuing losses were taken from ARR Book Two, and m is a dimensionless RORB exponent measuring the catchments non linearity. The value of Kç, a dimensionless RORB parameter, and the final initial loss value from within the range given in ARR Book Two was determined by calibrating against the FIT runs.

- m = 0.8
- IL = 15-20 mm
- CL = 3 mm/h

FIT run and final parameters based on Calibration

The February 2005 flood was used for the FIT run to calibrate the model and the sets of parameters gave the closest match between the generated and actual hydrographs. The best results for Kc were found using the Pearse Victorian Data (2002), as shown in Table 6. The other methods tested in the FIT run were Australia wide Dyer (1994) and Yu (1989) and AR&R Book Five equation 3.2.2 for Victorian catchments

Table 5 RORB FIT run parameters

	Kc	m	IL	CL
Morgans Mill	18.10	0.8	15	10.22
Browns	22.38	0.8	15	5.21
Catchment outlet	22.36	0.8	15	5.21

Table 6 RORB FIT run parameters

	Kc	m	IL	CL
Morgans Mill	65.53	0.8	15	10.22
Browns	65.53	0.8	15	5.21
Catchment outlet	65.53	0.8	15	5.21

Design run

For the design run, the Pearse Kc equation was adopted because it produced better results in the FIT run. A continuing loss of 3.00 mm/h was adopted as recommended in ARR Revision Project 6. The RORB model results at junction node Y and Z were of particular interest as they were used to create the inflow boundaries for the 1D2D hydraulic model. Junction node Y is situated on the Tyers River, marking the start of the 1D model, while junction node Z is on a tributary that joins the Tyers River downstream of node Y. A 24 hour design duration gave the highest discharge for 2 and 1% AEP and best fit with the FFA and historic storms. For flows 5-20% AEP, the 12 hour duration produced better results.

The final design run peak flow results are shown in Table 9 and Table 10 and the hydrographs are shown in Appendix C, Figure 26 to Figure 32

Table 7 RORB design run parameters

	Kc	m	IL	CL
Morgans Mill	65.53	0.8	15	3.00
Browns	65.53	0.8	15	3.00
Catchment outlet	65.53	0.8	15	3.00

Sensitivity analysis

Sensitivity analysis was completed as part of the design run process by adjusting the value of different parameters to determine their effect on results. Changes to losses appeared to have only a minor effect on results. The chosen Kc value had a much greater bearing on the outcome.

Assumptions

- Moondarra Reservoir is full
- Fraction impervious of zero
- Catchment centroid coordinates used for IFD calculation

RORB results

Table 8 Design flows at model outlet from RORB model

Average Recurrence Interval (ARI)	Flow at outlet based on RORB design run model
years	m^3/s
2	12.8534
5	29.4716
10	64.5651
20	88.2467
50	130.811
100	202.517

2.7 Summary of hydrology results

There was a great amount of variation between the different flow estimation methods. It is important to note that these are simply estimates of the expected flows and were only used as a guide for verifying the flood frequency analysis results. According to ARR, the rational method could have errors between 25 and 70% (Ladson, 2008), so a large variation in results between methods is normal. The primary calibration methods were the RORB FIT run and flood frequency analysis, as these were derived from recorded historical data.

None of the rational or regional methods at the outflow take the Moondarra Reservoir into account, and none are able to. In the Sobek design runs the inflows were taken from RORB models where the reservoir was assumed full and represented by a drowned reach. Assuming that it is full allowed for the assumption that the amount of water entering and leaving the reservoir must be the same, and the outlet flows could be compared with the rational methods.

The FIT run continuing loss at Morgans Mill of 10.22 is very high, only approximately 2% of catchments have a value higher than this.

The RORB model could not be made to match both the historical data in the FIT run and the rational methods at the outflow, even though the RORB design run results at Browns were close to the flood frequency analysis results and largely within the range of the rational methods. This difference was most likely a result of RORB calculating losses that the rational methods do not consider. This is consistent with the observation of higher peak flows at junction Y than at the outflow. The continuing losses outweigh the inflows because junction Z is on the only tributary after junction Y and rainfall is lower towards the outflow.

The accuracy of the hydrology could have been improved had there been more data available. A lack of gauge data means that no flood frequency analysis could be completed downstream of Moondarra Reservoir. A more accurate rainfall distribution would have been produced if there were more rain gauges available.

Table 9 Summary of design flows at Browns based on estimates and model

Average Recurrence Interval (ARI)	Nikolaou and von't Steen equation	Rational method based on 1987 IFD	Rational method based on 2013 IFD	Zaman et. al. (2013) equations	Flow based on flood frequency analysis	Flow based on RORB design run model
years	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
2		47.12	37.88	32.4	42.20	29.8461
5		72.38	62.49	83.4	84.95	64.9346
10		96.23	83.69	147.8	116.18	88.4101
20		125.49	108.92	209.0	150.92	130.177
50		167.09	145.53	313.0	203.26	189.04
100	269.98	207.65	182.09	404.9	248.39	245.099

Table 10 Summary of design flows at the catchment outlet based on estimates and model

Average Recurrence Interval (ARI)	Nikolaou and von't Steen equation	Rational method based on 1987 IFD	Rational method based on 2013 IFD	Zaman et. al. (2013) equations	Flow based on RORB design run model
years	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
2		65.72	56.94	42.14	29.4716
5		104.12	94.33	115.74	64.5651
10		134.17	126.93	191.64	88.2467
20		174.85	165.49	269.34	130.811
50		232.64	222.14	436.21	202.517
100	388.38	289.23	278.73	515.91	268.375

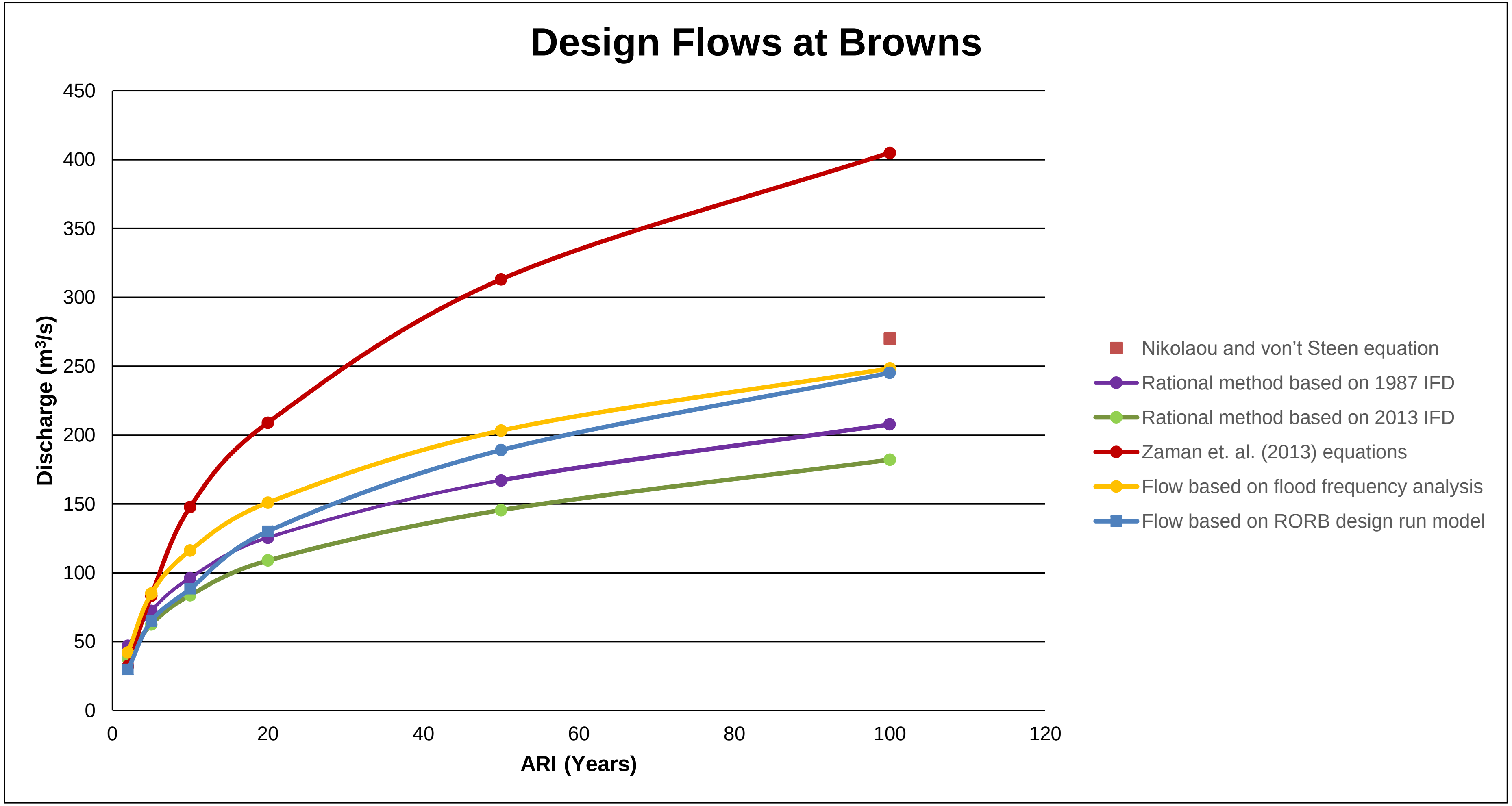

Figure 6 Design flows at Browns

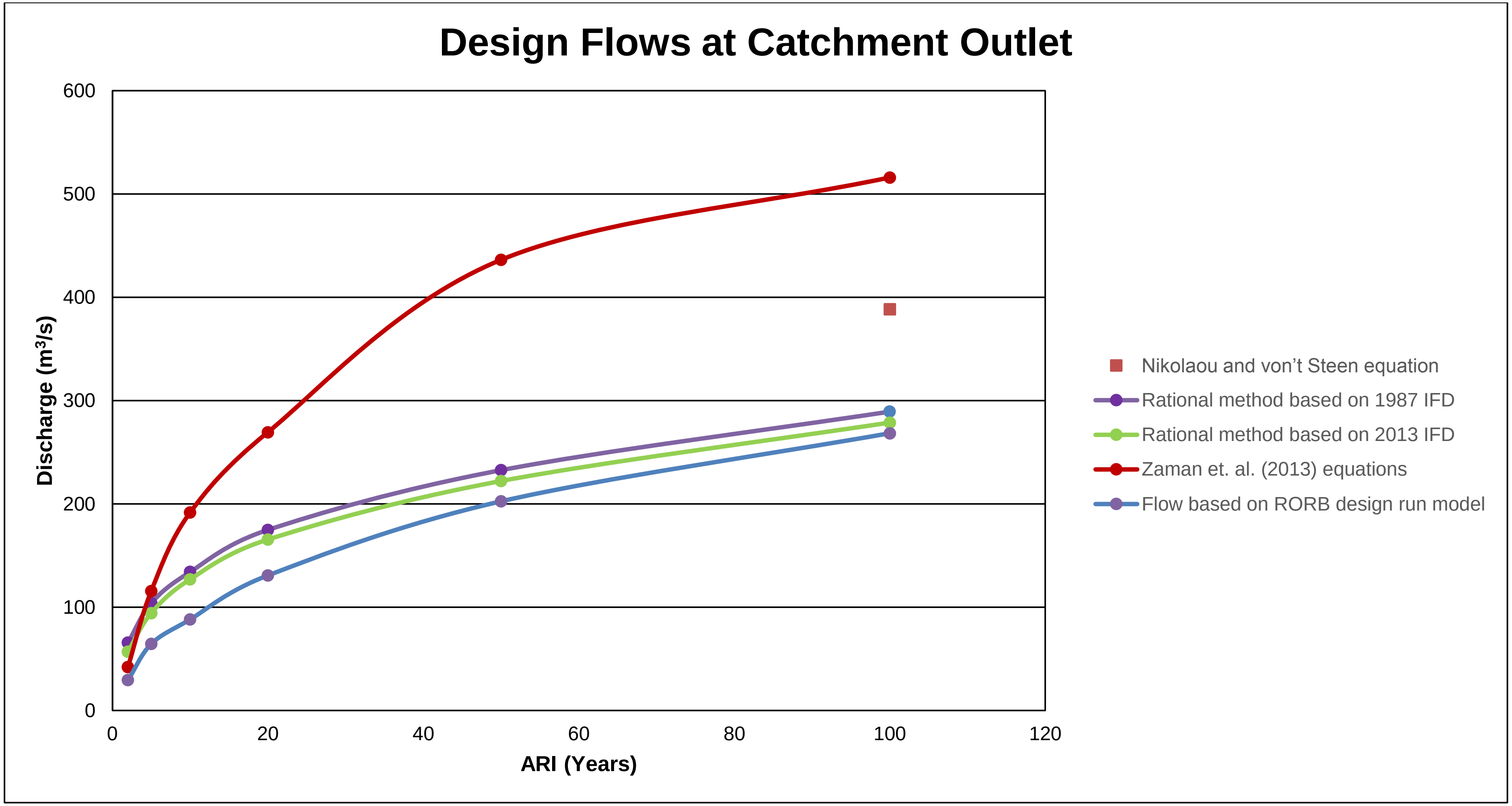

Figure 7 Design flows at catchment outlet

3 Hydraulics

3.1 Description of hydraulic modelling approach adopted

The hydraulic study consisted of a catchment extent model using hydrograph inflows from the RORB model. The used 5x5 metre grid cells, a 1D channel for Tyers River Creek with bridges and culverts and a uniform roughness value of 0.04. Due to the steep banks of the upper catchment, only the floodplain in the downstream section of the catchment was modelled, beginning near Pipeline Road, Yallourn North. LiDAR was available for the upper catchment, but the tall, dense vegetation makes it less accurate than the LiDAR in the lower catchment.

3.2 Available data

LiDAR topographic data for the 2D grid and 1D cross sections data was available for the hydraulic study area from two sources; Macalister Irrigation District (MID) and Latrobe and Latrobe Northeast. Both had a resolution of 1x1 metre. Also available for the 1D channel was the designated waterway mapping, used to locate the Tyers River channel. The waterway mapping is generally accurate, but can deviate slightly from the path of the waterways in some places. Tile mosaic aerial photography provided the Sobek background and was used as guide for cross section placement and width. The existing VFD flood and Latrobe River Flood Study (2015) extents were used to verify the extent of the final results

3.3 Key hydraulic features

The only key hydraulic feature in the Tyers catchment that needs to be modelled in 1D is the bridge on Brown Coal Mine Road 3.4km from the end of the Tyers River, as shown in Appendix D, Figure 33. A representation of bridge was included in the 1D component of the Sobek model.

3.4 Catchment extent hydraulic model

Model extent

The Tyers River was expected to break out in the floodplain at the downstream portion of the catchment and flow to the model outflow boundary at the Latrobe River. The outflow heights of all floods were set to match the 10% AEP height of the Latrobe River Flood Study (2015). Only the end of the catchment was included in the hydraulic model as the rest of the catchment’s steep banks make significant flooding unlikely. By removing this area it was possible to create a more detailed model of the floodplain by reducing the distance between cross sections and using smaller grid cells while maintaining a reasonable run time.

The outflow boundaries were placed in the Latrobe floodplain. The Sobek model is not as accurate close to the boundary so it was necessary to model past the area of interest, the Tyers floodplain, so that a more accurate simulation of the flows through the Tyers catchment could be produced. The final inaccurate section of the model could be removed from the maps without removing data of any importance.

Inflow boundaries for the hydraulic model used hydrographs taken from RORB. The main inflow from the Tyers River was placed in the 1D inflow boundary and the inflow from the remaining tributary was modelled with a 2D line boundary with a width equal to 1m for every $1m^3/s$ at the peak flow of the 1% AEP design run, rounded up to the nearest 10m. The corner nodes at the ends of the line boundary were placed two grid cells (20m) apart.

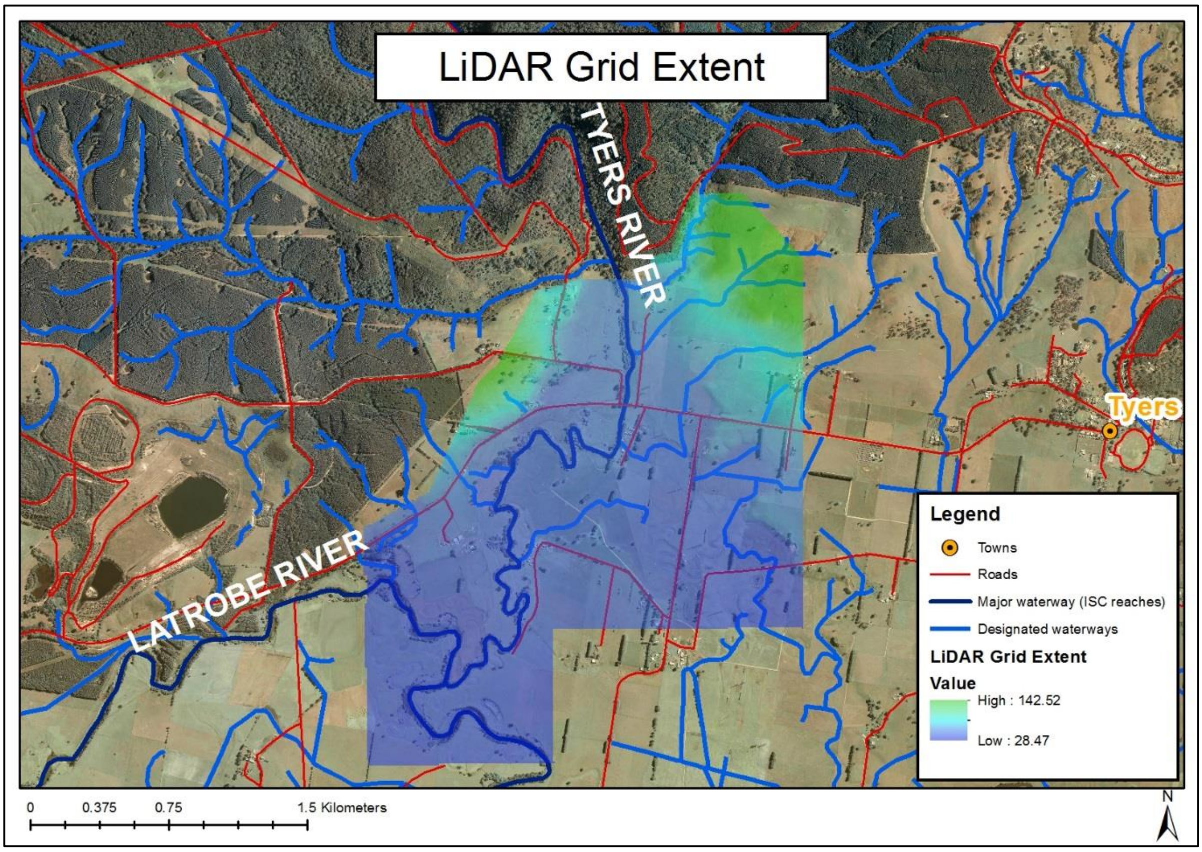

Figure 8 LiDAR grid extent

Input data

LiDAR topographic data was taken from three sources: Latrobe Northeast, MID and Latrobe and Reach 26-10. These LiDAR datasets were clipped to the required extent, merged, resampled from the original one metre grid cells to 10 metre cells and converted to ASCII files. The 10 metre grid was used as a 2D elevation grid. The one metre grid was used to create the cross sections for the 1D model. Cross sections were placed every 300 metres, as well as upstream and downstream of the bridge on Brown Coal Mine Road for a total of 15 cross sections. Each cross section was constructed from elevation points taken from the LiDAR gird at one metre intervals. The cross sections varied in width according to the channel width at each point.

Bridge data was obtained from both surveys and Latrobe City Council plans. Design plans could be used to obtain structural dimensions, but surveys were still required to align deck levels with the LiDAR and obtain bed levels, which are subject to change over time.

Flow data was taken from RORB. All draft runs used the final 1% AEP flows at the critical duration of 24 hours.

Assumptions

The following assumptions were made for the hydraulic model:

- 10x10 metre grid cells
- Tyers River only channel represented in the 1D component
- Boundary water levels same as Latrobe River Flood Study (2015)10% AEP
- 2D inflow width of 1m per 1m^3/s at peak flow
- Initial channel depth of 0.2m

The floodplain and channel roughness values were chosen by relating observations from field inspections to values recommended for different surface types by Brisbane City Council (2003). These values were then adjusted following recommendations from hydraulics consultant Chris Beardshaw, who also recommended the inflow boundary width of one metre per cubic metre of flow.

Breakouts were not expected to occur in the upper catchment. This was assumed because of the steep slopes observed in the elevation contours and LiDAR, and the dense vegetation visible in the tile mosaics. This area was therefore excluded from the hydraulic model

The initial outflow height and channel depth conditions were set to maximise model stability without having a noticeable impact on the results. The outflow boundary conditions were set at a height that allowed backfilling of only the Latrobe River escarpment. The initial channel depth of 0.2 metres was set to provide some pre-wetting without impacting too greatly on the model results.

The Tyers River was the only channel represented in 1D. Other channels were observed in the LiDAR to be shallow and poorly defined in some places, and it was considered unnecessary to model them in 1D.

The model was run with no blockage at the bridge on Brown Coal Mine Road. This was based on observations made during surveys and other site visits, where the bridge appeared to be clear of any blockages.

Methodology

The hydraulic modelling consisted of an initial 2D model of the entire river on a grid with 40x40 metre cells. The 1D component was then added to a model of the downstream component with 10x10 metre cells. It was possible to reduce the cell size further but this would have increased the run time. The purpose of the initial 2D full length model was to determine where the flows would begin to break out so a starting point for the detailed 1D-2D model could be set. The 1D model was used to determine the main stream flows and the 2D model was used to determine the breakout depth, velocity and extent.

Cross sections of the 1D channel were placed approximately every 300m as well as immediately upstream and downstream of the bridge on Brown Coal Mine Road, for a total of 16 cross sections. Calculation points between the cross sections are placed every 50 metres.

The Brown Coal Mine Road Bridge was represented using a soil bed bridge cross section node. Sobek does not allow piers to be added to this bridge type. To compensate for this, the bridge was narrowed so that it had the correct area. The piers are thin, representing approximately five percent of the width of the bridge, meaning that they are more likely to affect flow by causing a build-up of debris on the upstream side, rather than directly impeding flows. The bridge deck was modelled by raising the 2D grid cells above the bridge to the road height. This created a model where the flow under the bridge was modelled in 1D and any overtopping was modelled in the 2D component, as would happen in any other situation where the capacity of the 1D channel was exceeded. The bridge was calibrated by modelling it in the HEC-RAS 1D hydraulic modelling program. The rating curves from HEC-RAS and Sobek were compared and the Sobek model adjusted accordingly. This method was used because of the restricted means in which bridges are added to Sobek. The piers cannot be added and the bridge must be symmetrical so a bridge that behaves in a similar way to the more detailed bridge in HEC-RAS was used.

The cross sections were produced in ArcMap using a LiDAR DEM with 1x1 metre grid cells. Points were taken every 1m along each cross section, placing them closer together would not necessarily improve the accuracy of the cross sections as the points would be placed at intervals smaller than the LiDAR grid cells. The cross sections were between 22.45 and 60.05 metres wide depending on the width of the river at each cross section. As the 1D-2D Sobek model works best if the cross sections are wider than the grid cells, these cross sections could be used on a grid with cells up to 20x20 metres.

The main outflow line boundary was placed vertically across the Latrobe River escarpment downstream of the Tyers River. It used a fixed height in metres AHD set to match the level of the Latrobe River Flood Study (2015) 10% AEP flood level at the point where the two rivers meet. A second boundary was placed horizontally along the escarpment to allow a breakout flow to exit the model. A third boundary over the Latrobe River upstream of the Tyers River filled the Latrobe River.

Parameters and settings

The following parameters were adopted:

- Five second time step
- 3 day, 23 hour and 2 day, 23 hour simulation times
- Initial water depth of 0.2 metres
- 10x10 metre grid cells
- Grid runs from floodplain to outflow
- Outflow line boundaries across the Latrobe River and along the escarpment where the breakout flow meets the river
- Main Tyers River inflow on 1D channel
- Tributary inflow uses 2D line boundaries with a width of 1m per 1m^3/s at peak flow
- Roughness coefficient of 0.04
- Manning’s roughness set at 0.03 for 1D channel
- 1D channel outflow modelled as connection node to 2D grid

- Highest level of embankment (Grid cells raised to match cross sections)
- 300 metres between cross sections.

2% and 1% AEP models used a three day, 23 hour simulation time, and 5-50% used a two day 23 hour simulation time. This was chosen to match the length of the 24 and 12 hour storm duration hydrographs imported from the RORB model. Flooding had subsided in the draft runs by this point, so the simulation time did not need to be extended past this point.

The 2D grid used 10x10 metre cells. This was the smallest grid resolution that could be run within an acceptable time frame. The results may have been improved by the use of smaller grid cells.

The design run models had two outflow line boundaries. One was placed over the Latrobe River and the other along the edge of the Latrobe River escarpment. The draft run flood extents were used to determine their locations. A boundary would not normally be placed downstream of the Latrobe River, but the narrow angle at which the Tyers River meets the Latrobe made this difficult. A third boundary over the Latrobe River was placed on the upstream side to fill the river. As stated in Assumptions the water surface elevation was set to flood only the Latrobe River escarpment.

The main model inflow on the Tyers River was entered on the 1D channel. This was considered the most accurate way of representing channel flow in a model that begins upstream of any breakouts. Flows would enter the model in the Tyers River before breaking out onto the floodplain.

The 1D channel outflow was modelled as connection node to the 2D grid. The only alternative offered in Sobek is for the 1D channel to extend past the 2D grid and end on a 1D boundary node. The model could not be made to run this way, so a connection node within the 2D grid was used. Any water in the channel at this point would be released onto the 2D grid.

The method of 1D overflowing to 2D chosen was to assume highest level of embankment. With this setting, the grid cells are raised to match cross sections. Using this setting, flows break out of the 1D channel and onto the 2D grid when depth exceeds the channel height on either side of the channel. Had the lowest level of embankment been chosen, any points higher than the embankment on the lower overbank would have been omitted from the higher overbank. Therefore, using this setting may have resulted in false breakouts.

The cross sections were placed 300 metres apart, with additional cross sections either side of the bridge. This cross section spacing was chosen as a compromise between a more detailed 1D channel (shorter spacing) and short run times (longer spacing). Placing additional cross sections either side of the bridge improves the stability of the 1D model and makes inputting and aligning the bridge easier.

Refer to Assumptions on page 30 for descriptions of the roughness and inflow width.

Sensitivity analysis

Sensitivity analysis was conducted for the following parameters during the draft runs. The level or method of variation is as described.

- Boundary condition height (±20%)
- Inflows (Different RORB model runs)
- Roughness coefficients (±0.02)

Results

The results of the Sobek model show the Tyers River breaking out to the west almost immediately after the start of the model in floods greater than 5% AEP. These flows re-join the river when it heads west, downstream of Brown Coal Mine Road. The flood extent on Tyers River is narrower beyond this point.

In floods greater than 5% AEP, Brown Coal Mine Road appears to redirect water breaking out on the left overbank towards a series of ephemeral streams that flow south east towards the Latrobe River. The 10% AEP floods does not enter the stream because it does not have sufficient breakout flow to cross Brown Coal Mine Road on the eastern side of the bridge and the five year ARI does not break out on the left overbank at all upstream of the bridge. These streams are not in the Tyers River catchment and not all of them have been identified as designated waterways. Sawyers lane was identified as a breakline restricting these breakout flows in this stream. This can be seen in the depth and velocity maps in Appendix G, Figure 59 to Figure 63 and Appendix I, Figure 69 to Figure 73 respectively. The flow is deeper upstream (west) of the road and faster over it.

The extent of the 1% AEP flood is a reasonably close match for the Latrobe flood study along the Tyers River, but the eastern breakout is narrower. This could be caused by either lower flows or by the smaller grid cells in the Tyers River model better representing the roads. The fact that the Tyers model breaks out upstream of Brown Coal Mine Road suggests that it is the cell size rather than the flow. The area between Christensons Road and the Latrobe River escarpment that was covered by the VFD but not by Latrobe River Flood Study (2015) remained unflooded.

The smooth curve of the stage discharge graphs from Appendix E, Figure 39 to Figure 43 suggest that that there is no overtopping of the bridge on Brown Coal Mine Road, and this is confirmed in the river long sections in Appendix E, Figure 49 to Figure 53.

The grid cell size of 10 metres was chosen because it was the smallest that could be run in a reasonable time. A five metre grid was considered unnecessary as the model had a 1D component. The behaviour of the model showed that this was sufficiently small to identify breaklines and streams, with the impact of Brown Coal Mine Road and Sawyers Lane. A five metre grid would have improved detail along roads and streams but it is unlikely that the improvement would have been great enough to justify the additional run time. Grids with smaller cells could be easily produced and run if additional detail is required at some point.

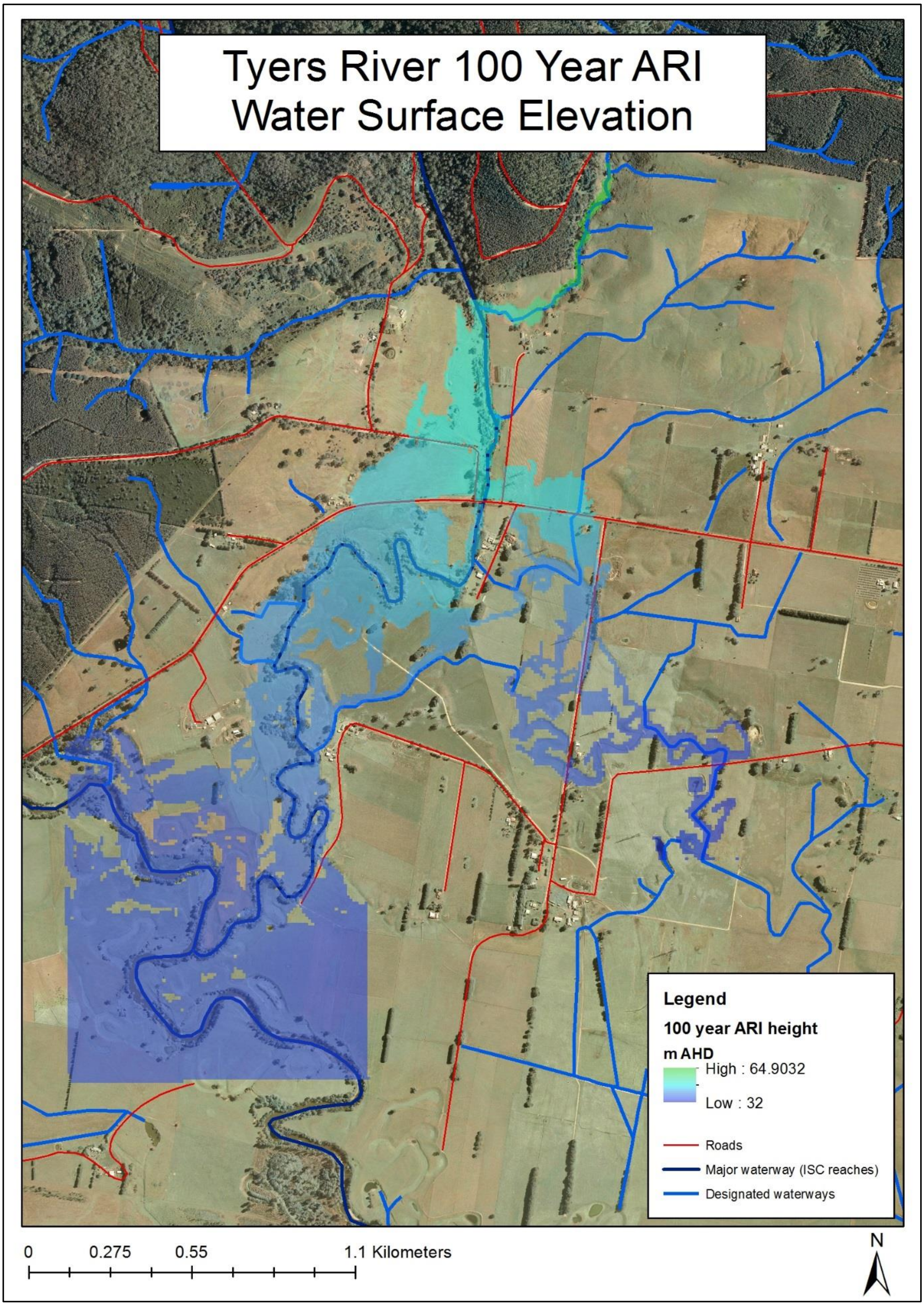

Figure 9 1% AEP maximum water surface elevation

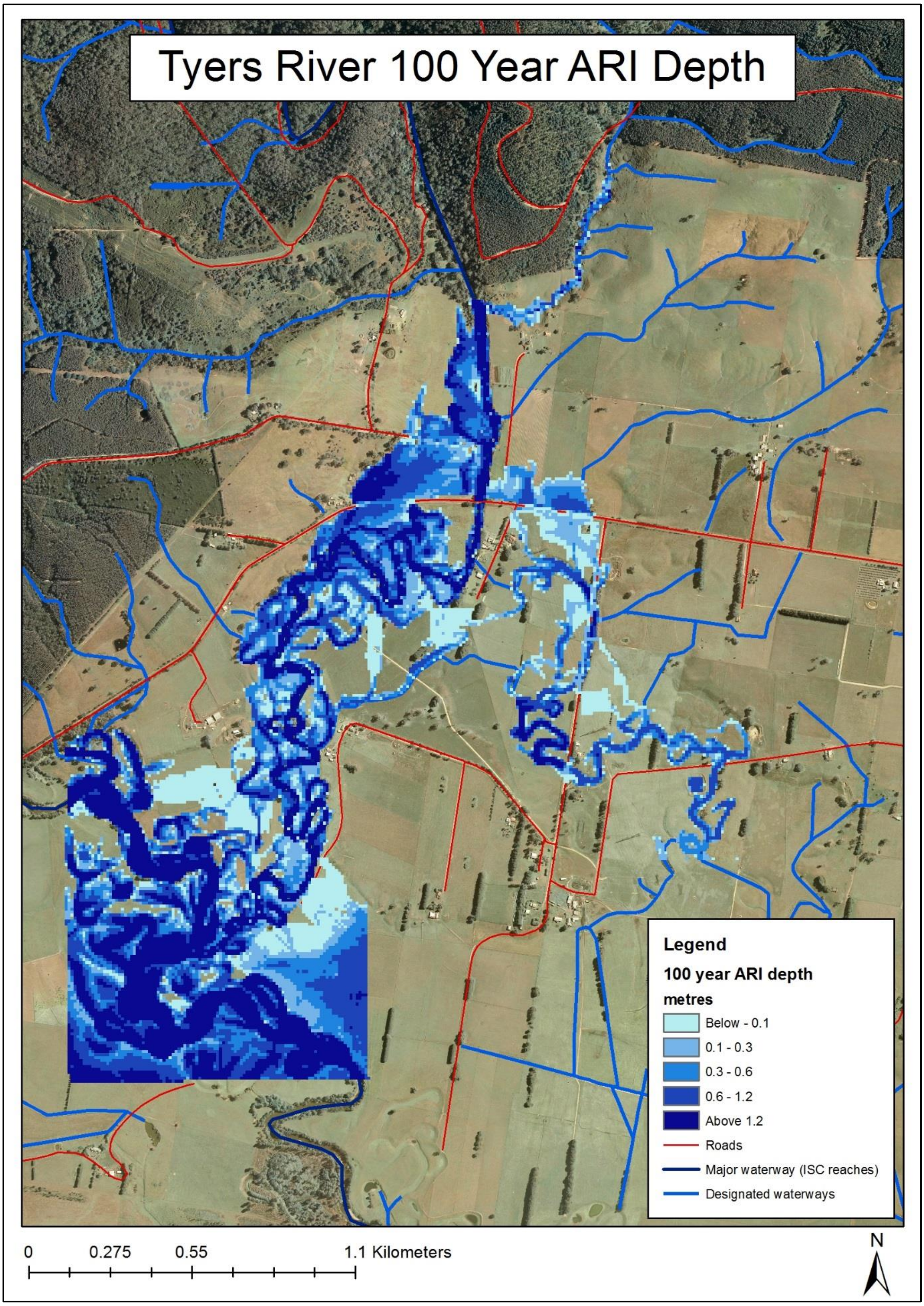

Figure 10 1% AEP maximum depth

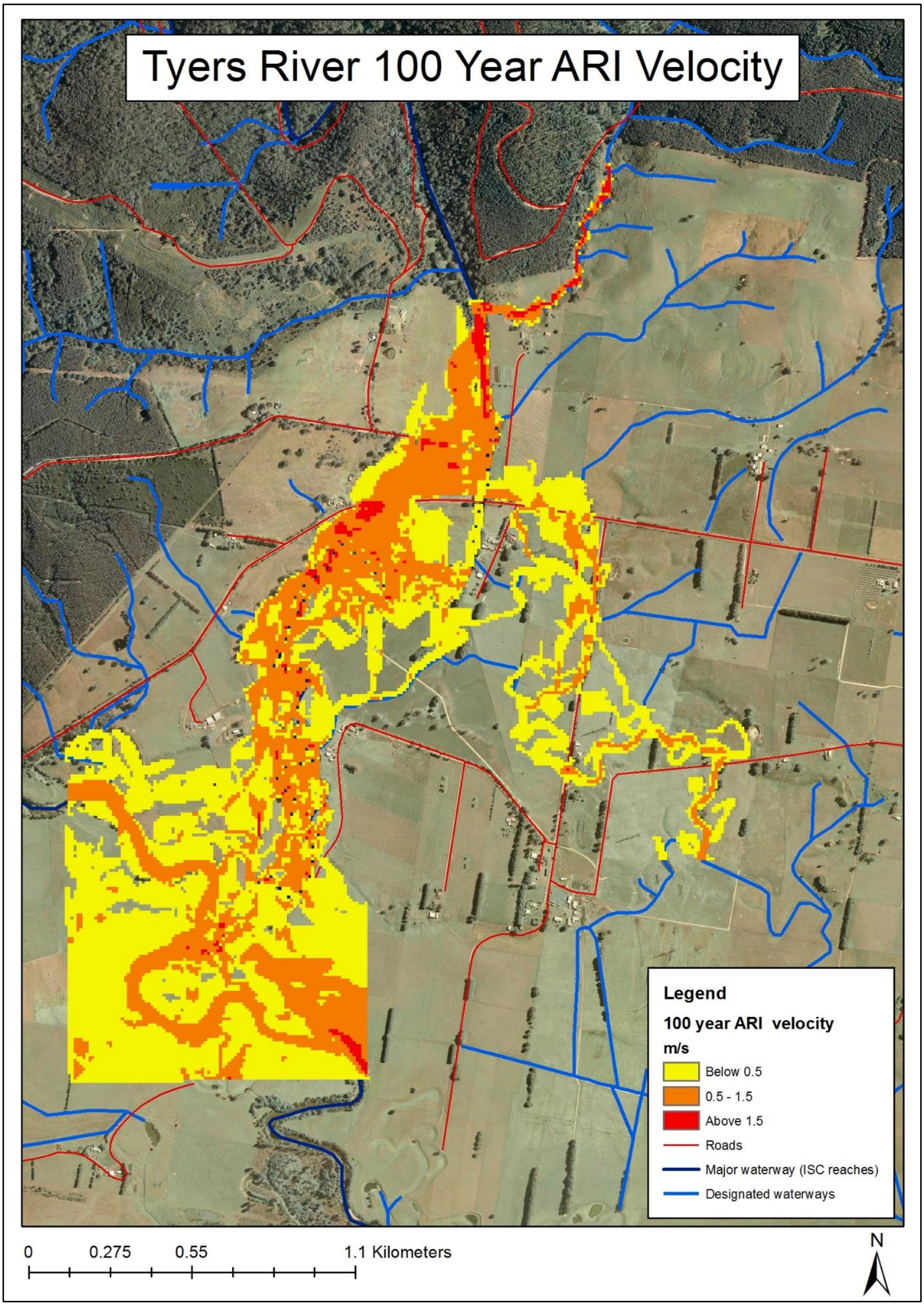

Figure 11 1% AEP maximum velocity

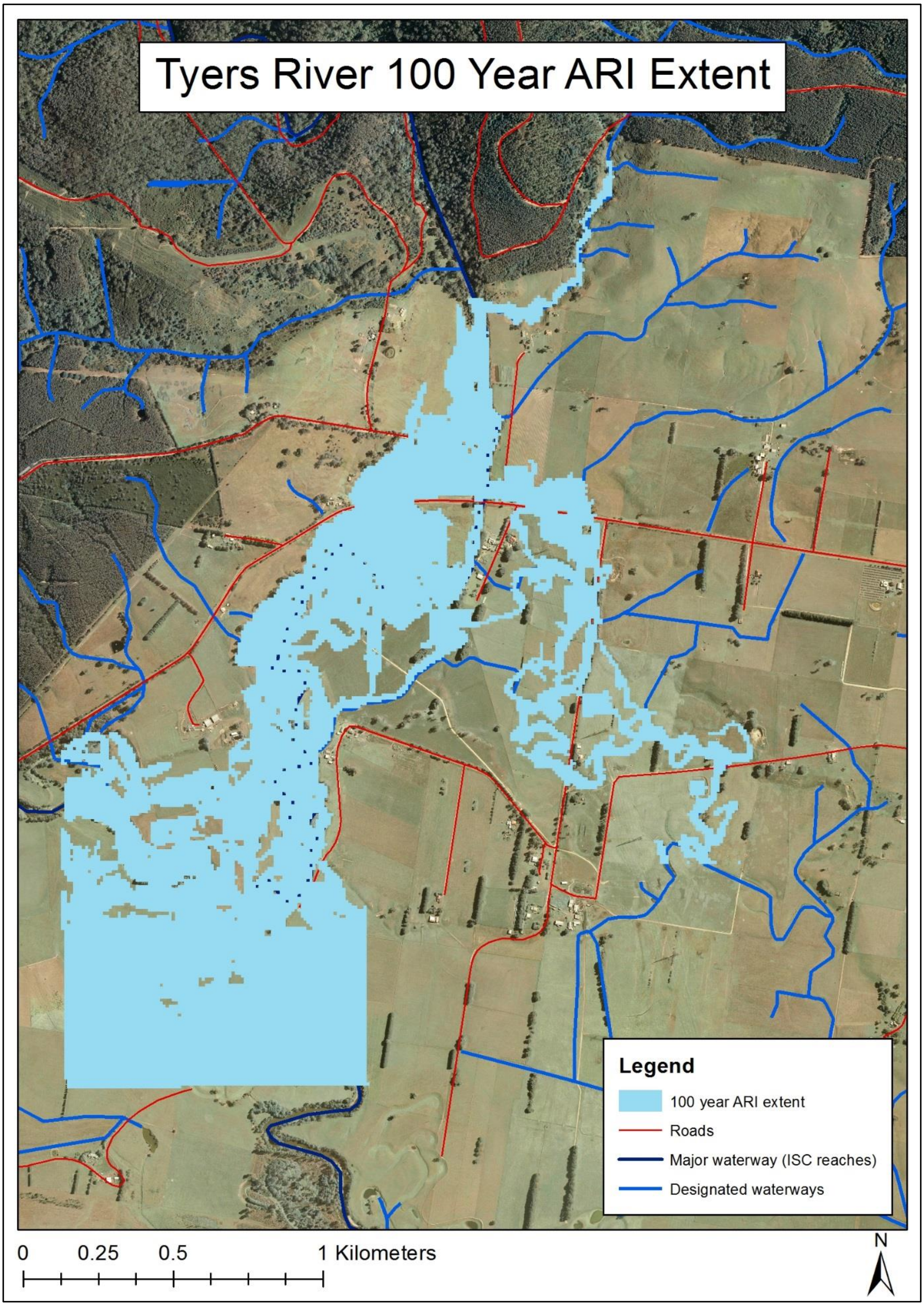

Figure 12 1% AEP extent

4 Conclusion and Recommendations

4.1 Conclusion

From the results of this flood study it can be concluded that the Tyers River experiences flooding north of Brown Coal Mine road, an area that is currently not identified in the VFD as being subject to flooding. This is reasonably consistent with the Latrobe River Flood Study (2015) on the west overbank. The breakout path on the east overbank follows a similar path to the Latrobe River Flood Study (2015), but the extent is narrower and begins upstream of Brown Coal Mine Road rather than downstream.

The results support the observation of area between Christensons Road and the Latrobe River escarpment. As in the Latrobe River Flood Study (2015), flows from either side travel around this area and into the Latrobe River.

Although the extent is narrow, a large proportion of it is deeper than 0.3 metres. Because all of the land within the flood extent is zoned for farming purposes, these results would affect the placement of new dwellings and the design of new dwellings and agricultural sheds. The extent of flooding shown in this study is generally smaller than the VFD. Aside from those immediately upstream of Brown Coal Mine Road, no new properties have been identified as being subject to inundation.

Comparison between the RORB model and flood frequency analysis suggest that the Pearse Victorian Data K_c equation and regional IFD table work best for hydrologic models in this region. Varying the initial loss within the range recommended in ARR Book 2 did not have a significant impact on the results. Of the different initial flow estimation methods probabilistic rational method based on the 1987 IFD table provided the closest match with the flood frequency analysis.

4.2 Recommendations

The closest initial flow estimation method was still approximately 20 percent (40m^3/s at 1% AEP) from the flood frequency analysis results. Further research into an appropriate regional method for Gippsland catchments needs to be undertaken for use in flood studies of ungauged catchments. The flood frequency analysis data from the Tyers River could be useful for this. Flood frequency analysis at Morgans Mill should be completed once a sufficient amount of data has been collected. It could also be completed eventually at Tyers Junction if large flows can be recorded there.

There is also a general lack of hourly rainfall data around the Tyers catchment. This became apparent when searching for storm data for the FIT run. This would not only improve future flood studies of the Tyers River, but other catchments in the area.

One recommendation from this study would be for more data collection to occur on the Tyers River. Flows recorded downstream of Moondarra Reservoir would be unusable for flood frequency analysis, so the lack of data here is not an issue for flood mapping.

Based on the results of this flood study and the Latrobe River Flood Study (2015), the area not inundated in either study could be considered for removal from the VFD. Another possible change is the inclusion of flooding upstream of Brown Coal Mine Road. Flooding is shown to occur here from the Tyers River and in the Latrobe River Flood Study (2015).

A more general recommendation is that more sensitivity analysis should be completed for hydraulic models. While sensitivity analysis was an ongoing part of the hydrologic analysis and draft hydraulic models, time constraints preventing additional hydraulic models from being run meant that sensitivity analysis for variables such as blockages and roughness could not be completed.

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Appendix A: Preliminary data collection

Table 11 1987 IFD table at the catchment centroid (mm/h)

DURATION	1 Year	2 years	5 years	**10 years**	20 years	50 years	100 years
5Mins	48.5	65.6	93.4	113	139	177	210
6Mins	45.4	61.5	87.3	106	130	166	196
10Mins	37	50	70.8	85.6	105	134	158
20Mins	26.6	35.9	50.8	61.3	75.1	95.3	112
30Mins	21.5	28.9	40.9	49.2	60.3	76.4	90.1
1Hr	14.6	19.6	27.4	32.9	40.1	50.6	59.4
2Hrs	9.85	13.1	18	21.4	25.9	32.3	37.7
3Hrs	7.82	10.4	14.1	16.6	19.9	24.7	28.6
6Hrs	5.28	6.93	9.18	10.7	12.7	15.5	17.8
12Hrs	3.54	4.61	5.99	6.89	8.1	9.8	11.2
24Hrs	2.33	3.02	3.88	4.44	5.2	6.25	7.1
48Hrs	1.48	1.91	2.45	2.79	3.26	3.92	4.44
72Hrs	1.11	1.43	1.82	2.07	2.41	2.88	3.26

Raw data	2i1	2i12	2i72	50i1	50i12	50i72	Skew	F2	F50
	20.06	4.73	1.46	46.52	9.12	2.7	0.30	4.25	15.15

Table 12 1987 IFD table at centroid of catchments above Browns (mm/h)

DURATION	1 Year	2 years	5 years	10 years	20 years	50 years	100 years
5Mins	51.5	69.1	96.3	115	140	177	207
6Mins	48.3	64.7	90.1	108	131	165	193
10Mins	39.4	52.7	73.2	87.3	106	133	156
20Mins	28.3	37.9	52.4	62.3	75.6	94.7	111
30Mins	22.9	30.6	42.2	50.1	60.6	75.9	88.6
1Hr	15.7	20.8	28.5	33.7	40.6	50.6	58.9
2Hrs	10.7	14.1	19.1	22.4	26.9	33.3	38.6
3Hrs	8.53	11.3	15.1	17.7	21.1	26	30
6Hrs	5.84	7.67	10.1	11.8	14	17.1	19.6
12Hrs	3.96	5.17	6.74	7.76	9.15	11.1	12.7
24Hrs	2.6	3.38	4.35	4.98	5.84	7.03	7.99
48Hrs	1.63	2.11	2.69	3.06	3.57	4.27	4.83
72Hrs	1.22	1.58	1.99	2.25	2.61	3.11	3.51

Raw data	2i1	2i12	2i72	50i1	50i12	50i72	Skew	F2	F50
	21.22	5.31	1.61	46.52	10.38	2.92	0.35	4.25	15.13

Table 13 2013 IFD at the catchment centroid (mm)

DURATION	1 Year	2 years	5 years	10 years	20 years	50 years	100 years
4Mins	4.2	4.8	6.7	8.1	9.5	11.4	13.0
5Mins	4.9	5.6	7.9	9.5	11.2	13.5	15.4
10Mins	7.4	8.5	12.1	14.7	17.3	21.0	23.9
15Mins	9.1	10.4	14.8	18.0	21.2	25.7	29.3
30Mins	12.2	13.9	19.6	23.8	28.0	33.9	38.6
1Hr	15.7	17.8	24.9	30.1	35.4	42.8	48.9
2Hrs	20.2	22.9	31.7	38.2	45.0	54.6	62.6
3Hrs	23.7	26.7	36.9	44.6	52.6	64.1	73.7
6Hrs	31.9	35.9	49.5	59.9	71.0	87.2	100.8
12Hrs	43.6	49.1	68.1	82.6	98.4	121.5	141.1
24Hrs	58.8	66.4	92.7	112.7	134.2	165.7	192.4
48Hrs	75.5	85.4	119.2	144.5	171.1	209.4	241.6
72Hrs	84.4	95.4	132.2	159.4	187.6	227.9	261.3

Table 14 2013 IFD at centroid of catchments above Browns (mm)

DURATION	1 Year	2 years	5 years	10 years	20 years	50 years	100 years
4Mins	4.3	4.9	6.8	8.2	9.6	11.5	13
5Mins	5	5.7	8	9.6	11.2	13.5	15.3
10Mins	7.5	8.6	12.2	14.8	17.4	21	23.8
15Mins	9.2	10.5	14.9	18.1	21.3	25.7	29.2
30Mins	12.3	14.1	19.8	23.9	28.1	33.9	38.5
1Hr	16	18.1	25.2	30.4	35.6	42.8	48.7
2Hrs	20.7	23.4	32.2	38.7	45.4	54.8	62.5
3Hrs	24.4	27.4	37.6	45.2	53.1	64.5	73.8
6Hrs	32.8	36.8	50.6	61	72.1	88.3	101.9
12Hrs	44.9	50.5	69.9	84.7	100.7	124.3	144.4
24Hrs	60.9	68.7	95.8	116.5	138.9	171.7	199.6
48Hrs	79.4	89.6	124.7	151.2	179.2	219.7	253.8
72Hrs	89.8	101.2	139.6	168.1	197.9	240.7	276.2

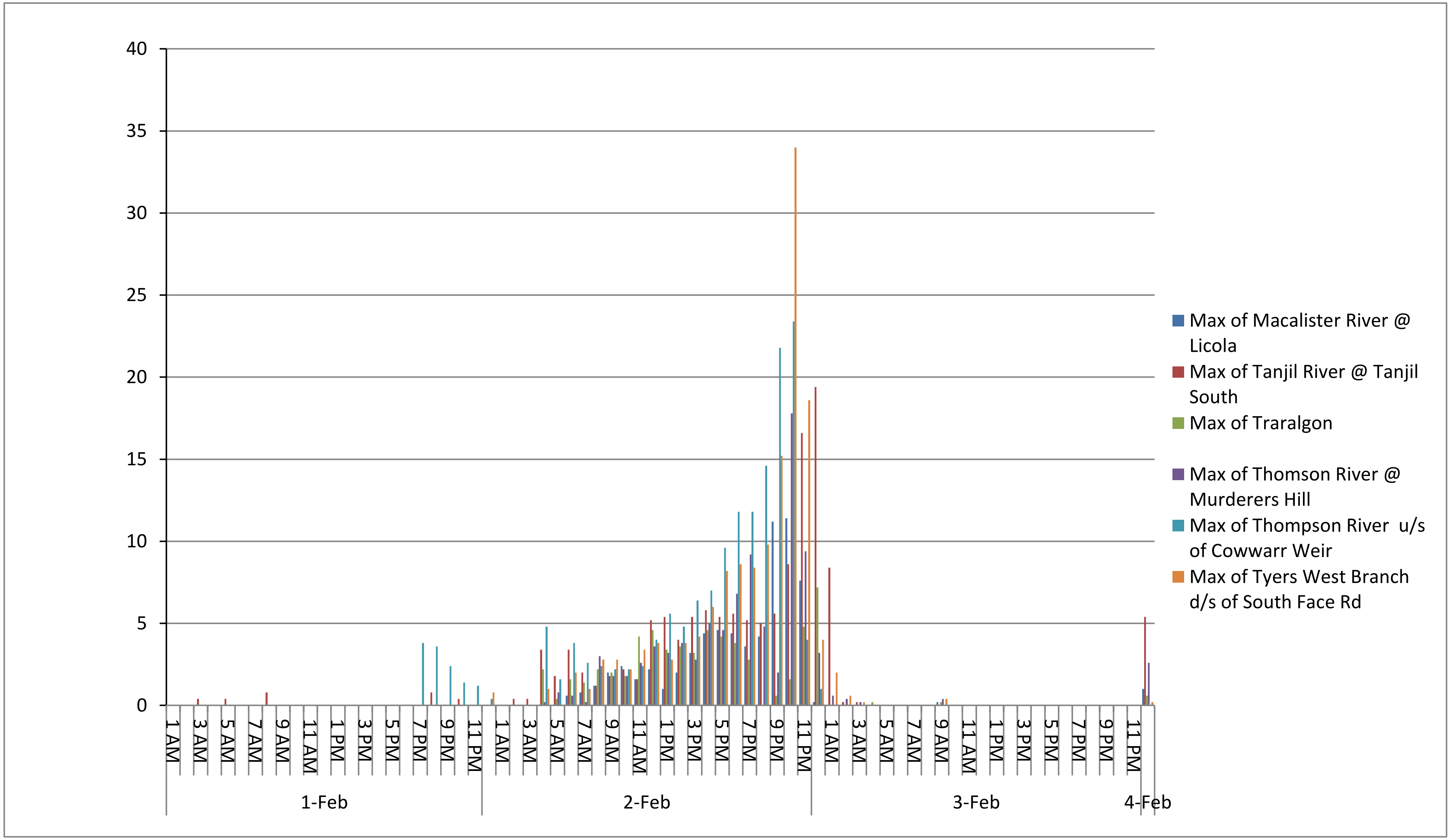
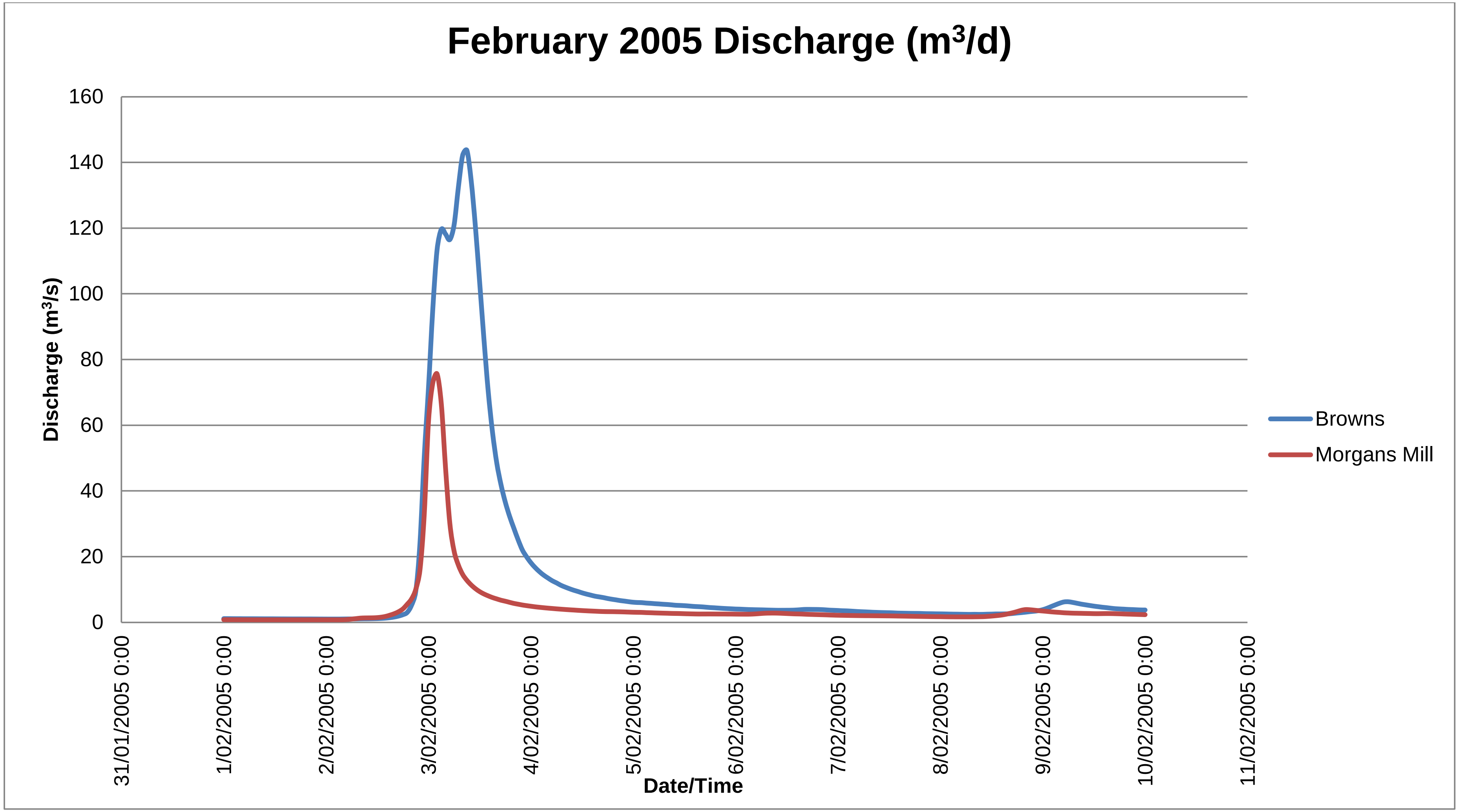


Figure 13 February 2005 hyetographs


February 2005 Discharge (m³/d)
Discharge (m³/s)
160
140
120
100
80
60
40
20
0
31/01/2005 0:00
1/02/2005 0:00
2/02/2005 0:00
3/02/2005 0:00
4/02/2005 0:00
5/02/2005 0:00
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10/02/2005 0:00
11/02/2005 0:00
Date/Time
Browns
Morgans Mill

Appendix B: Hydrologic model input data

RORB Parameters

Table 15 RORB Subcatchment areas

Subcatchment	Area	Subcatchment	Area	Subcatchment	Area
A1	10.1	H8	3.165	R3	2.456
A2	2.933	I	9.26	R4	1.27
A3	7.672	J	3.281	S1	5.709
A4	4.972	K	2.005	S2	2.618
B	11.429	L	9.428	S3	3.898
C1	11.4	L1	1.796	S4	8.225
C2	1.97	M1	5.075	S5	2.881
C3	4.207	M2	5.466	T1	7.026
C4	2.975	M3	5.127	T2	2.693
C5	2.564	M4	2.645	T3	9.943
C6	2.293	N1	3.523	T4	5.261
C7	2.075	N2	5.219	U1	6.434
C8	3.224	N3	4.454	U2	4.829
D	8.766	O1	7.604	U3	3.69
H1	3.419	O2	11.942	V1	3.282
H2	11.474	P	4.085	V2	4.338
H3	10.769	Q	11.264	W	4.738
H4	2.691	Q1	3.152	X	5.354
H5	5.019	R1	10.75	Y	10.258
H6	4.422	R2	2.393	Z	3.213
H7	4.186				

Table 16 RORB Kc equations

	Equation
Australia wide (Yu)	$0.96D_{av}$
Australia Wide (Dyer)	$1.14D_{av}$
VicMAR<800mm	$0.49A^{0.65}$
VicMAR>800mm	$2.57A^{0.45}$
Pearse Victorian Data	$1.25D_{av}$
Default RORB	$2.2A^{0.5}$

Table 17 RORB FIT run Parameters - Vic MAR >800mm Kc run

	Kc	m	IL	CL
Morgans Mill	18.10	0.8	15	10.22
Browns	22.38	0.8	15	5.21
Catchment outlet	22.36	0.8	15	5.21

Table 18 RORB FIT run Parameters - Pearce Kc run

	Kc	m	IL	CL
Morgans Mill	65.53	0.8	15	10.22
Browns	65.53	0.8	15	5.21
Catchment outlet	65.53	0.8	15	5.21

Table 19 RORB design run parameters

	Kc	m	IL	CL
Whole catchment	65.53	0.8	15	3.00

Table 20 Subcatchment rainfall, February 2005

Subcatchment	Rainfall (mm)	Subcatchment	Rainfall (mm)	Subcatchment	Rainfall (mm)
A1	161.58	H8	158.34	R3	138.39
A2	177.09	I	153.75	R4	136.14
A3	182.22	J	154.28	S1	130.59
A4	172.93	K	154.54	S2	134.20
B	162.50	L	154.34	S3	137.21
C1	155.98	L1	154.69	S4	140.46
C2	158.32	M1	151.89	S5	125.97
C3	156.46	M2	150.83	T1	115.56
C4	153.85	M3	150.62	T2	122.18
C5	154.08	M4	151.25	T3	129.43
C6	156.62	N1	147.76	T4	127.95
C7	155.06	N2	145.87	U1	120.43
C8	153.90	N3	148.24	U2	112.57
D	158.46	O1	145.82	U3	107.36
H1	155.59	O2	152.20	V1	118.35
H2	153.41	P	150.99	V2	115.23
H3	158.64	Q	147.51	W	101.17
H4	156.11	Q1	150.27	X	109.12
H5	157.61	R1	143.82	Y	96.47
H6	159.04	R2	142.71	Z	94.49
H7	159.03				

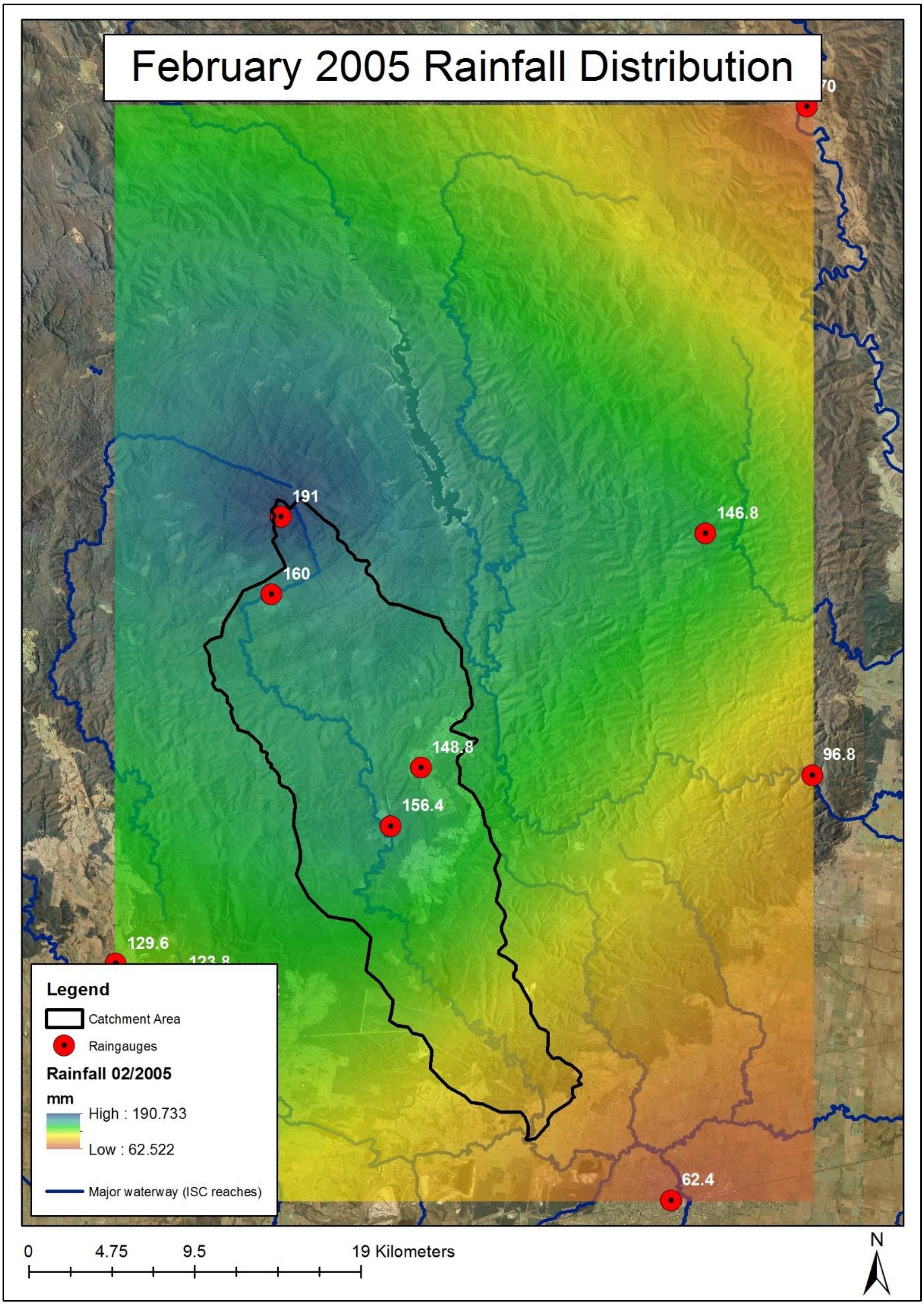


Figure 14 February 2005 rainfall distribution

Flood Frequency Analysis

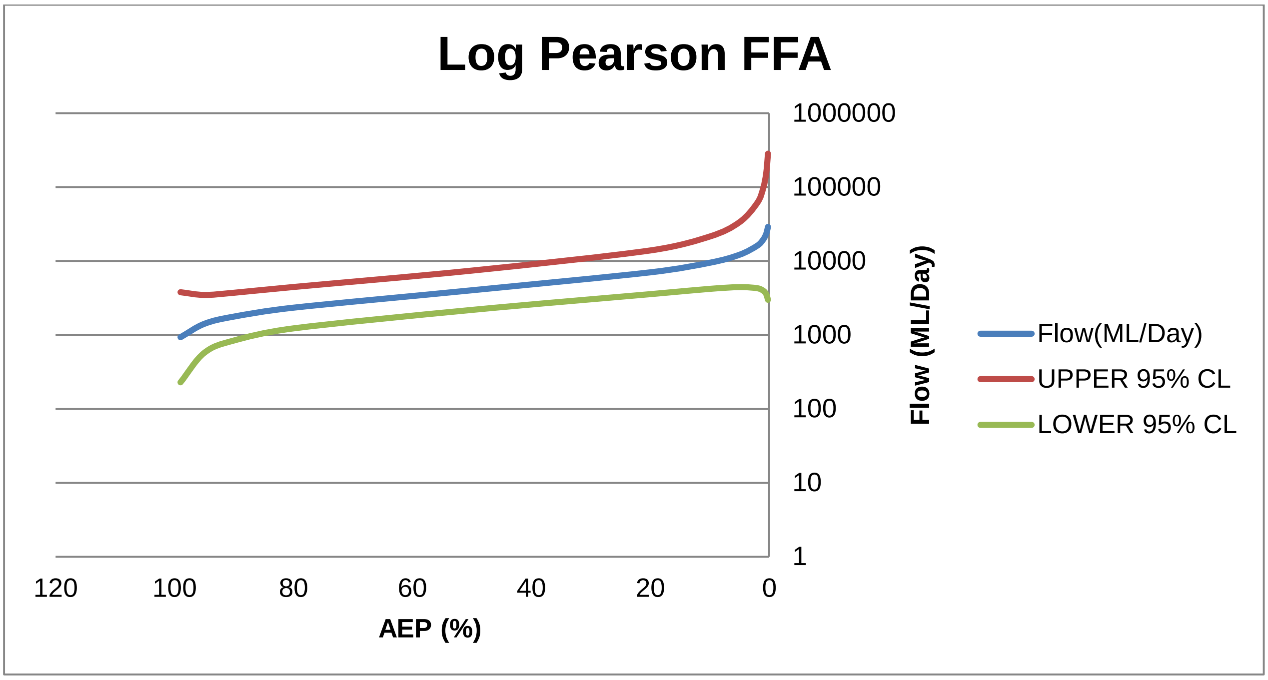


Figure 15 Log Pearson FFA

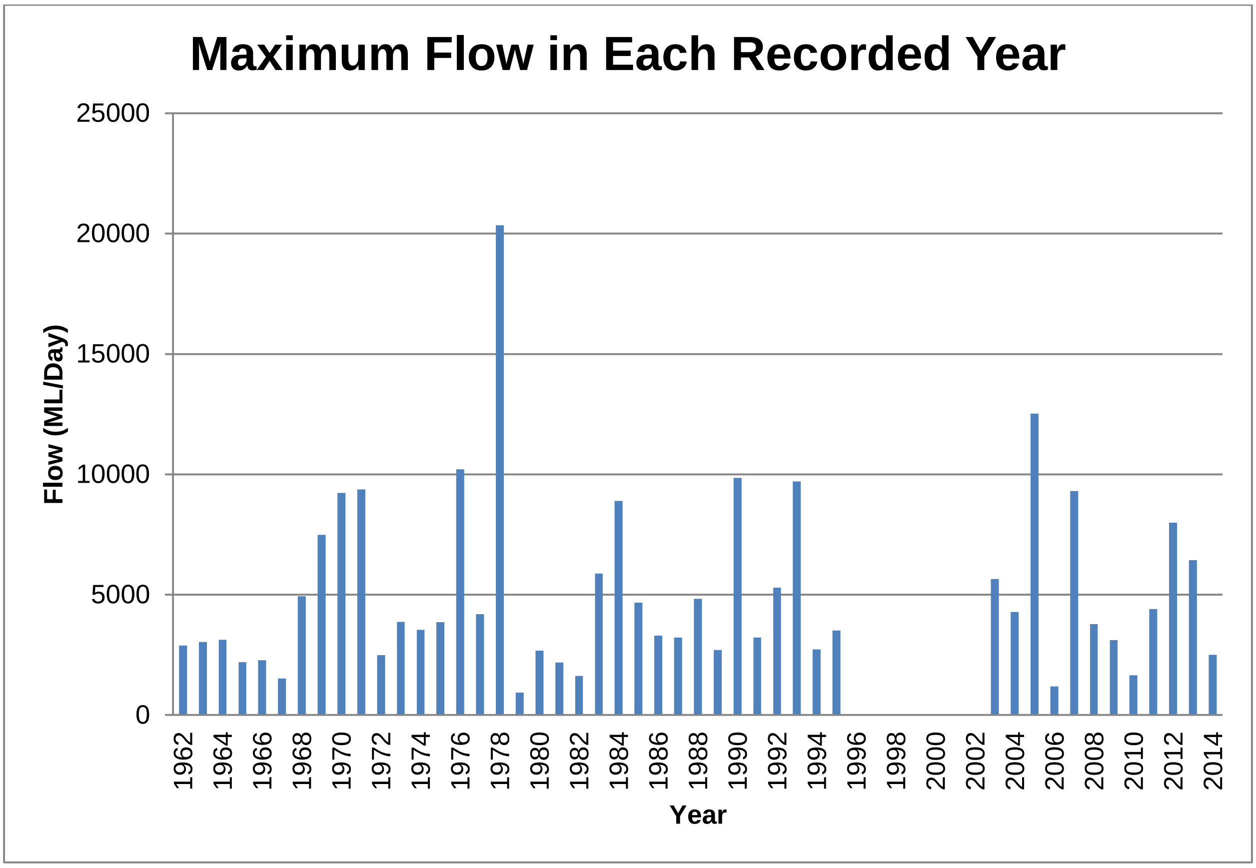


Figure 16 Annual maximum flow recorded at Browns

Table 21 Browns quantile estimation historic intensities

Year	Max. discharge m^3/s	AEP	ARI	Year	Max. discharge m^3/s	AEP	ARI
1962	33.47	33.47	70.56	1985	54.05	38.10	2.63
1963	35.10	35.10	68.40	1986	38.28	57.58	1.74
1964	36.15	36.15	64.07	1987	37.22	61.90	1.62
1965	25.41	25.41	85.71	1988	55.84	35.93	2.78
1966	26.41	26.41	83.55	1989	31.31	74.89	1.34
1967	17.53	17.53	94.37	1990	114.07	7.79	12.83
1968	57.13	57.13	33.77	1991	37.29	59.74	1.67
1969	86.69	86.69	22.94	1992	61.24	31.60	3.16
1970	106.82	106.82	16.45	1993	112.37	9.96	10.04
1971	108.49	108.49	12.12	1994	31.52	72.73	1.38
1972	28.80	28.80	81.39	1995	40.64	55.41	1.80
1973	44.85	44.85	46.75	2003	65.43	29.44	3.40
1974	40.91	40.91	53.25	2004	49.63	42.42	2.36
1975	44.63	44.63	48.92	2005	144.93	3.46	28.88
1976	118.19	118.19	5.63	2006	13.78	96.54	1.04
1977	48.52	48.52	44.59	2007	107.75	14.29	7.00
1978	235.54	235.54	1.30	2008	43.71	51.08	1.96
1979	10.76	10.76	98.70	2009	36.05	66.23	1.51
1980	31.01	31.01	77.06	2010	19.13	90.04	1.11
1981	25.22	25.22	87.88	2011	50.97	40.26	2.48
1982	18.75	18.75	92.21	2012	92.56	20.78	4.81
1983	68.04	68.04	27.27	2013	74.45	25.11	3.98
1984	103.02	103.02	18.61	2014	28.95	79.22	1.26

Table 22 Browns FLIKE historic intensities

Year	Max. discharge m^3/s	AEP	ARI	Year	Max. discharge m^3/s	AEP	ARI
1963	35.10	69.93	1.43	1986	38.28	58.82	1.7
1964	36.15	65.36	1.53	1987	37.22	63.29	1.58
1965	25.41	85.47	1.17	1988	55.84	36.76	2.72
1966	26.41	83.33	1.2	1989	31.31	74.07	1.35
1967	17.53	94.34	1.06	1990	114.07	7.96	12.56
1968	57.13	34.48	2.9	1991	37.29	60.98	1.64
1969	86.69	23.47	4.26	1992	61.24	32.26	3.1
1970	106.82	16.81	5.95	1993	112.37	10.17	9.83
1971	108.48	12.39	8.07	1994	31.52	71.94	1.39
1972	28.80	81.30	1.23	1995	40.63	56.50	1.77
1973	44.85	47.85	2.09	2003	65.42	30.12	3.32
1974	40.91	54.35	1.84	2004	49.63	43.29	2.31
1975	44.63	50.00	2	2005	144.93	3.54	28.25
1976	118.19	5.75	17.38	2006	13.78	96.15	1.04
1977	48.52	45.66	2.19	2007	107.75	14.60	6.85
1978	235.54	1.33	75.33	2008	43.70	52.08	1.92
1979	10.76	99.01	1.01	2009	36.05	67.57	1.48
1980	31.01	76.34	1.31	2010	19.13	90.09	1.11
1981	25.22	87.72	1.14	2011	50.97	41.15	2.43
1982	18.75	91.74	1.09	2012	92.56	21.23	4.71
1983	68.04	27.86	3.59	2013	74.45	25.64	3.9
1984	103.02	19.01	5.26	2014	28.95	78.74	1.27
1985	54.05	38.91	2.57				

Table 23 FLIKE FFA Results – Log normal

Number	Deviate	Expected_par_quantile		ARI	Lower_90%_prob_limit		Upper_90%_prob_limit	
		Log(m^3/s)	m3/s					
1	-2.330	1.000	10.010		0.781	6.040	1.149	14.100
2	-1.335	1.282	19.150		1.169	14.760	1.375	23.700
3	-0.842	1.425	26.620		1.336	21.700	1.507	32.100
4	-0.431	1.546	35.140		1.466	29.230	1.624	42.100
5	-0.180	1.620	41.710	1.5	1.542	34.870	1.700	50.100
6	0.000	1.674	47.200	2	1.598	39.590	1.754	56.700
7	0.431	1.804	63.650		1.727	53.349	1.888	77.300
8	0.842	1.929	84.949	5	1.846	70.210	2.023	105.499
9	1.282	2.065	116.18	10	1.968	92.830	2.184	152.700
10	1.645	2.179	150.92	20	2.064	115.891	2.331	214.398
11	2.054	2.308	203.269	50	2.165	146.272	2.511	324.004
12	2.326	2.395	248.39	100	2.228	168.990	2.637	434.000

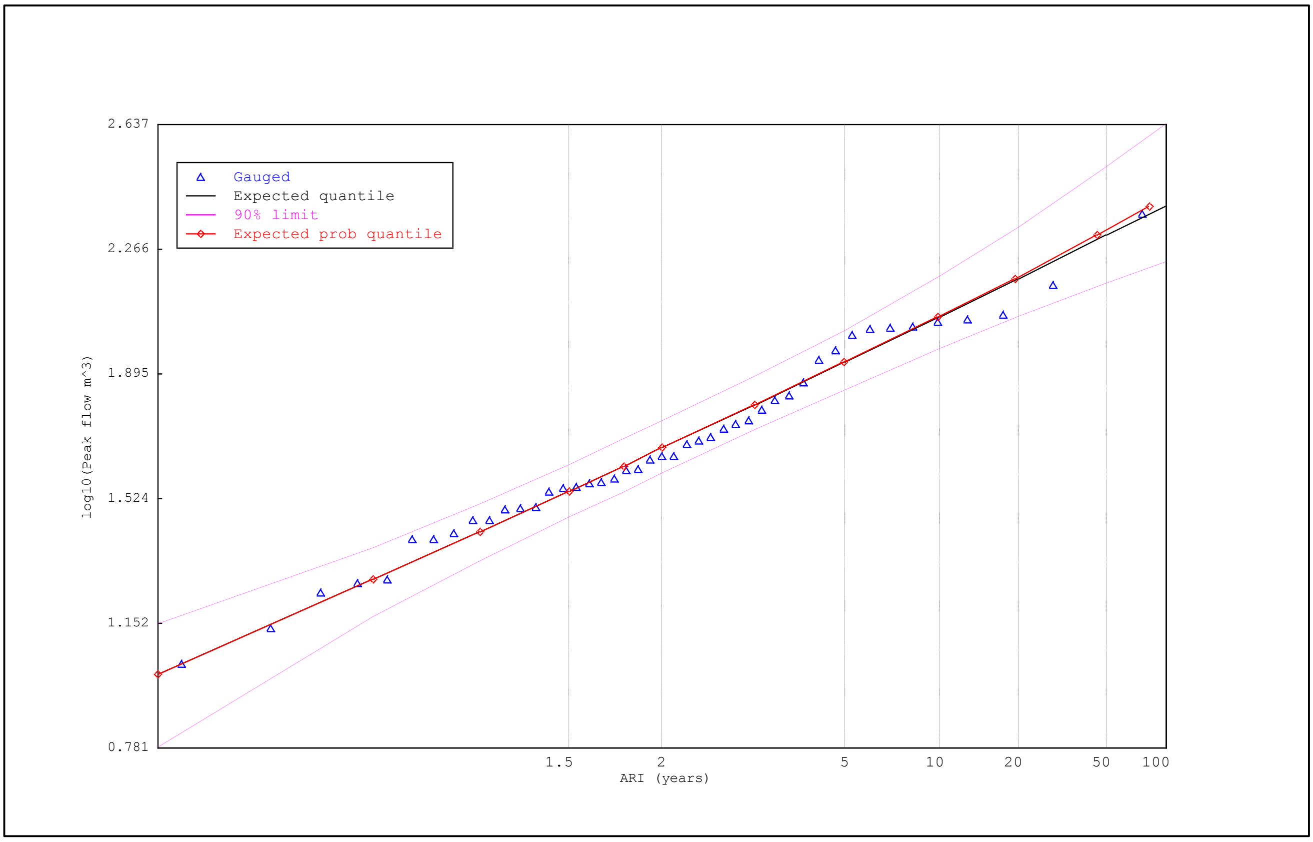


Figure 17 FLIKE Log-normal FFA

Table 24 FLIKE FFA Results – Gumbel, Gumbel log

Number	Deviate	Expected_par_quantile		ARI	Lower_90%_prob_limit		Upper_90%_prob_limit	
		Log(m^3/s)	m3/s					
1	-1.529	1.000	10.010		0.781	6.040	.149	14.100
2	-0.875	1.282	19.150		1.169	14.760	1.375	23.700
3	-0.476	1.425	26.620		1.336	21.700	1.507	32.100
4	-0.094	1.546	35.140		1.466	29.230	1.624	42.100
5	0.166	1.620	41.710	1.5	1.542	34.870	1.700	50.100
6	0.367	1.674	47.200	2	1.598	39.590	1.754	56.700
7	0.903	1.804	63.650		1.727	53.349	1.888	77.300
8	1.500	1.929	84.949	5	1.846	70.210	2.023	105.499
9	2.250	2.065	116.18	10	1.968	92.830	2.184	152.700
10	2.970	2.179	150.92	20	2.064	115.891	2.331	214.398
11	3.902	2.308	203.269	50	2.165	146.272	2.511	324.004
12	4.600	2.395	248.39	100	2.228	168.990	2.637	434.000

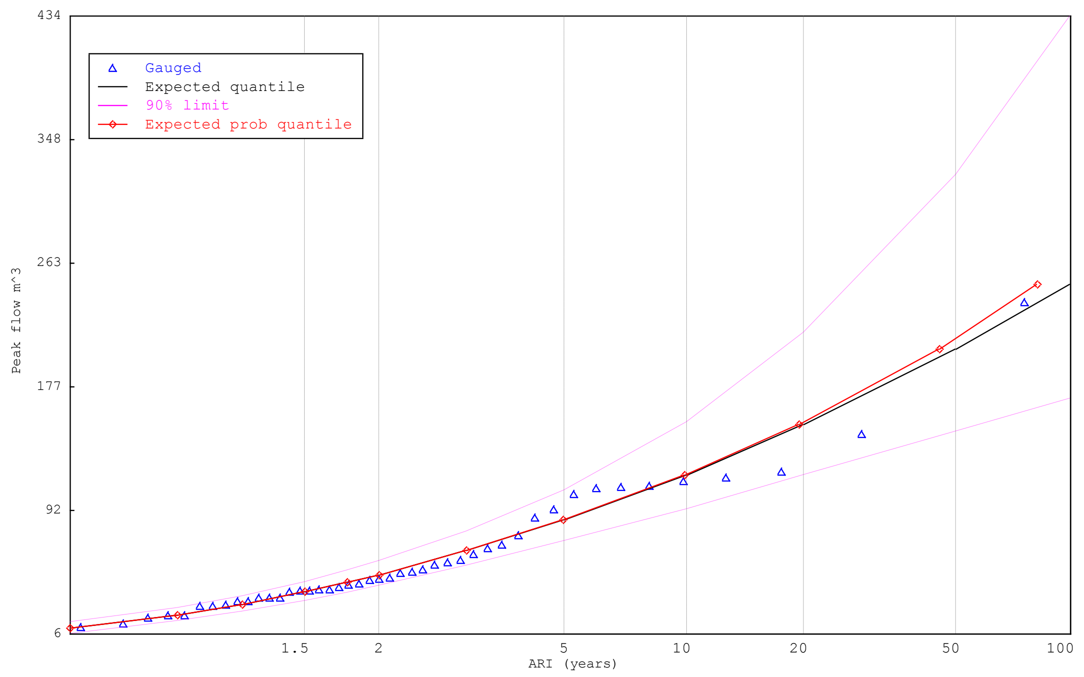


Figure 18 FLIKE Gumbel FFA

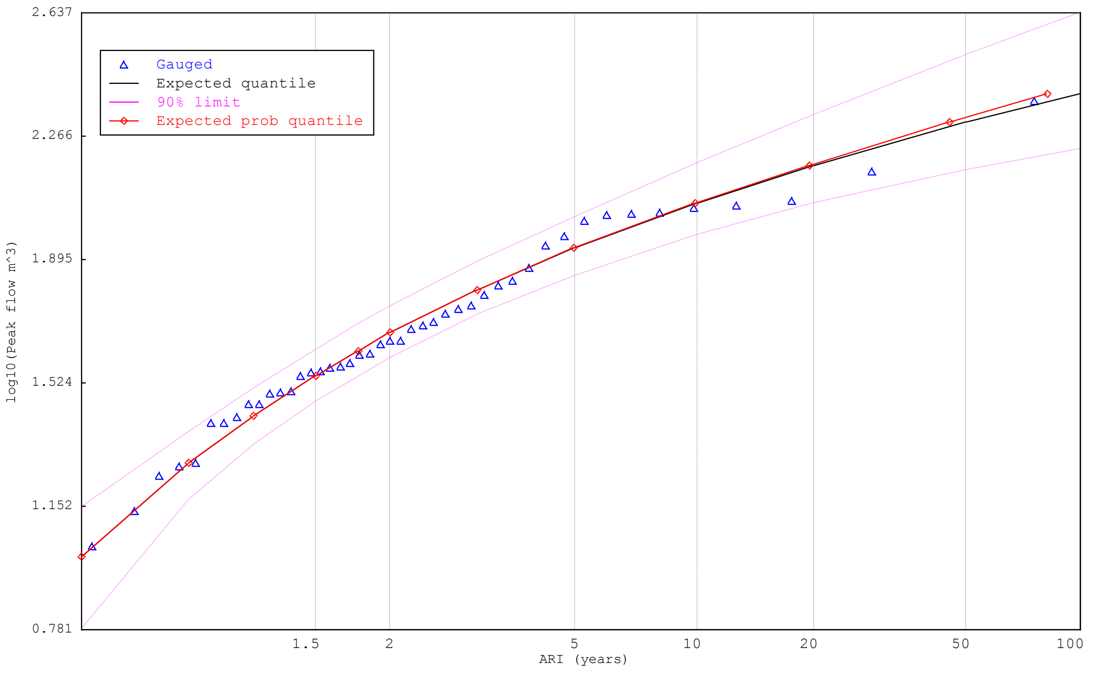


Figure 19 FLIKE Gumbel-log FFA

Table 25 FLIKE FFA Results – exponential, exponential log

Number	Deviate	Expected_par_quantile m3/s	ARI	Lower_90%_prob_limit	Upper_90%_prob_limit
1	Deviate	10.010		6.040	14.100
2	0.010	19.150		14.760	23.700
3	0.095	26.620		21.700	32.100
4	0.223	35.140		29.230	42.100
5	0.405	41.710	1.5	34.870	50.100
6	0.560	47.200	2	39.590	56.700
7	0.693	63.650		53.350	77.300
8	1.099	84.949	5	70.210	105.500
9	1.609	116.18	10	92.830	152.700
10	2.303	150.92	20	115.890	214.400
11	2.996	203.269	50	146.270	324.000
12	3.912	248.39	100	168.990	434.000

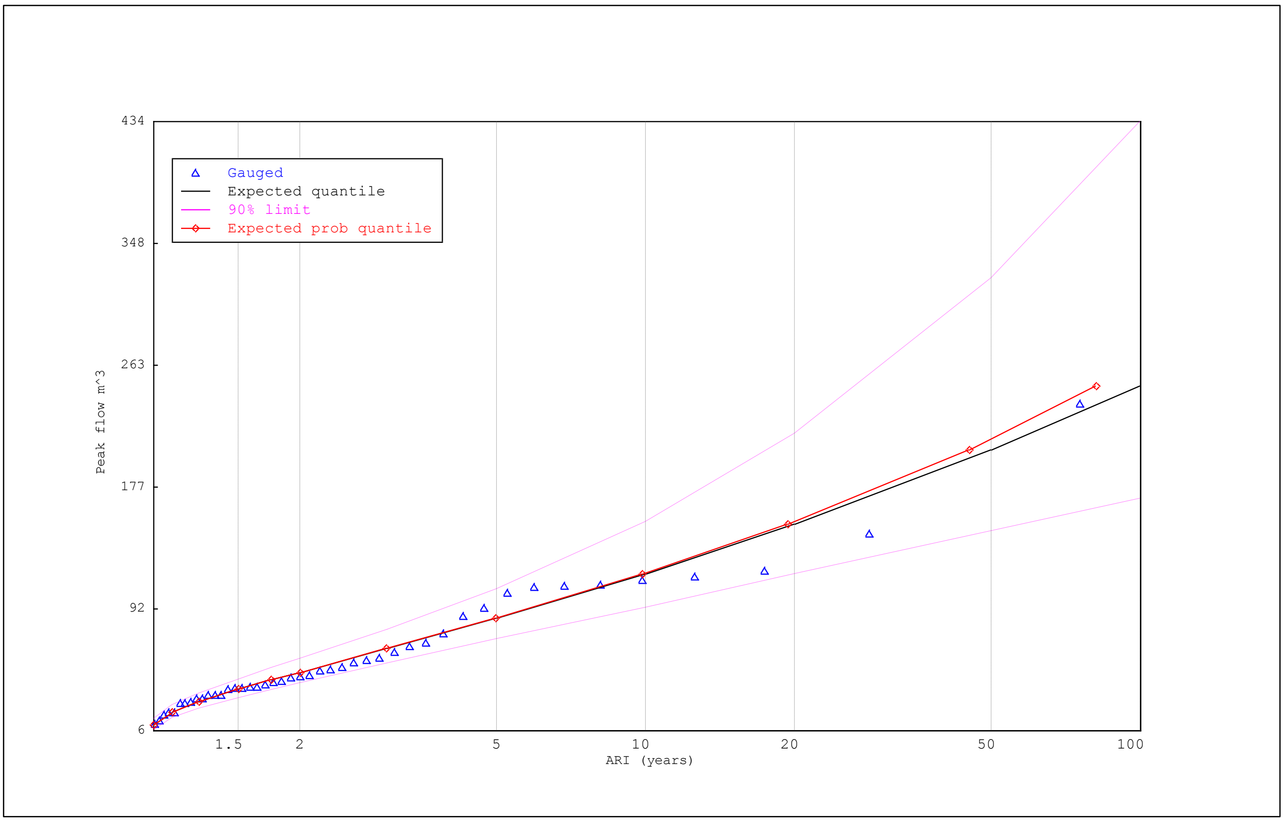


Figure 20 FLIKE Exponential FFA

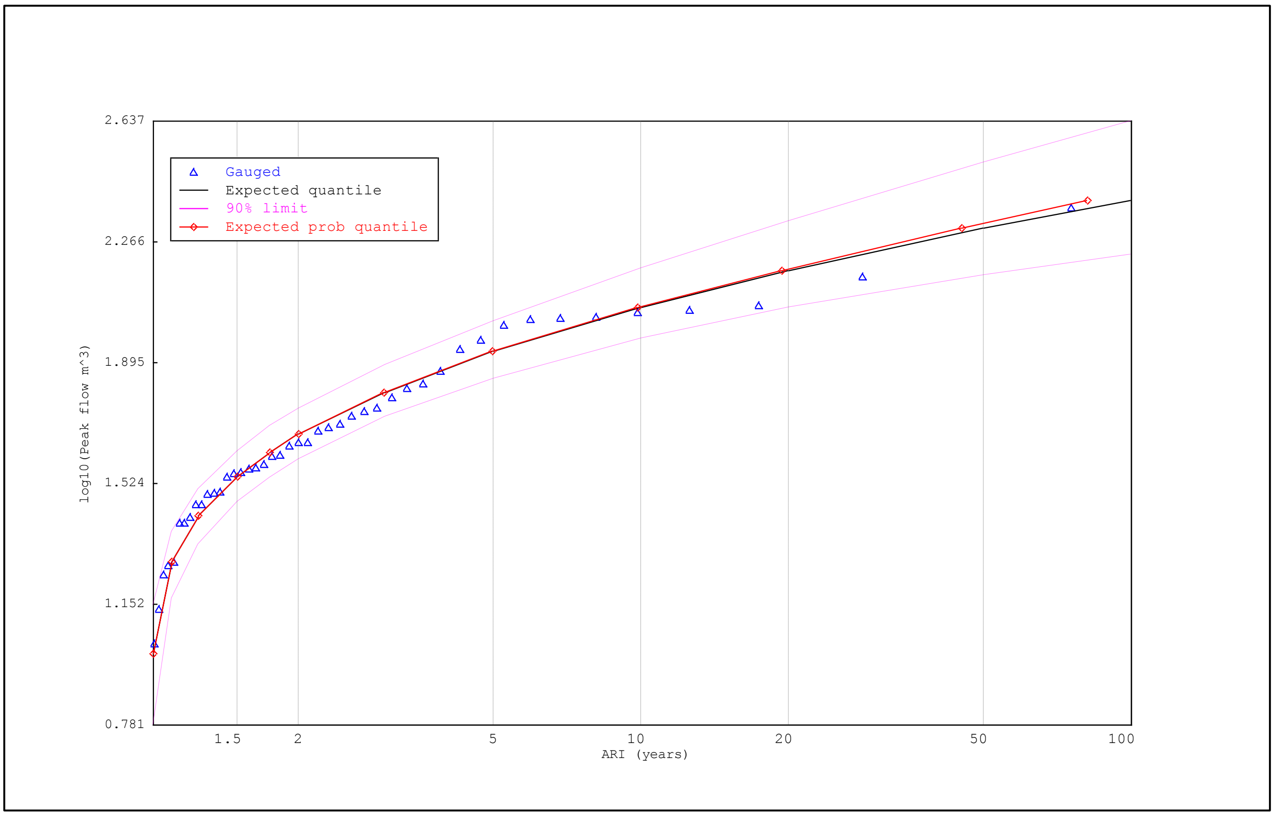


Figure 21 FLIKE Exponential Log FFA

Appendix C: Output data from hydrologic model

Table 26 RORB design run peak flows for all ARIs and durations

ARI	Duration	Browns	Inflow Y	Inflow Z	Outflow
5 Years	1 Hour	8.488	41.4451	6.9971	8.5073
	2 Hour	25.039	50.3449	9.0927	17.4875
	3 Hour	31.8963	58.5462	8.9935	22.2503
	6 Hour	59.4321	63.0418	11.2211	45.3848
	12hour	64.9346	65.2249	6.7999	64.5651
	24 Hour	61.5917	62.3373	6.6907	61.7129
	48 Hour	44.1651	44.1291	2.4556	43.7234
	72 Hour	33.8571	34.4237	1.9122	34.1934
10 Years	1 Hour	15.2337	62.0629	10.8583	14.4527
	2 Hour	40.7808	70.8562	12.8033	28.2798
	3 Hour	50.2823	80.7707	12.8252	34.8499
	6 Hour	82.8404	81.3471	14.5754	65.5709
	12hour	88.4101	89.0707	8.3532	88.2467
	24 Hour	83.5582	85.4052	8.1047	84.5855
	48 Hour	66.3658	67.006	3.1298	66.5579
	72 Hour	48.5907	51.4877	2.5882	51.3917
20 Years	1 Hour	25.5314	89.1171	16.0068	22.6069
	2 Hour	66.8851	103.377	18.0356	46.4159
	3 Hour	80.1656	109.278	18.5039	55.7048
	6 Hour	120.18	105.409	19.2159	98.5457
	12hour	130.177	131.941	10.6965	130.811
	24 Hour	124.172	130.322	10.0389	129.207
	48 Hour	99.0999	99.6927	4.2548	98.9389
	72 Hour	73.5296	78.8555	3.4567	78.7738
50 Years	1 Hour	44.9773	128.601	23.9293	36.2432
	2 Hour	107.248	144.875	25.6371	75.3013
	3 Hour	127.319	147.946	26.4213	89.5973
	6 Hour	176.425	156.592	25.6588	149.834
	12hour	193.598	198.047	13.8819	196.202
	24 Hour	189.04	204.332	12.699	202.517
	48 Hour	151.873	158.769	5.832	158.985
	72 Hour	114.296	128.009	4.5832	126.487
100 years	1 Hour	64.4635	161.564	30.6809	48.5141
	2 Hour	145.757	180.316	32.3514	103.74
	3 Hour	170.256	179.48	33.1019	121.464
	6 Hour	222.667	202.042	30.9073	193.282
	12hour	249.019	256.492	16.4311	254.186
	24 Hour	245.099	270.714	14.8467	268.375
	48 Hour	195.701	211.693	7.0754	212.691
	72 Hour	149.539	171.9	5.4959	171.18

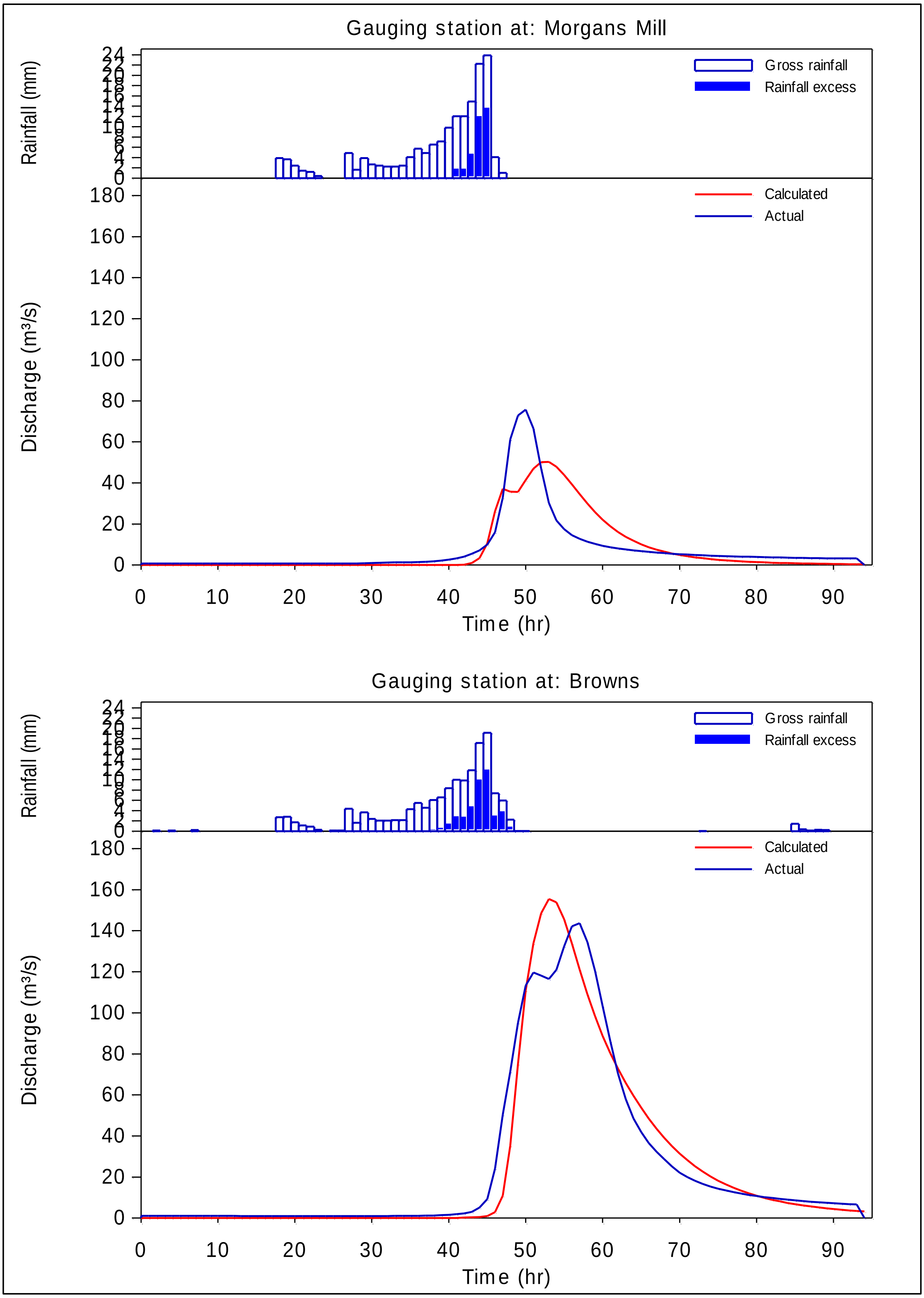


Figure 22 Hydrographs at Morgans Mill and Browns for Vic MAR > 800mm RORB model

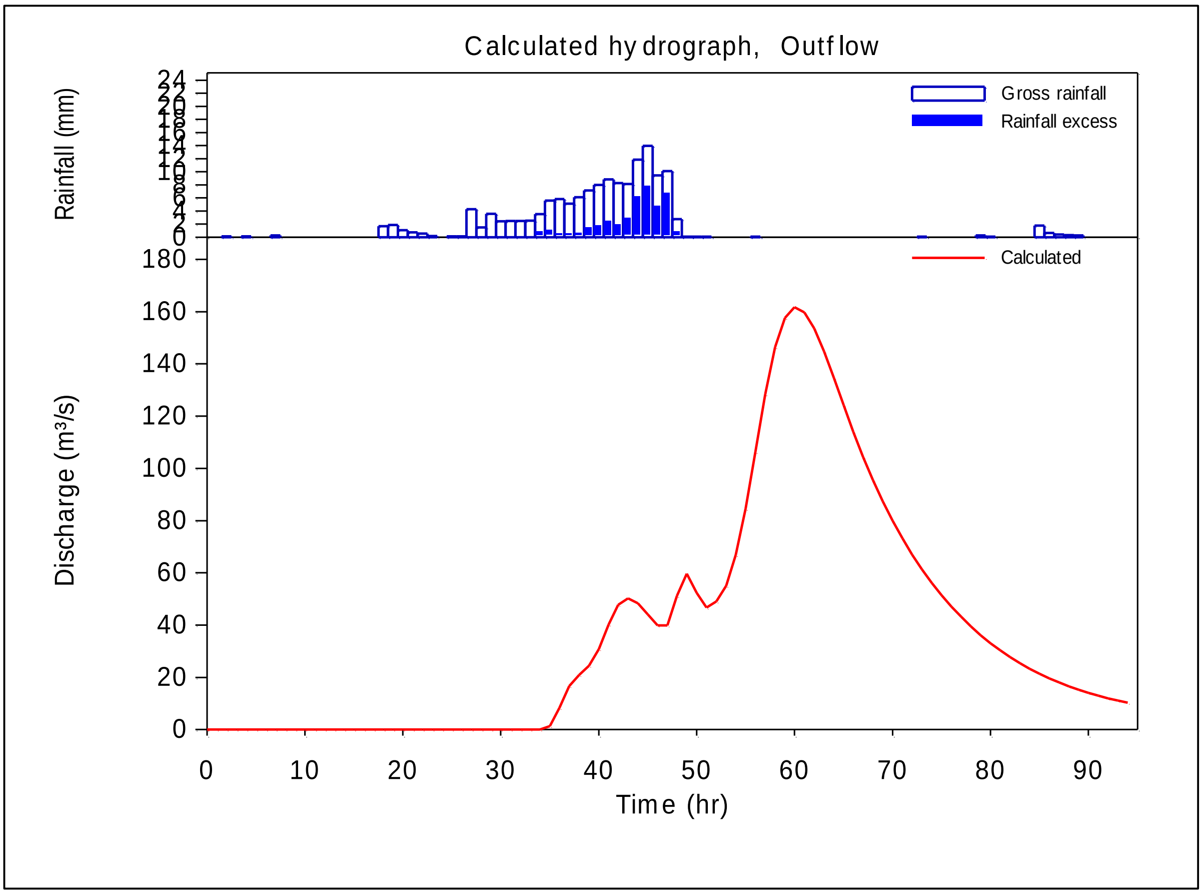


Figure 23 Calculated hydrograph at outflow for Vic MAR > 800mm RORB model

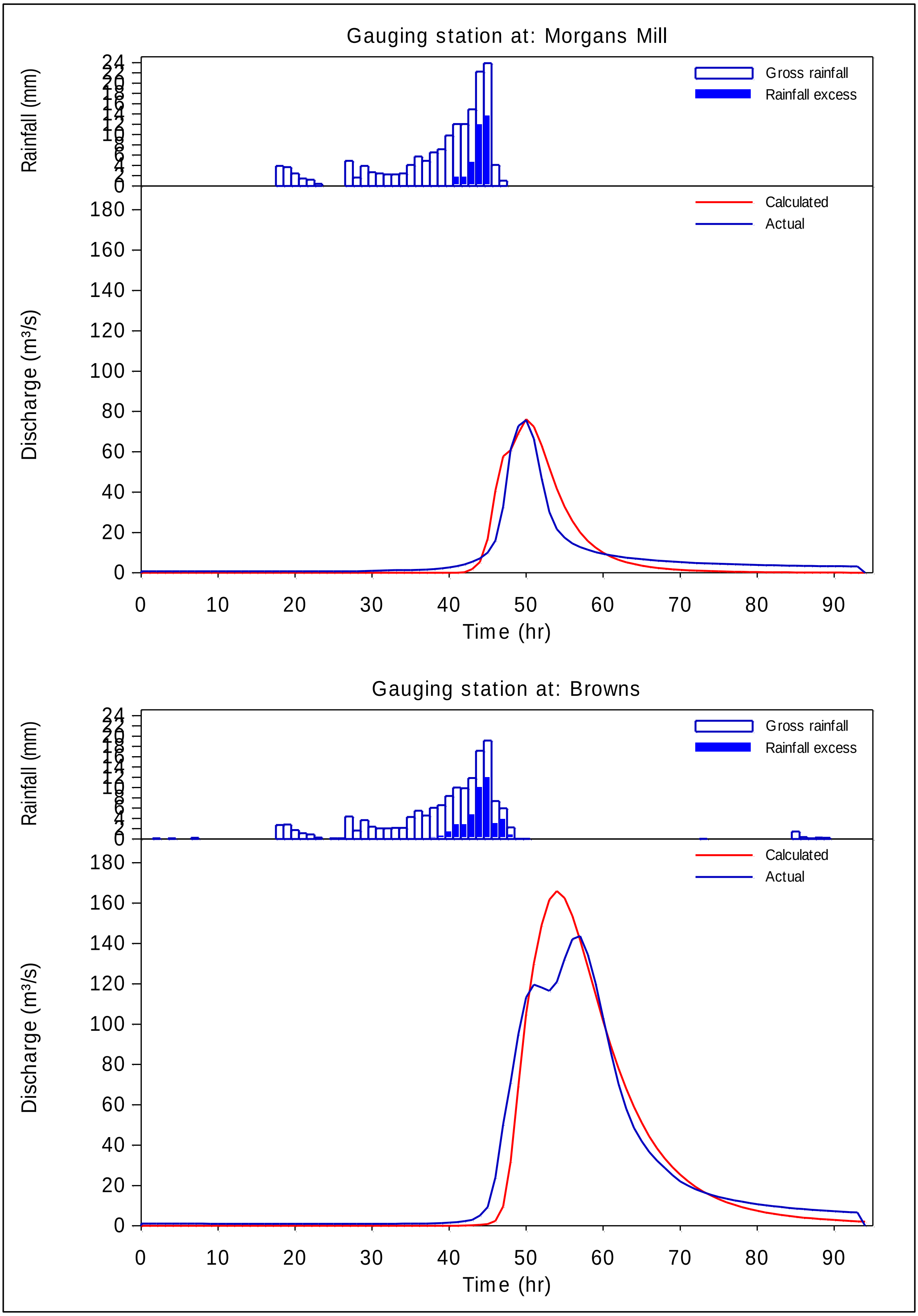


Figure 24 Hydrographs at Browns and Morgans Mill for Pearce RORB model

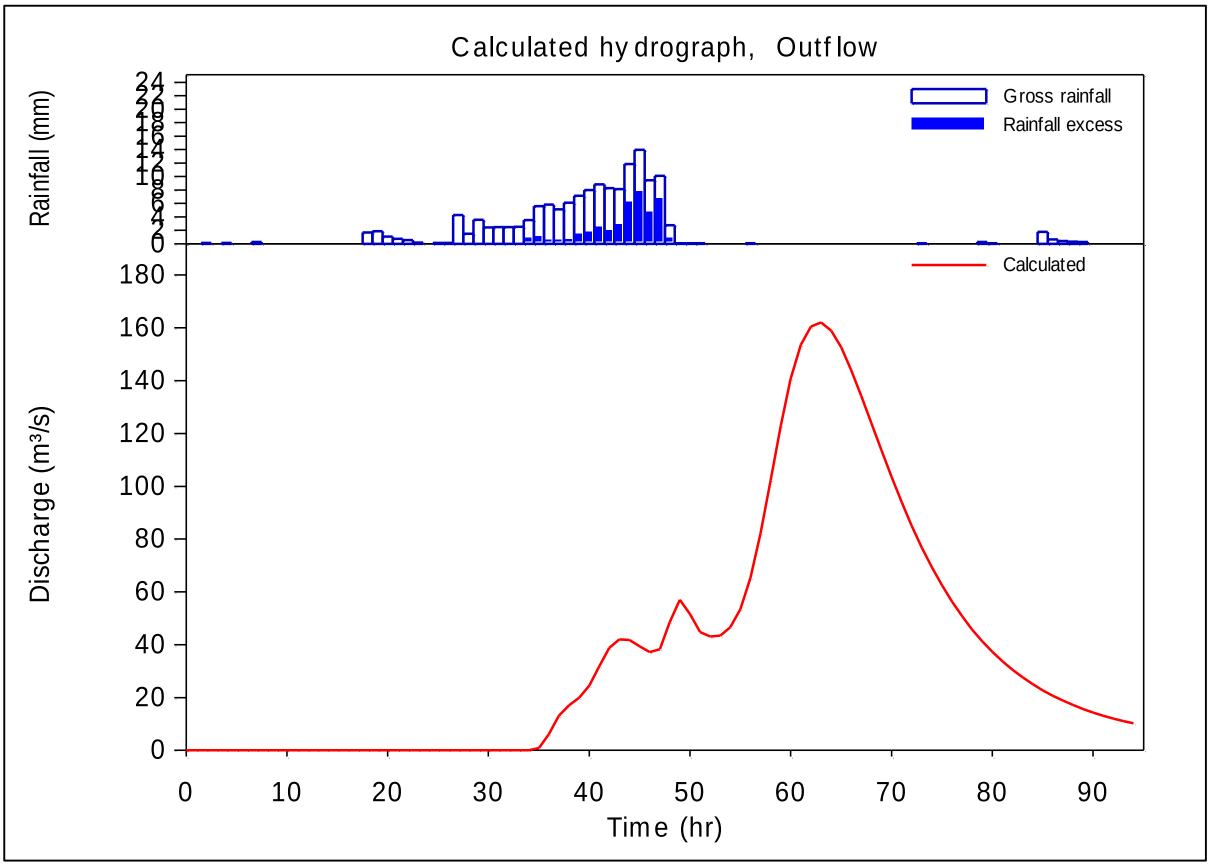


Figure 25 Hydrographs at outflow for Pearce RORB model

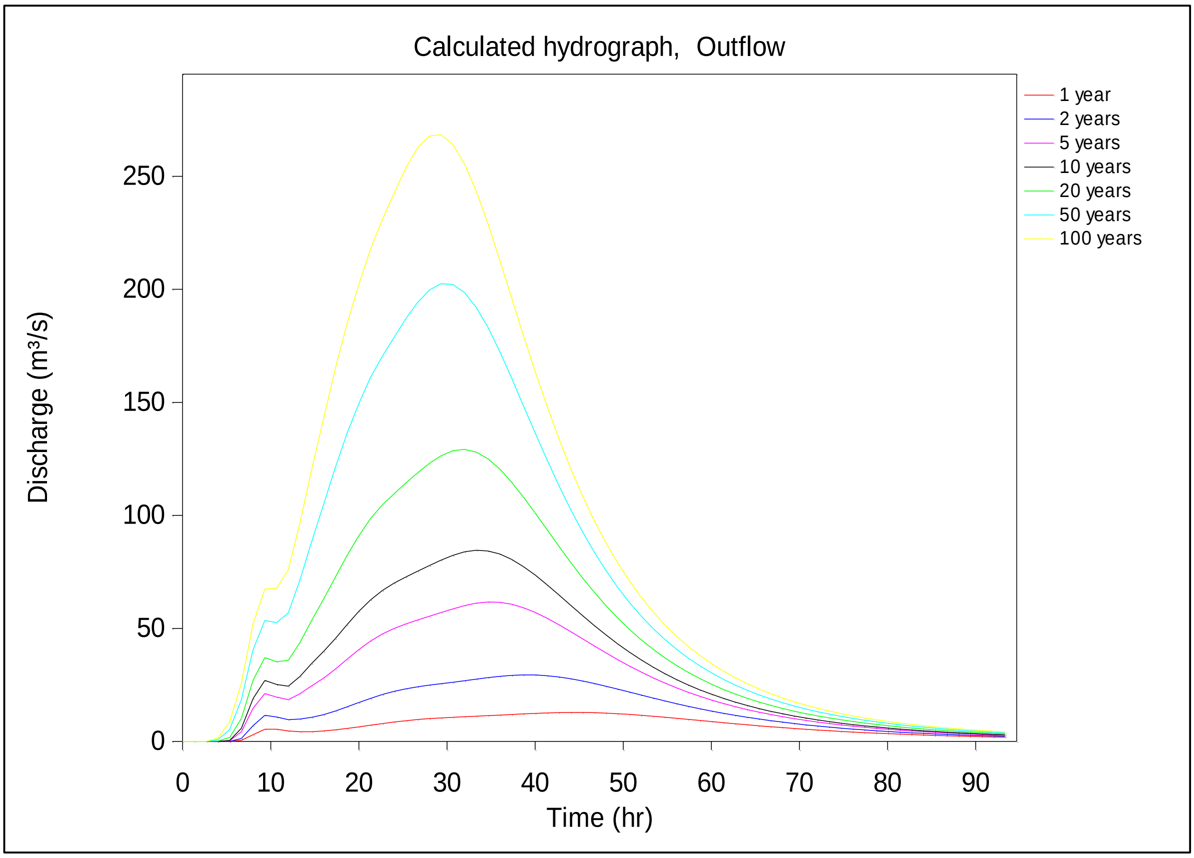


Figure 26 RORB 24 hour design run hydrographs - outflow

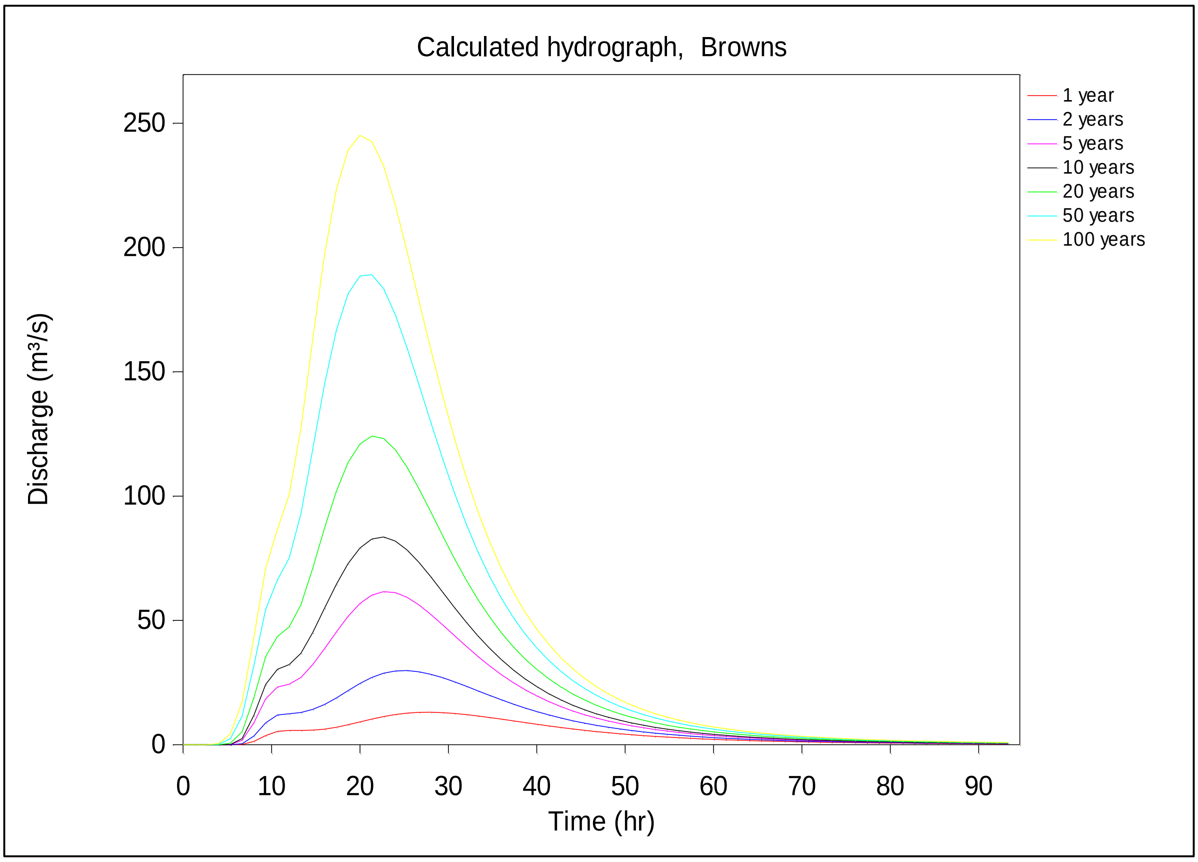


Figure 27 RORB 24 hour design run hydrographs – Browns

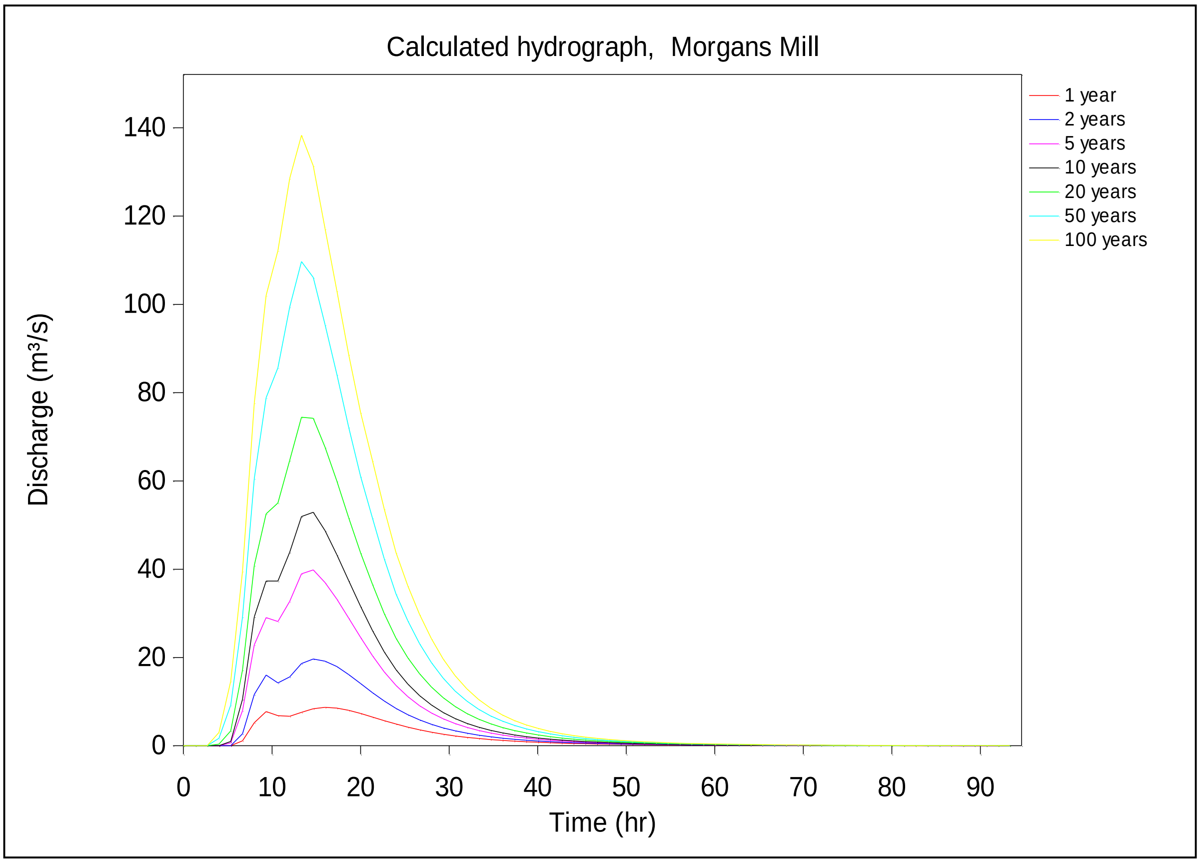


Figure 28 RORB 24 hour design run hydrographs - Morgans Mill

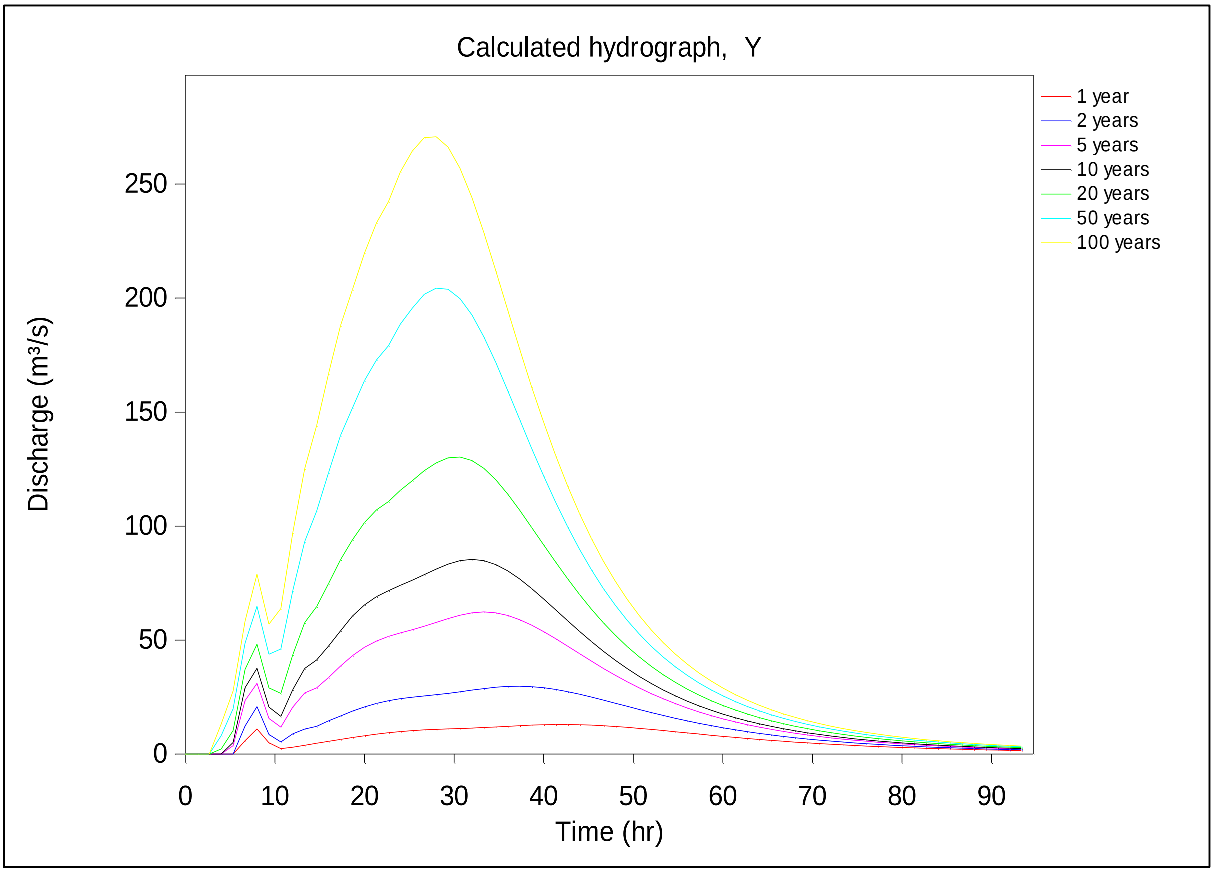


Figure 29 RORB 24 hour design run hydrographs – Y

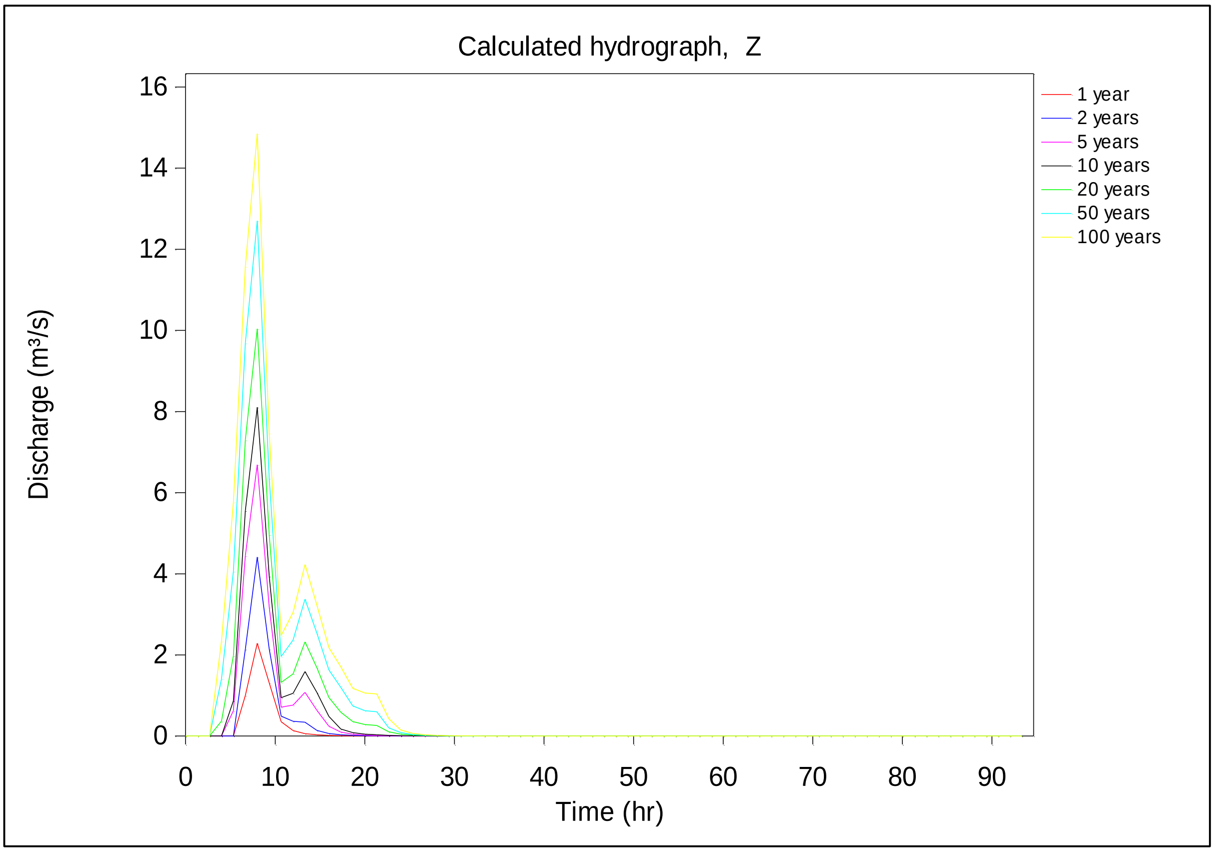


Figure 30 RORB 24 hour design run hydrographs – Z

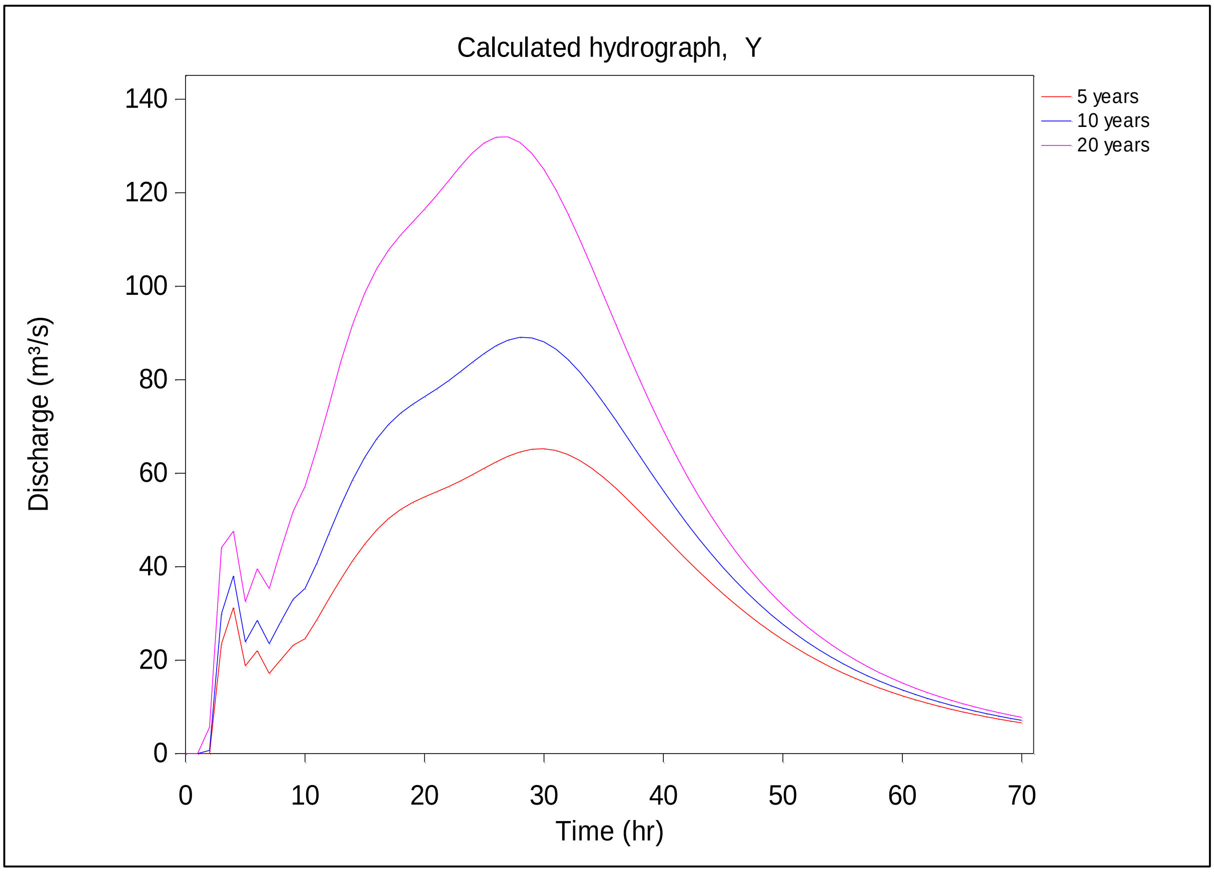


Figure 31 RORB 12 hour design run hydrographs – Y

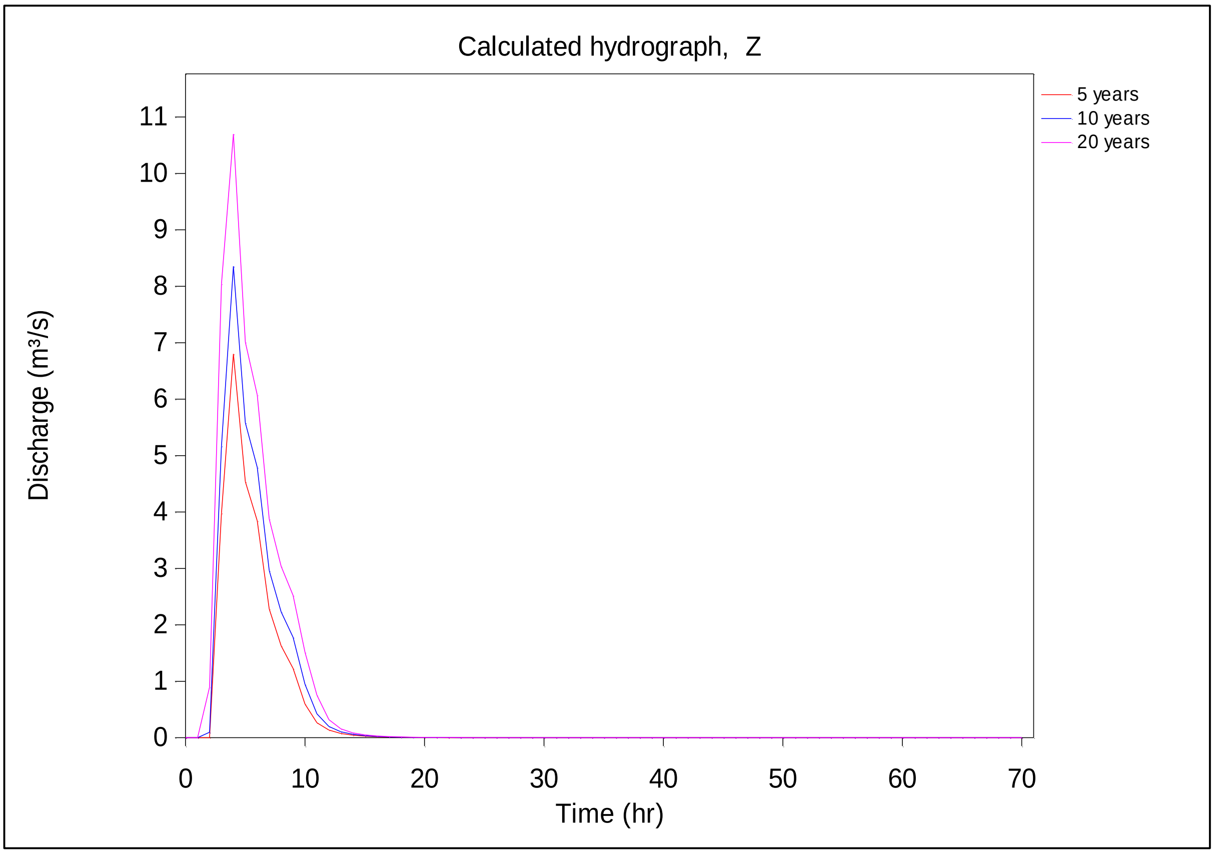


Figure 32 RORB 12 hour design run hydrographs – Z

Appendix D: Hydraulic model input data

Sobek model parameters

Table 27 Sobek model parameters

Topography Grid Size and 1D elements	
Parameter	Value
Grid Cells Size	10m x 10m
Grid Cells (x direction)	270 columns
Grid Cells (y direction)	324 rows
Total Grid Cells	87,480
Friction (Manning)	0.04
Cross sections	16
Other 1D elements	1

Run details

Table 28 100 year run details

100 year run details	
Parameter	Value
Tyers River inflow	Figure 29 - 100 year
Unnamed tributary inflow	Figure 30 - 100 year
Outflow height	33.5m AHD
Initial channel depth	0.2m
Simulation Time	3 days, 23 hours
Approx. Run Time	2 hours, 11 minutes
Timestep	5 seconds
Outputs	Hourly

Table 29 50 year run details

50 year run details	
Parameter	Value
Tyers River inflow	Figure 29 - 50 year
Unnamed tributary inflow	Figure 30 - 50 year
Outflow height	33.5m AHD
Initial channel depth	0.2m
Simulation Time	2 days, 23 hours
Approx. Run Time	2 hours, 2 minutes
Timestep	5 seconds
Outputs	Hourly

Table 30 20 year run details

20 year run details	
Parameter	Value
Tyers River inflow	Figure 31- 20 year
Unnamed tributary inflow	Figure 32 - 20 year
Outflow height	33.5m AHD
Initial channel depth	0.2m
Simulation Time	2 days, 23 hours
Approx. Run Time	1 hour, 48 minutes
Time step	5 seconds
Outputs	Hourly

Table 31 10 year run details

10 year run details	
Parameter	Value
Tyers River inflow	Figure 31- 10 year
Unnamed tributary inflow	Figure 32 - 10 year
Outflow height	33.5m AHD
Initial channel depth	0.2m
Simulation Time	2 days, 23 hours
Approx. Run Time	1 hour, 39 minutes
Timestep	5 seconds
Outputs	Hourly

Table 32 5 year run details

5 year run details	
Parameter	Value
Tyers River inflow	Figure 31 - 5 year
Unnamed tributary inflow	Figure 32- 5 year
Outflow height	33.5m AHD
Initial channel depth	0.2m
Simulation Time	2 days, 23 hours
Approx. Run Time	1 hour, 32 minutes
Timestep	5 seconds
Outputs	Hourly

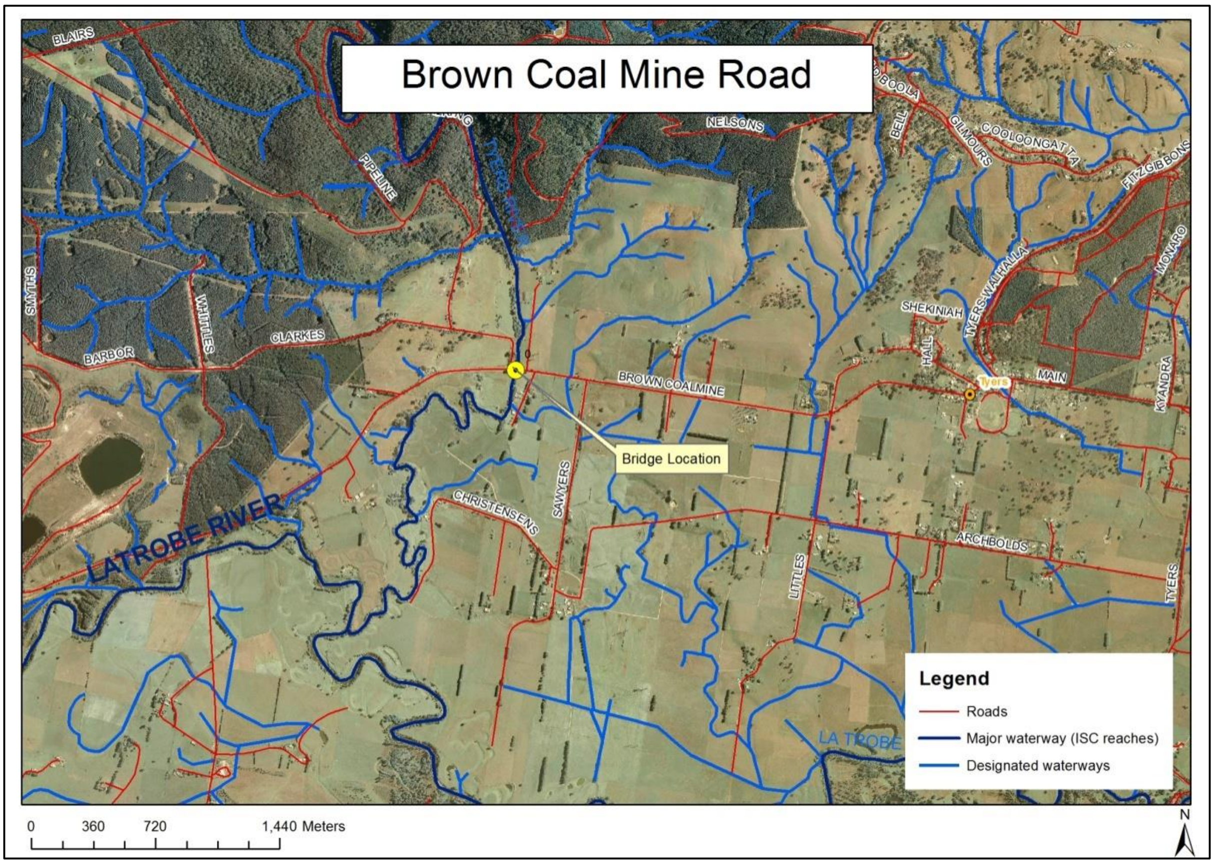


Figure 33 Brown Coal Mine Road Bridge location

Figure 34 Brown Coal Mine Road north (upstream) side

Figure 35 Brown Coal Mine Road south (downstream) side

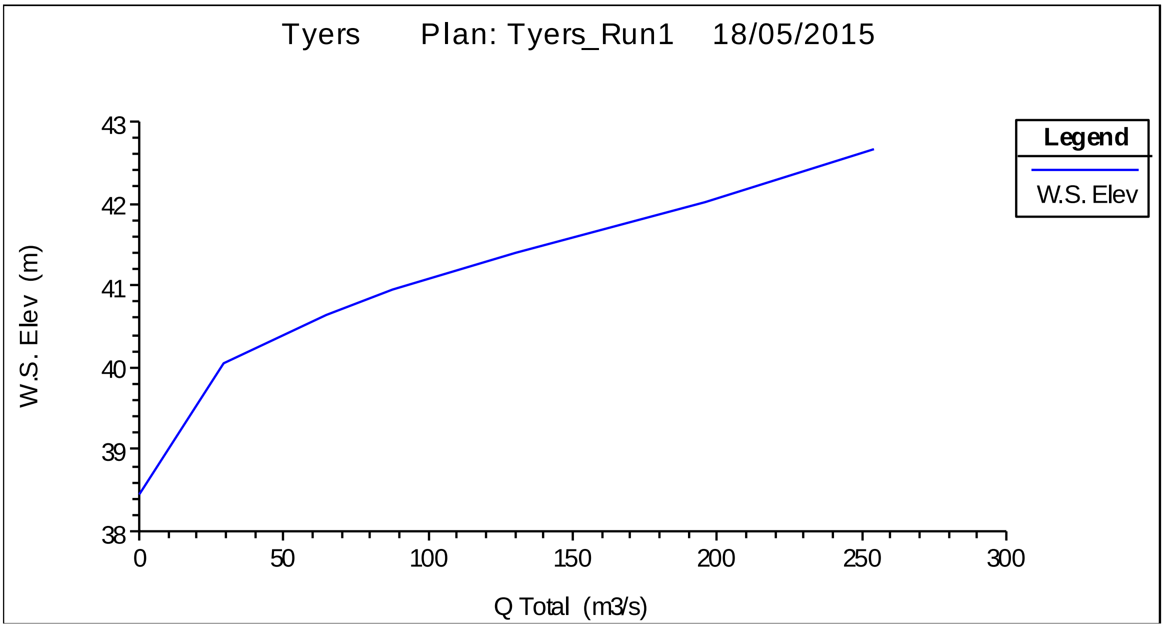


Figure 36 HEC-RAS Rating curve - upstream

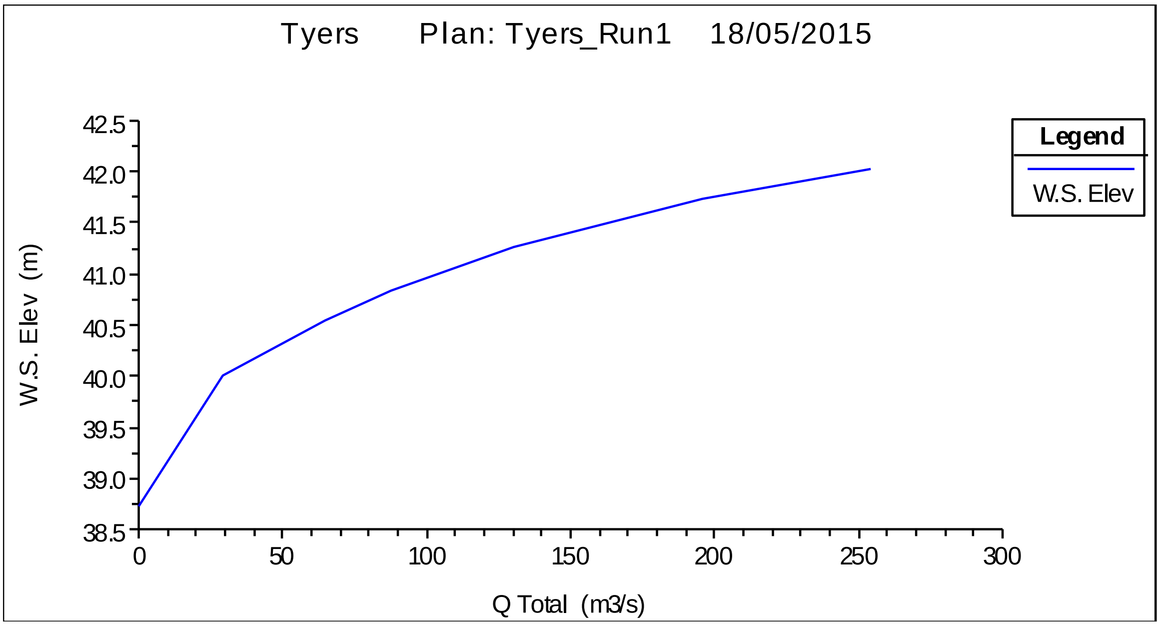
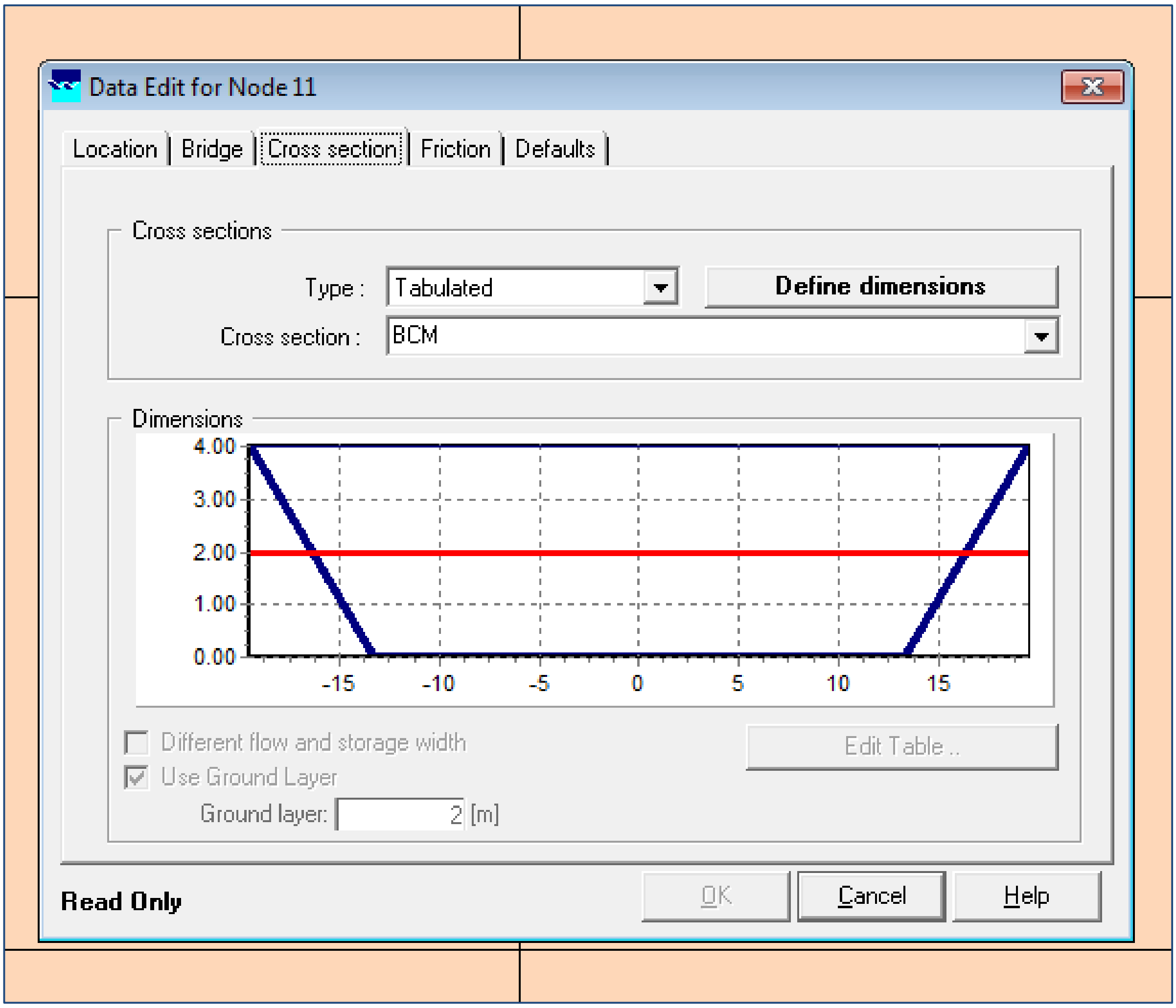


Figure 37 HEC-RAS rating curve – downstream



Type : Tabulated

Cross section : BCM

☐ Different flow and storage width

☑ Use Ground Layer

Ground layer: 2 [m]

Read Only

Figure 38 Sobek bridge cross section

Appendix E: Output data from hydraulic model

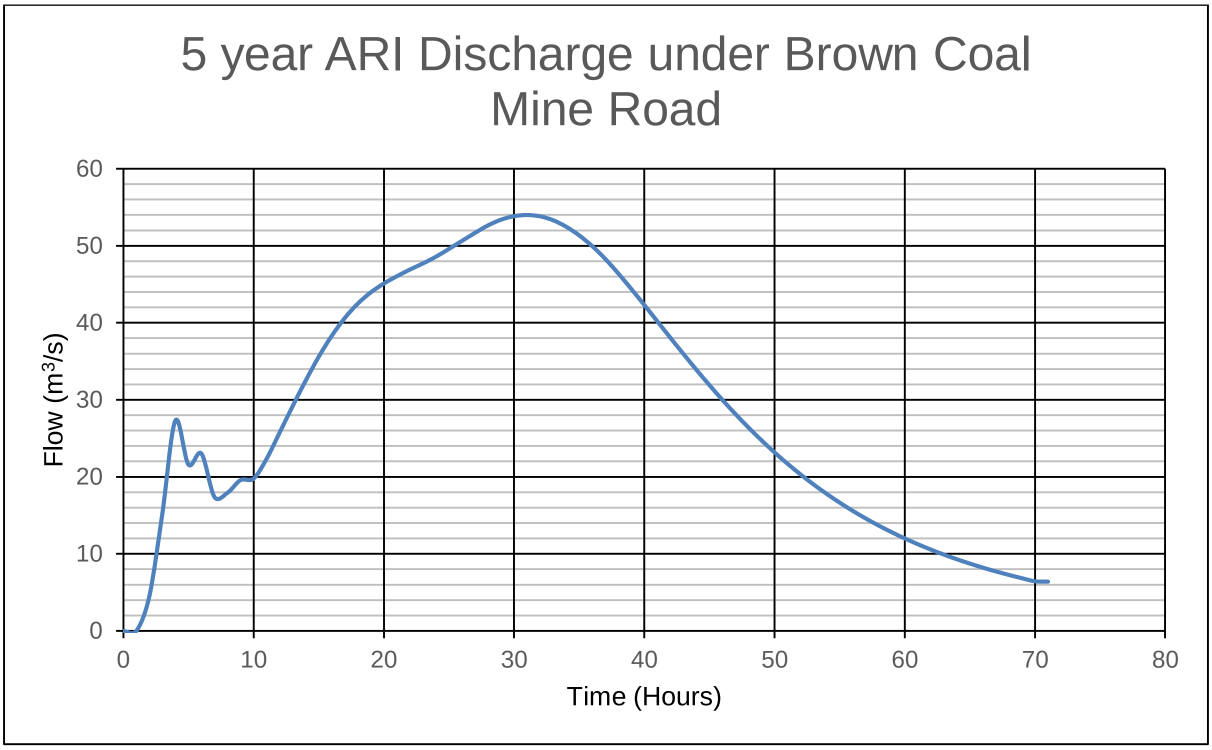


Figure 39 20% AEP discharge under Brown Coal Mine Road

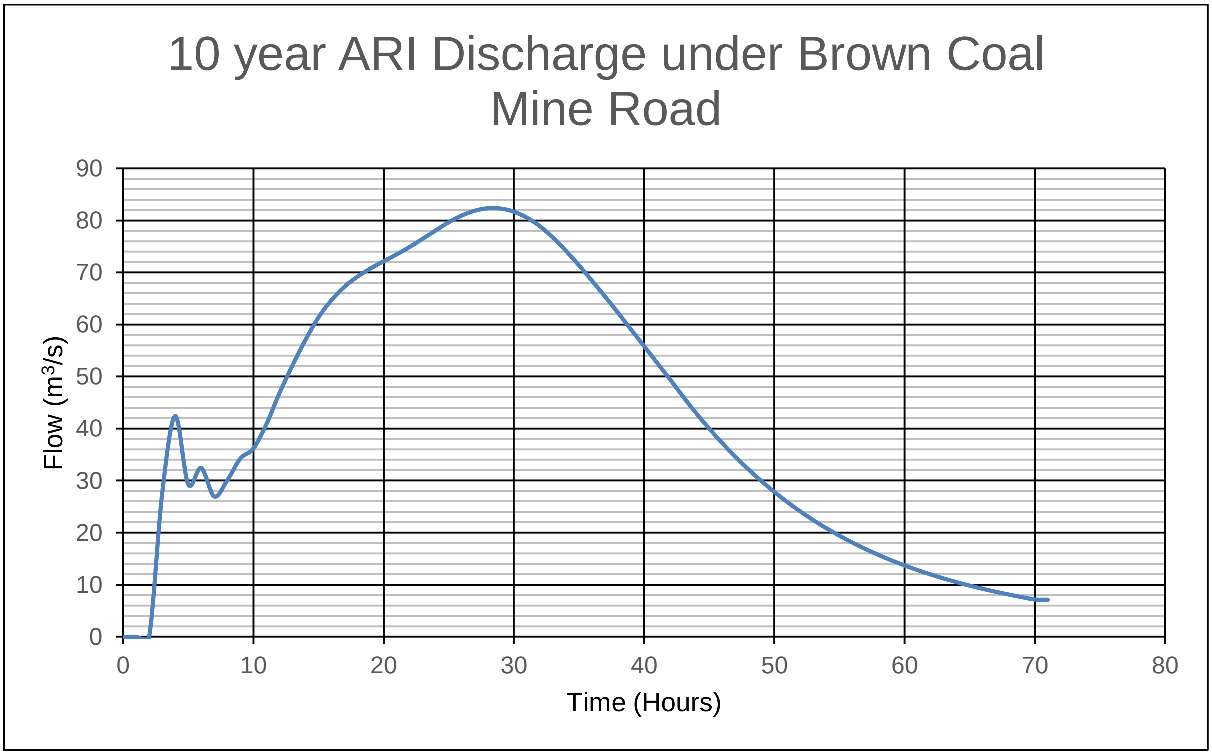


Figure 40 10% AEP discharge under Brown Coal Mine Road

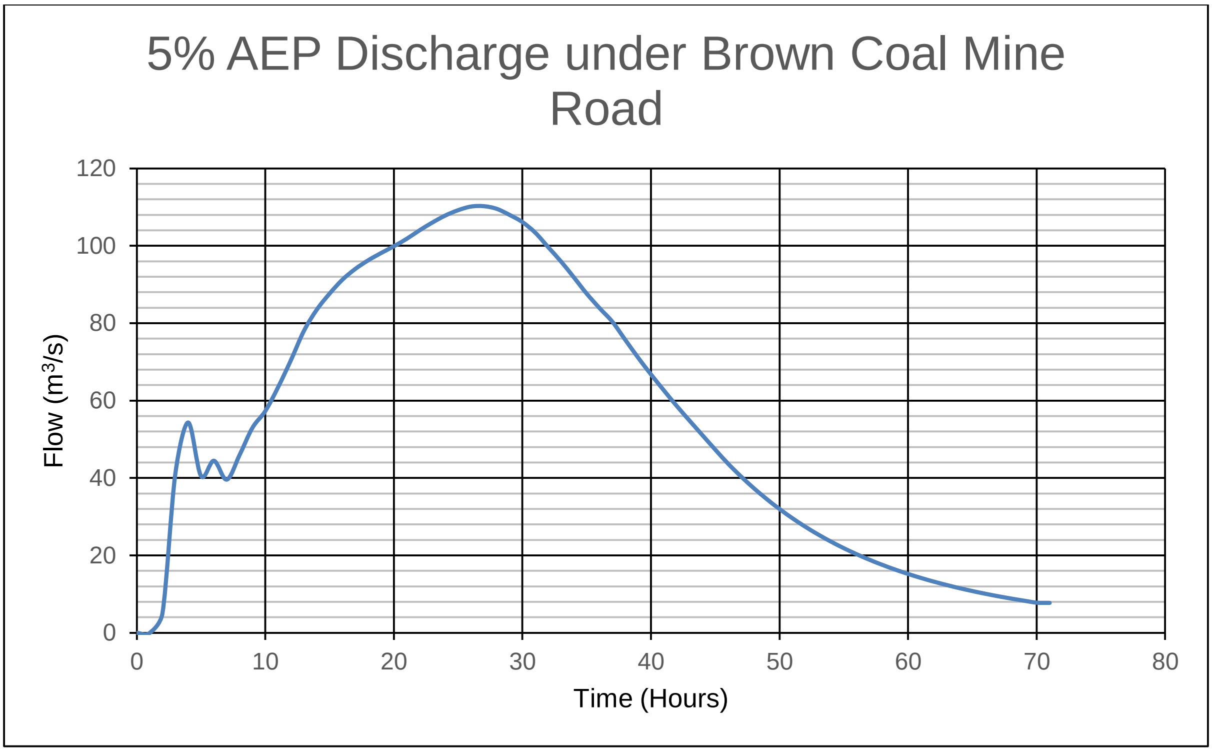


Figure 41 5% AEP discharge under Brown Coal Mine Road

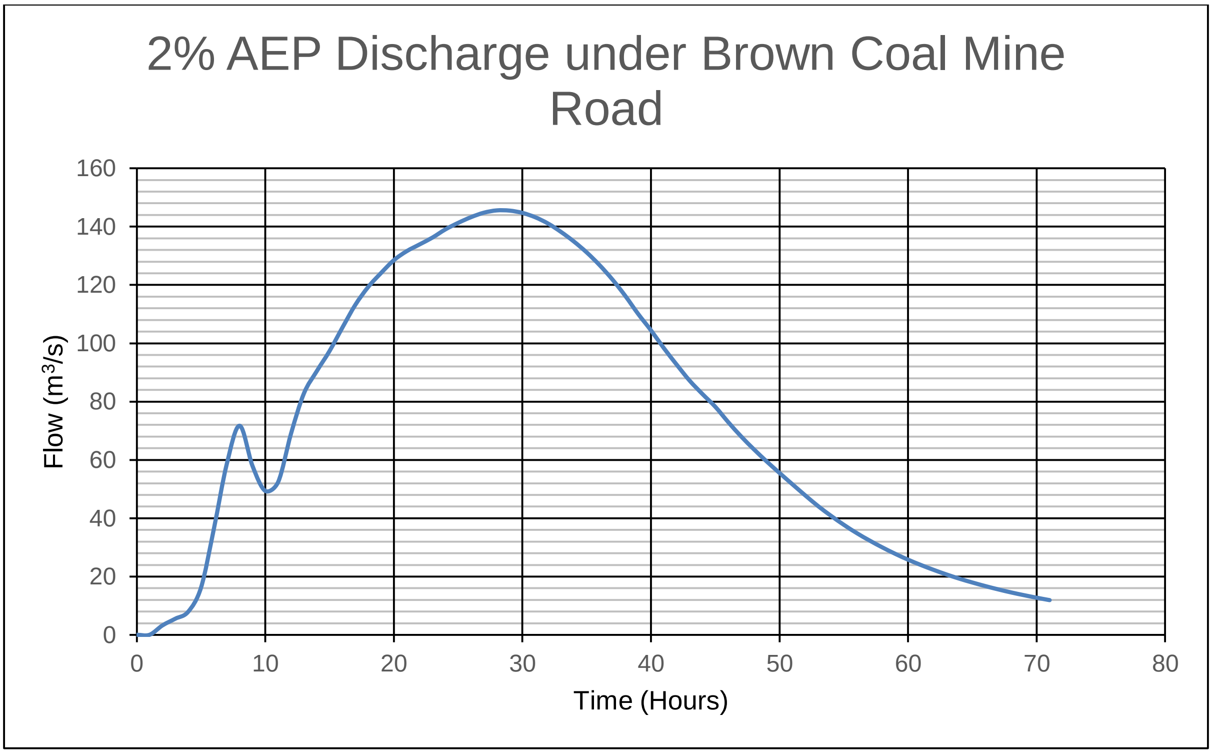


Figure 42 2% AEP discharge under Brown Coal Mine Road

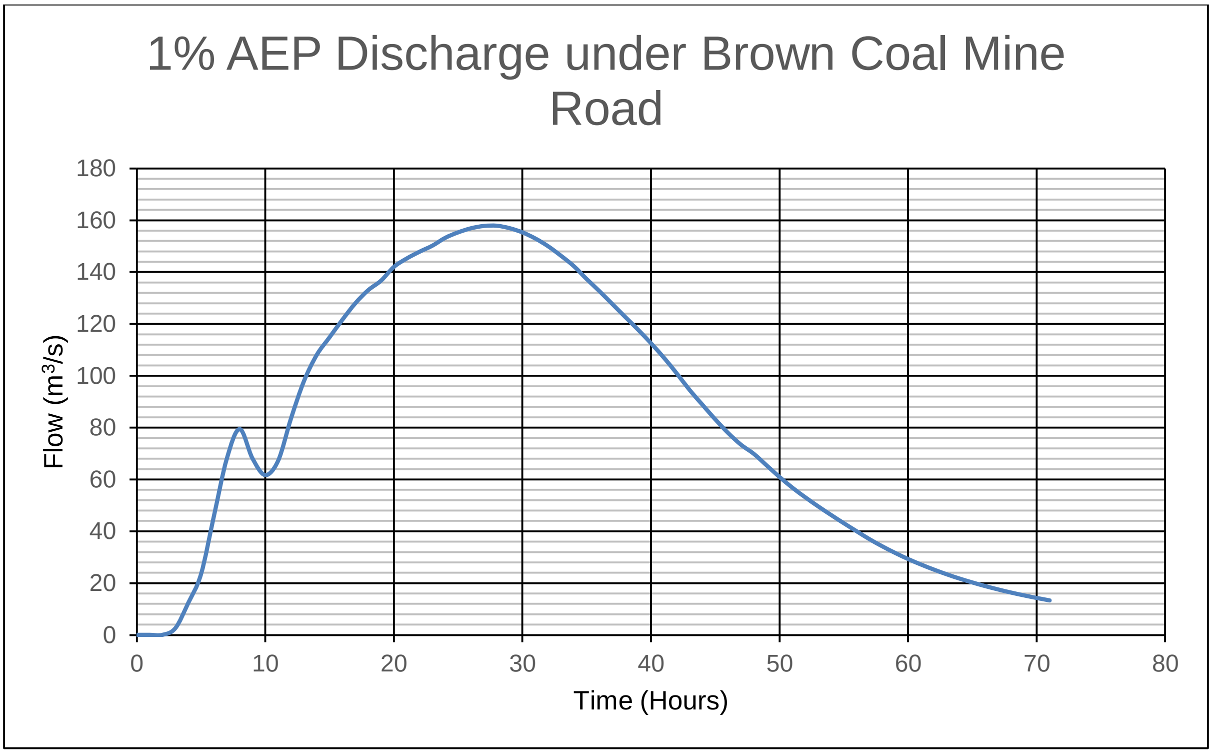


Figure 43 1% AEP discharge under Brown Coal Mine Road

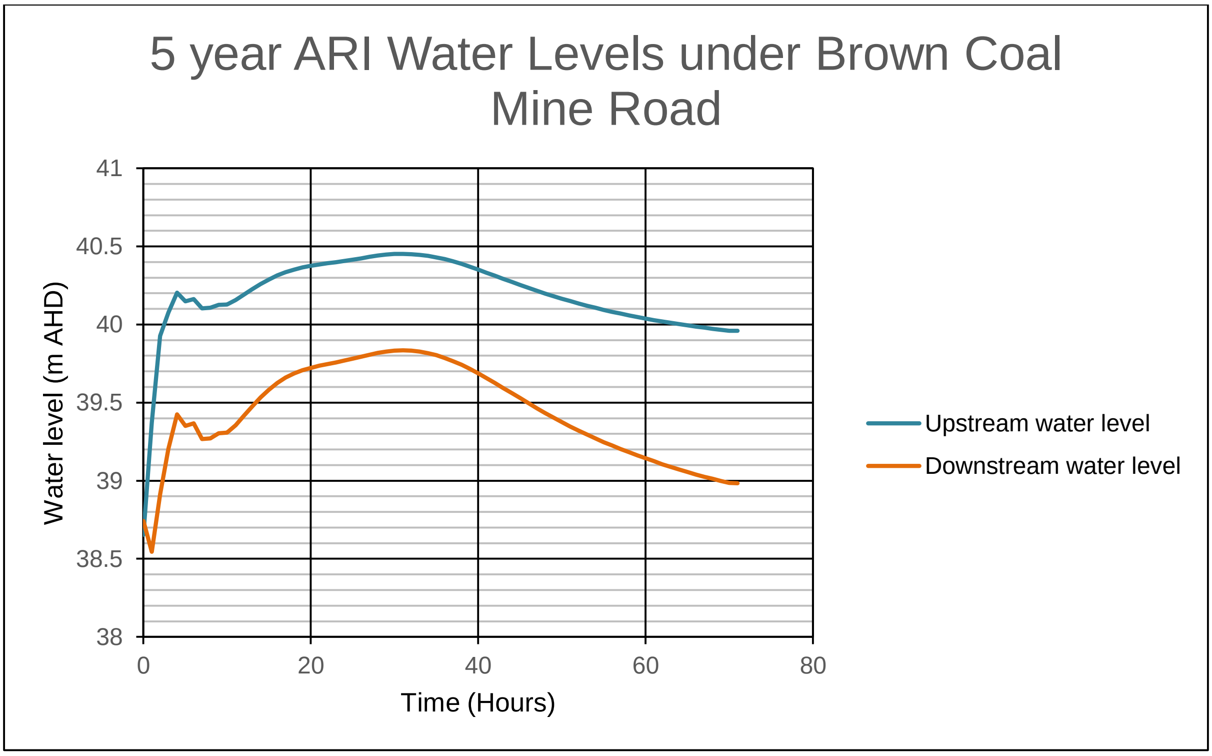


Figure 44 20% AEP water levels under Brown Coal Mine Road

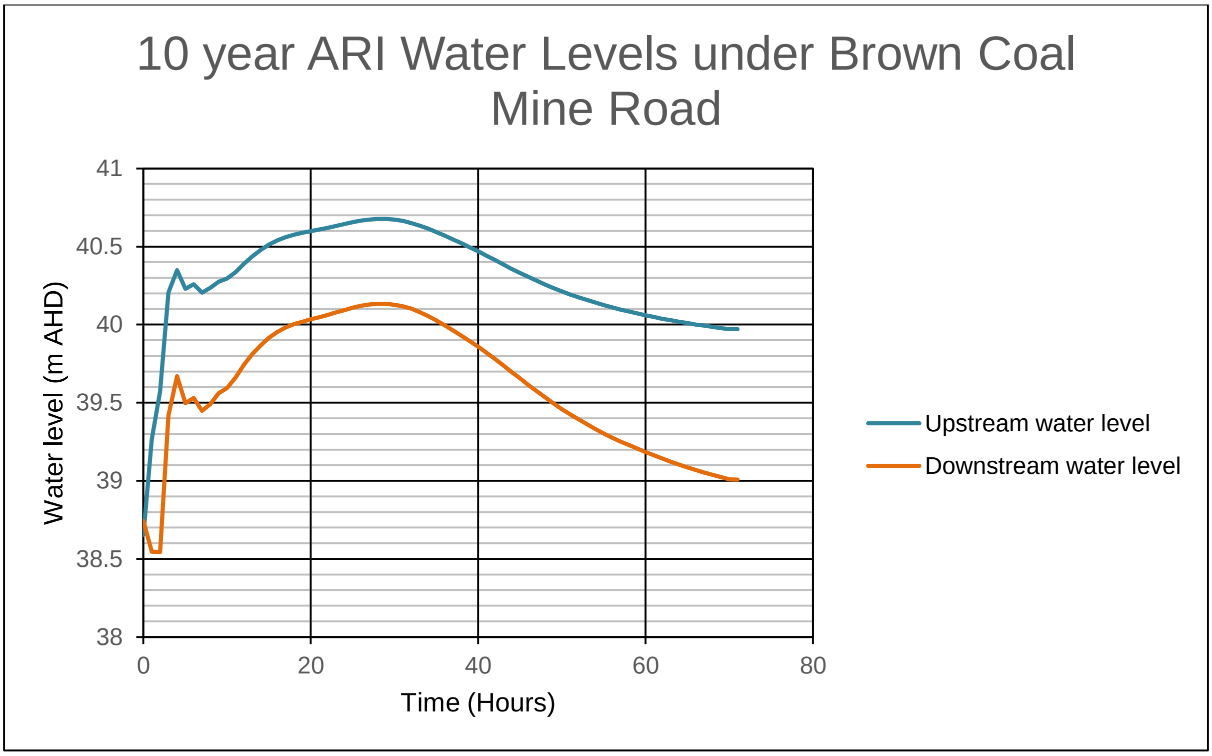


Figure 45: 10% AEP water levels under Brown Coal Mine Road

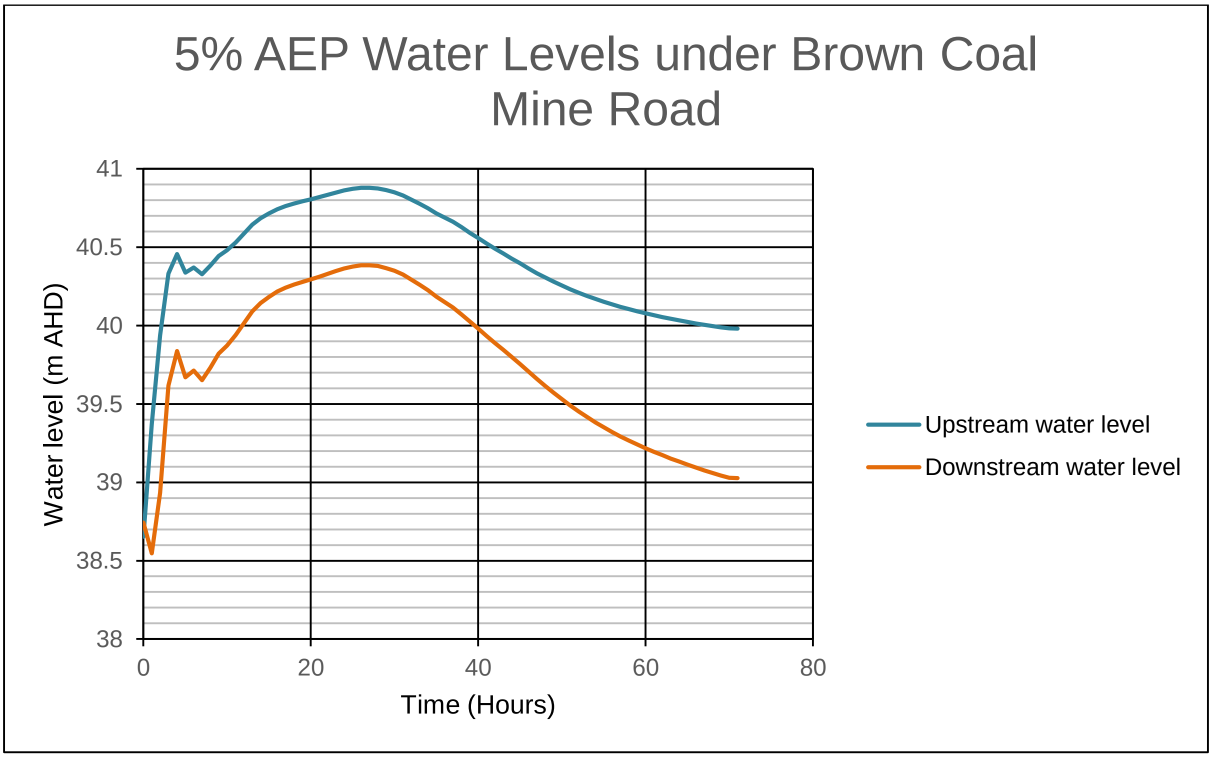


Figure 46 5% AEP water levels under Brown Coal Mine Road

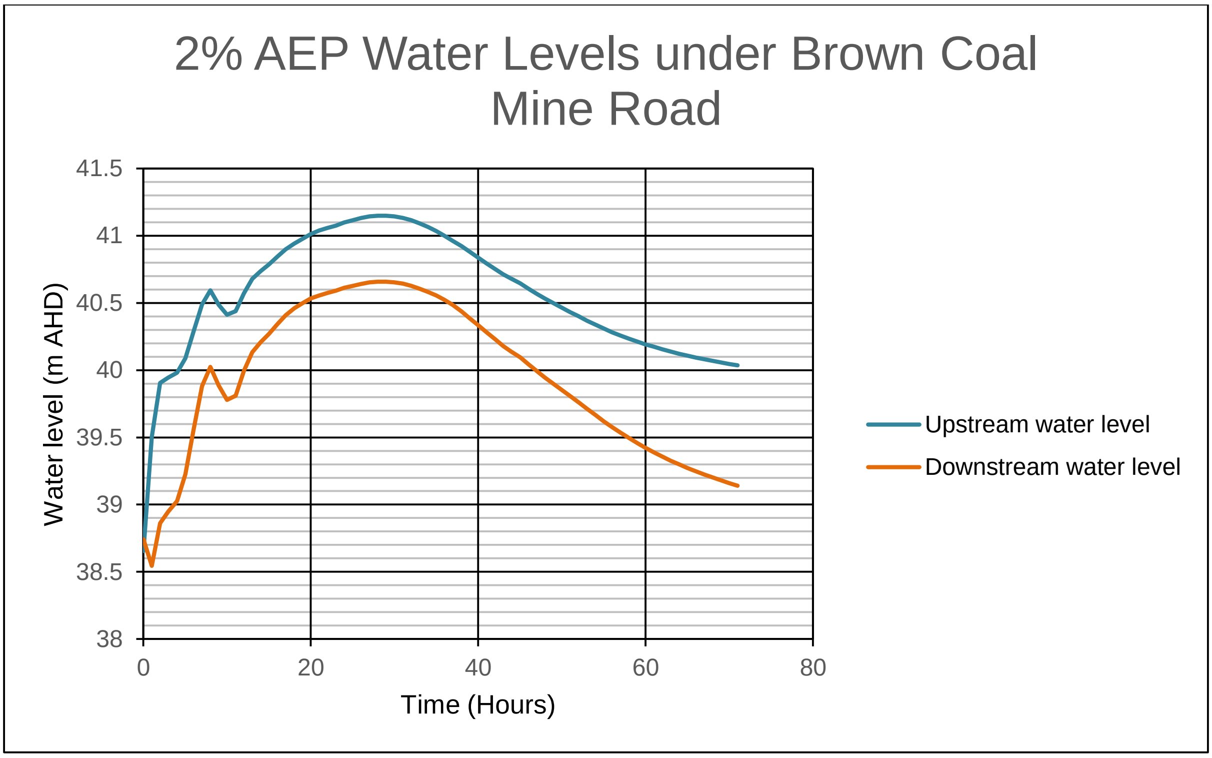


Figure 47 2% AEP water levels under Brown Coal Mine Road

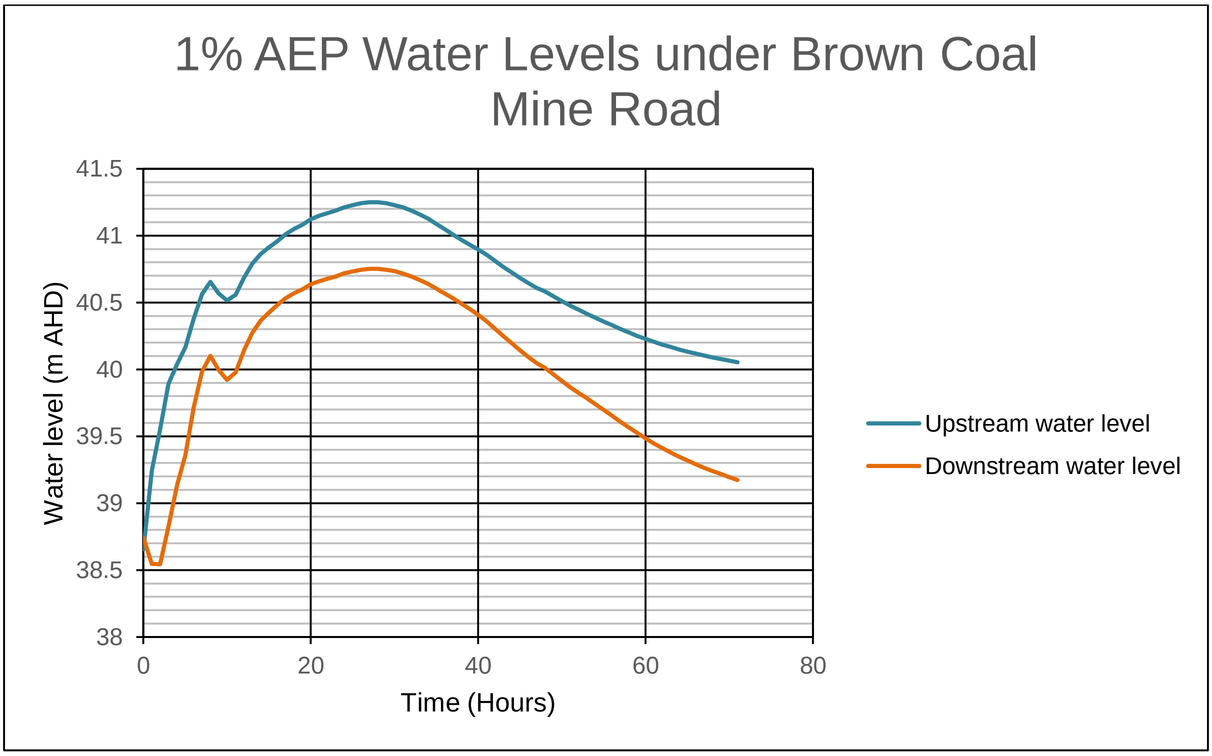


Figure 48 1% AEP water levels under Brown Coal Mine Road

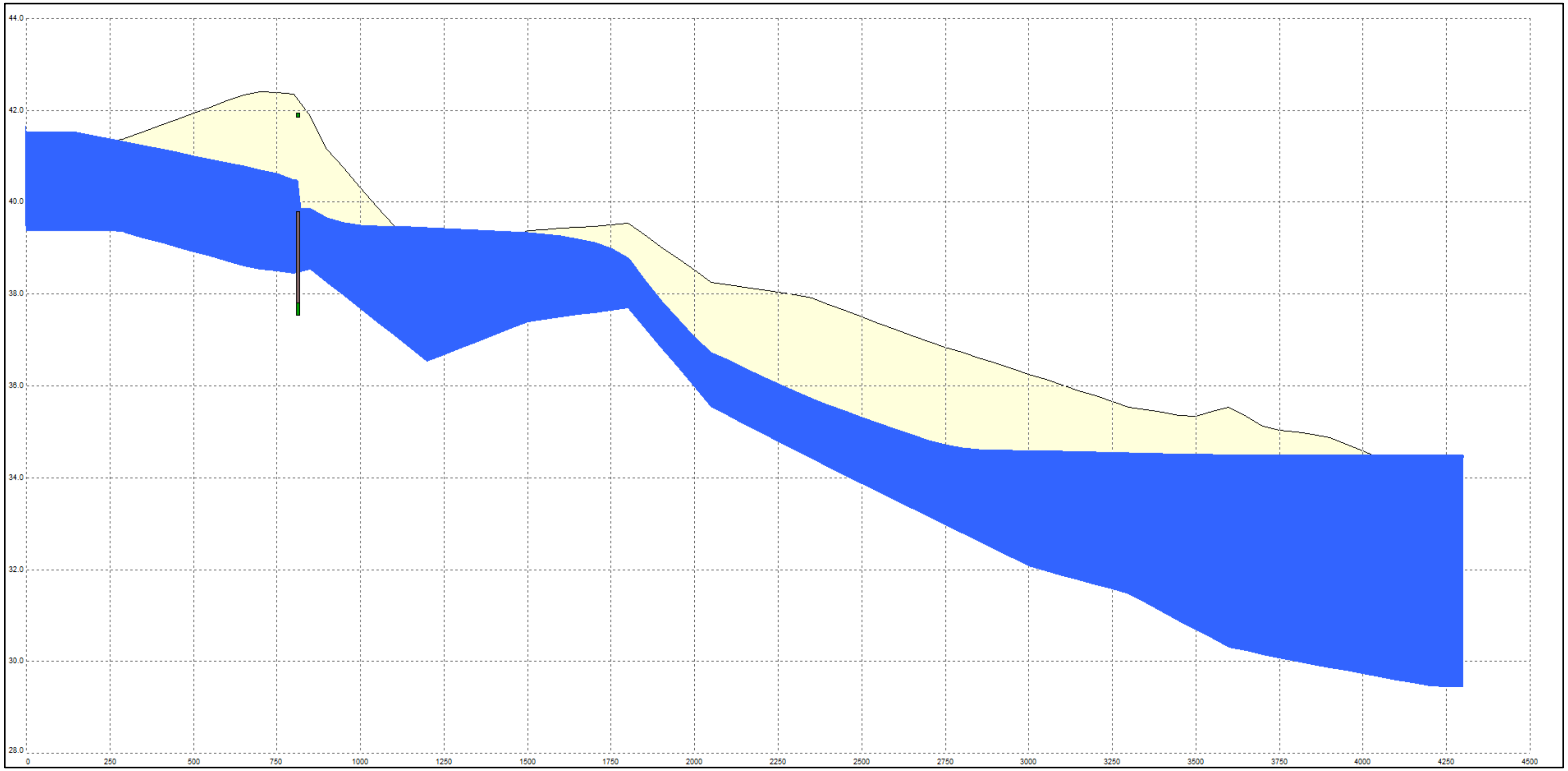


Figure 49 20% AEP maximum depth long section

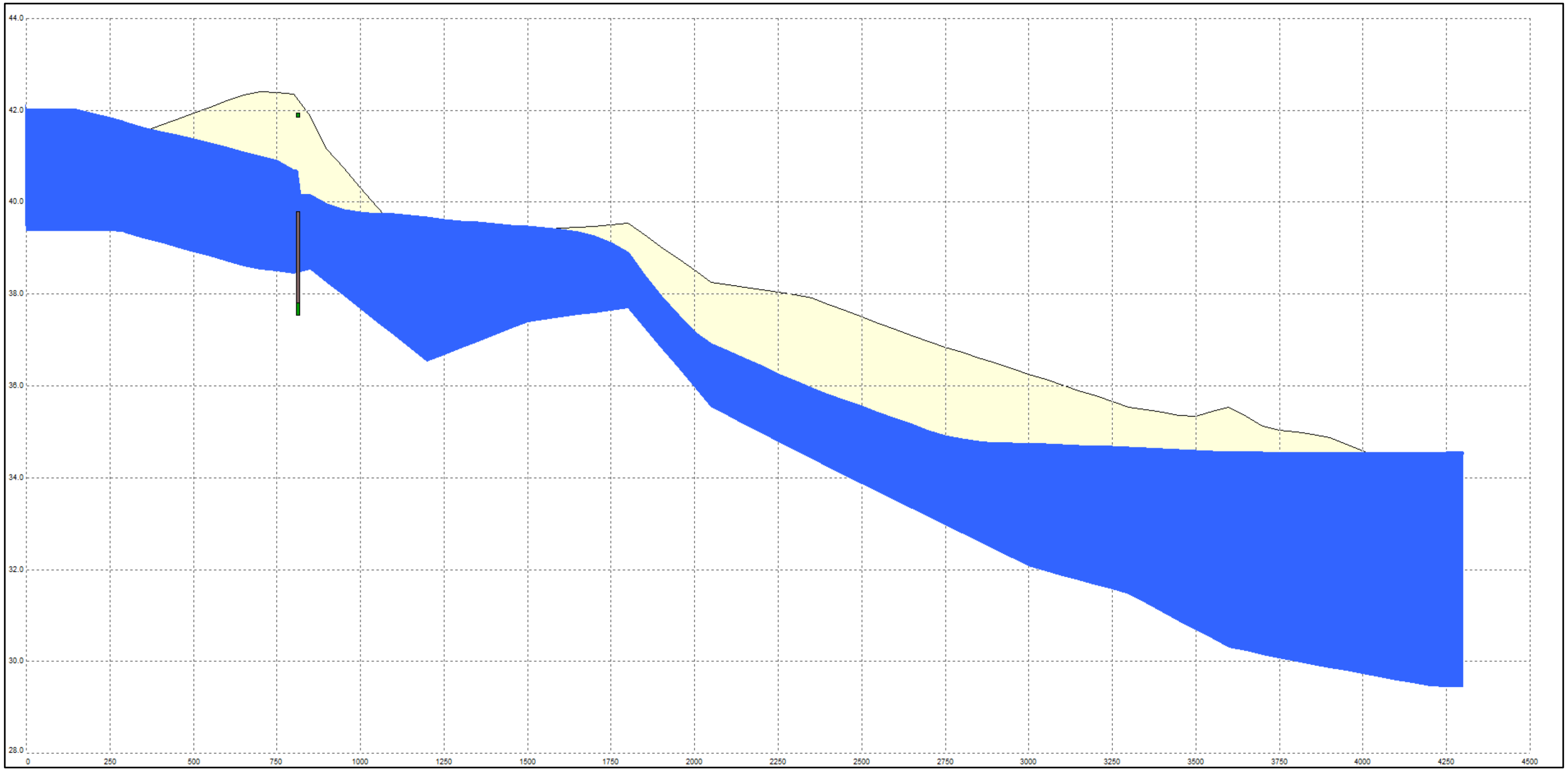


Figure 50 10% AEP maximum depth long section

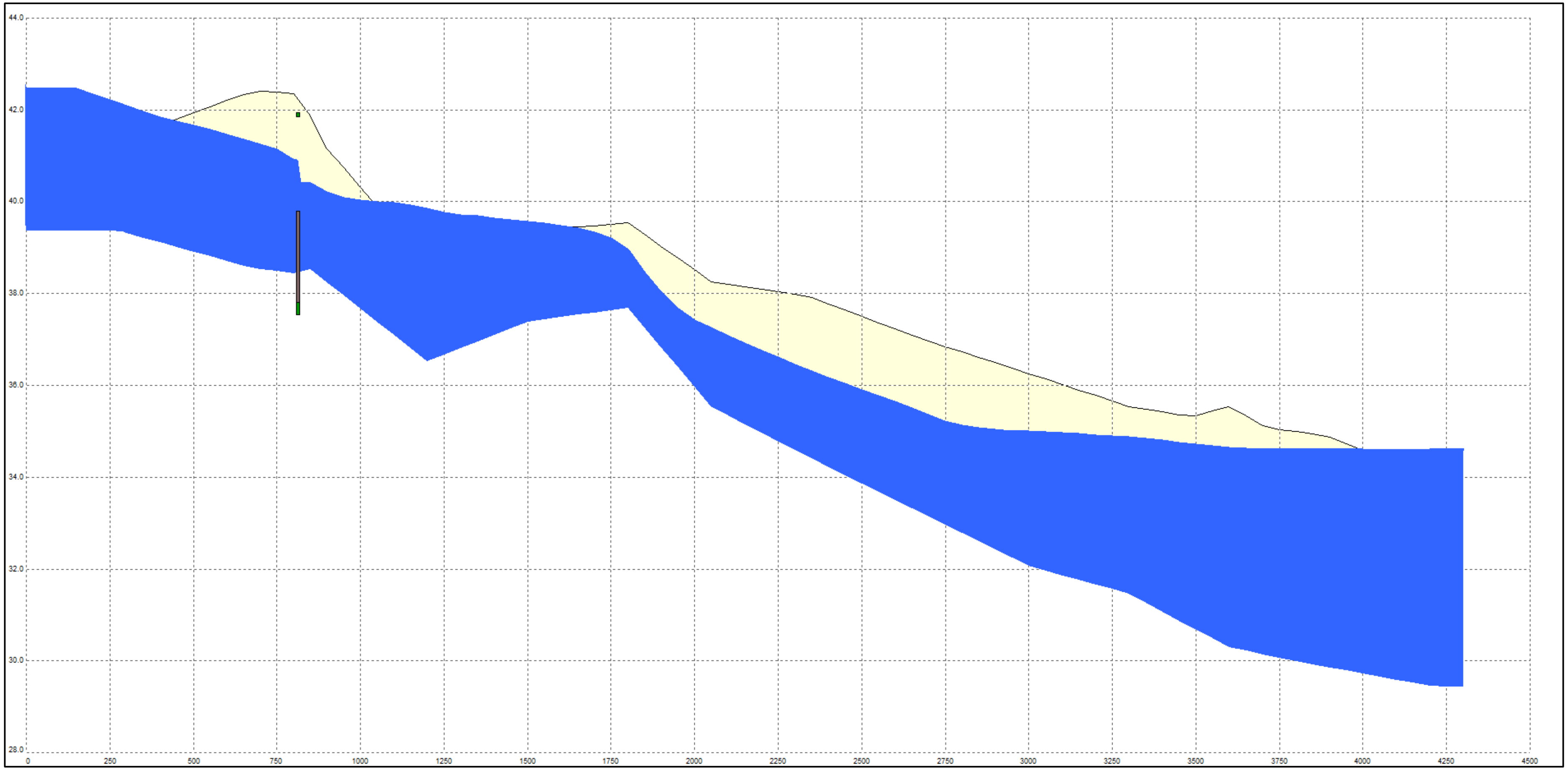


Figure 51 5% AEP maximum depth long section

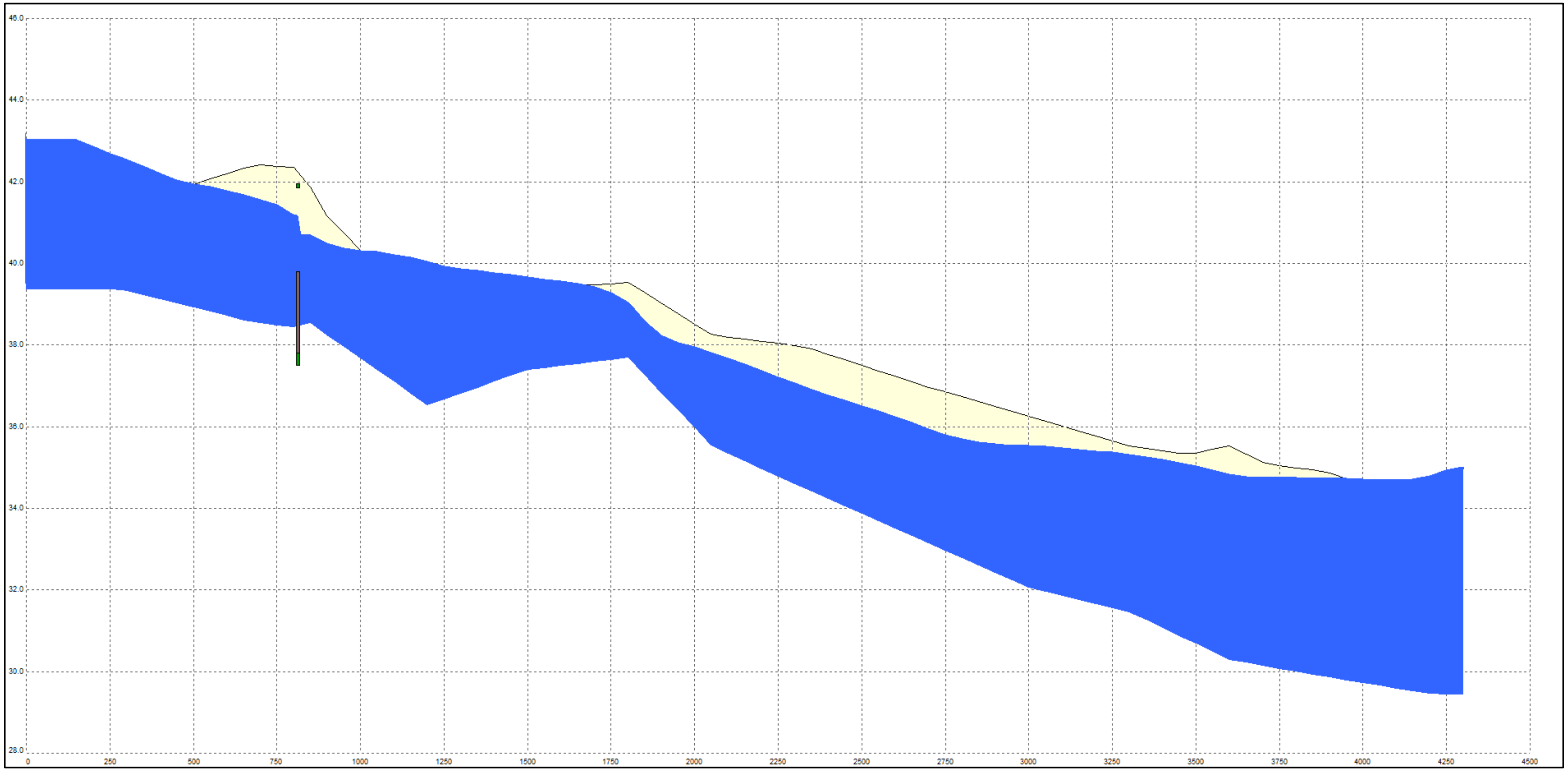


Figure 52 2% AEP maximum depth long section

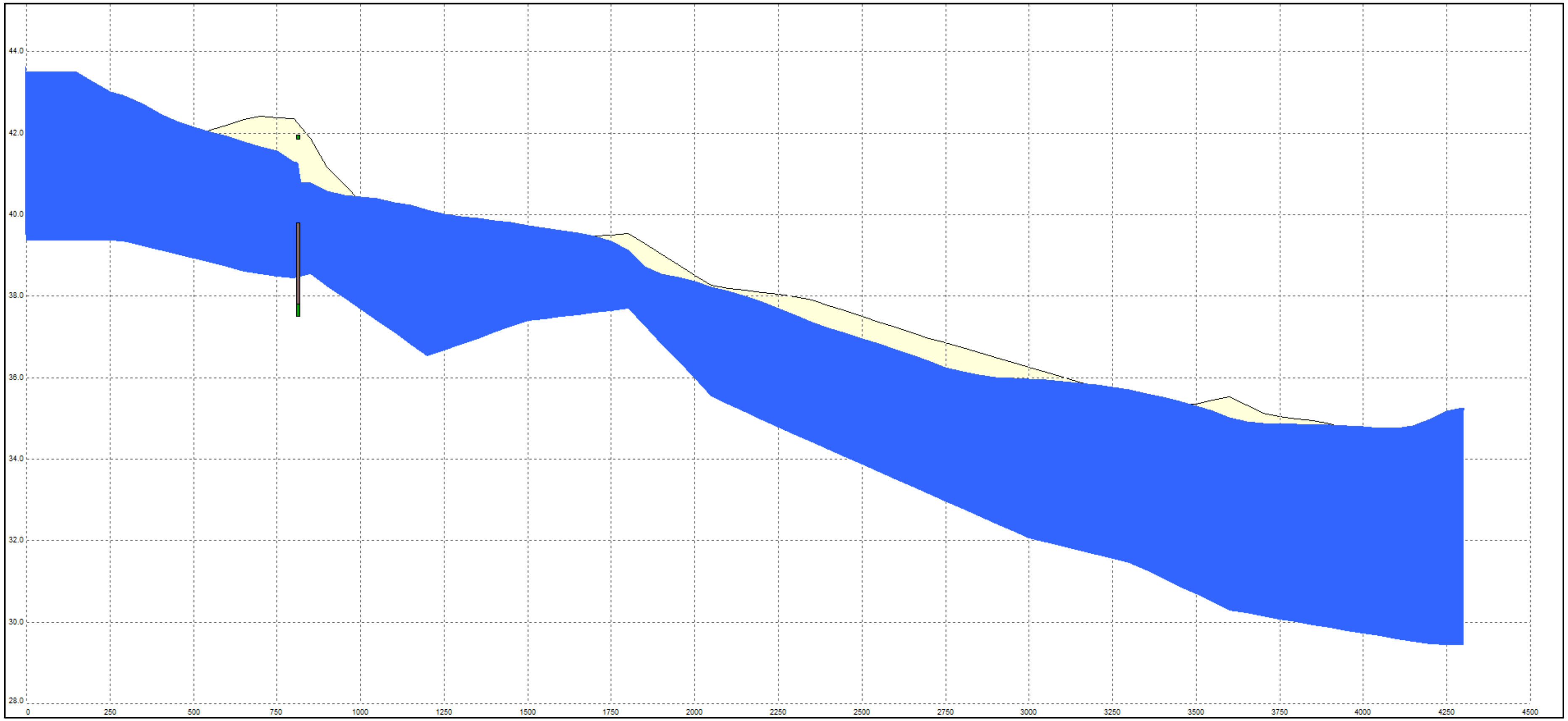


Figure 53 1% AEP maximum depth long section

Appendix F: Flood level maps

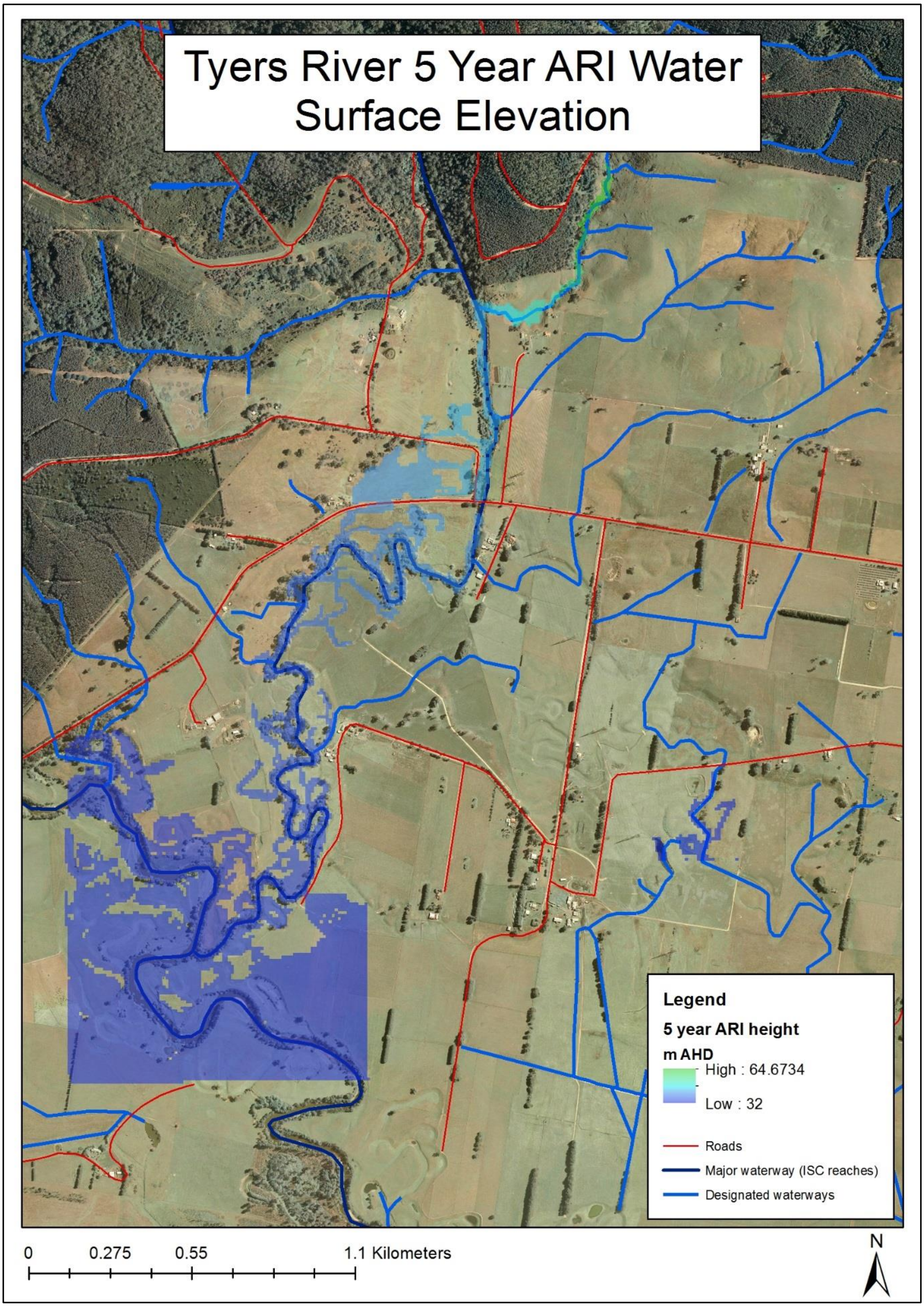


Figure 54 20% AEP maximum water surface elevation

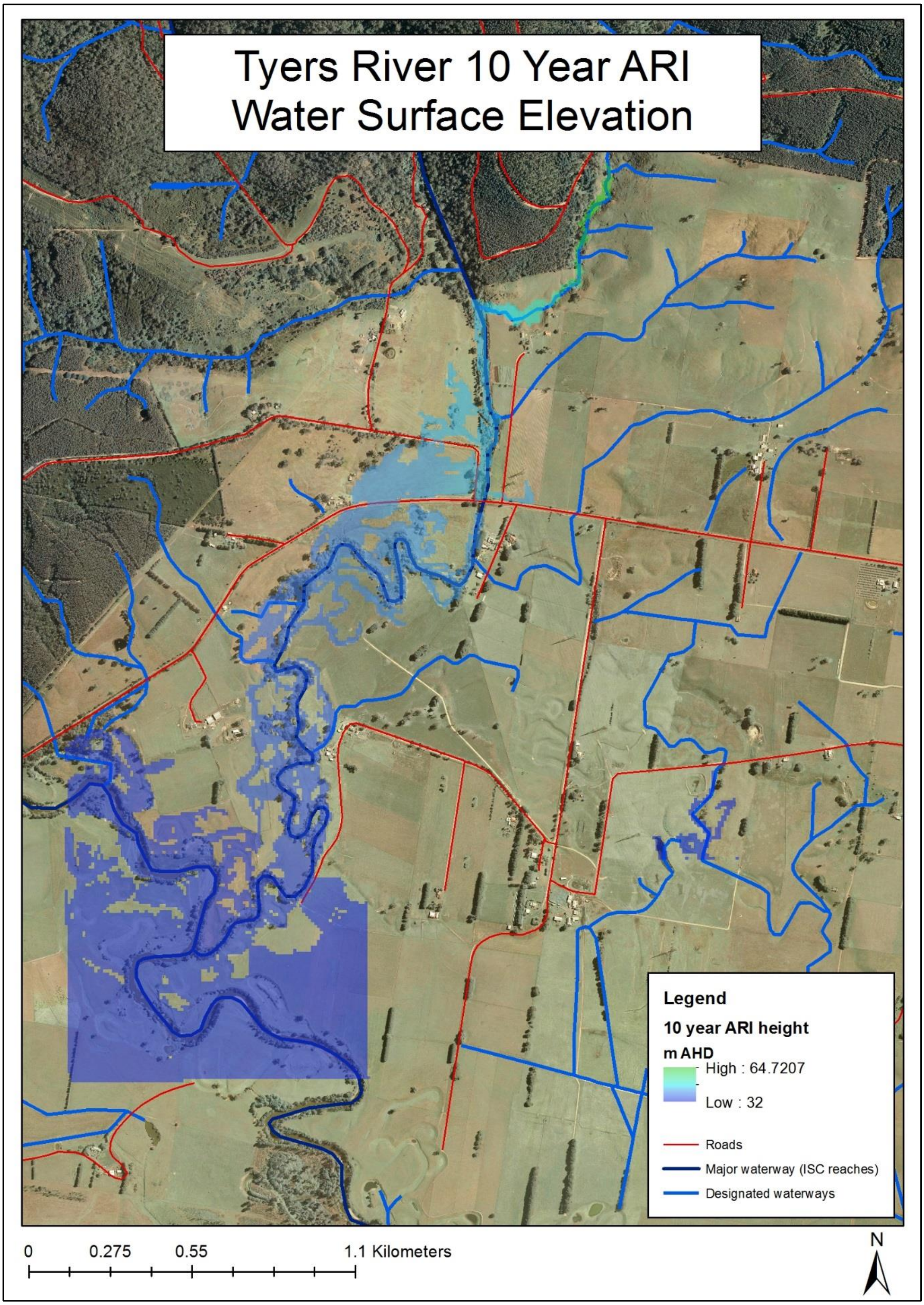


Figure 55 10% AEP maximum water surface elevation

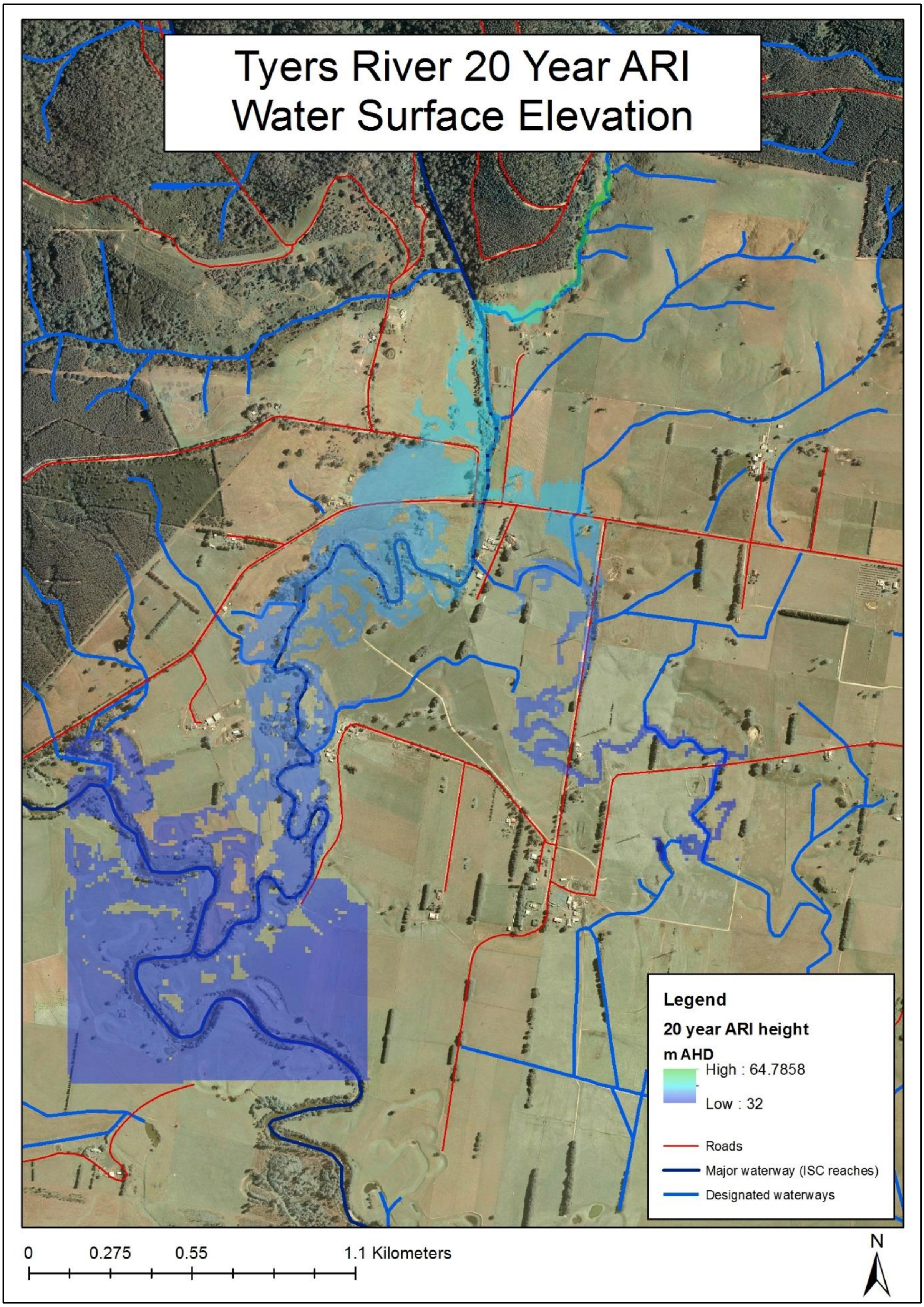


Figure 56 5% AEP maximum water surface elevation

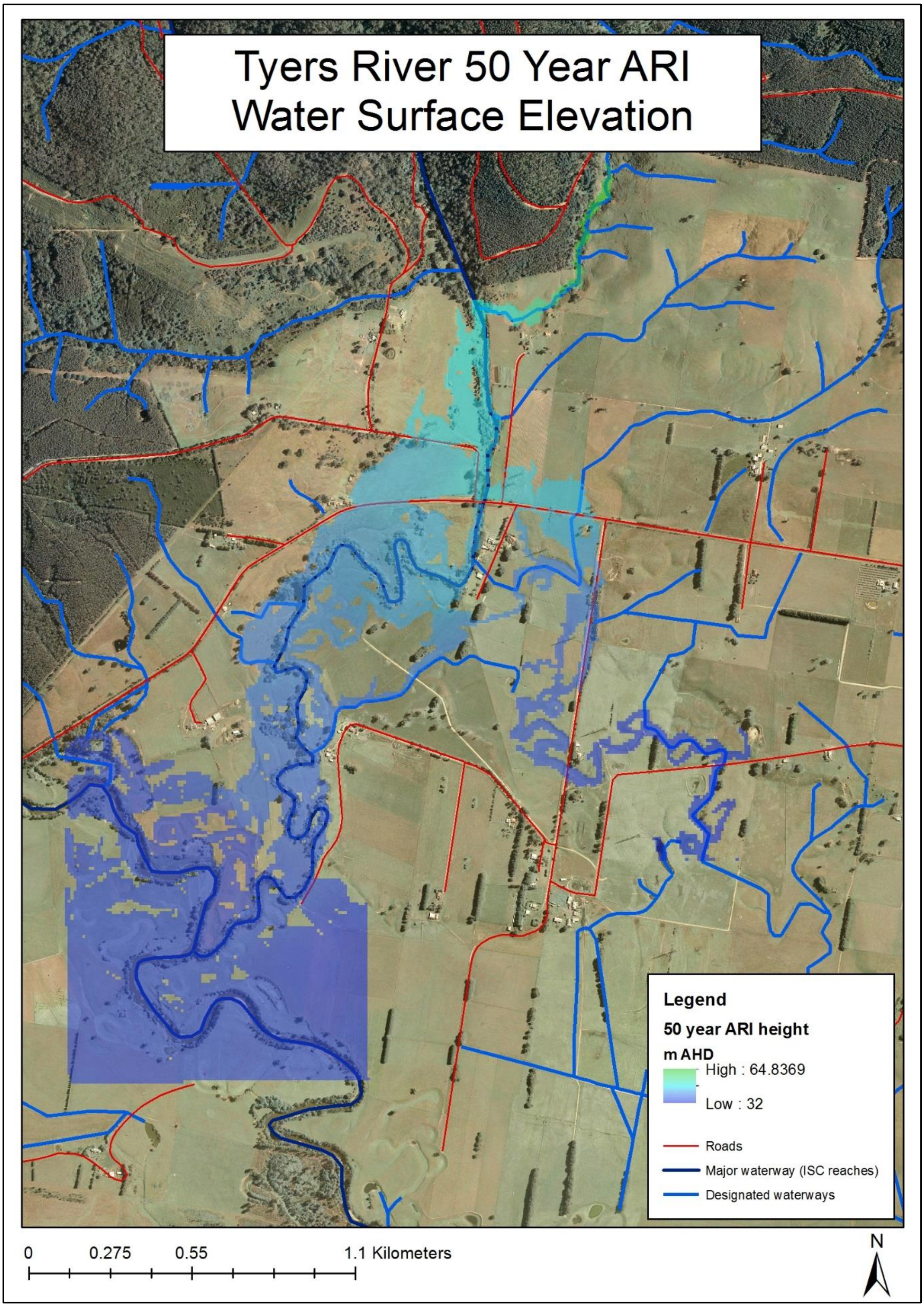


Figure 57 2% AEP maximum water surface elevation

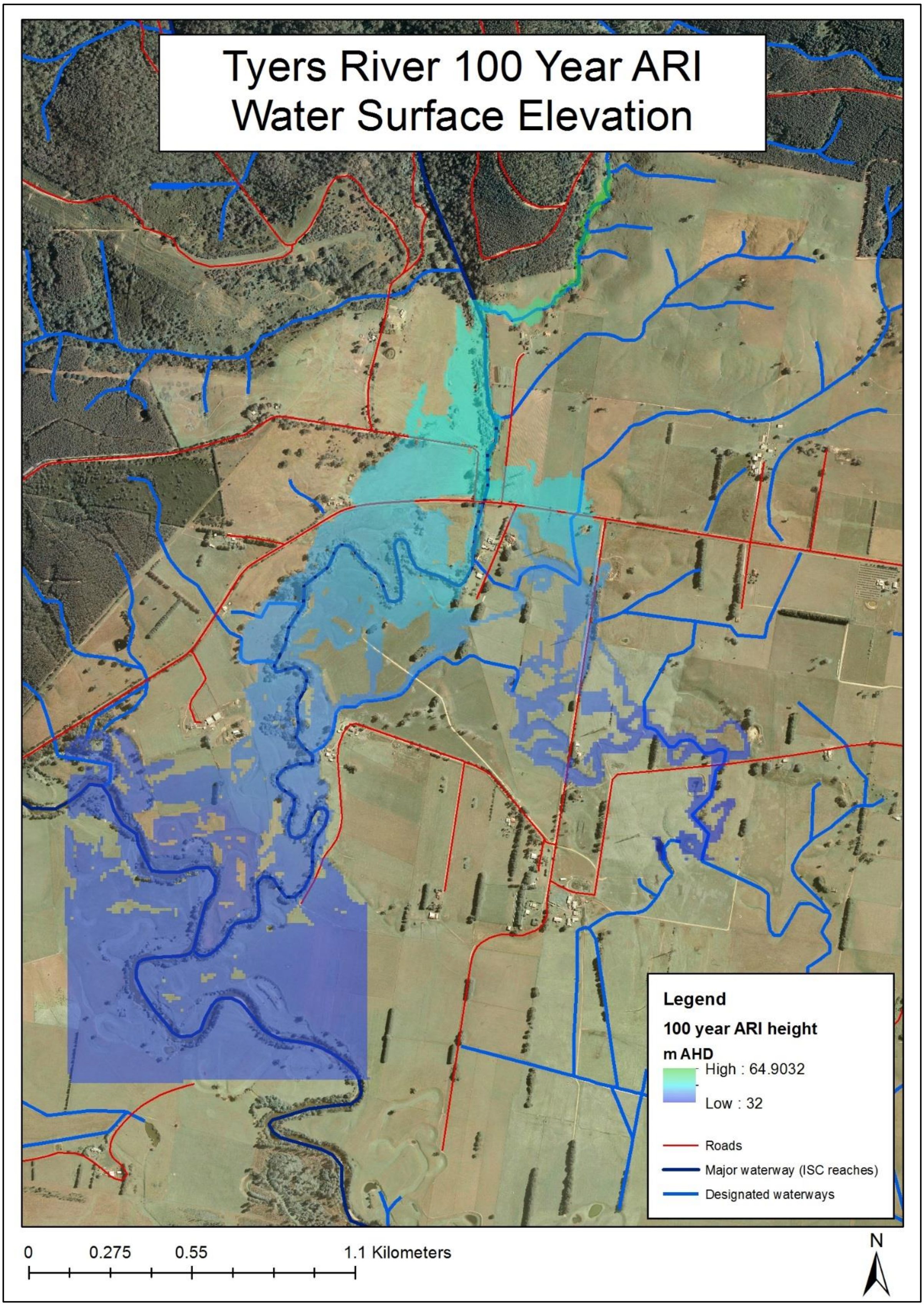


Figure 58 1% AEP maximum water surface elevation

Appendix G: Flood depth maps

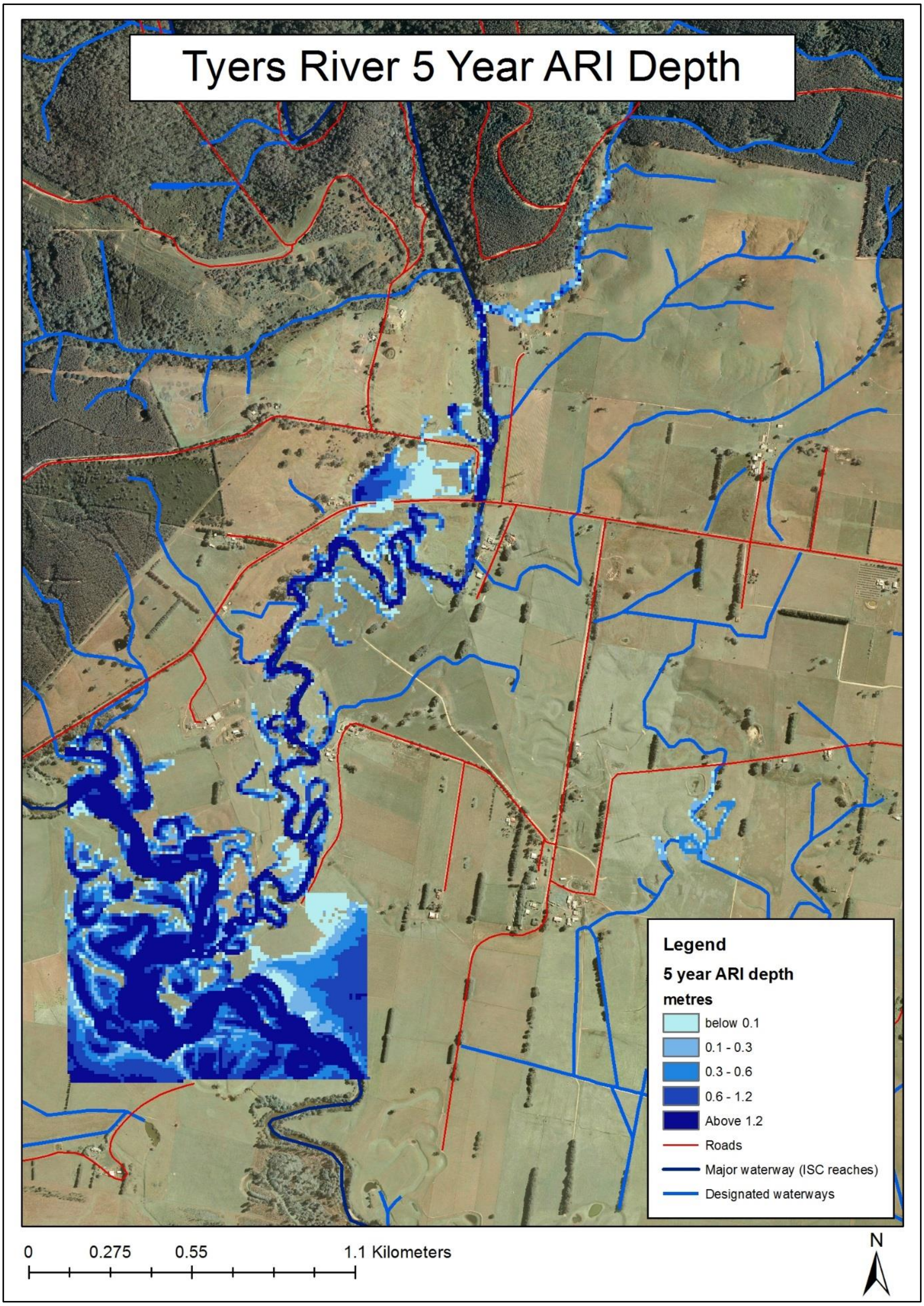


Figure 59 20% AEP maximum depth

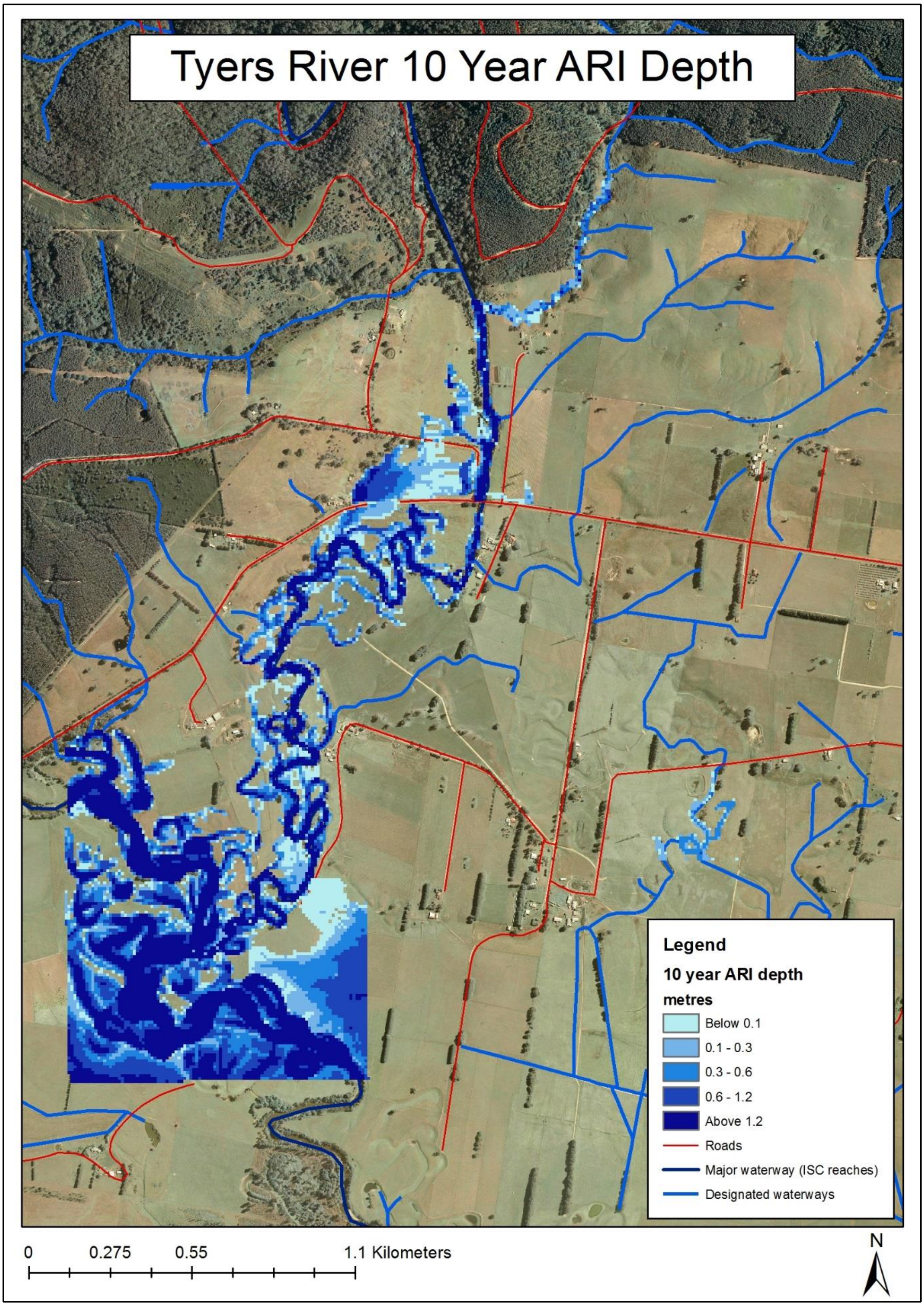


Figure 60 10% AEP maximum depth

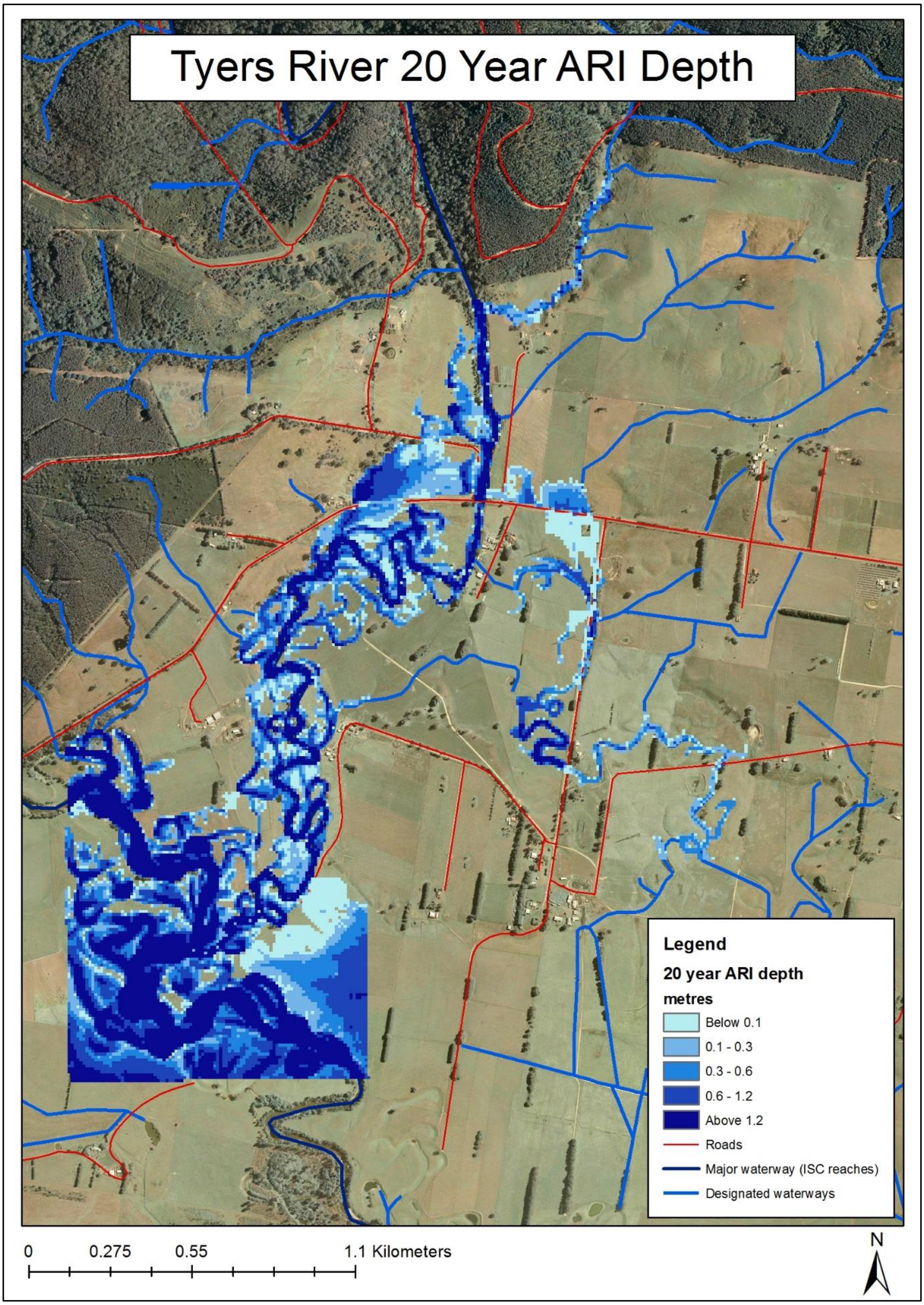


Figure 61 5% AEP maximum depth

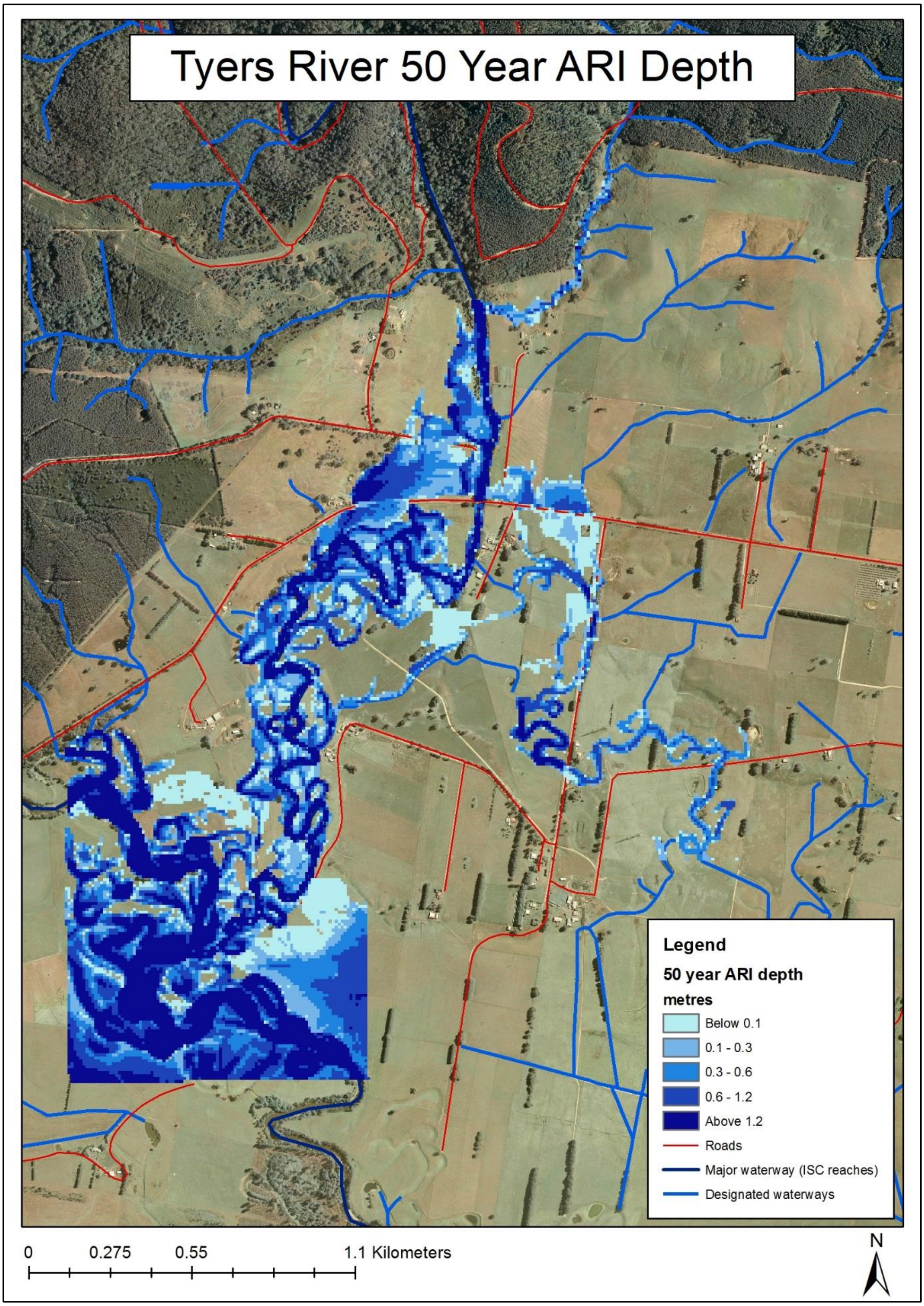


Figure 62 2% AEP maximum depth

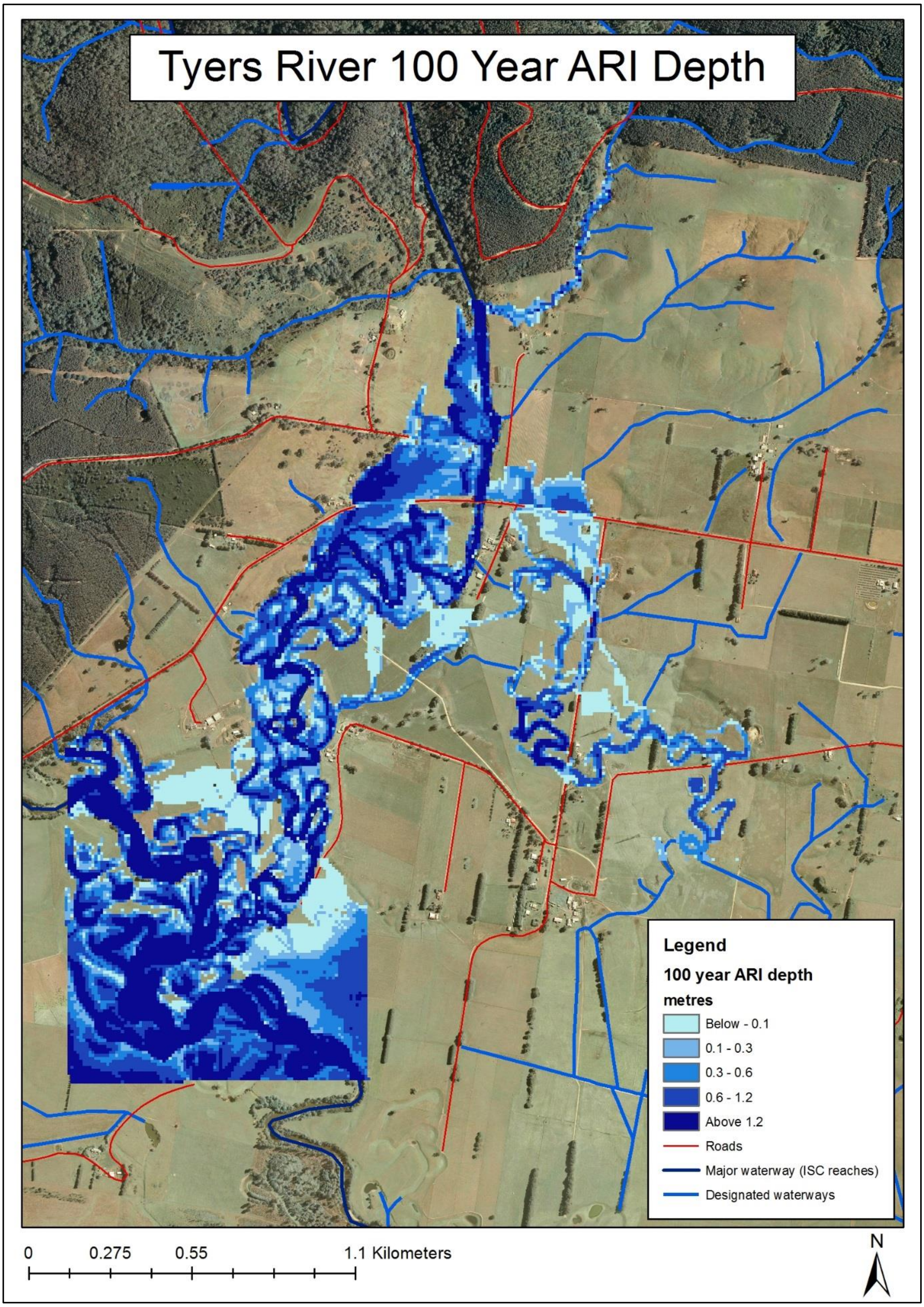


Figure 63 1% AEP maximum depth

Appendix H: Flood extent maps

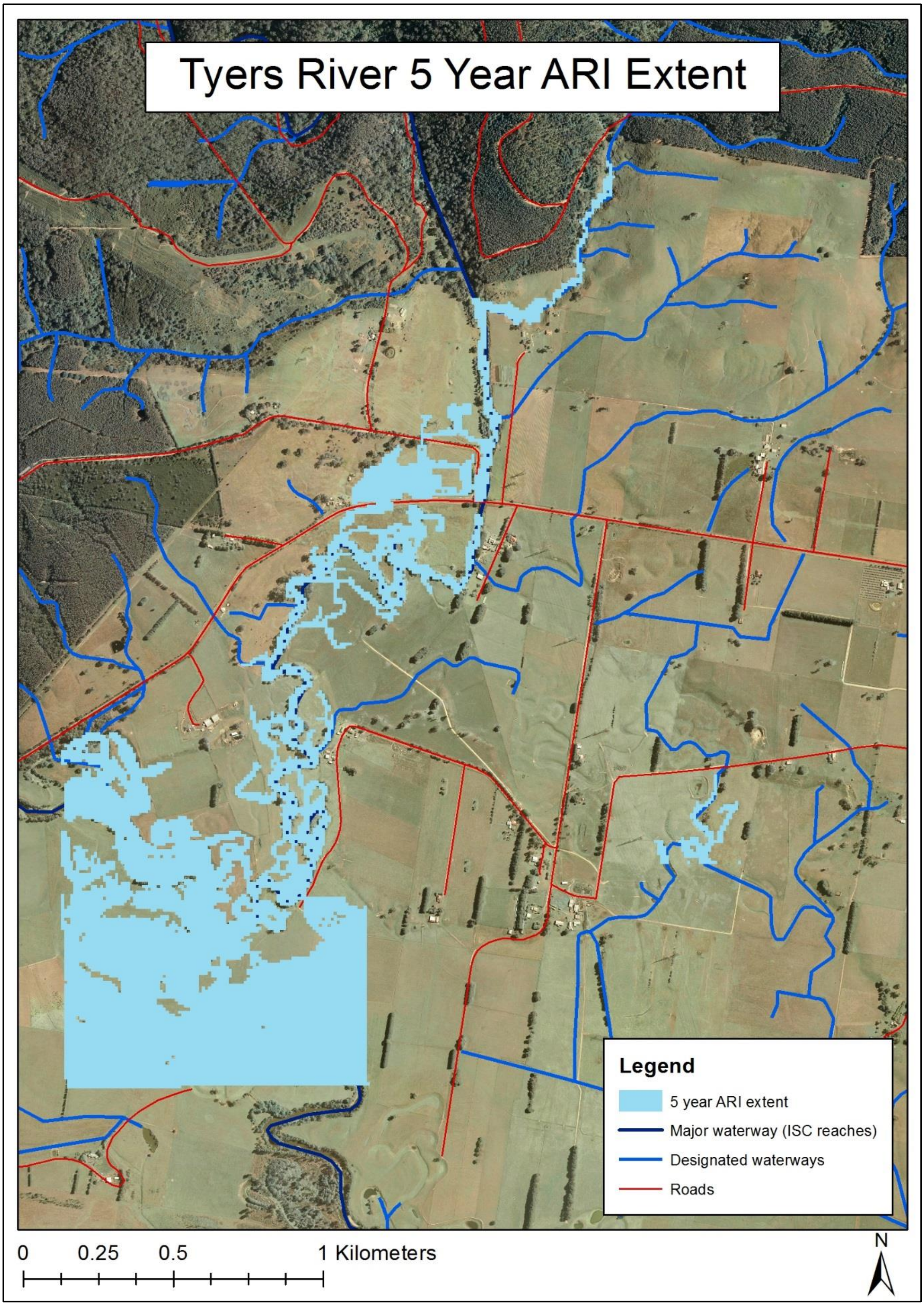


Figure 64 20% AEP extent

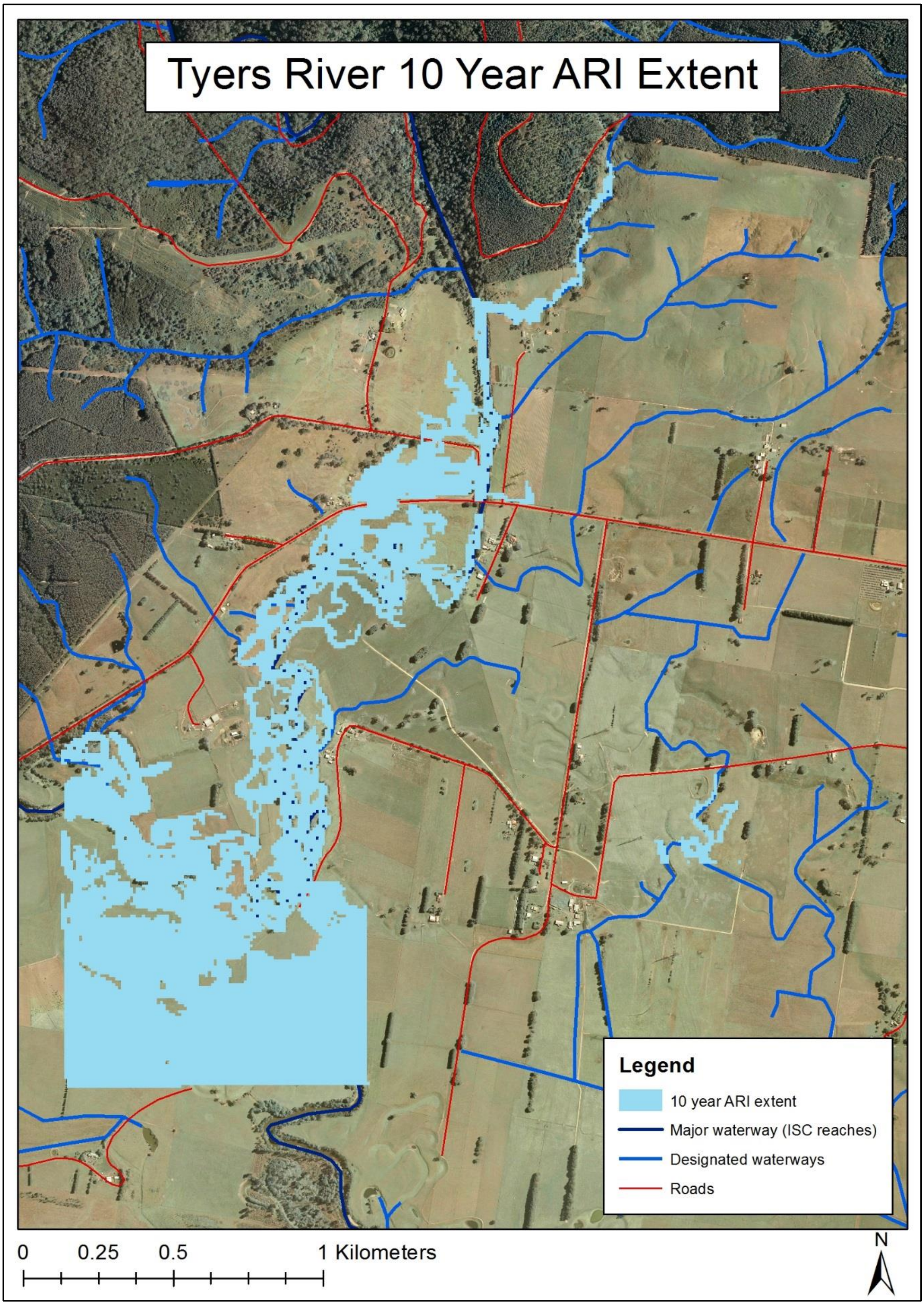


Figure 65 10% AEP extent

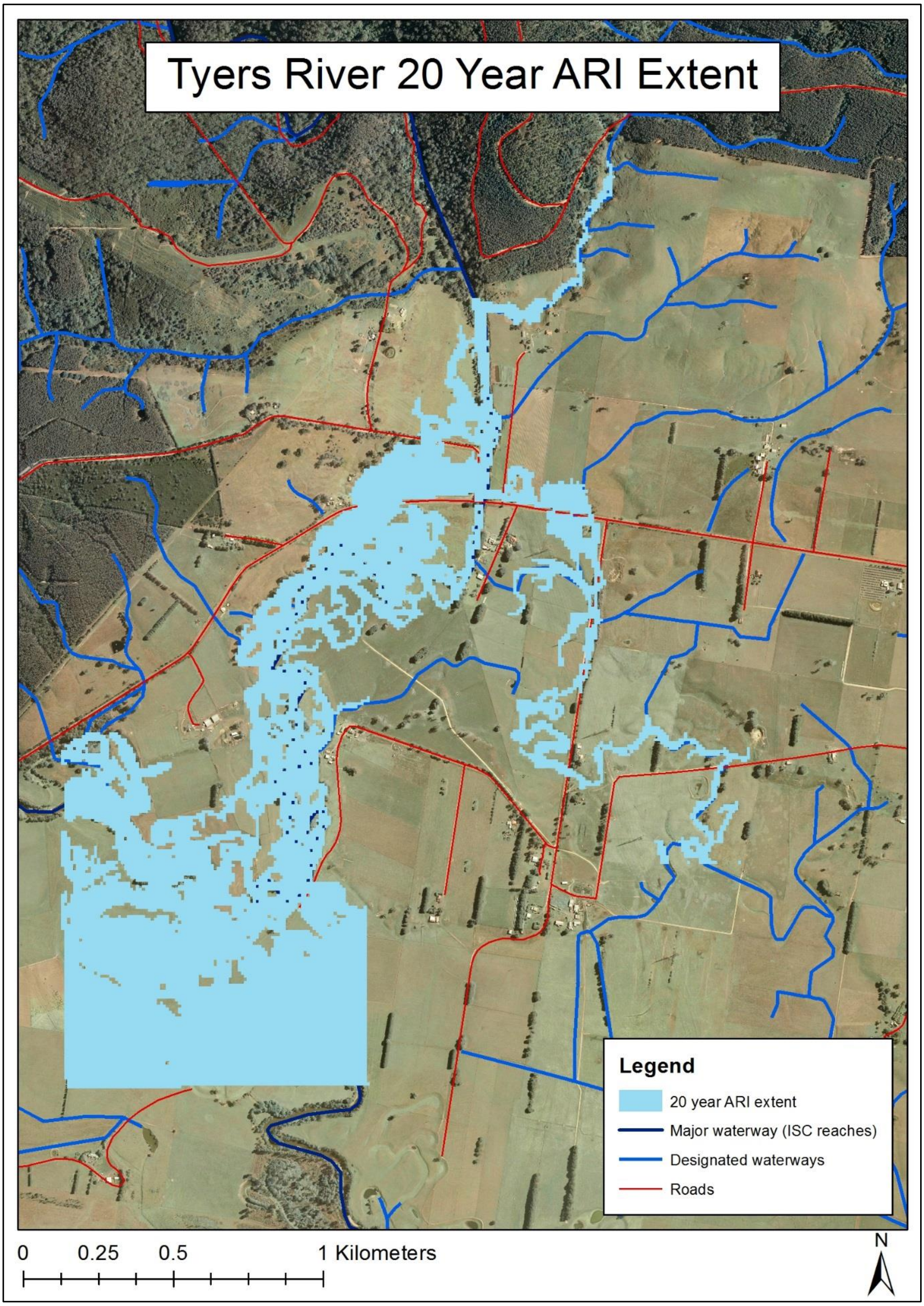


Figure 66 5% AEP extent

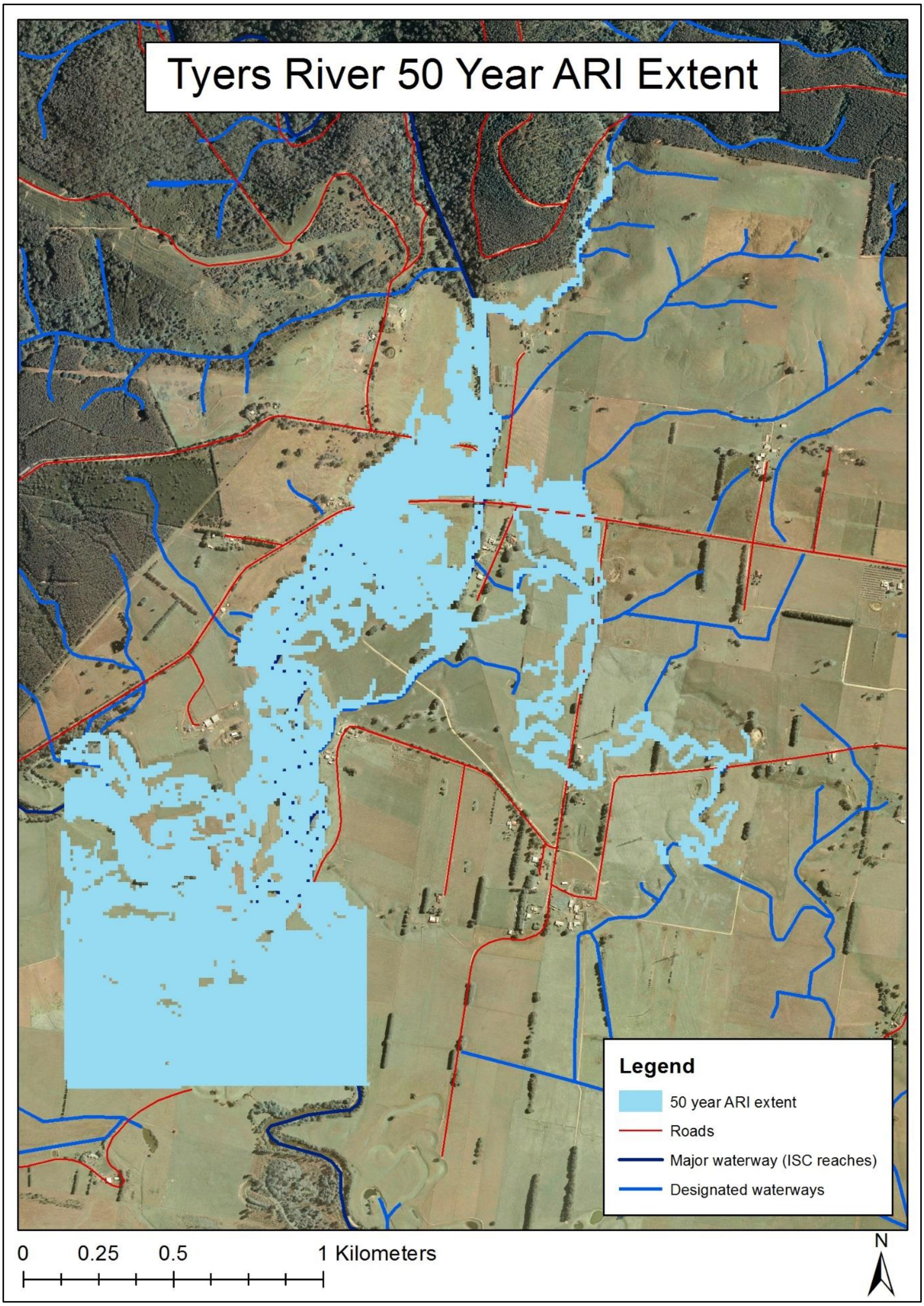


Figure 67 2% AEP extent

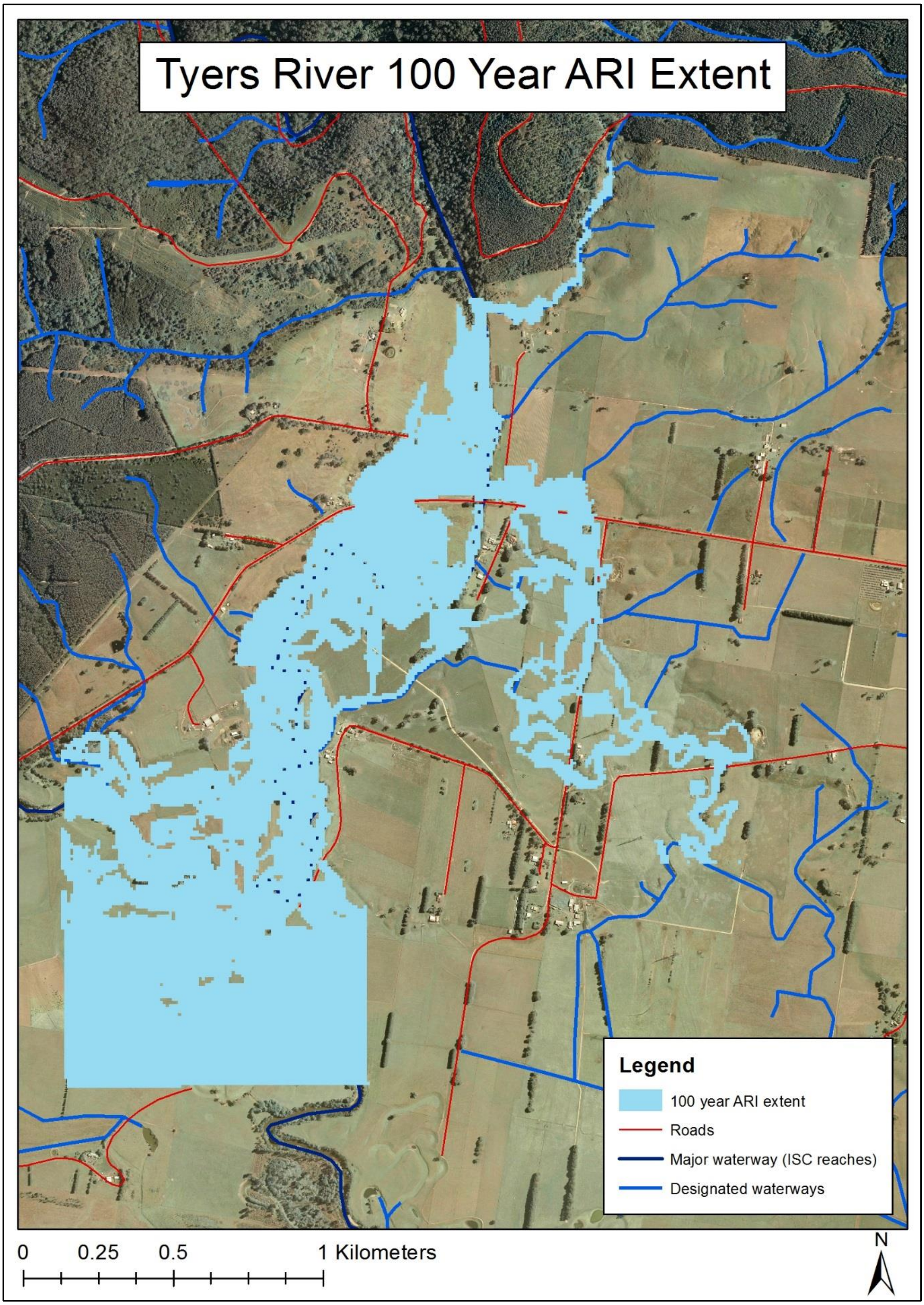


Figure 68 1% AEP extent

Appendix I: Flood flow velocity maps

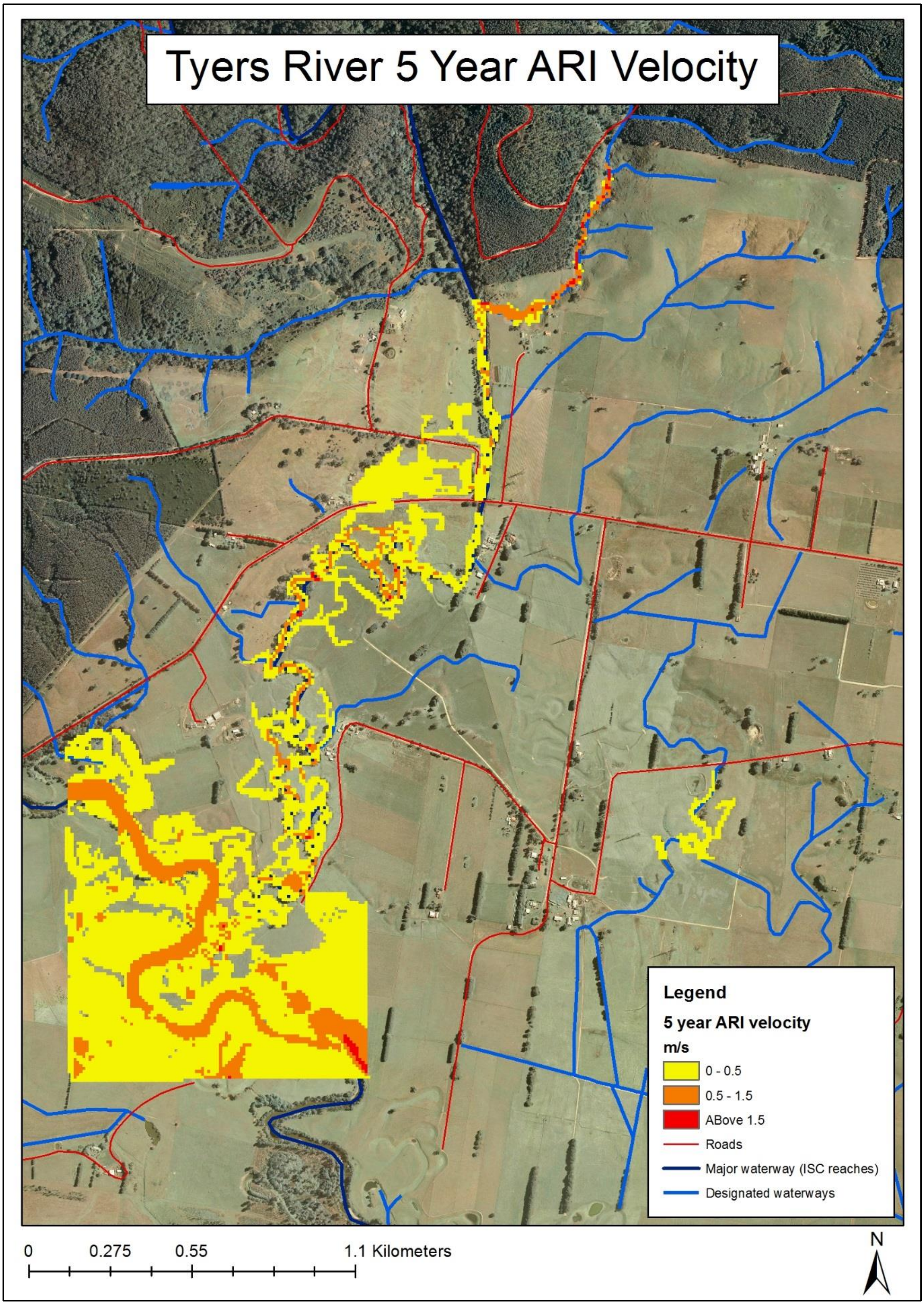


Figure 69 20% AEP maximum velocity

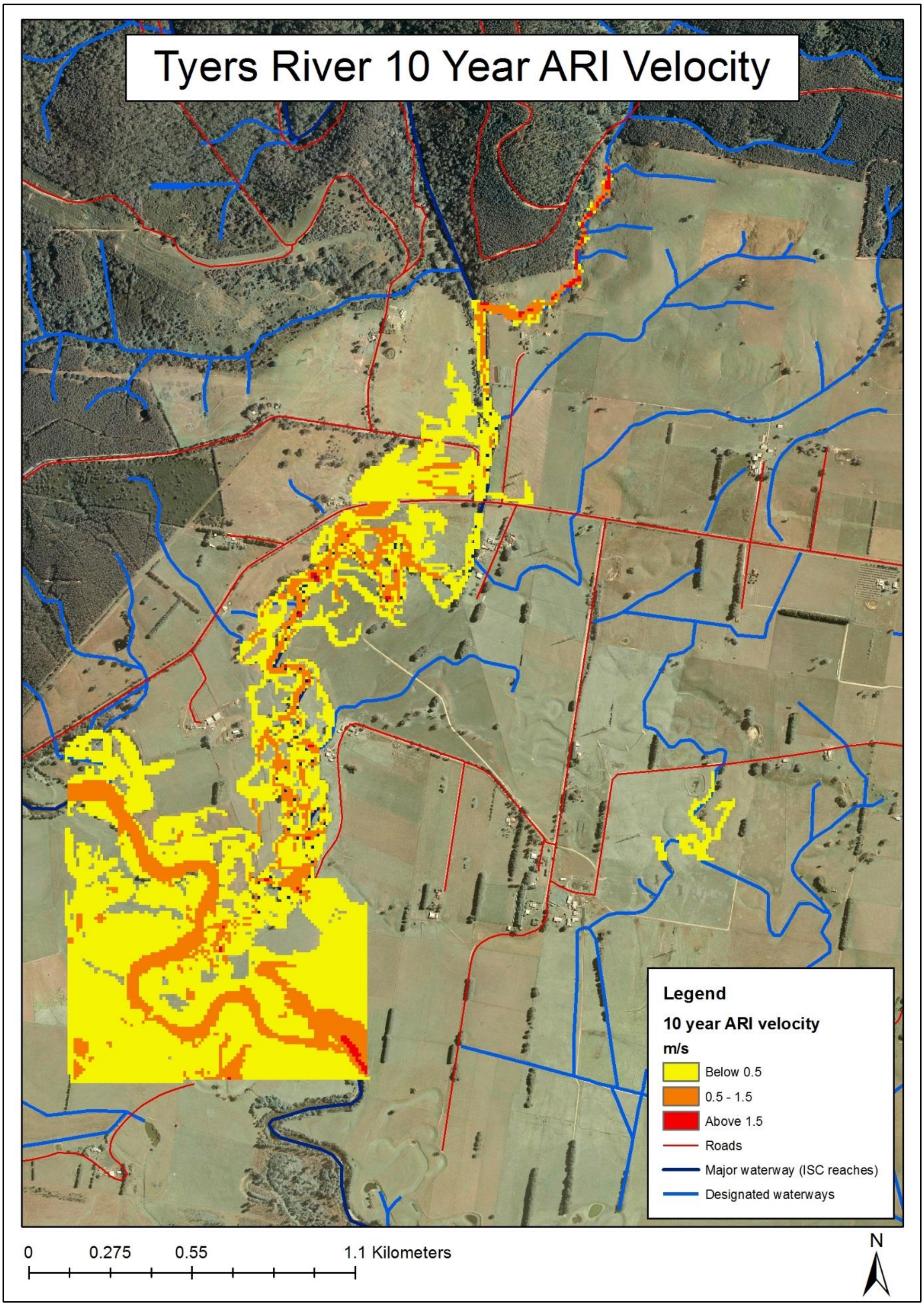


Figure 70 20% AEP maximum velocity

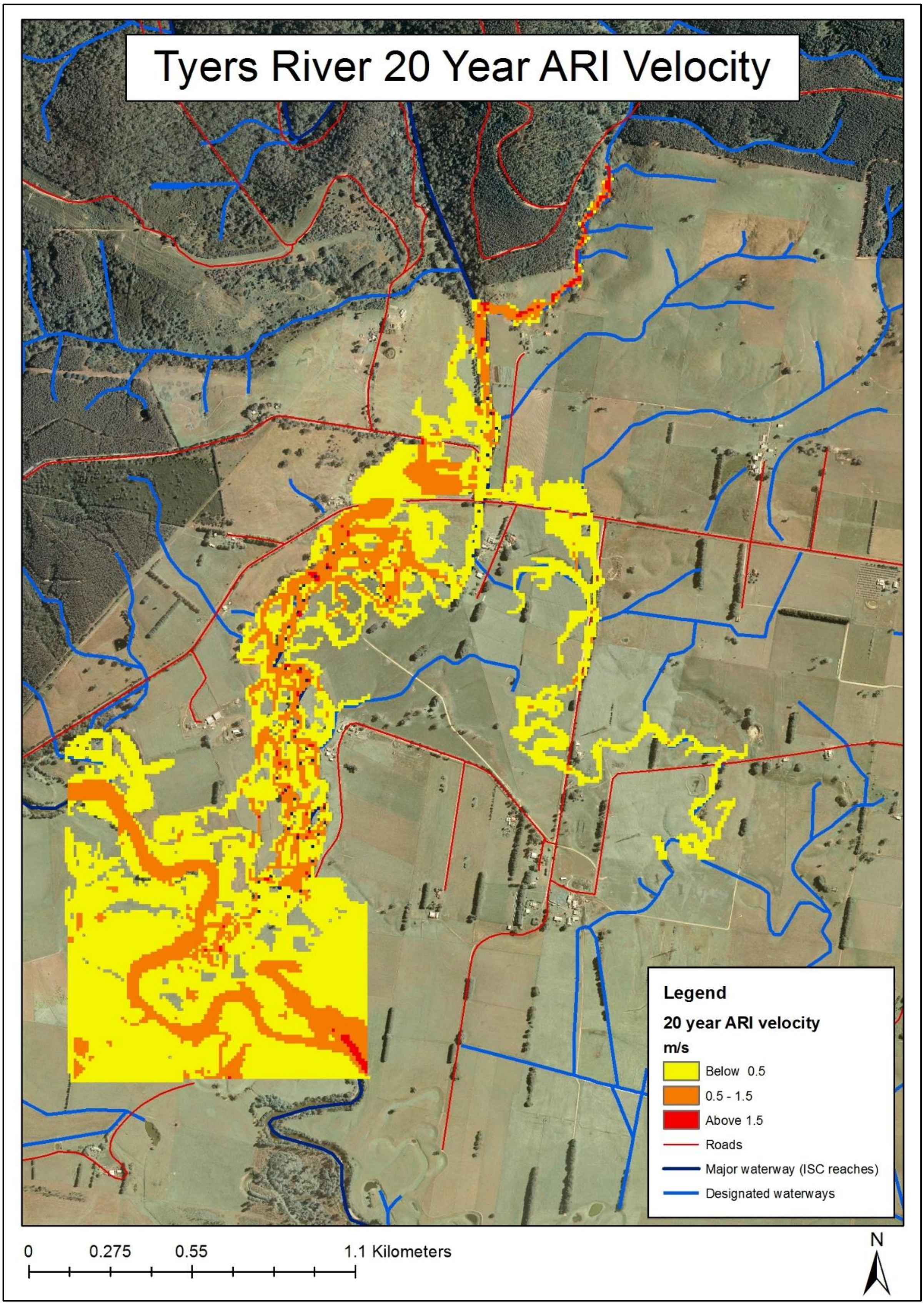


Figure 71 5% AEP maximum velocity

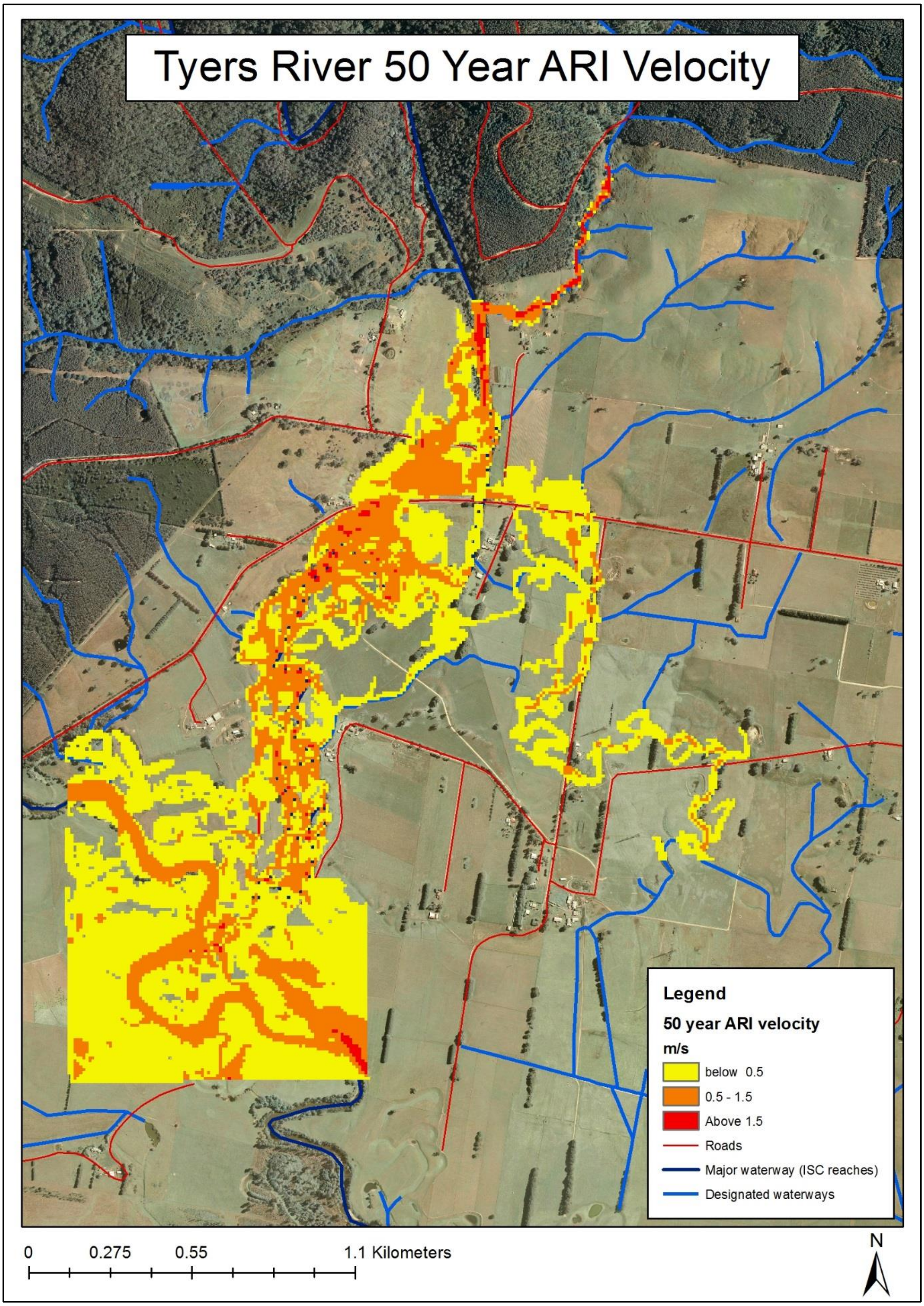


Figure 72 2% AEP maximum velocity

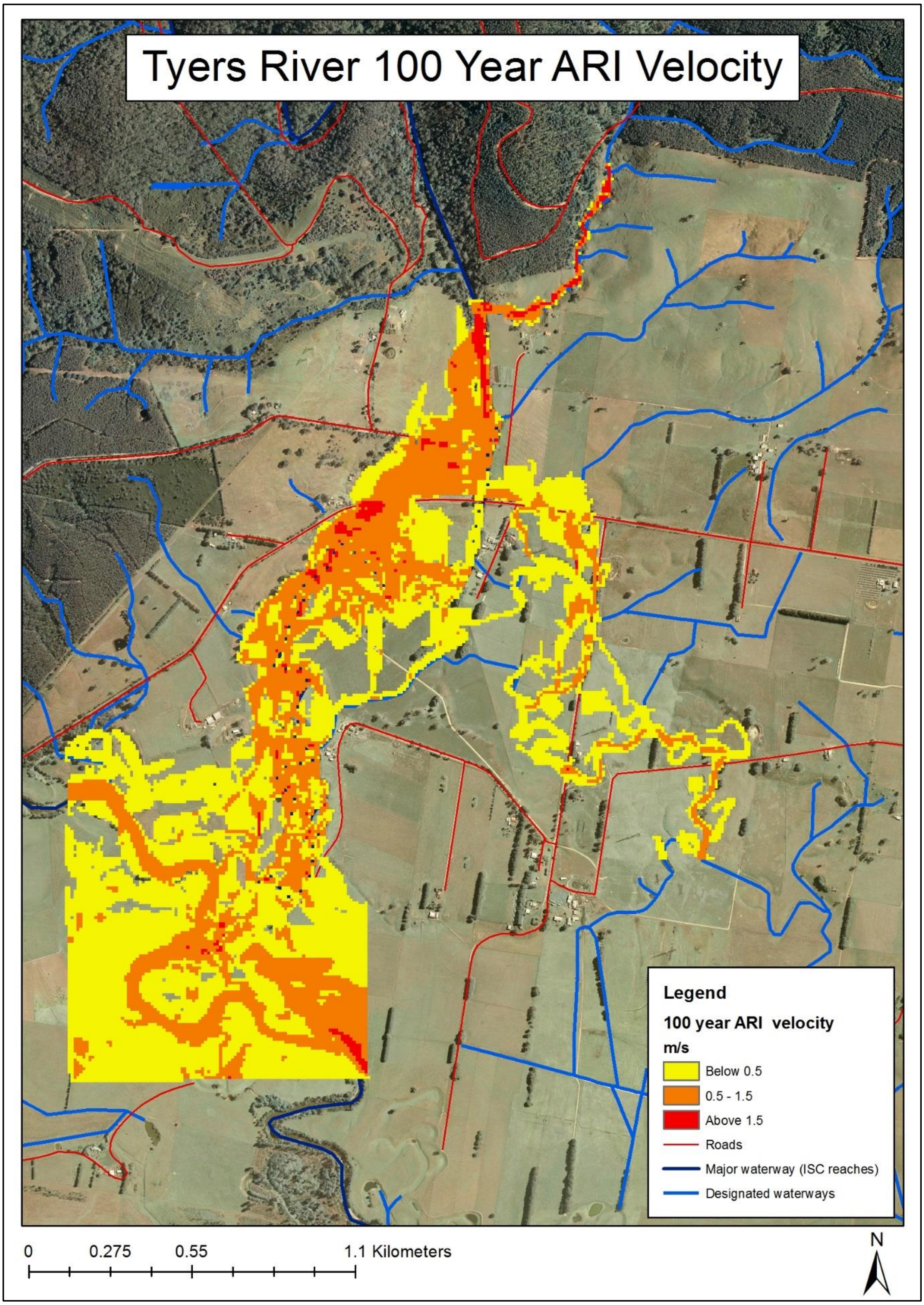


Figure 73 1% AEP maximum velocity