WGCMA Floodplain Mapping Program

Floodplain mapping for Rintouls Creek

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List of Abbreviations

ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff
FO	Floodway overlay
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
RL	Relative Level
ROG	Rain on grid
SES	State Emergency Service
VFD	Victorian Flood Database
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 Rintouls Creek, 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 Rintouls Creek floodplain mapping project as set out by the WGCMA are:

- Produce a RORB hydrologic model for the whole of the Rintouls Creek catchment area, using the elevation contours and reaches to determine sub catchments locations.
- Calculate and tabulate expected design flow hydrographs for Rintouls Creek 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 1% AEP flood extents, depths and velocities and prepare maps

1.3 Catchment description and history

Rintouls Creek is located in the Latrobe basin, beginning six kilometres south east of Erica running south to the Latrobe River between Tyers and Glengarry West, as shown in Figure 1. It is 34.98km long and has an 84.72km^2 catchment. Over this distance the elevation drops from 405 to 28m AHD, giving it a gradient of 10.85m/km. The catchment can be divided into two different areas, the upstream section with dense vegetation and steep banks and the downstream section consisting mostly of agricultural land with some residential dwellings.

The residential dwellings are situated along the south western edge of the catchment in a rural living zone in the locality of Tyers. There is no LiDAR available for this part of the catchment, but the VicMap elevation contours show that they are well elevated above the surrounding waterways. There no townships within the catchment. Tyers is located to the south west of the catchment, and it would take a significant breakout flow for flood water to reach the Tyers Township. The few properties in Glengarry West are more likely to be affected by flooding in Rintouls Creek.

There is only one hydraulic structure on Rintouls Creek in the floodplain area; the bridge on Glengarry West Road.

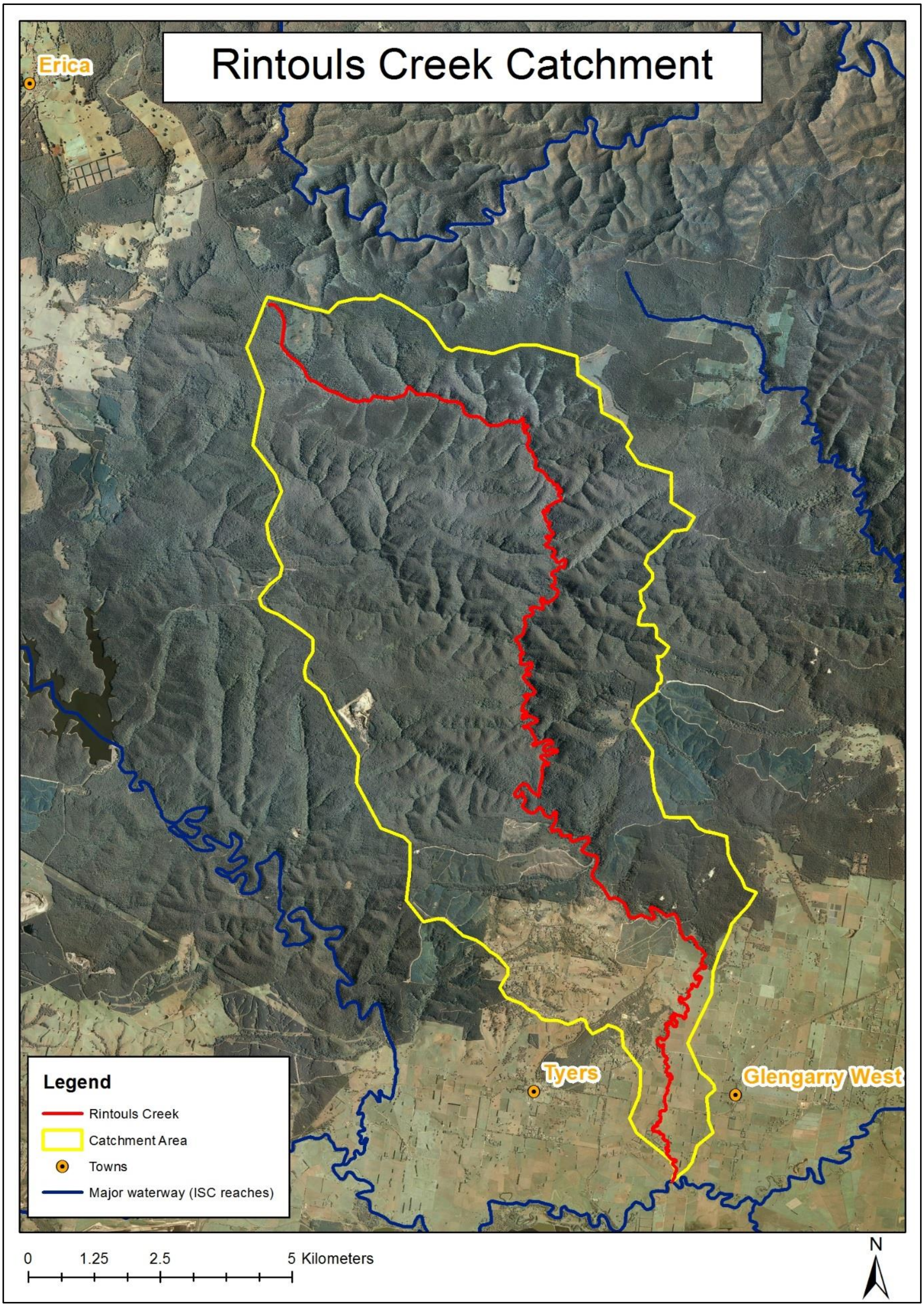

Figure 1: Rintouls Creek catchment area

1.4 Flood history

Rintouls Creek is ungauged, so there is no historic flow or rainfall data available. There are only two flood levels recorded within the catchment. The ARI of these levels and the year they were recorded are unknown.

1.5 Previous decision-related data

As of December 2015, the 1% AEP flood extent for Rintouls Creek only covers the final five kilometres of the creek. This extent has not been verified by a flood study or historic flood levels. The 100 year flood extent from the Latrobe River Flood Study (2015) also covers the end of Rintouls Creek. Both flood extents are similar, but the VFD includes flooding outside the boundary of the Latrobe River Flood Study (2015). These results a strong indication of how the Rintouls flood extent should look in this area.

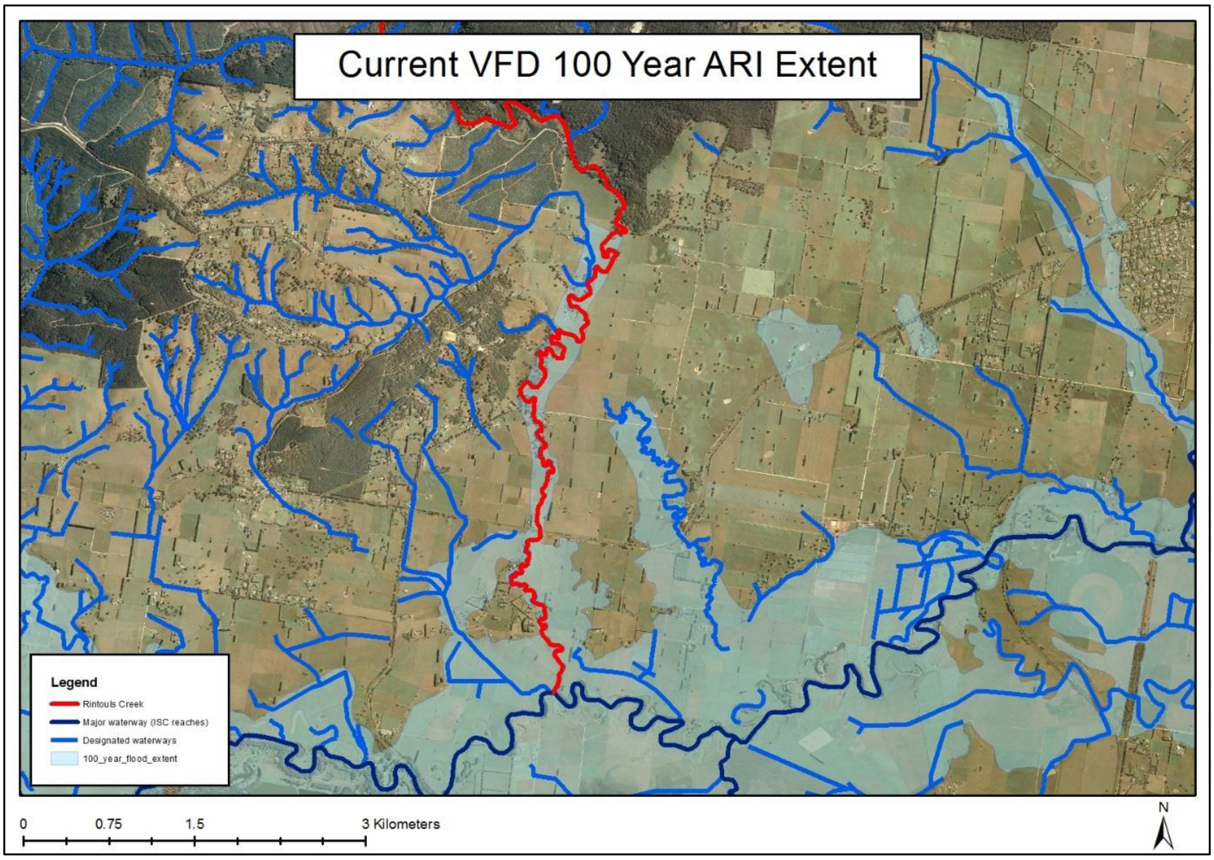

Figure 2 Current VFD 1% AEP flood extent

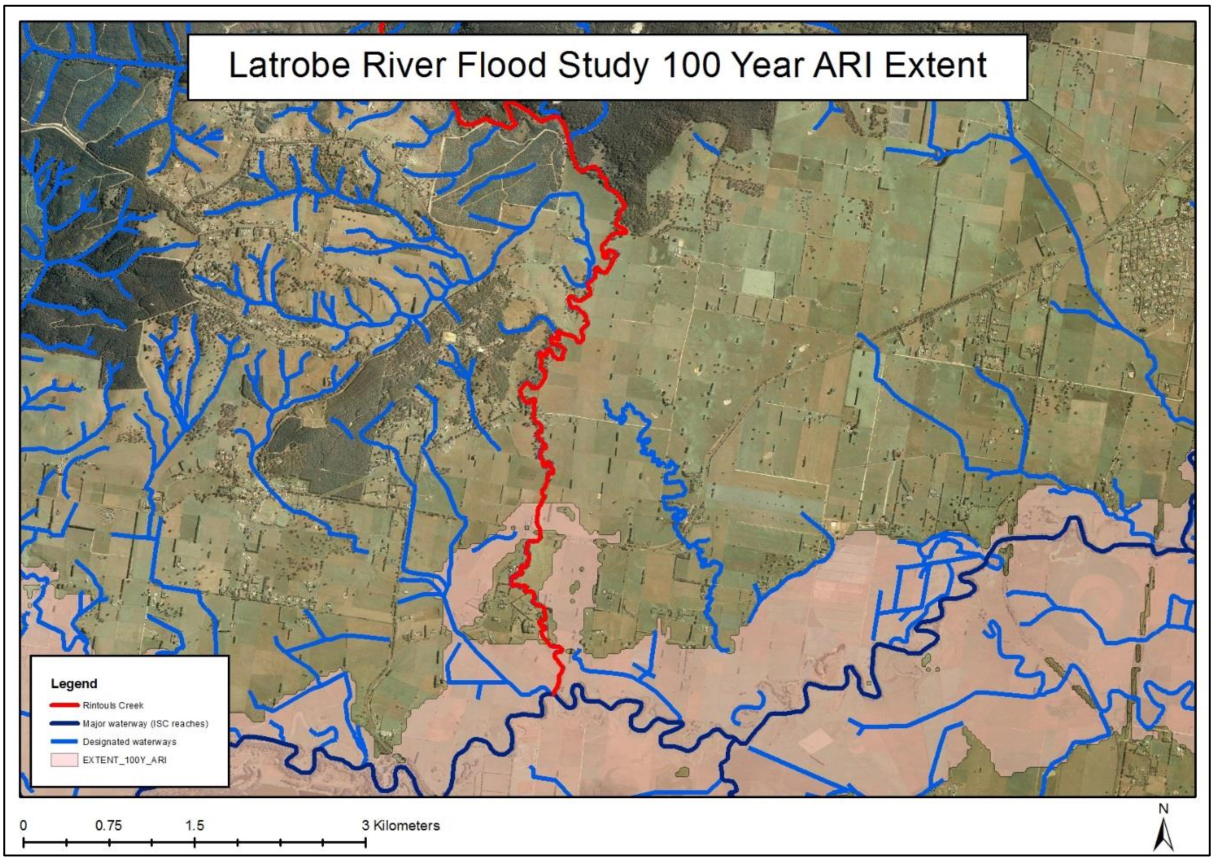

Figure 3 Latrobe River Flood Study (2015) 1% AEP flood extent

2 Hydrology

2.1 Description of hydrologic modelling approaches adopted

As Rintouls Creek is an ungauged catchment, the hydrological analysis consisted only of regional and rational methods and a RORB model. The RORB design loss parameters were taken from ARR book two (1998) and calibrated against the regional and rational results.

Regional and rational methods

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, which is entered into the 1987 and 2013 BOM IFD programs to calculate the intensity for the Zaman (2013) Regional method and probabilistic rational method

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.

Zaman (2013) Regional Method

The Zaman (2013) et al (2013) regional flow estimation method was used to determine flows for 2-1% AEP events. The equations in the Zaman (2013) method, shown below in Table 1, 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 (2013) Regional Equations

ARI	Equation	R_2	SEE	Eq.
2	$\log_{10}(Q_2) = -3.055 + 1.186l \log_{10}(area) + 2.103\log_{10}(I_{tc\_2})$	0.780	0.21	2.1-5
5	$\log_{10}(Q_5) = -2.847 + 1.182 \log_{10}(area) + 2.0891\log_{10}(I_{tc\_5})$	0.805	0.22	2.1-6
10	$\log_{10}(Q_{10}) = -2.476 + 1.13 \log_{10}(area) + 1.932\log_{10}(I_{tc\_10})$	0.764	0.23	2.1-7
20	$\log_{10}(Q_{10}) = -2.476 + 1.13 \log_{10}(area) + 1.932\log_{10}(I_{tc\_10})$	0.763	0.21	2.1-8
50	$\log_{10}(Q_{20}) = -2.766 + 1.173 \log_{10}(area) + 2.108\log_{10}(I_{tc\_20})$	0.722	0.22	2.1-9
100	$\log_{10}(Q_{100}) = -2.789 + 1.159\log_{10}(area) + 2.135\log_{10}(I_{tc\_100})$	0.684	0.25	2.1-10

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.

Regional and rational calculations were completed at the catchment outlet each of the Sobek inflow points, shown in Figure 4.

RORB

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 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 value for 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 Eaglehawk Creek: 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, **Error! Reference source not found.**. The loss values are entered manually and can be obtained from multiple sources including ARR Book Two, ARR Revision Project Six and Hill et al (1998).

The hydrograph tables for the completed 50, 20, 10, 5, 2 and 1 percent AEP RORB models were saved in spreadsheets and used as inflows for the corresponding hydraulic models.

2.2 Available data

Available data for the Rintouls Creek hydrology consisted of:

- Aerial photography
- Designated waterway mapping
- VicMap elevation contours
- LiDAR
- 1987 and 2013 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.

Bureau of Meteorology (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.

2.3 Initial hydrologic estimates

Initial hydraulic estimates were completed at the catchment outlet and at the hydraulic model inflow points. The location of these points are shown in Figure 4. The results are shown in Table 2 to Table 4. 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, no single method can be relied on for RORB model calibration.

Table 2 Summary of initial hydrologic estimates at inflow J

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		m^3/s	m^3/s	m^3/s	m^3/s
2	0.098		16.60	15.43	12.05
5	0.117		26.92	25.86	34.84
10	0.130		35.19	34.87	61.51
20	0.143		46.39	45.50	87.18
50	0.156		62.62	61.02	135.36
100	0.169	127.26	78.56	76.44	180.54

Table 3 Summary of initial hydrologic estimates at inflow KL

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 (2013) et. al. (2013) equations
years		m^3/s	m^3/s	m^3/s	m^3/s
2	0.098		1.63	1.47	1.42
5	0.117		2.79	2.52	4.61
10	0.130		3.76	3.41	9.00
20	0.143		5.09	4.46	13.57
50	0.156		7.10	5.96	23.24
100	0.169	12.99	9.10	7.44	33.57

Table 4 Summary of initial hydrologic estimates at outflow

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 (2013) et. al. (2013) equations
years		m^3/s	m^3/s	m^3/s	m^3/s
2	0.098		18.05	16.11	13.02
5	0.117		29.21	26.91	37.47
10	0.130		38.12	36.16	65.84
20	0.143		50.25	47.08	93.29
50	0.156		67.72	62.99	156.18
100	0.169	138.15	84.9	78.11	191.83

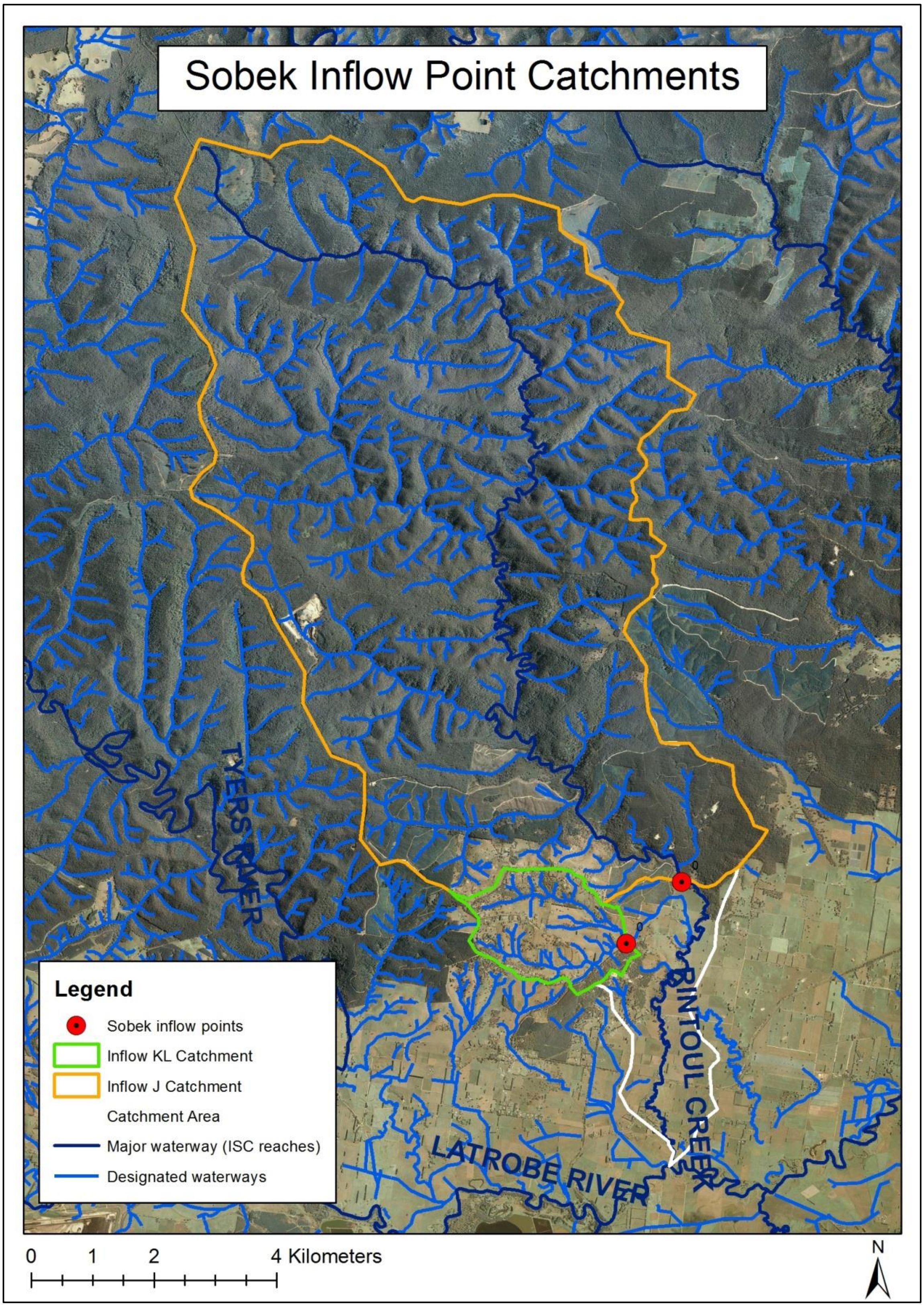

Figure 4 Sobek inflow point catchments

2.4 RORB hydrologic model

The RORB hydrologic model was used to generate hydrographs for the hydraulic model. The model consisted of 13 subcatchments delineated in ArcMap around the designated waterways using the VicMap elevation contours to identify the ridge lines. Nodes representing the catchment centroids and outlets and the hydraulic model inflow points were connected by natural reaches where the slope was less than five percent. Where the slope was greater than five percent, an excavated unlined reach was used, because slopes cannot be entered on natural reaches.

The RORB model could be run with a 1987 IFD table from any capital city, or a user defined IFD table can be manually entered. For Rintouls Creek, the 1987 IFD table for the catchment centred was used.

FIT runs could not be completed for Rintouls Creek because there was no flow data available. 1% AEP design runs where completed for multiple durations to find the critical duration, the duration that gives the greatest flow. Regional and rational methods were then used as a calibration guide for selecting the Kc at the critical duration. The Hill (1998) equation was used to calculate the initial loss and the continuing loss was set at 3.00 as recommended in ARR Project 6. ARR Project 6 also contains a new equation for initial loss, but this has not yet been completed and was therefore not used.

Areal patterns in RORB can either be uniform or non-uniform. Non uniform weighted areal patterns represent the percentage of the total rainfall falling in each subcatchment. Non-uniform areal patterns are created by multiplying the rainfall in each subcatchment as a percentage of the average rainfall by their subcatchment area expressed as a percentage of the total catchment area. Although a test areal pattern based on a single storm produced good results in the Eaglehawk Creek flood study, non-uniform areal patterns are not commonly used (Ladson, 2008) and the rainfall distribution can vary heavily between storms (Hughes, 2013). For these reasons as well as the considerable time required to produce them, non-uniform areal patterns were not used for Rintouls Creek.

Sub-area and reach delineation

As much as possible, the subcatchments for the RORB model were delineated according to the RORB manual guidelines, with subcatchments containing between five and 25 percent of the total catchment area, and no more than one third of the main channel length in any subcatchment. This was completed in ArcMap using Light Detection and Ranging (LiDAR), elevation contours and designated waterways to locate the subcatchment boundaries, formed by ridgelines between the tributaries. To keep the subcatchment sizes within this range, ephemeral streams and minor tributaries were not given their own subcatchments. The exception to this was subcatchment H, which contains less than 5 percent of the total catchment area but prevents subcatchment G from being too large. Subcatchments K, L and M are also very small. These subcatchments were delineated from each other to place a hydrograph at the outflows of J and K, where a Sobek inflow is needed. This was not an ideal situation but is preferable to having a print node without a complete subcatchment above it.

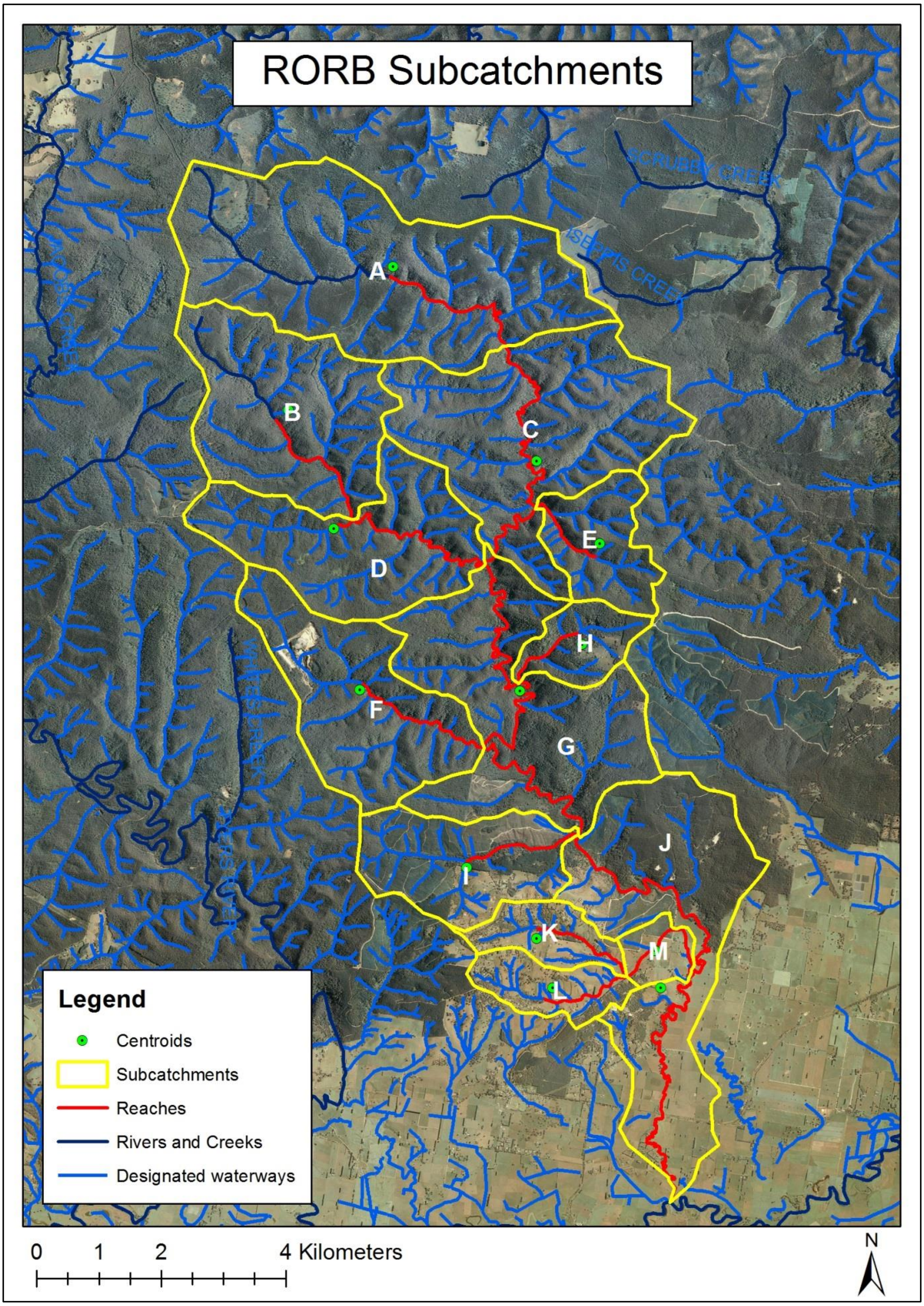

Figure 5 RORB subcatchments

Parameters

The K_c values in Table 5 were calculated in RORB using the equations contained in Appendix B, Table 14.

Table 5 Kc parameters

K_c equation					
Yu	VicMAR>800mm	VicMAR<800mm	Dyer	Pearse Victorian Data	Default RORB
19.77	19.33	9.04	23.48	25.75	20.71

ARR Project 6 recommends a continuing loss of 3.00 for Victoria, and this is the value that was adopted. Using the equation developed by Hill et al (1998), and the average annual rainfall from the BoM pan evaporation map in Appendix A, Figure 13, an initial loss of 24.77 was calculated. The Hill et al (1998) equation is the most recent initial loss calculation aside from ARR Project 6, which has not been completed.

Design run

Design run parameters are listed below in Table 6. The initial loss was calculated using the Hill et al (1998) equation and the continuing loss was taken from ARR project 6. The Kc was chosen by comparing the RORB results for each Kc value against the regional and rational flow values. The Pearse Victorian Data Kc value was chosen, giving a critical duration of 36 hours for inflow J and the outflow at most ARIs.

Non-uniform areal patterns are not commonly used (Ladson, 2008) and the rainfall distribution can vary heavily between storms (Hughes, 2013). Because of this and the amount of time needed to generate a non-uniform areal pattern, the model was only run with a uniform areal pattern.

The chosen design run parameters resulted in peak flows for each ARI approximately halfway between the probabilistic rational method and the Zaman (2013) regional method, with a peak flow for the 1% AEP storm close to the Nikolaou and von’t Steen equation.

Table 6 RORB design run parameters

Parameter	Value
K_c	25.75 (Pearse)
M	0.8
Initial loss (mm)	24.77
Continuing loss (mm/h)	3.0

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. Changing the initial loss from ARR Book two values to the Hill et al (1998) value was found to have the biggest impact, shifting the results upwards towards the Zaman (2013) regional flows.

Assumptions

- Victorian average continuing loss applicable to Rintouls Creek
- Hill initial loss
- Average annual rainfall of 800mm

RORB results

Table 7 Design flows at inflow J from RORB model

Average Recurrence Interval (ARI)	Flow at outlet based on RORB design run model
years	m^3/s
2	19.33
5	41.04
10	59.93
20	82.87
50	114.19
100	146.95

Table 8 Design flows at inflow KL from RORB model

Average Recurrence Interval (ARI)	Flow at outlet based on RORB design run model
years	m^3/s
2	2.98
5	5.46
10	7.11
20	9.16
50	11.12
100	13.34

Table 9 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	17.29
5	36.82
10	53.92
20	76.05
50	107.31
100	138.45

2.5 Summary of hydrology results

As it was not possible to complete a flood frequency analysis, the RORB model could only be compared with the rational and regional flows. The results were as expected following the results from hydrologic modelling Eaglehawk Creek, with the RORB model producing flows between the ARR87 rational method and the Zaman (2013) regional method using the Hill et al (1998) initial loss and Project 6 continuing loss. The RORB 1% AEP design flow was only 0.30m^3/s higher than the 1% AEP flow value obtained using the Nikolaou and von’t Steen regional equation. Had the older ARR87 losses been used, the results would have likely matched the rational method flows for 50 and 1% AEP, but produced lower flows for 50, 20, 10 and 5% AEP storms.

The flows recorded at inflow J were higher than at the catchment outflow in the RORB model but not the regional and rational equations. This is likely a product of the different ways that RORB and the regional/rational methods work. In the regional and rational methods, the largest catchment will always have the higher flows if the IFD table and runoff coefficient are the same. Inflow J is located near the end of the catchment, giving it a near identical IFD table to the catchment outlet. Because its catchment is smaller than the overall catchment, it has a lower flow than the catchment outlet. RORB takes subcatchment reaches into account, and as only one of them is located downstream of inflow J, the losses outweigh the inflows between inflow J and the outlet.

The accuracy of the hydrology results would have been better if Rintouls Creek was gauged, as flood frequency analysis could have been completed. A flow gauge is unlikely to be installed, however, because the population along the creek is too small to justify the expense. There are no townships within the catchment, and Tyers and Glengarry West would not be impacted by flooding in Rintouls Creek. There is only has a small number of dwellings on the southwest edge of the catchment in the locality of Tyers. Even if one was installed it would be several years before a sufficient amount of data was collected.

Table 10 Summary of design flows 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 (2013) et. al. (2013) equations	Flow at outlet based on RORB design run model
years	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
2		18.05	16.11	13.02	18.05
5		29.21	26.91	37.47	37.47
10		38.12	36.16	65.84	53.92
20		50.25	47.08	93.29	93.29
50		67.72	62.99	156.18	107.31
100	138.15	84.9	78.11	191.83	138.45

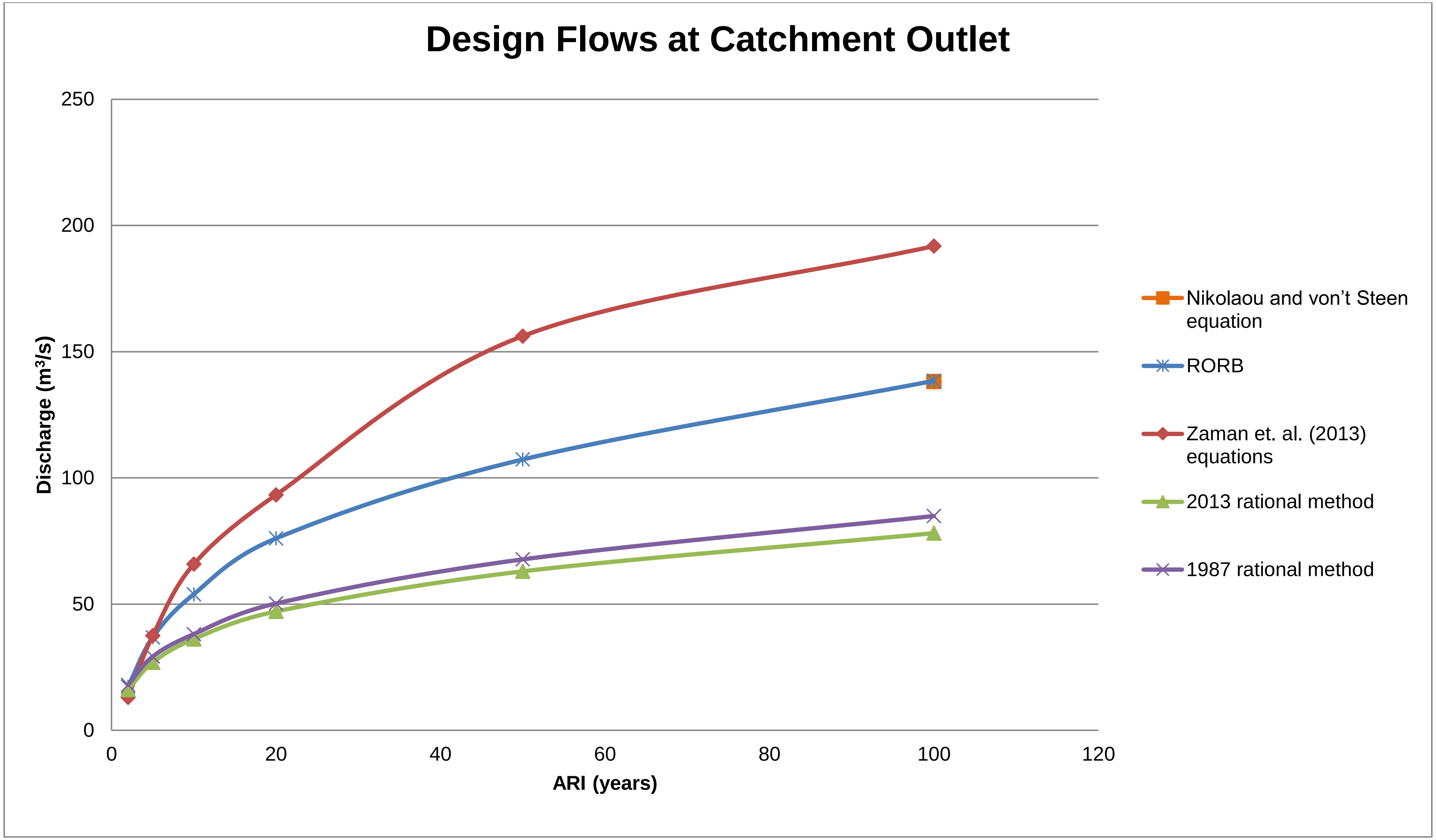

Figure 6 Design flows at catchment outlet

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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 model used 10x10 metre grid cells, a 1D channel for Rintouls Creek with the bridge over Glengarry West Road 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. LiDAR was available for the upper catchment, but the tall, dense vegetation makes it far less accurate than the LiDAR in the lower catchment. Additionally, preliminary hydraulic modelling of the Eaglehawk Creek catchment covering the entire river demonstrated that a Sobek model with grid cells small enough to pick up the small upstream tributaries will either run too slowly or not at all.

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 Rintouls Creek 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

Rintouls Creek has only one bridge in the lower catchment, located on Glengarry West Road. This bridge consists of a flat deck and a trapezoidal bed. It has no piers. Plans provided by Latrobe City Council indicate a flood level of 36.2m RL. The ARI of this flood is unknown.

3.4 Catchment extent hydraulic model

Model extent

The Rintouls Creek 2D model covers the river floodplain only, extending past the catchment boundary to model any flows that escape the catchment. The initial model extent was selected based on the LiDAR surface, assuming that some flows would breakout and not return to the Latrobe River confluence. The initial 2D grid extended over the southern embankment of the Latrobe River, with the outflow boundary placed on the Latrobe River downstream of Rintouls Creek. This initial setup was used to better identify a suitable location above the Latrobe River for the outflow boundary, and the height that it should be set to. The final setup with the boundary along the Latrobe River escarpment provided a stable outflow boundary with an area that could be removed from the final output maps without losing any important data. The area downstream of the Latrobe River escarpment is already covered in the Latrobe River Flood Study (2015).

The final outflow boundaries was placed across Rintouls Creek and at the point where breakout flows reach the bottom edge of the model. This allowed the model to run faster than it would have if the boundary extended across bottom of the model.

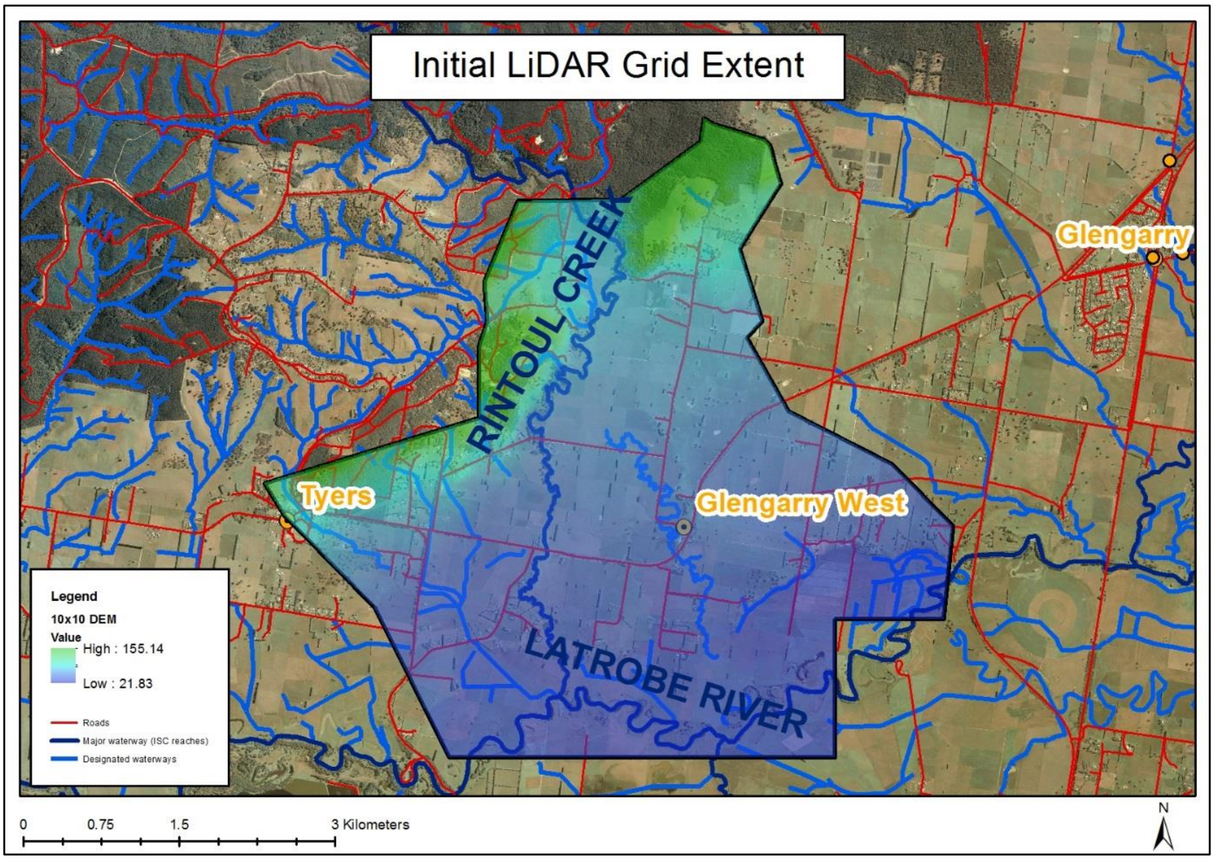

Figure 7 Initial LiDAR extent

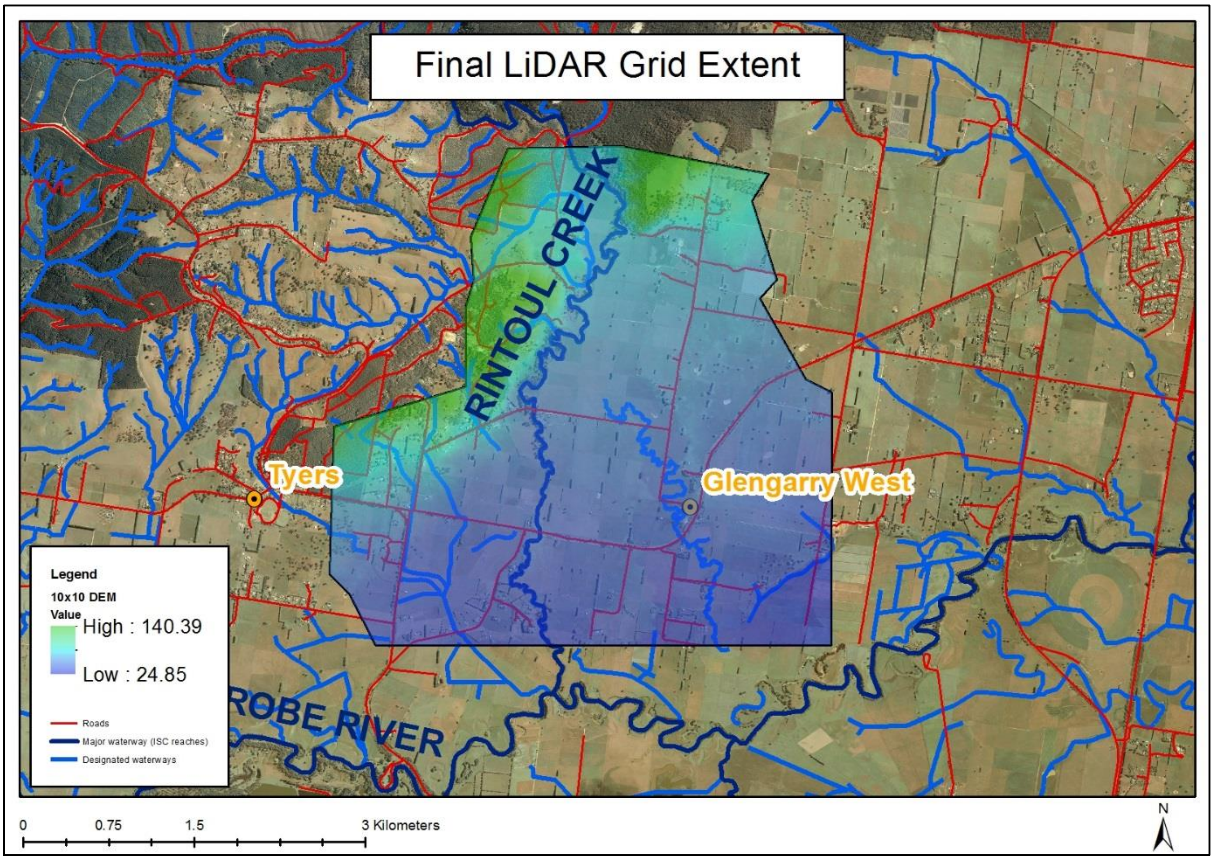

Figure 8 Final LiDAR grid extent

Input data

LiDAR topographic data was taken from two sources: Latrobe Northeast and MID and Latrobe. These LiDAR datasets were clipped to the required extent, merged, resampled from the original one metre grid cells to 10 and 20 metre cells and converted to ASCII files. The 20 metre grid was used as a 2D elevation grid to run early draft models quickly. The 10 metre grid was used for later draft runs and the design runs.

The one metre grid was used to create the cross sections for the 1D model. Cross sections were placed every 500 metres, as well as upstream and downstream of very bridge and culvert, 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 vary 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 because plans for many bridges use RL rather than AHD for levels, 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 inflow J critical duration of 36 hours. Using KL critical duration flows at inflow KL was considered, but the critical duration at this inflow decreased from 30 to two hours as the ARI increased. This would have resulted in a reduction in volume as the ARI increased, despite the increase in peak flow.

Assumptions

The following assumptions were made in the hydraulic model

- Floodplain roughness of 0.04
- Assumed no breakouts in upstream section of catchment
- Boundary water levels same as Latrobe River Flood Study (2015)
- 2D inflow width of 1m per 1m^3/s at peak flow
- Rintouls Creek only channel to be represented in 1D
- Channel roughness of 0.03
- 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.

Rintouls Creek 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 models were run with no blockage at the bridge on Glengarry West Road. This was based on observations made during surveys and other site visits, where the bridge was observed to be clear of any blockages.

Parameters and settings

The following parameters and settings were adopted for the hydraulic model

- Initial water depth of 0.2 metres
- 10 metre grid cells
- Grid runs from floodplain to outflow
- Outflow line boundaries placed along north bank of Latrobe River at points where channel and breakout flows meet the river
- Tributary inflow KL used 2D line boundary 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
- Main inflow modelled as 1D boundary node on 1D channel
- 1D channel outflow modelled as connection node to 2D grid
- Highest level of embankment (Grid cells raised to match cross sections)
- Five day, 23 hour simulation time
- 500 metres between cross sections

All models used a five day, 23 hour simulation time. This was chosen to match the length of the 30 and 36 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 placed along north bank of the Latrobe River at points where channel and breakout flows met the river. The draft run flood extents were used to determine their locations. This reduced the run time over a model with a single line boundary across the entire bottom width. As stated in Assumptions, the water surface elevation was set to flood only the Latrobe River escarpment.

The main model inflow on Rintouls Creek 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 Rintouls Creek before breaking out onto the floodplain.

The 1D channel outflow was modelled as a 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 500 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 20 for descriptions of the roughness and inflow width.

2D feature input

The 2D grid was derived from on two LiDAR DEMS; MID and Latrobe and Latrobe Northeast, and used RORB hydrograph inflows. A 1D2D model including only the floodplain area on the grid shown in Figure 7 with 20x20 metre cells was produced based on topography and the likely flow behaviour. The initial grid started upstream of the floodplain 400 metres south of Rintouls Creek Road and extends down past the Latrobe River, over which a 2D line boundary was placed. The area downstream of the Latrobe River escarpment was then removed from the 2D grid for later draft and design runs. This 2D grid still extended downstream of the Latrobe River escarpment slightly because the outflow boundary conditions affect flood model behaviour as flows approach the boundary and this area had already been modelled as part of the Latrobe River Flood Study (2015).

1D feature input

The main channel flow at the start of the model entered the model on the 1D channel. The 1D channel was 8.5km long and consisted of 16 cross sections placed 500 metres apart and either side of the bridge on Glengarry West Road. These cross sections were produced from a 1x1 metre LiDAR DEM, taking points along each cross section at one metre intervals. The width of the narrowest cross section should be wider than the 2D grid cells, restricting the grid cells to 20m or smaller on the draft grid, as the narrowest cross section was 27.0m wide. Calculation points were placed every 50 metres.

The only hydraulic structure on Rintouls Creek is the bridge Glengarry West Road, shown in Appendix D, Figure 22. The deck of the Glengarry West Road Bridge was represented by raising the grid cells to the road level. A bridge node at this point on the 1D channel represented the channel under the bridge. Flows through the structure were 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. Piers cannot be added, but as this bridge does not contain any piers, was not a problem.

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

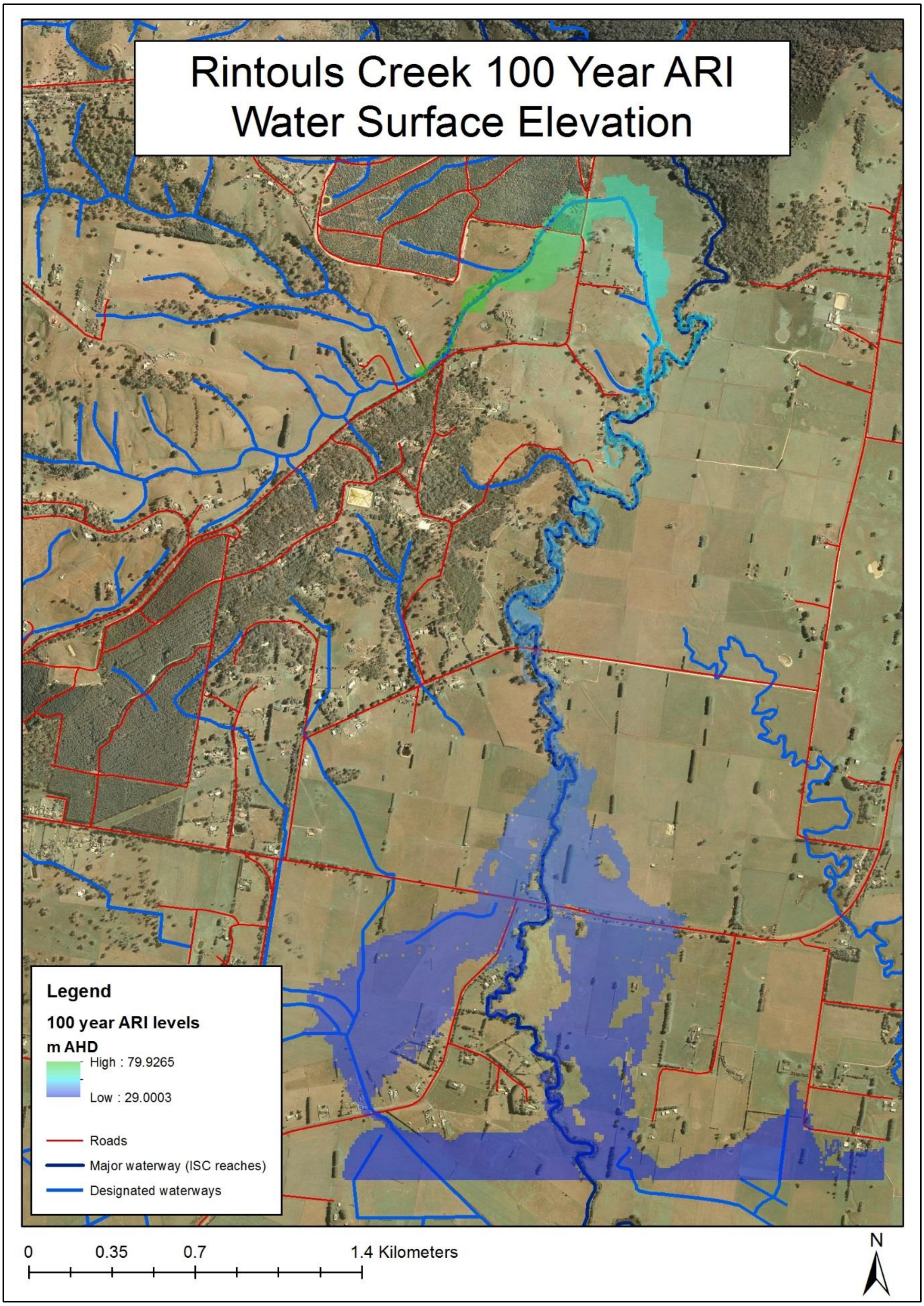

Figure 9 1% AEP maximum water surface elevation

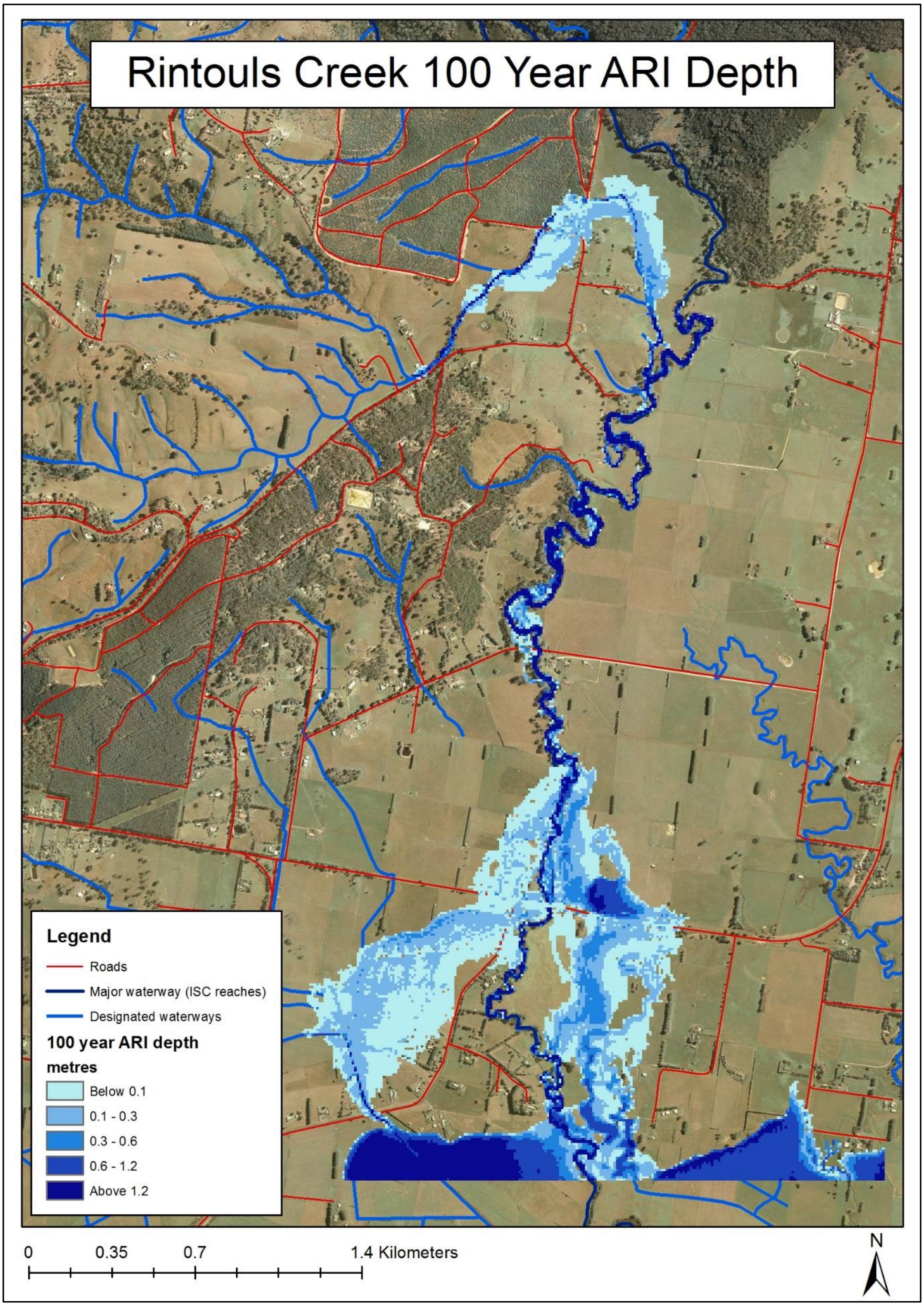

Figure 10 1% AEP maximum depth

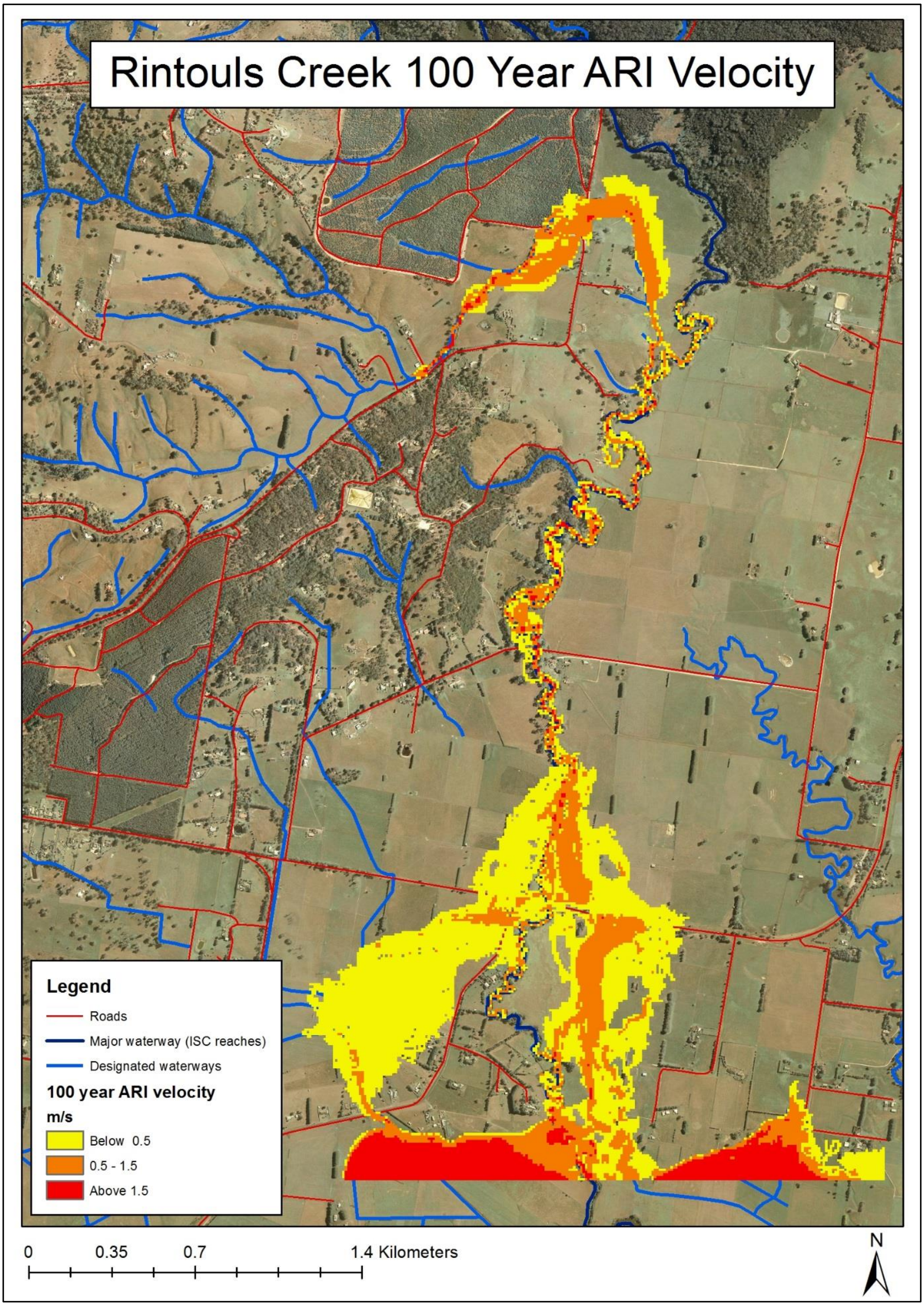

Figure 11 1% AEP maximum velocity

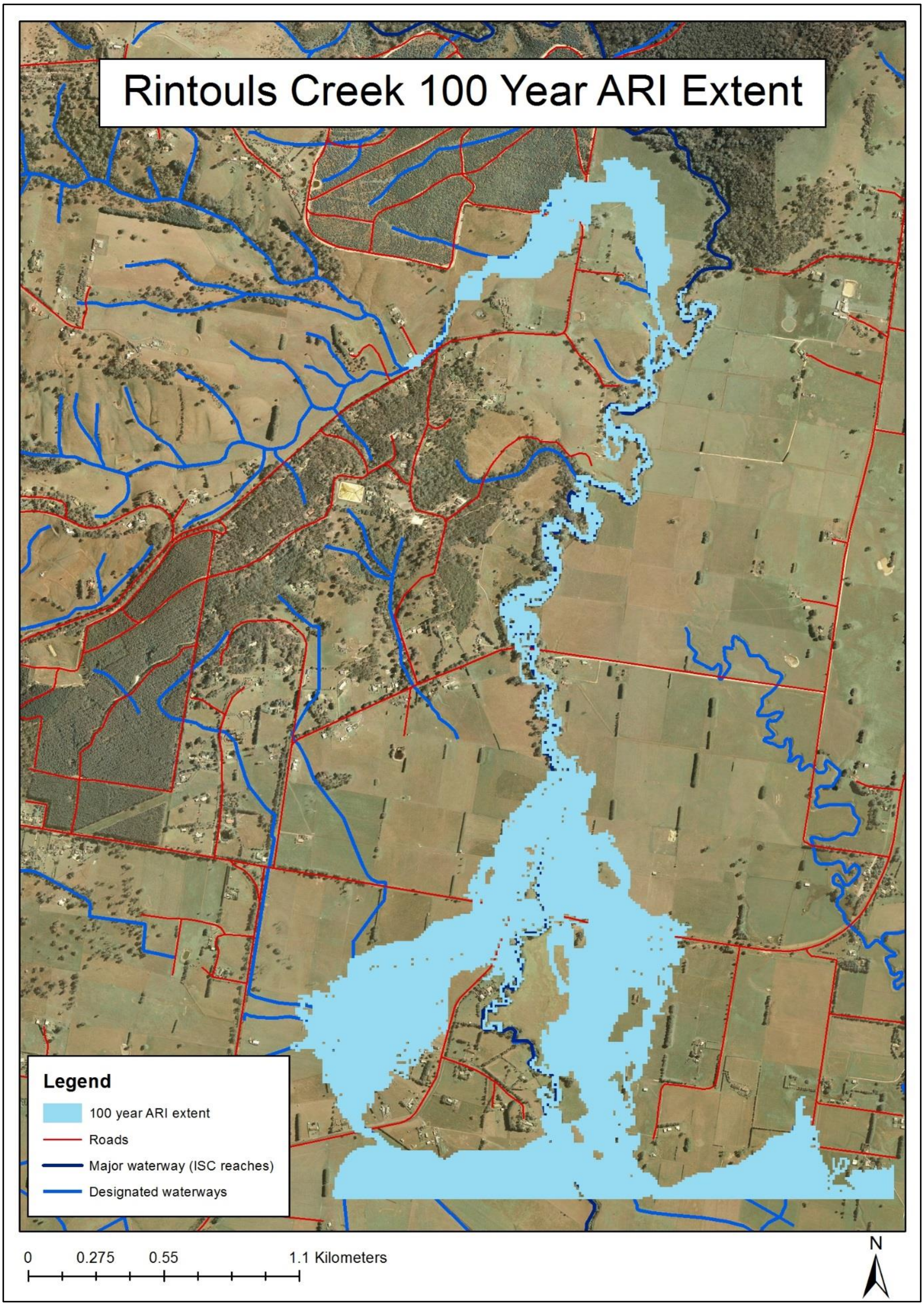

Figure 12 1% AEP flood extent

3.5 Summary of hydraulics results

The extent maps results for the 1% and 2% AEP floods both show that flooding is largely confined for most of the channel's length, only breaking out approximately 650 metres upstream of Glengarry West Road. Flooding is noticeably deeper on the upstream side of Glengarry West Road than downstream, but its function as a break line limiting overland flow is limited, with flows mostly unimpeded. Flood depths are mostly less than one metre, but the channel itself is very deep, with extreme (greater than 1.2m) depths occurring along most of its length. This provides an explanation for why the 5 to 50% AEP runs did not experience any major flooding. The 5% AEP run still produced depths greater than four metres in Rintouls Creek. The breakout along the tributary at inflow KL is similar in depth and extent for all ARIs. The depths only exceed 0.3m in the channel as it approaches Rintouls Creek at up to approximately 1.7 metres deep.

The extent of the 1% AEP flood is a close match for the Latrobe River Flood Study (2015), but shows a smaller extent than what is currently in the VFD, particularly along the channel upstream of Glengarry West Road. The breakout on the west overbank is wider than in both the VFD and the Latrobe River Flood Study (2015) and begins further upstream. The 1% AEP extent upstream of the Latrobe River Flood Study (2015) boundary is narrower than the VFD extent and LSIO, with flows mostly confined to within 20 metres for the channel. It is unclear from the LiDAR how the VFD extent was determined, as the ground is very flat, but the 10 metre grid cells in the Sobek model could have restricted flow here.

Even in the 1 and 2% AEP events, the flood extent did not show flooding observed by a Glengarry West resident on their property in December 2014. This flooding is not shown in the Latrobe River Flood Study (2015) either. This flooding could have been a result of a localised breakout not shown in the LiDAR, or rainfall runoff from the road that the Sobek model cannot simulate.

4 Conclusion and Recommendations

4.1 Conclusion

The flood extent at the end of Rintouls Creek closely matches the VFD and the Latrobe River Flood Study (2015), but as expected with from the smaller system, it has a much shallower depth than the Latrobe River. The results in this area would suggest that the flood extent described in these existing sources is accurate. The shallow flooding along the stream receiving flows from inflow KL had not been previously identified, but it is shallow and only partially covers four properties in a farming zone. It is unlikely to have any significant impact on statutory or emergency planning.

While there are some residential dwellings in the area, the results show that the vast majority of them are not subject to flooding. These were not covered by this flood study because there was no LiDAR available. Even LiDAR data was available and these dwellings were included, flooding from Rintouls Creek would still only occur within farming zones because the VicMap elevation contours show that the rural living zones in this area are elevated well above Rintouls Creek and its closest tributaries. A rain on grid flood study for certain parts of the Tyers locality could have provided flood extent estimates for these dwellings, but the topography of the area would likely prevent any major flooding.

Under the current WGCMA flood depth criteria of 0.3 metres, these results would only prevent one property in the rural living zone in Tyers from being subdivided. New or replacement dwellings could be placed on any of the farming properties.

4.2 Recommendations

The accuracy of this study was limited by the lack of historic flood data available. There were no levels from surveys or flood photography available, and Rintouls Creek is ungauged. Flow data from gauges would have made flood frequency analysis possible, improving the hydrology results and in turn improving the hydraulics results, but setting up flow gauging stations on Rintouls Creek is not recommended because population and flood hazard are too low to justify having them. A more appropriate means of verifying the accuracy of this flood study and improving future studies would be to conduct more surveys during flood events along with the gauged Tyers and Latrobe Rivers. This may have been limited in the past by a lack of flooding as a result of Rintouls Creek's depth that contains flows less than 2% AEP. Even photography that showed no flooding during storms that flooded Eaglehawk Creek or Tyers River would have been useful. Future flood studies would also benefit from improved regional flow estimation methods, which could be developed using data from gauged catchments in the region. The peak RORB flow for the 1% AEP design flood was almost identical to the Nikolaou and von't Steen regional equation, but this equation does not work for other ARIs. The rational method and Zaman (2013) regional method under- and overestimated flows respectively compared with RORB, highlighting the need for more research into choosing an appropriate regional method.

The hydraulic model results in both this flood study and the Latrobe River Flood Study (2015) did not indicate flooding where it has been recently observed. This could be could be explained by a site inspection to locate any areas along the creek overbank that may have been eroded or modified since the LiDAR was produced. If this does not find anything then a rain on grid model for Glengarry West could be completed. A rain on grid model would identify any flow paths generated by rainfall rather than the channel breakouts covered by this model.

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Appendices

Appendix A: Preliminary data collection

Table 11 1987 IFD table at catchment centroid

DURATION	1 Year	2 years	5 years	10 years	20 years	50 years	100 years
5Mins	45.2	61.7	90.3	111	138	179	214
6Mins	42.3	57.7	84.4	104	129	167	200
10Mins	34.4	46.9	68.4	83.9	104	135	161
20Mins	24.8	33.7	49.1	60.2	74.7	96.4	115
30Mins	20	27.2	39.5	48.4	60.1	77.5	92.4
1Hr	13.5	18.3	26.4	32.1	39.7	50.8	60.4
2Hrs	9.03	12.1	17	20.4	24.9	31.4	36.9
3Hrs	7.13	9.49	13	15.4	18.6	23.2	27.1
6Hrs	4.76	6.24	8.23	9.55	11.3	13.8	15.8
12Hrs	3.15	4.09	5.27	6.03	7.07	8.51	9.69
24Hrs	2.02	2.64	3.43	3.94	4.64	5.62	6.42
48Hrs	1.24	1.64	2.21	2.58	3.1	3.82	4.43
72Hrs	0.911	1.21	1.65	1.95	2.34	2.9	3.38

Raw data	2i1	2i12	2i72	50i1	50i12	50i72	Skew	F2	F50
	18.82	4.19	1.24	48.76	7.85	2.69	0.35	4.24	15.15

Table 12 1987 IFD intensities for times of concentration based on Adams formula

		J	KL	Outflow
Time of concentration (hrs)		3.94	1.25	3.96
2 Years	Intensity (mm/hr)	8.05	15.72	7.86
5 Years		10.88	22.45	10.60
10 Years		12.80	27.22	12.45
20 Years		15.34	33.53	14.92
50 Years		18.98	42.82	18.43
100 Years		21.98	50.70	21.33

Table 13 2013 IFD intensities for times of concentration based on Adams formula

		J	KL	Outflow
Time of concentration (hrs)		3.94	1.25	4.11
2 Years	Intensity (mm/hr)	7.48	14.15	7.01
5 Years		10.45	20.24	9.77
10 Years		12.69	24.67	11.81
20 Years		15.04	29.33	13.98
50 Years		18.49	35.97	17.14
100 Years		21.39	41.43	19.77

Appendix B: Hydrologic model input data

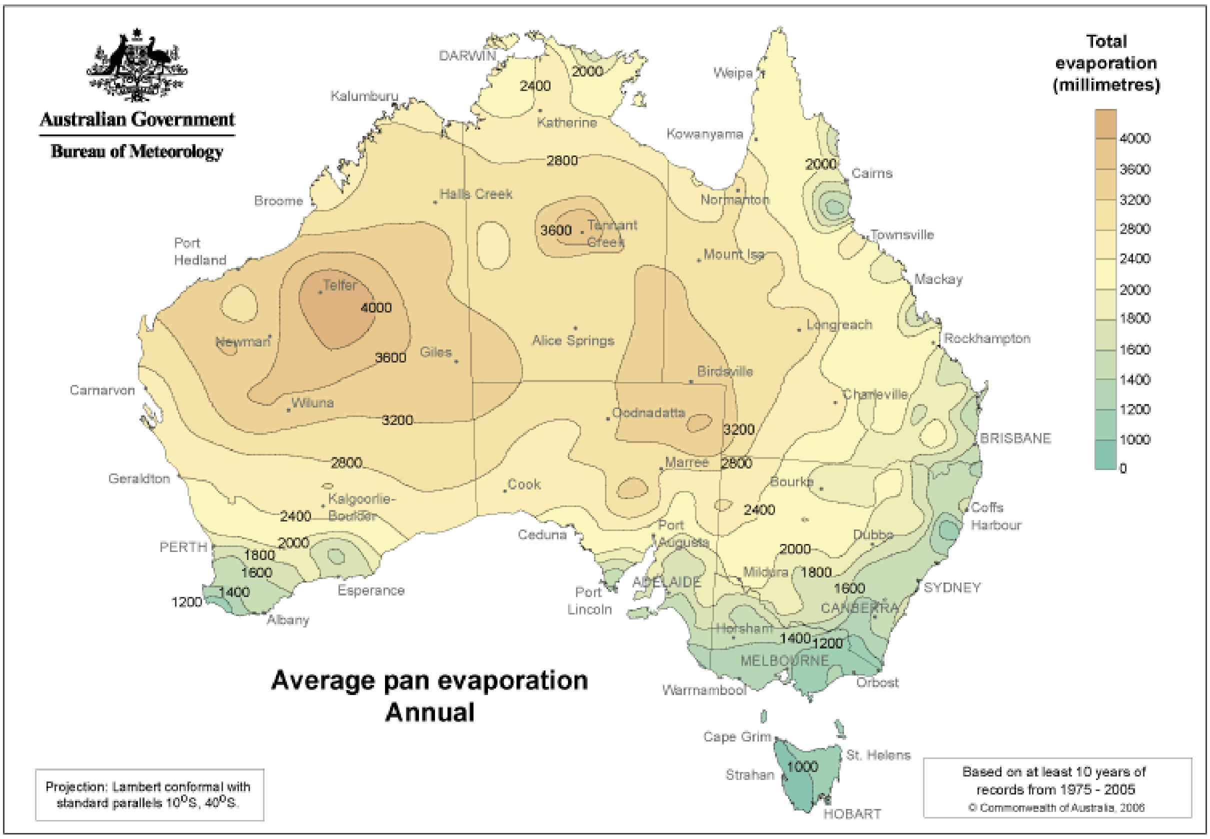

Figure 13 Bureau of Meteorology average annual pan evaporation map

Table 14 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	$2.2A^{0.5}$

Where D_{av} is the average distance of all subcatchment flow distances and A is the catchment area.

Table 15 Kc values

K_c equation					
Yu	VicMAR>800mm	VicMAR<800mm	Dyer	Pearse	Default RORB
19.77	19.33	9.04	23.48	25.75	20.71

Table 16 RORB subcatchment areas

Subcatchment	Area	Subcatchment	Area	Subcatchment	Area
A	15.045	E	2.983	I	4.866
B	8.295	F	7.339	J	10.589
C	10.992	G	10.392	K	1.652
D	7.457	H	1.916	L	1.969
M	1.022				

Appendix C: Output data from hydrologic model

Table 17 RORB peak flows or all durations and ARIs

ARI	Dur	Rain(mm)	ARF	Inflow J	Inflow KL	Outflow
1y	1h	14.01	0.8	0	0	0
	1.5h	16.68	0.81	0	0	0
	2h	18.82	0.82	0	0	0
	3h	22.24	0.84	0	0	0
	4.5h	26.26	0.85	0	0	0
	6h	29.54	0.86	0	0	0
	9h	34.91	0.88	0.0484	0.0228	0.0387
	12h	39.32	0.89	3.2669	1.1178	2.8816
	18h	45.31	0.9	1.2121	0.4066	1.0692
	24h	49.98	0.92	1.8078	0.5751	1.5961
	30h	53.79	0.94	7.1758	1.5203	6.3728
	36h	56.96	0.95	2.7703	0.6203	2.4673
	48h	61.93	0.96	6.8505	1.4878	6.0882
	72h	68.26	0.97	0.0305	0.0083	0.0269
2y	1h	18.26	0.8	0	0	0
	1.5h	21.6	0.81	0	0	0
	2h	24.25	0.82	0	0	0
	3h	28.48	0.84	0	0	0
	4.5h	33.4	0.85	0.1104	0.0579	0.0603
	6h	37.4	0.86	0.6866	0.2399	0.6059
	9h	43.91	0.88	5.4652	1.7355	4.8201
	12h	49.22	0.89	8.3264	2.2869	7.3507
	18h	56.95	0.9	8.3449	1.6898	7.3949
	24h	63	0.92	8.7846	1.8459	7.8061
	30h	67.95	0.93	14.7159	2.7154	13.0225
	36h	72.09	0.94	19.3277	2.9822	17.2913
	48h	78.62	0.96	17.7947	2.8673	15.954
	72h	87.04	0.97	2.9998	0.4407	2.6531
5y	1h	26.85	0.8	0	0	0
	1.5h	31.07	0.81	0.0094	0.0145	0.0124
	2h	34.34	0.82	0.5249	0.3801	0.3625

	3h	39.41	0.84	3.2944	1.2403	2.8887
	4.5h	45.18	0.85	6.7625	1.8408	5.9659
	6h	49.79	0.86	8.0968	1.8482	7.1505
	9h	57.14	0.88	18.7999	5.1639	16.5923
	12h	63.02	0.89	24.447	4.7051	21.6701
	18h	73.89	0.9	19.0502	3.2053	16.8655
	24h	82.53	0.92	26.3766	5.1478	23.7396
	30h	89.69	0.93	30.7474	4.718	27.6046
	36h	95.76	0.94	41.0425	5.4602	36.8236
	48h	105.51	0.95	39.4668	5.1037	35.2994
	72h	118.65	0.97	14.2982	1.4305	13.8799
10y	1h	33.09	0.8	0.3692	0.2807	0.2468
	1.5h	37.83	0.81	2.7554	1.4361	1.4374
	2h	41.43	0.82	5.2841	2.2341	2.6243
	3h	46.95	0.84	10.075	3.1304	8.8834
	4.5h	53.13	0.85	13.3477	3.2429	11.779
	6h	58.02	0.86	18.34	3.6658	16.2131
	9h	65.74	0.88	28.4558	7.3224	25.1079
	12h	71.86	0.89	36.8396	6.1245	32.6845
	18h	84.89	0.9	33.6923	4.5095	30.0215
	24h	95.32	0.92	42.2509	7.3351	38.2512
	30h	104.03	0.93	48.7048	6.0672	43.6697
	36h	111.47	0.94	59.925	7.111	53.9218
	48h	123.53	0.95	58.0255	6.6626	52.857
	72h	140.14	0.97	28.5137	2.554	28.298
20y	1h	41.33	0.8	6.4237	3.1242	3.2895
	1.5h	46.75	0.81	11.1082	4.4095	5.7971
	2h	50.81	0.82	14.7232	5.1018	7.7018
	3h	56.95	0.84	21.8993	5.9862	19.3224
	4.5h	63.74	0.85	27.9596	5.8663	24.7102
	6h	69.06	0.86	31.4648	5.7828	27.8503
	9h	77.39	0.88	44.4523	10.298	39.245
	12h	83.94	0.89	53.4791	8.406	47.5264
	18h	99.79	0.9	55.5193	6.3725	49.7885
	24h	112.58	0.92	60.9349	9.6669	56.2378
	30h	123.32	0.93	74.8173	7.8569	68.7145
	36h	132.54	0.94	82.0669	9.1558	76.0491
	48h	147.62	0.95	80.7656	8.6939	76.393
	72h	168.73	0.96	50.5591	4.257	50.868
50y	1h	53.65	0.8	20.7082	8.5142	11.6953
	1.5h	59.93	0.81	28.5978	9.5794	16.3876
	2h	64.54	0.82	34.3507	10.2802	19.5377
	3h	71.41	0.84	42.4054	10.0158	37.4215
	4.5h	78.9	0.85	50.6453	9.2903	44.8152

	6h	84.7	0.86	56.0089	9.2269	49.6237
	9h	93.7	0.88	65.1484	13.1322	57.6625
	12h	100.7	0.89	78.4989	11.567	69.9412
	18h	120.64	0.9	82.8859	8.3308	75.4216
	24h	136.84	0.91	89.0847	12.1612	84.9108
	30h	150.54	0.93	103.98	9.5808	98.6708
	36h	162.37	0.94	114.185	11.1191	107.306
	48h	181.9	0.95	111.159	10.6458	107.824
	72h	209.77	0.96	71.2797	5.575	73.1001
100y	1h	64.25	0.8	36.1897	13.6198	21.8937
	1.5h	71.15	0.81	46.3542	14.294	28.2727
	2h	76.15	0.82	52.9972	14.7851	31.8826
	3h	83.5	0.84	62.6325	13.5325	55.3025
	4.5h	91.43	0.85	72.3571	12.4263	64.0911
	6h	97.54	0.86	78.4255	12.7751	69.6427
	9h	106.94	0.88	87.8749	16.0337	77.9898
	12h	114.21	0.89	98.3418	13.9173	87.8535
	18h	137.53	0.9	107	10.0653	98.458
	24h	156.6	0.91	114.575	14.6333	111.008
	30h	172.79	0.93	132.3	11.4929	125.349
	36h	186.83	0.93	146.946	13.3354	138.45
	48h	210.15	0.95	141.421	12.9169	137.968
	72h	243.84	0.96	92.604	6.9986	95.6781

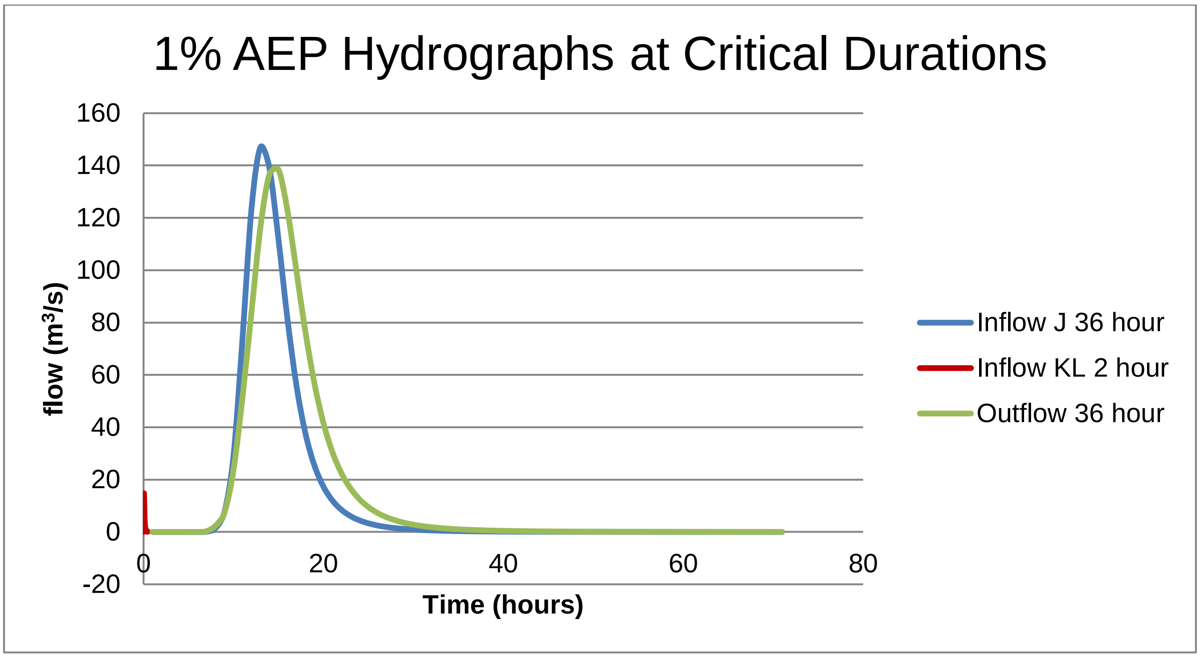

Figure 14 1% AEP hydrographs at critical durations

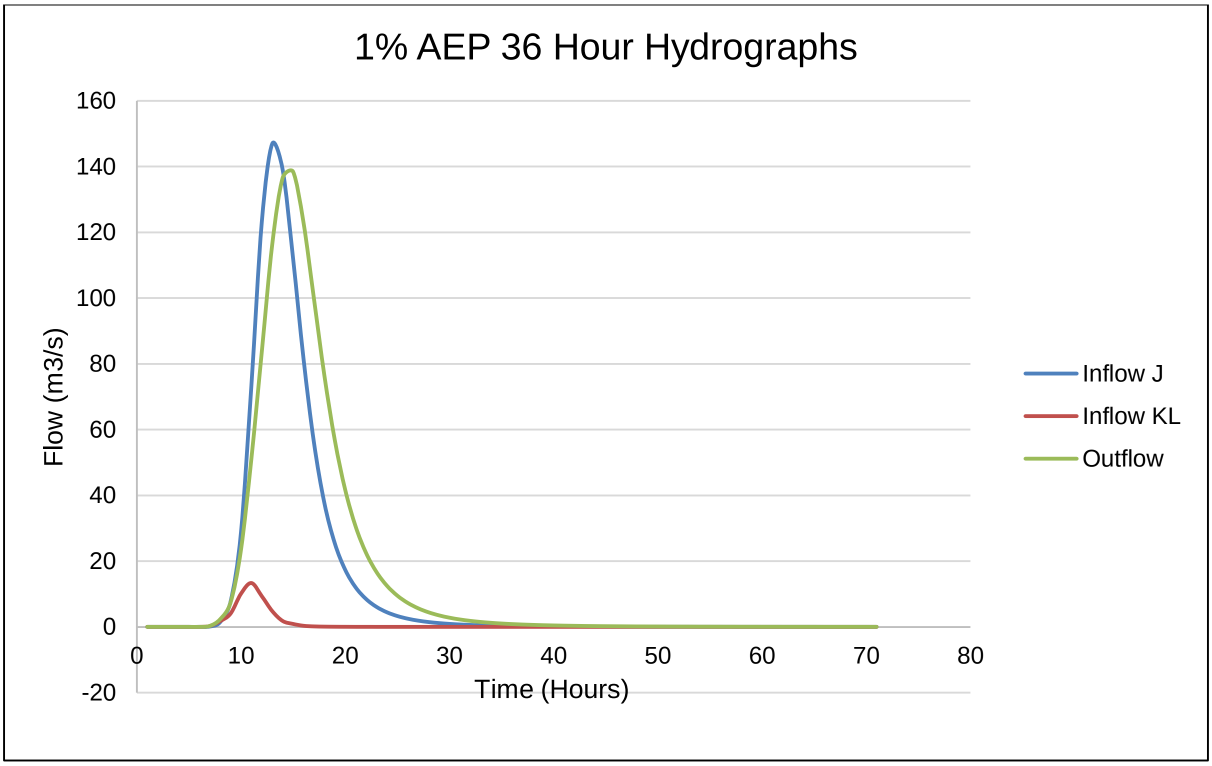

Figure 15 1% AEP 36 hour hydrographs

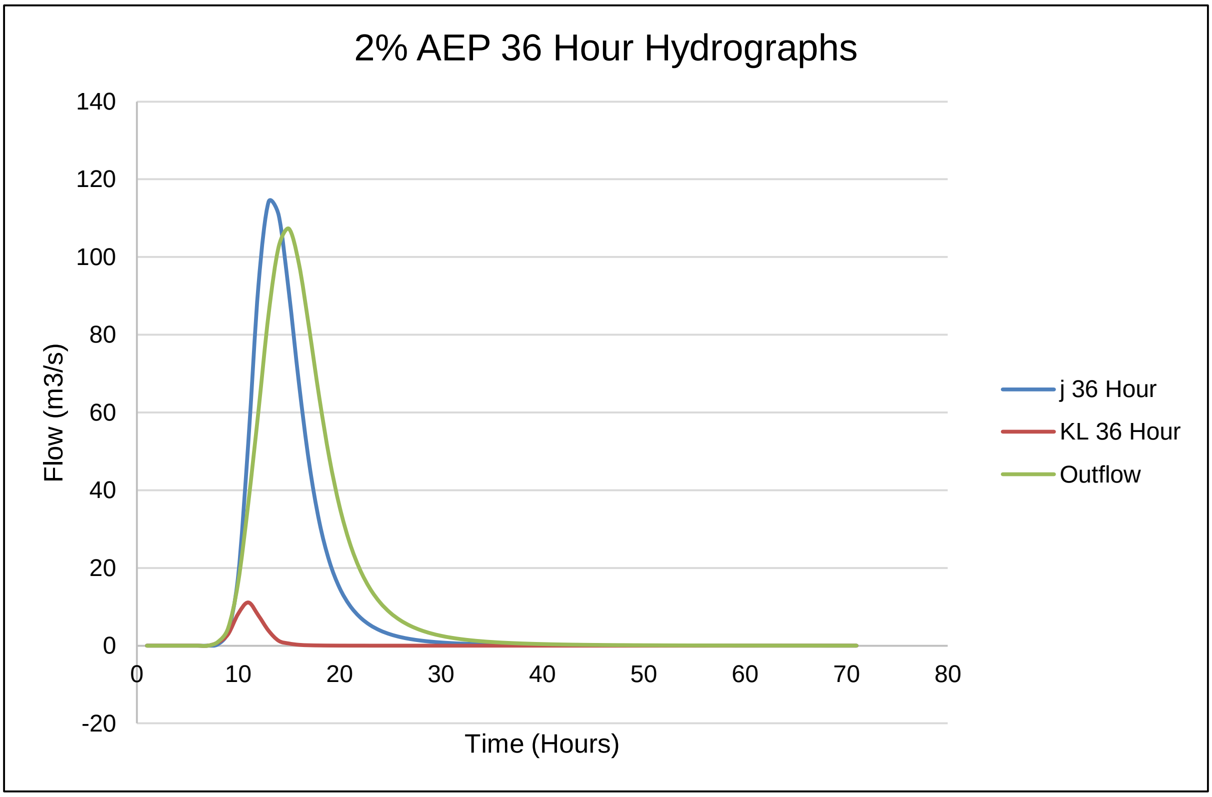

Figure 16 2% AEP 36 hour hydrographs

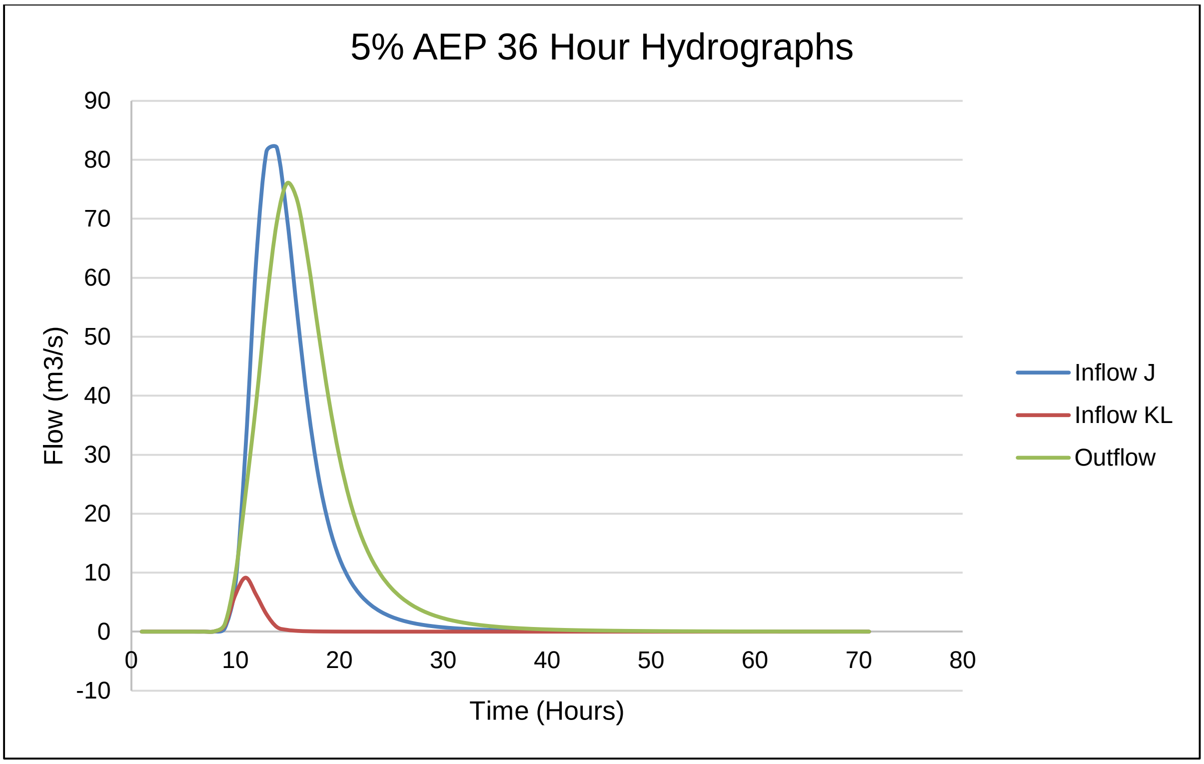

Figure 17 5% AEP 36 hour hydrographs

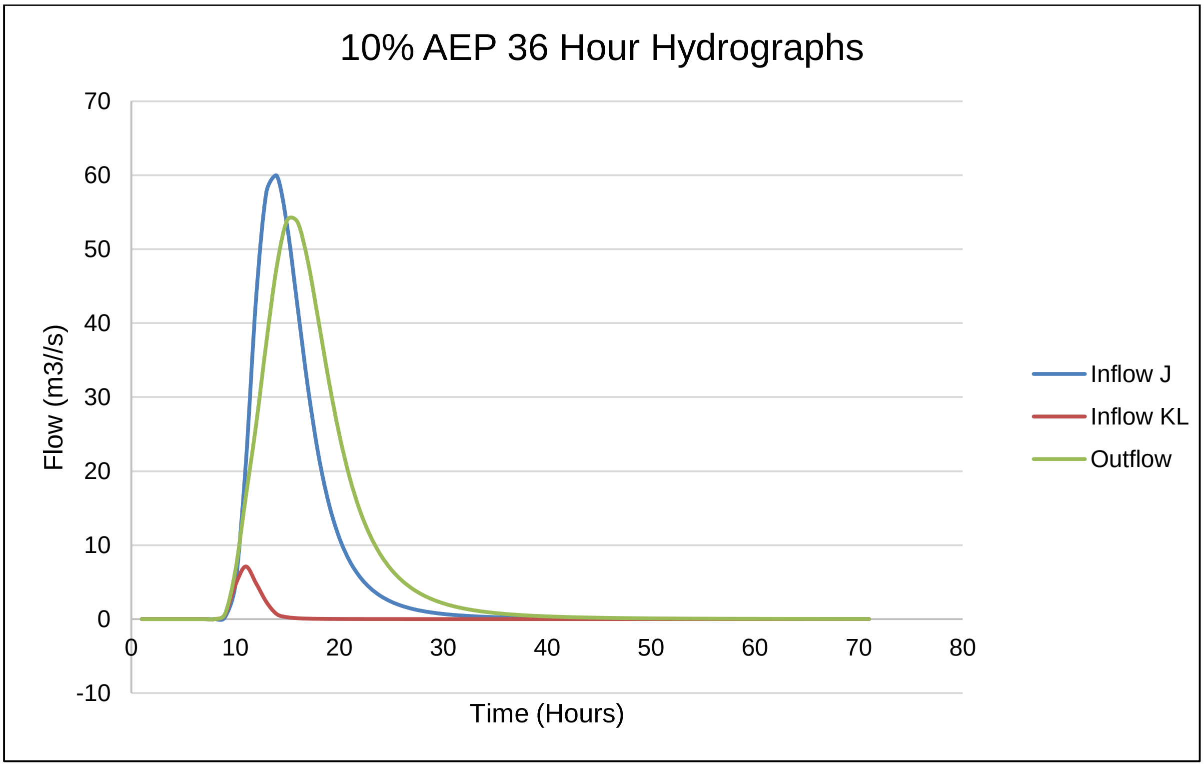

Figure 18 10 year 36 hour hydrographs

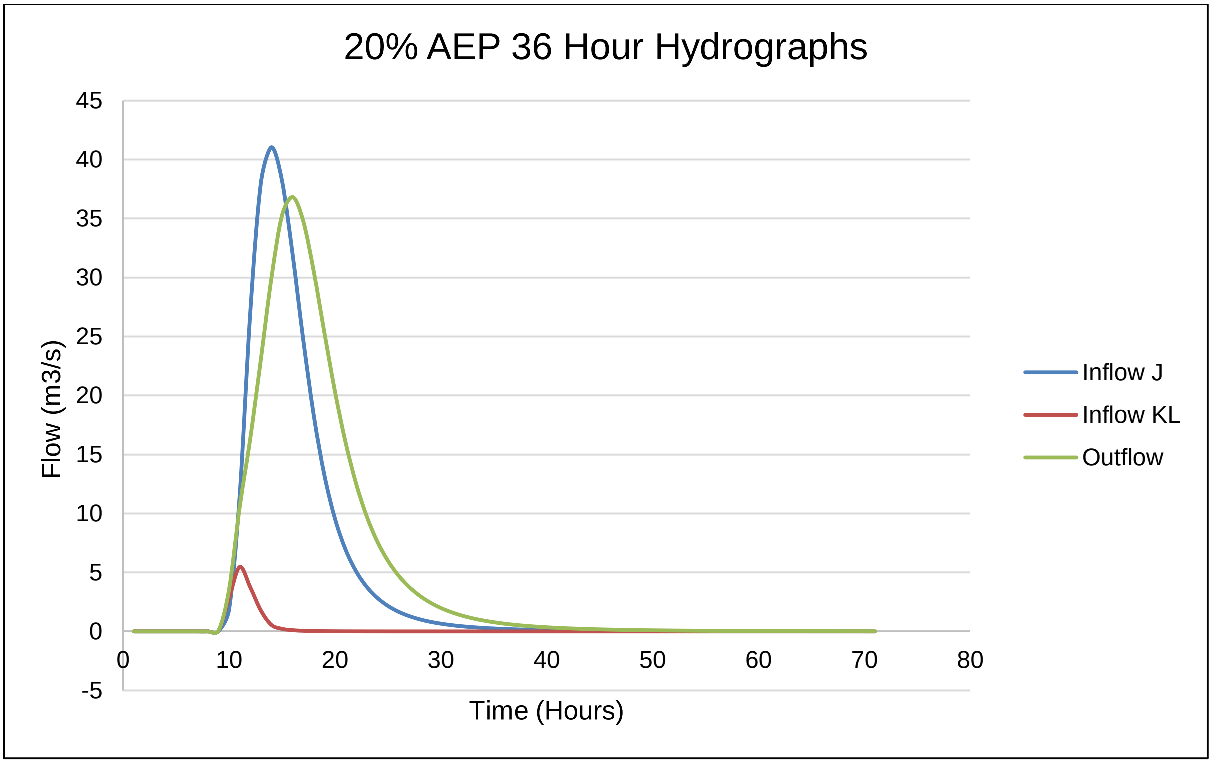

Figure 19 5 year 36 hour ARI hydrographs

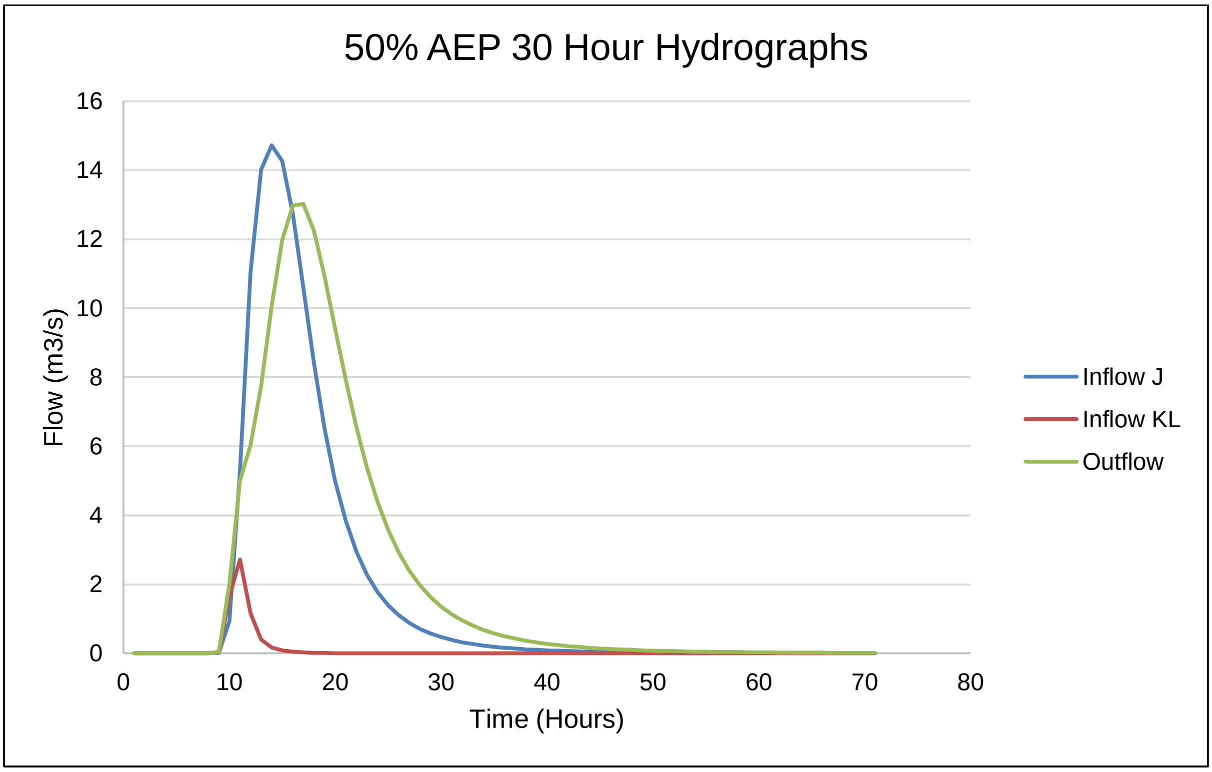

Figure 20 2 year 30 hour ARI hydrographs

Appendix D: Hydraulic model input data

Table 18 Hydraulic model input data

Model area	14.873km^2
Cell size	10x10m
No. of cells	X: 327
	Y: 456
	Total:149,112
2D grid roughness	0.04
1D channel roughness	0.03
Bridge roughness	0.03
Channel length	8.5km
No. of cross sections	15
Simulation time	5 days, 23 hours
Run time	100 year: 4 hours, 38 minutes
	50 year: 4 hours, 38 minutes
	20 year: 4 hours, 23 minutes
	10 year: 4 hours, 18 minutes
	5 year: 4 hours
	2 year: 3 hours, 52 minutes

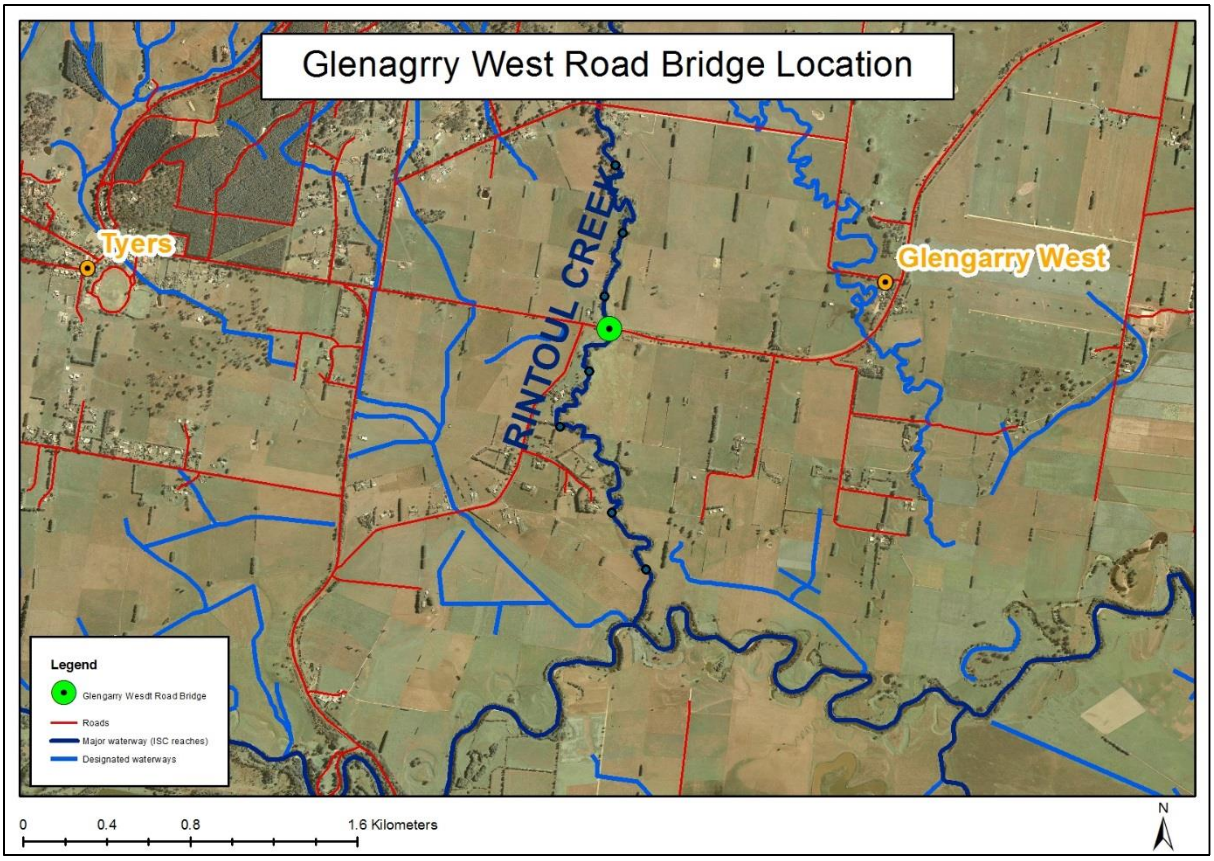

Figure 21 Glengarry West Road bridge location

Figure 22 Bridge **over** Glengarry West Road

Appendix E: Output data from hydraulic model

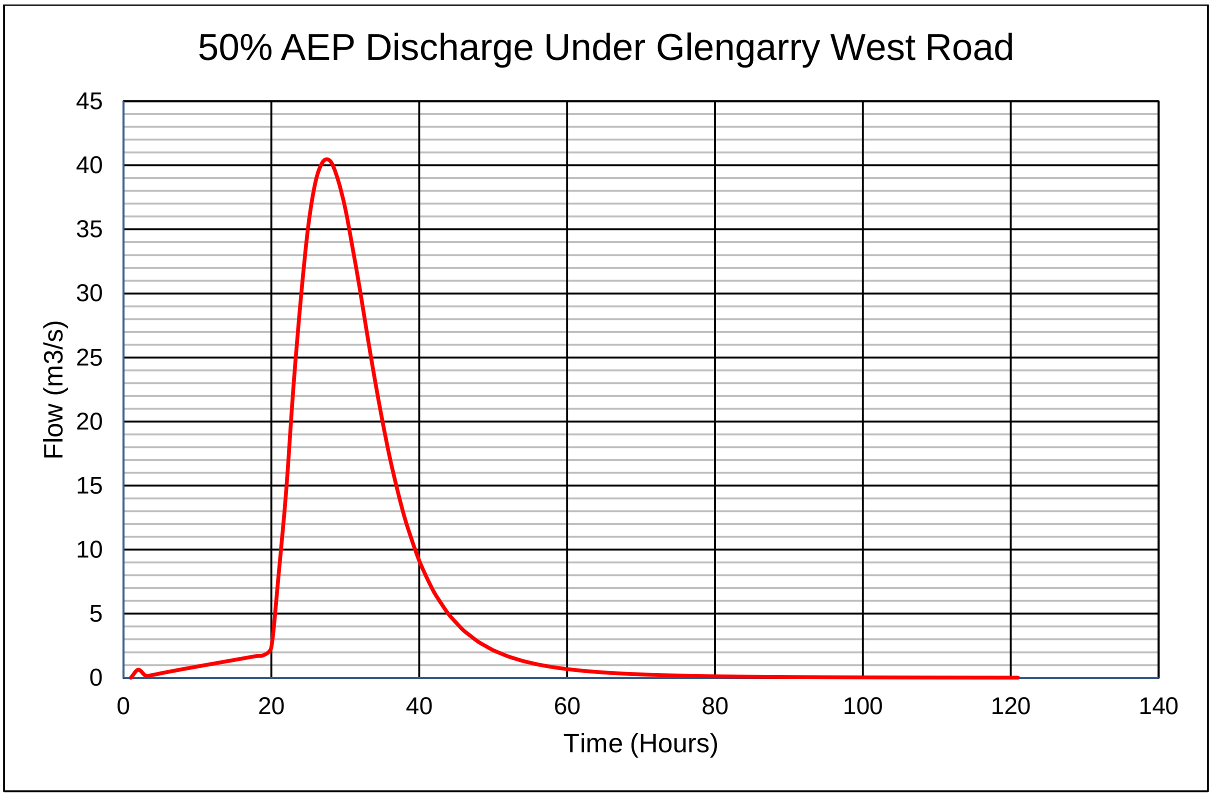

Figure 23 50% AEP discharge under Glengarry West Road

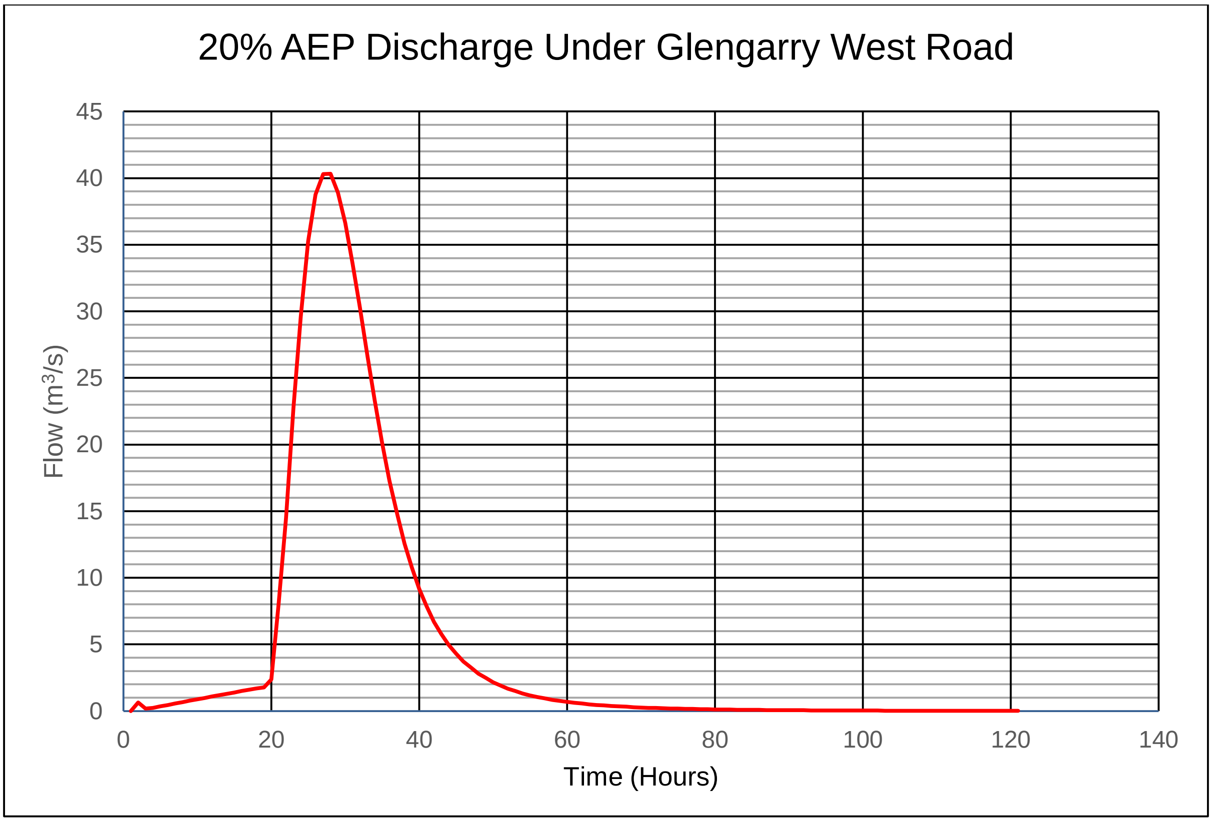

Figure 24 20% AEP discharge under Glengarry West Road

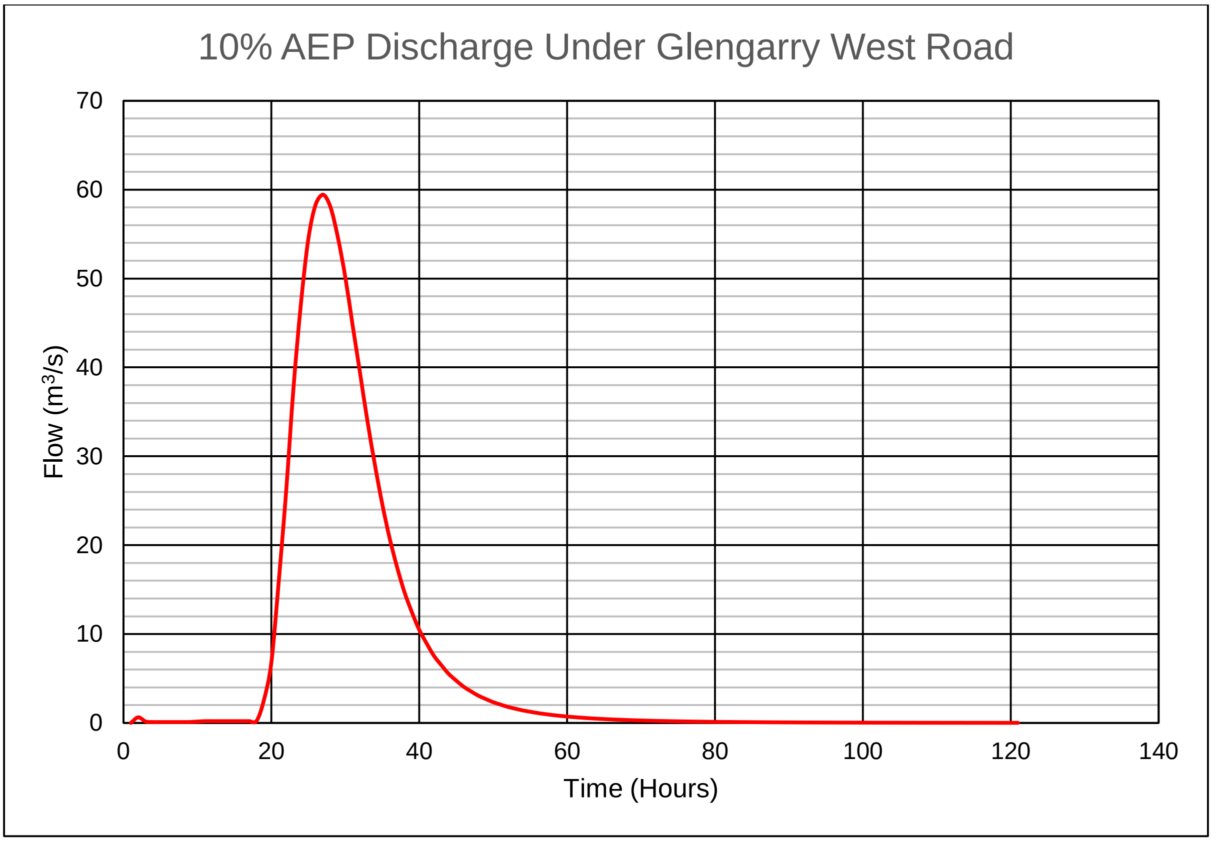

Figure 25 10% AEP discharge under Glengarry West Road

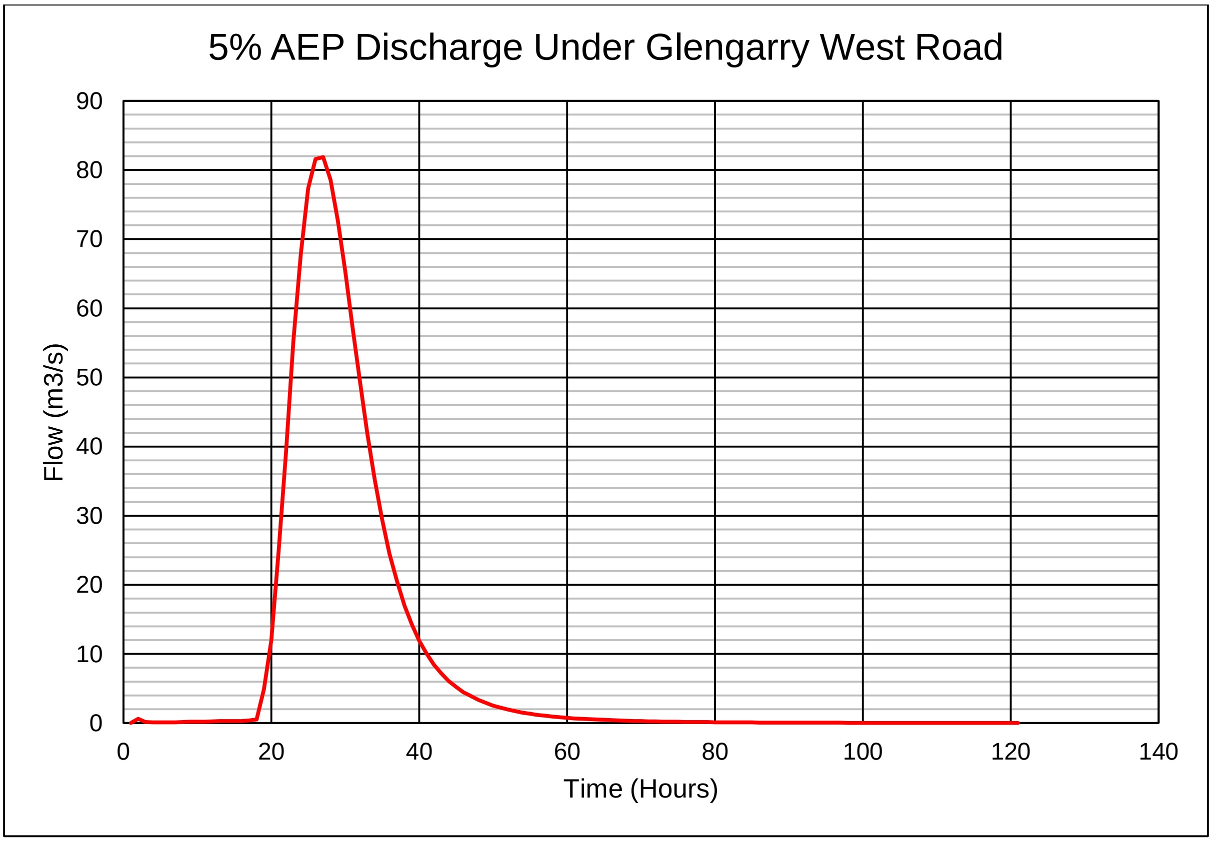

Figure 26 5% AEP discharge under Glengarry West Road

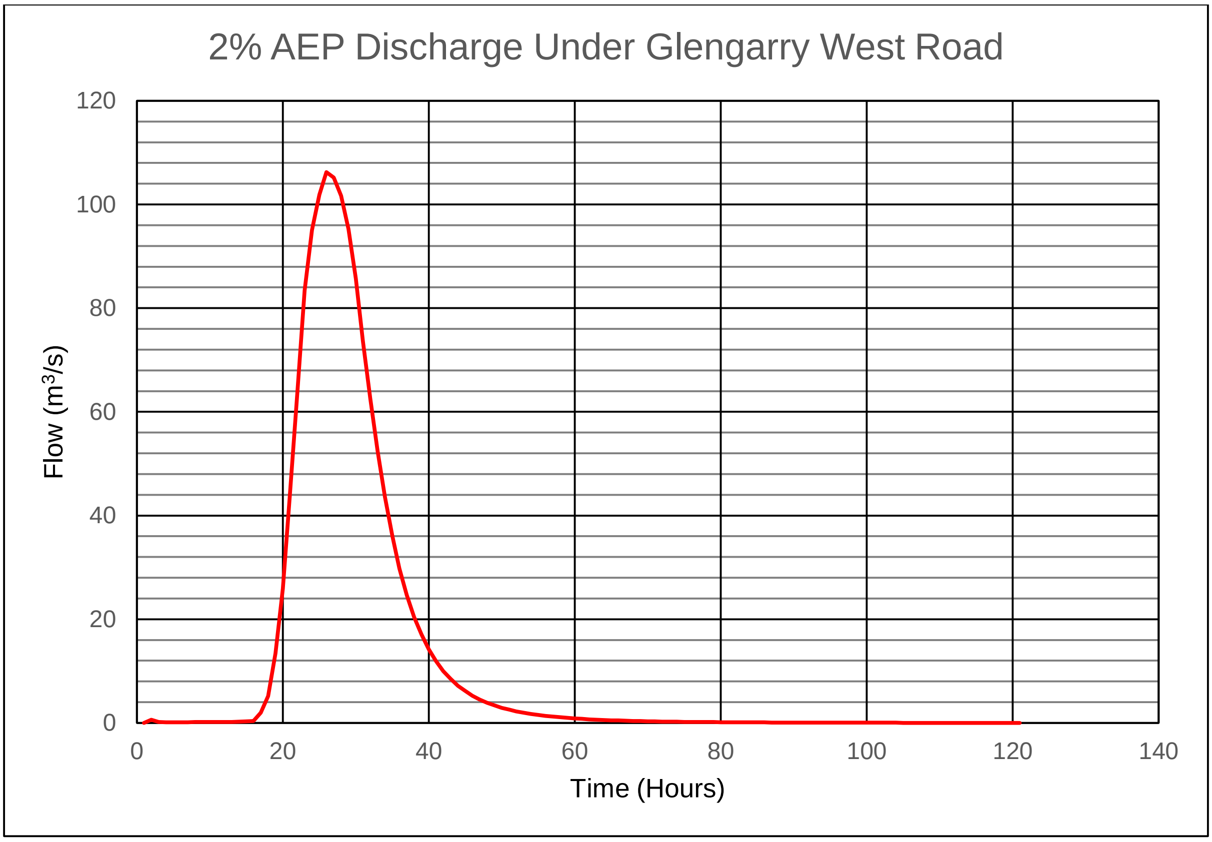

Figure 27 2% AEP discharge under Glengarry West Road

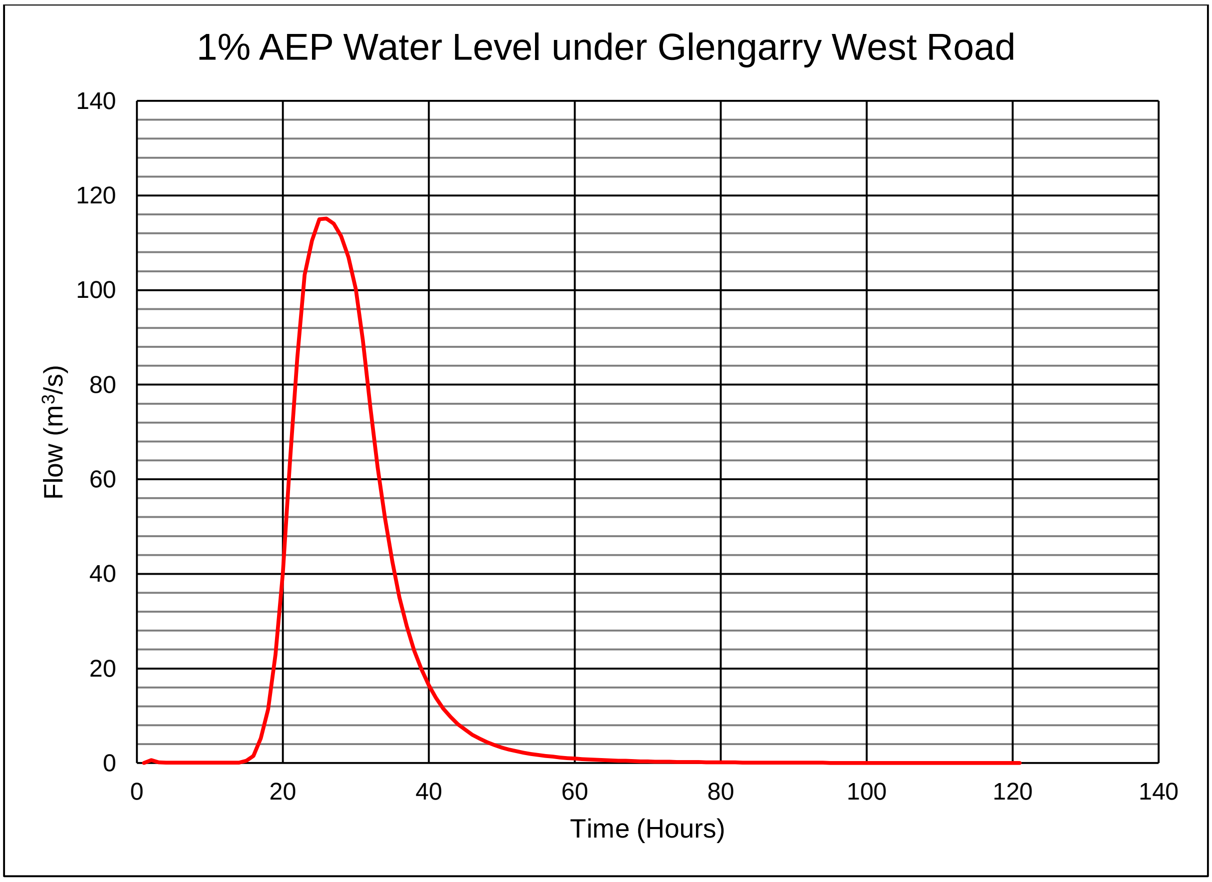

Figure 28 1% AEP discharge under Glengarry West Road

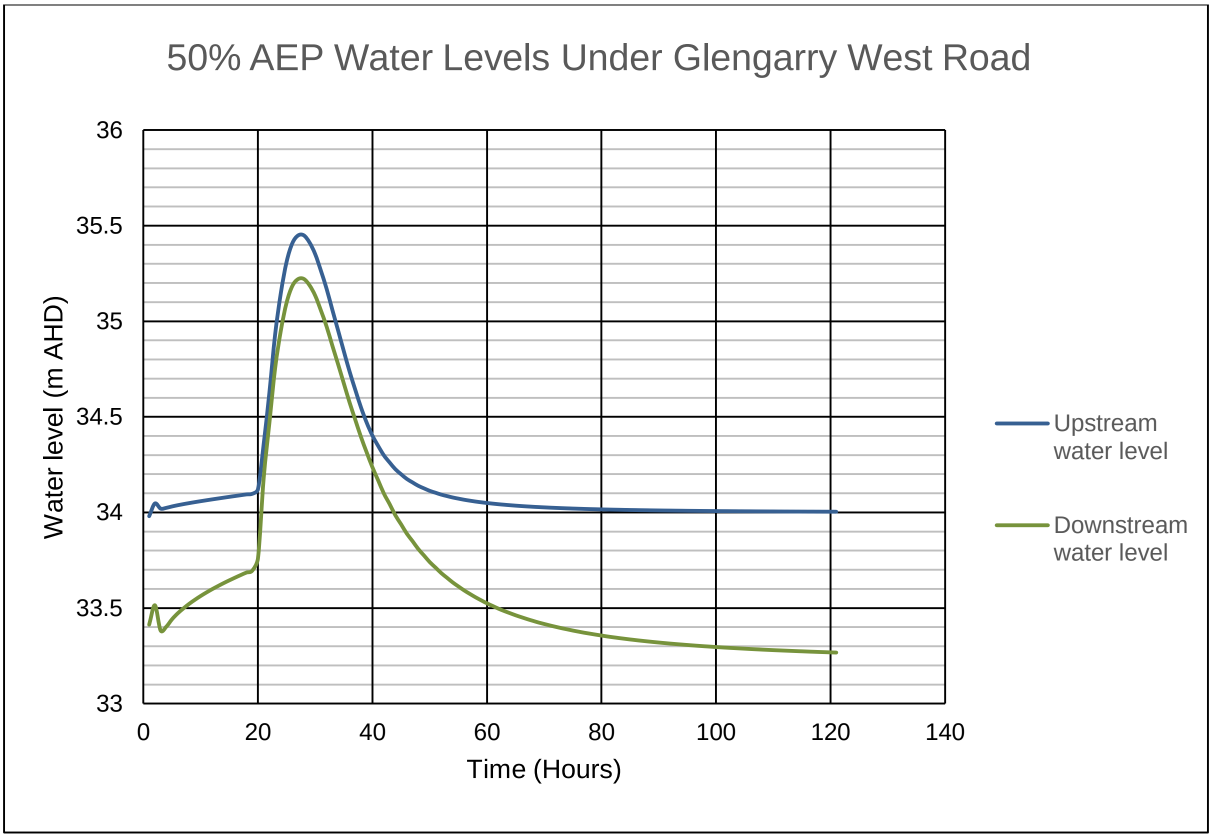

Figure 29 50% AEP water levels under Glengarry West Road

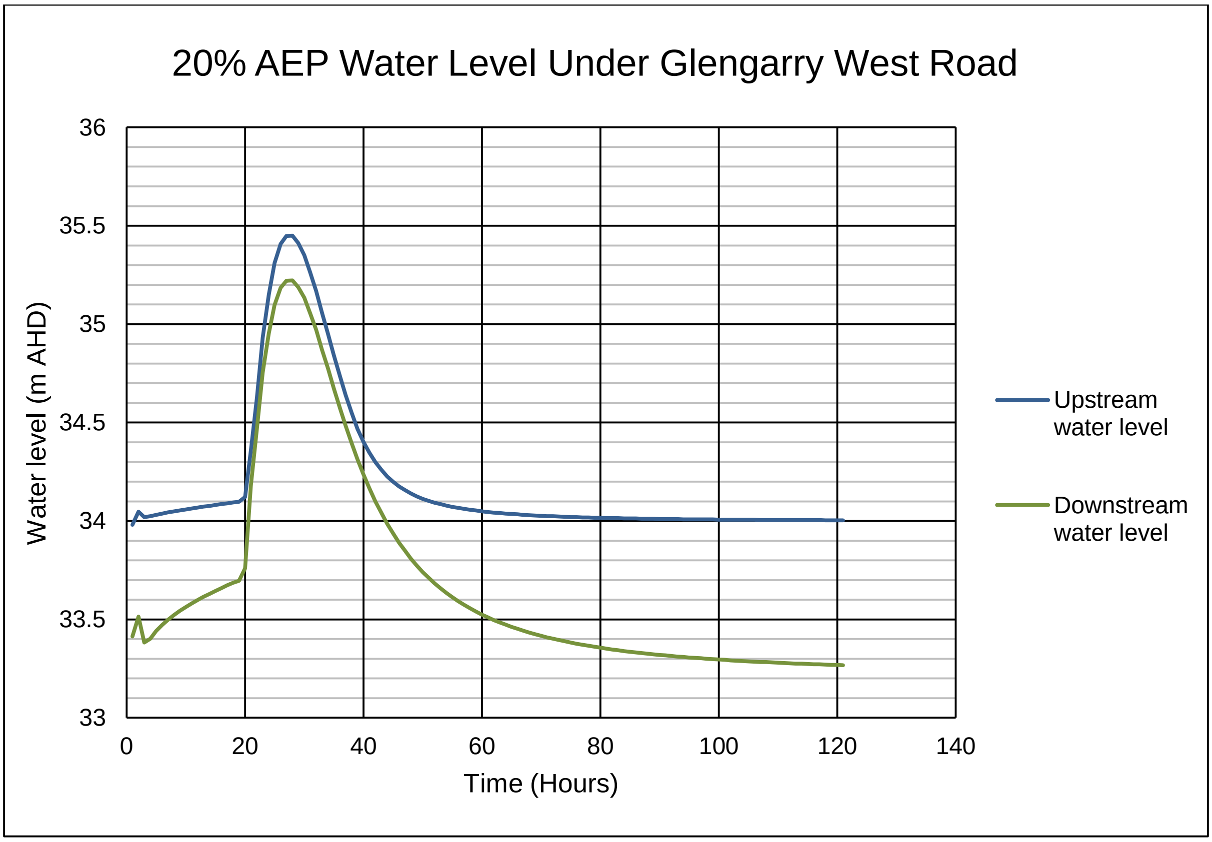

Figure 30 20% AEP water levels under Glengarry West Road

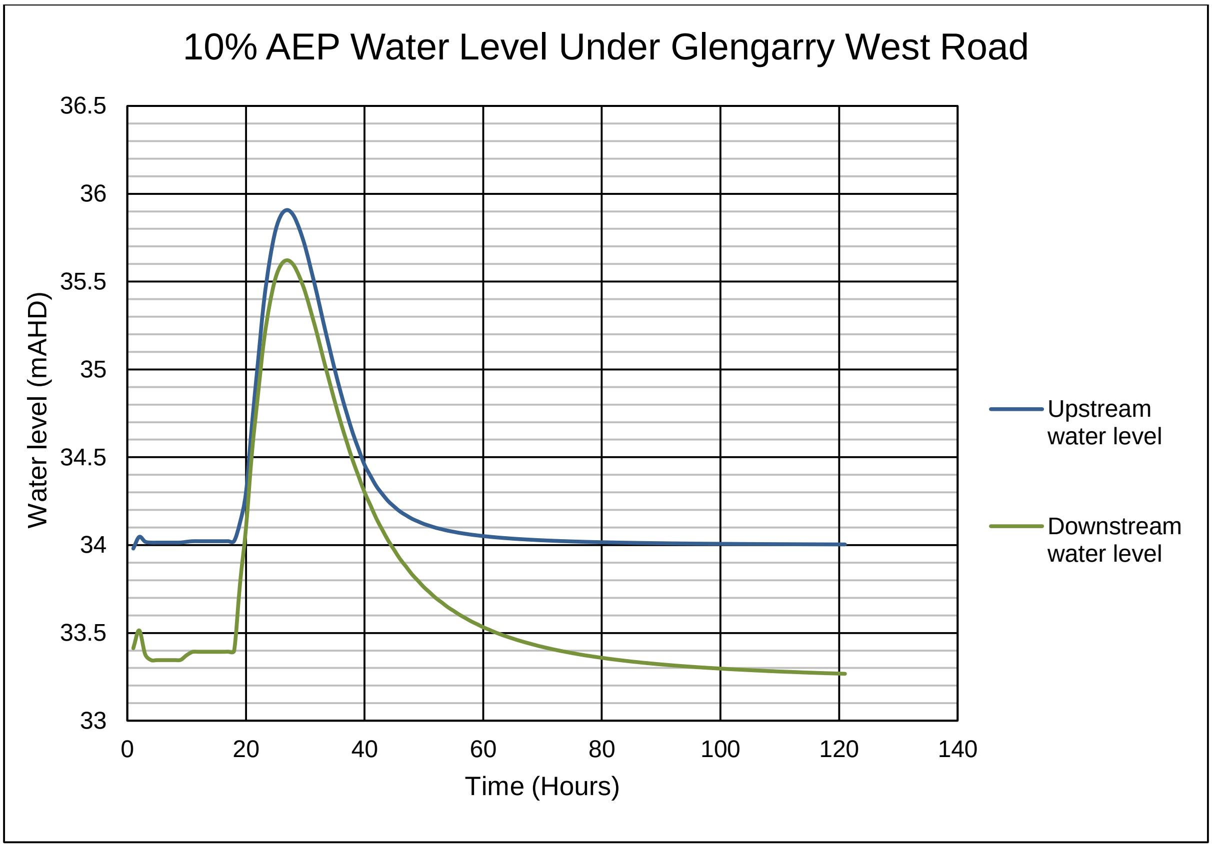

Figure 31 10% AEP water levels under Glengarry West Road

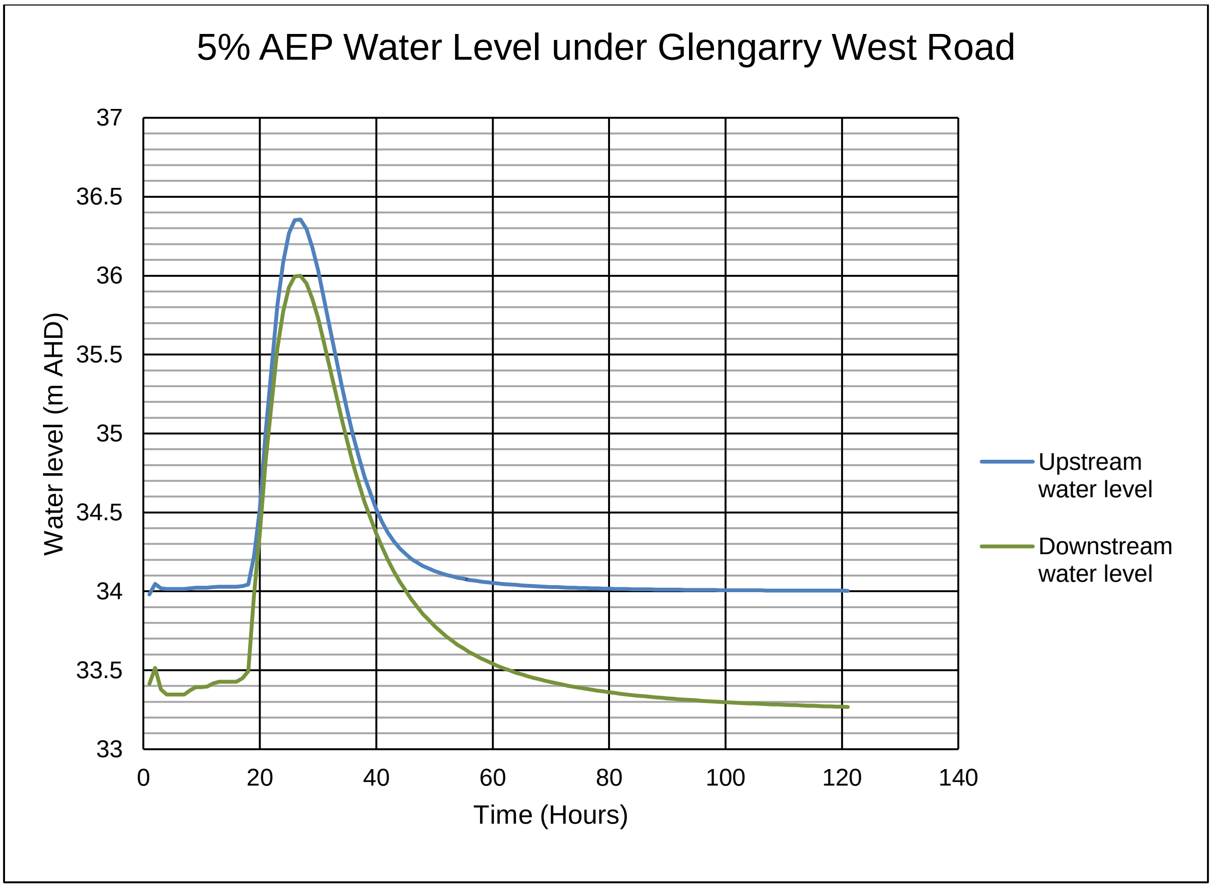

Figure 32 5% AEP water levels under Glengarry West Road

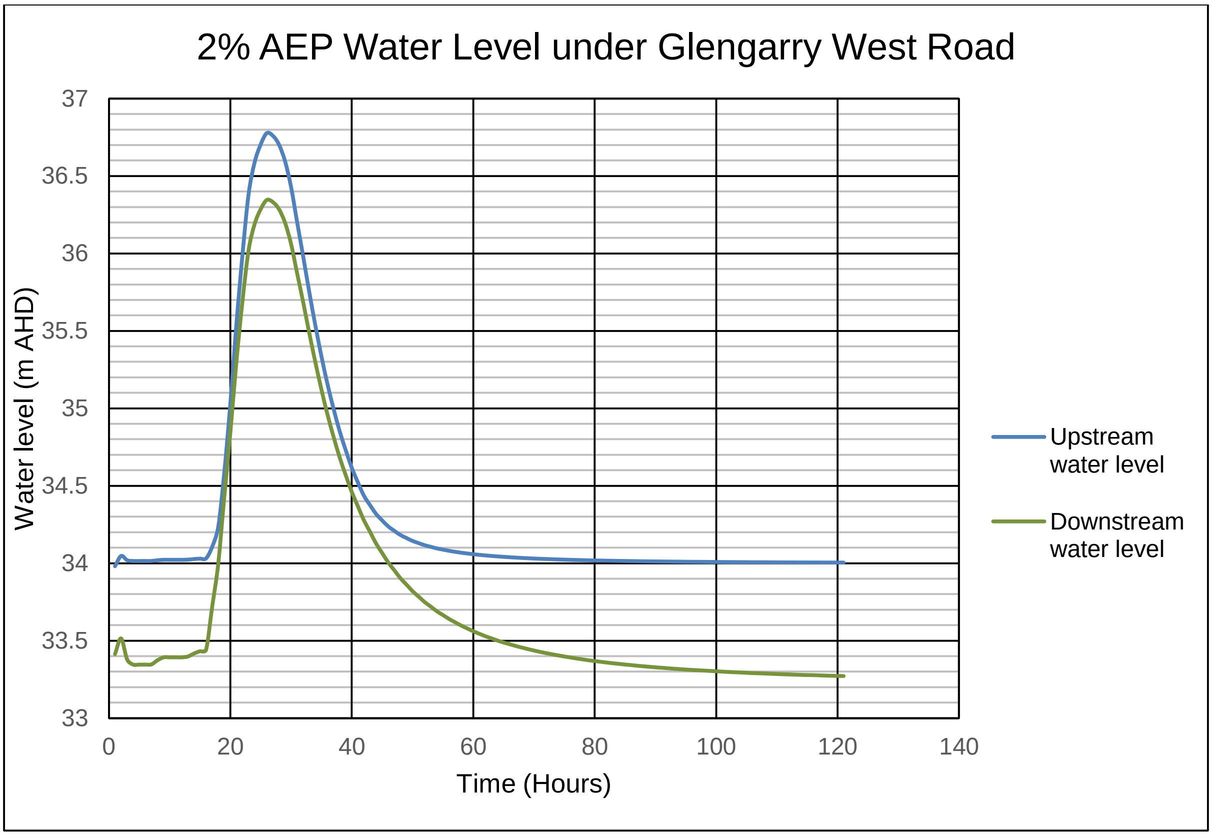

Figure 33 2% AEP water levels under Glengarry West Road

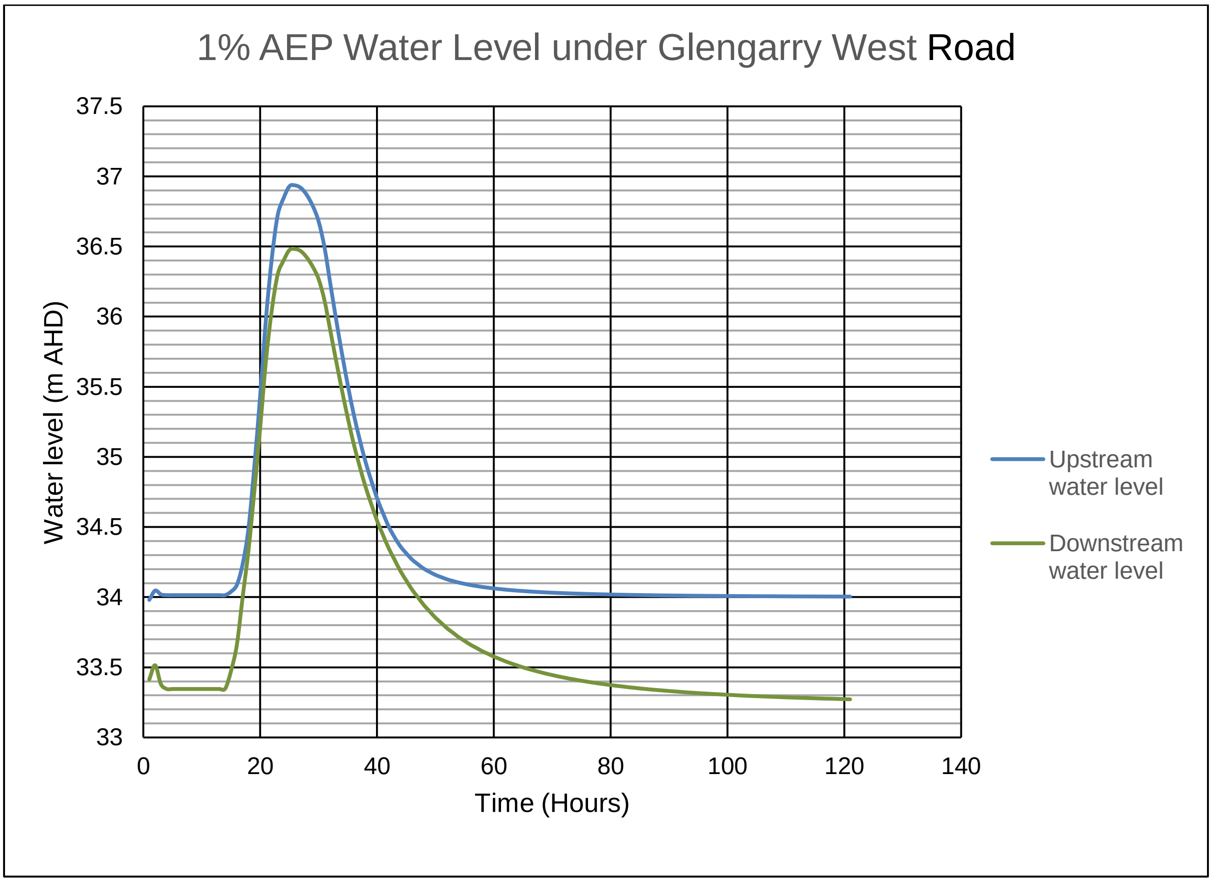

Figure 34 1% AEP water levels under Glengarry West Road

Appendix F: Flood level maps

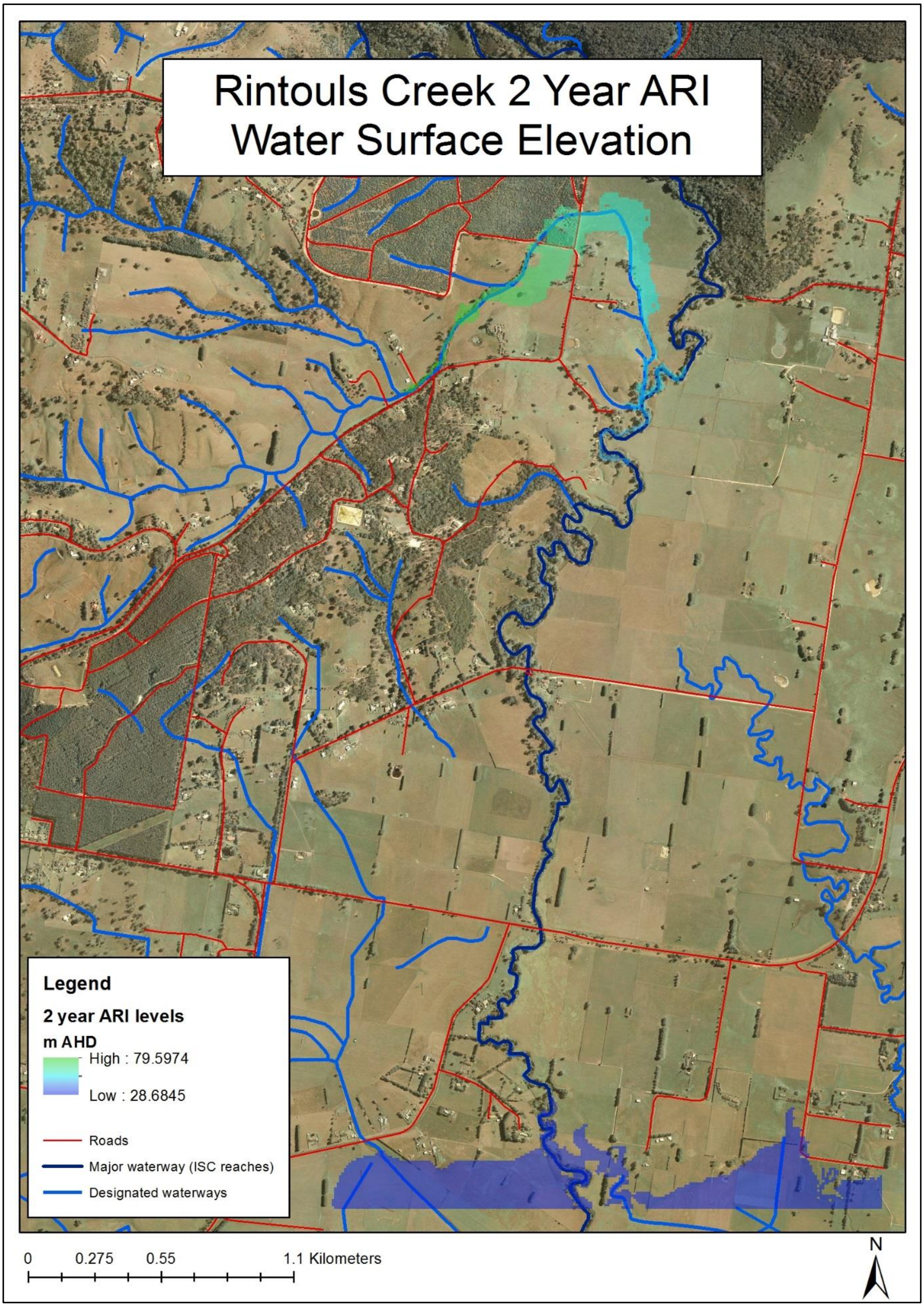

Figure 35 50% AEP maximum water surface elevation

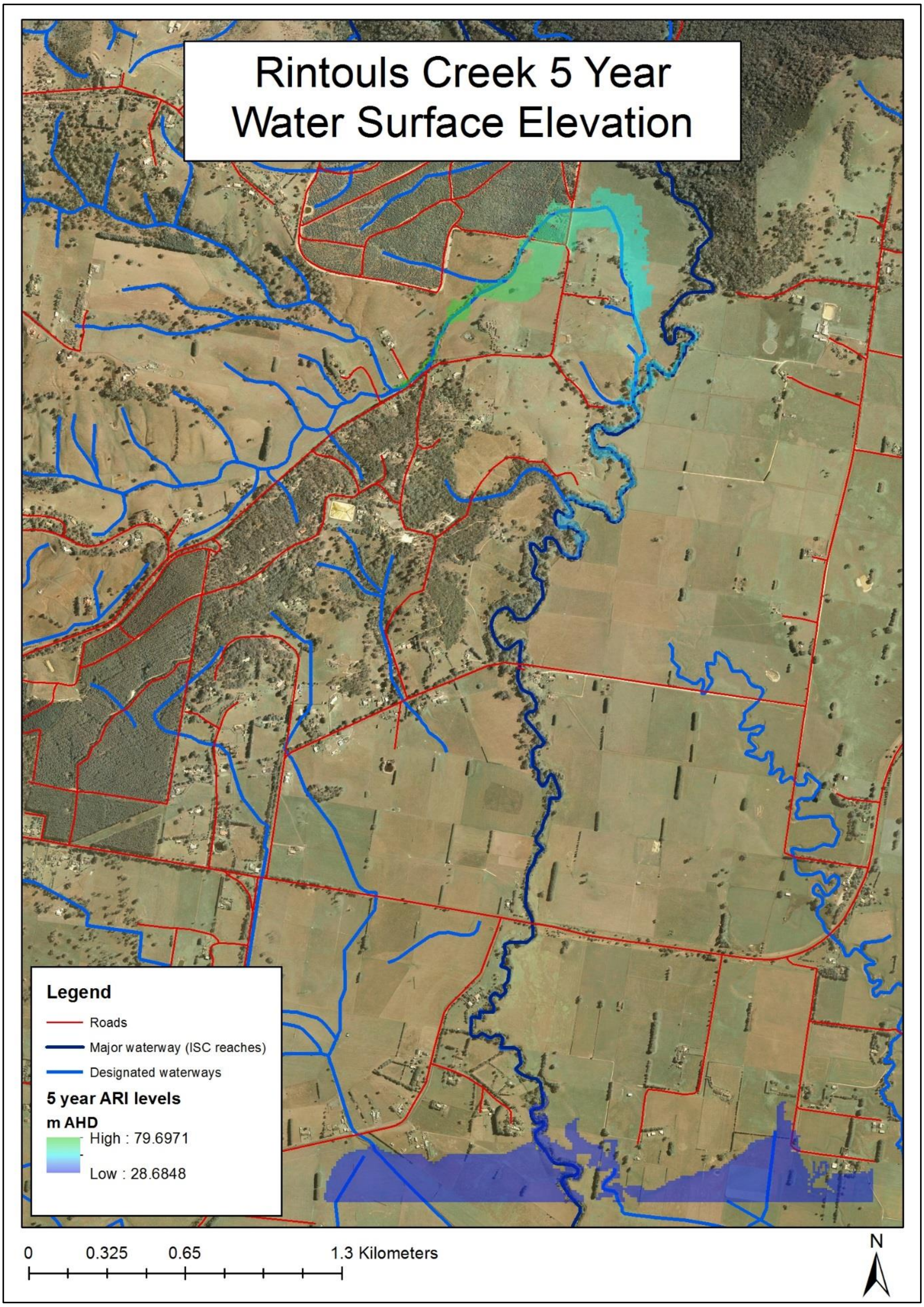

Figure 36 20% AEP maximum water surface elevation

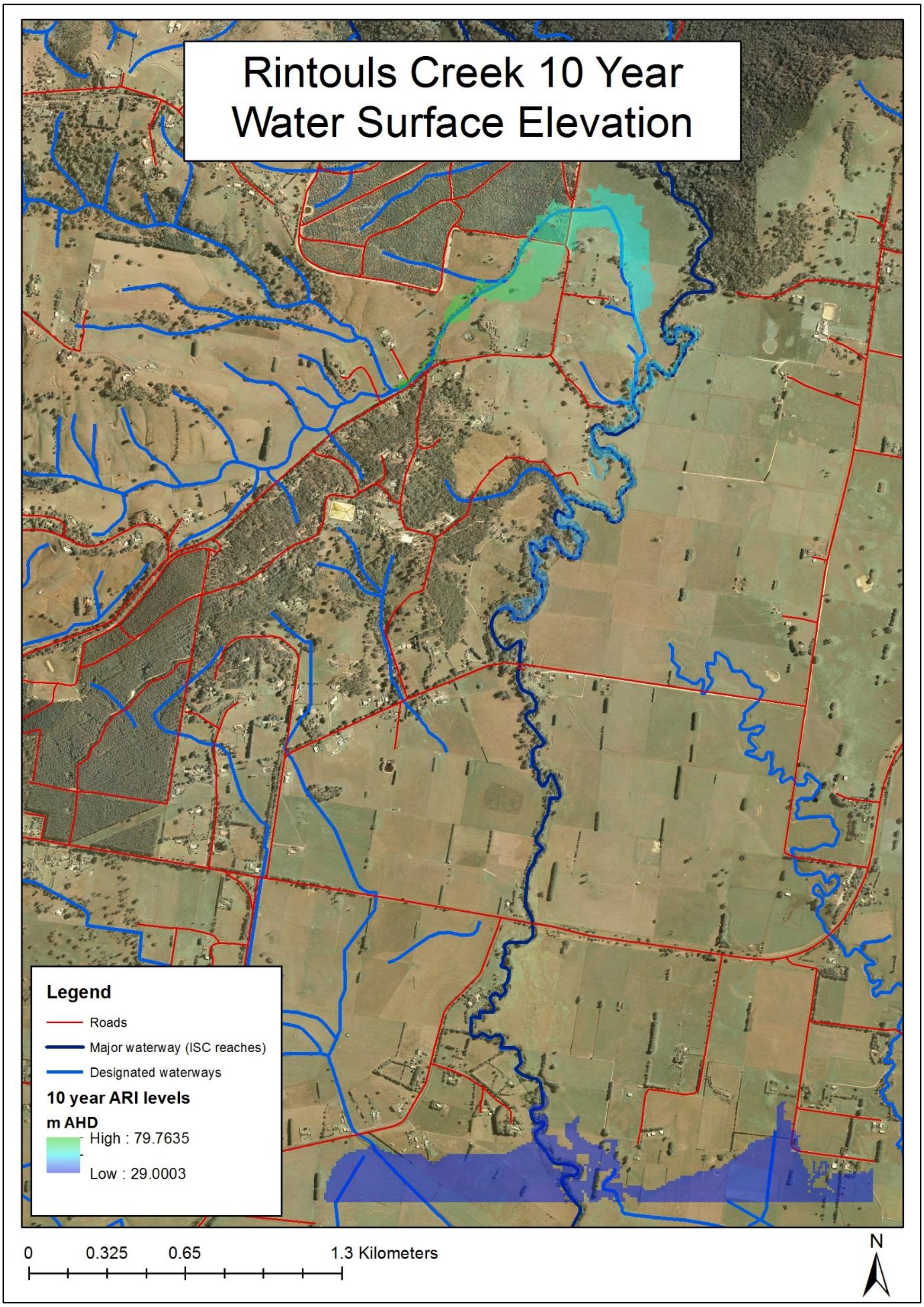

Figure 37 10% AEP maximum water surface elevation

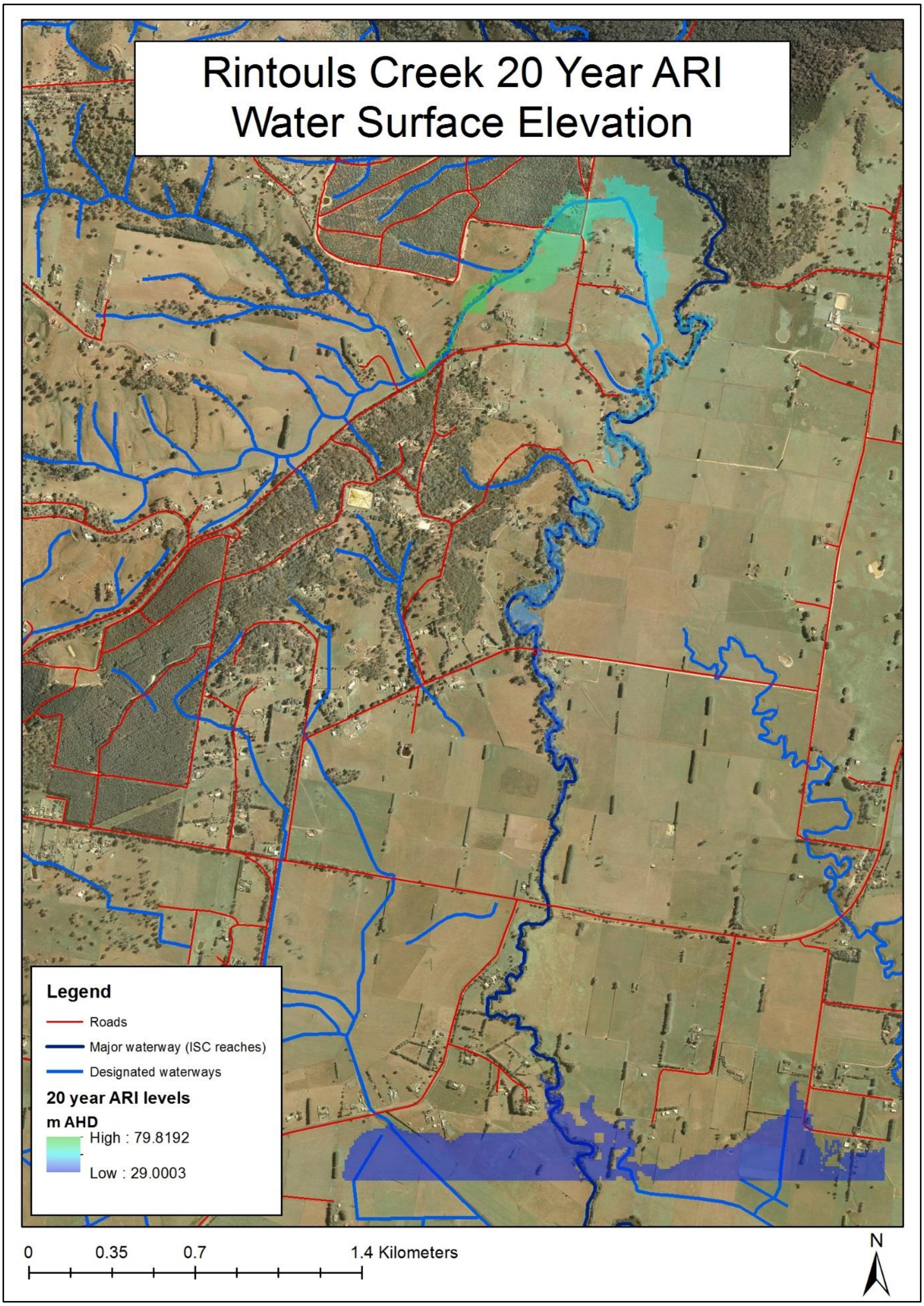

Figure 38 5% AEP maximum water surface elevation

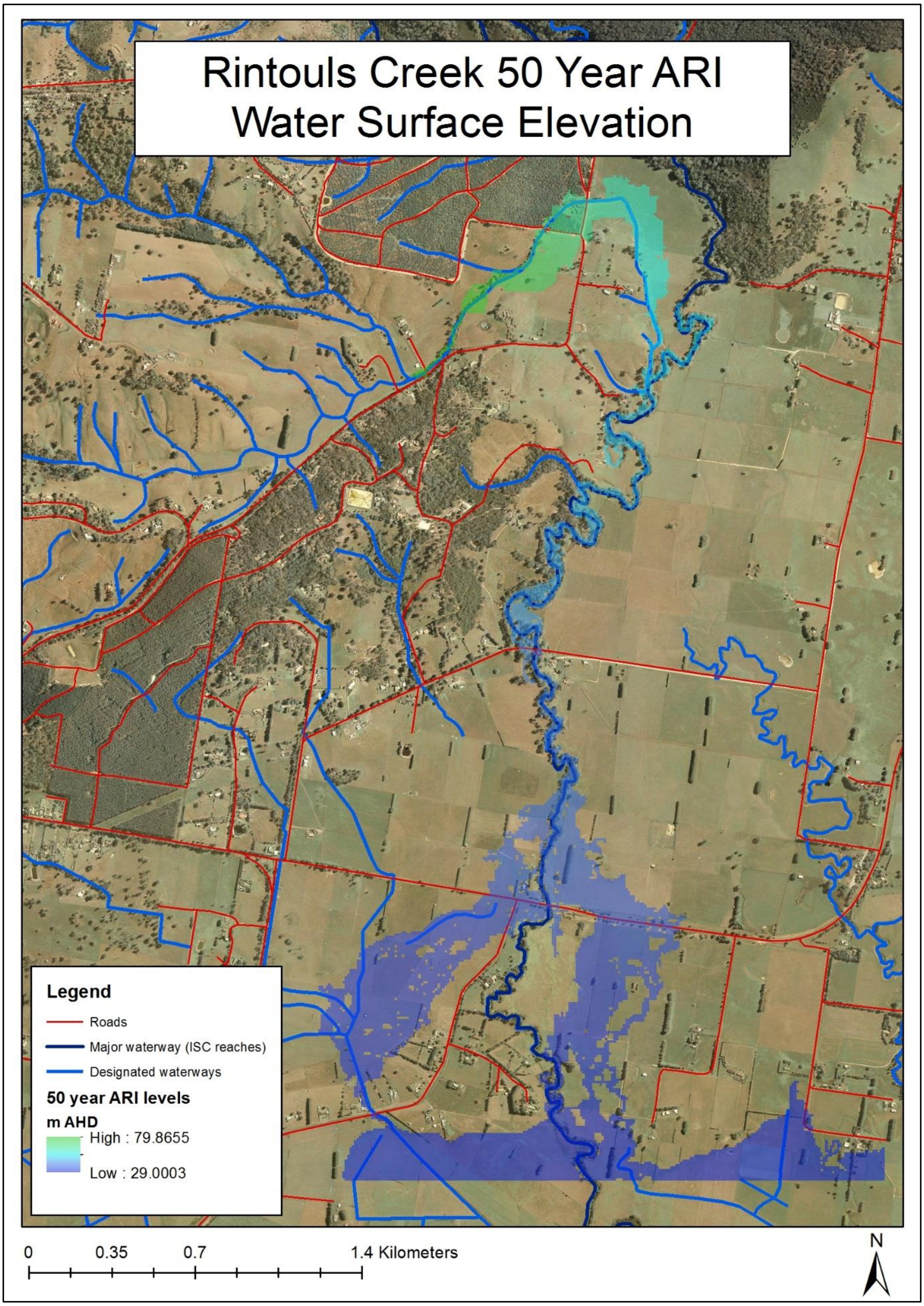

Figure 39 2% AEP maximum water surface elevation

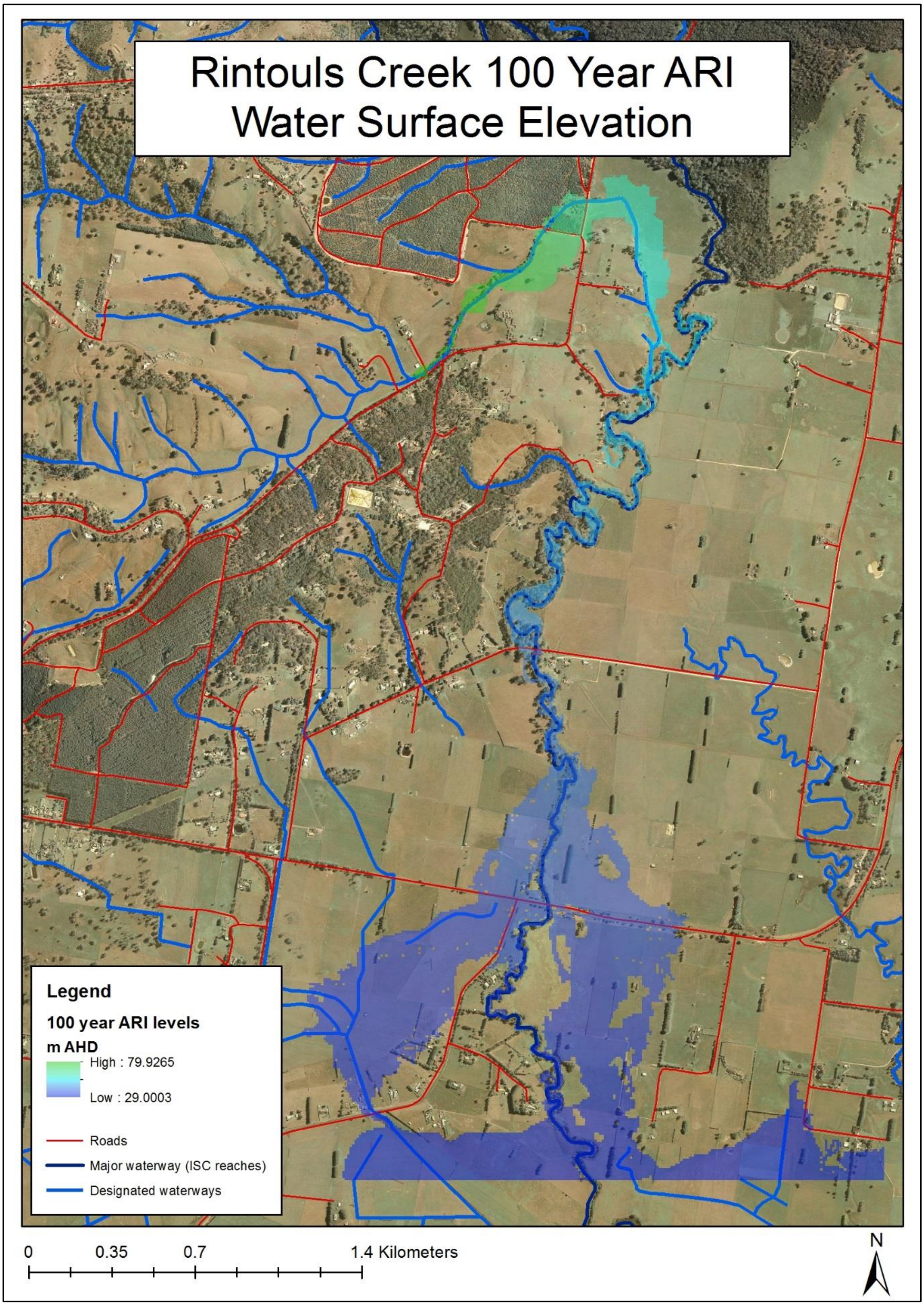

Figure 40 1% AEP maximum water surface elevation

Appendix G: Flood depth maps

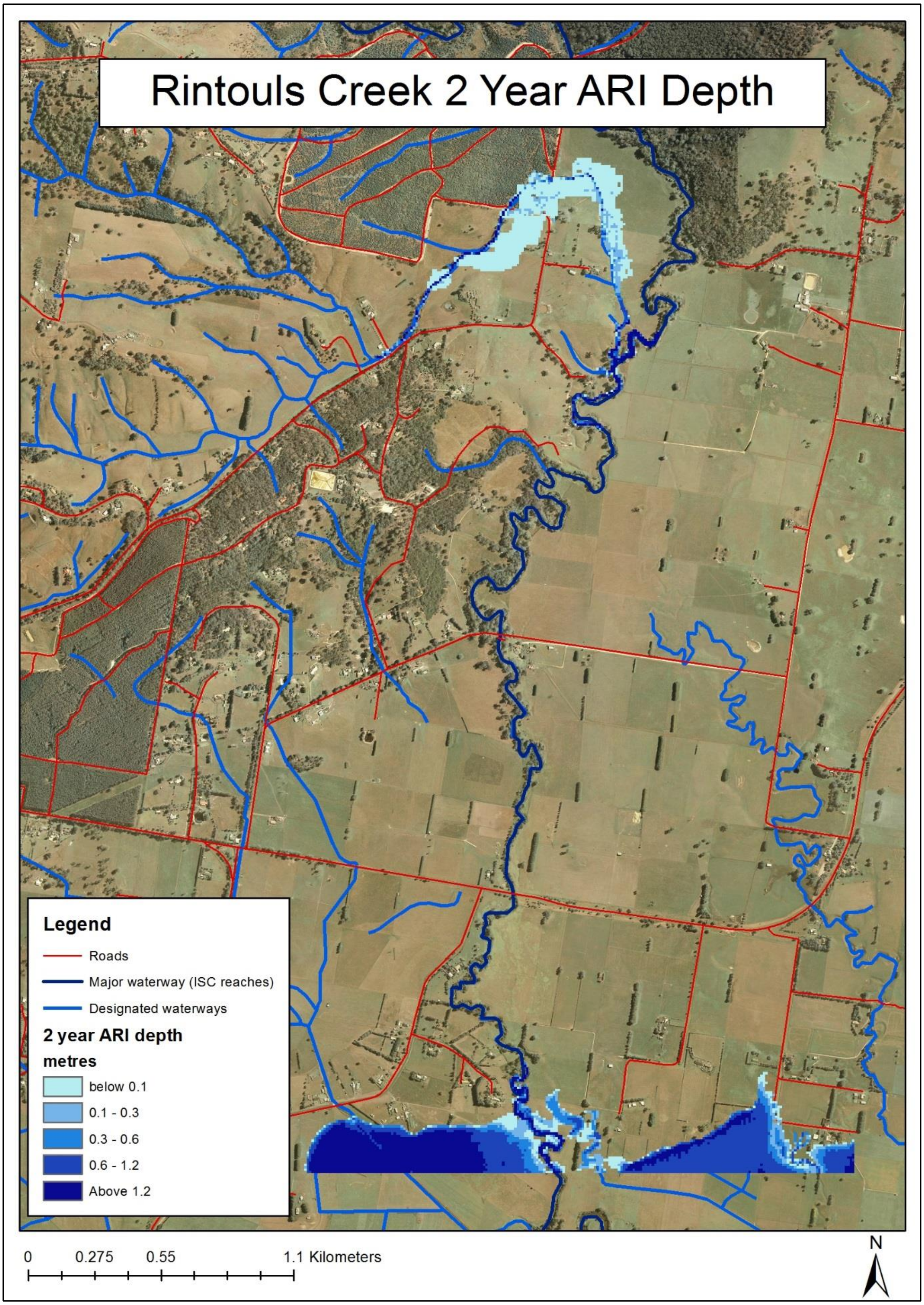

Figure 41 2 year maximum ARI depth

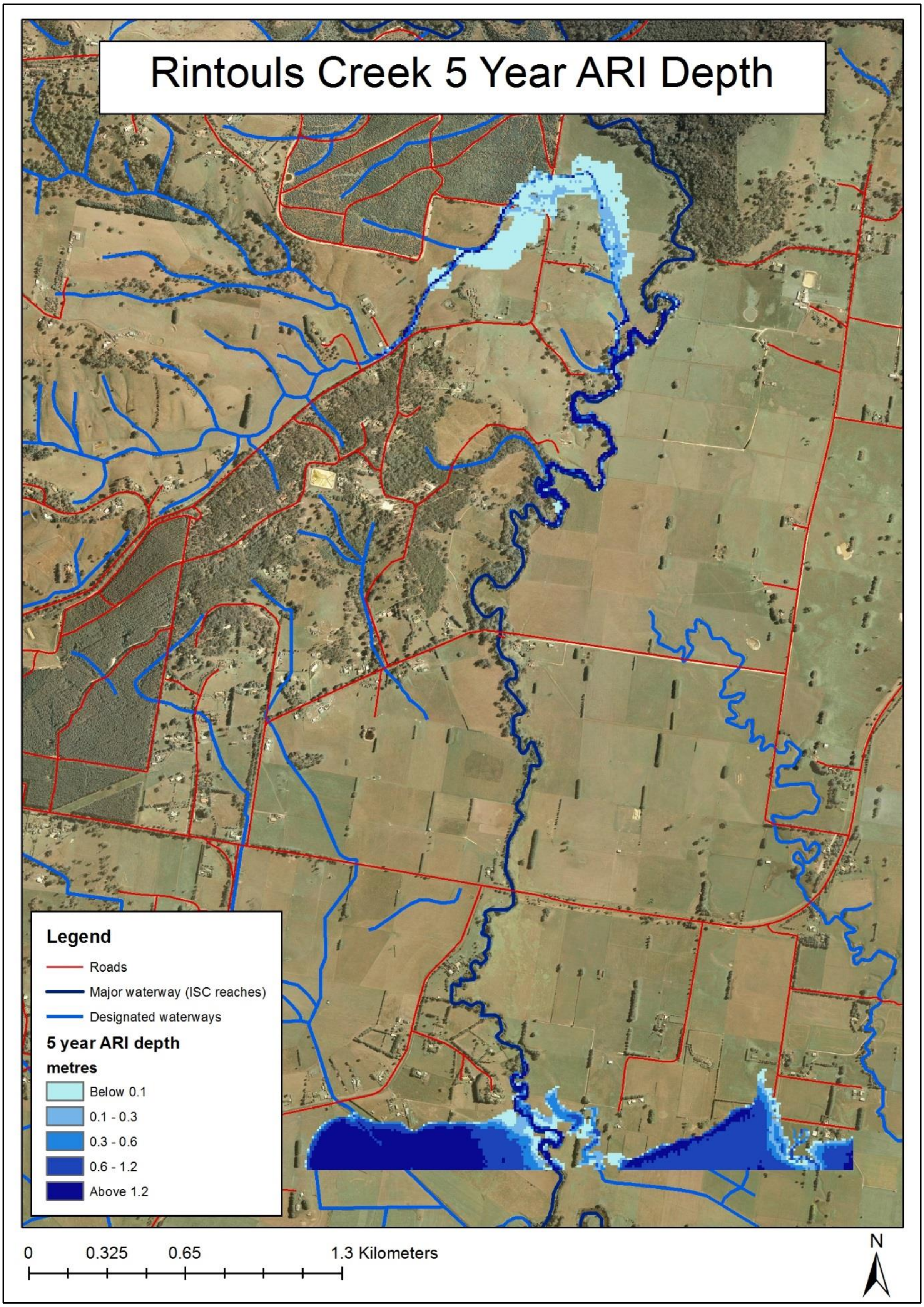

Figure 42 5 year maximum ARI depth

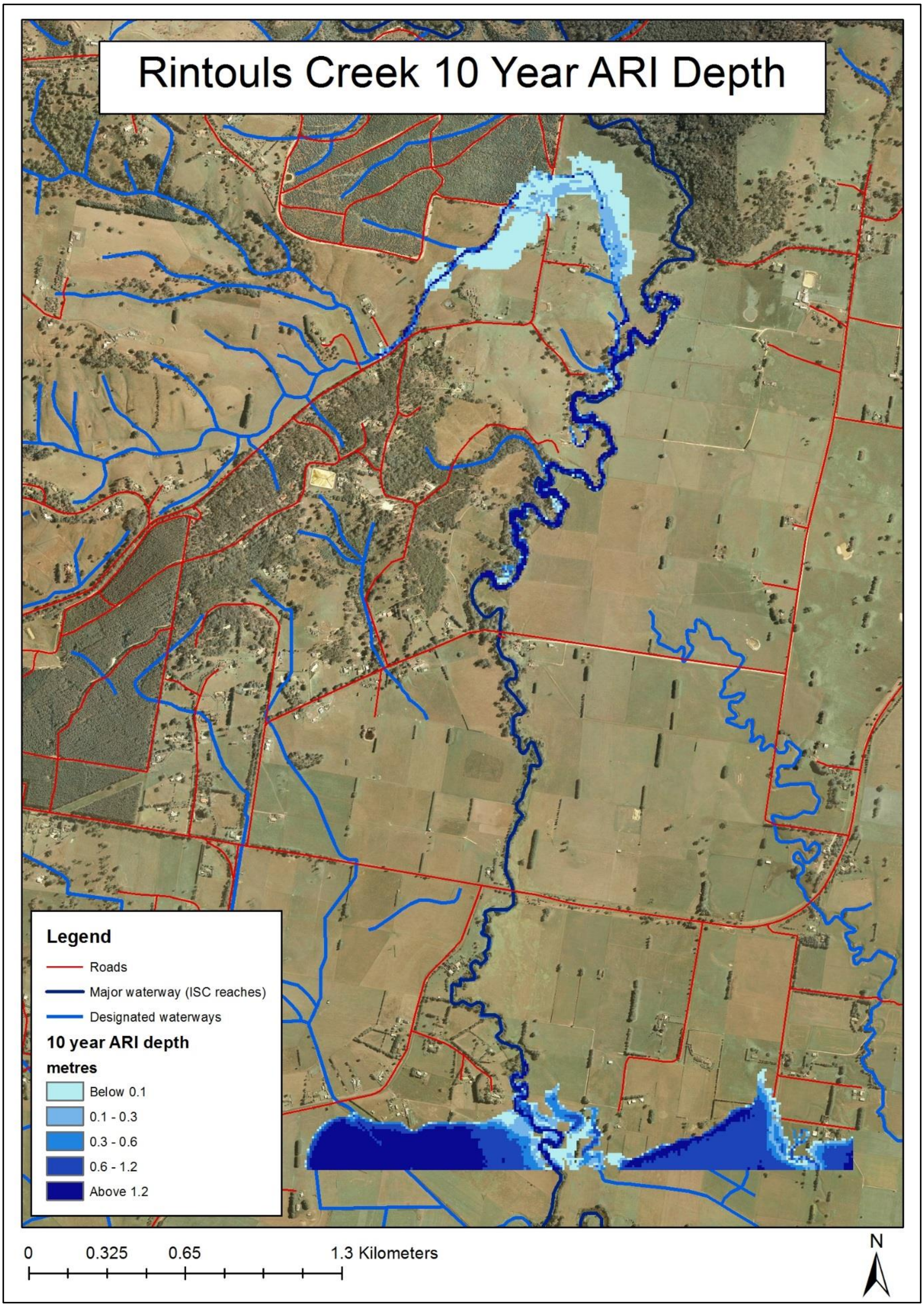

Figure 43 10 year maximum ARI depth

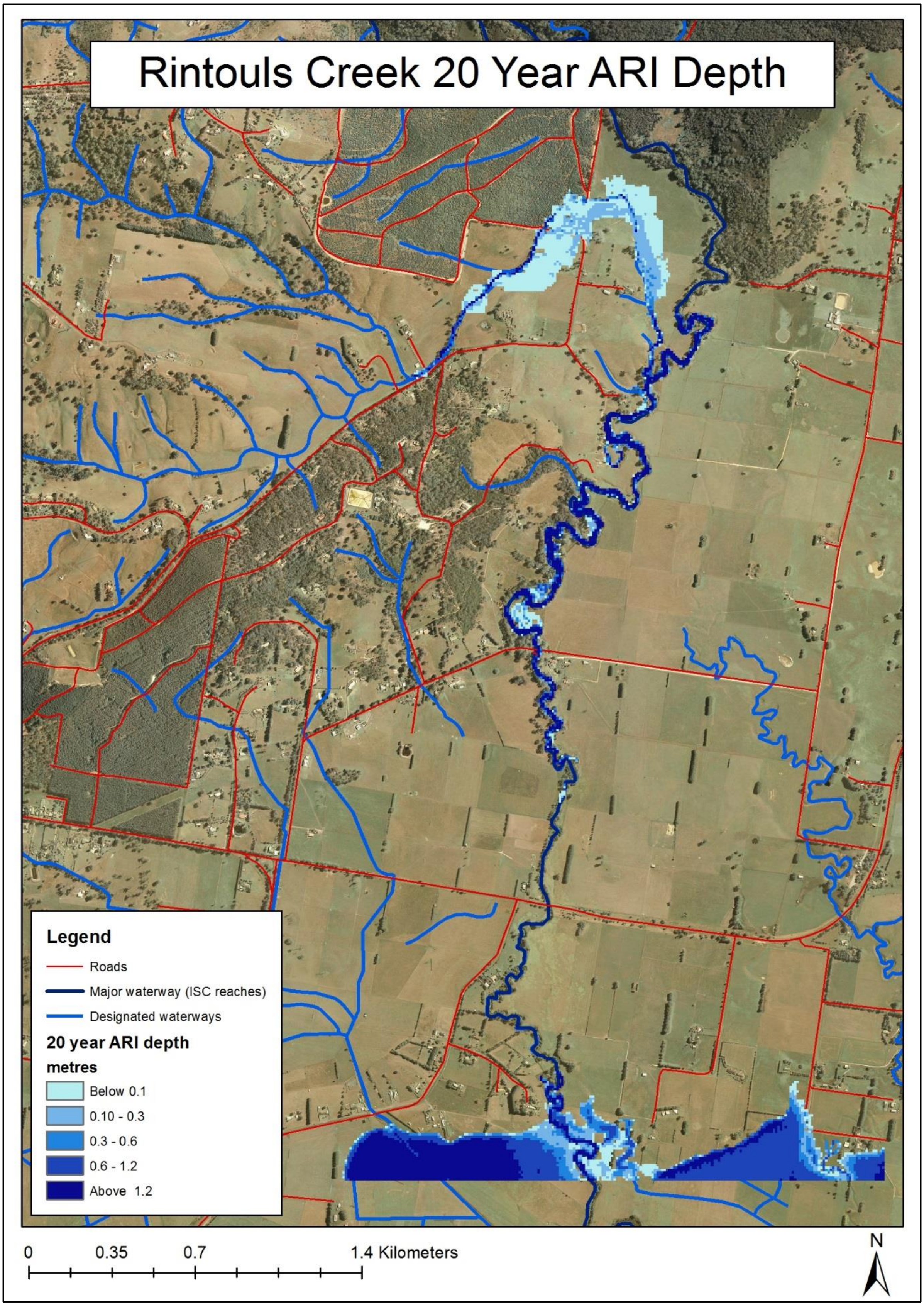

Figure 44 5% AEP maximum depth

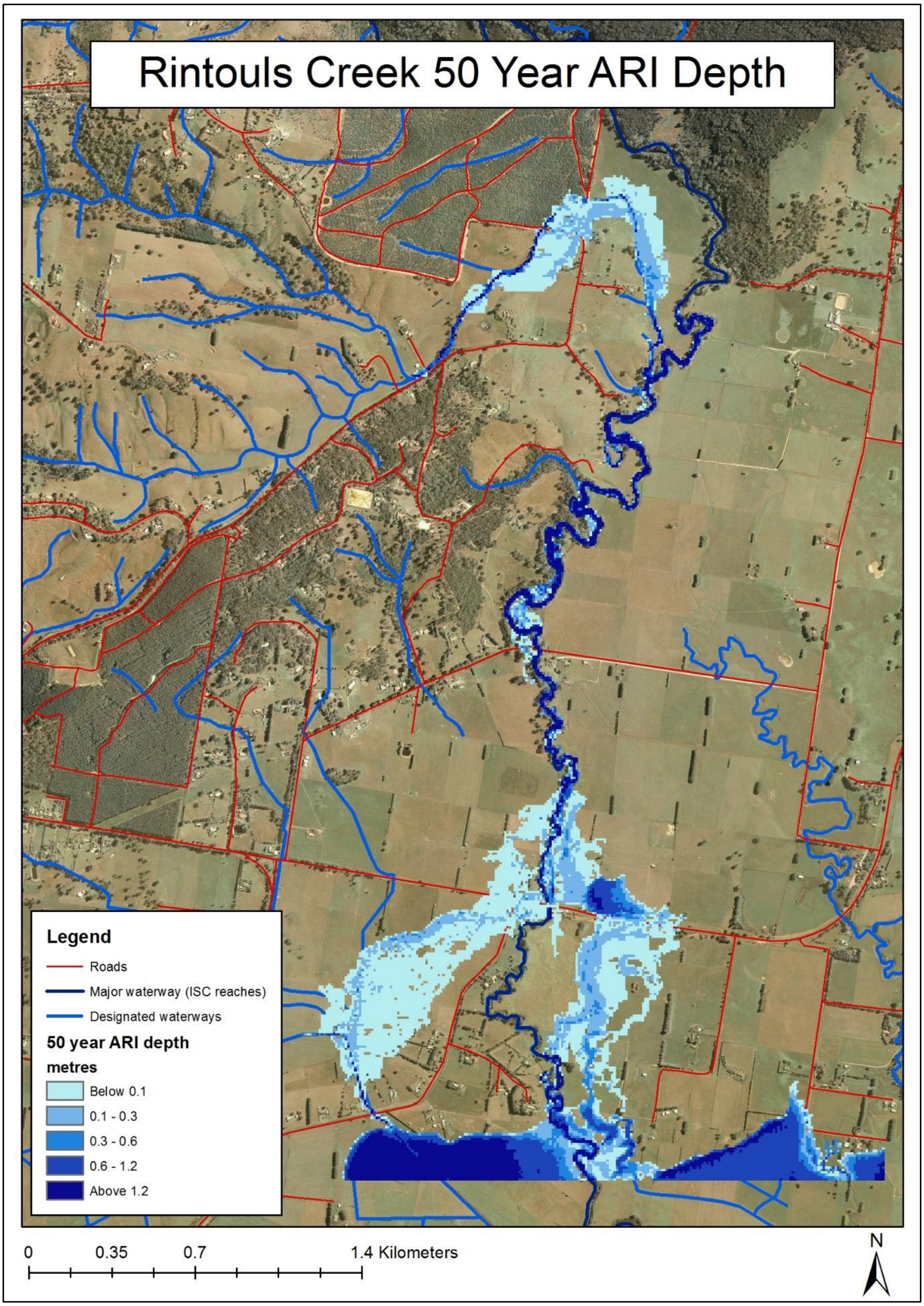

Figure 45 2% AEP maximum depth

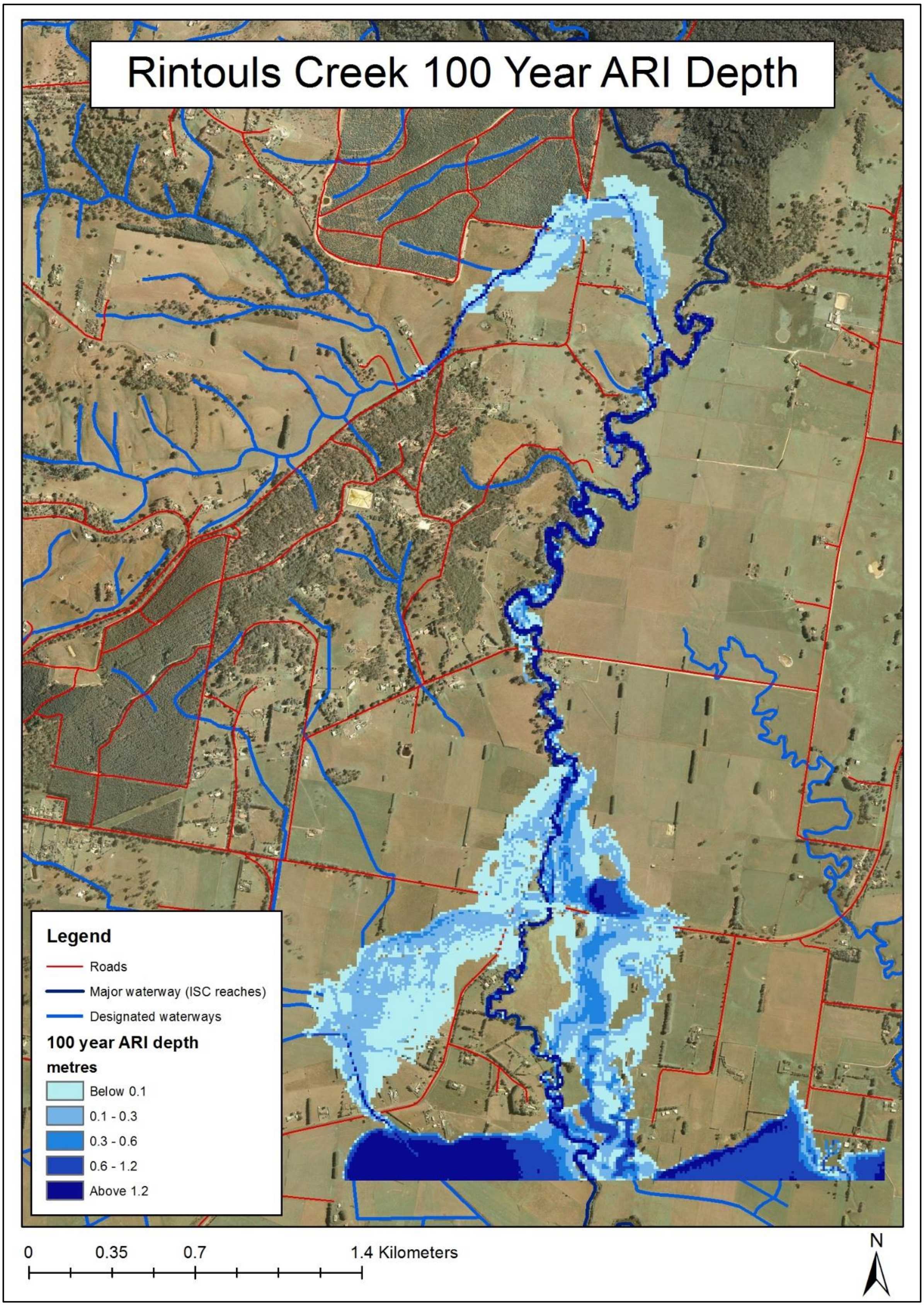

Figure 46 1% AEP maximum depth

Appendix H: Flood extent maps

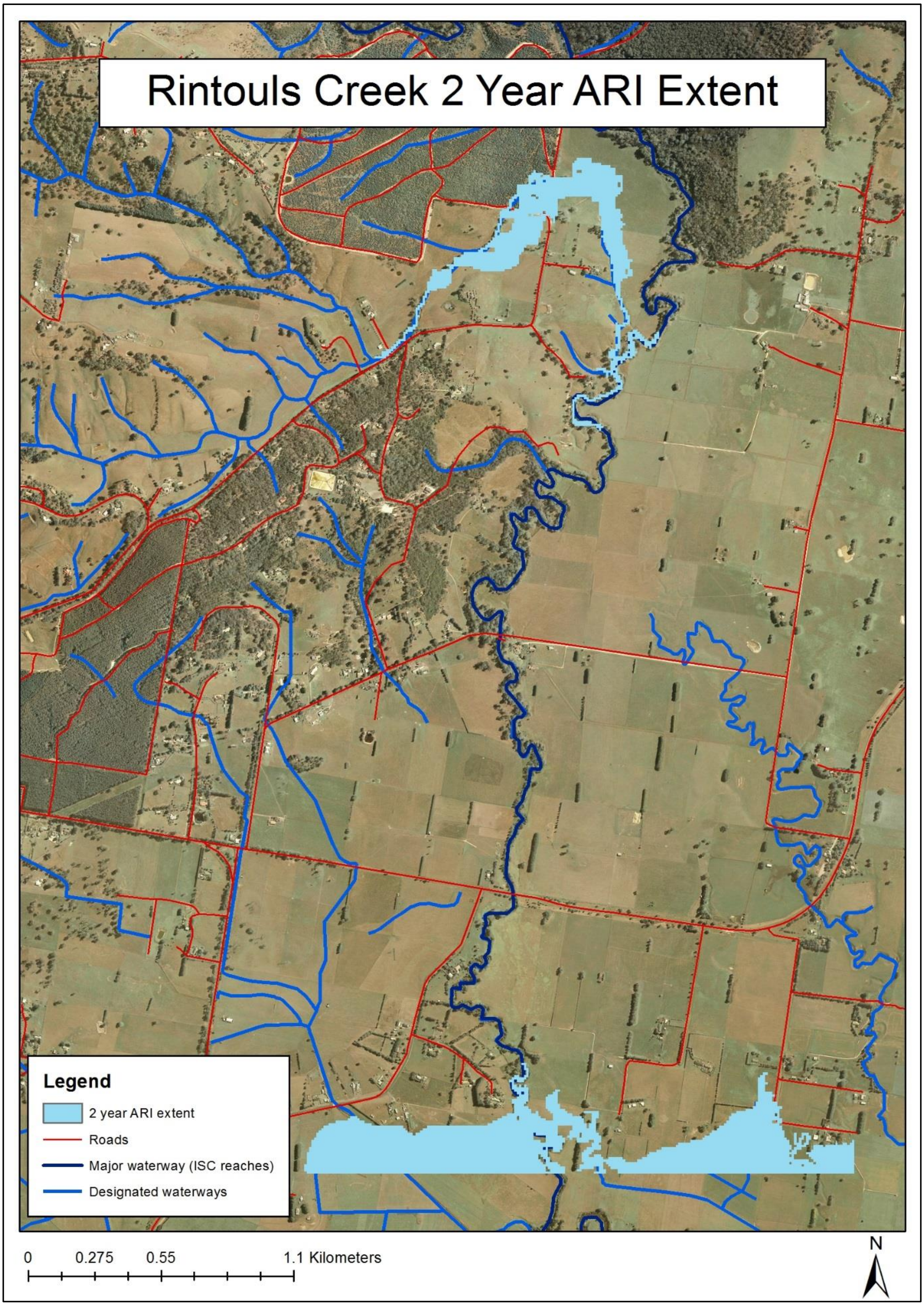

Figure 47 50% AEP extent

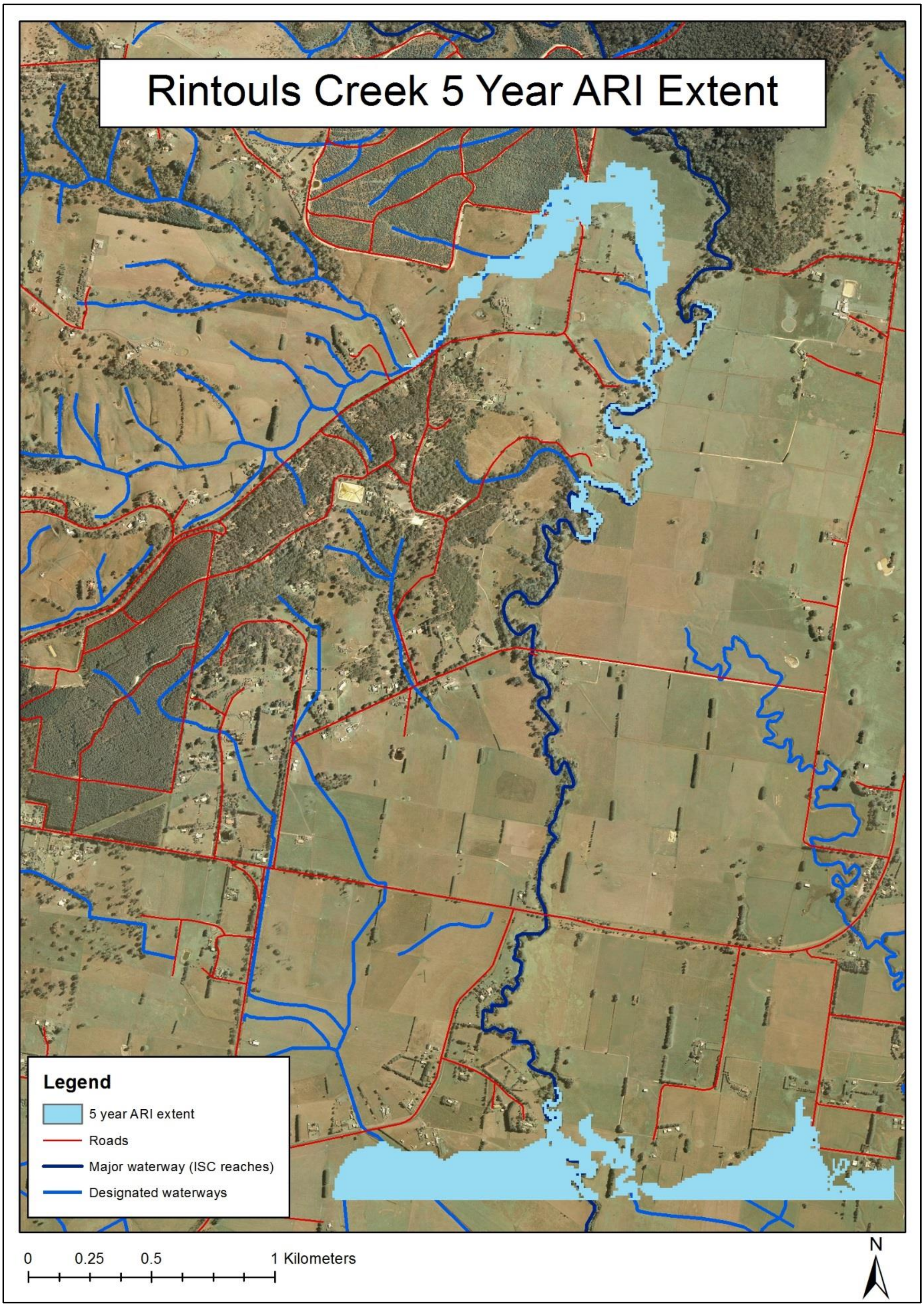

Figure 48 20% AEP extent

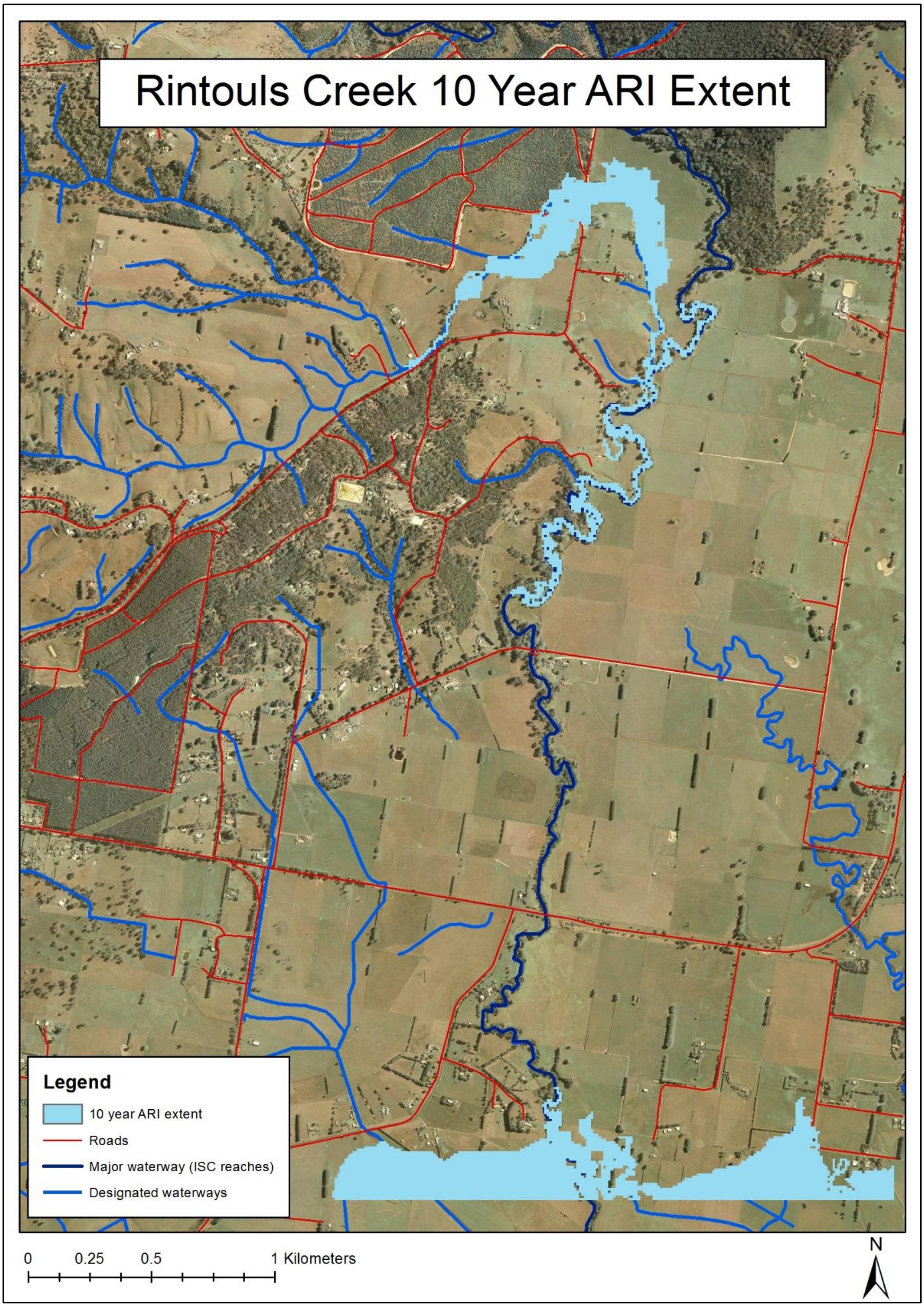

Figure 49 10% AEP extent

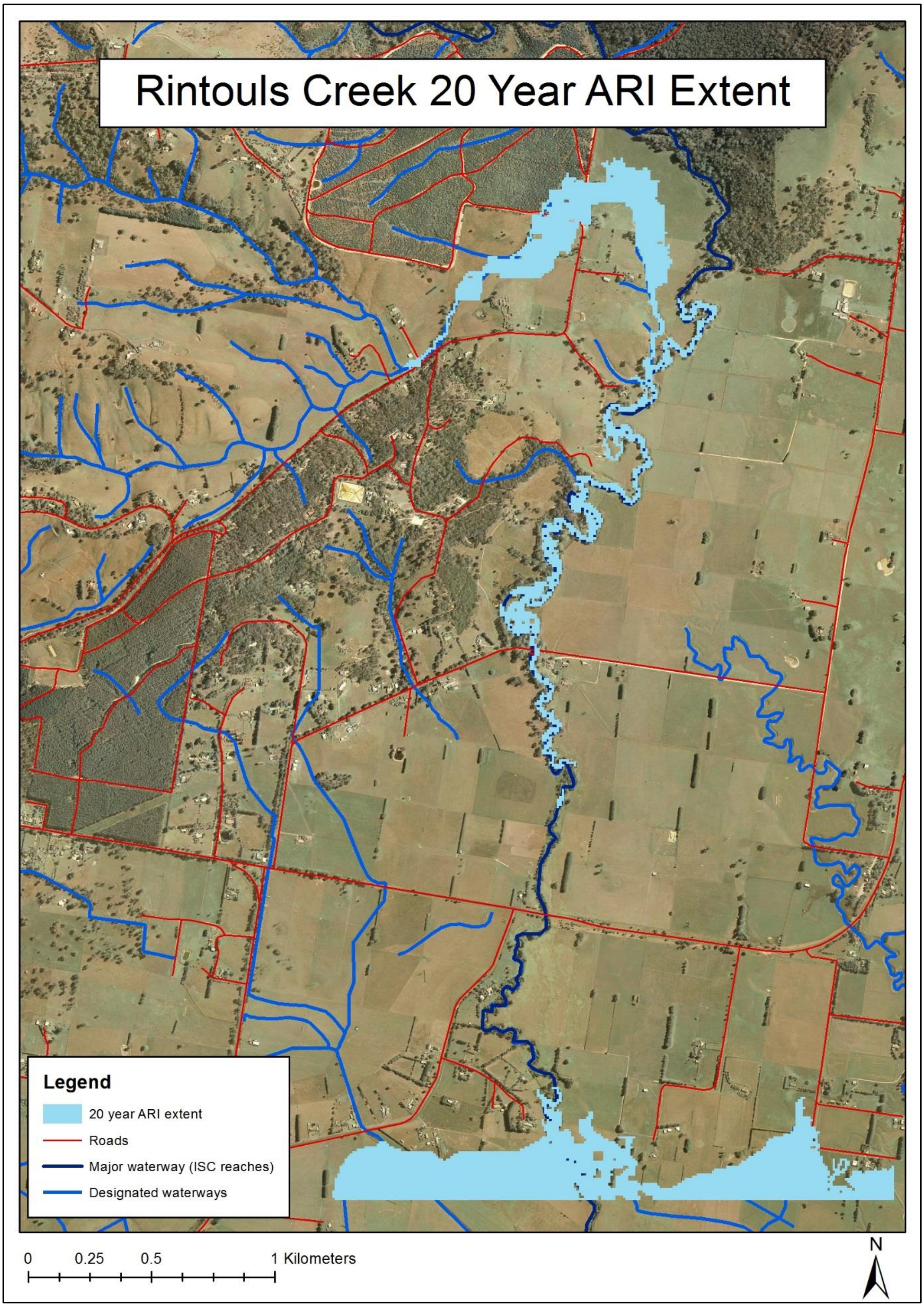

Figure 50 5% AEP extent

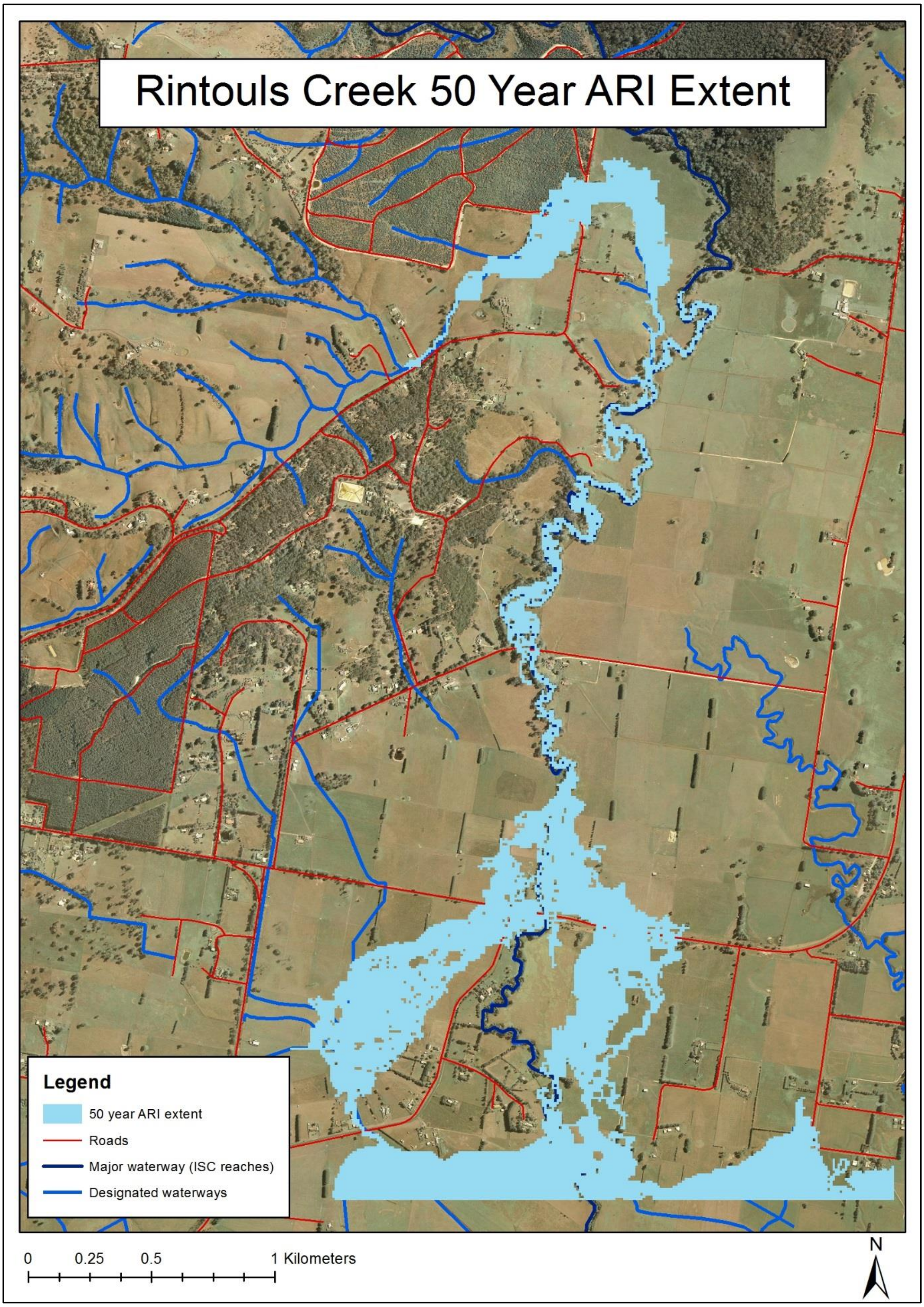

Figure 51 2% AEP extent

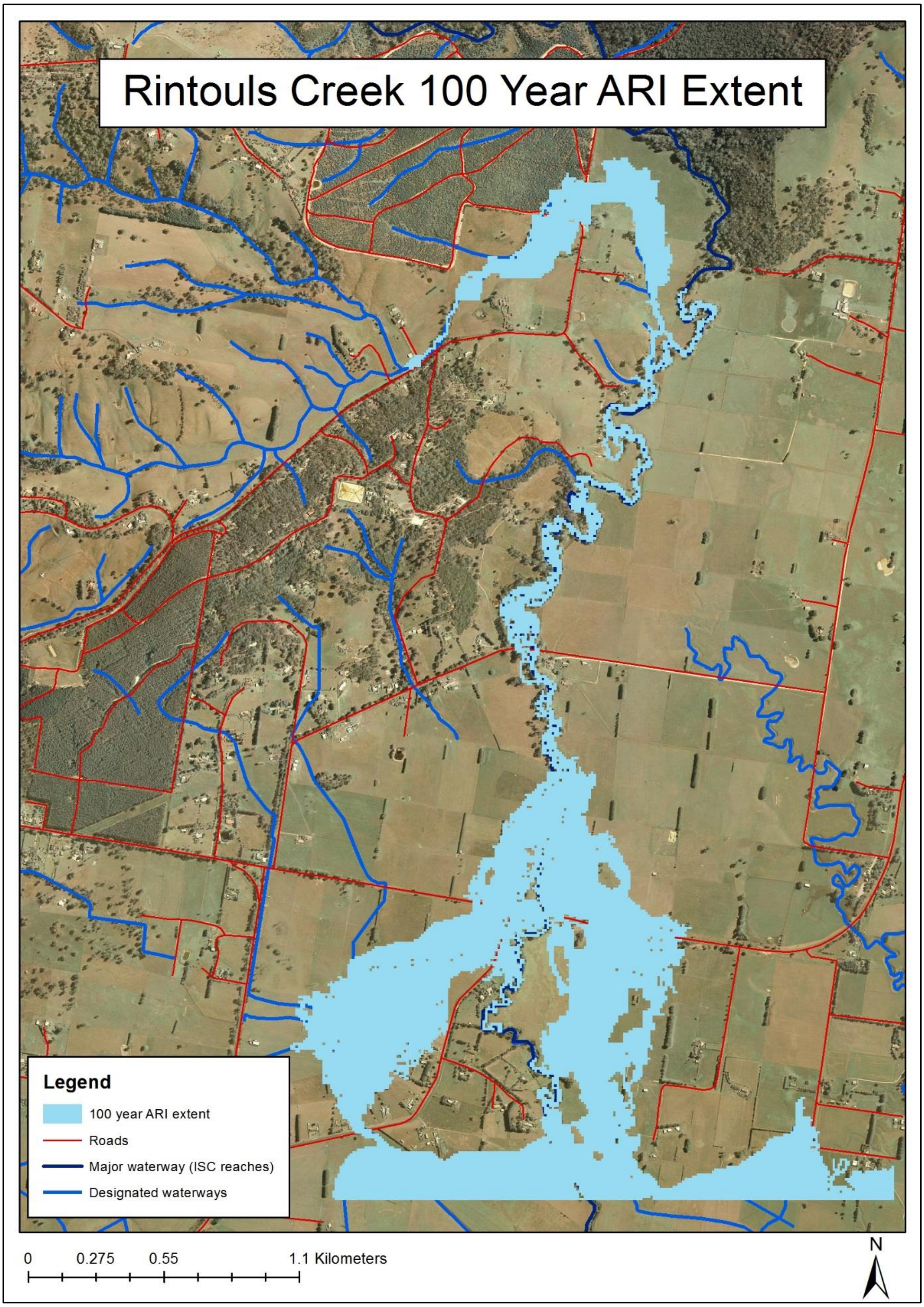

Figure 52 1% AEP extent

Appendix I: Flood flow velocity maps

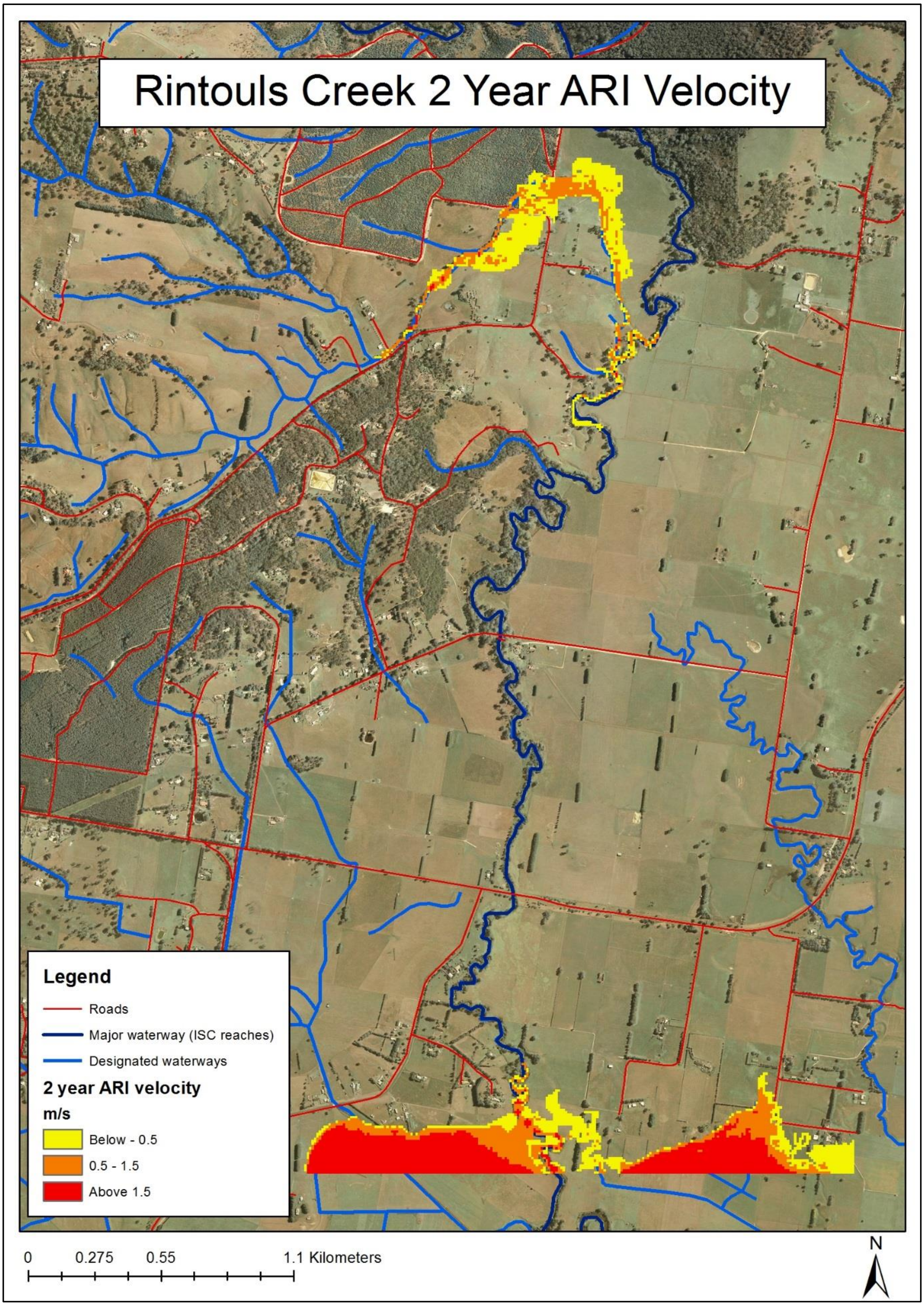

Figure 53 50% AEP maximum velocity

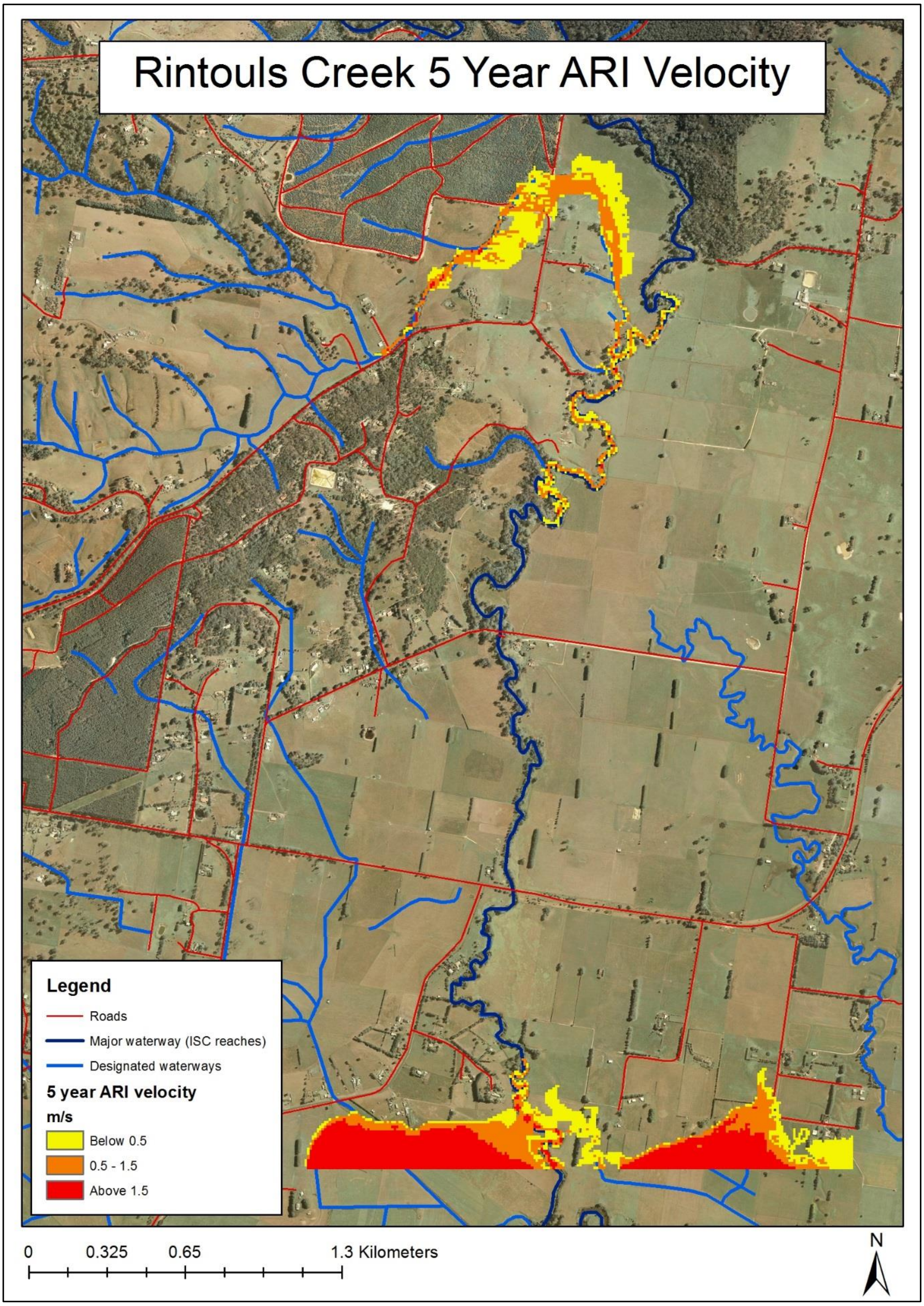

Figure 54 20% AEP maximum velocity

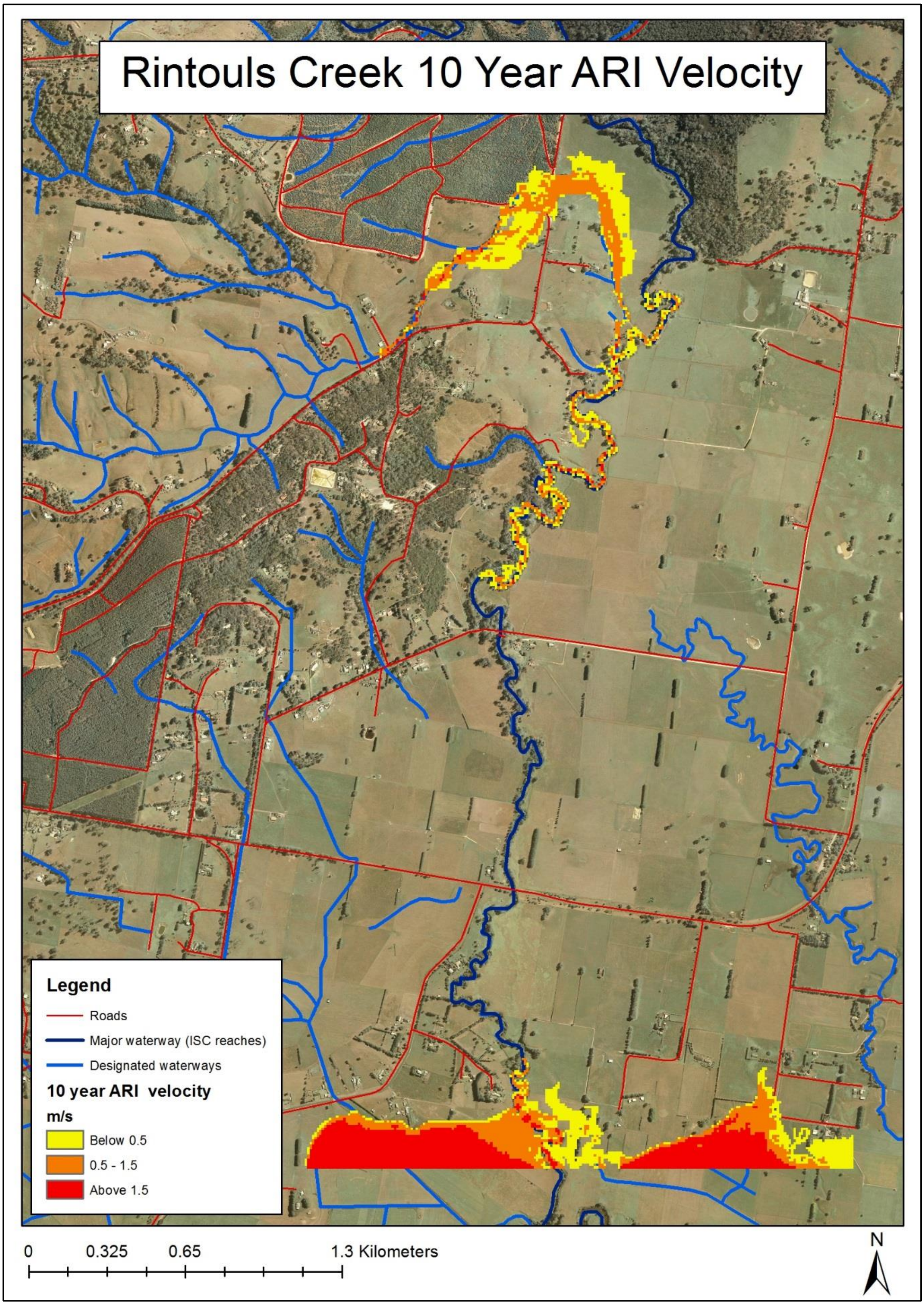

Figure 55 10% AEP maximum velocity

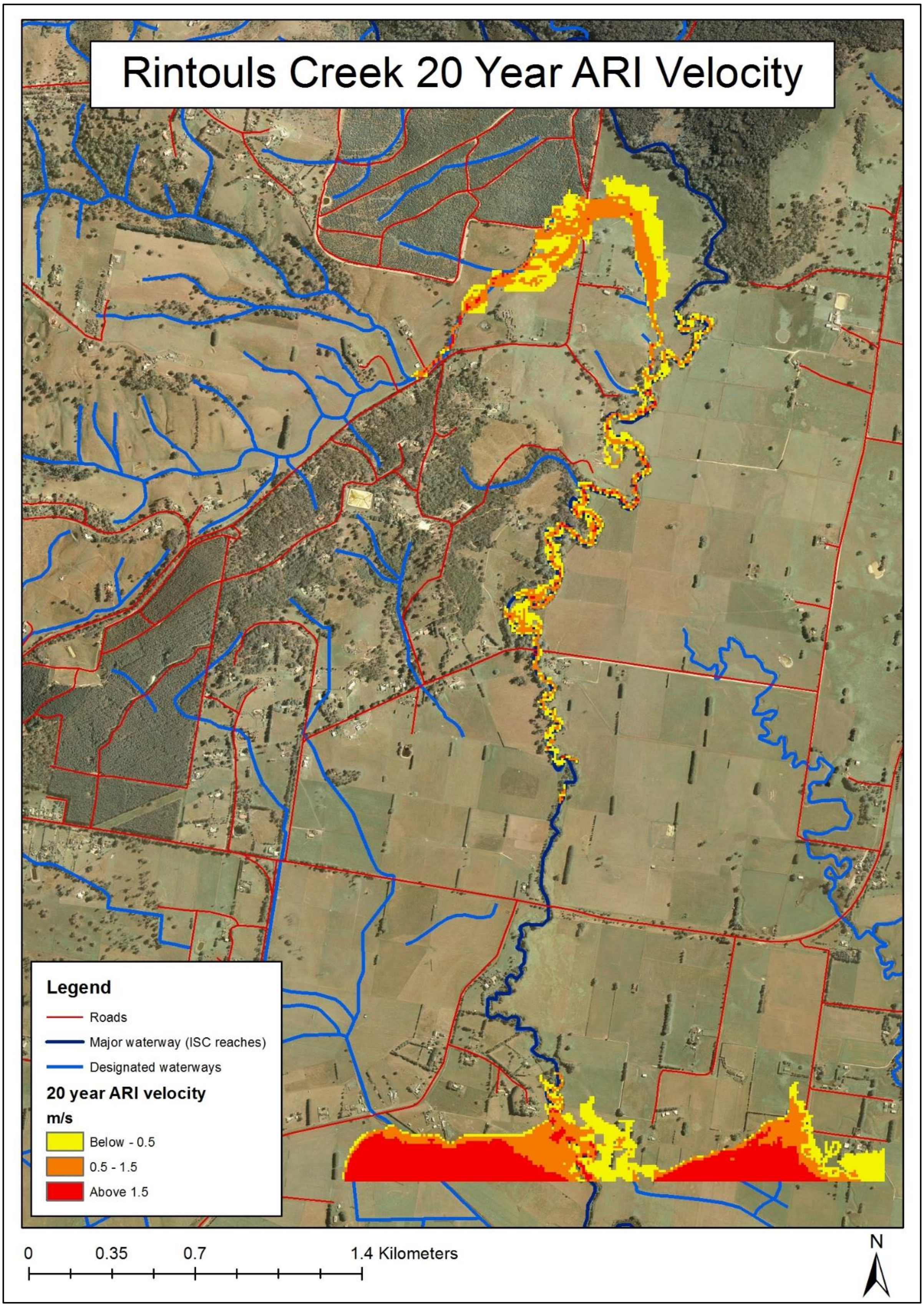

Figure 56 5% AEP maximum velocity

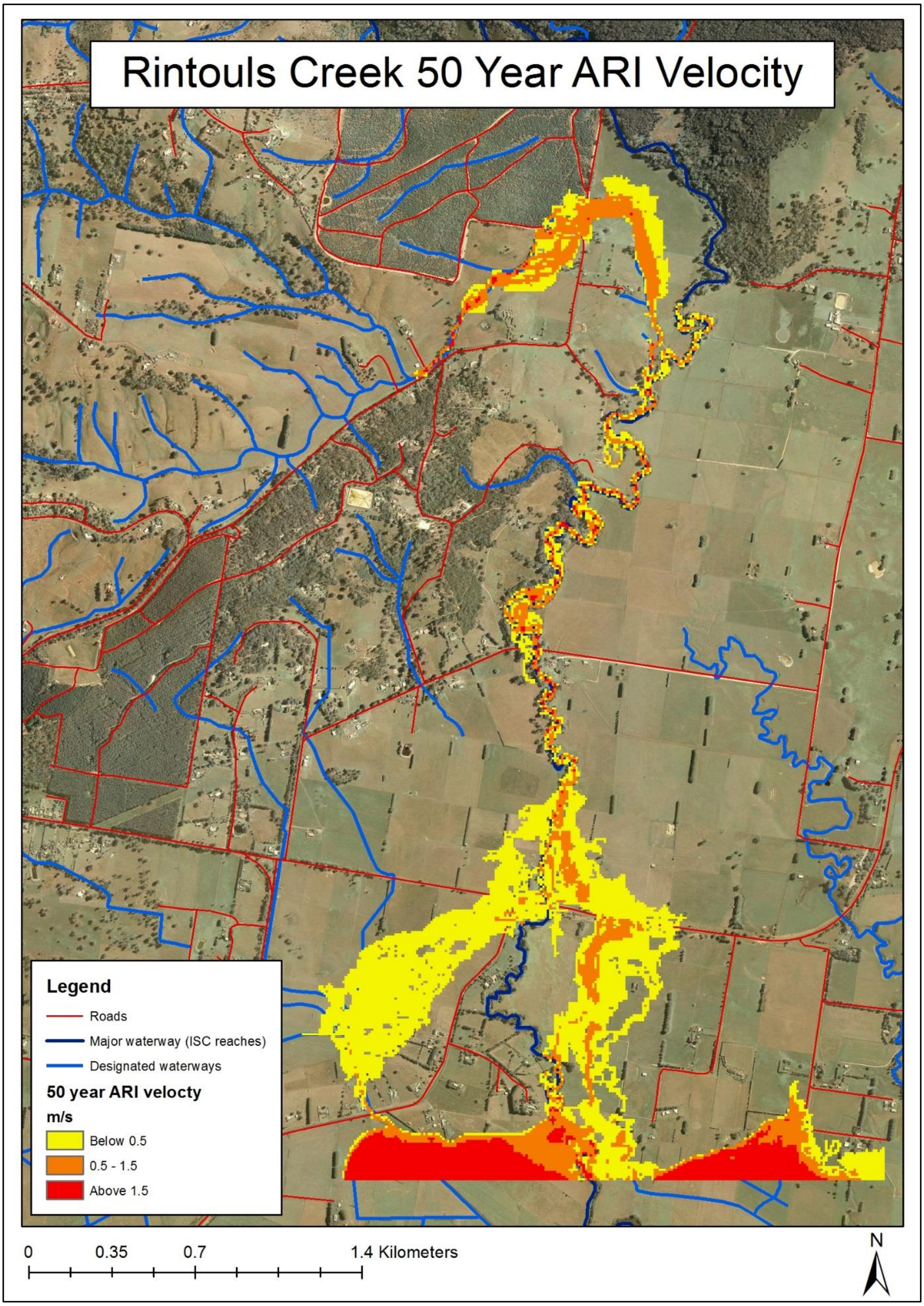

Figure 57 2% AEP maximum velocity

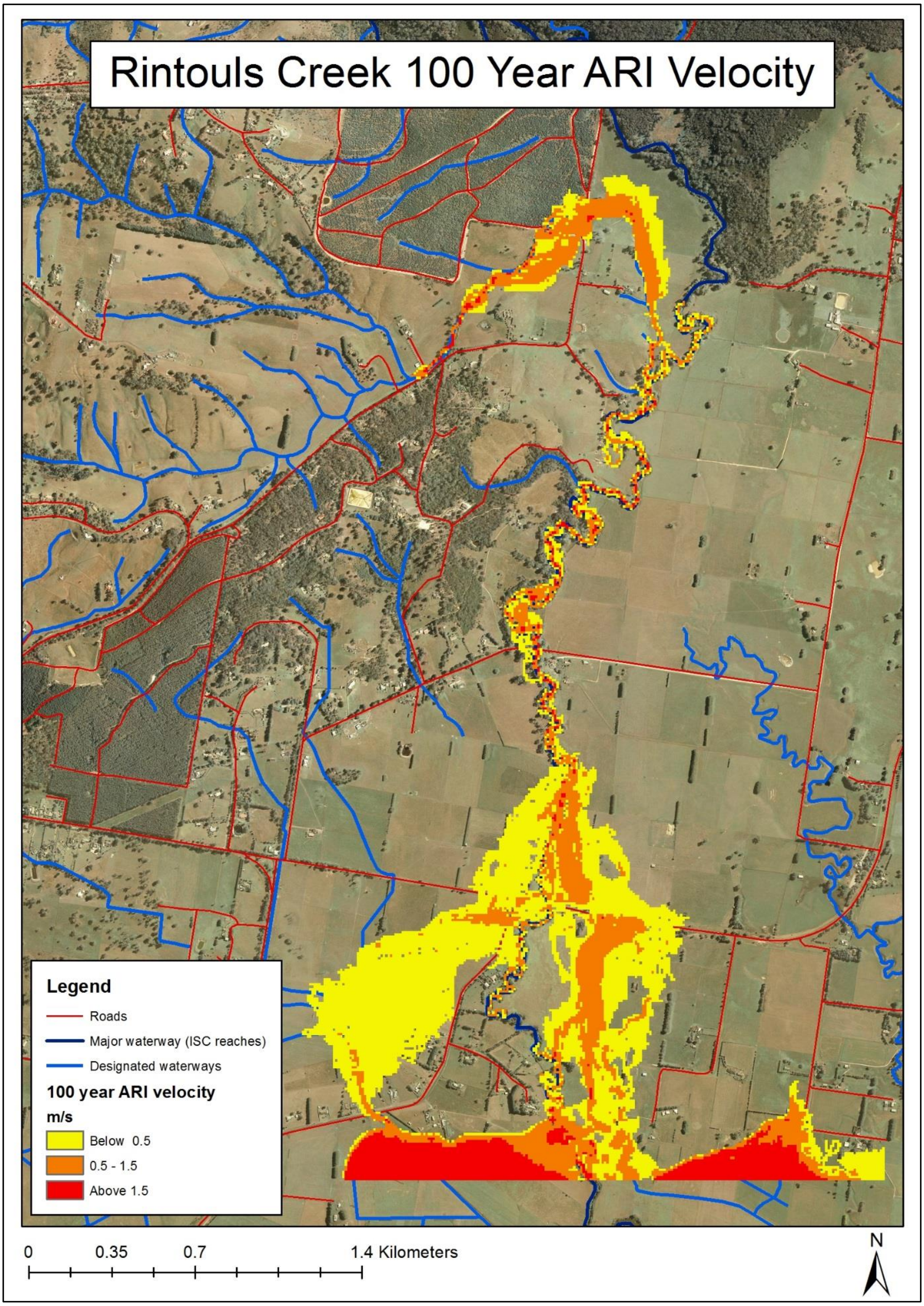

Figure 58 1% AEP maximum velocity