Joint Validation Modelling Report

Teesdale Flood Risk Identification Study

Golden Plains Shire

12 April 2023

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Cover Image: Native Hut Creek, January 2011

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GLOSSARY OF TERMS

Afflux	Refers to the difference in water level (or depth) between two modelling scenarios, usually measured in metres and a change in extent (e.g. "was wet, now dry")
Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded; it would be fairly rare but it would be of extreme magnitude.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. A 10 year ARI flood is expected to be exceeded on average once every 10 years. A 100 year ARI flood is expected to be exceeded on average once every 100 years. The AEP is the ARI expressed as a percentage.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Design flood	A design flood is a probabilistic or statistical estimate, being generally based on some form of probability analysis of flood or rainfall data. An average recurrence interval or exceedance probability is attributed to the estimate.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from elevated sea levels and/or waves overtopping coastline defences.
Flood frequency analysis	A statistical analysis of observed flood magnitudes to determine the probability of a given flood magnitude.
Flood hazard	Potential risk to life and limb caused by flooding. Flood hazard combines the flood depth and velocity.

Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Flood storages	Those parts of the floodplain that are important for the temporary storage, of floodwaters during the passage of a flood.
Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Intensity frequency duration (IFD) analysis	Statistical analysis of rainfall, describing the rainfall intensity (mm/hr), frequency (probability measured by the AEP), duration (hrs). This analysis is used to generate design rainfall estimates.
LiDAR	Spot land surface heights collected via aerial light detection and ranging (LiDAR) survey. The spot heights are converted to a gridded digital elevation model dataset for use in modelling and mapping.
Peak flow	The maximum discharge occurring during a flood event.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Average Recurrence Interval.
Probable Maximum Flood	The flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area.
RORB	A hydrological modelling tool used in this study to calculate the runoff generated from historic and design rainfall events.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Topography	A surface which defines the ground level of a chosen area.

1 INTRODUCTION

1.1 Overview

Water Technology has been commissioned by Golden Plains Shire Council (Council) to undertake the Teesdale Flood Risk Identification Study. The investigation area covers the Native Hut Creek and tributaries in the township of Teesdale, as shown in Figure 1-1. Teesdale is identified as a Priority Flood Risk Area in the Corangamite Regional Floodplain Management Strategy (2018), which identifies both riverine and flash flood risks for the town and states that "*flooding associated with Native Hut Creek has damaged several residential properties*".

Previous flood investigations covering Teesdale include CCMA investigations undertaken in 2008 and 2019. The 2008 study utilised RORB hydrologic modelling and HEC-RAS one-dimensional hydraulic modelling, while the 2019 study utilised HEC-RAS two-dimensional hydraulic modelling. A regional flood study of the Barwon River catchment which covers the study area was also completed in 2016 (GHD, 2016).

The CCMA modelling completed in 2019 indicates that the current flood mapping which is the basis for the Floodway Overlay (FO) and Land Subject to Inundation Overlay (LSIO) in the Golden Plains Planning Scheme understates the flood hazard in Teesdale. The Flood Risk Identification Study is being carried out to ensure that the planning scheme mapping accurately reflects flood hazard to ensure that growth in Teesdale is managed appropriately into the future. As such, updated flood mapping suitable for inclusion in the Golden Plains Planning Scheme is a key output required from the study.

In addition, the study will produce flood intelligence information for use in emergency management situations, assess the current flood impact/exposure in terms of annual average damages caused by flooding in Teesdale, investigate structural and non-structural mitigation options to reduce damages, investigate and make recommendations for establishing a flood warning system for the town.

This report is one of a series documenting the outcomes of the Teesdale Flood Risk Identification Study. Each reporting stage is shown below:

- R01 - Data Review and Validation
- **R02 – Joint Validation Modelling Report - This Report**
- R03 – Design Hydrology and Hydraulic Modelling Report
- R04 – Flood Intelligence and Flood Warning Report
- R05 – Flood Damages and Mitigation Assessment Report
- R06 – MFEP Documentation
- R07 – Final Summary Report

1.2 Study Area

Teesdale is located approximately 8.5 km north of Inverleigh and is situated on the banks of Native Hut Creek. The Native Hut Creek catchment begins approximately 22.5 km north of Teesdale near the town of Meredith. The creek meanders south across agricultural land, the vast majority of which has been historically cleared of large vegetation in line with its use as farmland.

The catchment within and upstream of the study area is mostly cleared agricultural land and the main waterway (Native Hut Creek) has several onstream dams of varying size along its alignment. The Native Hut Creek catchment draining to Teesdale is approximately 110 km^2. The entire catchment is located within the Golden Plains municipal area. The study area is focussed on the township of Teesdale and includes the following waterway structures:

- Two large on-stream dams approximately 3km upstream of the township.
  - An indicative assessment of the impact of the upstream dams was completed in R01 – Data Collation and Validation. The assessment found the dams would have minimal impact on peak flow rate or flood levels in a significant storm event.
- Road crossings, formal or informal, at the following roads:
  - Tolson Road/Stones Road
  - Sutherland Street
  - Bannockburn-Shelford Road
  - Barkers Road
- Several off-stream dams throughout the town.

1.3 Previous Reporting

This report follows report R01 - Data Review and Validation. The Data Review and Validation report detailed the data available for use in the study and highlighted any data gaps. The most significant data gap in this study is the lack of available calibration information as the study area has no stream gauges, few rain gauges within the catchment and the absence of accurate historical flood level information. The absence of this information makes thorough calibration of the hydrologic and hydraulic models difficult to achieve as there is no suitable data to calibrate the models against. To overcome this, a joint validation approach that relies heavily on anecdotal information has been adopted.

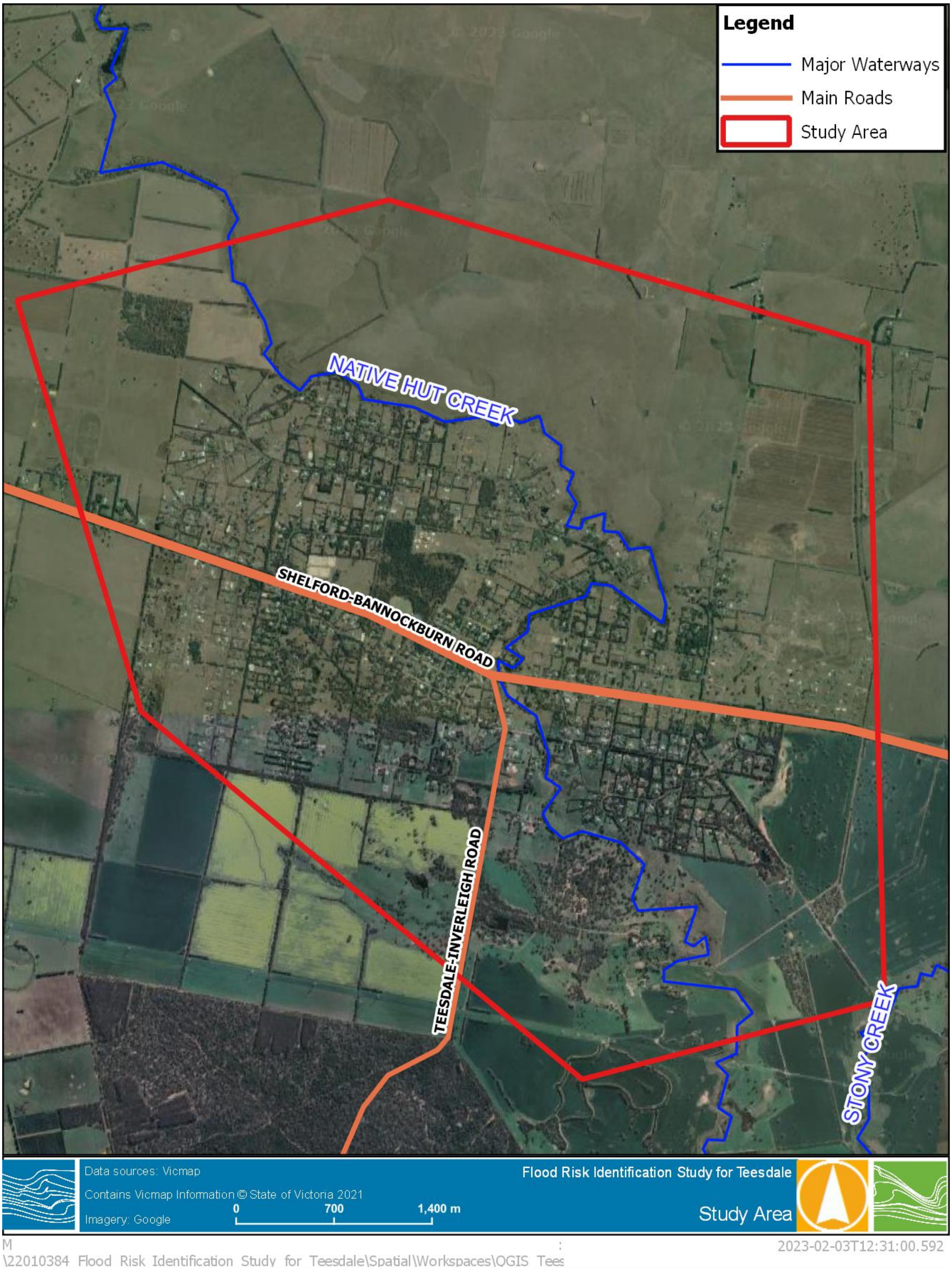

Figure 1-1 Study Area

2 METHOD

In order to investigate and define flood risk in Teesdale, a hydrologic/hydraulic modelling approach has been adopted. The approach utilises the RORB and TUFLOW modelling packages. Catchment hydrology will be simulated in a hydrologic (RORB) model with flows extracted from the RORB model and applied to the hydraulic (TUFLOW) model to simulate flows through the study area and determine the resultant flood levels, depths, velocities and hazard associated with various historic and design event magnitudes.

The catchment has no active or historic stream gauges, and only one rain gauge within the catchment that is no longer active. Due to this, a joint approach to validating the model outputs has been adopted whereby past rain events will be simulated in RORB and the flows applied to TUFLOW. Resultant flood behaviour will then be presented to the community and feedback on how closely the modelling represents real events obtained. This will guide model parameter selection for design modelling, where design flood magnitudes will be modelled and mapped.

The modelling results will then be applied to various flood risk management activities, including defining the existing flood risk in terms of Average Annual Damages, determining properties and houses at risk of above and below floor flooding in various events, testing structural and non-structural flood mitigation options and advising on potential flood warning improvement possibilities for the township.

The below sections detail the RORB and TUFLOW model builds and results from validation runs completed. Validation runs have been completed for events that occurred in February 1973, April 2001, and January 2011. It is understood these are most recent notable events in Native Hut Creek.

3 HYDROLOGY

3.1 RORB

3.1.1 Overview

A hydrologic model of the Native Hut Creek catchment in its entirety through to the outfall to the Barwon River was developed to determine design flow hydrographs at waterway locations within the catchment to be used as inflow boundary conditions in the hydraulic model.

RORB is a non-linear rainfall-runoff and streamflow routing model for the calculation of flow hydrographs in drainage and stream networks. The model requires catchments to be divided into subareas, connected by a series of conceptual reaches and storage areas. Observed or design storm rainfall is input to the centroid of each subarea. Initial and continuing losses are then deducted, and the excess runoff is routed through the reach and storage network to produce streamflow hydrographs at selected locations within the model (referred to as “print” locations).

The adopted methodology described below is based on current guidelines described in the 2019 revision of Australian Rainfall and Runoff (ARR2019). An ensemble approach was used in this assessment to determine the design flow inputs. The ensemble approach modelled 10 available temporal patterns for each duration recommended in ARR2019. The temporal pattern which determined the median peak flow for each duration was then adopted as the design flow.

3.1.2 Model Setup

3.1.2.1 Subarea and Reach Delineation

Among the data provided to Water Technology by CCMA and Council included a RORB model of the Native Hut Creek catchment developed by CCMA and most recently revised in 2019. The model was reviewed and while it was deemed unsuitable for direct use in this study due to the subarea sizes in the township, the catchment delineation was used as a basis for further division and manipulation of subareas to produce a model which provided a more refined representation of the subareas within the township.

Topographic data which was utilised in the RORB model construction came from a mosaic of two datasets, captured in 2004 and 2008 as part of the National Action Plan for Salinity and Water Quality (NAP). The NAP datasets have a resolution of 5 metres and a stated vertical accuracy of 50cm. While this is not suitable for 2-dimensional hydraulic modelling at the level of resolution and accuracy required for this study, it is suitable for use in subarea and reach delineation for the hydrologic RORB model. In order to make the topographic data “hydrologically correct”, sinks (i.e. local depressions) were filled to allow a continuous flow path to form along the terrain.

The CCMA catchment delineation was compared against a catchment delineation produced using the SAGA GIS topographic processing capabilities in QGIS. The overall delineation was deemed accurate and acceptable after some minor adjustments were made where flow paths were known to follow alternate routes such as culverts or road drainage. The township area was then divided further, with two interstation areas created to allow the two local catchments to be represented at a finer detail while maintaining the same K_c/D_{av} ratio as the rest of the catchment. The interstation areas are shown in Figure 3-2.

Reach lengths were determined using GIS software, following the hydrologically corrected topography in a continuous flow path to the outlet. Reach types in the upper catchment were set to “natural” where a defined waterway was not present and “excavated unlined” where a defined waterway was present. No lined/piped reaches were used. The shapefiles were then imported to ArcRORB where the final data manipulations occurred and the RORB .catg file was produced.

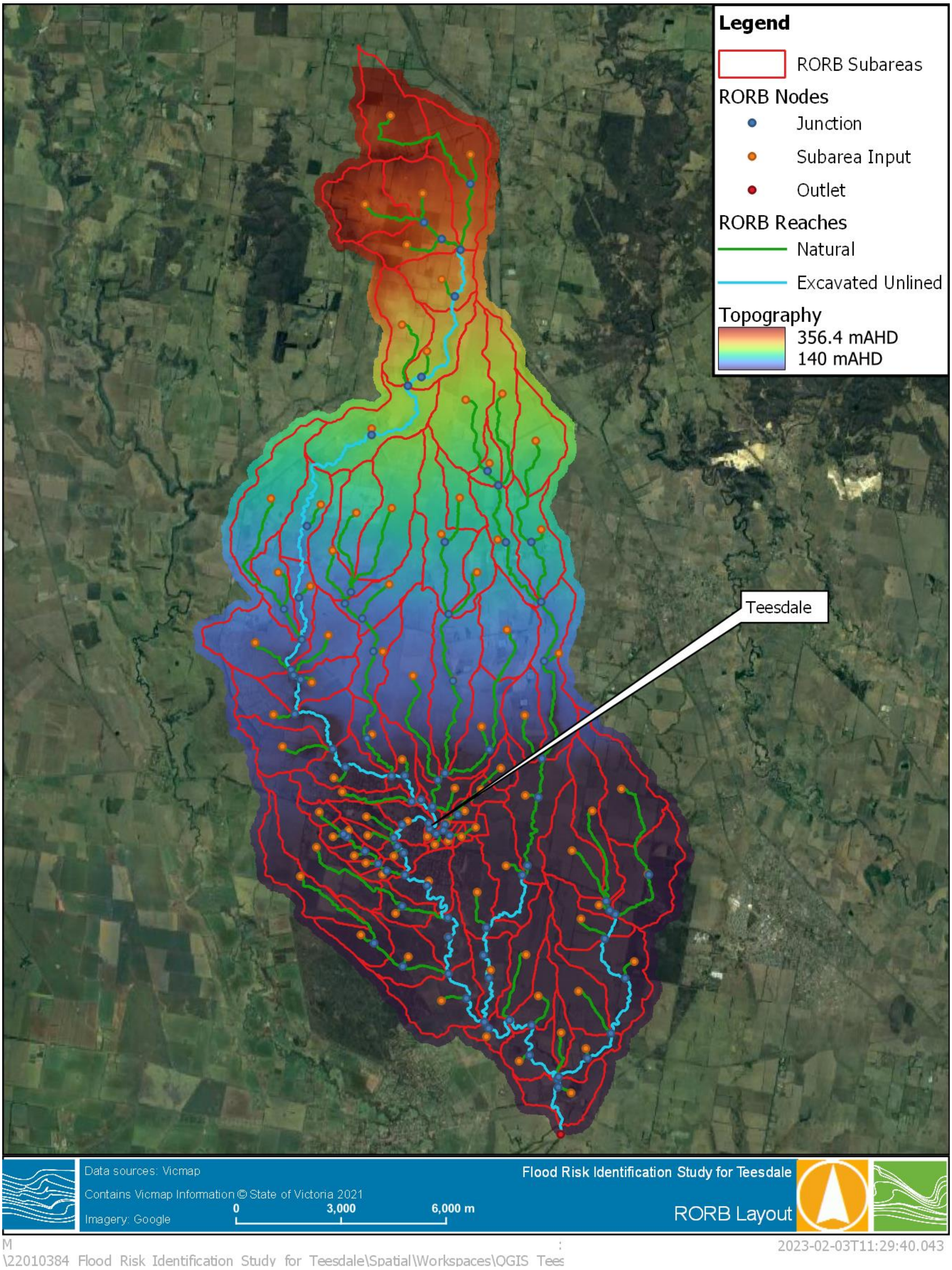

Figure 3-1 RORB model layout

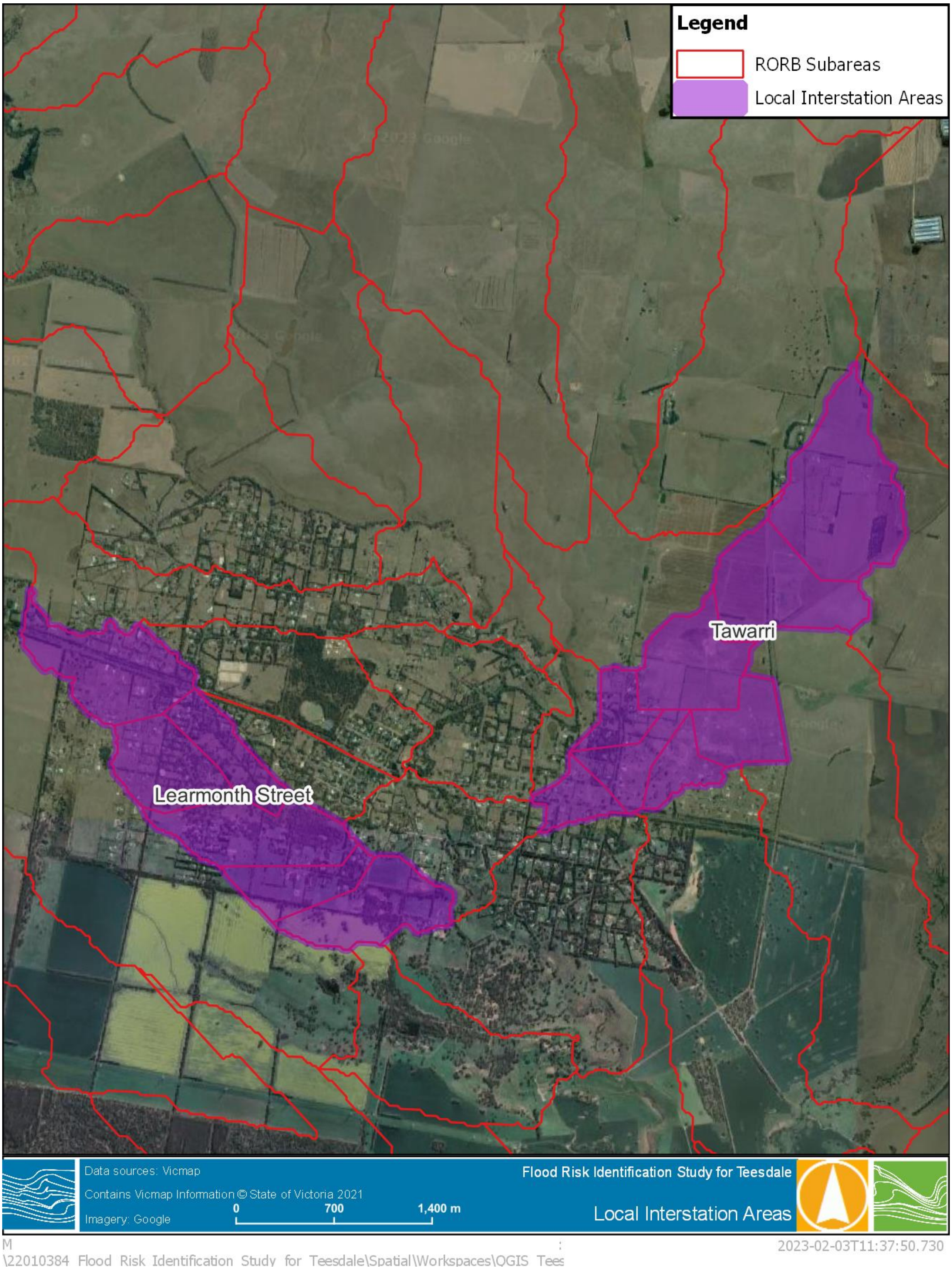

Figure 3-2 RORB Interstation Areas

3.1.2.2 Fraction Impervious

Fraction Imperviousness (FI) was added to each subarea using ArcRORB. A Fraction Imperviousness layer was produced based on the planning scheme zoning and industry standard FI values and was complemented by inspection of aerial photography. Inspection of aerial photography also informed some required changes where the standard FI value was inappropriate for the area. In line with the dominant land use within the catchment, the catchment is largely pervious with the Farming Zone assigned a FI value of 5% (0.05).

The adopted Fraction Impervious distribution is shown in Figure 3-3 and Figure 3-4 below.

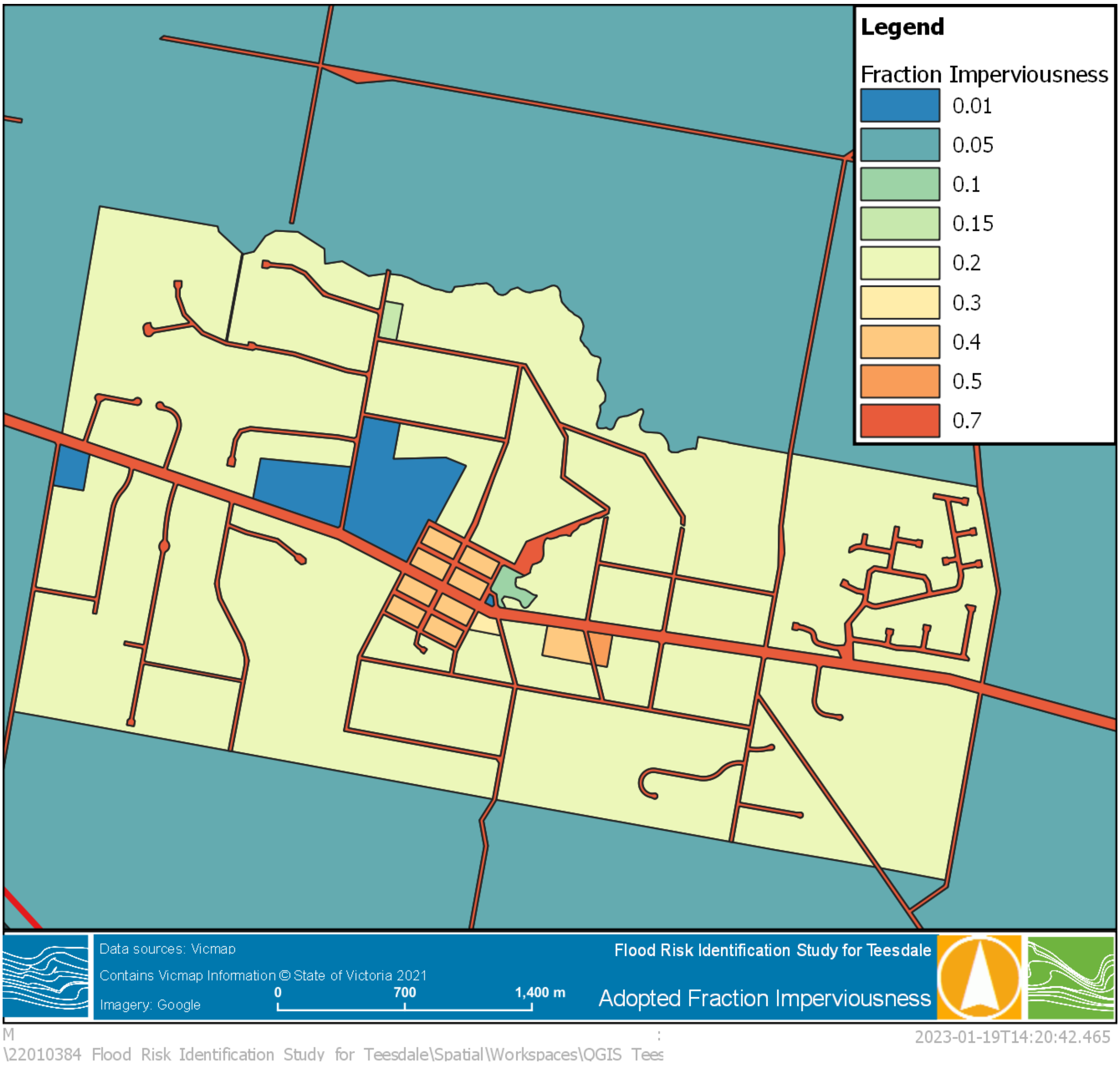

Figure 3-3 Adopted Fraction Imperviousness – Township

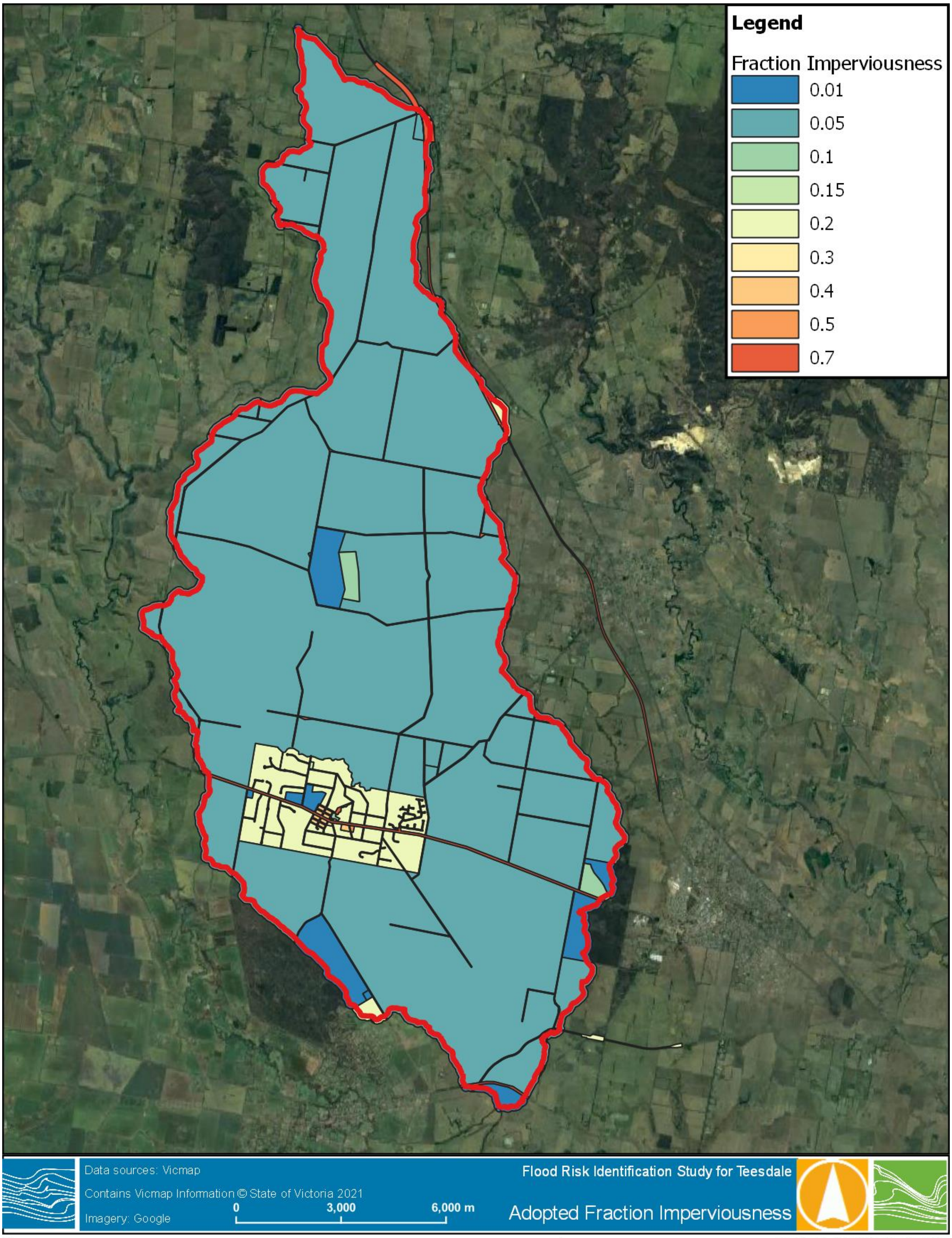

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Figure 3-4 Adopted Fraction Imperviousness – RORB Extent

3.1.3 Rainfall

Daily and sub-daily rainfall stations within or near the catchment that had suitable records for validation modelling are shown in Figure 3-5 and detailed in Table 3-1.

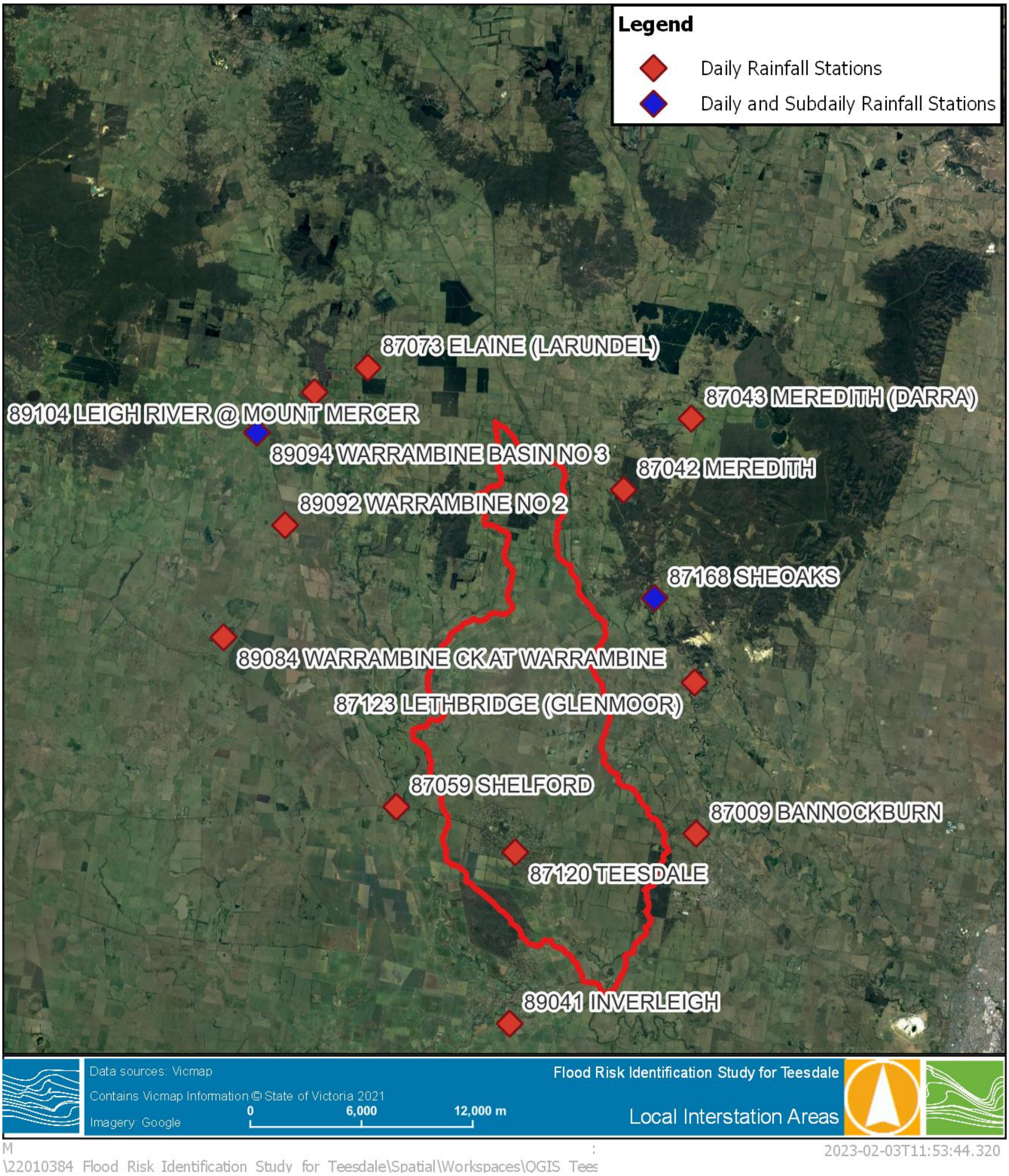

Figure 3-5 Utilised Daily Rainfall Stations

Table 3-1 Daily Rainfall Stations

Site	Name	Start Date	End Date
87042	Meredith	Dec 1887	Current
87009	Bannockburn	Feb 1898	Aug 2016
87059	Shelford	Jan 1887	Dec 2007
87123	Lethbridge (Glenmoor)	Jun 1968	Jul 2001
87168	Sheoaks	Jun 1994	Current
89084	Warrambine Ck At Warrambine	Feb 1972	Current
89092	Warrambine No 2	Jan 1972	Dec 2016
87162	Gnarwarre (Barwon River At Pollocksford)	Oct 1996	Current
89104	Leigh River @ Mount Mercer	Dec 2000	Current
87043	Meredith (Darra)	Sep 1914	Current
87120	Teesdale	Nov 1968	Sep 1979
89041	Inverleigh	Nov 1953	Mar 1974
87073	Elaine (Larundel)	Mar 1888	Oct 1977

Daily rainfall gauges within the area of interest not utilised in this study include Meredith (Wattle Vale) (Station No. 87044) and Teesdale (87092). The period of record for these gauges finished in 1971 and 1914 respectively.

The is minimal sub-daily rainfall stations within the catchment. Sheoaks (87168) records 6-minute pluviograph rainfall and is the closest pluviograph station to the catchment. 6-minute rainfall from the Sheoaks gauge and was utilised to obtain a temporal pattern in hydrologic modelling of the January 2011 and April 2001 events, however does not cover the February 1973 event. For the February 1973 event, rainfall records from Warrambine No. 3 were utilised to obtain a temporal pattern for that storm.

Design Rainfall

Design rainfall depths were obtained from the Bureau of Meteorology Design Rainfall Data System[1]. Rainfall depths were obtained in ascii grid format to enable spatial variation of rainfall to be considered in line with the recommendations of ARR2019 for catchments exceeding 20km^2. Areal reduction factor (ARF) parameters and temporal patterns were obtained from the ARR Datahub[2].

Temporal patterns for the catchment were adopted from the Southern Slopes (Vic) region. Due to the size of the catchment, areal temporal patterns are recommended for use by ARR2019. Areal temporal patterns are available for storms 12 hours in duration and longer. As the 12-hour storm was shown to be the critical duration at Teesdale, point temporal patterns were also tested to check if a shorter storm might produce the critical peak flow. For most events, point temporal patterns also showed the 12-hour storm as being the critical duration, thus areal temporal patterns were applied in design modelling unless there was a significant deviation in the results.

[1] http://www.bom.gov.au/water/designRainfalls/revised-ifd/
[2] https://data.arr-software.org/

The ARF was calculated with an area of 110.14 km^2, corresponding with the catchment area upstream of the Teesdale Bridge. This ensures that the ARF does not overly reduce design rainfalls by considering the entire RORB catchment area of 207 km^2.

3.1.4 Spatial Variation of Design Rainfall

Due to the size of the catchment, spatial variation of the design rainfall was applied in RORB. GIS tools were used to assign a point rainfall (taken as the average of rainfall grid cells that intersect a subarea) to each subarea, and the weighted average rainfall for the catchment and the percentage of the weighted average to be applied to each subarea.

A custom Intensity-Frequency-Duration (IFD) data file was prepared for the catchment, assigning each event magnitude and duration a rainfall depth equal to the weighted average rainfall for that event in the catchment, as shown in Table 3-2. The rainfall depths shown in Table 3-2 are before application of the ARF.

Table 3-2 Native Hut Creek IFD (Weighted Average) Rainfall Totals

	Annual Exceedance Probability (AEP)						Average Recurrence Interval (ARI)			
Duration	50%	20%	10%	5%	2%	1%	1 in 200	1 in 500	1 in 1000	1 in 2000
1 hour	13.0	18.5	22.5	26.7	32.7	37.5	43.1	50.3	56.1	62.3
1.5 hour	14.9	20.9	25.2	29.8	36.1	41.2	47.3	55.2	61.6	68.4
2 hour	16.4	22.8	27.5	32.3	38.9	44.3	50.9	59.3	66.2	73.6
3 hour	19.0	26.1	31.2	36.4	43.7	49.5	57.1	66.7	74.6	83.0
4.5 hour	22.2	30.2	36.0	41.8	49.9	56.5	65.4	76.6	85.7	95.6
6 hour	24.9	33.8	40.1	46.5	55.6	62.8	72.9	85.5	95.9	107.1
9 hour	29.5	40.0	47.4	54.8	65.6	74.2	86.3	101.4	113.8	127.2
12 hour	33.3	45.2	53.6	62.1	74.3	84.2	97.9	115.0	129.2	144.5
18 hour	39.3	53.8	64.0	74.3	89.1	101.0	117.1	137.4	154.0	171.9
24 hour	43.9	60.6	72.4	84.2	101.3	115.0	132.5	155.0	173.3	193.0
30 hour	47.5	66.2	79.3	92.5	111.3	126.3	146.6	171.7	192.3	214.3
36 hour	50.5	70.8	85.0	99.5	119.8	135.9	157.1	183.7	205.3	228.4
48 hour	55.0	77.9	94.1	110.6	132.9	150.8	171.9	199.4	221.6	244.8
72 hour	60.5	86.6	105.4	124.5	149.5	169.0	188.3	215.6	237.2	259.5
96 hour	63.5	91.2	111.4	132.2	158.1	178.6	197.0	224.5	245.7	267.6
120 hour	65.2	93.5	114.4	136.1	162.6	183.3	202.7	230.8	252.7	275.3
144 hour	66.2	94.4	115.8	137.8	164.5	185.4	206.7	236.4	259.8	284.1
168 hour	66.8	94.5	116.0	138.0	164.8	185.8	209.8	241.7	267.3	294.2

An example of spatially varied rainfall depths applied to each subarea is shown in Figure 3-6 below for the 1% AEP, 12-hour event. Design rainfall depths range from 76.9 mm in the south of the catchment up to 95.3 mm in the north for this event. It should be noted that the design spatial pattern differs for every event magnitude and duration.

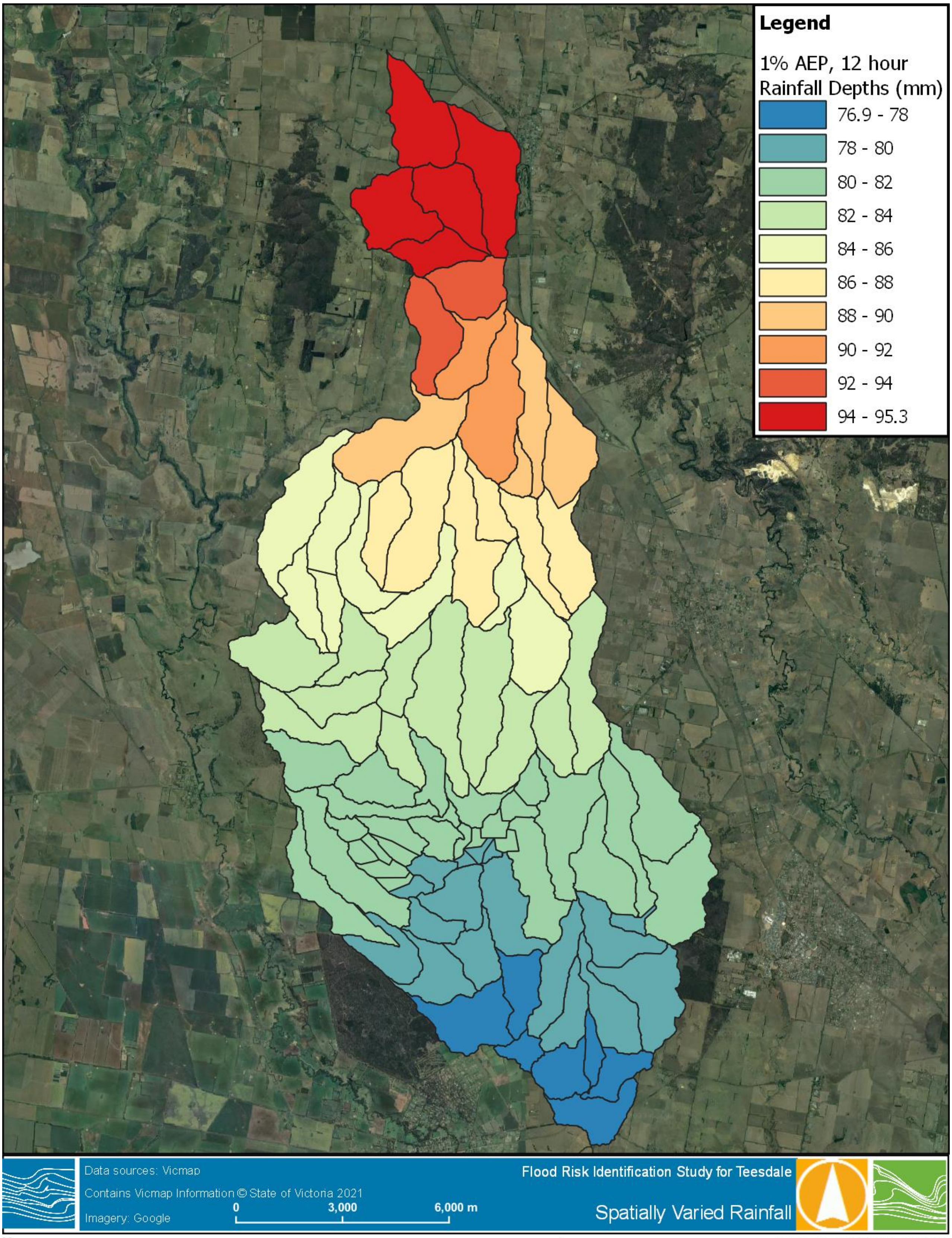

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Figure 3-6 Example of Spatially Varied Rainfall, 1% AEP 12 Hour Event

3.1.4.1 Pre-burst

Losses derived from the ARR datahub are intended to be applied to a whole storm event, while design rainfall depths obtained from the Bureau of Meteorology represent storm bursts. The application of pre-burst rainfall is intended to represent a complete storm by appending the pre-burst to the start of the burst rainfall. This can be achieved by modelling the complete storm and applying the storm Initial Loss, or lowering the Initial Loss to represent a burst Initial Loss according to the following equation:

$$\mathrm{IL}_b = \mathrm{IL}_s - \text{pre-burst depth}$$

For this study, burst Initial Losses were applied by subtracting the median pre-burst depth from the storm Initial Loss and applying the resultant burst Initial Loss to the design burst rainfall.

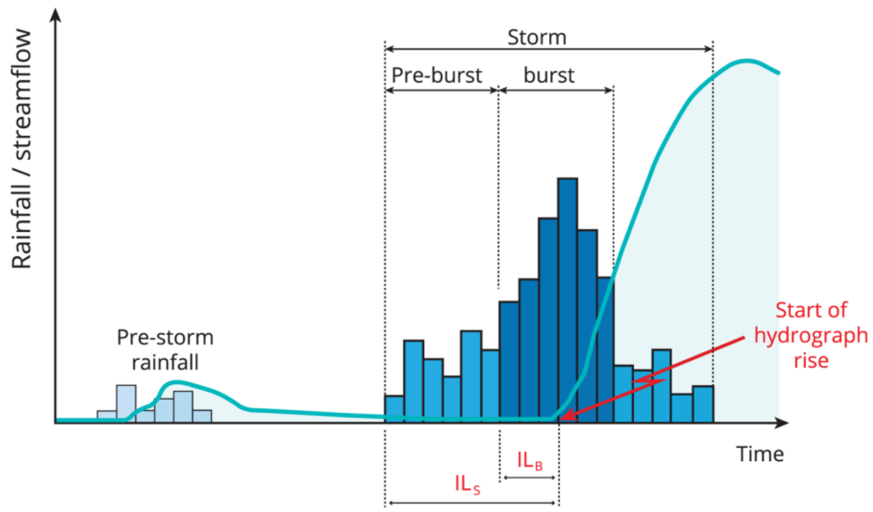

Figure 3-7 Conceptualisation of storm vs burst rainfall and its interaction with Initial Loss[3]

Consideration was given to the Victorian Specific Information of the ARR datahub, which recommends the use of 75th percentile pre-burst depths when applying datahub values for other hydrologic inputs[4]. The median pre-burst depth was selected for the following reasons:

- The catchment sits at the border between loss regions 2 and 3, and the Victorian Specific Information relates only to loss region 3.
- While the adopted losses came from the ARR Datahub, their adoption considered validated loss values from the neighbouring Inverleigh Flood Study, which is considered to be hydrologically similar.
- The adopted losses were reconciled with Regional Flood Frequency Estimation (RFFE) in Table 3-3 below.

Table 3-3 Reconciliation of flows, RORB and RFFE

Event AEP	RFFE (m^3/s)	RORB, Pearse K_c (m^3/s)
10%	51.2	39.7
1%	116	117.7

[3] Sourced from ARR2019, Book 5 Chapter 3
[4] https://data.arr-software.org/vic_specific

3.1.5 Losses

Rainfall losses were sourced from the ARR datahub and compared to losses from previous studies in Table 3-4 below. The datahub losses were similar to those applied in the calibrated Inverleigh Flood Study. Previous CCMA modelling adopted an Initial Loss/Runoff Coefficient modelling approach and is not directly comparable with and Initial Loss/Continuing Loss model.

Table 3-4 Adopted and comparative losses

Model/Source	Storm Initial Loss (mm)	Continuing Loss (mm/hr)
ARR Datahub (adopted)	**17**	**3.2**
Inverleigh Flood Study	24	3.1
GHD Regional Study	31	1
CCMA Native Hut Creek	24	N/A (Runoff Coefficient)

Given the close agreement between the datahub values and those adopted in the Inverleigh Flood Study, Datahub losses were adopted for validation and design modelling.

3.1.6 RORB Parameters

In addition to the previously discussed inputs, RORB requires two parameters which influence the catchment storage, routing and non-linearity. K_c impacts the relative delay time of reach storages in the model and m is a representation of the catchment's non-linearity. In accordance with the recommendations of the RORB manual and current standard practice in RORB modelling, the m value was left at the default value of 0.8.

In selecting a value of K_c in the absence of streamflow data to calibrate the model with, previous modelling of the catchment and neighbouring catchments was considered. A number of published relationships are available with several recommended in the RORB software program. Most of the relationships are of similar form and involve only the single catchment variable, area A in km^2, since this has been found to be the dominant variable. ARR2019 Book 7 recommends the use of a regional or local based adoption of k_c value where a lack of calibration information is available. To undertake the validation/verification modelling, a range of previously adopted K_c values from local or nearby catchments were considered and are shown in Table 3-5.

Table 3-5 K_c values adopted in previous/nearby modelling

Model	K_c	K_c/D_{av}
Leigh River - Upstream of Mt Mercer (CCMA, 2017)	25.6	0.72
Leigh River - between Mt Mercer and Shelford (CCMA, 2017)	17.5	0.84
Leigh River -between Shelford and Inverleigh* (CCMA, 2017)	13.5	1
Native Hut Creek Flood Model (CCMA, 2017)	17.4	0.72
Low/Mid Barwon Flood Model (CCMA, 2016)	Not extracted	1.25**
Regional Flood Mapping - Native Hut Creek area (GHD, 2016)	28	N/A

* There are only 3 subareas between Shelford and Inverleigh in the Leigh River flood model.

** The Low/Mid Barwon Flood Model was not focussed on Native Hut Creek, but adopted the Kc/Dav relationship developed by Pearse et al (2002)5 and available in the RORB interface.

[5] Pearse, M., Jordan, P. and Collins, Y. (2002), A simple method for estimating RORB model parameters for ungauged rural catchments. Instn. Engrs. Australia, 27th Hydrology and Water Resources Symposium, CD_ROM, 7 pp.

A range of values from which to select this ratio are provided in the above table, thus the initial validation modelling has taken two ratios, 0.72 (based on the nearby catchment ratio listed as CCMA) and 1.25 (based on Pearse equation), as starting points for modelling with a view to verifying the results through community consultation. The sensitivity of peak flow rate and ultimately peak flood levels throughout the town are discussed in Section 5. The final kc parameter will be selected based on feedback from community consultation and the project steering committee.

It is common practice to adopt the same ratio of K_c/D_{av} when translating the K_c parameter between models of similar catchments. To maintain similar routing characteristics for Native Hut Creek and the tributaries to be mapped, the K_c/D_{av} ratio was maintained at the chosen ratio for all areas. Thus different values of K_c were applied to each area as shown in Table 3-6. Throughout the remainder of the report, when referring to kc values, the Native Hut Creek catchment value will be used.

Table 3-6 Adopted K_c values at each interstation area

Interstation Area	D_{av}	K_c, CCMA Ratio (K_c/D_{av}=0.72)	K_c, Pearse Mean (K_c/D_{av}=1.25)
Tawarri	2.04	1.46	2.55
Learmonth Street	2.49	1.79	3.11
Native Hut Creek	26.32	18.90	32.90

4 HYDRAULICS

4.1 TUFLOW

4.1.1 Overview

A hydraulic model of Teesdale was built using the TUFLOW modelling package. The model utilised a cell size of 3 metres, considered sufficient to represent the waterway and hydraulic features while keeping run times within reasonable limits. Hydraulic structures were represented as 2-dimensional flow constrictions (bridges) and 1-dimensional structures (culverts and pipes). Model topography utilised the recently captured 2021 Golden Plains LiDAR. A summary of key model parameters has been provided in Table 4-1 below.

Table 4-1 Key TUFLOW Parameters

Parameter	Value
Model Build	2023-03-AA-iSP-w64
Model Precision	Single Precision
Grid Cell Size	3 metres
Sub Grid Sampling	Not adopted
Solution Scheme	HPC
Inflows	Source-Area boundaries coupled with streamlines
Outflow	Height-Flow Slope of 0.3%
Hydraulic Roughness	Manning's 'n', varies with land use
1-Dimensional elements	Culverts and pipes linked to 2-D domain

4.1.2 Model Boundaries and Extent

Flows extracted from the RORB model (discussed in Section 2.1) were applied to the TUFLOW hydraulic model via 2-dimensional source area (2d_sa) boundaries. Where a waterway existed, streamlines were utilised to apply flows hydrographs to the waterway. The downstream boundary comprised of a height-flow (HQ) boundary with the slope set to 0.3%, which was derived from the stream bed slope, as measured from LiDAR in the vicinity of the boundary. The model extent was set to capture the entirety of the Native Hut Creek and tributary floodplains within Teesdale.

The model extent and boundary locations are shown in Figure 4-1.

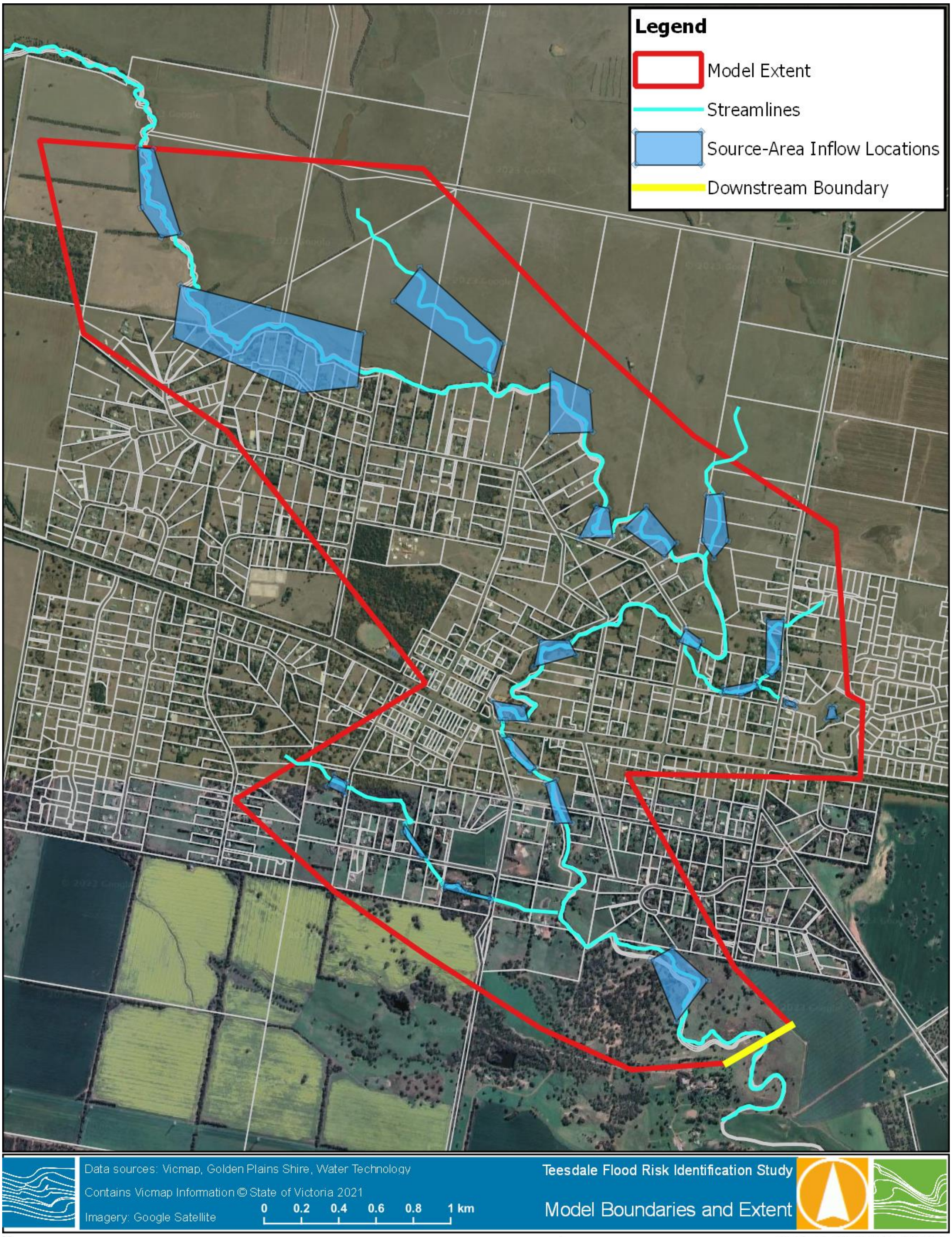

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Figure 4-1 TUFLOW Extent and Model Boundaries

4.1.3 Model Topography

The Digital Elevation Model (DEM) used for hydraulic modelling was developed from the 2020-2021 Golden Plains Area LiDAR, supplied by the Department of Energy, Environment and Climate Action (DEECA, formally the Department of Environment, Land, Water and Planning) under a Creative Commons 4.0 Licence[6]. The dataset was sourced from Elvis Elevation and Depth[7]. LiDAR data utilised in the model was verified against feature survey of road transects as described in R01 – Data Collation and Validation. The verification found the LiDAR data was suitable for use in the hydraulic modelling. The 0.5 metre resolution DEM was resampled within TUFLOW to 3 metre resolution.

Alterations to the LiDAR DEM were made as follows:

- Barker Street was reinstated at the crossing (LiDAR post processing had removed the culverts/road surface from the DEM).
- The Tawarri basin wall was removed from the DEM for historic event validation runs.

The model topography, as processed by TUFLOW, is shown in Figure 4-2 below.

[6] https://creativecommons.org/licenses/by/4.0/legalcode
[7] https://elevation.fsdf.org.au/

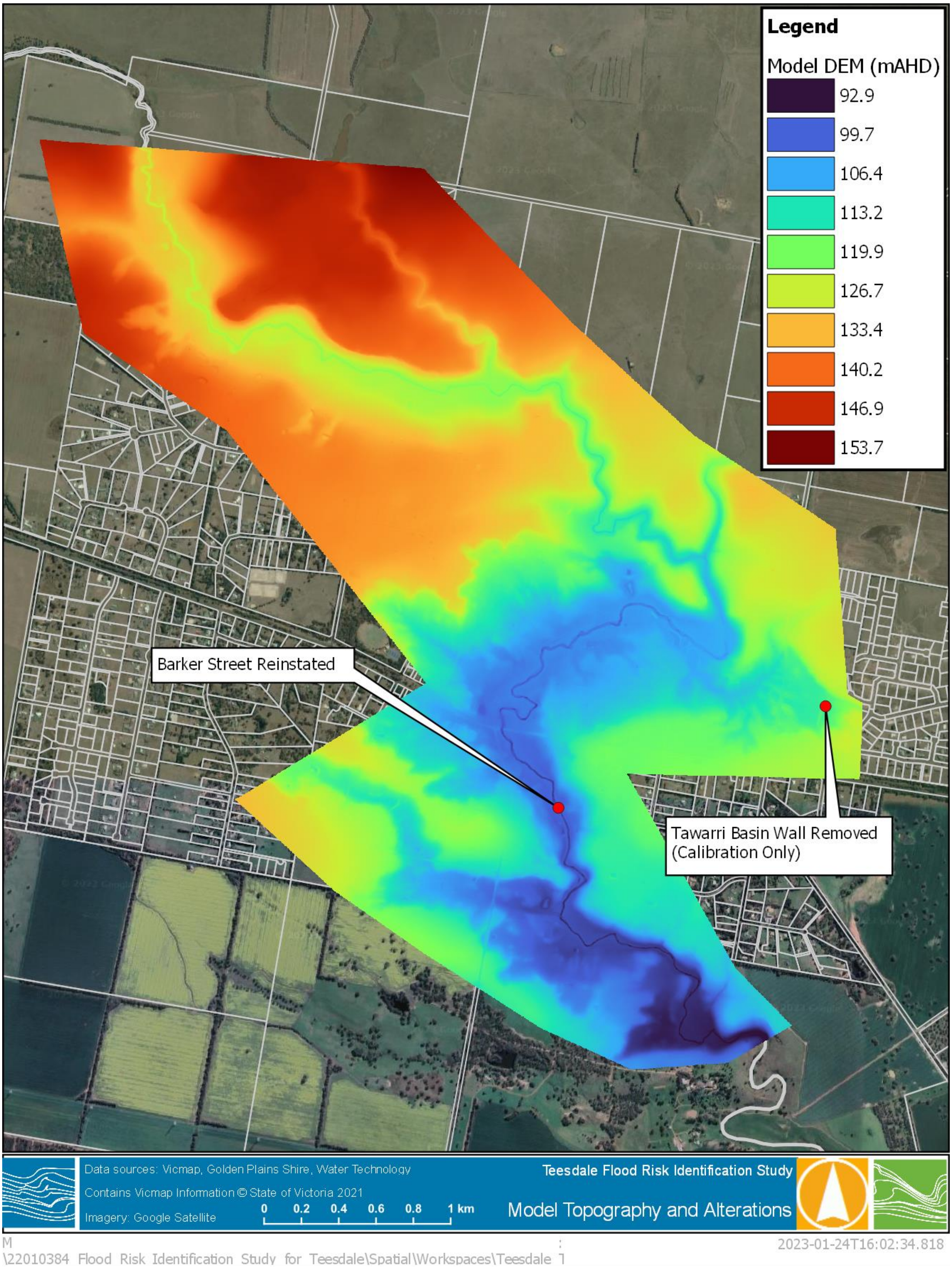

Figure 4-2 Model Topography

4.1.4 Hydraulic Roughness

Hydraulic roughness within the 2-dimensional model domain was applied as Manning's 'n' roughness coefficient. Manning's 'n' was determined using aerial imagery and land use classifications as determined from the Golden Plains Planning Scheme. Roughness coefficients were determined using industry standard/expected values and adjusted during the validation model runs.

During the validation process, roughness values were adjusted after further inspection of aerial photography, photographs taken during the site visit, and analysis of results against available information. This resulted in the waterway roughness being increased to account for its vegetated ephemeral nature, and delineation of areas of moderate vegetation (trees).

The adopted roughness coefficients are summarised in Table 4-2. Figure 4-3 shows a map of the adopted roughness values.

Table 4-2 Hydraulic Roughness

Land use / Topographic description	Roughness coefficient (Manning's n)
Pasture and Grasses	0.05
Sealed Roads (entire reserve)	0.02
Unsealed Roads (entire reserve)	0.03
Township Zone	0.20
Low Density Residential	0.06
Medium Density Bushland	0.08
Vegetated Ephemeral Waterway (Native Hut Creek)	0.07

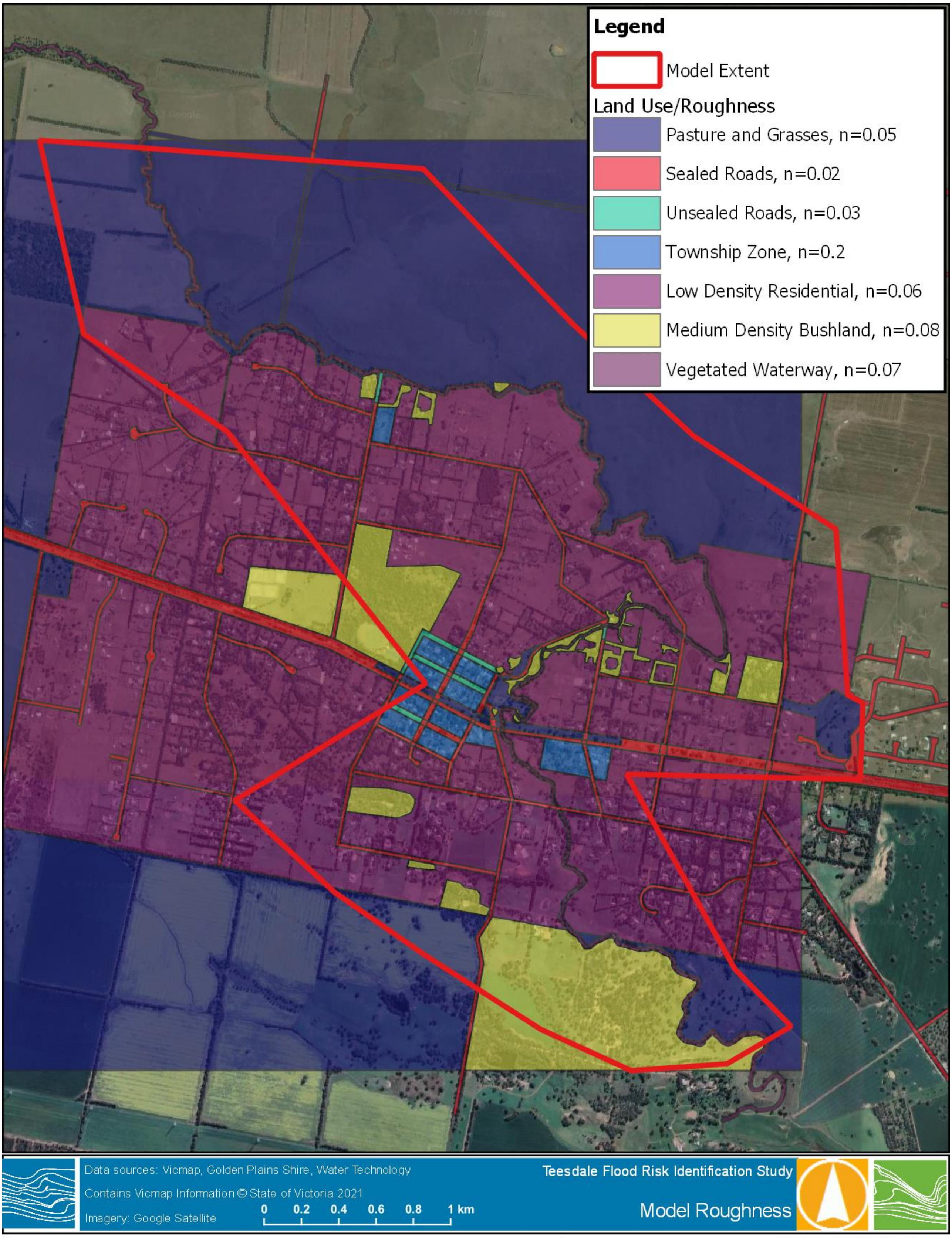

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Figure 4-3 Hydraulic model roughness

4.1.5 Structures

Several key waterway structures were included in the hydraulic model. The Tolsons Road/Stones Road and Main Road (Bannockburn-Shelford Road) bridges were modelled as 2-dimensional layered flow constrictions. Bridge data was obtained from design drawings and feature survey, with pier form loss coefficients determined in accordance with the methods detailed in *Hydraulics of Bridge Waterways* (1978) and deck/railing form losses estimated in accordance with advised coefficients on the TUFLOW wiki[8].

The model included culverts as 1-dimensional components. Culvert data was supplied by Golden Plains Shire with data gaps filled from LiDAR (invert levels) and a site visit for unknown diameters. Barker Street is the only culvert located on Native Hut Creek within the model extent and was surveyed as detailed in R01 – Data Collation Report.

The locations of hydraulic structures included in the model are shown in Figure 4-4 below.

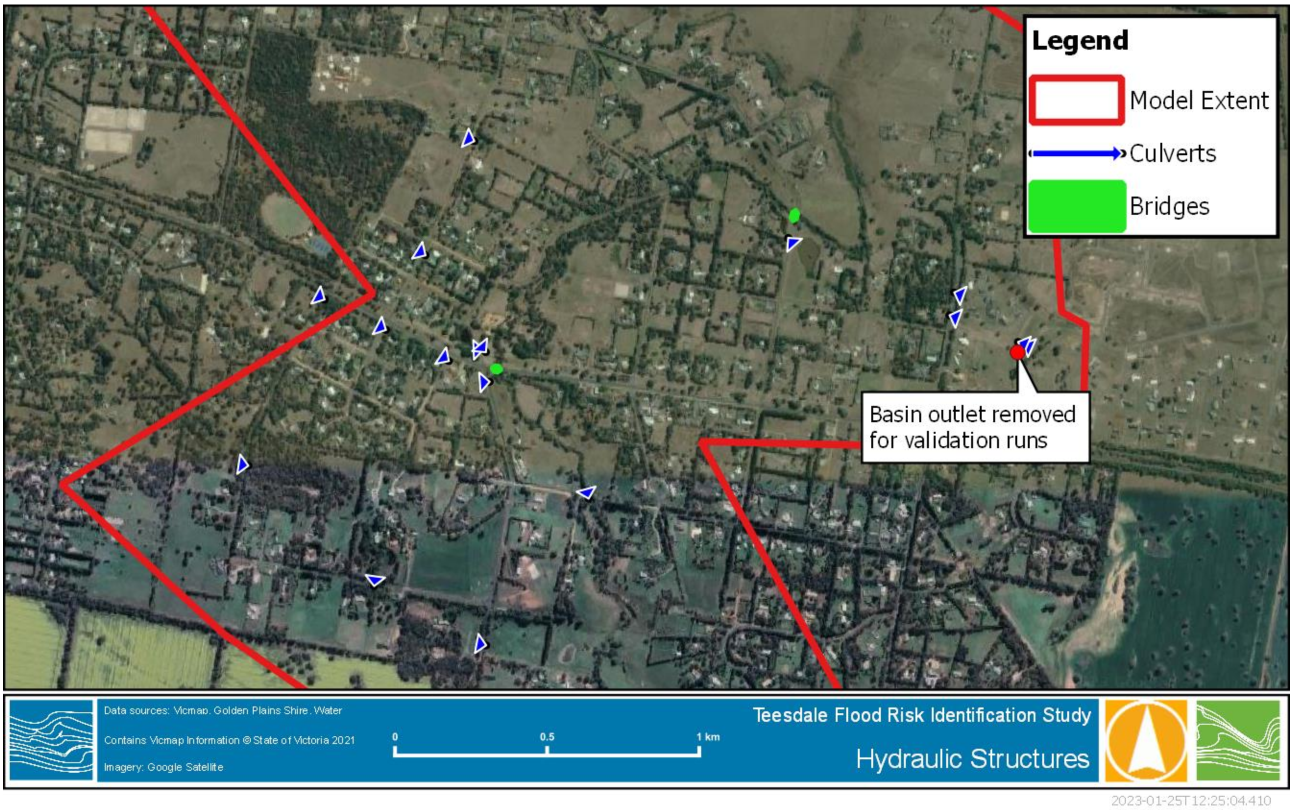

Figure 4-4 Hydraulic structures

[8] https://wiki.tuflow.com/index.php?title=TUFLOW_2D_Hydraulic_Structures

5 MODEL RESULTS

5.1 Validation Runs

Due to the lack of calibration information (no streamflow gauge or measured flood heights), information gained from community consultation was used to rank the major flood events along the Native Hut Creek. This included anecdotal evidence and photos of the flooding. From this information, three flood events were agreed upon to undertake a combined hydrology/hydraulic validation.

The following sections detail the validation modelling completed for three recent significant flow events in Native Hut Creek: February 1973, April 2001, and January 2011. The rainfall from these three events has been input to the RORB hydrological model described in section 2.1 and the resultant flows extracted from the model and applied as inputs to the TUFLOW hydraulic model described in section 2.2. The resultant flood levels, depths and velocities have been presented to the community for comment at a follow up consultation session with additional feedback utilised to determine the design parameters.

5.1.1 February 1973

Significant rainfall fell across central Victoria from the 4th – 6th of February with major flooding occurring at Teesdale, Inverleigh, Yea and Seymour and flooding also occurring more locally at Lara and Little River. Flooding at Teesdale occurred as a result of rainfall totals throughout the Native Hut Creek catchment generally ranging from 170mm to 190mm in two days. It is understood this flood is one of the largest flood events of living residents. Information from this event included photographs provided during the community consultation session (Figure 5-5).

Reporting in The Age[9] newspaper on the 7th of February 1973 stated:

At Teesdale, the swirling floodwaters surged through the township, causing widespread damage and flooding homes. Three new tennis courts were wrecked as the floodwaters peeled back the new malthoid topping on the courts.

And in a separate article on the same day:

At least another 30 homes in the nearby townships of Batesford, Teesdale and Shelford were evacuated when the swirling floodwaters — believed to be the worst on record — swept through at about midday yesterday.

5.1.1.1 Rainfall

Rainfall totals recorded between 9am on the 4th February and 9am on the 6th February at stations near and within the Native Hut Creek catchment are shown in Table 5-1, with the rainfall distribution and isopleths are shown in Figure 5-1.

---

[9] The Age, *Swirling Floodwaters cut off Geelong,* February 7 1973, accessed from https://www.watoday.com.au/national/victoria/from-the-archives-1973-swirling-floodwaters-cut-off-geelong-20230202-p5chfm.html

Table 5-1 February 1973 Rainfall Totals

Station	Name	Total to 9am 5th February (mm)	Total to 9am 6th February (mm)	Total Rainfall (mm)
89092	Warrambine No 2	35.8	146.1	**181.9**
89084	Warrambine Ck at Warrambine	0*	155.2	**155.2**
87123	Lethbridge (Glenmoor)	72.1	117.6	**189.7**
87059	Shelford	40.6	117.9	**158.5**
87042	Meredith	65.5	128.8	**194.3**
87009	Bannockburn	47.5	134.6	**182.1**
87043	Meredith (Darra)	62.5	125.2	**187.7**
87120	Teesdale	71.1	106.7	**177.8**
89041	Inverleigh	33.5	101.6	**135.1**
87073	Elaine (Larundel)	75.4	136.4	**211.8**

* While not clearly indicated in the data, it is assumed that the 155.2mm recorded at Warrambine Ck at Warrambine was recorded over two days.

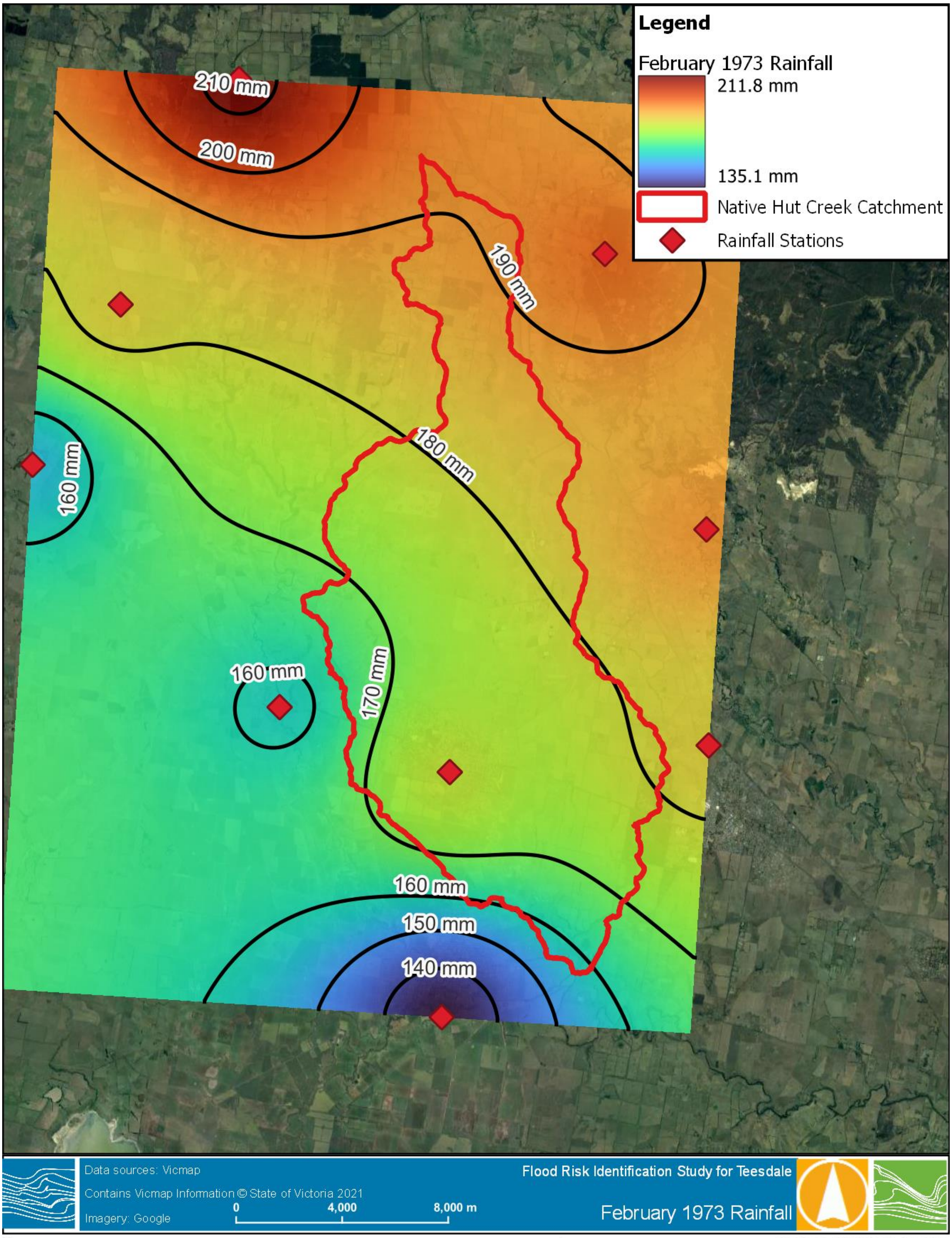

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Figure 5-1 Rainfall Distribution and Isopleths for February 1973

5.1.1.2 Streamflow

Flow hydrographs extracted from the RORB model at the Bannockburn-Shelford Road bridge are shown in Figure 5-2 for the two modelled K_c values discussed in section 2.1.5. The peak flow rates between the two events are similar for both k_c values with the CCMA value (18.9) producing a peak flow rate of 180 m^3/s compared to 158 m^3/s. Adopting Pearse kc of 32.9 shows a relatively large delay in the peak timing (~8-10 hours).

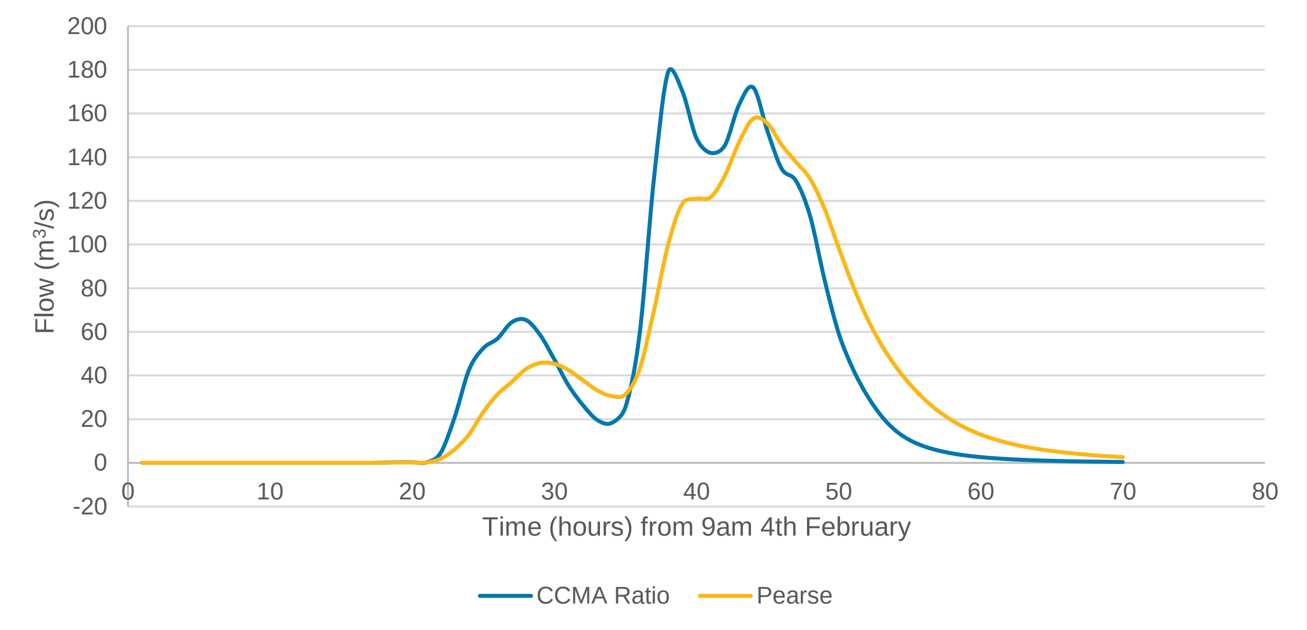

Figure 5-2 February 1973 modelled streamflow at Teesdale Bridge

5.1.1.3 Flood Behaviour

Flow hydrographs were extracted from the RORB model at various locations suitable for inclusion in the TUFLOW model (see section 2.2.2 for more detail). Peak water levels, depths and velocities are similar between the two runs given the similarities in flow. On average, adoption of the CCMA ratio resulted in flood levels ~60mm higher than the Pearse ratio.

Modelled flood impacts include inundation of the northern portion of residential properties along River Drive and Squires Road (however no residential properties appear to have existed there at that time), with the flood spreading out of bank at the bend in Native Hut Creek upstream of the Tolsons/Stones Road bridge. Beyond this point the floodplain is engaged, with the flow path ranging from 115 to 330 metres wide. The Tolsons/Stones Road bridge is drowned out, Pantics Road is completely inundated (see Figure 5-5) including the intersection with Squires Road, generally to depths greater than 0.5 metres. The northern part of Sutherland Street is inundated, with depths on that road exceeding 1 metre in places. Turtle Bend is completely inundated and the Bannockburn-Shelford Road overtops, downstream of which three current houses appear to be close to inundated by floodwater. At Barker Street and downstream, the flood extent begins to narrow before meeting the Learmonth Street tributary and spreading out again towards the Woolbrook homestead property.

The similarities between the two scenarios provide little point of separation at a broader scale. It is recommended the maps be presented for comment by the community to identify if any of the subtle differences can be reconciled with anecdotal evidence. One point of difference between the two model runs occurs at the Bannockburn-Shelford Road bridge, where the CCMA ratio run completely overtops the road while the Pearse ratio leaves small islands at the bridge abutments. The peak flood depths for the study area and township are shown in Figure 5-3 to Figure 5-4 and photos along Pantics Road from the event are shown in Figure 5-5.

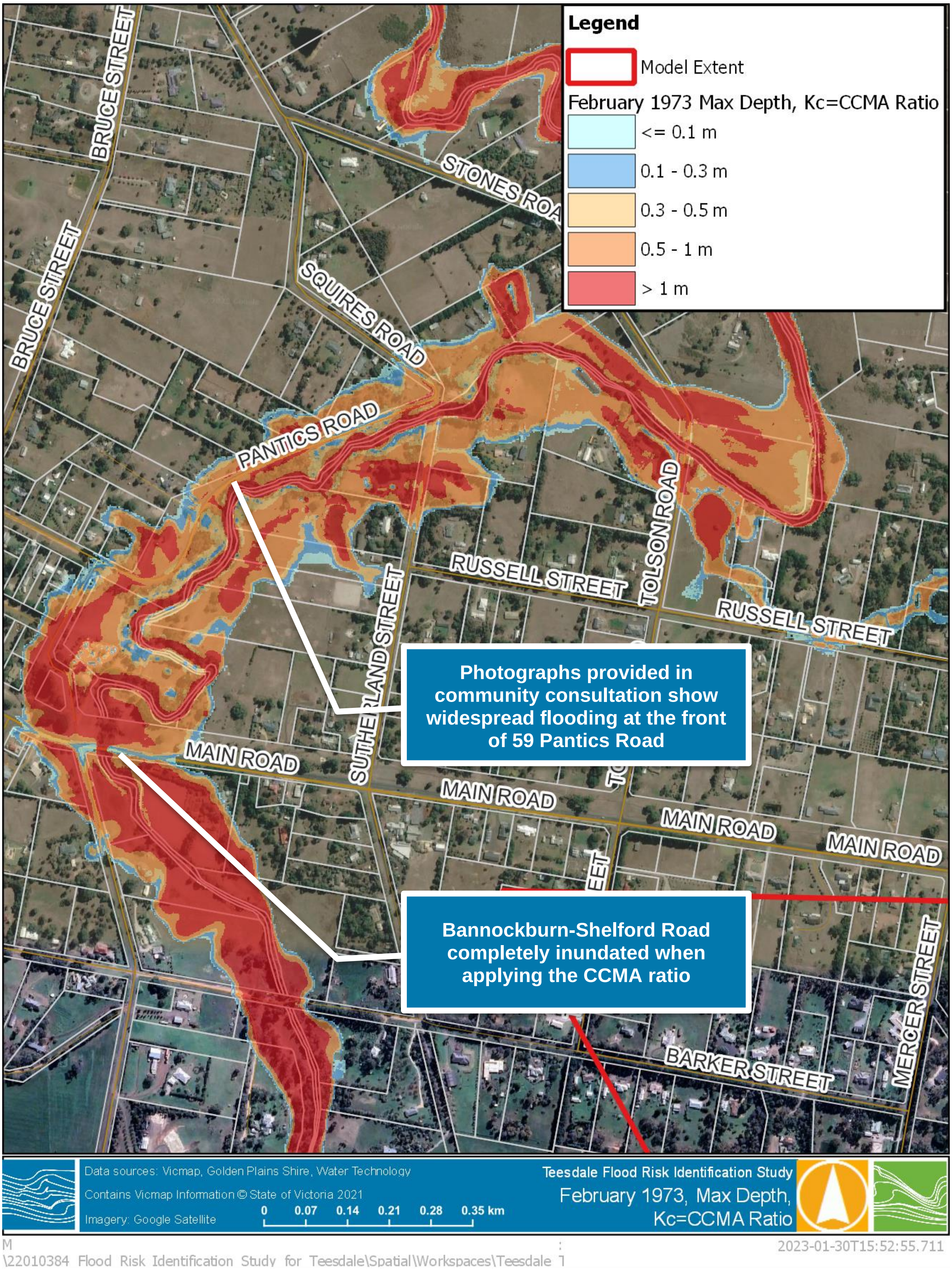

Figure 5-3 February 1973 Flood Depths, K_c=CCMA Ratio (Township)

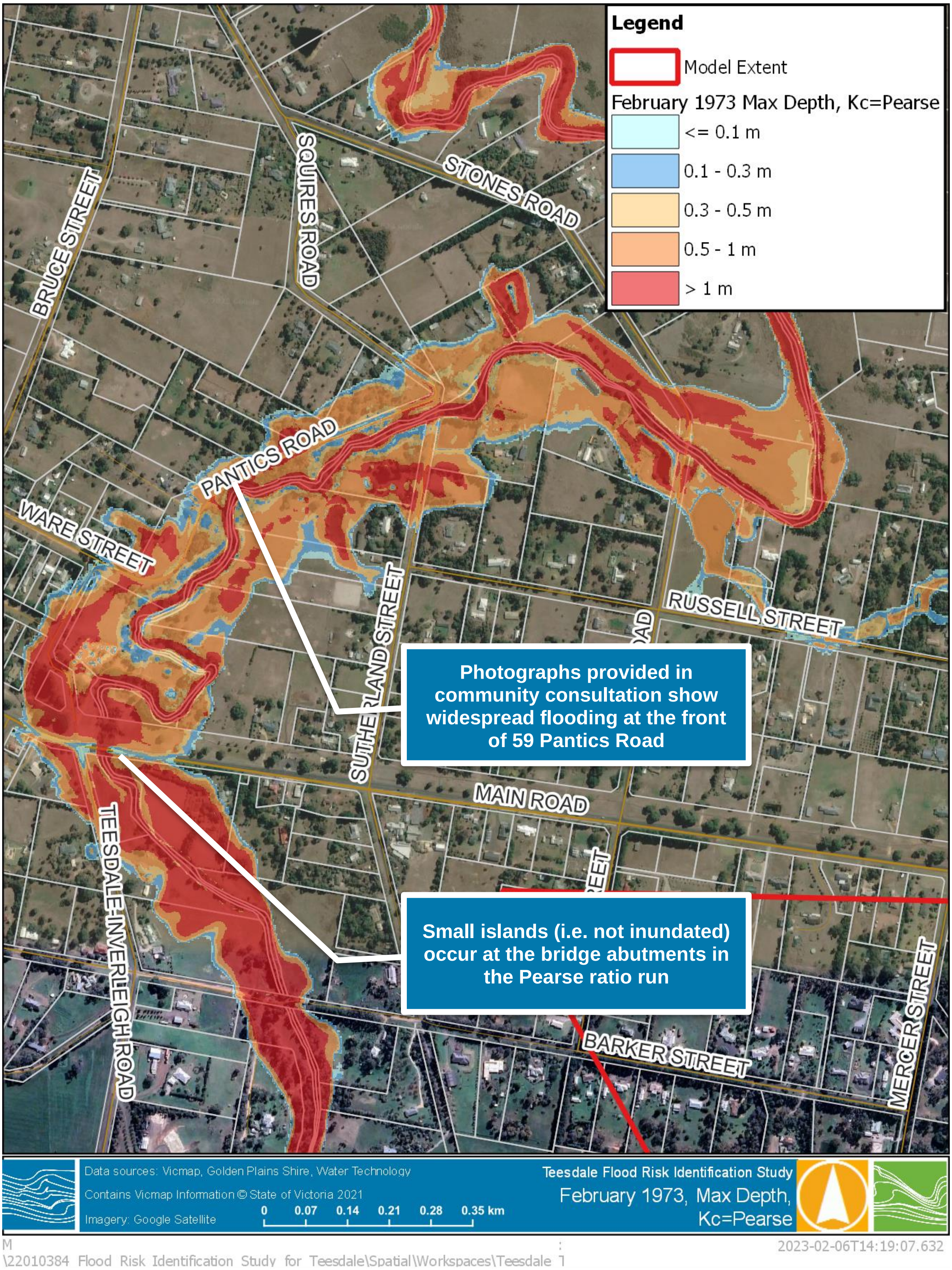

Figure 5-4 February 1973 Flood Depths, K_c=Pearse (Township)

Figure 5-5 Photographs of 1973 flood event provided by the resident of 59 Pantics Road

5.1.2 April 2001

A significant rain event occurred in the Barwon and Moorabool catchments from the 21st to the 24th of April, 2001. The event caused moderate flooding in Geelong. The event was mentioned during the first community consultation session for the Teesdale Flood Risk Identification Study, with one attendee recalling that the Bannockburn-Shelford Road was overtopped during the event causing the road to be temporarily closed. During the second community consultation, it was noted that the Turtle Bend area experienced minor, if any, inundation. While these two observations are conflicting, the closure of the road may not have been a result of riverine flooding and further information regarding the closure has not been obtained. It is understood this event was not as large as the 1973 event. Rainfall totals in the Native Hut Creek generally varied between 140mm and 150mm for the three-day event.

5.1.2.1 Rainfall

Rainfall totals recorded between 9am on the 21st April and 9am on the 24th April at stations near and within the Native Hut Creek catchment are shown in Table 5-2, with the rainfall distribution and isopleths are shown in Figure 5-6.

The rainfall temporal pattern was extracted from the Sheoaks pluviograph rainfall station which recorded 30-minute rainfall intervals.

Table 5-2 April 2001 Rainfall Totals

Station	Name	Total to 9am 22nd April (mm)	Total to 9am 23rd April (mm)	Total to 9am 24th April (mm)	Total Rainfall (mm)
89104	Leigh River at Mount Mercer	52	48.8	24.6	**125.4**
89092	Warrambine No 2	72.2	50	23	**145.2**
87168	Sheoaks	65	50	36	**151**
87162	Gnarwarre (Barwon River at Pollocksford)	66	64	31	**161**
87123	Lethbridge (Glenmoor)	72	53	37	**162**
87059	Shelford	72.8	58.2	18.6	**149.6**
87009	Bannockburn	missing	106.6	26.2	**132.8**
87043	Meredith (Darra)	62.6	31.8	51	**145.4**

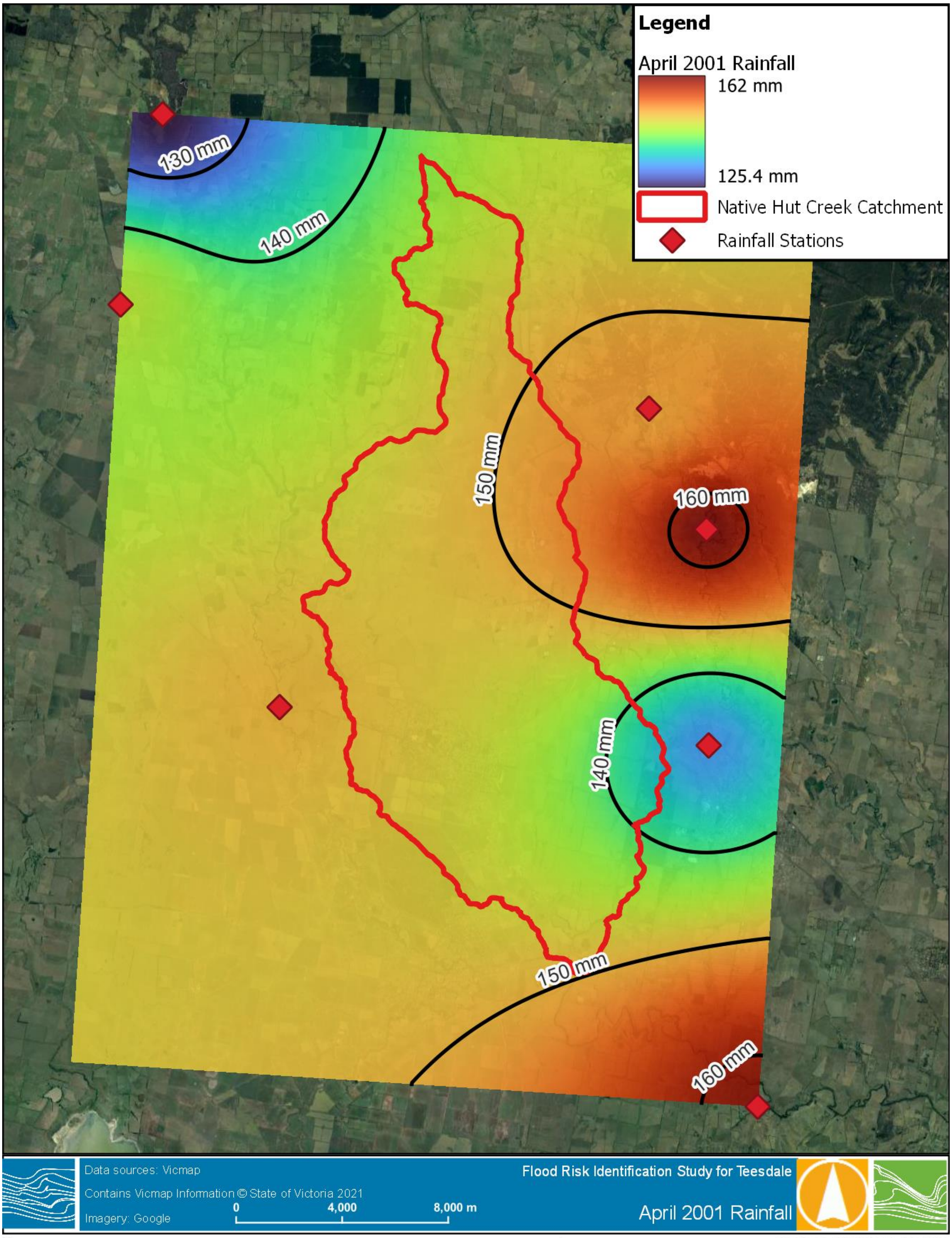

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Figure 5-6 Rainfall Distribution and Isopleths for April 2001

5.1.2.2 Streamflow

Flow hydrographs extracted from the RORB model at the Bannockburn-Shelford Road bridge are shown in Figure 5-2 for the two modelled K_c values discussed in section 2.1.5. Both modelled values of K_c produce four distinct peaks with a significant impact on the peak flood level of 91 m^3/s (CCMA) and 53 m^3/s (Pearse) kc adopted. The lower K_c value modelled exhibits higher peaks and lower troughs in the hydrograph, with runoff getting through the system much faster with the lower relative delay time.

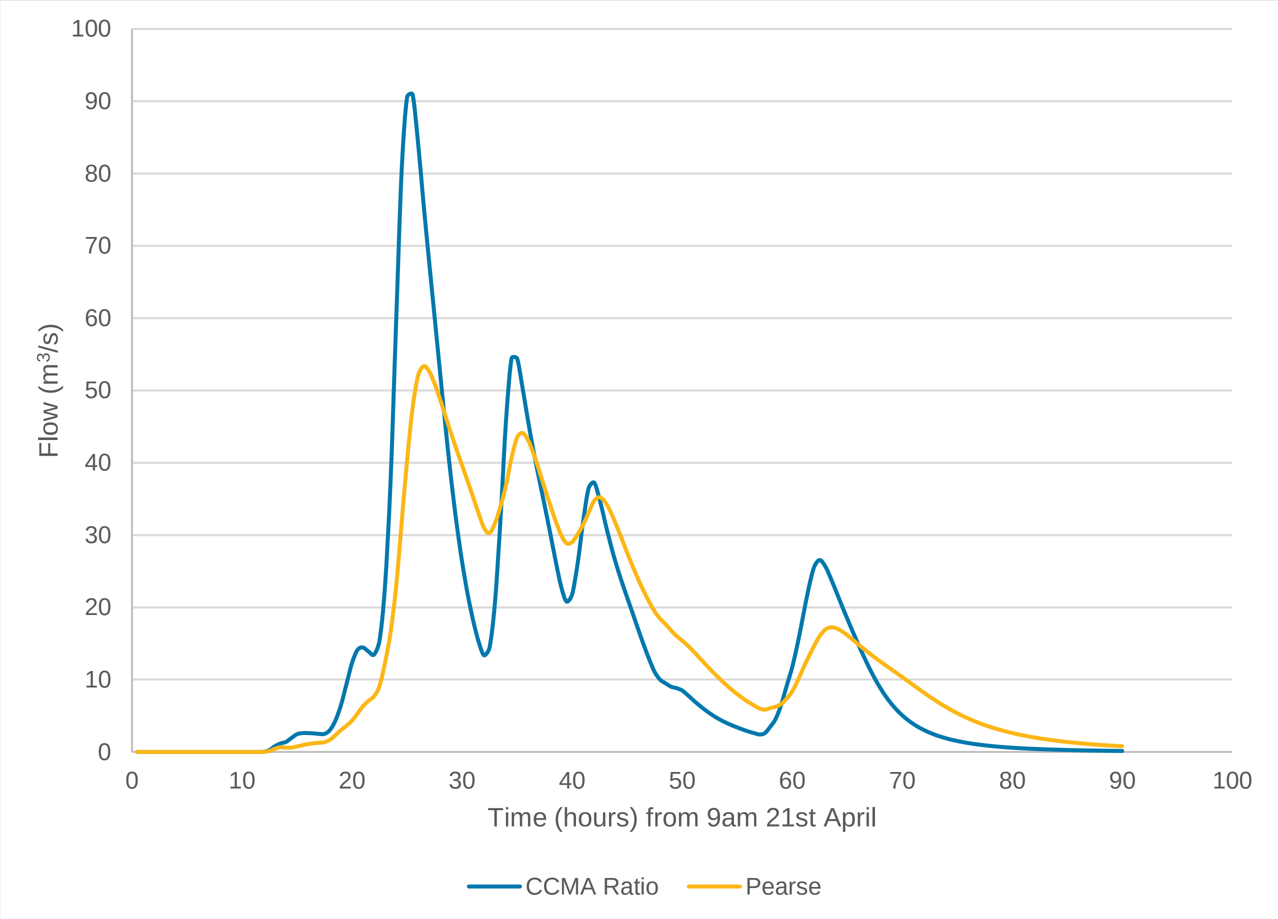

Figure 5-7 April 2001 modelled streamflow at Teesdale Bridge

5.1.2.3 Flood Behaviour

Unlike the February 1973 modelling runs, the difference in K_c selection caused a significant difference in flood levels and depths in the results. While both events feature out of bank flows, the increase in peak flow associated with the lower K_c translates to differences in water levels, of generally between 0.3 to 0.5 metres through the main flow paths.

The lower K_c scenario (CCMA Ratio) resulted in overtopping of the Shelford-Bannockburn Road as discussed in the community consultation but did not occur in the Pearse ratio scenario. The CCMA ratio scenario also resulted in much greater depths of flooding on Turtle Bend, in contrast to one of the community observations gathered.

The peak flood depths for the study area and township are shown in Figure 5-8 to Figure 5-9.

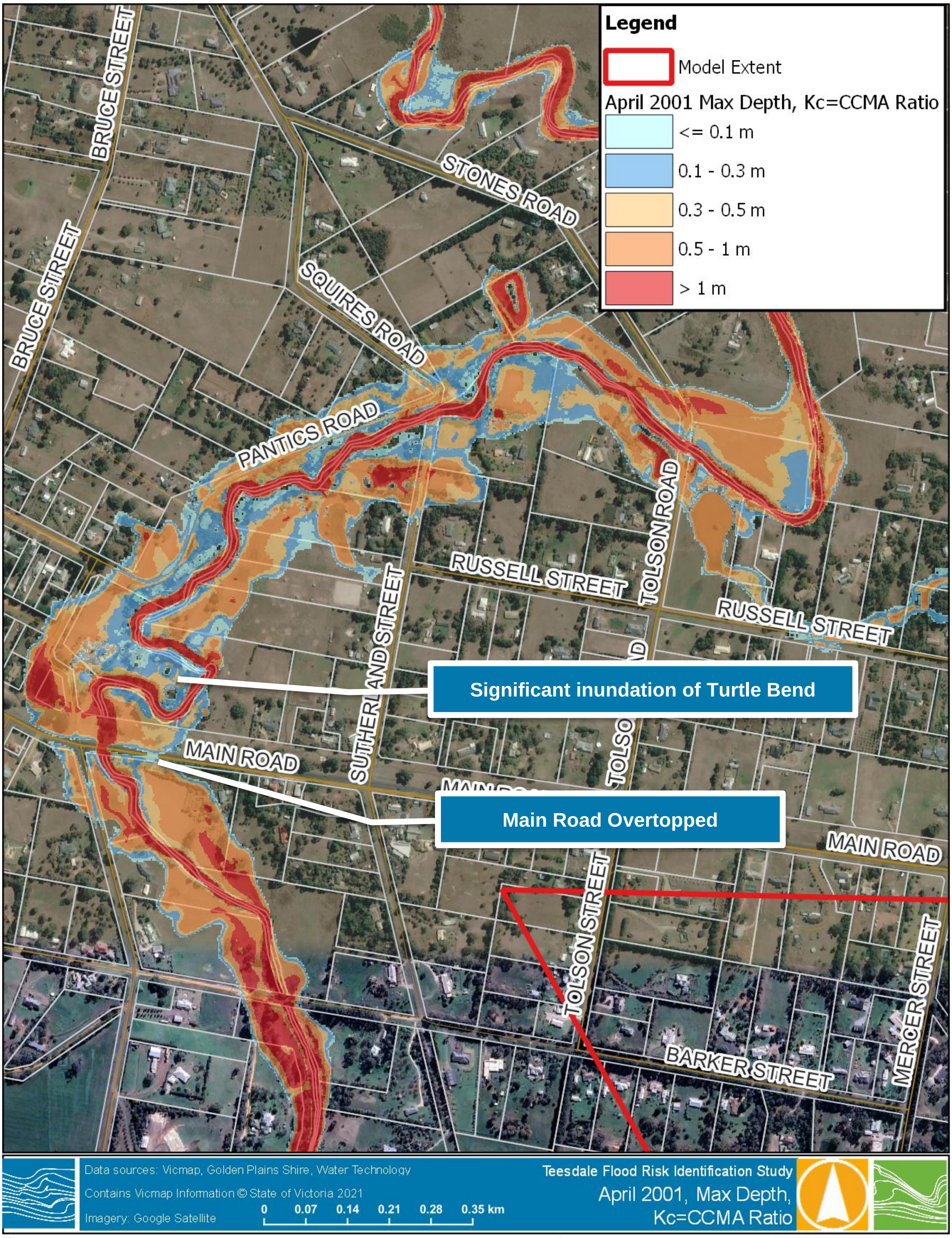

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Figure 5-8 April 2001 Flood Depths, K_c=CCMA Ratio (Township)

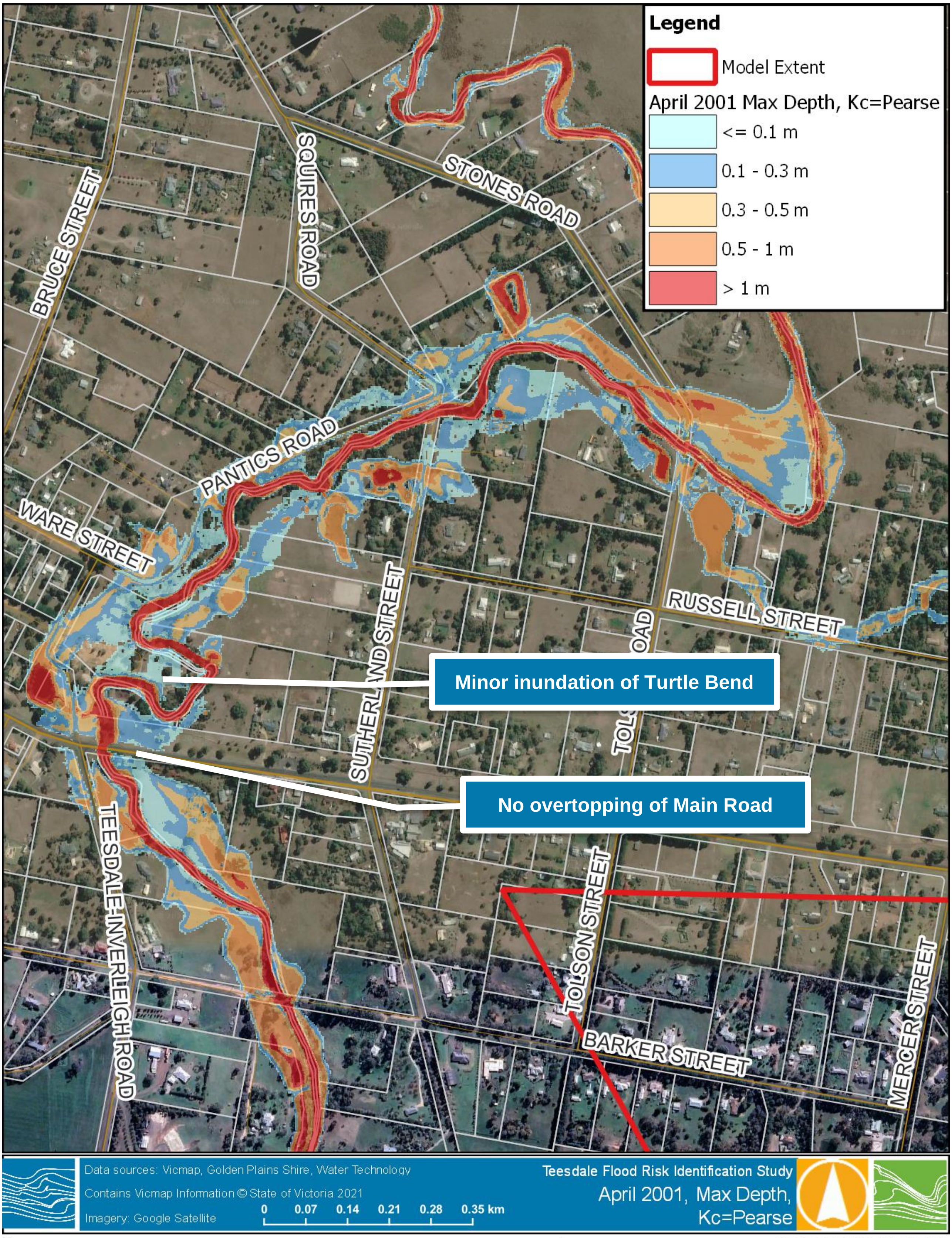

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Figure 5-9 April 2001 Flood Depths, K_c=Pearse (Township)

5.1.3 January 2011

Over a period of four days from 9am on the 10th of January until 9am on the 14th January, significant rainfall occurred over the Leigh River and Barwon River catchments causing flooding at Inverleigh and Geelong, along with widespread flooding across much of Victoria. The Native Hut Creek catchment was spared the worst of the flooding, with rainfall totals in the catchment ranging from ~95mm to 125mm over the four days.

5.1.3.1 Rainfall

Rainfall totals recorded between 9am on the 10th of January and 9am on the 14th of January at stations near and within the Native Hut Creek catchment are shown in Table 5-3 with the rainfall distribution and isopleths are shown in Figure 5-10.

Table 5-3 January 2011 Rainfall Totals

Station	Name	Total to 9am 11th January (mm)	Total to 9am 12th January (mm)	Total to 9am 13th January (mm)	Total to 9am 14th January (mm)	Total Rainfall (mm)
89104	Leigh River at Mount Mercer	43.4	42.4	12	52.6	**150.4**
89092	Warrambine No 2	34.8	37.2	39.6	41.6	**153.2**
89084	Warrambine Ck at Warrambine	31.4	37.8	10.2	44.8	**124.2**
87168	Sheoaks	31.2	35.8	6	35	**108**
87042	Meredith	29.4	39.4	10.4	35.4	**114.6**
87009	Bannockburn	26.6	32.4	3.2	32	**94.2**
87043	Meredith (Darra)	29.4	36.4	8.2	32.8	**106.8**
90167	Winchelsea	25	34	4	44.8	**107.8**

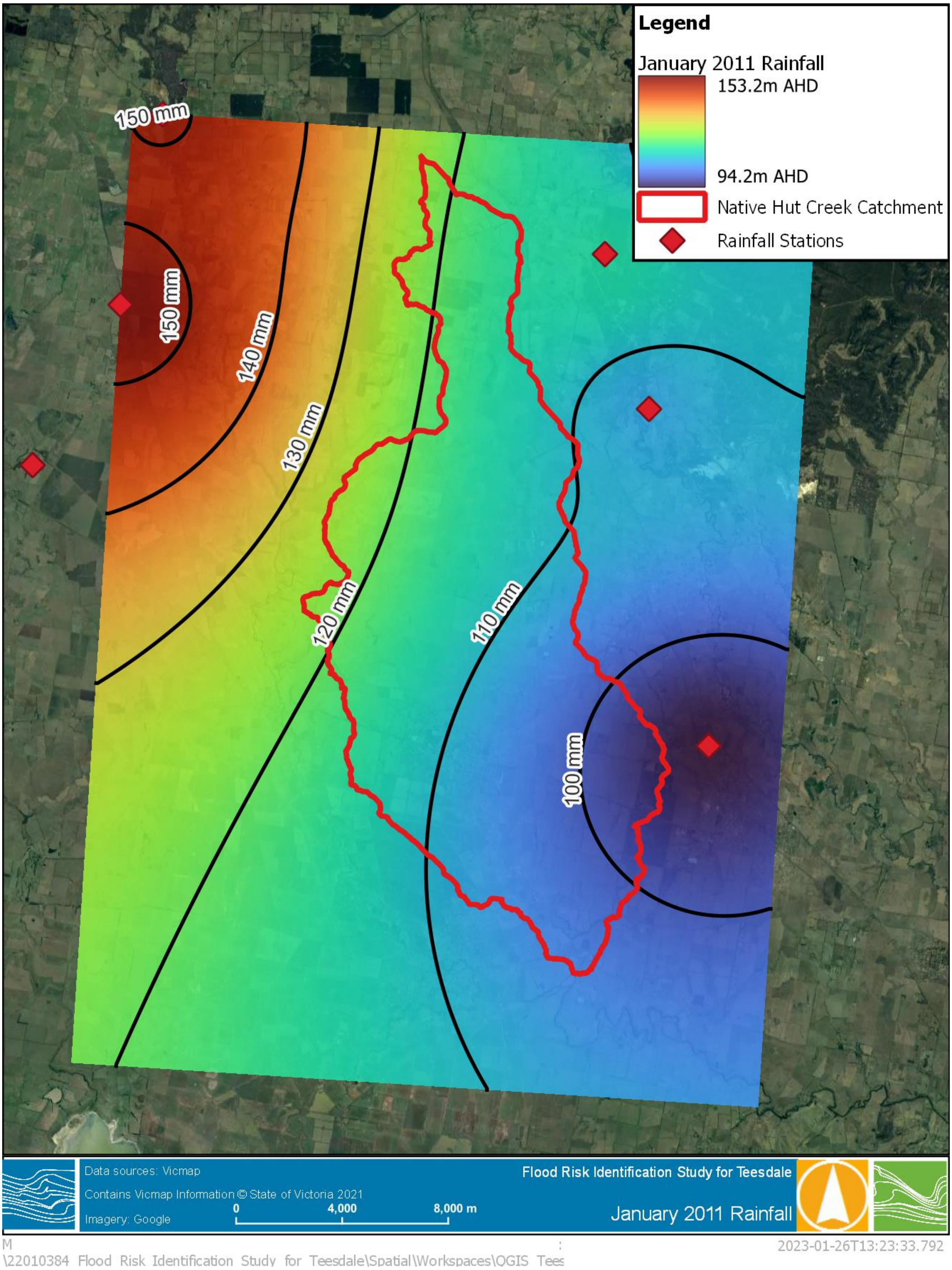

Figure 5-10 Rainfall Distribution and Isopleths for January 2011

5.1.3.2 Streamflow

Flow hydrographs extracted from the RORB model at the Bannockburn-Shelford Road bridge are shown in Figure 5-11 for the two modelled K_c values discussed in section 2.1.5. Much like the April 2001 event, the January 2011 event is characterised by bursts of rainfall which show the attachment response is highly sensitive and the kc parameter produces significant changes in the peak flows observed with 41 m^3/s (CCMA) and 24 m^3/s (Pearse). Lower values of K_c produce a hydrograph with significantly varying peaks and troughs, while higher values of K_c produce a more smoothed hydrograph.

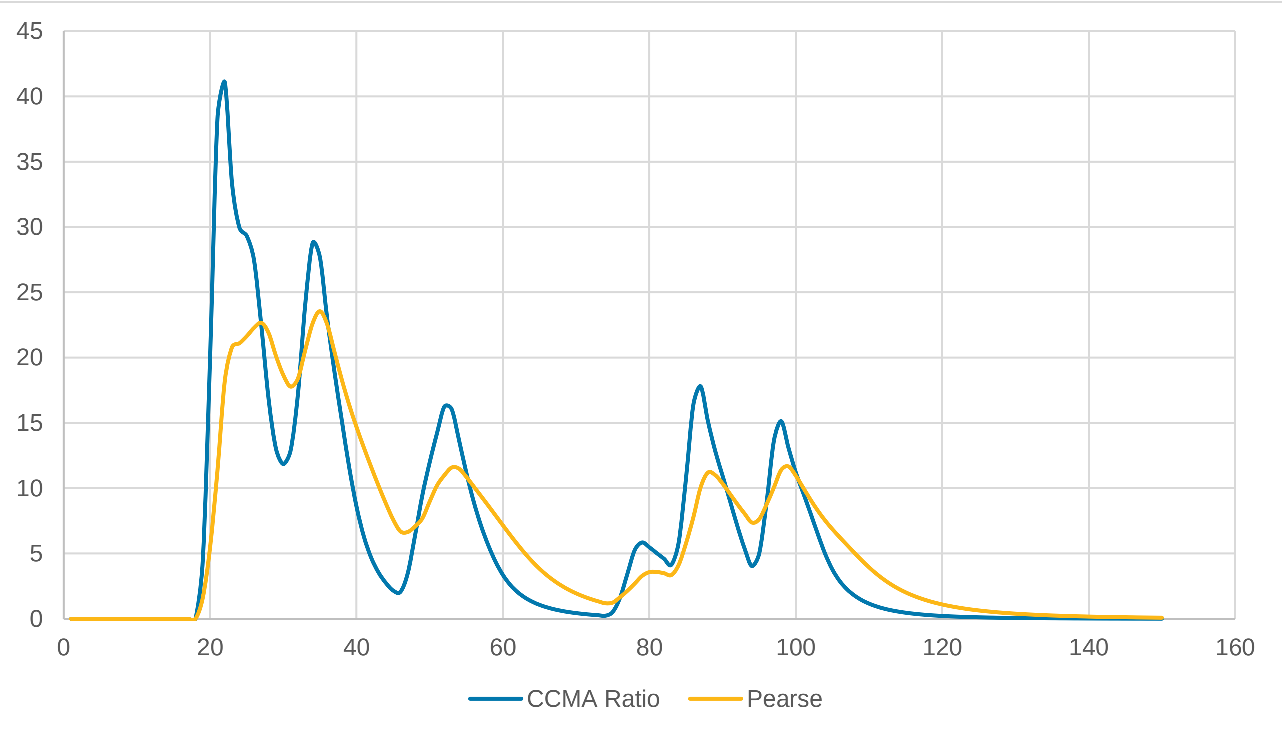

Figure 5-11 January 2011 modelled streamflow at Teesdale Bridge

5.1.3.3 Flood Behaviour

Due to the substantial variance in peak flows between the two modelled events, there is a notable difference in flood behaviour with the Pearse kc producing much lower peak flows which are largely contained within the banks of Native Hut Creek compared to the CCMA kc equation which shows flood waters breaking out of channel in several locations.

Photographs for this event have been provided by residents located in Sutherland Street at the community consultation session. The photos show water in the Creek being high but not out of bank at that location. The Pearse K_c equation replicates this while the CCMA equation does not, with the latter showing a breakout of flows onto 75 Sutherland Street which is understood to not have occurred.

The peak flood depths for the study area and township are shown in Figure 5-12 to Figure 5-13.

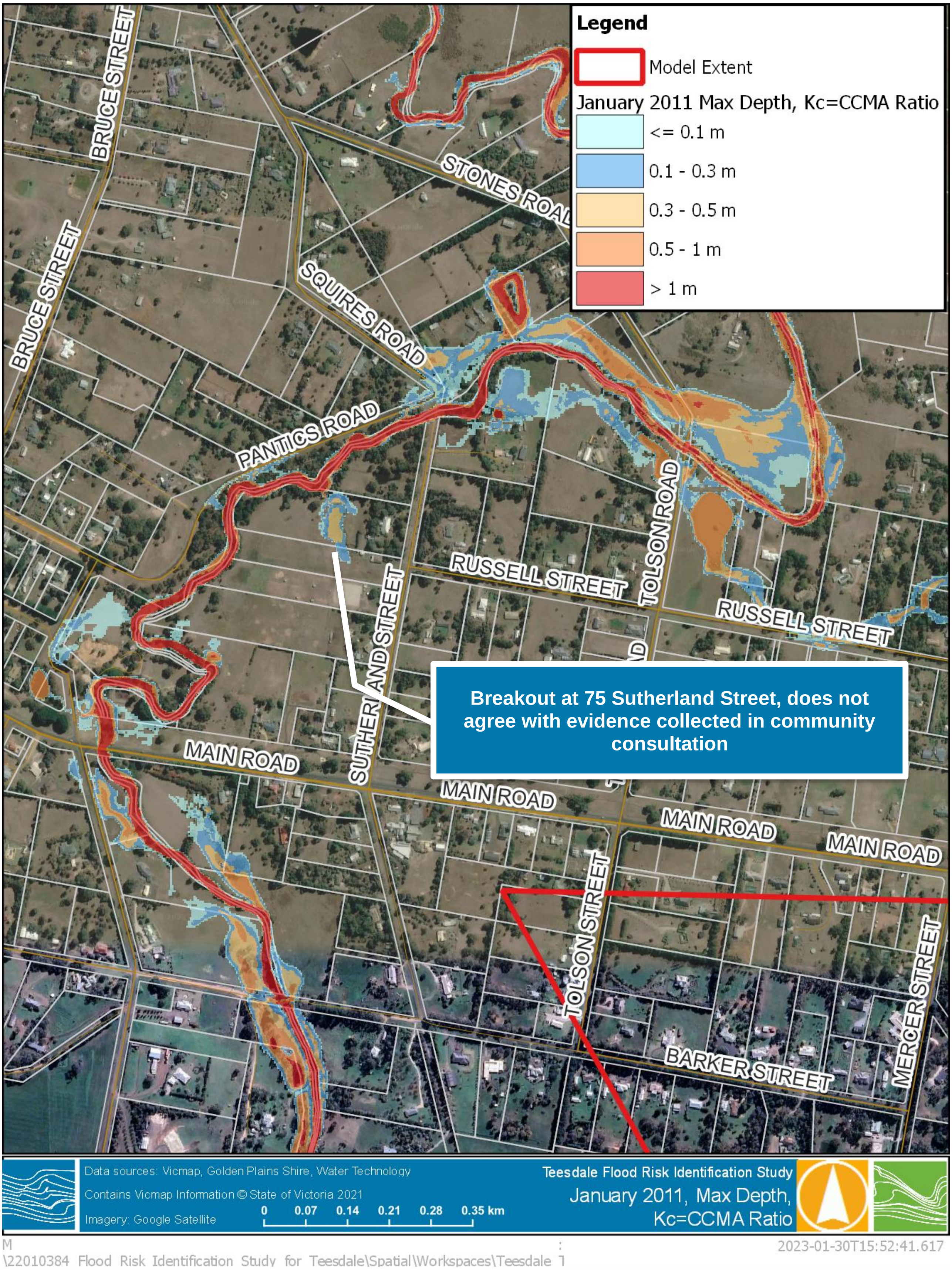

Figure 5-12 January 2011 Flood Depths, K_c=CCMA Ratio (Township)

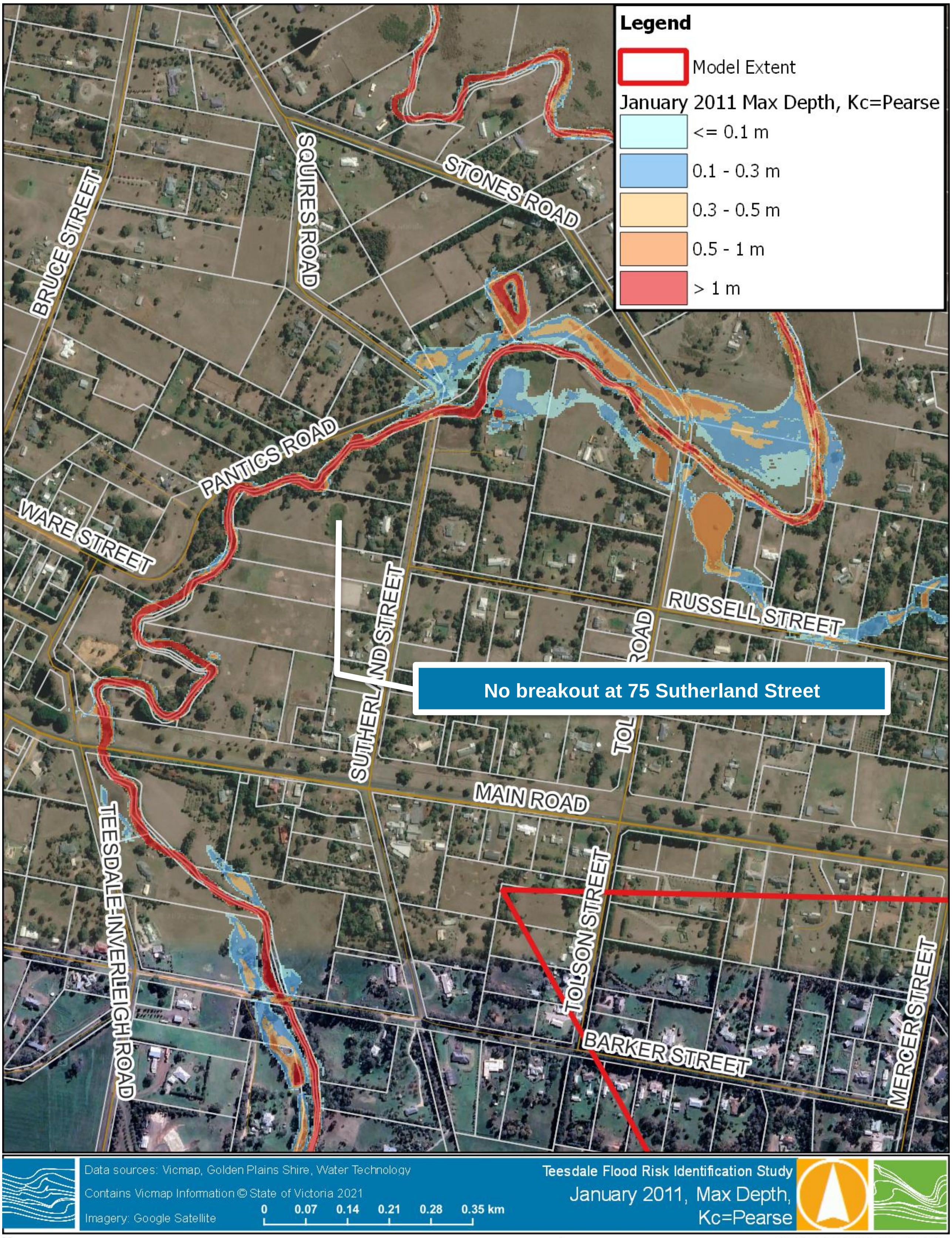

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Figure 5-13 January 2011 Flood Depths, K_c=Pearse (Township)

Figure 5-14 Photo provided by the residents of 75 Sutherland Street Teesdale during the 2011 flood showing flows contained within Native Hut Creek

5.2 Validation Results Discussion

No information exists for recording the stream level, resulting in the reliance of community information and anecdotal evidence. The simulation of the three events and comparison of flood levels within the town confirms as expected the magnitude of the flood events with the 1973 event producing the highest flood level followed by the 2001 and then 2011 events.

The simulation of three known flood events on Native Hut Creek has been undertaken with the adoption of two sets of kc parameters and fixed loss parameters. The RORB parameters adopted (namely initial loss, continuing loss and kc) appear to sit within reasonable ranges based on regional parameters from ARR2019 and RORB regional approximation equations.

As expected, adopting a lower k_c value results in a more reactive catchment, with flows routing through the catchment and stream network faster resulting in higher flow and shorter timing peaks of flooding. This is pronounced in events with short, intense bursts of rainfall such as April 2001 and January 2011 but has less influence on the February 1973 event which was a longer steadier rainfall pattern.

While the loss values adopted have not been changed, it is noted that the three events modelled occurred in Summer and Autumn months and similar antecedent conditions would be expected across the catchment (typically a lower soil moisture/drier catchment) compared to a flood event occurring in late winter/spring months.

For the 2011 event, the lack of flooding on 75 Sutherland Street observed with the higher kc value using the Pearse equation gives some confidence in the adoption of the higher K_c value. As discussed earlier, the flows for this event are understood to have generally stayed within bank. Discussions held at the second community consultation session held in March 2023, further confirmed that no breakouts were observed by the community during the January 2011 event.

When comparing the levels modelled in the 2001 event, it is the opposite, with the lower CCMA kc value producing results that show the Shelford-Bannockburn Road overtopped, while the Pearse equation does not produce modelling results which overtop the Shelford-Bannockburn Road. During discussions at the second community consultation session held in March 2023, a resident revealed that after the 2001 event a significant clean up of Native Hut Creek was undertaken with rubbish, tyres and overgrown vegetation removed from the bed and banks. These conditions were not explicitly included in the model as they were unknown at the time of modelling, however they may explain the overtopping of the road particularly if the bridge was partially blocked.

The 1973 event resulted in widespread inundation of the Native Hut Creek floodplain, as evidenced by photographs provided during community consultation for the study. The two modelled values of K_c produce similar flows and flood behaviour with the average flood level difference being 64mm across the study area. This minor increase in level translates to a similarly minor increase in extent, with the only substantial difference between the two modelled events being that the Bannockburn-Shelford Road was completely inundated when adopting the CCMA ratio of K_c.

Based on the above, it appears the adoption of the higher K_c value represents the January 2011 event quite well and will be adopted for design modelling. The overtopping of Bannockburn-Shelford Road in April 2001 is not represented by this value of K_c, however the influence of rubbish and overgrown vegetation within the channel at the time of that event, particularly in partially blocking the bridge, may influence the bridge's capacity and could cause overtopping of the road.

6 SUMMARY

The joint validation process has shown the combination of the RORB and TUFLOW models is suitable to replicate a range of flow events from relatively minor in-channel events (January 2011) through to larger, rarer floods such as the February 1973 event. The validation process has relied heavily on photography and anecdotal evidence with limited recorded flood information available. The RORB model has shown high sensitivity to the adoption of a k_c value. The RORB parameters adopted (namely initial loss, continuing loss and k_c) sit within expected ranges based on regional parameters from ARR2019 and RORB regional approximation equations. The results of the joint validation identify the parameters adopted in both the RORB and TUFLOW models are suitable for adoption in design flood modelling for Native Hut Creek.

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