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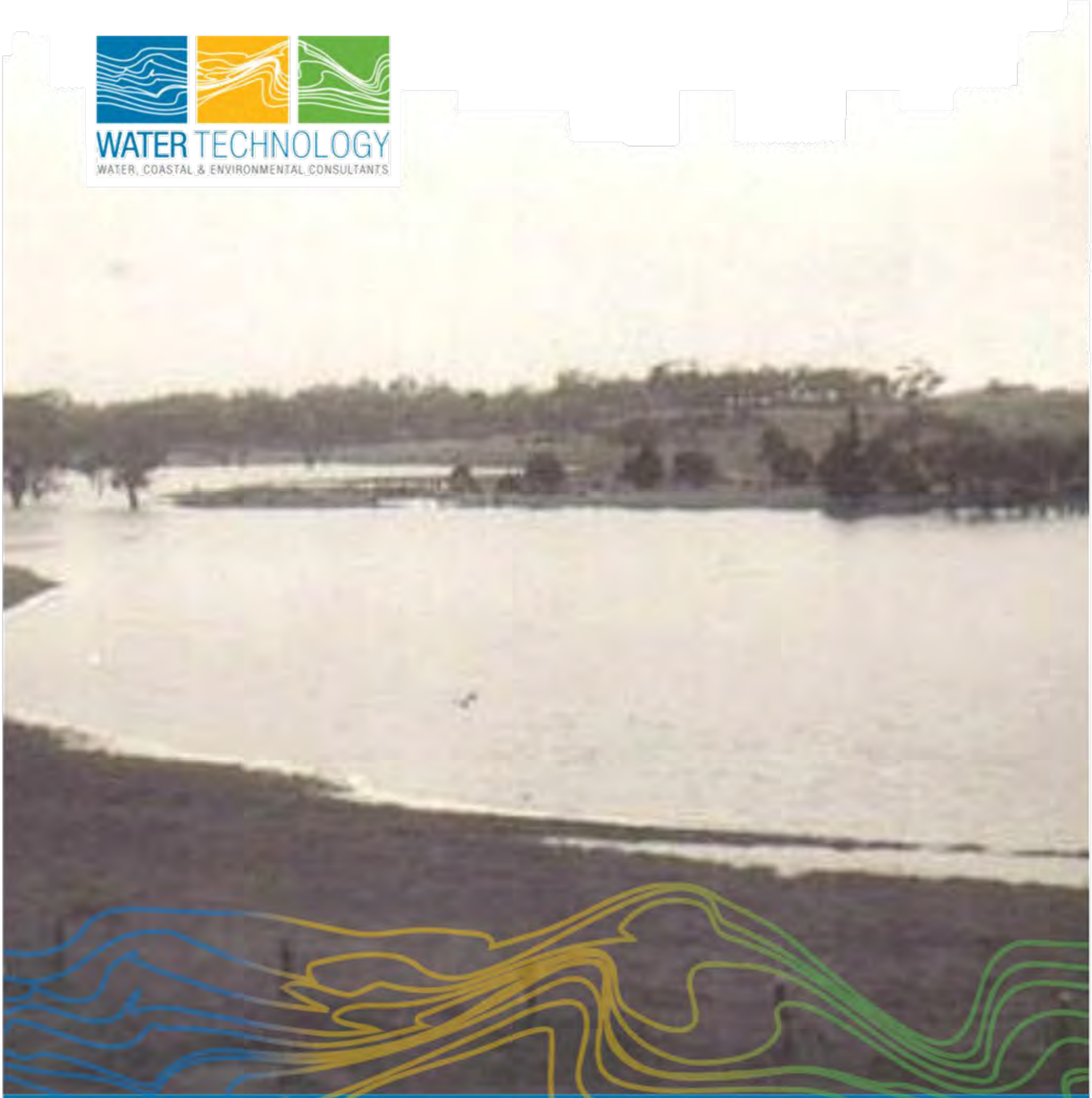

Summary Report

Teesdale Flood Risk Identification Study

Golden Plains Shire

12 May 2023

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GOLDEN PLAINS SHIRE

Cover Image: Native Hut Creek in Flood, Teesdale, 1949

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EXECUTIVE SUMMARY

Water Technology were engaged by Golden Plains Shire to deliver the Teesdale Flood Risk Identification Study. The project has been funded through the Risk and Resilience Grants Program, with equal parts funding from Local, State and Federal Government.

The study has reviewed the available flood data for Native and Hut Creek, and produced flood modelling and mapping in line with current industry best practices and the recommendations of Australian Rainfall and Runoff 2019. Flood modelling and mapping has been produced for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% and Probable Maximum Flood (PMF) events.

In addition to the flood modelling and mapping, flood intelligence products detailing the flood behaviour and impacts in Teesdale have been developed and included in a draft update to the Golden Plains Municipal Emergency Management Plan (MFEP). Intelligence products developed include the following:

- A rating table for a proposed gauge on Native Hut Creek at the Bannockburn-Shelford Road bridge
- Summaries of flood behaviour and impacts in concise tables;
- Flood peak timing estimates from the beginning of rainfall;
- A simple tool to link rainfall to potential flood impacts, and;
- Recommended Flood Class Levels for the proposed gauge in line with the Bureau of Meteorology's Flood Class definitions.

Additional components to improve the flood warning capability for Teesdale were recommended, with two additional gauges proposed to improve the town's flood monitoring capacity.

The Average Annual Damages (AAD) caused by flooding in Teesdale were assessed in line with industry standard methods. Flooding in Teesdale is estimated to cost, on average, $113,366 per year. Three mitigation options to reduce the AAD were investigated and their benefit/cost ratios estimated. The options investigated were raising Pantics Road, placing additional culverts under Bannockburn-Shelford Road, and clearing Native Hut Creek of vegetation. None of the options investigated achieved a favourable financial benefit/cost ratio.

Non-structural mitigation in the form of planning scheme mapping has also been developed and is recommended for inclusion in the Golden Plains Planning Scheme. The mapping is based on the 1% AEP flood with projected increased rainfall intensity to 2100 under Representative Concentration Pathway RCP8.5. Draft planning scheme amendment documentation has been provided to Council with the proposed mapping.

The study outputs will support floodplain management in Teesdale into the future by providing a sound basis for the implementation of planning controls to ensure development within the floodplain is appropriate and responds to the risk. Future flood events can be responded to in a more proactive way through utilisation of the intelligence products produced.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

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 current 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 requirement of 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
- 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 – This 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 agricultural use.

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 and 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 R01 to R06 and summarises the completed project. This summary report will not delve into technical detail, instead focussing on project outputs and deliverables produced by the study. Readers will be directed to individual reports should additional information be required. The chapters and sections of this report broadly follow the previous reporting from R01 to R06 with a summary of the key points in each detailed report.

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Figure 1-1 Teesdale Flood Risk Identification Study - Study Area

2 DATA COLLATION AND REVIEW

The first stage of the project included the collation and review of available data relevant to flooding in Teesdale. This included the following:

- Previous flood studies and reports covering the area (see Table 2-1 below)

Table 2-1 Flood related studies completed in Teesdale and Native Hut Creek Region

Related Studies	Author	Year
Victorian Flood Data Transfer Project (2001)	DNRE/SKM	2001
Hydrologic and Hydraulic assessment (2008)	CCMA	2008
Regional Flood Mapping – Barwon River, Thompson Creek and Woady Yaloak Creek	GHD	2016
Updated Hydrologic and Hydraulic assessment (2019)	CCMA	2019

- Historical flood events and accompanying anecdotal evidence
  - Anecdotal evidence was the best available data for historical floods – no surveyed or otherwise measured flood heights were uncovered as part of the study
  - Evidence was gathered for the February 1973, April 2001 and January 2011 events, which were then selected for validation modelling based on the information available.
- Recorded streamflow
  - The catchment has no streamflow gauges
- Recorded rainfall
  - Includes both daily and sub-daily rainfall
- Road and drainage infrastructure
  - Some data was supplied by council with gaps infilled by survey for major structures and site visits for minor structures
- Topographic data
  - Multiple LiDAR data sets were available and were verified against survey captured for the project

The initial community consultation session also formed part of the data collation aspect of the project. The consultation session was held at the Teesdale Community Hall and had 17 residents in attendance. Information relevant to the study was gathered during the session however was limited to anecdotal evidence of flood behaviour in historic events.

The Data Collation Report (R01) also confirmed and detailed the modelling methodology for the following stages of the project.

3 JOINT VALIDATION MODELLING

3.1 Overview

The Joint Validation Modelling Report (R02) describes in detail the hydrologic (RORB) and hydraulic (TUFLOW) model builds and parameter selection adopted for the study. The report also details the validation modelling of historic events. Model performance and alignment with the anecdotal evidence was utilised to determine the RORB routing parameter Kc. Other parameters were selected based in consideration of adopted values from nearby flood studies and regional approximations in the absence of local calibration data.

3.2 RORB Summary

3.2.1 Model Build

The RORB hydrologic model build followed the following steps:

1. Catchment delineation utilising 10m resolution Vicmap DEM based on a flow accumulation and tracing method
2. Subareas and reaches defined from the above, with nodes placed at or near the centroid of each subarea and the junction of reaches
3. Reach slopes defined from the LiDAR dataset, with reach types assigned as “excavated (unlined)” where a waterway was clearly visible on aerial imagery and LiDAR
4. Interstation areas delineated for two local catchments that flow through Teesdale where hydrographs and mapping were required
5. Fraction impervious (FI) assigned to zones in the planning scheme in accordance with Table 3-1 below

Table 3-1 Adopted Fraction Impervious

Land Use/Zone	FI
Farming Zone	0.01 - 0.05
LDRZ	0.2
PCRZ/PPRZ	0.01 (one area assigned 0.1 due to buildings on site)
PUZ	0.05 – 0.5 (based on aerial imagery)
Roads	0.7
Township Zone	0.4
Transport Zone	0.0 – 0.7 (based on aerial imagery)

3.2.2 Model Parameters

RORB model parameters were assigned as follows:

- Initial and Continuing Loss were adopted from the ARR datahub after comparison with nearby calibrated losses
- The “m” parameter was left at the recommended 0.8

- A range of Kc values were selected for validation against historical events, with a Kc/Dav ratio of 1.25[1] selected for design modelling

3.2.3 Rainfall

3.2.3.1 Historic Events

Validation events utilised daily rainfall records from available gauges surrounding the Native Hut Creek catchment. Sub-daily records were obtained from the Sheoaks station (87168) for the April 2001 and January 2011 events and from the Warrambine Basin No. 3 station (890094) for the February 1973 event. Daily records informed the spatial pattern and total rainfall across the catchment with the sub-daily record informing the temporal pattern of each event.

3.2.3.2 Design Events

Design rainfall depths for the range of AEPs and durations were downloaded from the Bureau of Meteorology's IFD (Intensity-Frequency-Duration) Design Rainfall Data System[2]. Given the size of the catchment, spatial variation in design rainfall was considered by deriving the spatial pattern in accordance with the method shown in section 6.5.4 of ARR2019 Book 2 Chapter 6.

Pre-burst rainfall was accounted for by subtracting the median pre-burst depth from the storm initial loss (as provided by the ARR datahub and verified against nearby calibrated models) to produce the burst initial loss according to the below equation:

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

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[3]. 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).

[1] Pearse et al., 2002
[2] http://www.bom.gov.au/water/designRainfalls/revised-ifd/
[3] https://data.arr-software.org/vic_specific

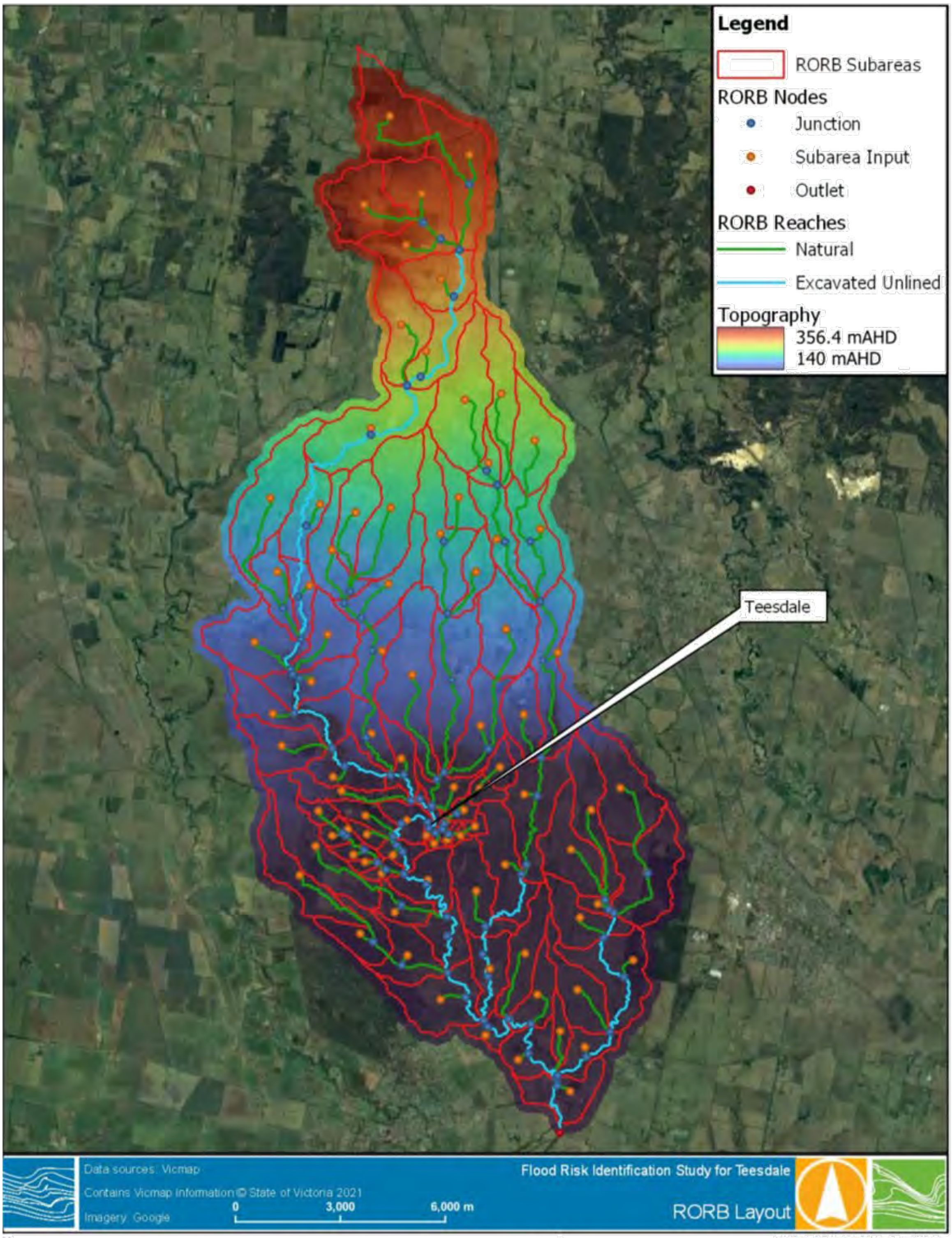

Figure 3-1 RORB model layout

3.3 TUFLOW Summary

3.3.1 Model Parameters and Design

The TUFLOW model design and parameter selection is described in detail in R02 – Joint Validation Report. A short summary of the modelling logic and selected parameters is provided below however readers wishing to know more about the model build should refer to the full report.

The key TUFLOW model parameters, along with the design approach for key components of the model, are shown in Table 3-2 below. The TUFLOW model extent and boundary areas are shown in Figure 3-2 below.

Table 3-2 Key TUFLOW model parameters

Parameter	Value/Approach
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% based on waterway slope
Hydraulic Roughness	Manning's 'n', varies with land use
1-Dimensional elements	Culverts and pipes linked to 2-D domain
Topography	2021 LiDAR dataset utilised after comparison and validation
Extent	The model extent was set such that the entire floodplain in Teesdale would be captured and main flow boundaries would be a sufficient distance from the town to have no influence on model results within the town
Roughness	Assigned based on land use (planning zones), see Table 3-3
Hydraulic Structures	Culverts and pipes were represented as 1-dimensional elements linked to the 2-dimensional domain Bridges were represented as layered flow constrictions within the 2-dimensional domain based on survey captured as part of the

Table 3-3 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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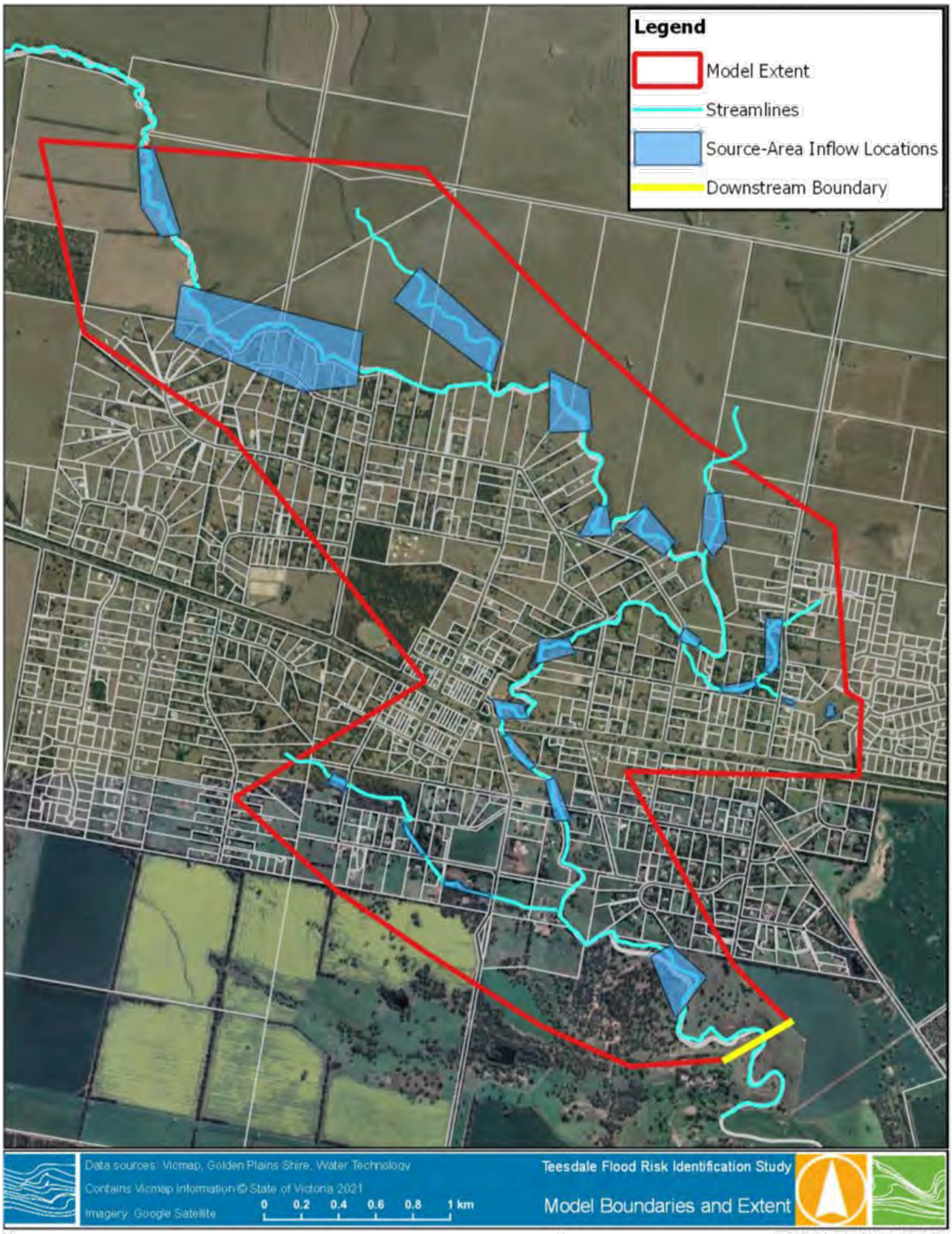

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Figure 3-2 TUFLOW Extent and Model Boundaries

3.4 Validation Modelling Results

The results of the validation modelling were used to ensure the models were performing as expected, and to inform the selection of the RORB parameter Kc. The model results were presented to community members at the second community consultation session held in March 2023. Feedback gathered during the session clearly supported the use of a Kc/Dav ratio of 1.25 over the lower ratio utilised in nearby modelling by the CCMA for the January 2011 and April 2001 events. Little feedback was gathered for the February 1973 event other than a photograph showing widespread flooding near Pantics Road.

Community feedback is summarised as follows:

- The January 2011 event was contained within the bed and banks of the waterway, with photographic evidence demonstrating no breakout at 75 Sutherland Street.
- Strong anecdotal evidence suggested only shallow inundation of Turtle Bend during April 2001.
- A community member recalled Bannockburn-Shelford Road was closed during April 2001, however this was not recreated in the model. Other participants informed the modelling team that after April 2001, a creek clean up removed significant amounts of rubbish and debris from the waterway occurred. As a result it is possible that the bridge was partially blocked, or that the road closure was a result of runoff rather than riverine inundation.

Modelling results for the April 2001 and January 2011 events are shown below.

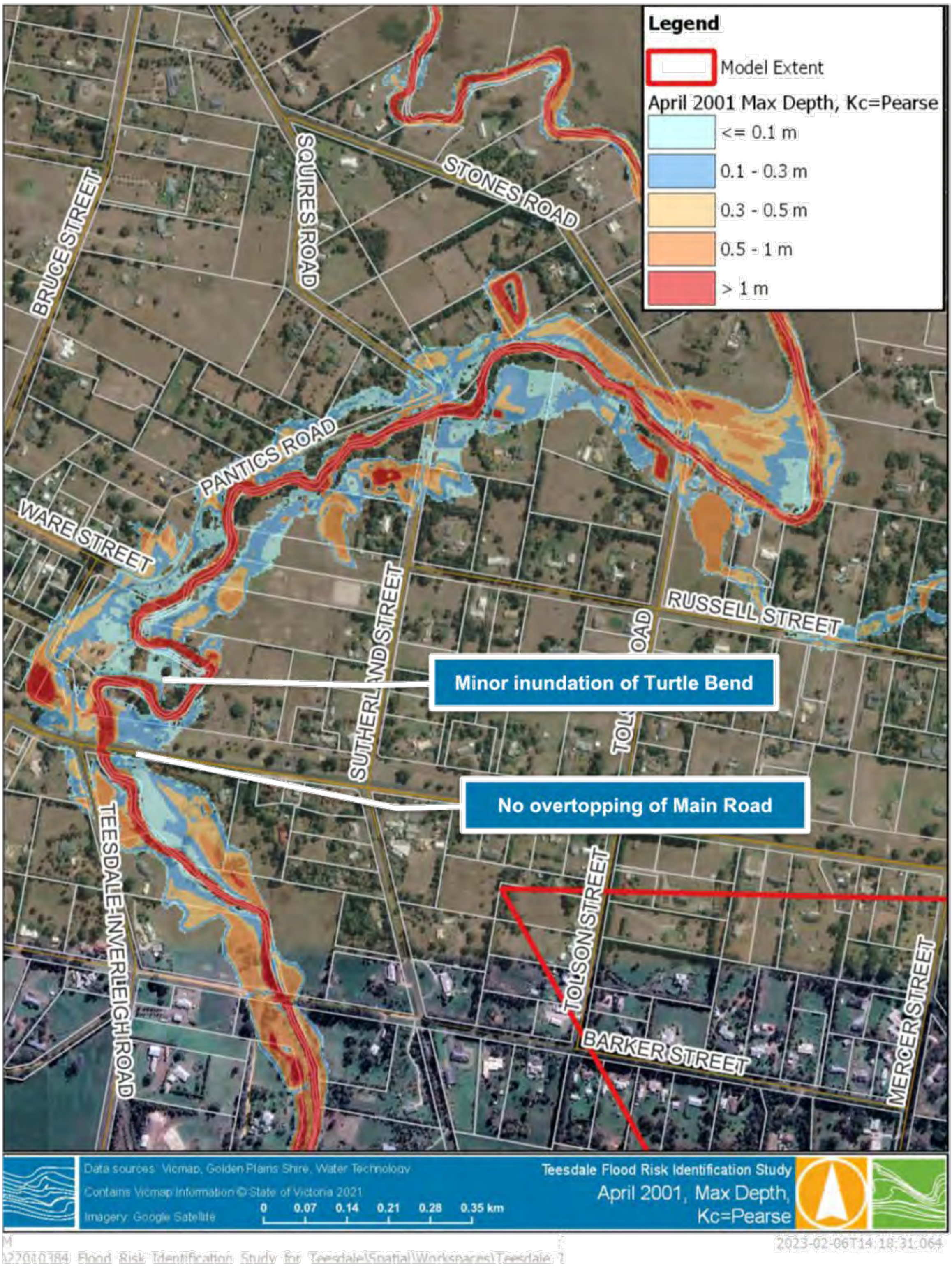

Figure 3-3 April 2001 Flood Depths, K_c=Pearse (Township)

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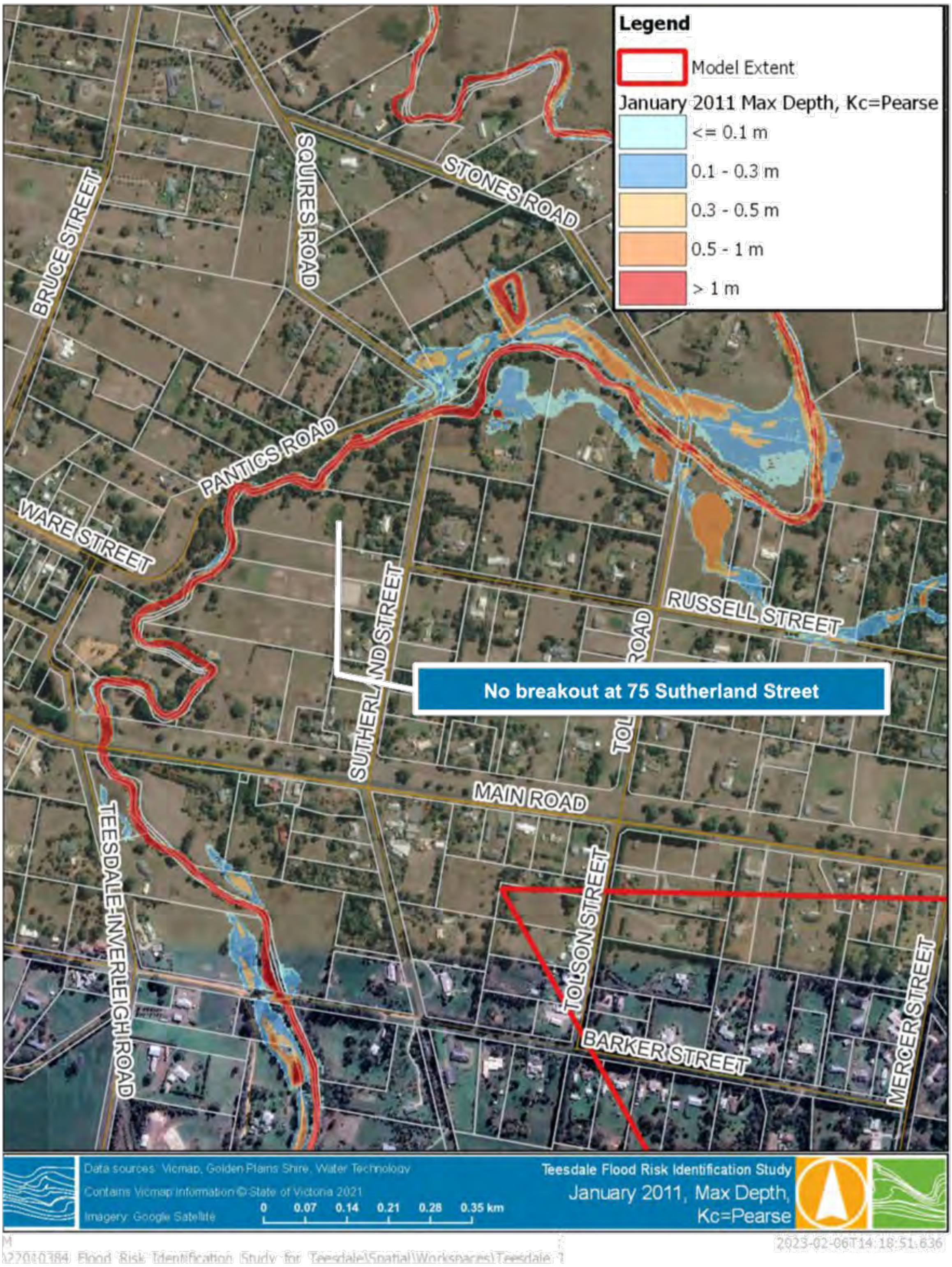

Figure 3-4 January 2011 Flood Depths, K_c=Pearse (Township)

Figure 3-5 Photo provided by the residents of 75 Sutherland Street Teesdale during the 2011 flood showing flows contained within Native Hut Creek

4 DESIGN MODELLING RESULTS

4.1 Hydrology

The RORB hydrologic model was ran for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% and PMF events. Critical event hydrographs at the Bannockburn-Shelford Road bridge for the design events (excluding the PMF) are shown in Figure 4-1 below.

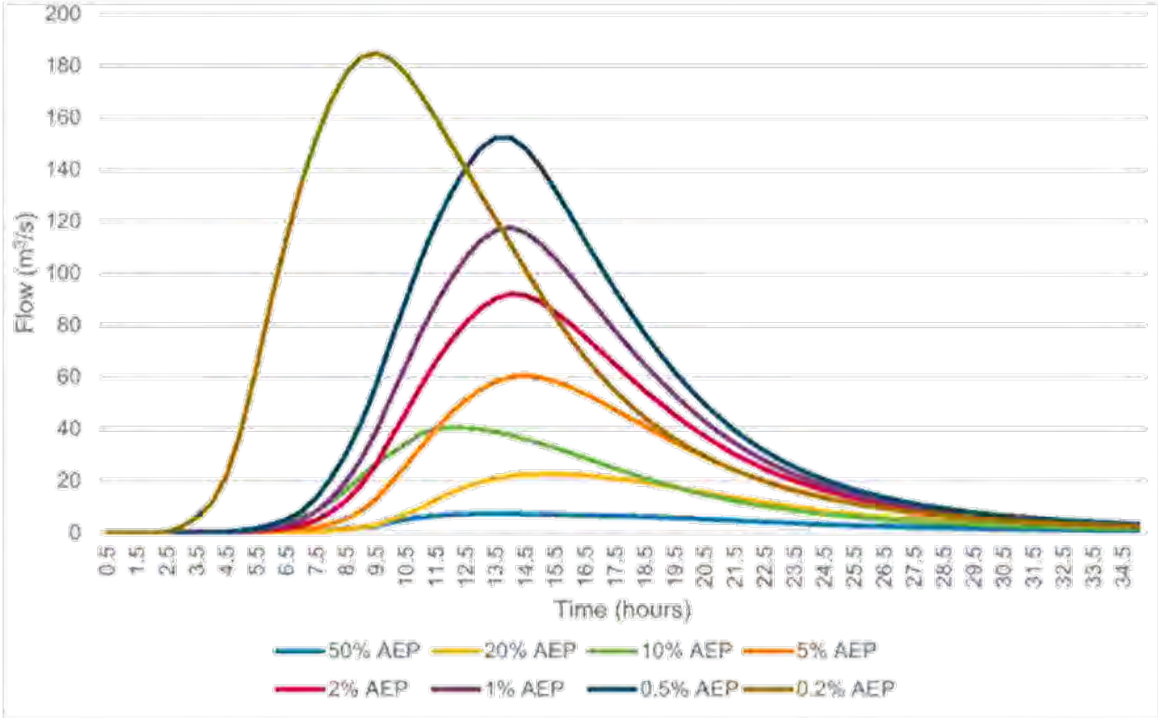

Figure 4-1 Design hydrographs, Native Hut Creek at Bannockburn-Shelford bridge

The impact of increased rainfall intensity associated with climate change was investigated for the 10% and 1% AEP events, with four scenarios modelled for both AEPs:

- Projected flows to 2050 under RCP4.5
- Projected flows to 2100 under RCP4.5
- Projected flows to 2050 under RCP8.5
- Projected flows to 2100 under RCP8.5

The resultant impact on flows at the Bannockburn-Shelford Road bridge are shown in Table 4-1 below. The 1% AEP flows under an RCP8.5, 2100 scenario are increased 44% and are between present day 0.2% and 0.5% AEP flows. Similarly, the 10% AEP flows for the same climate scenario are increased 59% and are between present day 5% and 2% AEP flows.

Table 4-1 Climate change assessment summary

10% AEP	RCP4.5 2050	RCP4.5 2100	RCP8.5 2050	RCP8.5 2100
IFD Rainfall (mm)	54.11	54.11	54.11	54.11
% Increase	5.4%	7.8%	7.3%	18.4%
Projected Rainfall Depth (mm)	57.03	58.33	58.06	64.06
Peak Flow at Bridge	46.79	50.06	49.50	64.66
Increase in Flow (%)	15.19	23.24	21.85	59.17
1% AEP	RCP4.5 2050	RCP4.5 2100	RCP8.5 2050	RCP8.5 2100
IFD Rainfall	85.06	85.06	85.06	85.06
% Increase	5.4%	7.8%	7.3%	18.4%
Projected Rainfall Depth (mm)	89.65	91.69	91.27	100.71
Peak Flow at Bridge	137.39	142.97	141.83	169.21
Increase in Flow (%)	16.75	21.49	20.52	43.79

4.2 Hydraulics

Hydrographs extracted from the RORB model at locations corresponding to the source-area inflow locations shown in Figure 3-2 were applied to the TUFLOW model. Peak flood depths for the 1% AEP and the 2100 1% AEP under RCP8.5 are shown in Figure 4-2 and Figure 4-3 below.

Figure 4-4 shows the difference in flood levels between the existing conditions 1% AEP event and the 2100 1% AEP under RCP8.5. In the township, flood levels increase in the order of 0.15 to 0.25 metres upstream of the bridge where the floodplain is relatively wide. Downstream of the bridge, increases in flood levels are between 0.4 and 0.5 metres, where the floodplain is more confined.

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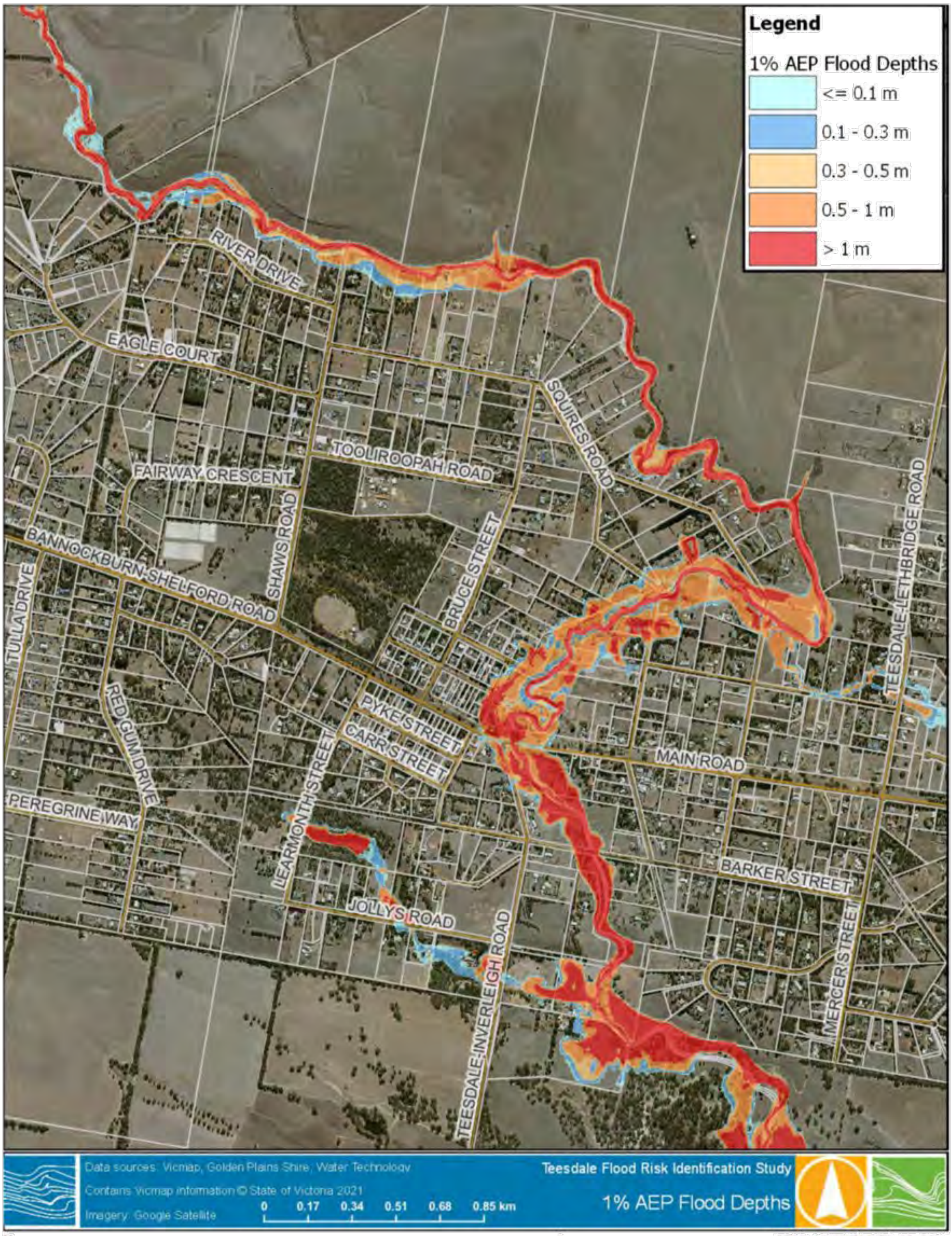

Figure 4-2 1% AEP Flood Depths in Teesdale (Existing Conditions)

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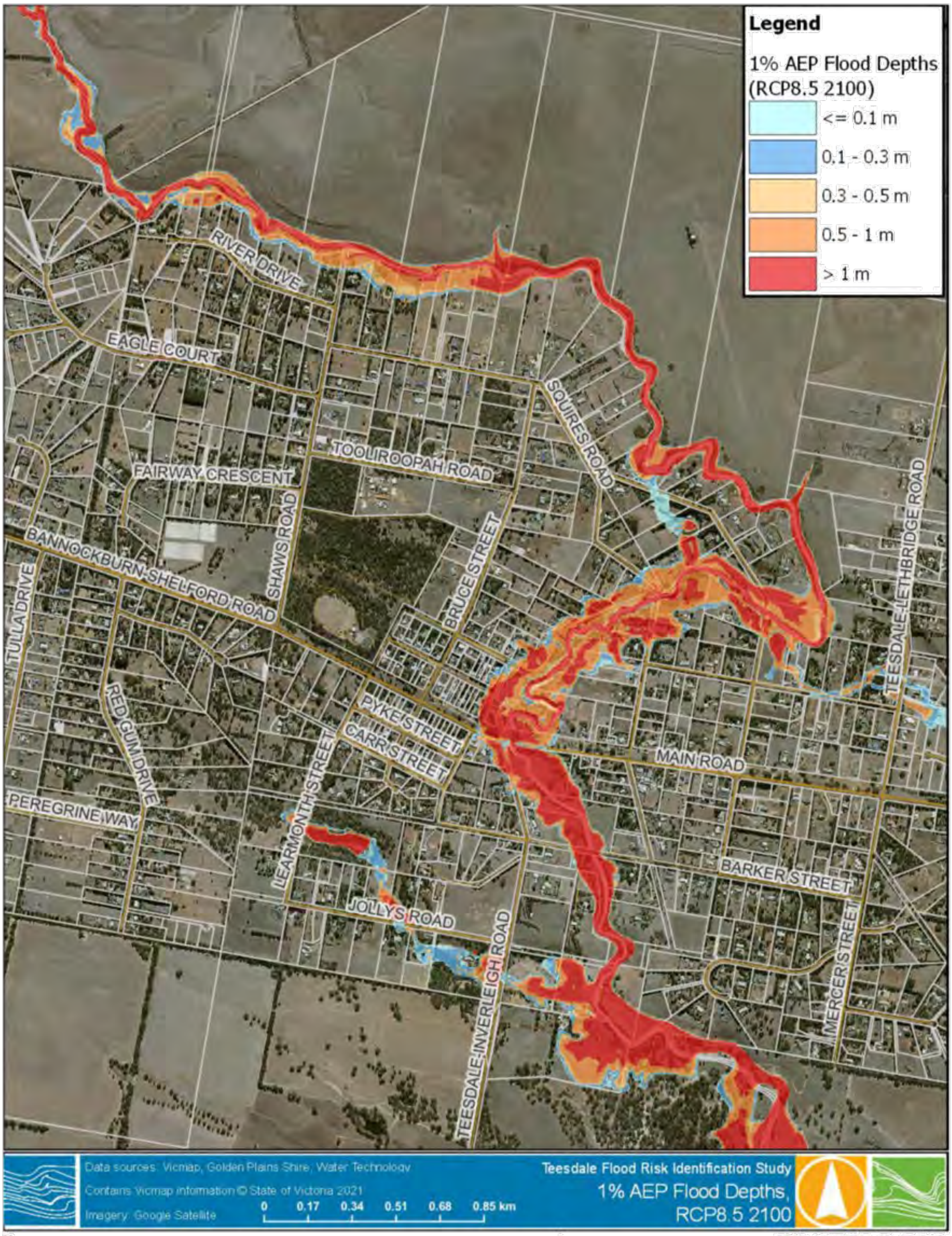

Figure 4-3 1% AEP Flood Depths in Teesdale under projected RCP8.5 to 2100

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Figure 4-4 Flood level increase under RCP8.5 projections to 2100 for the 1% AEP event

4.3 Sensitivity Testing

Model sensitivity testing was conducted on the hydrologic and hydraulic models for the following parameters:

- Losses (hydrology)
- Hydraulic roughness
- Structure (bridge) blockage
- Boundary conditions (slope)

The models were shown to be sensitive to continuing loss and hydraulic roughness. Reducing continuing loss from 3.3 to 1 mm/hr caused a 40.3% increase in flows for the 1% AEP event. Alterations to hydraulic roughness impacted flood levels across the modelling area. The area upstream of the Bannockburn-Shelford Road bridge appears to be the least sensitive area in the model to changes in roughness. This is indicative of the influence the road and bridge has on flood behaviour in that area as well as the width of the flow path. Flood levels upstream of the bridge increased in the order of 0.1 to 0.2 metres in the high roughness scenario, compared to raises of around 0.4 metres downstream of the bridge. The low roughness scenario resulted in lower flood levels of around 0.1 metres upstream and 0.2 metres downstream of the bridge.

5 FLOOD INTELLIGENCE AND WARNING

5.1 Overview

In line with the project brief, components of the Total Flood Warning System were assessed, and additional components recommended with the aim of improving flood warning and monitoring capability for Teesdale. The following flood intelligence products were produced:

- A rating curve for a potential gauging station on Native Hut Creek at the Bannockburn-Shelford Road bridge.
- Summary table of flood behaviour, impacts and roads inundated.
- Average flood peak travel time estimations.
- "Flood/No Flood" tool, providing a rough link between observed rainfall and flood magnitude.
- Recommended Flood Class Levels for Teesdale based on the potential gauging station.

The majority of the products were included in a draft update to the Golden Plains Municipal Flood Emergency Plan in addition to the Flood Intelligence and Warning Report (R04). The flood impacts summary table, flood peak travel time estimates and Flood/No Flood tool have been reproduced herein for reference.

Table 5-1 Flood Impacts Summary

Flood Event	Characteristics – Flood Behaviour	Roadways Inundated
50% AEP ~600 ML/d ~7.4 m³/s 99.99 m AHD at Bannockburn-Shelford Road bridge	Breakout occurs upstream of Stones Road, flowing along the north side of Native Hut Creek and filling local depressions. The breakout rejoins Native Hut Creek at Pantics Road.	▪ Learmonth St (<0.1m) ▪ Stones Road (<0.3m) ▪ Barker Street (<0.3m) ▪ Russel St (<0.1m)
20% AEP ~1,950 ML/d ~23 m³/s 101.05 m AHD at Bannockburn-Shelford Road bridge	Breakout upstream of Stones Road becomes more significant with deep flows on the north side of Native Hut Creek. Breakout from dam at 95 Tolson Road flows over paddocks south of Native Hut Creek, rejoining before Sutherland Street. Stones Road and Barker Street flooded to hazardous depths. Minor breakouts on west side of Native Hut Creek, north and south of Bannockburn-Shelford Road. Significant breakouts around and downstream of Barker Street and around Native Hut Drive.	▪ Learmonth St (<0.1m) ▪ Stones Road (>0.5m) ▪ Pantics Road (<0.1m) ▪ Barker Street (>0.5m) ▪ Russel St (~0.1m)
10% AEP ~3,400 ML/d ~40.5 m³/s 101.53 m AHD at Bannockburn-Shelford Road bridge	Floodplain fully engaged with breakout flows on both sides of Native Hut Creek throughout the town. Turtle Bend inundated with isolated islands. **Teesdale Kindergarten driveway and carpark inundated.** Access via community hall possible. **87 Pantics Road inundated above floor.**	▪ Learmonth St (<0.1m) ▪ Stones Road (>0.5m) ▪ Mercer Tce (~0.5m) ▪ Pantics Road (<0.3m) ▪ Barker Street (>1m) ▪ Sutherland Street (~0.3m) ▪ Russel St (<0.3m)

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Flood Event	Characteristics – Flood Behaviour	Roadways Inundated
5% AEP ~5,200 ML/d ~60.5 m^3/s 101.78 m AHD at Bannockburn-Shelford Road bridge	Generally as above with deeper, faster flowing water. Hazardous depths across floodplain. **Teesdale Kindergarten driveway and carpark inundated to hazardous depths. Access via community hall possible.**	▪ Learmonth St (<0.1m) ▪ Stones Road (~1m) ▪ Pantics Road (>0.3m) ▪ Mercer Tce (~0.9m) ▪ Barker Street (>1.0m) ▪ Sutherland Street (~0.5m) ▪ Teesdale-Inverleigh Road (<0.3m) ▪ Russel St (<0.3m)
2% AEP ~7,950 ML/d ~92 m^3/s 102.08 m AHD at Bannockburn-Shelford Road bridge	Generally as above with deeper, faster flowing water. Hazardous depths across floodplain. Bannockburn-Shelford Road overtopped. **844 Teesdale-Inverleigh Road inundated above floor.**	▪ Learmonth St (~0.1m) ▪ Bannockburn-Shelford Road (<0.1m) ▪ Jollys Road (<0.1m) ▪ Stones Road (>1m) ▪ Pantics Road (>0.5m, ~750m length) ▪ Mercer Tce (>1m) ▪ Barker Street (>1.0m) ▪ Sutherland Street (~0.8m) ▪ Teesdale-Inverleigh Road (~0.4m) ▪ Russel St (<0.3m)
1% AEP ~10,150 ML/d ~118 m^3/s 102.25 m AHD at Bannockburn-Shelford Road bridge	Generally as above with deeper, faster flowing water. Hazardous depths across floodplain.	▪ Learmonth St (~0.1m) ▪ Bannockburn-Shelford Road (<0.3m) ▪ Jollys Road (<0.1m) ▪ Stones Road (>1m) ▪ Pantics Road (>0.5m, ~750m length) ▪ Mercer Tce (>1m) ▪ Barker Street (>1.0m) ▪ Sutherland Street (>1m) ▪ Teesdale-Inverleigh Road (~0.6m) ▪ Russel St (<0.3m)

Flood Event	Characteristics – Flood Behaviour	Roadways Inundated
0.5% AEP ~13,100 ML/d ~ 52 m^3/s 102.48 m AHD at Bannockburn-Shelford Road bridge	Bannockburn-Shelford Road overtopped to depths greater than 0.3 metres. Generally as above with deeper, faster flowing water. Hazardous depths across floodplain.	▪ Learmonth St (~0.1m) ▪ Bannockburn-Shelford Road (>0.3m) ▪ Jollys Road (<0.1m) ▪ Stones Road (>1m) ▪ Pantics Road (>0.5m, ~750m length) ▪ Mercer Tce (>1m) ▪ Barker Street (>1.0m) ▪ Sutherland Street (>1m) ▪ Teesdale-Inverleigh Road (~0.9m) ▪ Russel St (<0.3m) ▪ Teesdale-Lethbridge Road (<0.1m)
0.2% AEP ~16,000 ML/d ~185 m^3/s 102.67 m AHD at Bannockburn-Shelford Road bridge	Generally as above with deeper, faster flowing water. Hazardous depths across floodplain.	▪ Learmonth St (~0.1m) ▪ Bannockburn-Shelford Road (<0.5m) ▪ Jollys Road (<0.1m) ▪ Stones Road (>1m) ▪ Pantics Road (>0.5m, ~750m length) ▪ Mercer Tce (>1m) ▪ Barker Street (>1.0m) ▪ Sutherland Street (>1m) ▪ Teesdale-Inverleigh Road (>1m) ▪ Teesdale-Lethbridge Road (<0.1m)

Table 5-2 Flood peak timing for Teesdale

Location From	Location To	Typical Travel Time	Comments	Duration
Teesdale (Native Hut Creek)				
Start of rainfall (catchment)	Teesdale	2 - 5 hours	Begin to rise from normal levels	Generally <24 hours
Start of rainfall (catchment)	Teesdale	7 - 30 hours	To peak – may be longer dependent on rainfall temporal pattern	

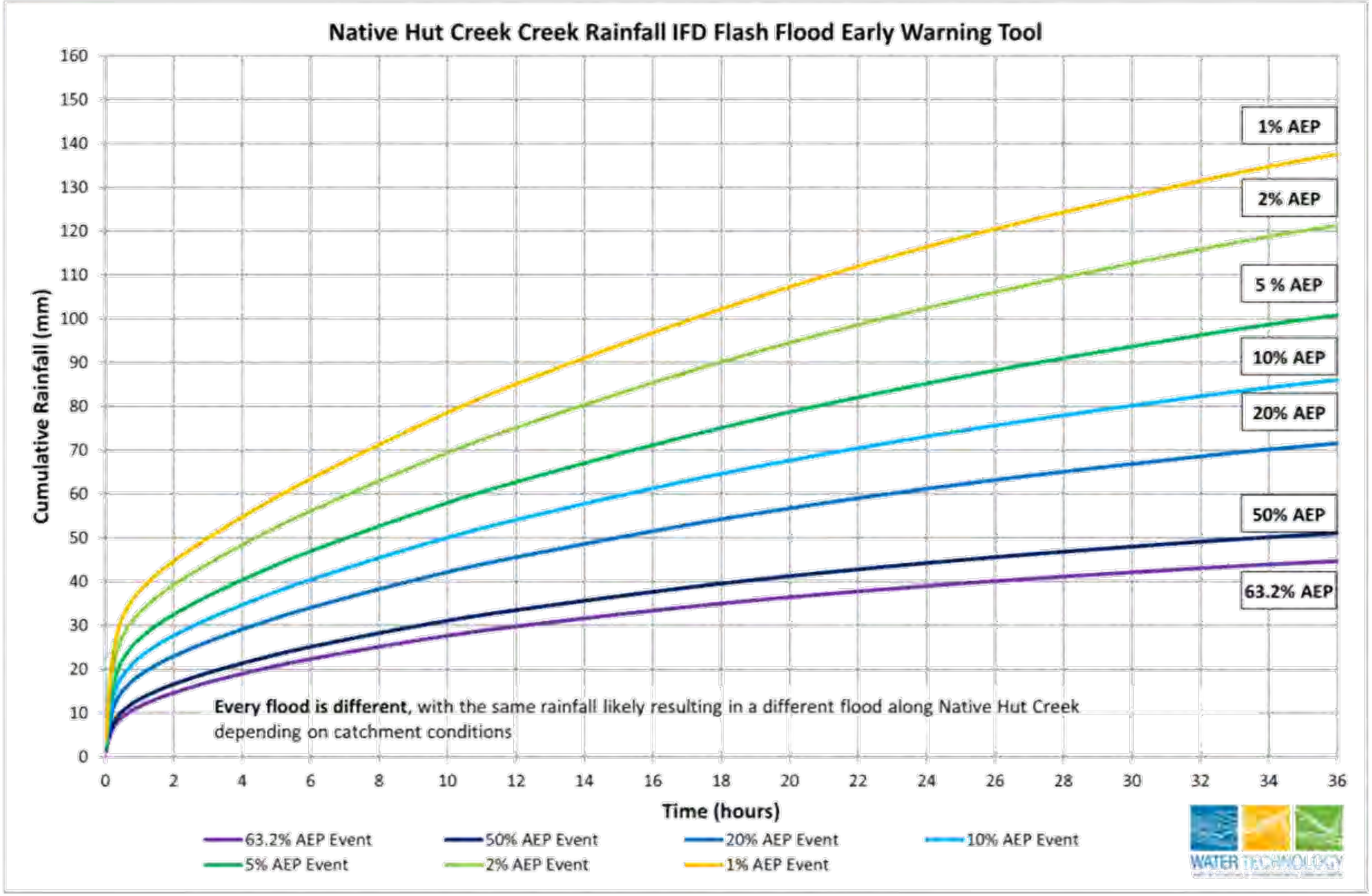

Figure 5-1 Teesdale Flood/No Flood Tool

6 FLOOD DAMAGES AND MITIGATION

6.1 Flood Damages Summary

Following completion of draft design modelling, floor level survey was commissioned for houses within or close to the draft 0.2% AEP flood extent. Flood model results for the range of existing conditions events were processed to calculate the Average Annual Damages (AAD) for Teesdale, which totals $113,366. The damages figure takes into account flooding of roads, properties and buildings. The damages assessment table is shown in Figure 6-1 below.

EXISTING CONDITIONS

ARI (years) / AEP	PMF 0.00001	500yr 0.002	200yr 0.005	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2	2yr 0.5
Residential Buildings Flooded Above Floor	16	2	2	2	2	1	1	0	0
Commercial Buildings Flooded Above Floor	2	0	0	0	0	0	0	0	0
Properties Flooded Below Floor	164	119	119	114	109	101	98	76	64
Total Properties Flooded	**182**	**121**	**121**	**116**	**111**	**102**	**99**	**76**	**64**
Direct Potential External Damage Cost	$1,582,730	$643,420	$583,954	$521,971	$470,489	$402,605	$319,425	$179,678	$87,892
								$0	$0
Direct Potential Residential Damage Cost	$2,173,478	$197,000	$185,013	$170,988	$160,202	$81,321	$73,152	$0	$0
Direct Potential Commercial Damage Cost	$418,468	$0	$0	$0	$0	$0	$0	$0	$0
Total Direct Potential Damage Cost	**$4,174,676**	**$840,420**	**$768,967**	**$692,959**	**$630,691**	**$483,926**	**$392,577**	**$179,678**	**$87,892**
Total Actual Damage Cost *(0.8*Potential)*	**$3,339,741**	**$672,336**	**$615,174**	**$554,367**	**$504,553**	**$387,141**	**$314,062**	**$143,742**	**$70,314**
Infrastructure Damage Cost	**$198,267**	**$102,406**	**$96,149**	**$83,456**	**$71,859**	**$53,936**	**$46,225**	**$15,463**	**$11,352**
Indirect Clean Up Cost									
Indirect Residential Relocation Cost									
Indirect Emergency Response Cost									
Total Indirect Cost	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Cost	**$3,538,008**	**$774,742**	**$711,323**	**$637,823**	**$576,412**	**$441,077**	**$360,287**	**$159,206**	**$81,665**

Average Annual Damage (AAD)	$113,366

Figure 6-1 Existing Conditions Average Annual Damages (AAD)

6.2 Flood Mitigation

6.2.1 Overview

Three options for structural flood mitigation were tested in the hydraulic model for all AEP events, and the resultant impact on flood damages assessed. Reductions in AAD (i.e. savings) were discounted by 6% per year over 30 years, with the total net present value of savings in that period compared to the estimated capital and maintenance costs of the mitigation works. The resultant total project cost was then produced along with a benefit/cost ratio to determine if the concept is financially sound.

The options tested are as follows:

- Raising of Pantics Road to above the 1% AEP flood level with 300mm freeboard;
- Additional culverts under Bannockburn-Shelford Road adjacent to the bridge; and
- Clearing Native Hut Creek of vegetation and large wood.

Each option is discussed below along with the results of the benefit/cost analysis.

6.2.2 Option 1: Raising of Pantics Road

For this option, raising of Pantics Road to 300mm above the 1% AEP flood level was investigated. The raised road is intended to act as a levee, preventing flooding of both the road and properties on the west side of the road. The impact of the raised road on 1% AEP flood levels is shown in Figure 6-2 below.

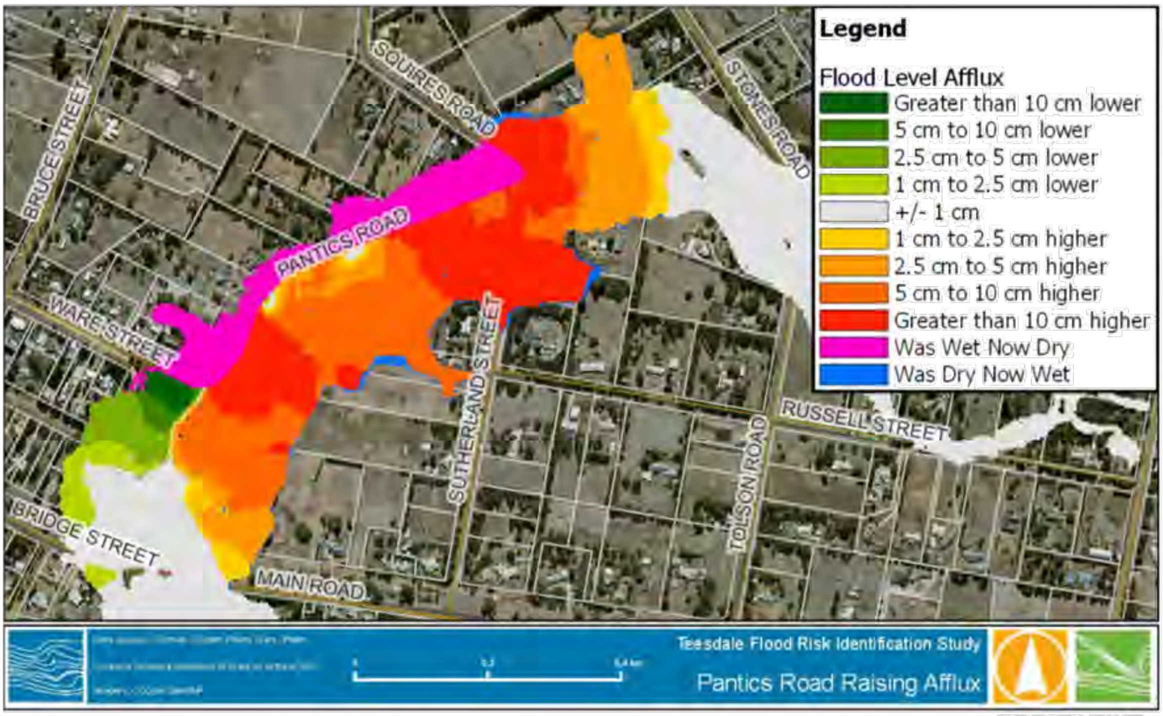

Figure 6-2 1% AEP Flood Level Afflux – Raising of Pantics Road

The raised road successfully prevents flooding of the trafficable surface and area to the west, however in doing so flood levels are raised for more properties than are protected by the levee. While a dwelling is protected from above floor flooding in events between a 10% AEP and 0.2% AEP, a different dwelling floods above floor in the 0.2% AEP event (where it does not in the existing conditions).

The resultant AAD under option 1 was $100,819 per year, providing an annual reduction of $12,547. The reduction in AAD is a result of seven properties now having flood immunity for events up to and including a 0.5% AEP flood.

The option is estimated to require capital investment of $905,556. The resultant net present value for option 1 was -$732,848.66, meaning the project will cost more than it will save, on average, over a 30-year period.

6.2.3 Option 2: Additional culverts under Bannockburn-Shelford Road

This option was iteratively modelled to attempt to alleviate flooding of Bannockburn-Shelford Road in the 2% and 1% AEP events. After several iterations, a new bank of culverts was included under the road on the east side of Native Hut Creek. The new bank consisted of 20 x 2.1m x 0.9m culverts, and also involved some manipulation of ground levels to allow flow to reach the new culverts.

The new culverts had little impact on flood levels and were unable to prevent overtopping of the road in the 1% or 2% AEP events. The impact of the culverts on 1% AEP flood levels is shown in Figure 6-3 below.

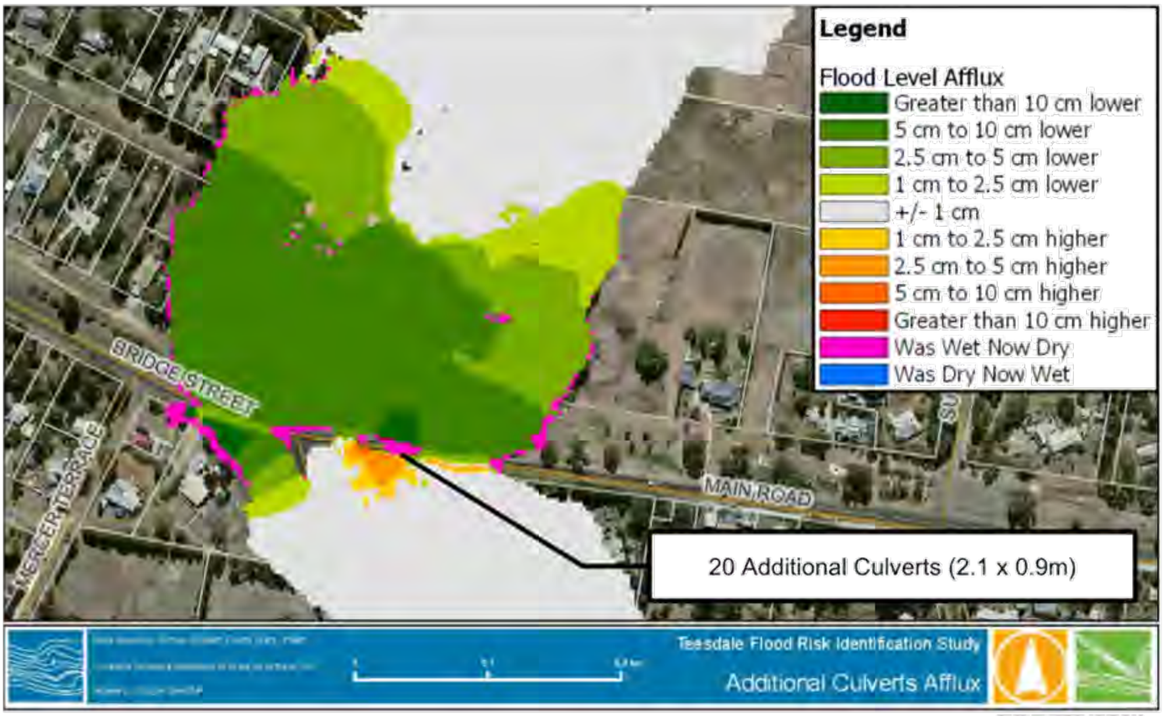

Figure 6-3 1% AEP Flood Level Afflux – Additional Culverts

The assessed reduction in AAD associated with Option 2 is $538 per year. This is a miniscule amount and reflects the lack of significant change the culverts were able to produce, with the road remaining overtopped in the same events as existing conditions. Slight reductions in extent and flood levels result in the minor reduction in AAD.

Option 2 is estimated to require capital investment of $681,620. The resultant net present value for option 2 was $674,213.27, meaning the project will cost more than it will save, on average, over a 30-year period.

6.2.4 Option 3: Waterway Vegetation Clearing

Option three tested a commonly perceived attitude in some flood affected communities: that clearing the waterway of vegetation and large wood will allow water to pass through faster and prevent inundation of properties. The option was tested by lowering the hydraulic roughness applied to Native Hut Creek in the model. Approximately 11km of waterway were "cleared" in the model by reducing the hydraulic roughness across the entire waterway corridor.

As shown during sensitivity testing, the model is highly sensitive to selection of the hydraulic roughness parameter. Reducing roughness to simulate waterway clearing therefore had a significant impact on flood levels in Teesdale. Flood levels were lowered by around 0.2 to 0.3 metres in confined areas of the waterway. The works had less impact in areas of engaged floodplain where a greater proportion of flow is outside the waterway corridor. Flood levels in the area between the Stones/Tolson Road breakout and the Bannockburn-Shelford Road bridge were lowered by less than 0.1 metres. Downstream of the bridge, flood levels were lowered between 0.1 and 0.25 metres generally.

The increased waterway conveyance benefits the two dwellings liable to above floor inundation. 87 Pantics Road is no longer inundated above floor in a 10% AEP event (although is still above floor in a 5% AEP event) while 844 Teesdale Inverleigh Road is now inundated above floor in the 1% AEP event but not the 2% AEP event.

The 1% AEP flood level afflux results are shown in Figure 6-4 below.

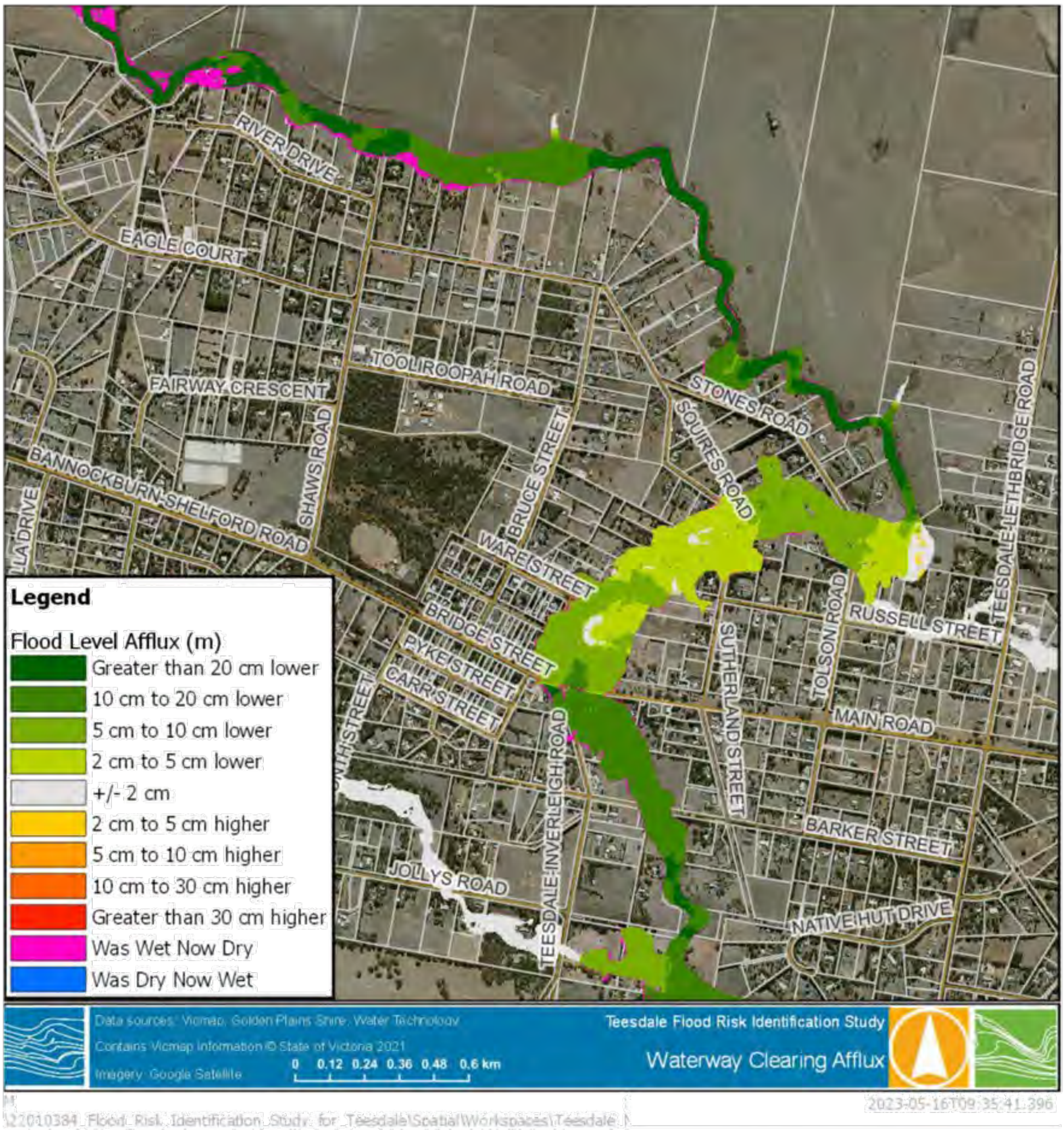

Figure 6-4 1% AEP Flood Level Afflux – Clearing of Native Hut Creek

The resultant reduction in assessed AAD is $17,363 per year. The works have been estimated to cost $4,394,473 upfront with maintenance of $38,500 per year in follow up vegetation management. The cost estimate includes the physical excavation works and makes allowances for required permits and native vegetation offsets which are significant and represent the bulk of the cost.

Given the estimated maintenance costs more per year than the amount saved in AAD, the project can not reach a positive cost/benefit ratio. The resultant net present value for option 3 was -$4,685,420.44, meaning the project will cost more than it will save, on average, over a 30-year period. Removing the ongoing maintenance cost reduces the NPV to -$4,155,474.44 which is still a significant deficit.

Notwithstanding the significant financial cost associated with the project, there remains a potentially insurmountable hurdle of permitting and approvals required prior to undertaking the works. Clearing of the waterway is likely to destroy significant habitat, which would need to be quantified. In addition, waterway clearing often creates ongoing erosion issues which can threaten private land when the waterway course and shape changes. Sediment deposition downstream also contributes to further habitat degradation.

6.2.5 Cost-Benefit Summary

Table 6-1 summarises the three mitigation methods assessed from financial performance. For each option the benefit/cost ratio has been calculated as the sum of AAD reductions in present value terms minus the capital and maintenance cost in present value terms. A benefit/cost ratio of 1 equates to a net present value of $0. Ideally cost benefit ratio should be greater than 1, however it should be acknowledged that achieving high CBR for flood mitigation works is highly unlikely and should not be the only factor considered. Community safety, resilience and vulnerability must also be taken into account.

Table 6-1 Cost-Benefit Summary

	Option 1	Option 2	Option 3
Capital Cost ($)	$730,345.20	$478,712.50	$4,394,473.20
Maintenance Cost ($/year)	$0.00	$0.00	$38,500.00
Reduction in AAD ($/year)	$12,547.00	$538.00	$17,363.00
Net Present Value ($, total)	-$557,637.86	-$471,307.02	-$4,155,474.44
Benefit/Cost Ratio	0.236	0.015	0.054

Table 6-1 clearly demonstrates that none of the mitigation methods investigated achieve favourable financial outcomes. None of the options are recommended for further investigation.

6.3 Planning Scheme Mapping

Inclusion of flood mapping in the planning scheme is a key non-structural mitigation measure to prevent flood risk from increasing into the future. The project has produced flood mapping suitable for inclusion in the planning scheme, as shown in Figure 6-5 below.

The mapping has been based on the 2100, RCP8.5 1% AEP event. Floodway delineation is based on the following criteria based on the Corangamite Catchment Management Authority's preferred delineation:

- Flood depths ≥ 0.3 metres, and/or
- Flood velocities ≥ 2.0 m/s, and/or
- Product of depth and velocity ≥ 0.3 m^2/s

The resultant draft planning scheme mapping is shown in Figure 6-5 below.

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Figure 6-5 Draft Planning Scheme Mapping

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7 SUMMARY

The Teesdale Flood Risk Identification Study has produced detailed flood modelling of Native Hut Creek through Teesdale. The mapping produced is fit for the purposes of flood emergency planning and response, statutory and strategic planning in the town. The study has also investigated the current flood impacts in terms of average annual damages and investigated structural mitigation to reduce those damages. Flood intelligence products have been produced and included in a draft update to the Golden Plains Municipal Emergency Management Plan. Options for improving flood warning and intelligence gathering have been recommended, with two additional gauges suggested for consideration.

The following actions are recommended for consideration by Golden Plains Shire and Corangamite Catchment Management Authority:

- That the findings of the study be considered by the relevant authorities;
- The additions to the draft Municipal Flood Emergency Plan are adopted into a working version of the plan;
- Flood mapping produced by the study is shared with the community;
- The draft planning scheme mapping is considered for adoption in the Golden Plains Shire planning scheme;
- Community education regarding flood damages and risk is carried out;
- The viability of additional gauges as recommended in the Flood Warning assessment are investigated in partnership with the Bureau of Meteorology;
- The model files and other deliverables of the study are filed by both authorities for future use.

Future flood events in Native Hut Creek should be monitored carefully and compared to the results of this study, with flood levels marked and surveyed where possible. Where flood behaviour appears to disagree with the findings of the study, the reason for the discrepancy should be investigated and an update to the study should be considered.

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Data Collation Report

Teesdale Flood Risk Identification Study

Golden Plains Shire

16 May 2023

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Water Technology Project Director	Johanna Theilemann
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CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY OF TERMS

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 Catchment Management Authority (CCMA) Regional Floodplain Management Strategy (CCMA, 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 - This Report**
- R02 – Joint Calibration Modelling 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

The data required for this study has been collated and reviewed. This report documents a summary of the available streamflow, rainfall and topographic data as well as the relevant previous projects and other information relevant to the study. The report also details verification of the available topographic datasets and details the hydrological and hydraulic modelling approach.

Following appointment and project inception, Water Technology engaged surveyors to capture structure details, waterway cross sections and ground levels for the purpose of LiDAR data verification as detailed in the project brief. The data captured is discussed in this report.

1.2 Objectives and Outputs

The Teesdale Flood Risk Identification Study outputs are required to meet several floodplain management objectives as highlighted in the project brief prepared by Golden Plains Shire and Corangamite CMA. The objectives of the investigation are described below:

- Provision of detailed flood mapping for a range of flooding scenarios across the study area.

Collate and review all available data and, through rigorous analysis, determine robust flood levels velocities, depths and extents.

- Update flood data for the township using current best practice modelling techniques and technology.

Produce robust flood mapping and associated documentation for inclusion in the Golden Plains Planning Scheme.

- Support the implementation of the Teesdale Structure Plan.

Update the Municipal Flood Emergency Plan.

1.3 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.
- 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.

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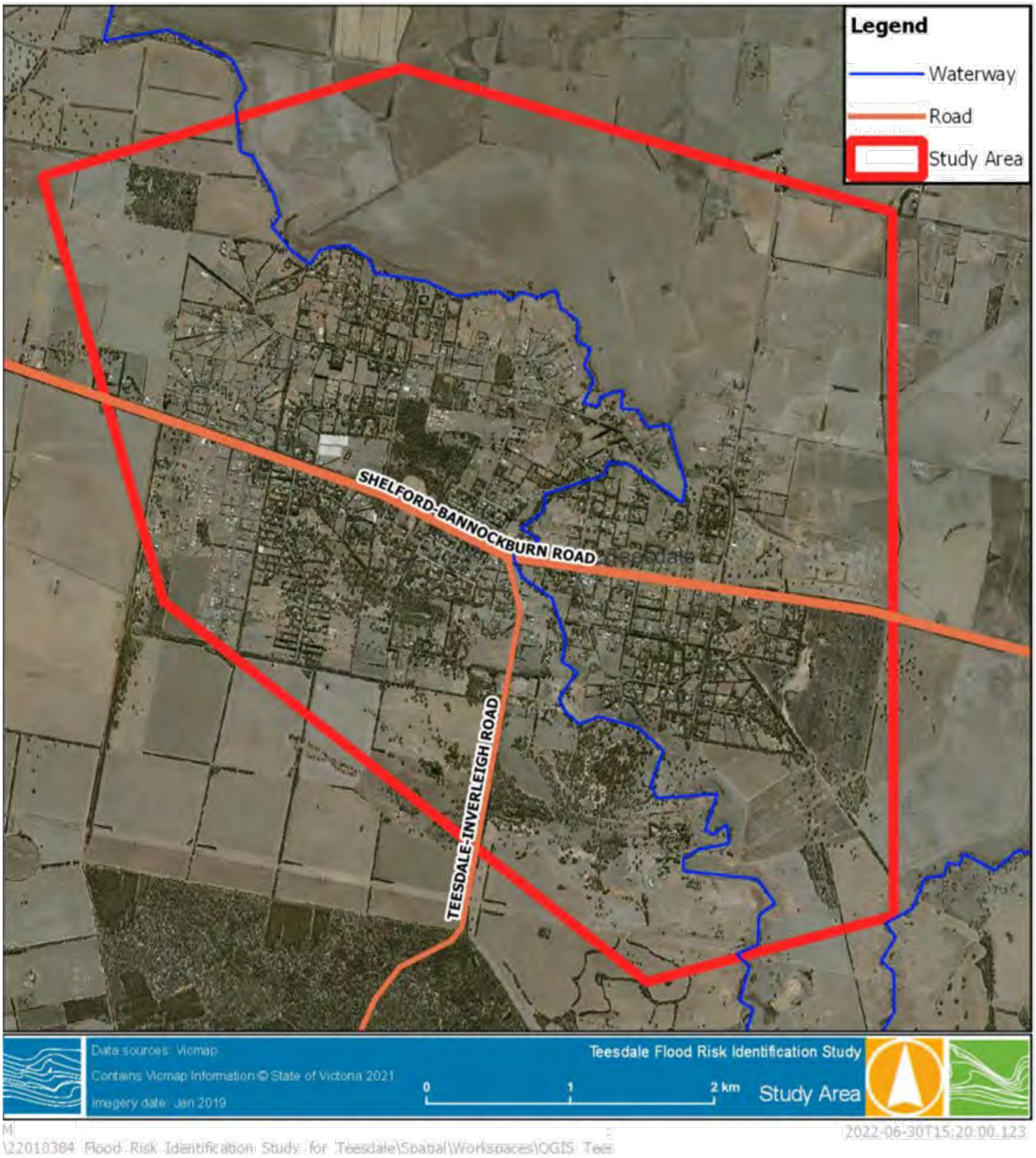

Figure 1-1 Teesdale Flood Risk Identification Study - Study Area

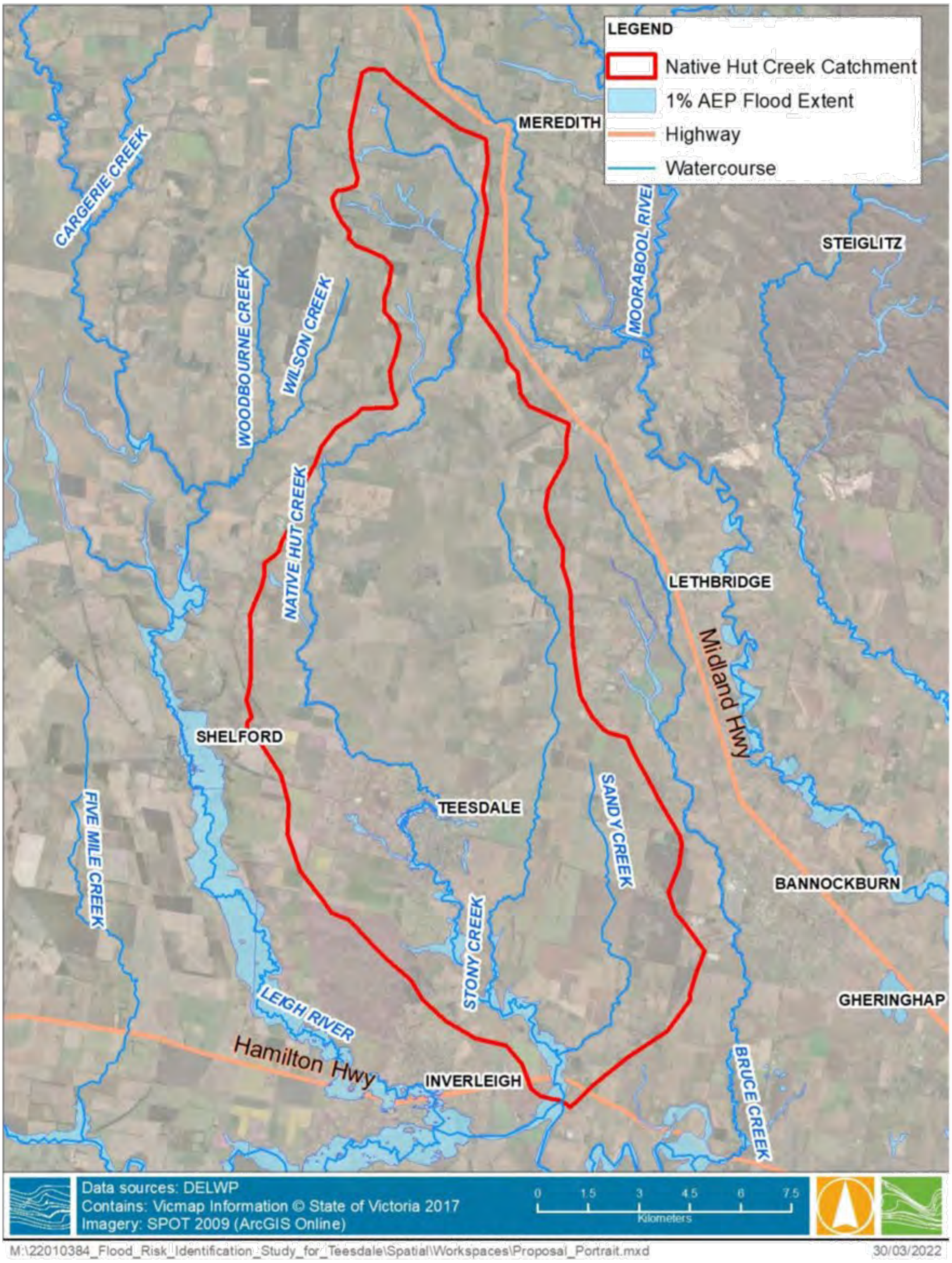

Figure 1-2 Native Hut Creek Catchment

2 DATA SUMMARY

2.1 Previous Studies

The following studies which produced flooding information for Native Hut Creek at Teesdale have been identified as part of the data collation and review:

- Victorian Flood Data Transfer Project (2001)

CCMA Hydrologic and Hydraulic Assessment (2008)

- Regional Flood Mapping – Barwon River, Thompson Creek and Woady Yaloak Creek (2016)

CCMA Updated Hydrologic and Hydraulic Assessment (2019)

A synopsis of each study is given below.

Victorian Flood Data Transfer Project (2001)

The Victorian Flood Data Transfer Project's Golden Plains Shire report was finalised and published in February 2001. The Project's main goal was to produce a *"high quality, consistent and comprehensive Geographic Information System (GIS) layer and hardcopy map products showing a range of flood data for urban and rural floodplains in Victoria"* (Sinclair Knight Merz, 2001). The project produced this data by reviewing available flood data, with no modelling being undertaken for most areas across the municipality including Teesdale. The Golden Plains Shire report states that an 'interpreted' flood extent was available for the Teesdale area in addition to topographic and geologic maps. It is assumed that this interpreted flood extent came from the former State Rivers and Rural Water Commission (SRRWC).

CCMA Hydrologic and Hydraulic Assessment (2008)

The Victorian Flood Data Transfer Project flood extent for Teesdale was superseded by a flood study of Native Hut Creek completed by CCMA in 2008. The CCMA report states that the Victorian Flood Data Transfer Project information is "*known to be inaccurate through Teesdale"* (CCMA, 2008). The CCMA work utilised a RORB hydrological model and HEC-RAS one-dimensional hydraulic model to estimate 1% AEP flood behaviour throughout Teesdale.

Floodplain inundation mapping produced from the HEC-RAS model outputs forms the current flood related overlay mapping in the Golden Plains Planning Scheme.

Regional Flood Mapping – Barwon River, Thompson Creek and Woady Yaloak Creek (2016)

GHD were engaged to undertake the Regional Flood Mapping project by the Department of Environment and Primary Industries (DEPI), now the Department of Environment, Land, Water and Planning (DELWP). The study was delivered in 2016 and utilised RORB hydrological mapping and TUFLOW GPU hydraulic modelling to produce floodplain mapping of the Barwon River catchment, totalling around 3,700 km^2 of catchment area. The modelling was undertaken prior to the release of TUFLOW HPC (Highly Parallelised Compute), which offered significant solver improvements including an upgrade in spatial accuracy from 1st order to 2nd order, and 1D-2D linking capabilities. The study had a number of limitations due to its large spatial coverage, and thus the information and findings produced by the study are subject to a number of qualifications including *"Due to its extensive coverage and consequent low reliability this data is not generally suitable for providing… specific information based on related to flood levels, extents or velocities."*

CCMA Updated Hydrologic and Hydraulic assessment (2019)

In 2019, an updated assessment of flooding in Native Hut Creek was undertaken by Tony Jones of CCMA. The assessment updated the RORB hydrologic modelling, taking advantage of new topographical information and GIS capabilities to better delineate the subareas and reaches of the model. The hydrologic assessment utilised the recommended rainfall Intensity Frequency Duration data and temporal patterns from Australian Rainfall and Runoff 1987.

Flows from the updated hydrologic model were input to a newly developed two-dimensional HEC-RAS hydraulic model of Native Hut Creek and its floodplain. The hydraulic model adopted a uniform Mannings roughness of 0.06 across the creek and floodplain with the exception of the Bannockburn-Shelford Road bridge, which was modelled with a higher roughness of 0.08 to account for the restriction of flows through the structure. Being a two-dimensional hydraulic model, outputs include gridded depth, velocity, water level and the product of depth and velocity.

The two dimensional HEC-RAS model outputs are understood to be the currently adopted "best available information" for flooding in Native Hut Creek through Teesdale and are utilised in assessments of planning referrals and floodplain advice responded to by the Corangamite CMA.

A summary of related studies completed in the Teesdale and Native Hut Creek region are summarised in Table 2-1.

Table 2-1 Flood related studies completed in Teesdale and Native Hut Creek Region

Related Studies	Author	Year
Victorian Flood Data Transfer Project (2001)	DNRE/SKM	2001
Hydrologic and Hydraulic assessment (2008)	CCMA	2008
Regional Flood Mapping – Barwon River, Thompson Creek and Woady Yaloak Creek	GHD	2016
Updated Hydrologic and Hydraulic assessment (2019)	CCMA	2019

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2.2 Flood Information

2.2.1 Historical Flood Records

There is no streamflow data available for Native Hut Creek. The 2011, 1995 and 1973 flood events were assessed in the 2016 GHD Regional Study however the assessment of these events was not specific to the Native Hut Creek catchment. These events along with other anecdotal evidence gathered from an initial community consultation meeting form the basis of the known historic flooding in Teesdale.

Table 2-2 Historical floods (descriptions as per community anecdotes)

Year	Description of Flooding	Data Available
February 1973	Widespread flooding in the Native Hut Creek and Leigh River, with flooding reported at Inverleigh and Teesdale.	Photographs and descriptions of flooding in Native Hut Creek provided during community consultation session.
November 1995	Significant flooding within the Barwon River catchment (including Barwon River at Inverleigh)	No information available. Understood to not have impacted road closures or houses in Teesdale.
April 2001	Flooding said to overtop the Bannockburn-Shelford Road.	Anecdotal data only available at this stage.
January 2011	Significant flooding on Leigh River including Leigh River at Shelford and Inverleigh.	Minimal information available. Understood to not have impacted road closures or houses in Teesdale. Photos showing flooding remained in channel through Teesdale

In addition to the above events, initial investigations have identified September 1880 as being a flood event which inundated houses in town (see right).


TEESDALE.
(FROM OUR OWN CORRESPONDENT.)
Monday.
The floods of Saturday and yesterday in this locality were such as have not hitherto been seen by a white man. The almost incessant rain of Friday and Saturday, coming so soon after the downpour at the beginning of the week, filled every gutter, gully, and creek early on Saturday. Shortly after mid-day on Saturday the Native Creek began to overflow its banks, and kept steadily rising until mid-day yesterday, when the flood was at its height. From dusk on Saturday till yesterday afternoon all traffic was suspended. The Stony Creek—the boundary line between the Shires of Leigh and Bannockburn—was also impassable. A young man resident here had a miraculous escape from drowning in that creek on Saturday evening. He attempted to cross the creek, but was washed away by the strength of the current, and, after being tossed hither and thither down the creek for well on to a hundred yards, the swollen flood gave him a sudden surge on to land, and thus he escaped. Mr Whorlow, of Shelford, while attempting to cross the same creek some miles above the main road, had his horse nearly washed away from under him, but after a little floundering both got safely across. A woman at Teesdale, who apprehended no danger and would leave not her house, was rescued on horse-back on Saturday afternoon. Several houses were partially submerged, but not seriously damaged. Nearly all the fencing abutting on the creek has been washed away; several of the farmers losing heavily in this respect. Nearly the whole of the low lying lands near the creek have been covered with a considerable thickness of barren sand. Some embankments on the road from here to Inverleigh have been washed away. The large and only dam on

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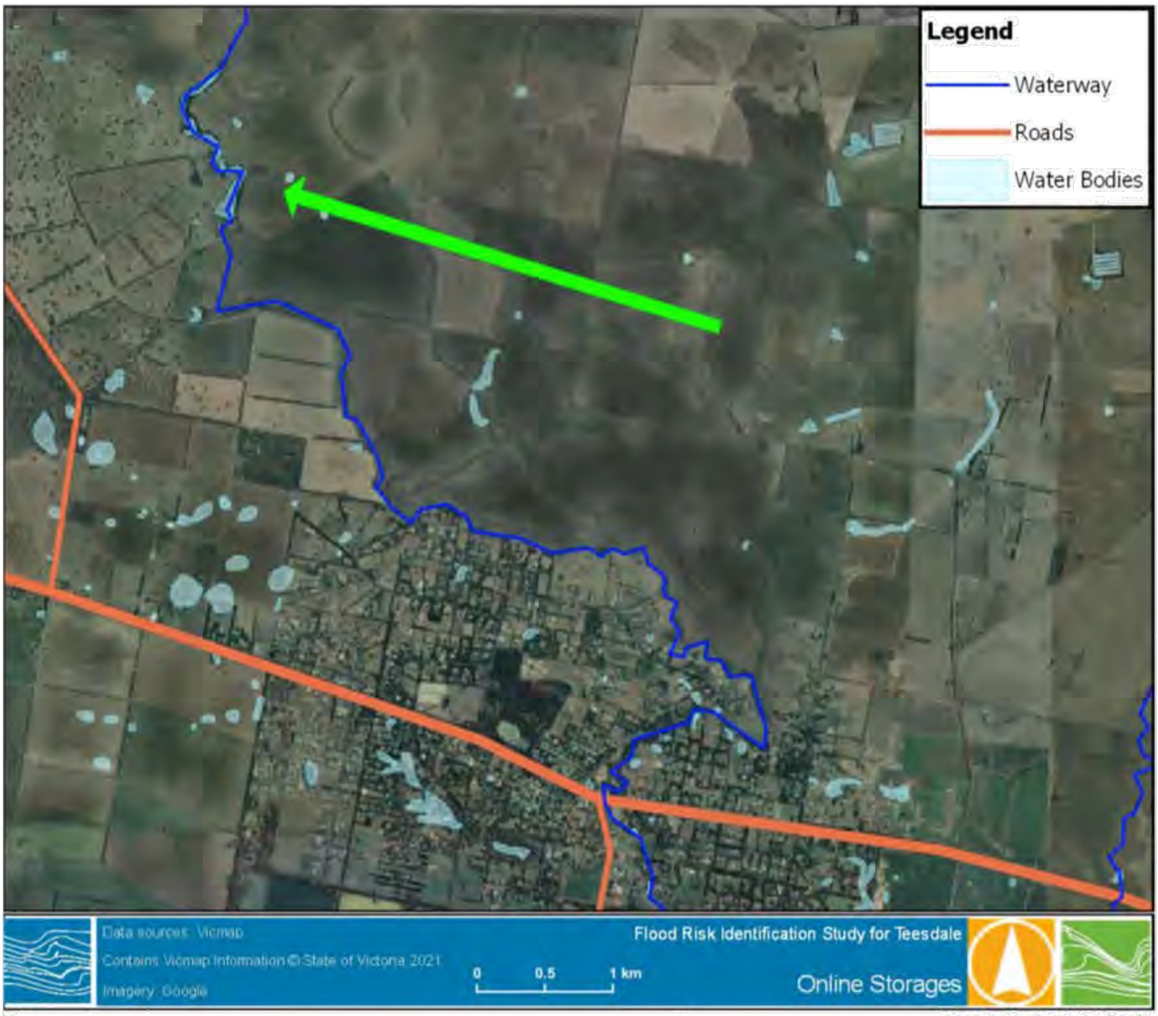
2.3 Storages

There are no formal storages within the Native Creek catchment, with any storages limited to farm dams. Two reasonably large dams are located on-line, i.e. the entire Native Hut Creek catchment flows through the dams, approximately 7-7.5km upstream of Teesdale. These farm dams have not been included in the previous CCMA RORB models.

It is understood the storages are privately owned and operated, and thus are unlikely to be operated for flood mitigation purposes. As such, design events will consider the storages to be full at the start of the event.

Notwithstanding the above, the potential impact of the storages on flood behaviour will be investigated as discussed in Section 4.2.3.

The location of the two farm dams is shown in Figure 2-1 and Figure 2-2.



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\22010384 Flood Risk Identification Study for Teesdale\Spatial\Workspaces\QGIS Tees 2022-08-04T10:01:42.507

Figure 2-1 Online storages – far view

Figure 2-2 Online Storages – close view

2.4 Streamflow Data

No streamflow data is available for Native Hut Creek. As identified in Section 2.2, the identification of key flood events is limited to adjacent waterways in the broader catchment. This relies on previous studies including the 2016 Regional Study and the 2018 Inverleigh Flood Study. Streamflow gauges from nearby waterways which may be used to identify broader catchment (Barwon River) flooding are shown in Table 2-3.

Table 2-3 Summary of available streamflow gauges

Station Name	Station No.	Status	Data Type	Period of record available
Leigh River @ Shelford	233213	Active	Instantaneous Flow	1954 to present
Leigh River @ Shelford (Golf Hill)	233248	Inactive	Instantaneous Flow	1994 to 2012
Barwon River @ Pollocksford	233200	Active	Instantaneous Flow	1906 to present*

Station Name	Station No.	Status	Data Type	Period of record available
Moorabool River @ Batesford	232202	Active	Instantaneous Flow	1908 to present**

* Manual daily readings from 1906 to 1922; no records 1922-1969

** Manual daily readings prior to 1959; no records 1922-1944

2.5 Rainfall Data

2.5.1 Overview

Historic daily and sub daily rainfall data is required for the hydrologic and hydraulic model validation. Daily rainfall gauges are used to provide a representation of spatial rainfall variation while sub daily gauges provide a representation of temporal rainfall distribution from historic events.

2.5.2 Daily Rainfall

Table 2-4 summarises the daily rainfall information available within or near the Native Hut Creek catchment. Daily rainfall stations located within the catchment are generally preferred, however the gauges outside of the catchment will be utilised to provide a suitable spatial representation of both event based and average design rainfall. Figure 2-3 displays the location of the daily rainfall gauges.

Table 2-4 Daily rainfall station information

Station Name	Station No.	Start	End
Bannockburn	87009	1898	Current
Meredith	87042	1887	Current
Meredith (Darra)	87043	1875	Current
Meredith (Wattle Vale)	87044	1905	1971
Shelford	87059	1887	2009
Teesdale	87092	1883	1914
Teesdale	87120	1968	1979
Lethbridge (Glenmoor)	87123	1968	2006
Shelford (Leigh River)	87132	1954	1982
Sheoaks*	87168	1990	Current
Inverleigh	89041	1940	1974
Leigh River @ Mount Mercer	89104	1956	Current

(*Sheoaks also provides sub-daily (6-minute) pluviography information)

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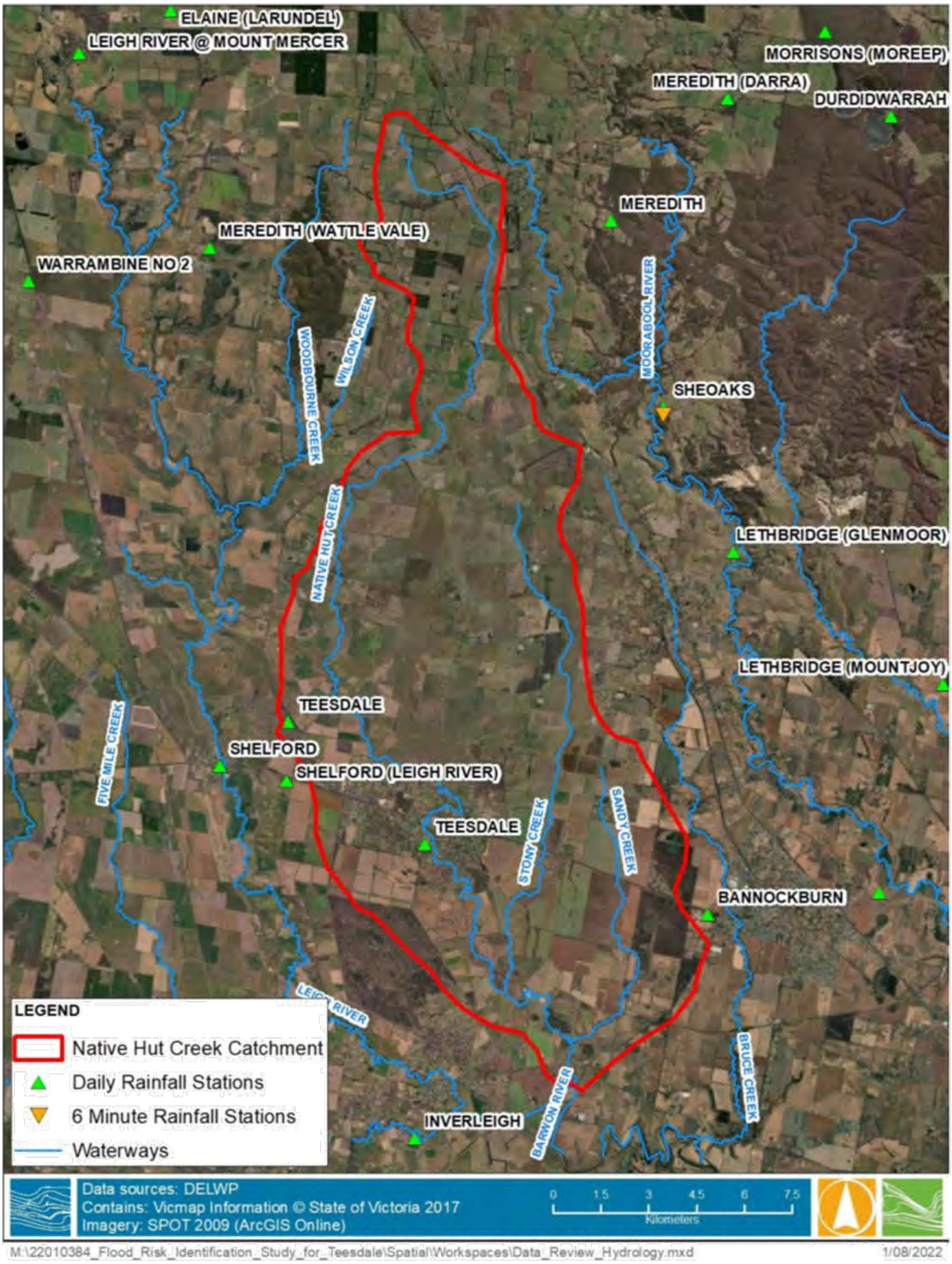

Figure 2-3 Daily Rainfall station in Native Hut Creek catchment

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2.5.3 Sub-Daily Rainfall

There are no sub-daily rainfall stations within the Native Hut Creek catchment. The locations of nearby current and closed sub-daily rainfall stations are shown in Figure 2-4. The nearest sub-daily catchment is Sheoaks, approximately 14.5 km northeast of Teesdale. Multiple sub-daily stations are available to the east of the catchment in more populated areas near Geelong and Lara, while to the west of the catchment stations are available at Colac and Ballarat.

Figure 2-4 Pluviograph stations near Native Hut Creek Catchment

2.6 Road and Drainage Infrastructure

Within the project area, there are several road structures on Native Hut Creek and several minor culverts on ephemeral tributaries/drainage lines within the town. These structures are listed in Table 2-5 and are highlighted in Figure 2-5, with numbers assigned to the crossings to provide a reference between the table and location as in Figure 2-5. A site visit was carried out on 4th August 2022 and all relevant road crossings along Native Hut Creek were visited with structure measurements taken, as shown in Table 2-5. Feature survey was also undertaken at three structures to both increase the accuracy of the modelling and be used as a basis for LiDAR verification (discussed further in Section 2.7.2).

Table 2-5 Native Hut Creek and Teesdale Drainage structures

Crossing (number)	Owner	Data collected/provided	Structure description / measurements
Bannockburn-Shelford Road	VicRoads	Feature survey of structure captured as part of project	Bridge
Stones Road/Tolson Road	Golden Plains Shire	Feature survey of structure captured as part of project; design plans provided	Bridge
Barker Street	Golden Plains Shire	Feature survey of structure captured as part of project	2x box culverts
Teesdale – Inverleigh Road (1)	Golden Plains Shire	Site Visit to measure structure, invert to be set from LiDAR	600 x 600mm box culvert, bluestone construction
Jollys Road (2)	Golden Plains Shire	Site Visit to measure structure, invert to be set from LiDAR	600 x 600mm box culvert, bluestone construction
Learmonth Street (3)	Golden Plains Shire	Site Visit to measure structure, invert to be set from LiDAR	300mm RCP
Learmonth St (4)	Golden Plains Shire	Site Visit to measure structure, invert to be set from LiDAR	2x 300mm RCP
Bruce Street (5)	Golden Plains Shire	Site Visit to measure structure, invert to be set from LiDAR	300mm RCP, partially buried
Sutherland Street (6)	Golden Plains Shire	Site Visit to measure structure, invert to be set from LiDAR	Walkway through waterway, no culvert or pipe present
Teesdale – Inverleigh Road (7)	Golden Plains Shire	Site Visit to measure structure, invert to be set from LiDAR	450mmm RCP west side (Mercer Street) 375mm RCP east side (Turtle Bend path)
Teesdale – Inverleigh Road (8)	Golden Plains Shire	Site Visit to measure structure, invert to be set from LiDAR	Culvert submerged, unable to measure

Figure 2-5 Location of key structures within model extent

2.7 Topography and Survey Data

2.7.1 LiDAR Data

An initial assessment of the spatial coverage of available LiDAR data datasets was undertaken during the data review phase. Four key datasets were available, these were as follows:

- 2021 Golden Plains LiDAR (GPS/DELWP)
  - This LiDAR was flown as part of the DELWP CIP program, the data is available as a 50cm DEM and covers the entire catchment and is the most recent data captured.
- 2014 Geelong-Anakie-Teesdale
  - This is a 1m DEM covers the south-east of the study extent and the Township of Teesdale. It overlaps with ISC LiDAR and the 2021 data.
- 2010 Index of Stream Condition (ISC) captured by Fugro

  - This is an 1m DEM covers the river systems Native Hut Creek. It has been noted through numerous studies there is generally a systematic 305mm error in this data which was found in the 2013 Skipton Flood Investigation.
- 2008 Corangamite CMA
  - This is a 5m DEM covers the study extent and broader Native Hut Creek catchment. This data was captured as part of the National Action Plan for Salinity and Water Quality.

Table 2-6 outlines the metadata information of the available LiDAR datasets used in this project. The GPS/DELWP LiDAR dataset, being the most recently captured data, is intended to be the main data source for the project as suggested in the request for quote. Before adopting the GPS/DELWP LiDAR, verification and comparison to other available datasets has been undertaken to ensure it is fit for purpose.

Table 2-6 Available Datasets

Dataset	Name	Source	Capture Date	Vertical Accuracy	Resolution
GPS/DELWP LiDAR	2021 Golden Plains LiDAR	LiDAR	2021	±0.15m	0.5m grid
CHW_LiDAR	Geelong-Anakie-Teesdale	LiDAR	2014	±0.15m	1m grid
ISC_LiDAR	2009-10 Victorian State Wide Rivers LiDAR Project – Corangamite CMA	LiDAR	2009 – 2010	±0.2m	1m grid
Corangamite_LiDAR	2007-08 South-West Region LiDAR – Corangamite	LiDAR	2006 – 2008	±0.5m	5m grid

2.7.2 LiDAR Verification

Topography data is the major source of data used in the project and was verified in order to ensure the hydraulic model can accurately replicate flood behaviour within the study area. This is critical in ensuring that model outputs, particularly peak water surface elevations, are accurate.

The capture of ground survey at three locations within the study area was commissioned to assist with verification of the available LiDAR datasets (Figure 2-6). The survey consisted of transects along the crest of roadways shown in Figure 2-6. Each transect is approximately 100 m in length with a spot height every 5 metres. The transect results compared with available LiDAR datasets are presented in Table 2-7.

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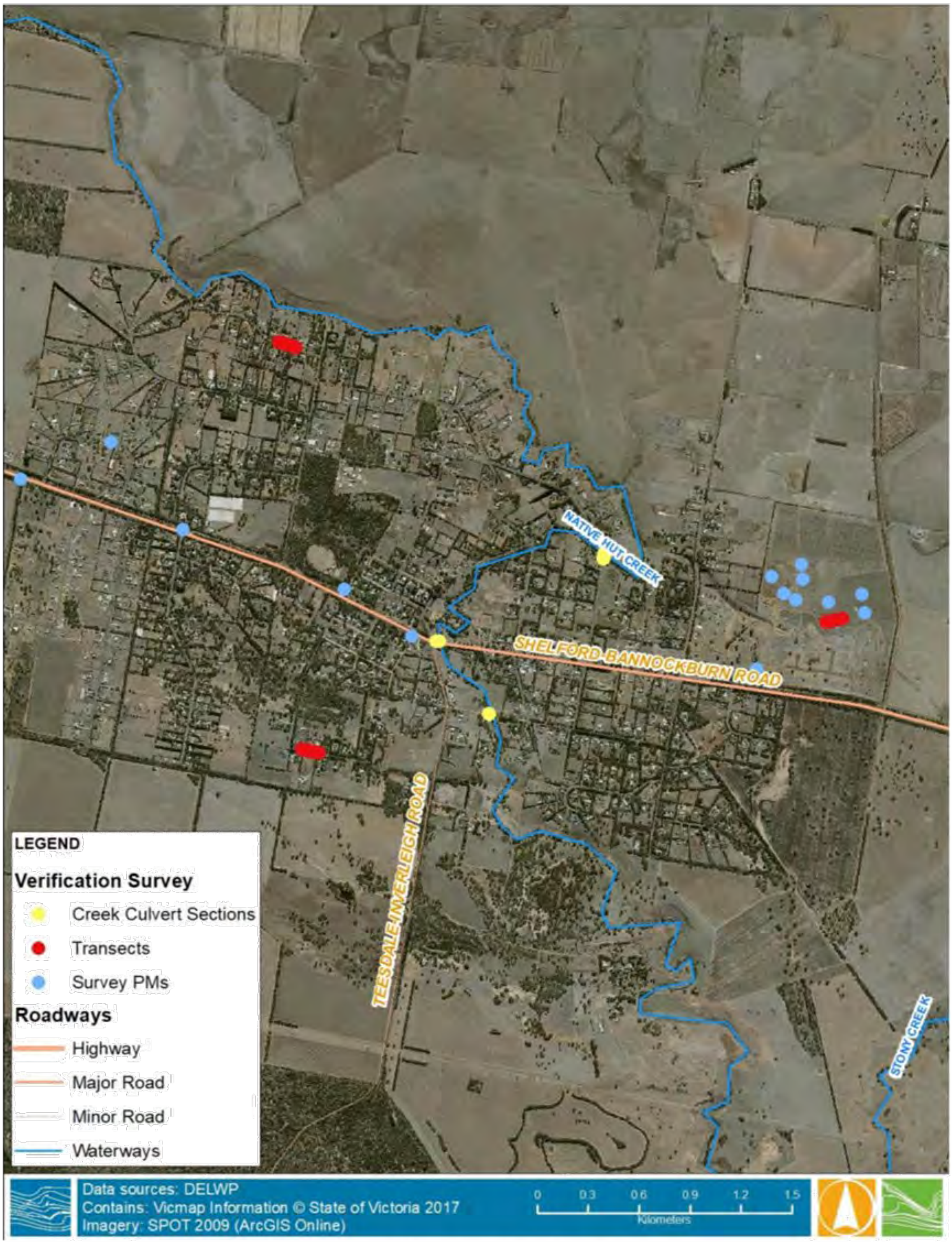

Figure 2-6 Verification Survey

The 2021 Golden Plains LiDAR was verified by comparison to surveyed road transects (captured at three road crossings). Comparison to cross section survey was completed in two ways; on a point by point basis to create a statistical distribution of the differences and as transects to get a visual comparison of the reliability of the data.

63 surveyed crest points were available across the road transects, each of the surveyed levels was compared to the level determined in the LiDAR data and the difference between the two calculated. The levels were plotted against the survey for the three transects shown in Figure 2-8 – Figure 2-10. Of the 63 points compared, 60 were within 0.05m. The average difference across the three transects is less than 2cm as shown in Figure 2-7 and Table 2-7. This shows a high degree of accuracy and indicates the LiDAR is suitable for use in the development of the Digital Elevation Model (DEM) for the hydraulic model.

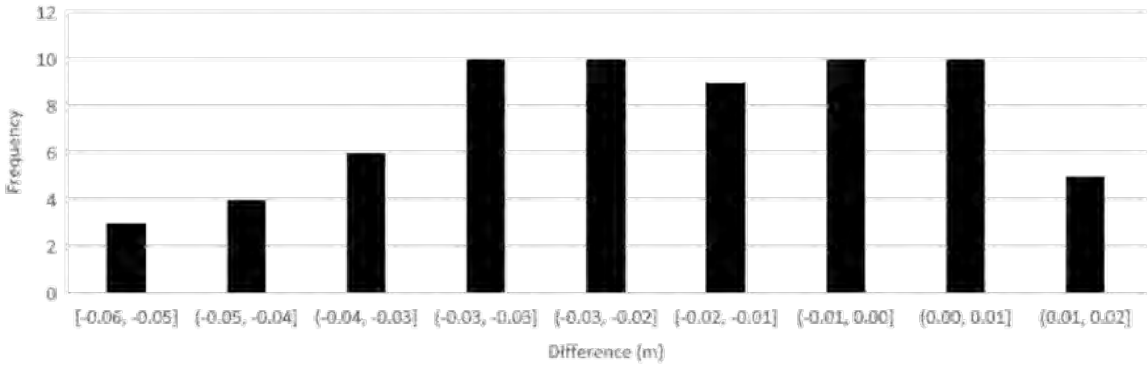

Figure 2-7 Distribution of survey and LiDAR comparison

Table 2-7 Field Survey – Road Transect LiDAR Comparison

Transect	Number of Points	Minimum Difference	Maximum Difference	Average Difference	Standard Deviation
1- River Dr, Teesdale	21	-0.055	0.010	-0.026	0.016
2- Jollys Rd, Teesdale	21	-0.058	-0.002	-0.025	0.015
3- Rocklea Rd, Teesdale	21	-0.032	0.016	-0.004	0.012
Total	63	-0.058	0.016	-0.018	0.018

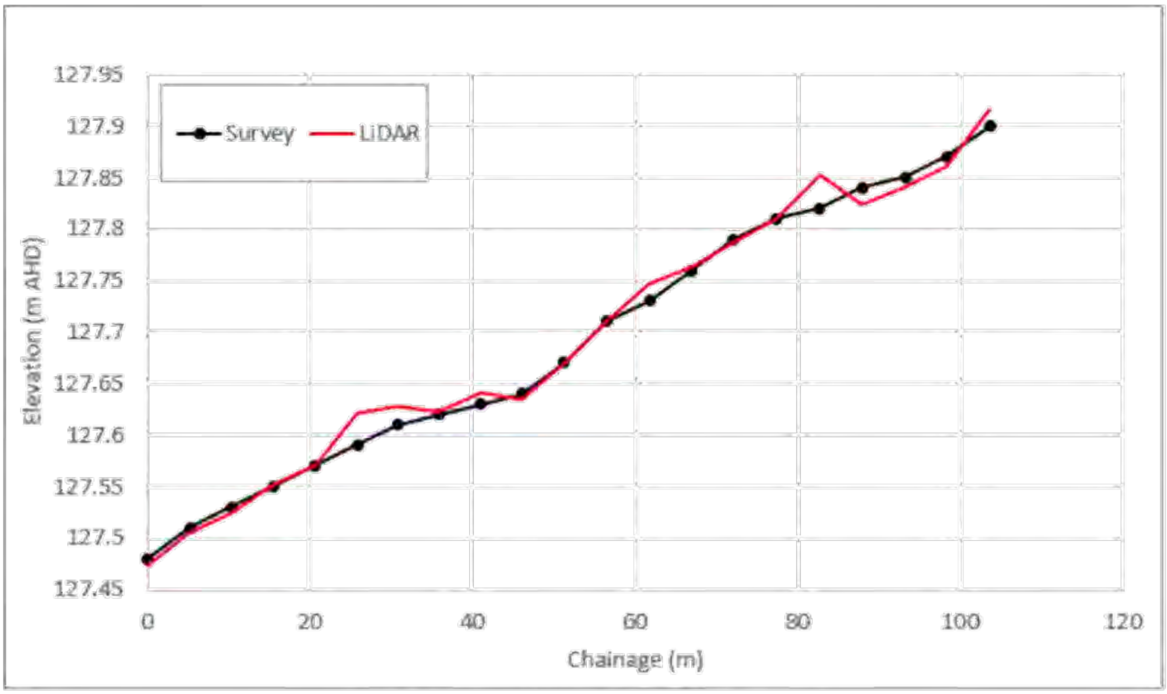

Figure 2-8 Rocklea Road – LiDAR verification

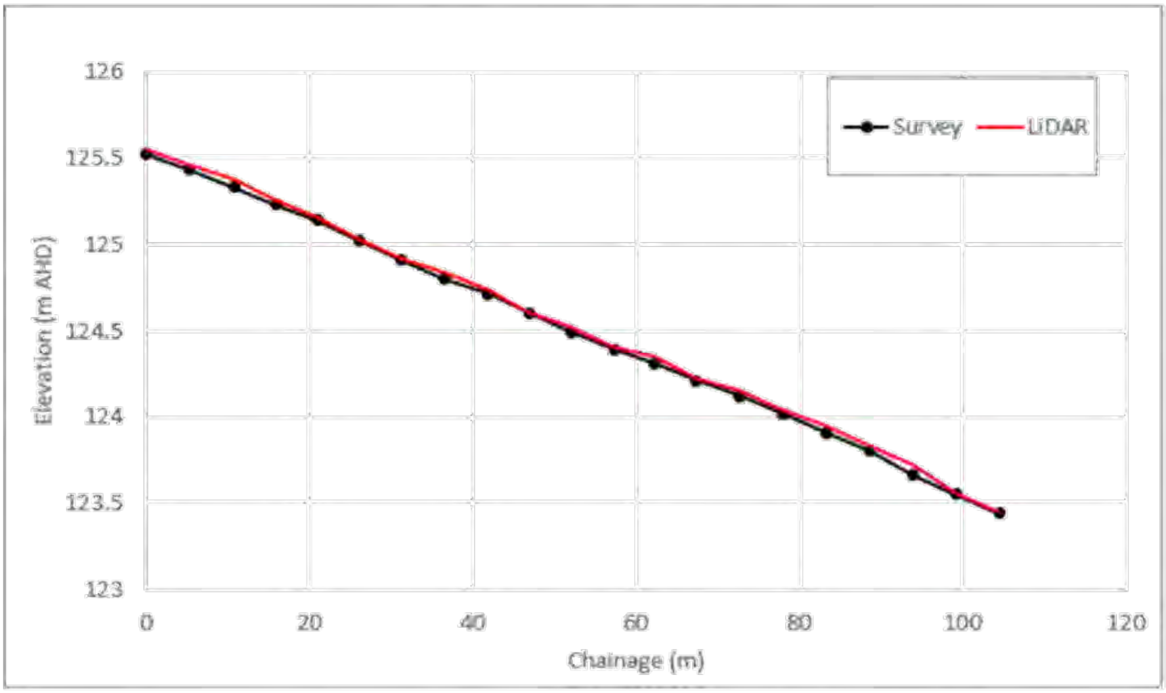

Figure 2-9 Jollys Road – LiDAR verification

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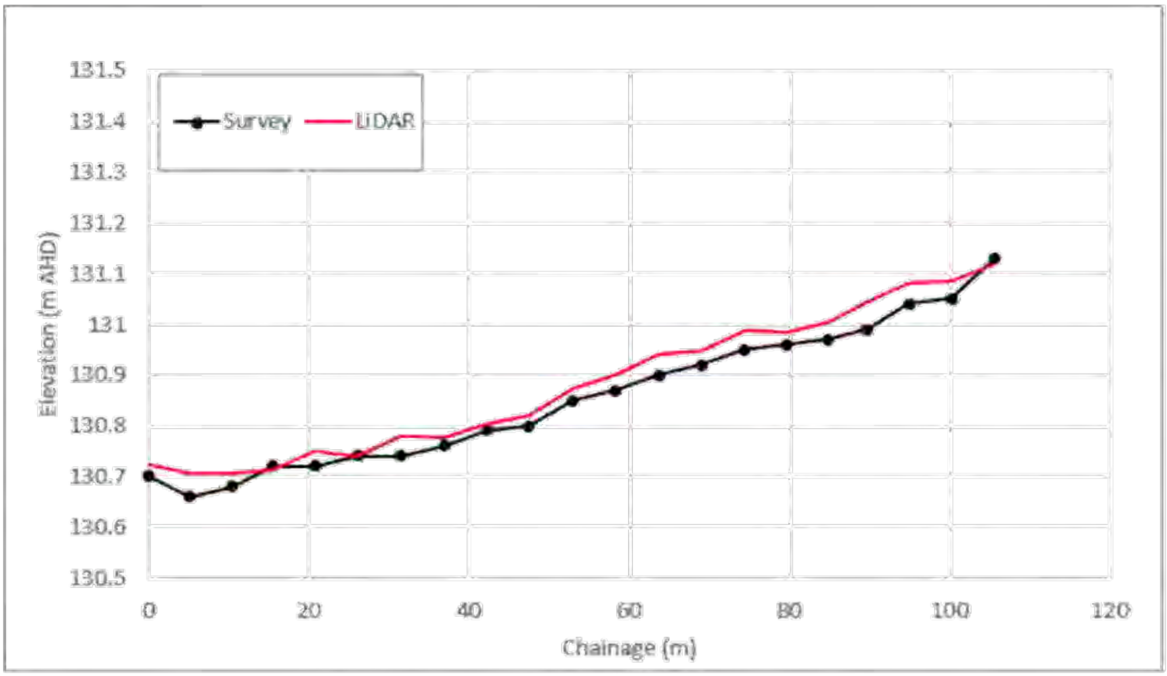

Figure 2-10 Sutherlands Road – LiDAR verification

2.7.3 LiDAR Comparison

Comparison between the 2021 Golden Plains LiDAR, the 2014 Geelong-Anakie LiDAR and the 2009-10 ISC data was made using the following calculations:

2021 Golden Plains LiDAR – 2014 Geelong-Anakie LiDAR

2021 Golden Plains LiDAR – 2009-10 Index of Stream Condition LiDAR

The result showed positive values where the 2021 LiDAR was higher and negative values where the 2014 & 2010 was higher. The comparison was made for the township of Teesdale where LiDAR was available from both required datasets, as shown in Figure 2-11 and Figure 2-12. The calculation determined a mean difference in the datasets of 0.192m between the 2021 and 2014 data and -0.081m between the 2021 and 2009/10 data.

A standout feature of the comparison between the 2021 and 2010 LiDAR is the vertical banding of errors, with the margin of error generally increasing in the easterly direction until a new 'band' begins. It is suspected, but not confirmed, that the bands are a result of data processing, with data having been collected in north/south flight paths. It is noted that the 2010 ISC LiDAR dataset has known accuracy issues, based on previous assessments of the data.

It is also noted that the 2021 LiDAR is, in general, consistently higher than the 2014 data. It was initially suspected that seasonality could be factor in this result, as the 2021 LiDAR was captured in June, when pasture is expected to be grown to a greater height than the 2014 dataset which was flown in February. While this does appear to be a factor in some locations, for example the large area northeast of the town centre, it is noted that most roads are also showing consistently higher results in the 2021 dataset. Sealed roads are not affected by seasonal vegetation growth, therefore it is concluded that seasonality is not a significant influence in the result. Given the extremely close agreement between the 2021 LiDAR and field survey observations as detailed above, a recommendation of this report is to adopt the use of the *Golden Plains 2021 LiDAR* dataset for the DEM in the hydraulic model build.

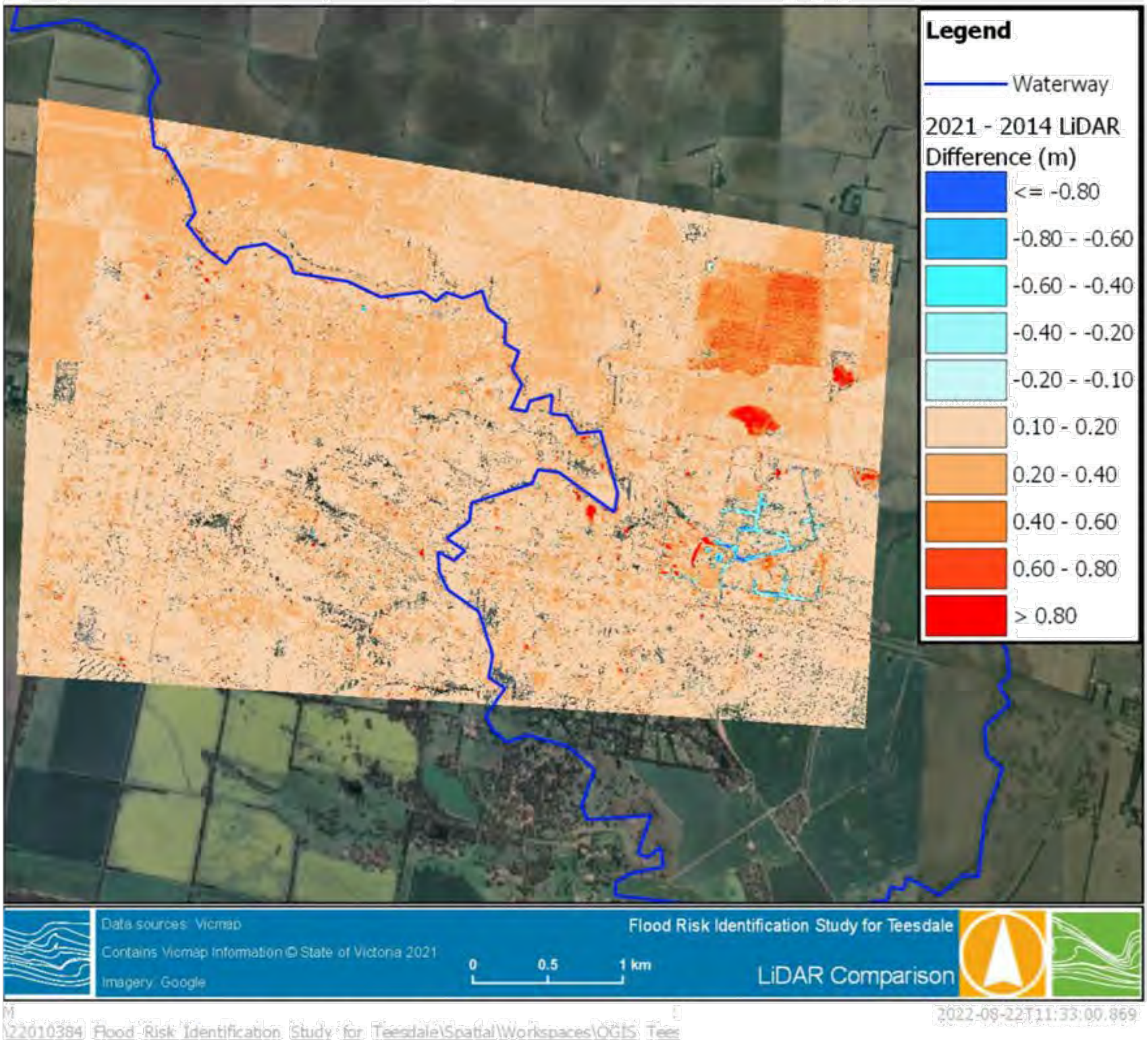

Figure 2-11 Comparison Between 2021 and 2014 LiDAR Datasets (± 0.1m not shown)

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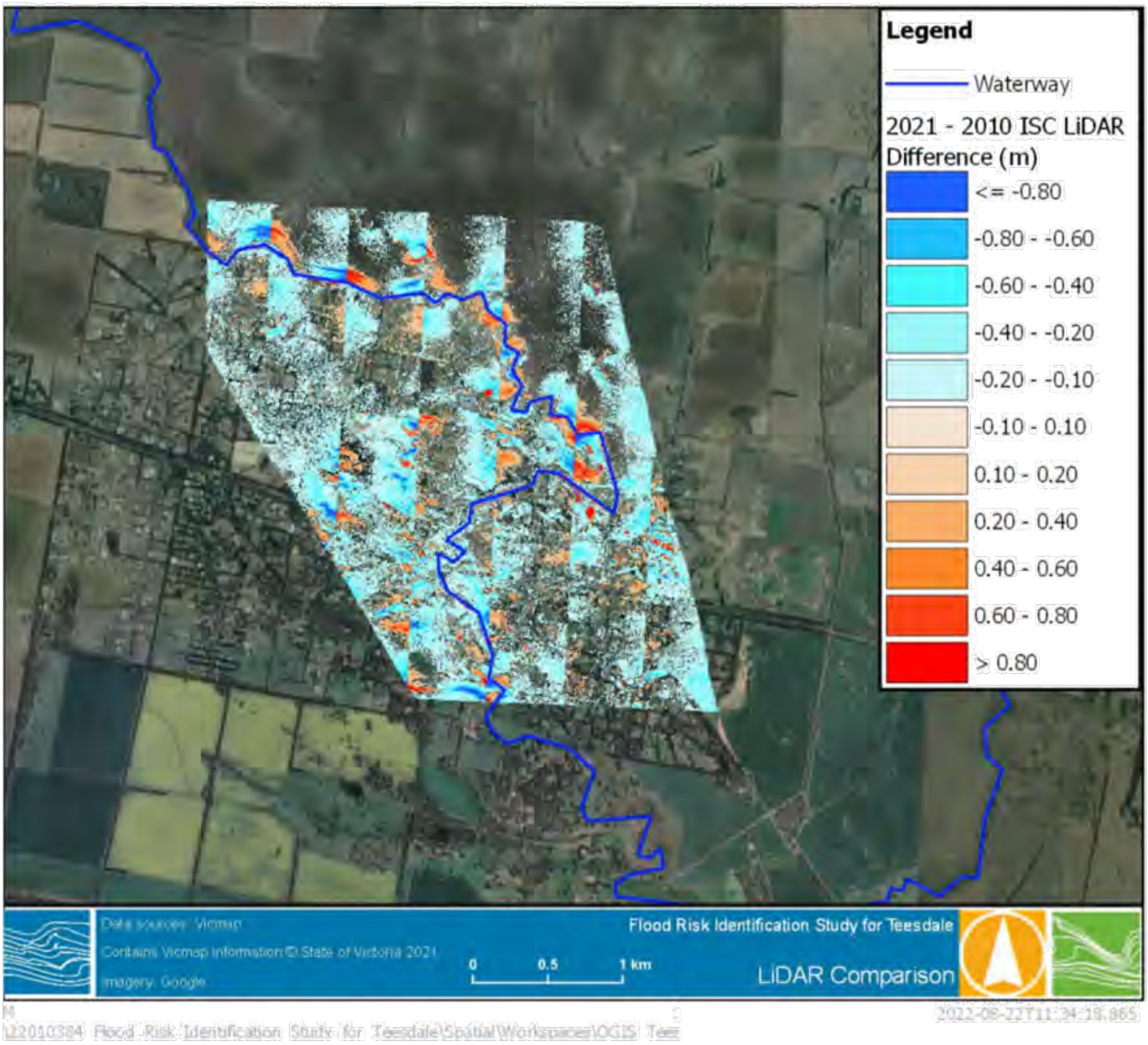

Figure 2-12 Comparison Between 2021 and 2010 LiDAR Datasets

2.7.4 Floor Level Survey

No floor level survey data was available along Native Hut Creek or within Teesdale. To determine the potential floor level survey requirements, preliminary 0.5% AEP modelling with a buffer of 250 metres will be used to highlight buildings at risk of inundation. This is to be discussed at a later stage of the project and recommendations provided in a standalone memorandum (Floor Level Survey Requirements).

2.8 Teesdale Structure Plan

The Teesdale Structure Plan was completed in 2020 and is the guiding strategy for future growth within the township. The Plan identifies a future Planning Scheme Amendment to take place upon completion of the Native Hut Creek Flood Study (i.e. this study). The plan identifies infill subdivision and the "North East Precinct" as the main sources of additional residential land within the town.

3 COMMUNITY CONSULTATION

Community consultation is a key component of any flood investigation. Meaningful consultation helps to ensure that local knowledge is captured and feeds into the study, which is immeasurably valuable in an area such as Teesdale where no formal flood data such as gauged stream levels or recorded flood heights exists.

The first community consultation session was held on the 4th August 2022 at the Teesdale Community Hall. Approximately 20 attendees shared information regarding inundation in the town from both stormwater and riverine catchment sources with Golden Plains Shire, VicSES and Water Technology officers. The majority of concerns raised at the session related to infill and greenfield subdivision and associated increased flows in local drainage, however, information regarding historical riverine flooding of Native Hut Creek was shared.

Information gathered during the session is summarised below:

- Teesdale has experienced recent notable flood events in 1973, 2001 and 2011.

The 1973 event was significant, with widespread overbank flooding and overtopping of Bridge Street (Bannockburn-Shelford Road).

  - Photocopies of photographs of the 1973 event were brought to the session, taken from Pantics Road and showing inundation of entire paddocks.

- An event in 1990 was noted, however this did not cause impacts and did not overtop the road.

An event in 2001 resulted in overtopping of Bridge Road for several hours.

  - Initial analysis of rainfall data suggests this was likely around 24/25 April 2001.

- There was a significant flow event in 2011, however it was contained within the banks for the majority of the town with no reported damage or impact.

Flooding in the mid twentieth century (understood to be in the 1950's) forced the relocation of the towns sporting oval to its current location.

In addition to the information gathered during the session, key contacts and names were shared for further follow up.

Figure 3-1 Community Consultation at the Teesdale Community Hall (4/8/2022)

4 HYDROLOGICAL AND HYDRAULIC MODELLING METHODOLOGY

4.1 Model Revision and Development

Water Technology propose to undertake the hydrology model build utilising RORB software and the existing RORB model for Native Hut Creek developed by the CCMA and construct a new 1D-2D hydraulic model using TUFLOW HPC. A review of the RORB model will be undertaken to ensure its suitability for use in the study, specifically ensuring the approach is in line with the recommendations of the latest *Australian Rainfall and Runoff (ARR2019)*, a significant improvement in the design modelling approach of ARR1987. Specific improvements in the approach include:

- 2016 Intensity – Frequency – Duration (IFD) data developed by the Bureau of Meteorology (BoM);

10 different temporal patterns available for every design event;

- Updated areal reduction factors;

Latest growth factors developed by the BoM for durations of 24 hours and greater;

- Modified approach for estimating rainfalls up to an AEP of 1 in 2000 for short durations; the growth factors are anchored on the 1% AEP estimates from the BoM rather than the 2% AEP, giving a higher reliability of the 1% AEP IFD data.

This section will detail the methodology for the hydrology revision and hydraulic model builds, calibration and design modelling for the Teesdale area.

4.2 Hydrological Modelling

4.2.1 RORB Model Revision and Modification

The existing RORB model once reviewed, will be calibrated/validated for three events (likely 2011, 2001 and 1973). We will use the parameters from the existing CCMA and GHD models as a starting point for the calibration of the Native Hut Creek catchment as there is no streamflow gauge available within the study area to calibrate to. We may be able to utilise the Barwon River at Pollocksford gauge to gain an understanding of expected timing of historic events, however the impact of Native Hut Creek at this gauge is likely to be relatively minor compared to flows from the remainder of the Barwon/Leigh River catchments.

4.2.2 Hydrological Modelling Validation (Historic and Design)

A K_C parameter value will be adopted for design model runs based on the historical calibration values. The design loss values will be compared with kc equation values as well as values adopted in nearby studies.

RORB will be run for the design events using the ensemble approach for a range of durations and AEPs. The new RORB hydrograph selector tool will be used to extract the model hydrographs. The new tool has been built into RORB and completes a similar process to that which Water Technology has been applying to recent flood studies manually. This allows the user to select the most appropriate hydrograph from the ensemble series to apply for design purposes. It will select the critical duration and temporal pattern which produces the median peak flow of the 10 temporal patterns for each AEP.

The above approach will be undertaken for all key locations in the model, including hydraulic model inflow boundary locations and key sites (i.e. waterway structure locations). The critical durations and temporal pattern combinations will then be selected for hydraulic modelling.

Monte Carlo Simulation will also be used to verify design flow estimates from the ensemble approach. This is considered to be a necessary check because in some cases the peak flows for the events around the median peak flow may vary considerably, so the selection of temporal pattern above or below the median peak flow can have a large influence on peak flow in these situations. In many situations though, the ensemble peak flows are reasonably close without a huge spread, and the peak flow adopted from the median is not significantly sensitive to this assumption.

4.2.3 Consideration of Storages

The potential impact of the two online storages discussed in section 2.3 has been investigated by considering the potential volume provided by the storages and comparing this to the rising limb of design hydrographs in frequent events. An example calculation based on an estimate of available storage in the dams from LiDAR and the design hydrograph output for a 1% AEP event from the CCMA RORB model is presented in Figure 4-1 below. This highlights the minimal storage available when compared to the overall hydrograph volume and indicates there is likely to be minimal impact whether the dams are full or empty at the time of a large flood event.

In minor events the storage may have an impact on flood behaviour for Teesdale. Design modelling will adopt the conservative approach of assuming the storages are full however this should be considered as part of the broader antecedent conditions.

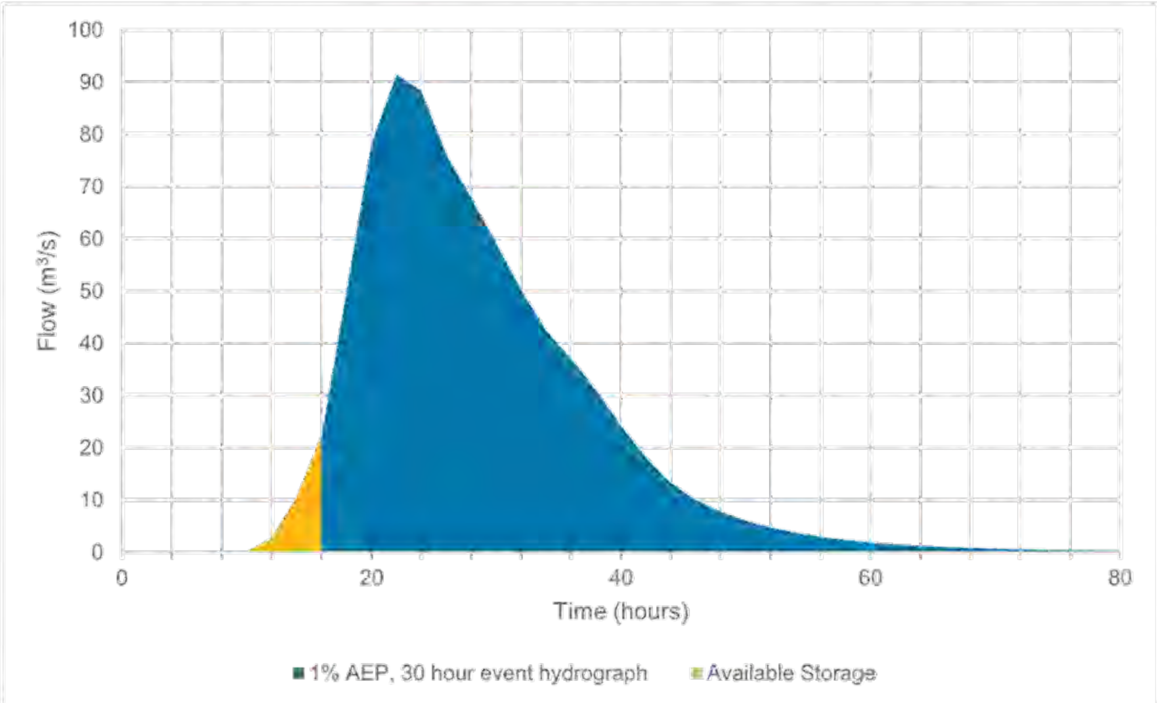

Figure 4-1: Example storage vs hydrograph volume comparison

4.3 Hydraulic Modelling

4.3.1 Hydraulic Model Development

A new hydraulic model of the Teesdale township and Native Hut Creek (and minor tributaries) floodplain will be produced for this investigation. TUFLOW (HPC) has been selected for the hydraulic modelling package.

Key bridges, culverts and pipes will be included in the TUFLOW hydraulic model as detailed 1D structures or layered 2D flow constrictions.

Major inflow boundaries will be applied at the upstream extent of the model on Native Hut Creek, two minor tributaries to the north of Teesdale as well as several minor runoff locations within Teesdale. For sub-catchment inflows along the major waterways not associated with a defined tributary, distributed source area inflow points are to be applied directly to the centre of Native Hut Creek close to the centroid of the RORB sub-areas.

Water Technology's spatial team will also develop a detailed roughness map using a remote sensing technique which will allow for most of the floodplain features to be accurately captured in the model. This is supplemented with VicMap layers to represent roads and residential/commercial properties. This technique can represent clumps of trees and provides a more comprehensive land use roughness map for traditional hand digitising or using planning layers to determine model roughness layers. A series of industry standard roughness values will be applied to the various roughness types identified by this technique.

The downstream boundary will be located approximately 2 km downstream of Teesdale township and will utilise a TUFLOW 2D HQ boundary which will allow the water to leave the model without having to set a boundary level. This approach will allow the downstream boundary to have no influence on the model within the model domain. Hence, sensitivity analysis will not be required on the 2D downstream boundary.

4.3.2 Hydraulic Model Validation

As identified earlier, there is minimal historic survey or flood marks to calibrate to, therefore a pseudo hydrology/hydraulic validation process will be undertaken based on the three historic flood events and the draft 1% AEP flood mapping. This will be presented at a later community meeting and also discussed with the CCMA and GPS.

4.4 Design Event Modelling

Design flood hydrographs for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% Annual Exceedance Probabilities (AEP) flood events, and the Probable Maximum Flood (PMF) at key inflow locations to the hydraulic model will be derived using the calibrated RORB model and appropriate design modelling parameters.

5 SUMMARY AND NEXT STEPS

The data captured as part of the data collation and review process has shown to be suitable for the Teesdale Flood Risk Identification Investigation. Despite there being no streamflow data at Teesdale or along Native Hut Creek to undertake a calibration process, it is hoped that adjacent catchment streamflow gauges and community input will provide suitable data to undertake a validation of the hydrology and hydraulic model results.

There are no outstanding data gaps, however further information on historical flooding in the town would provide rigour and increase confidence in the model validation.

The LiDAR validation survey data captured has shown the 2021 LiDAR meets the accuracy expectations and provides suitable representation of the ground surface for the hydraulic modelling.

Next steps in the project include:

- Hydrology Review

Hydraulic Model Refinement

- Hydrology/Hydraulic Validation

Community Consultation (round 2)

- Design Modelling

Floor Level Survey Capture

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Joint Validation Modelling Report

Teesdale Flood Risk Identification Study

Golden Plains Shire

12 April 2023

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CONTENTS

LIST OF FIGURES

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

LIST OF TABLES

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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.

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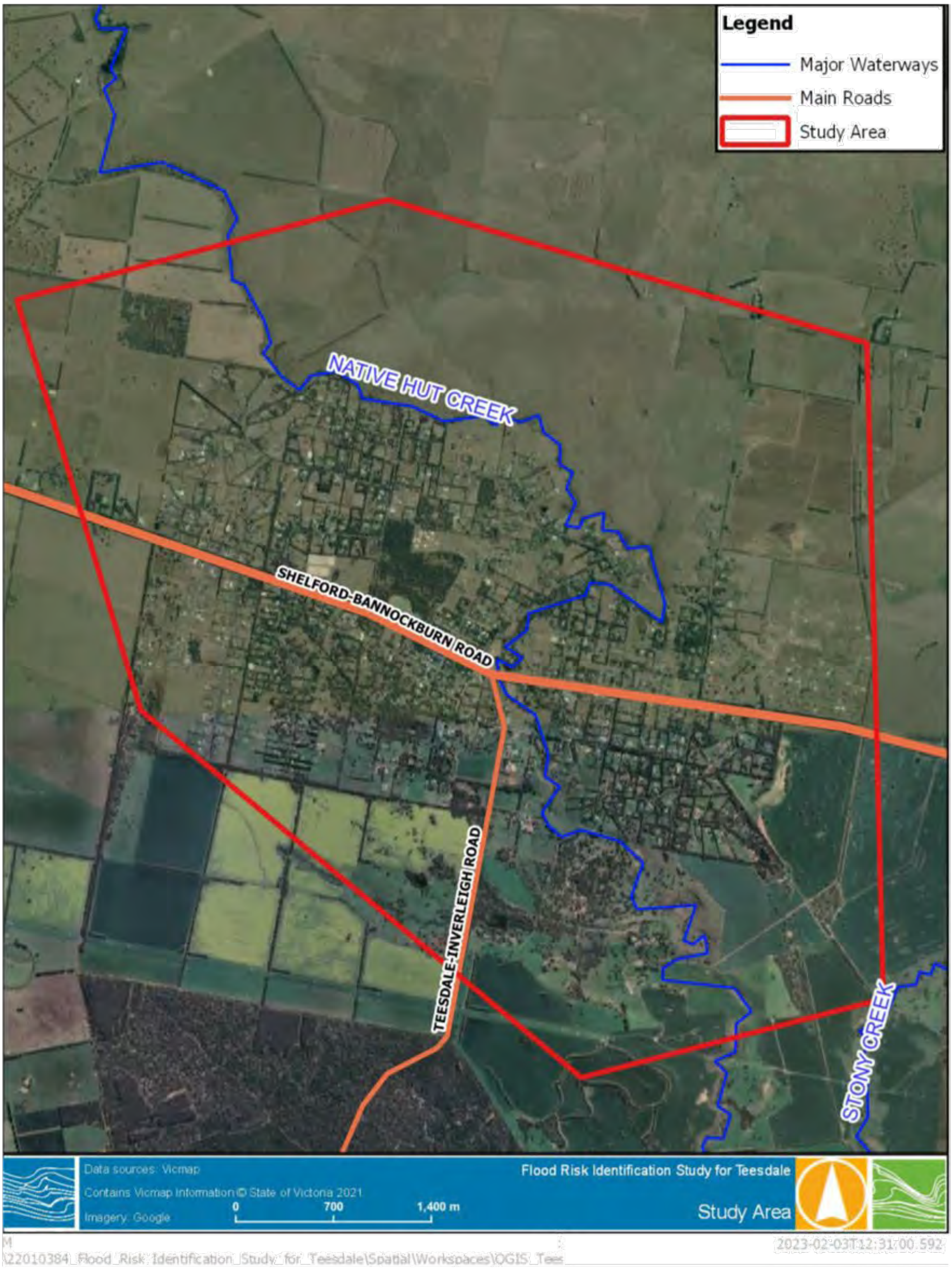

Figure 1-1 Study Area

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.

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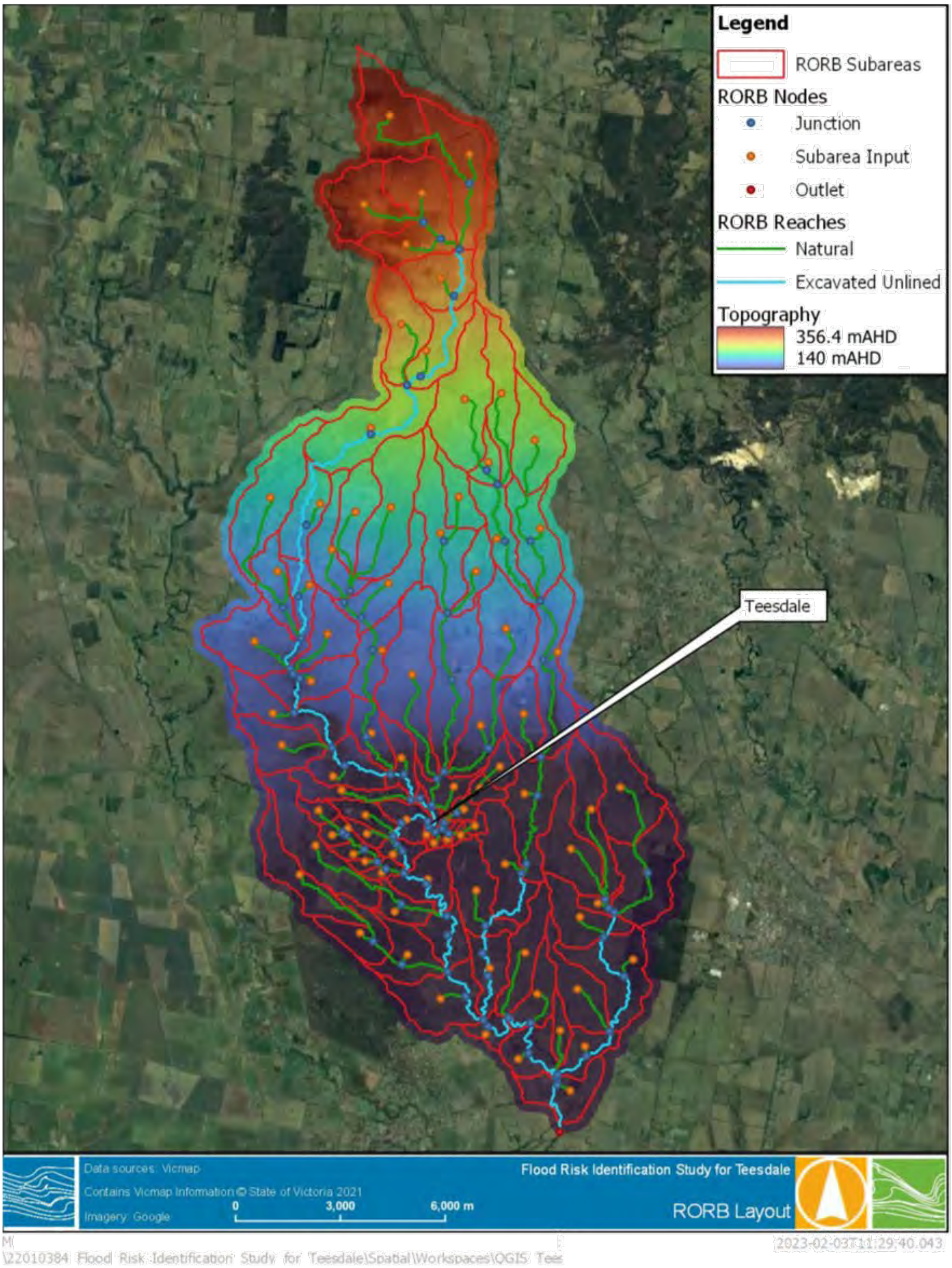

Figure 3-1 RORB model layout

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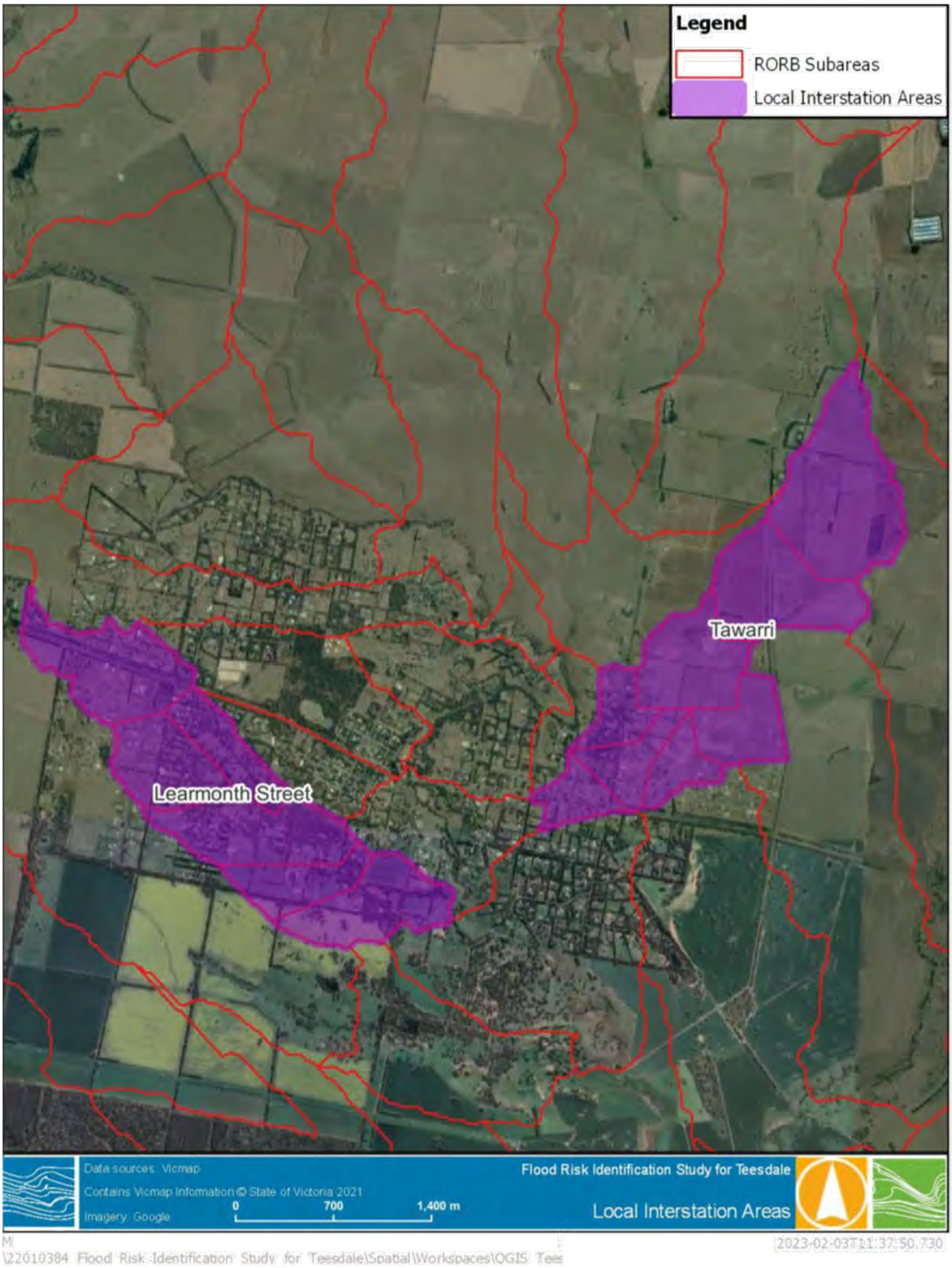

Figure 3-2 RORB Interstation Areas

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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.

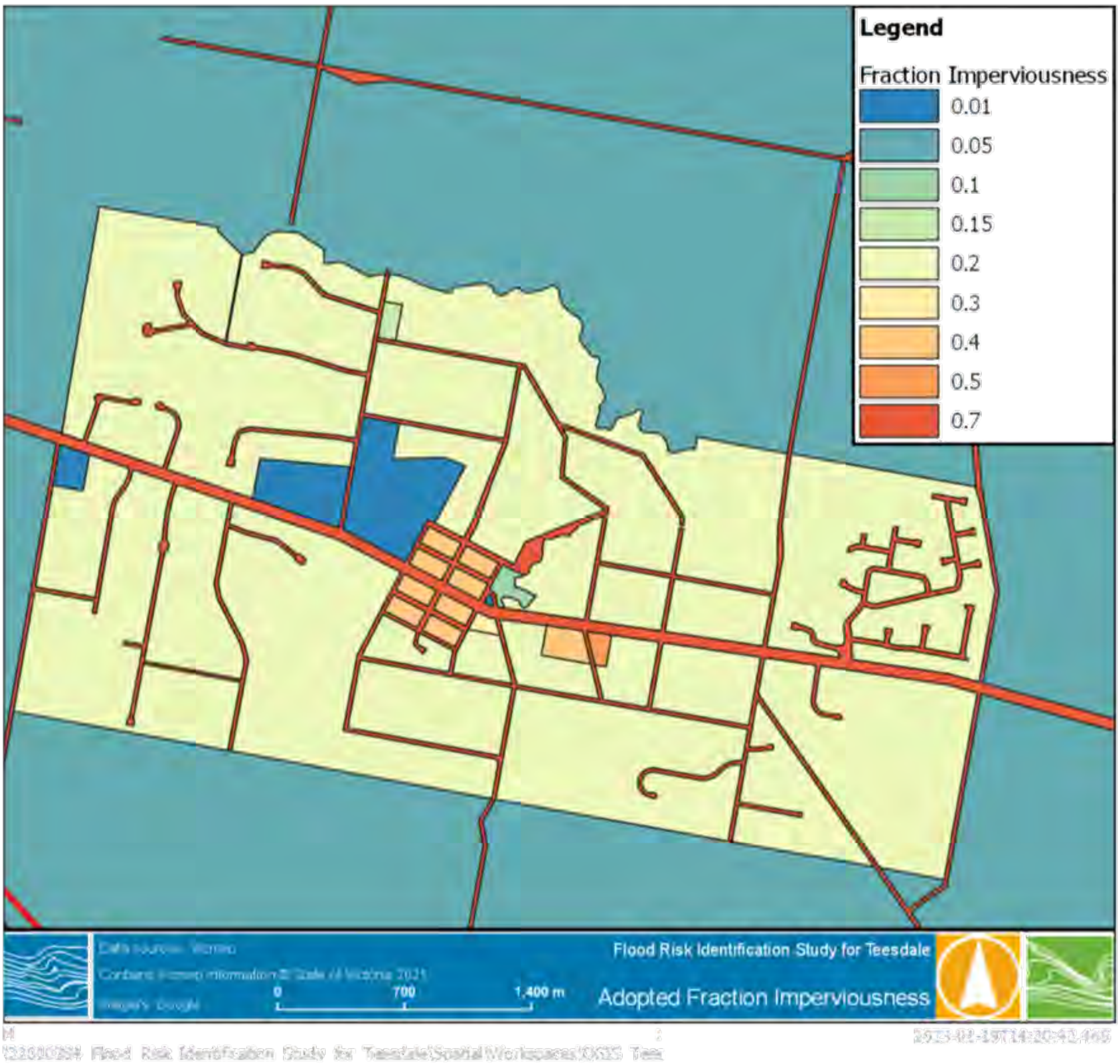

Figure 3-3 Adopted Fraction Imperviousness – Township

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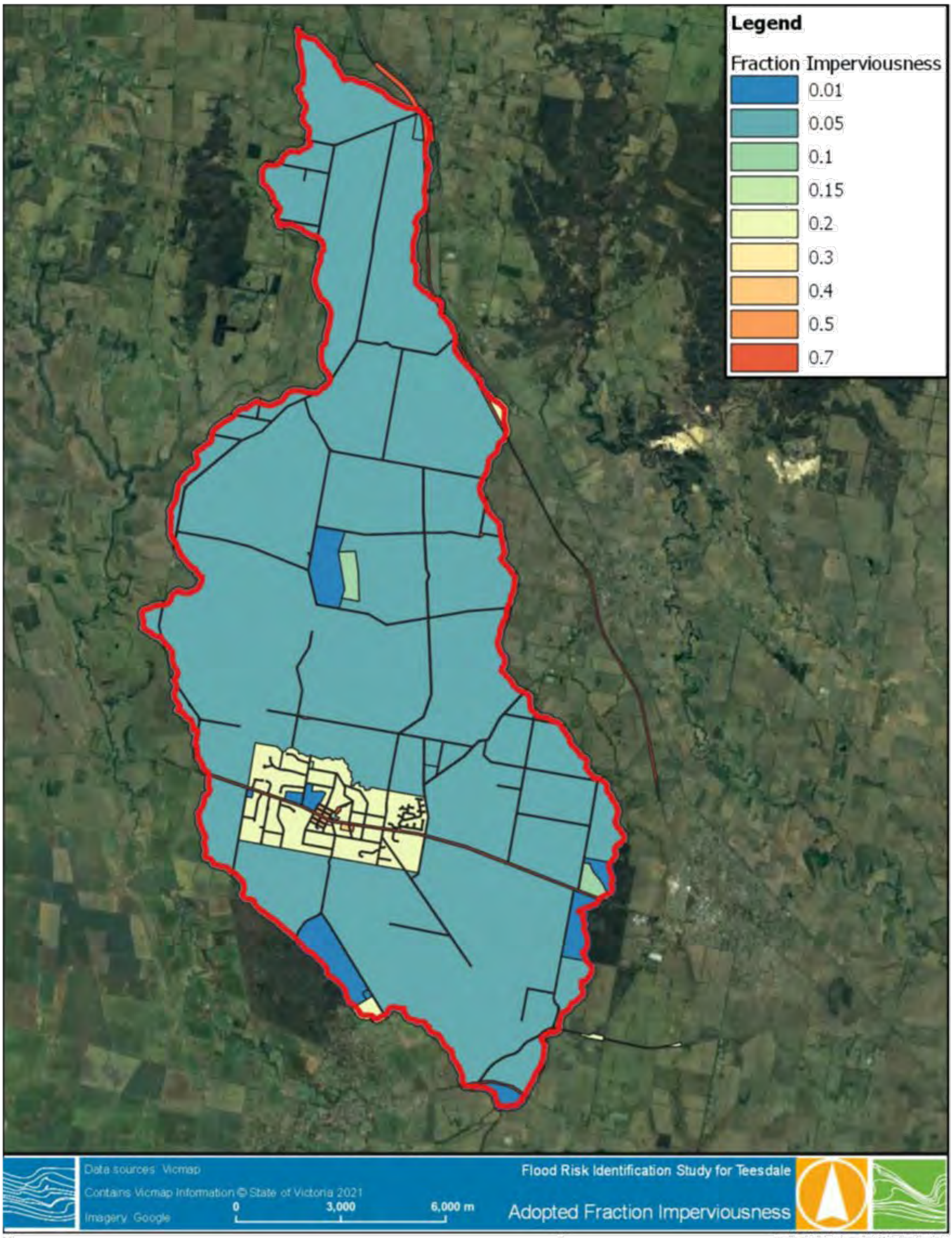

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Figure 3-4 Adopted Fraction Imperviousness – RORB Extent

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.

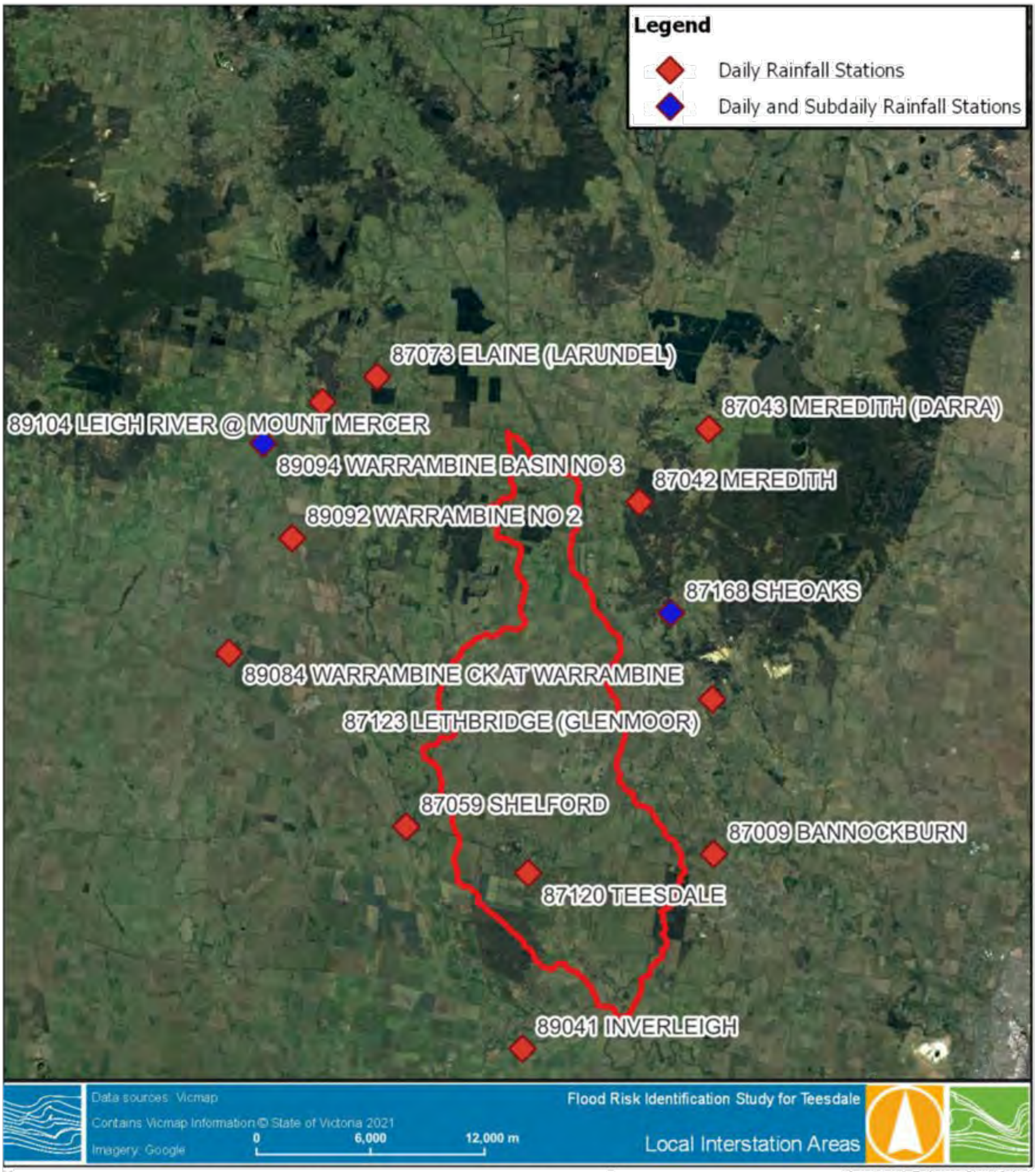

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Figure 3-5 Utilised Daily Rainfall Stations

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

Duration	Annual Exceedance Probability (AEP)						Average Recurrence Interval (ARI)			
	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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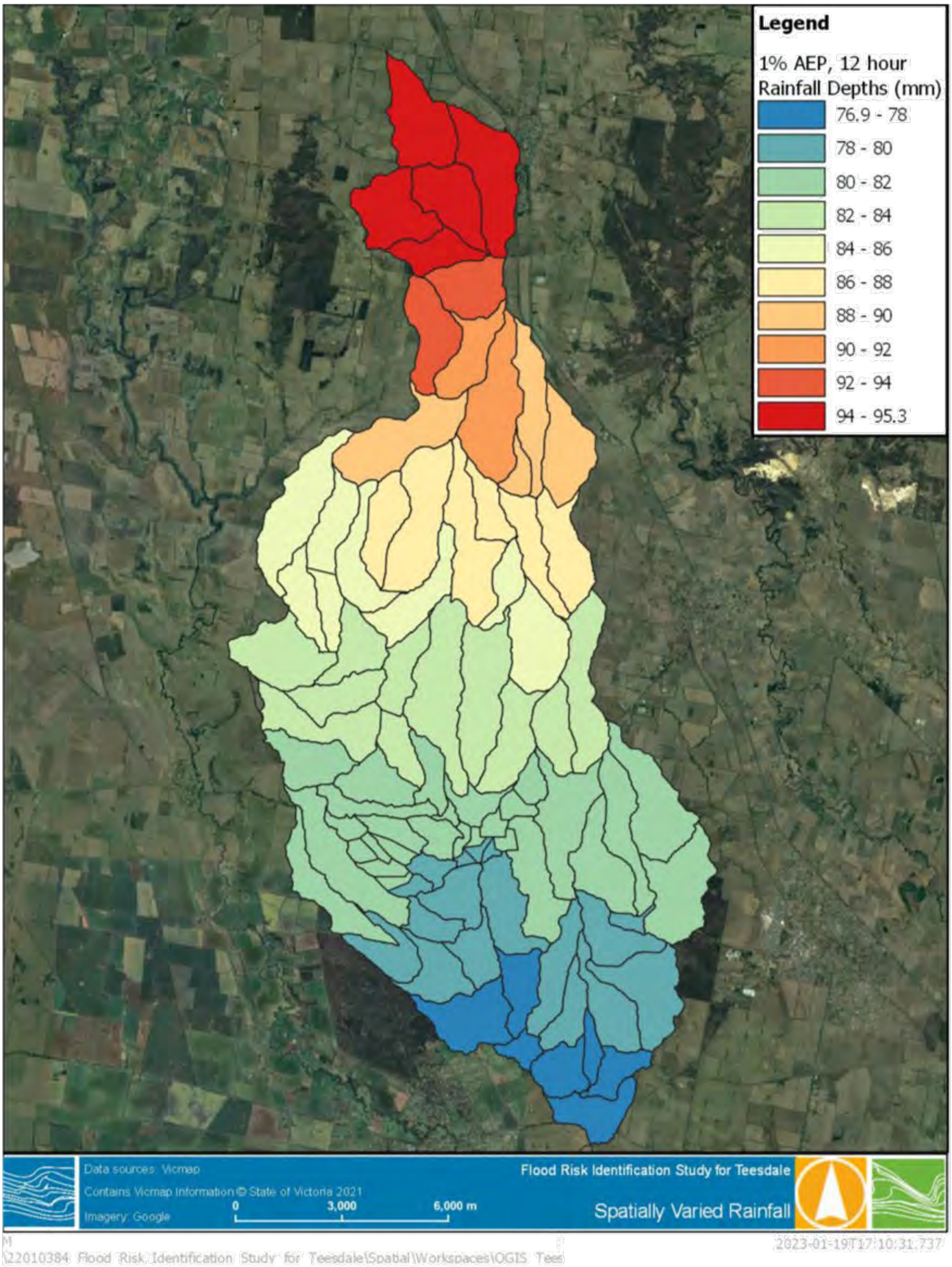

Figure 3-6 Example of Spatially Varied Rainfall, 1% AEP 12 Hour Event

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.

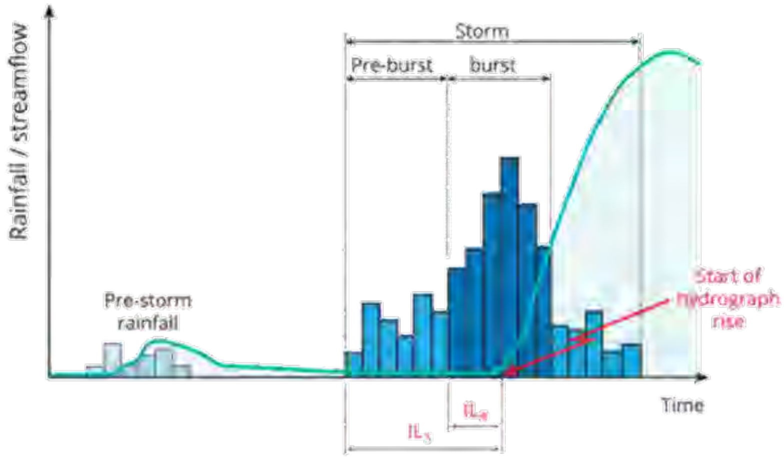

Figure 3-7 Conceptualisation of storm vs burst rainfall and its interaction with Initial Loss[3]

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.

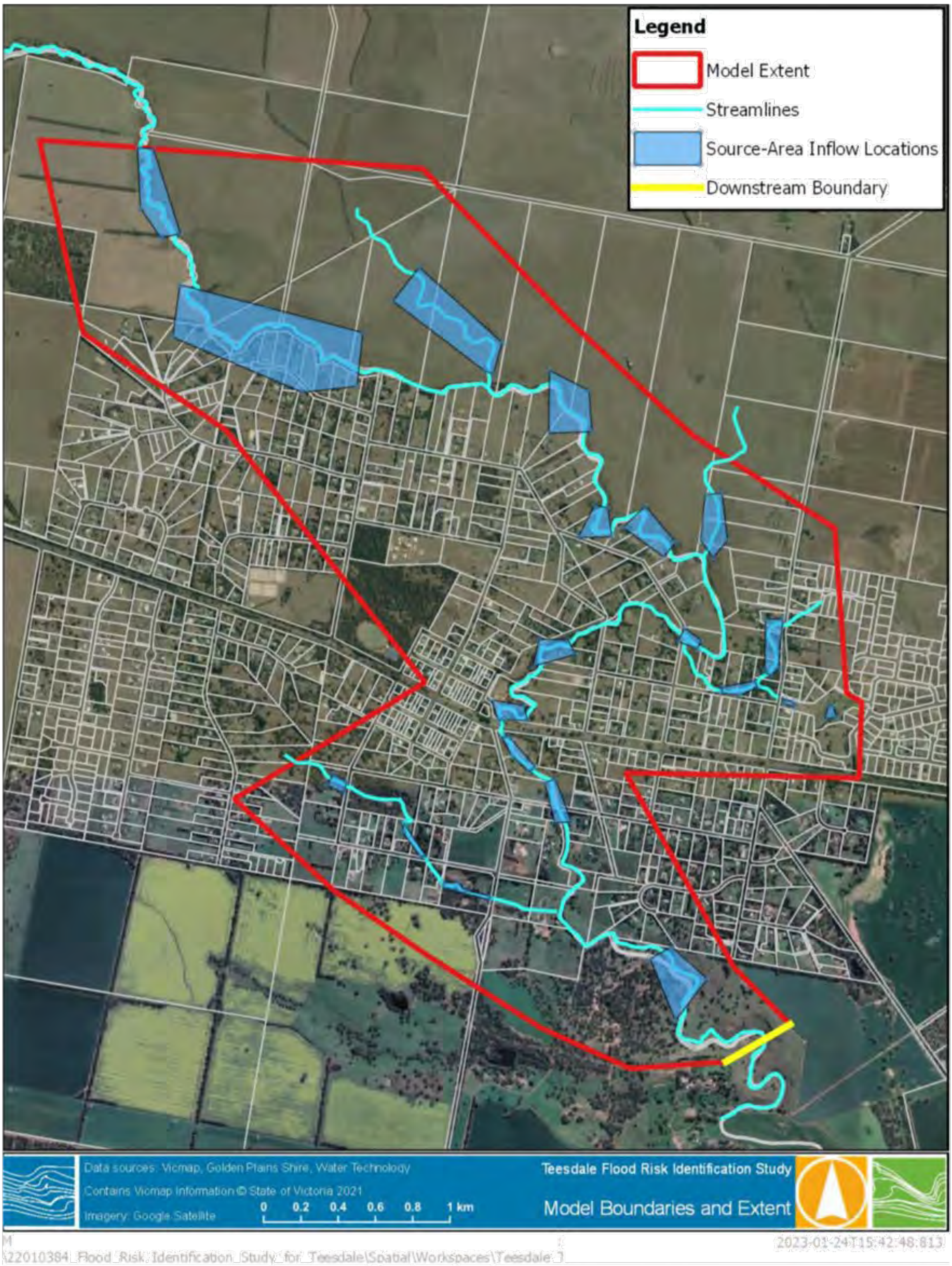

Figure 4-1 TUFLOW Extent and Model Boundaries

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/

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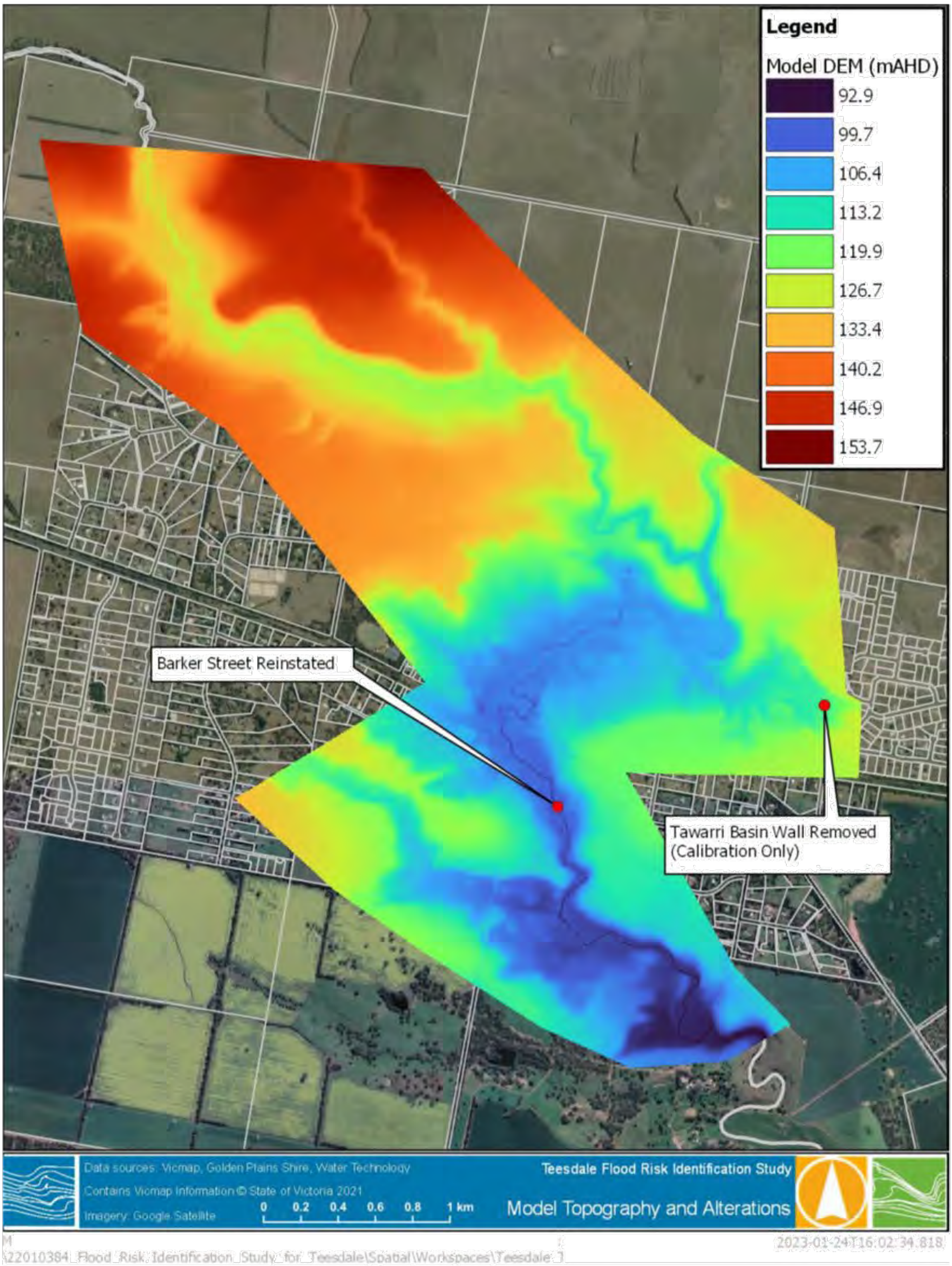

Figure 4-2 Model Topography

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

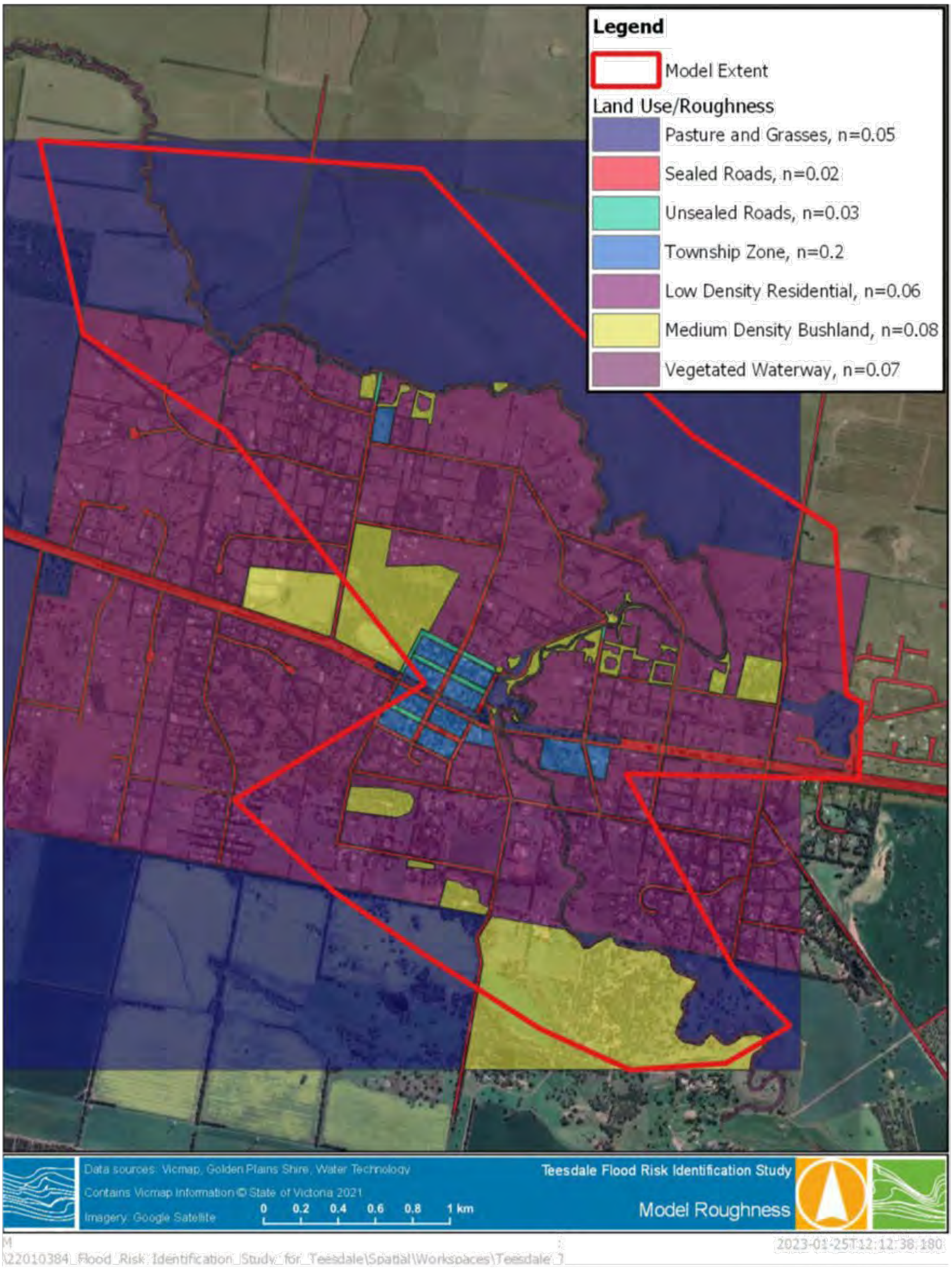

Figure 4-3 Hydraulic model roughness

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.

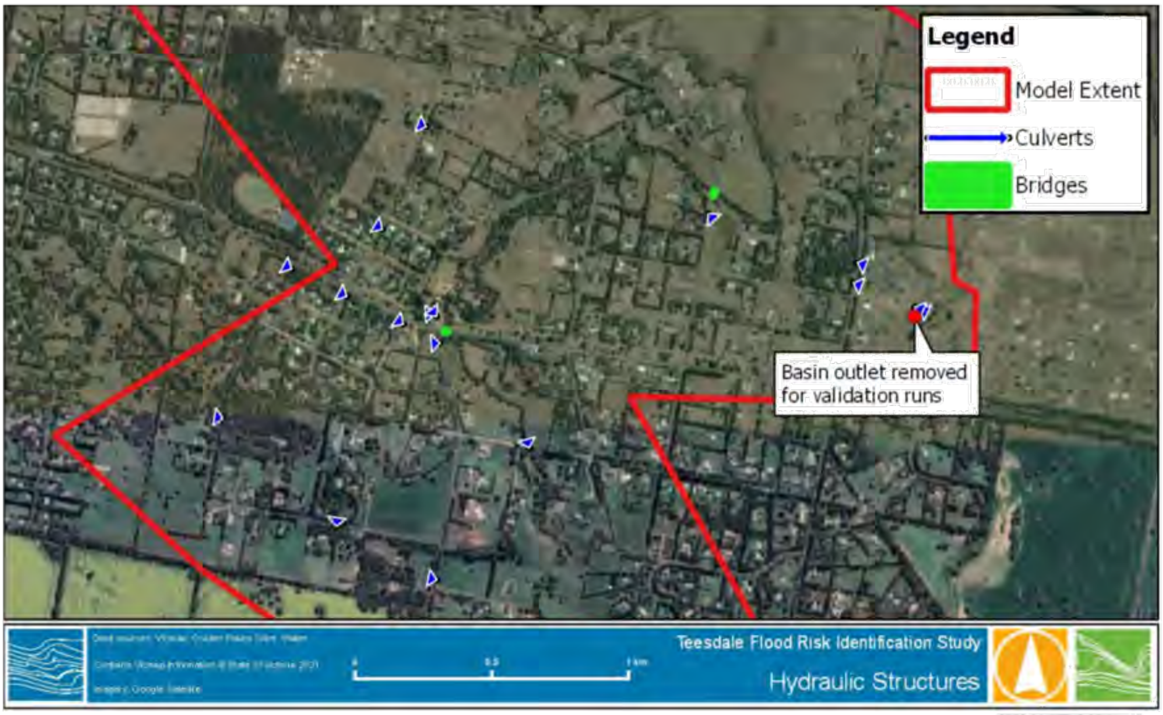

Figure 4-4 Hydraulic structures

[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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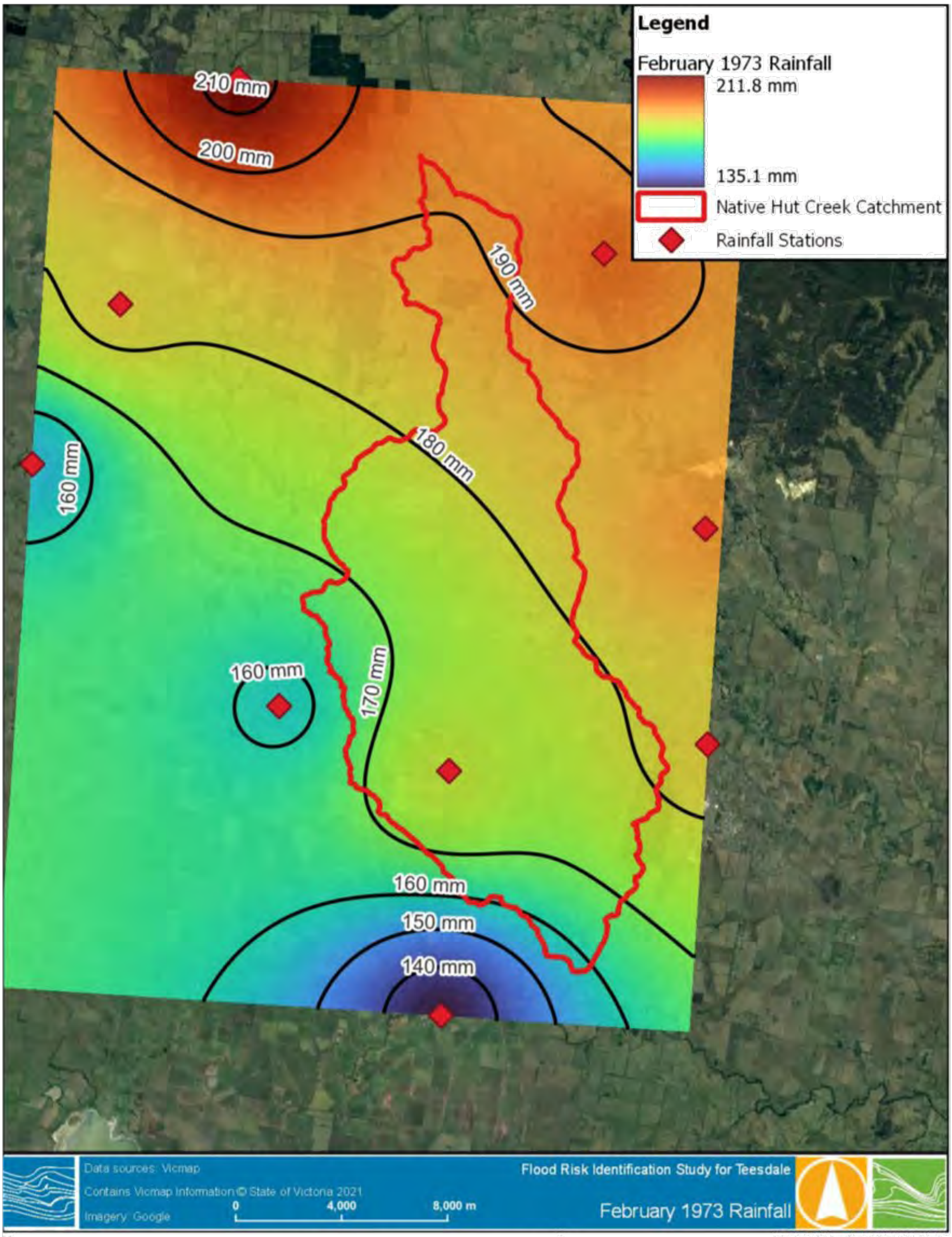

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\22010384 Flood Risk Identification Study for Teesdale\Spatial\Workspaces\QGIS Tees
2023-01-26T13:22:22.440

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).

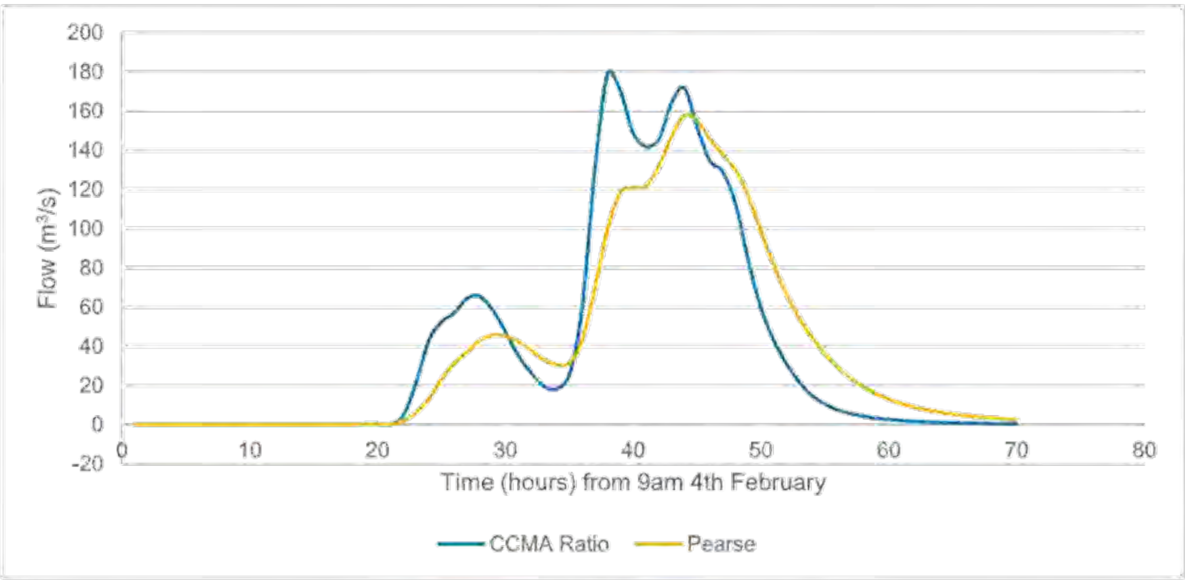

Figure 5-2 February 1973 modelled streamflow at Teesdale Bridge

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.

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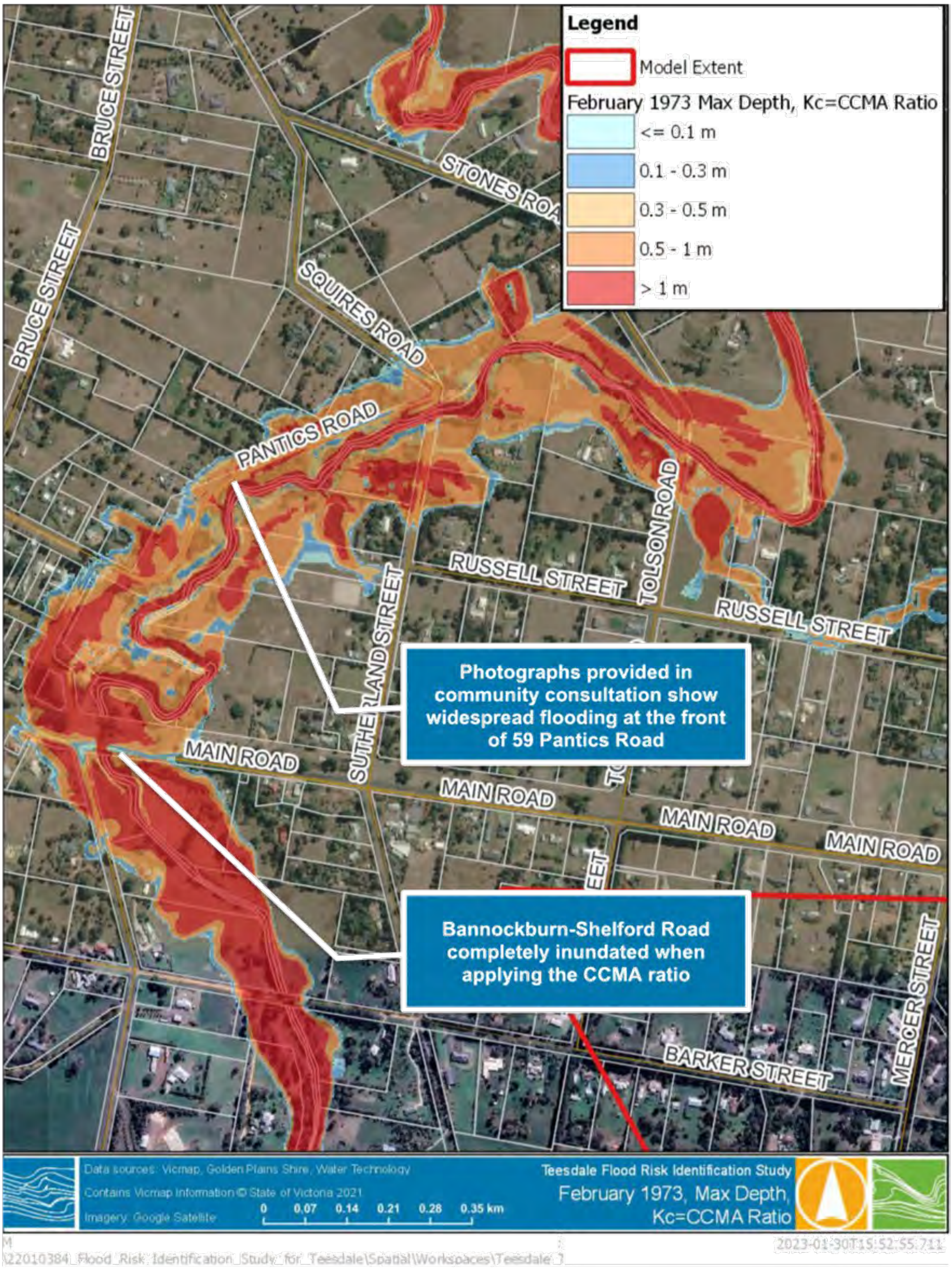

Figure 5-3 February 1973 Flood Depths, K_c=CCMA Ratio (Township)

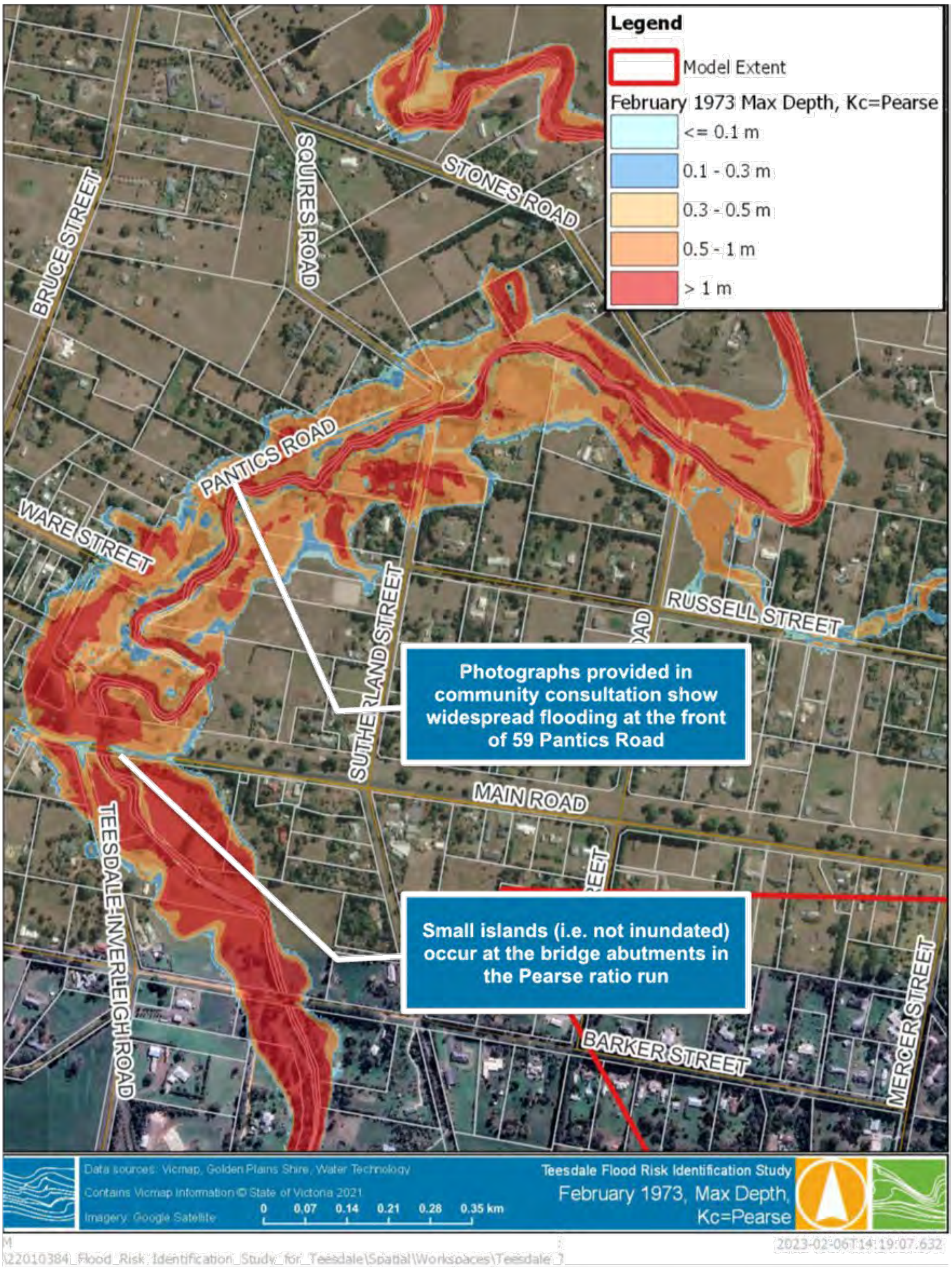

Figure 5-4 February 1973 Flood Depths, K_c=Pearse (Township)

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59 PANTICS RD

DOWNSTREAM

FAR SIDE FRONT DOOR TO FRONT GATE

FRONT GATE TO STORE

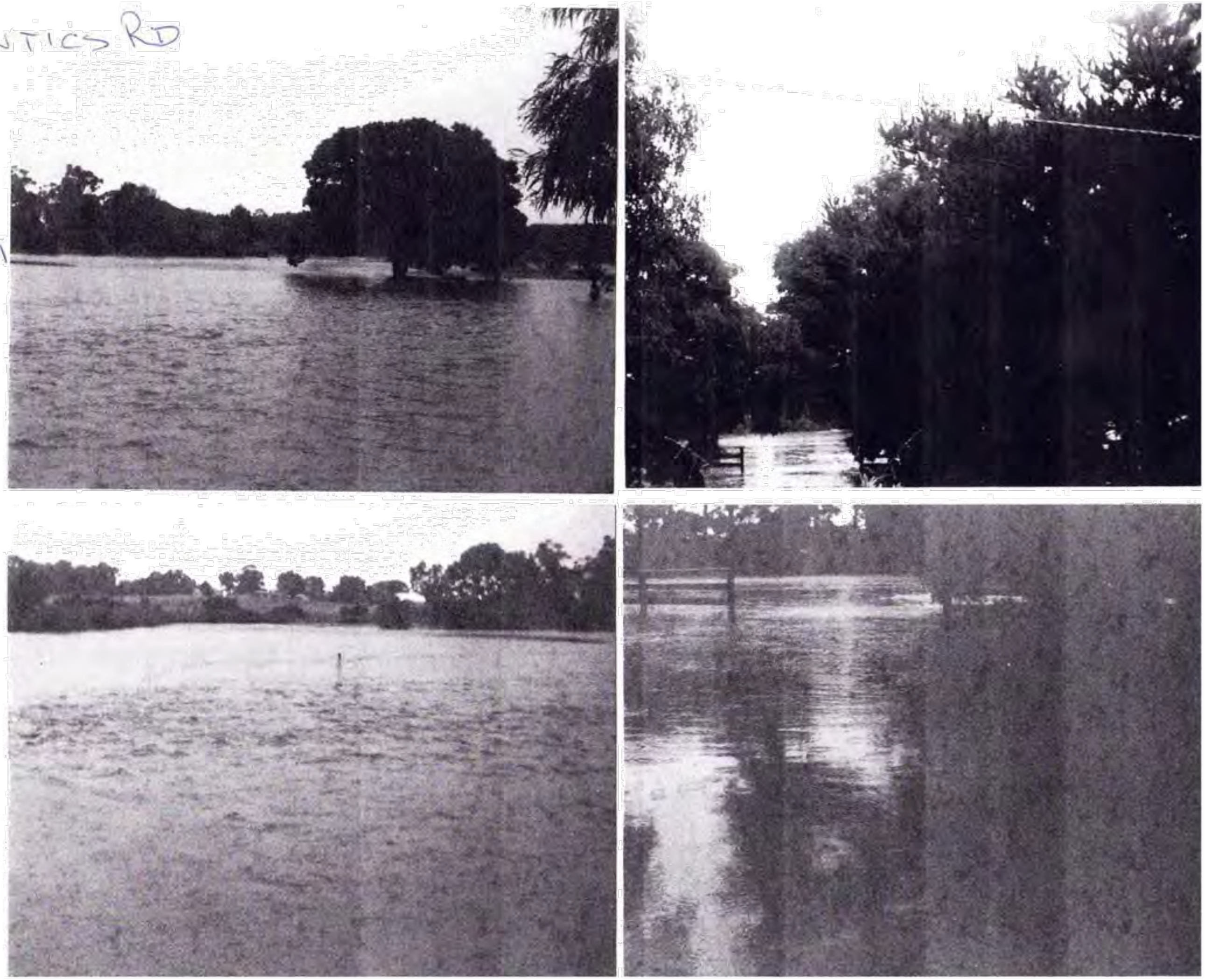

Figure 5-5 Photographs of 1973 flood event provided by the resident of 59 Pantics Road

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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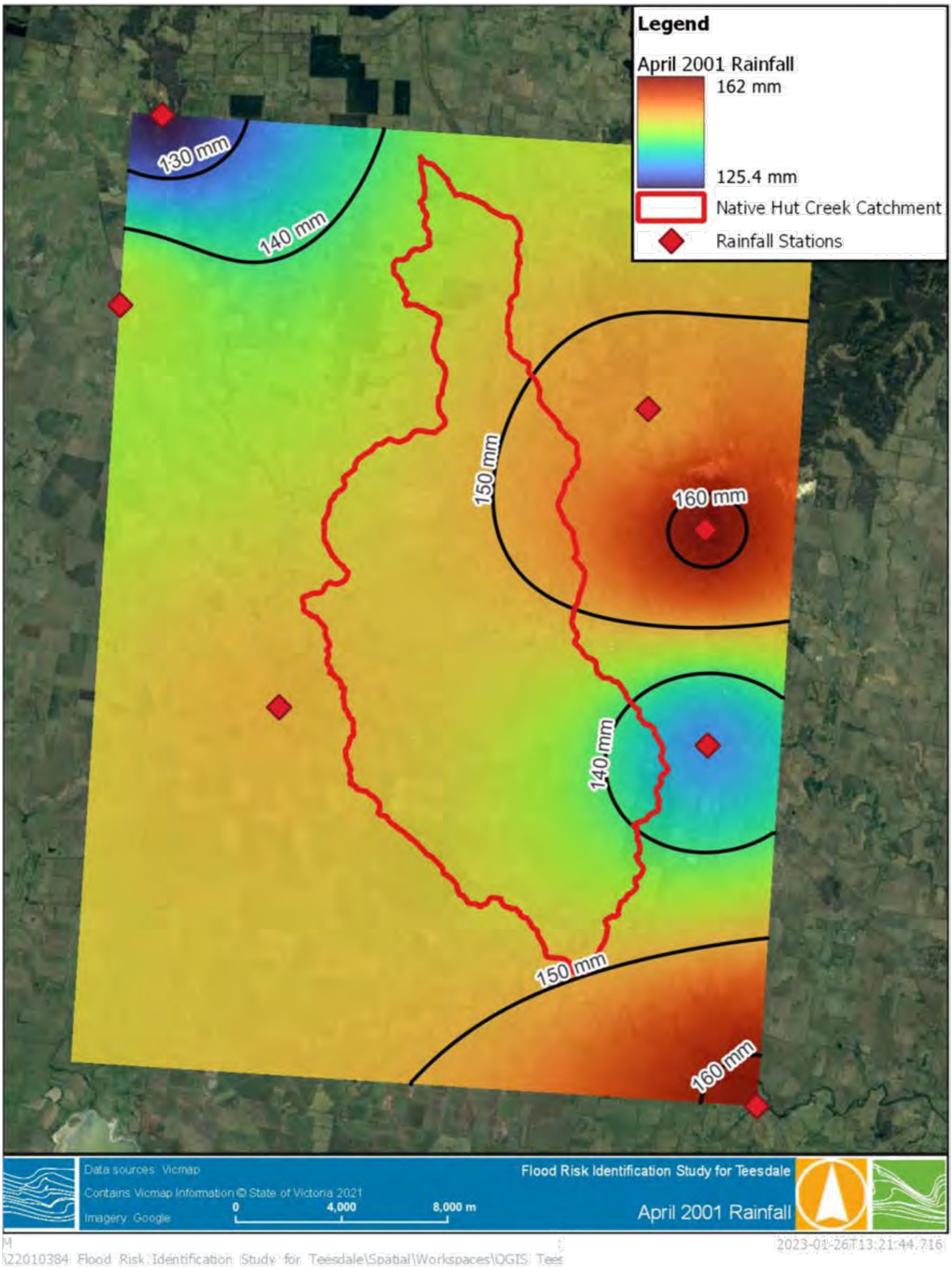

Figure 5-6 Rainfall Distribution and Isopleths for April 2001

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.

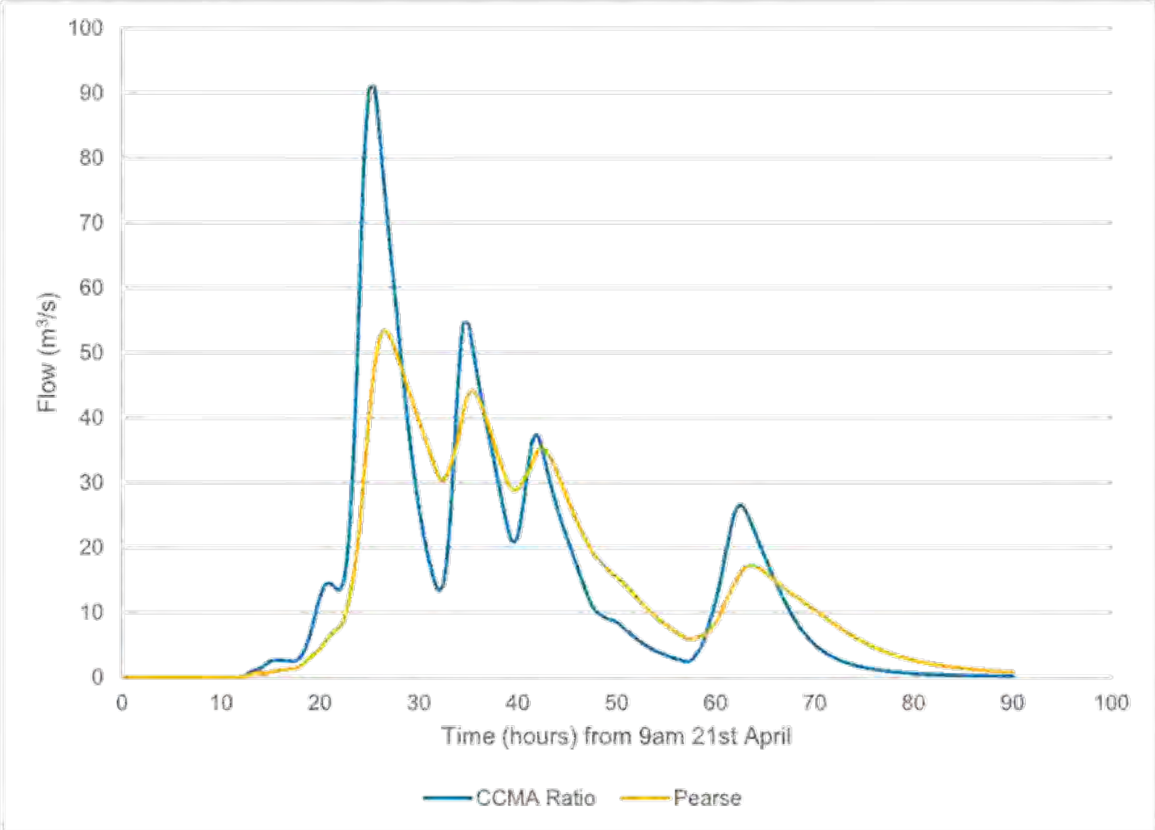

Figure 5-7 April 2001 modelled streamflow at Teesdale Bridge

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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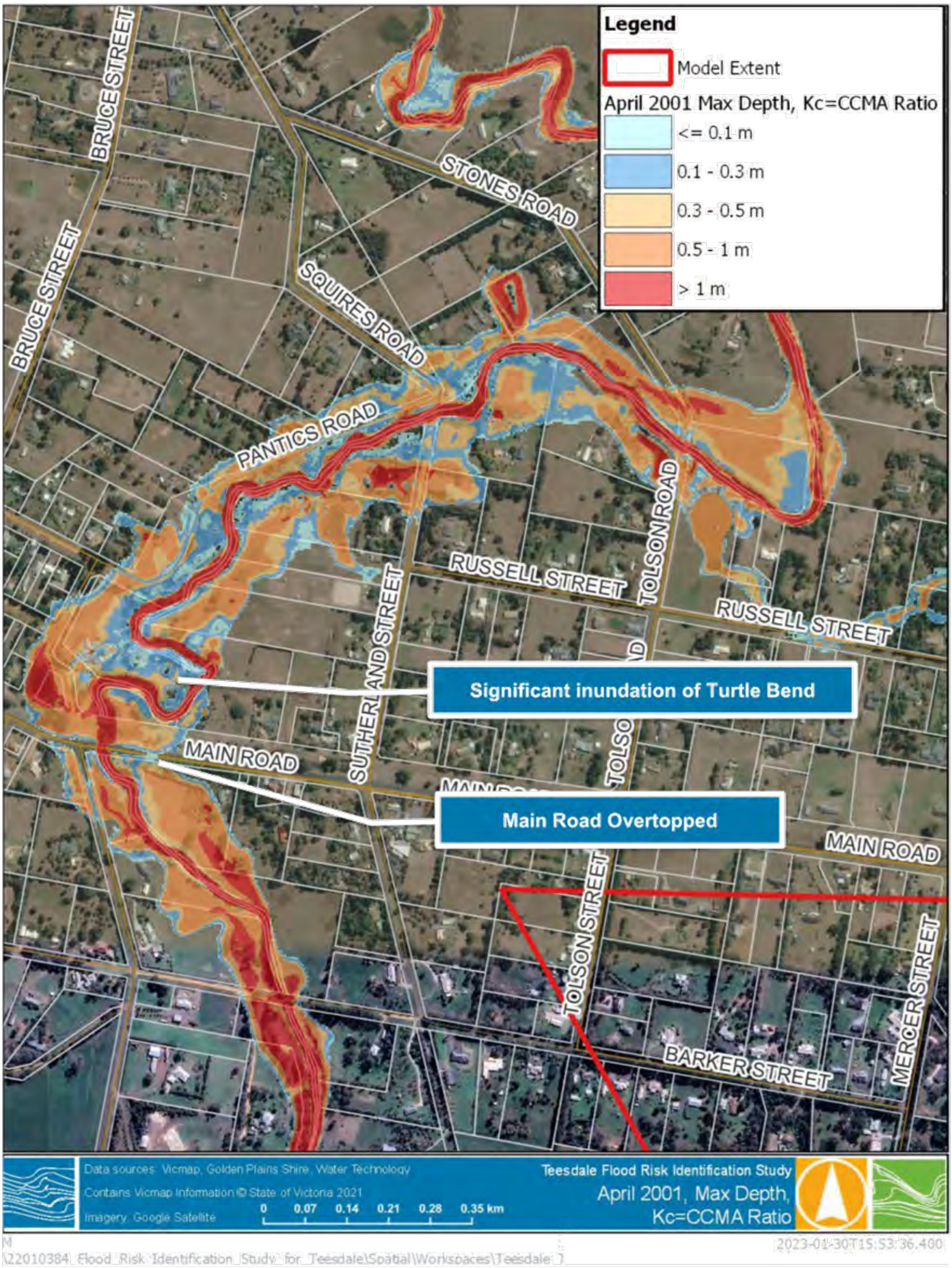

Figure 5-8 April 2001 Flood Depths, Kc=CCMA Ratio (Township)

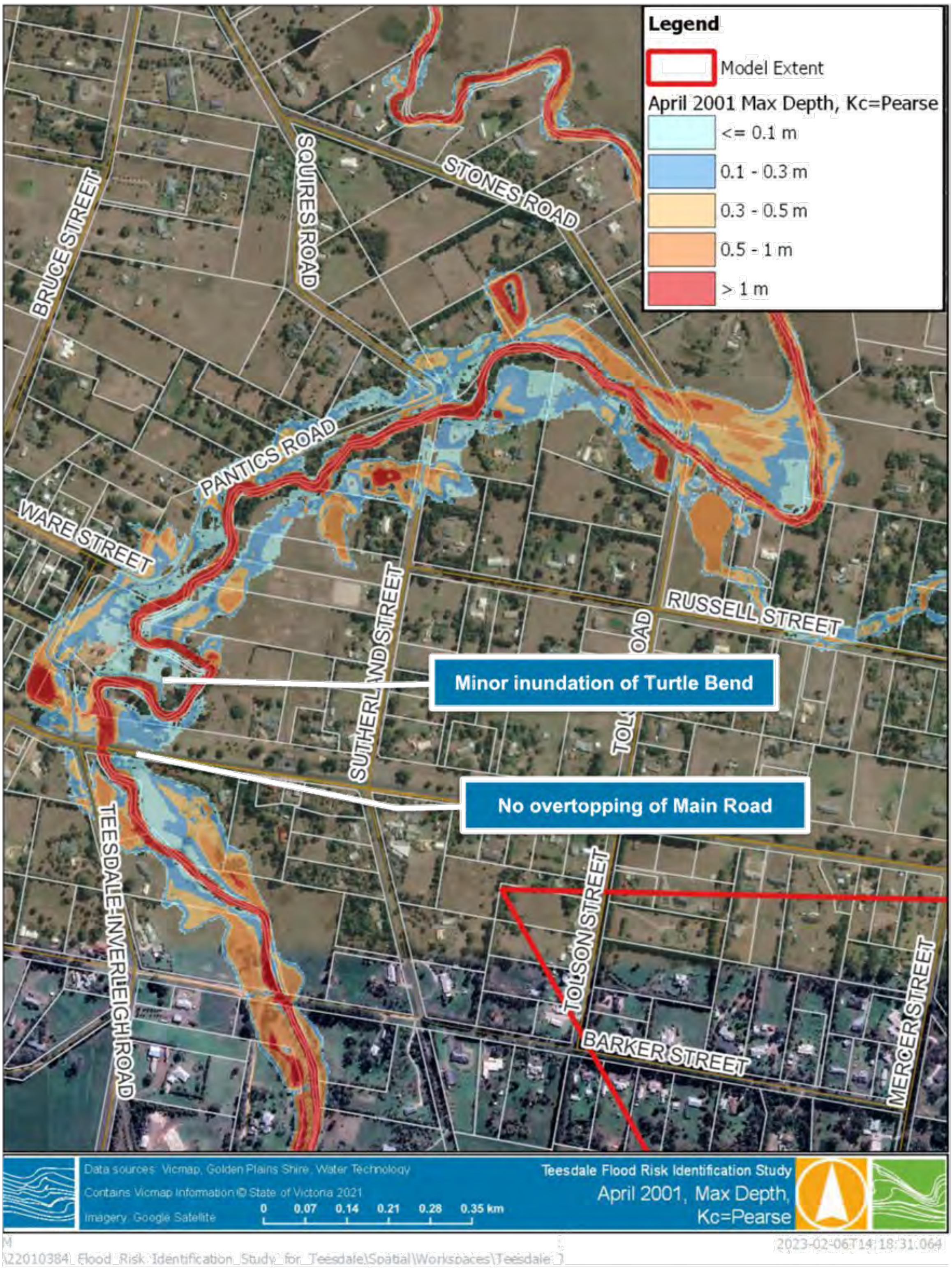

Figure 5-9 April 2001 Flood Depths, K_c=Pearse (Township)

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**

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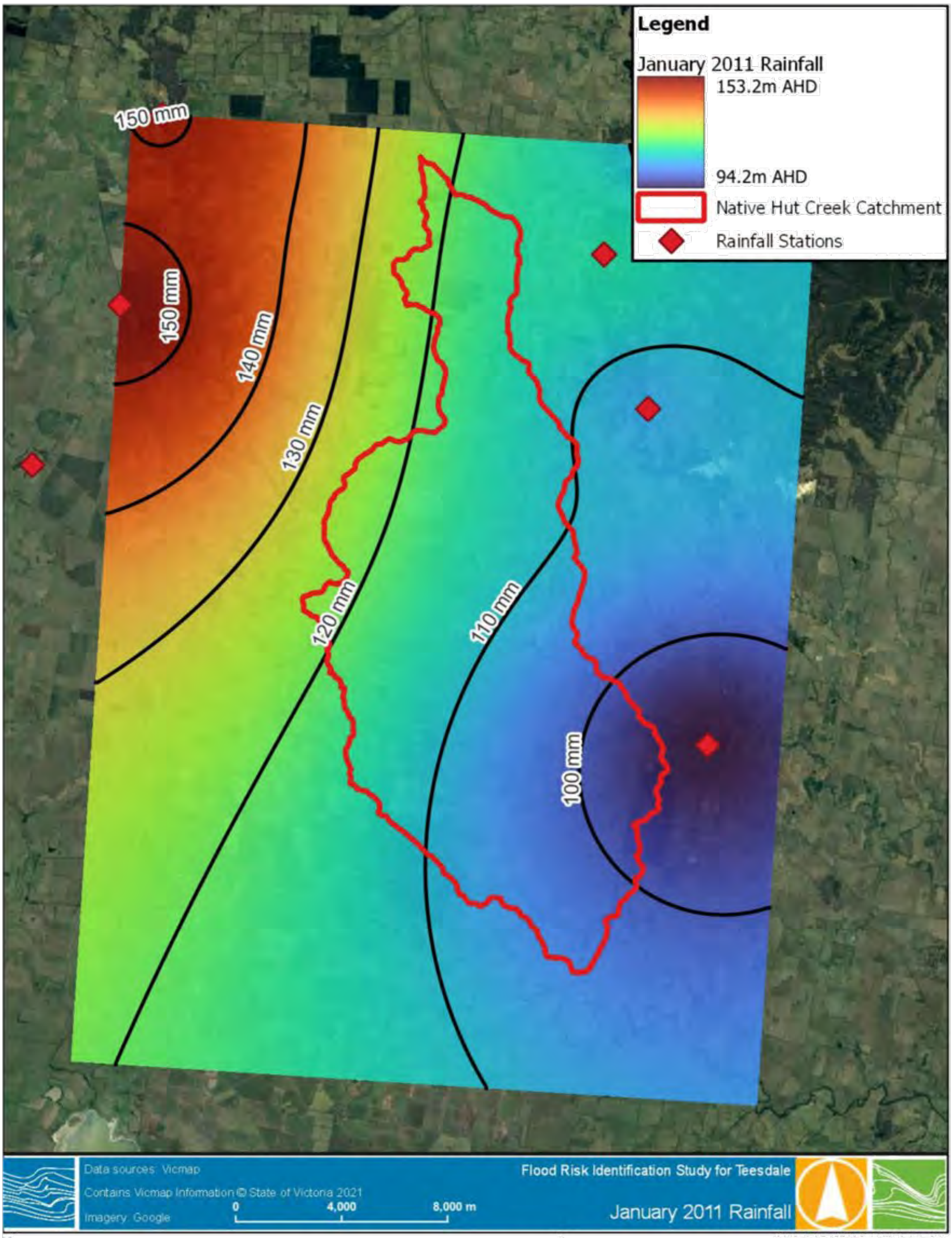

Figure 5-10 Rainfall Distribution and Isopleths for January 2011

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.

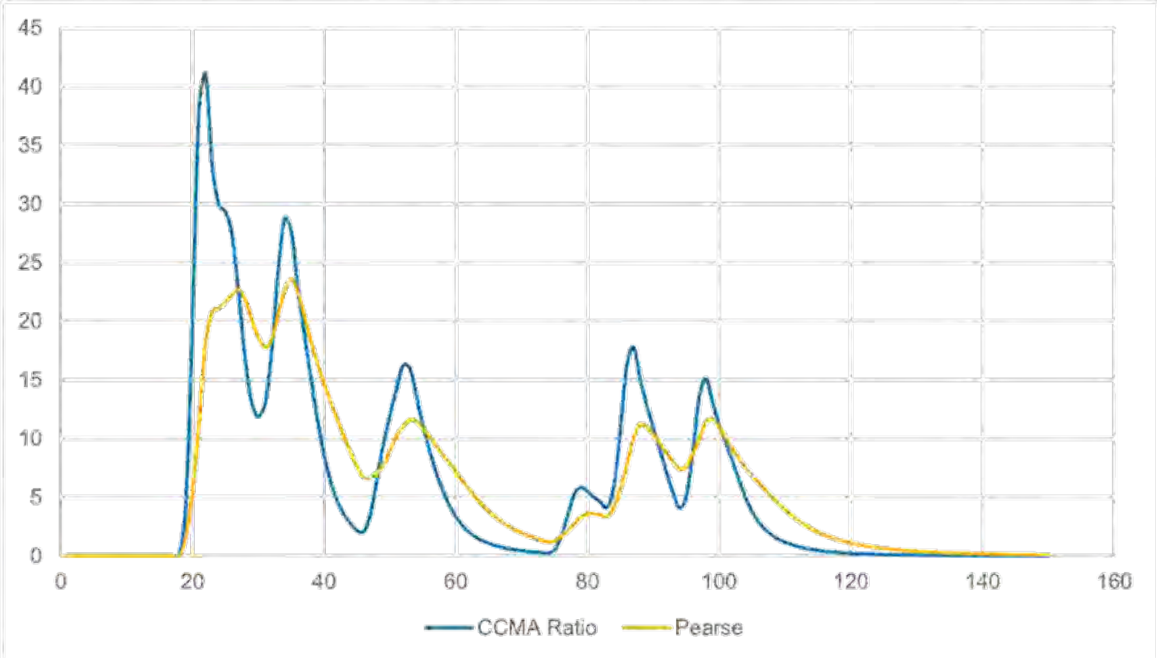

Figure 5-11 January 2011 modelled streamflow at Teesdale Bridge

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.

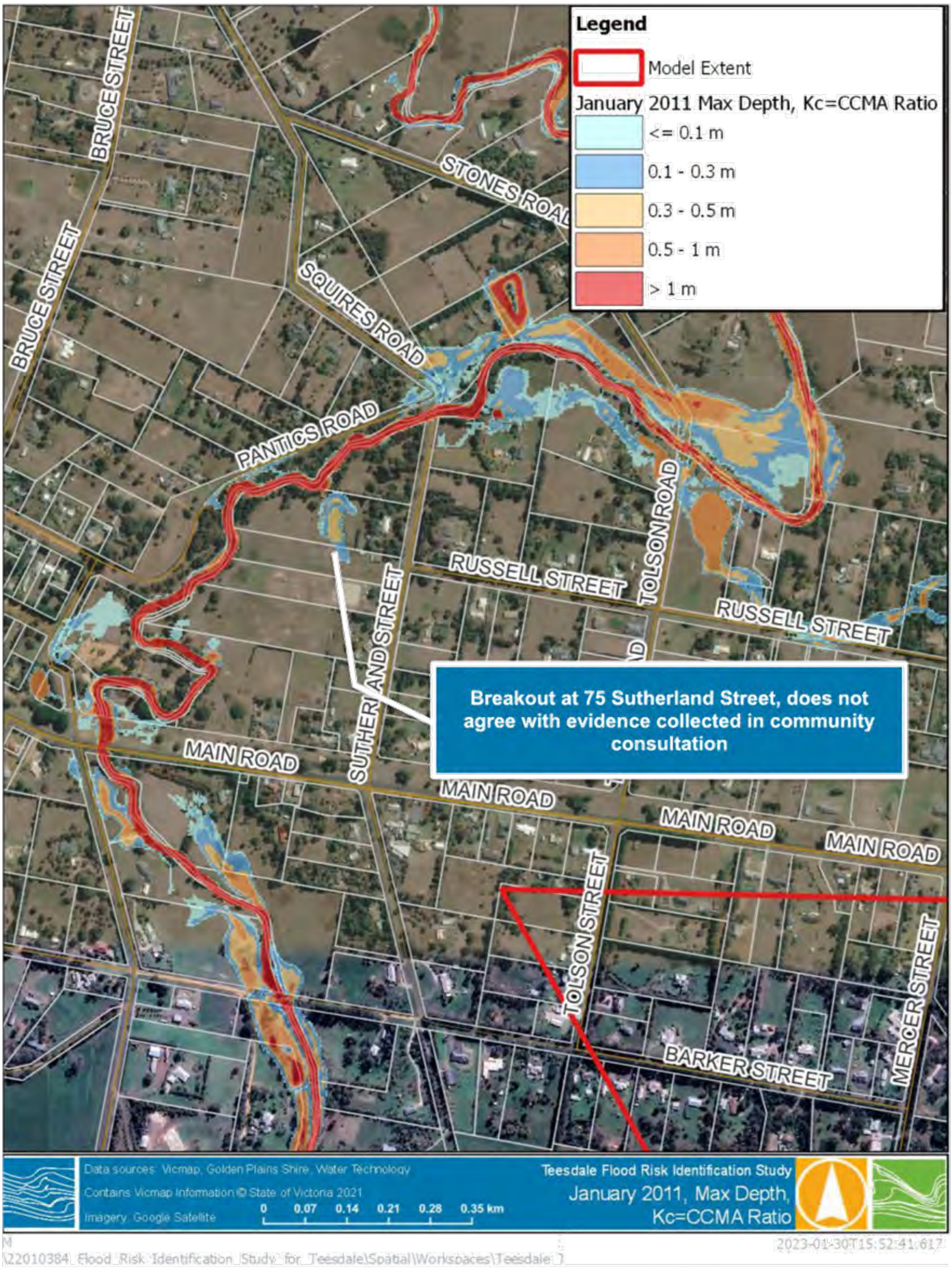

Figure 5-12 January 2011 Flood Depths, K_c=CCMA Ratio (Township)

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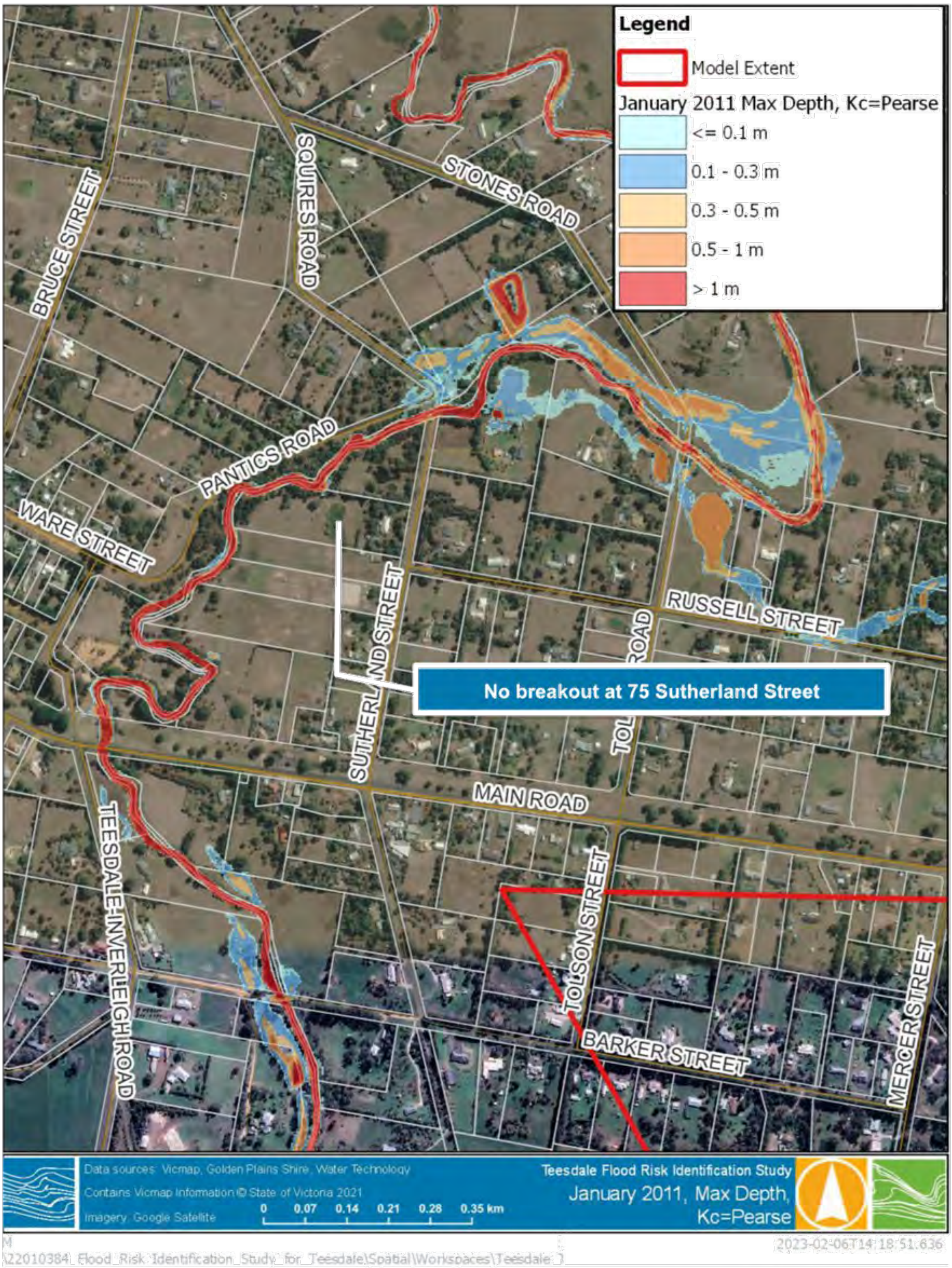

Figure 5-13 January 2011 Flood Depths, K_c=Pearse (Township)

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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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